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# LCA of Textile Waste Treatment Pathways

Project THREADs

2026

| ISBN NO. | ISSN NO. | REPORT TYPE | CONFIDENTIALITY |
|---|---|---|---|
| 978-82-8486-030-5 | 2703-8610 | Commissioned | Open |

NORSUS

**PROJECT TITLE**

LCA of textile waste treatment pathways in the NPA region

**PROJECT NUMBER**

3643

**COMMISSIONED BY**

Remiks Miljøpark AS

**REFERENCE**

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**INTERNAL QUALITY CONTROL**

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**NUMBER OF PAGES**

55

**KEY WORDS**

LCA, textile waste, textile recycling, reuse, incineration

**PHOTO FRONTPAGE**

https://evreka.co/blog/tackling-textile-waste-challenges-and-opportunities/

**FINANCING**

The work was financed by two INTERREG projects:

- TRÅD INTERREG Sverige - Norge, Nordens grønne belte
- THREADS INTERREG Textile and Habiliment Reuse for the Environment and NPA Area Development

Interreg Co-funded by the European Union Northern Periphery and Arctic

TRÅD

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# Summary

Textile waste is increasingly diverted from residual waste across the EU/EEA, driven by mandatory separate textile collection and forthcoming extended producer responsibility (EPR) schemes. For municipalities in sparsely populated areas, this raises a practical question: which handling pathway for textile waste performs best environmentally.

This study was carried out for five partners in the Norwegian, Swedish and Finnish parts of the Northern Periphery and Arctic (NPA) region, financed through Interreg NPA and Interreg Sverige-Norge: Trondheim municipality, Remiks Miljøpark (Tromsø/Karlsøy), Åre municipality, Kiertokaari (Oulu region) and Lumire (Luleå). A common challenge across the five partners is low population density and long transport distances to sorting and treatment facilities, resulting in lower waste volumes than in urban areas. Together, the partners' countries cover around 4 million inhabitants in the NPA area, generating an estimated 51 750 tonnes of textile waste per year.

The purpose of the study is to evaluate the environmental footprint of collecting, sorting and treating textile waste in these conditions, from collection to final fate, to support decision-making in the NPA region. The study combines life cycle assessment (LCA), partner interviews, desk research, a mapping of the European textile recycling sector and cost estimations.

The LCA uses a functional unit of one tonne of used textiles discarded by households and organizations, treated from the municipal collection point to its final fate. Fiber composition is based on a recent NTNU database of 16 464 discarded and donated garments (Pettersen et al., 2026): 27,0 % cotton, 17,9 % polycotton, 17,2 % polyester, 8,0 % other natural fibers, 5,9 % other synthetic fibers and 23,8 % soiled textiles. A system expansion approach credits each pathway for the production it avoids, such as district heating from incineration or virgin fibers from recycling. Eleven scenarios were modelled across four groups:

(1) incineration (local and remote, the reference),
(2) reuse (local, European and Sub-Saharan African),
(3) recycling (open loop, mechanical and chemical, via two proposed Scandinavian sorting hubs) and
(4) combinations of reuse and recycling.

The analysis is modelled in SimaPro and the results calculated for fossil global warming potential using IPCC 2021. ecoinvent 3.12 is used as background database.

The results confirm the waste hierarchy. Incineration causes the highest emissions of all pathways, 0,61 to 0,89 tonne $CO_2$ eq. per tonne, and is the least preferable option; transport distance to the plant makes little difference. Reuse gives the largest potential climate benefit, -4,0 to -4,3 tonne $CO_2$ eq. per tonne, mainly by avoiding new garment production. Among the recycling routes, open loop recycling performs best (-1,6 to -1,7 tonne CO2 eq. per tonne), followed by mechanical recycling (-0,6 to -0,7 tonne $CO_2$ eq. per tonne). Chemical recycling instead causes a net climate impact (0,3 to 0,6 tonne $CO_2$ eq. per tonne): its strict purity requirements route more waste to incineration and its process burden is higher, though it still beats incineration alone. Combining reuse with recycling gives the best overall results, -4,3 to -5,8 tonne $CO_2$ eq. per tonne. Transport contributes little to the results in any scenario, even when distances to the sorting hubs are tripled in the sensitivity analysis. The exception is chemical recycling, which turns into a net climate burden once road transport increases by 3 500 to 5 900 km depending on the country, beyond which incineration performs better. A separate check on the fibre composition of the functional unit changes the absolute results but not the ranking between pathways, strengthening the conclusions.

The study also reviews costs. Incineration is a pure cost to municipalities, estimated at 80 to 250 EUR/tonne. A sorted reusable fraction can generate revenue, from around 1 000 to 1 200 EUR/tonne for lower-quality export fractions up to 4 000 to 5 000 EUR/tonne for top-quality garments in Western markets. Recycling costs vary widely by technology, from around 280 EUR/tonne for open loop mechanical recycling to 2 600 EUR/tonne for chemical pulping, and generally exceed the value of the resulting materials, making the current business case for recycling weak, though this is expected to shift once EPR schemes place this responsibility on producers.

The reuse and recycling systems assessed are not yet mature and the development of the EPR scheme is expected to alter these markets. The system studied is subject to changes and prone to uncertainties, which means that the results should be read as indicative rather than absolute. Best-case assumptions are used for reuse and recycling rates, which likely overestimate what is achievable. The results are sensitive to the assumed substitution effects, which depend on downstream markets that do not yet exist at scale for all pathways. The assessment also excludes collection bags and sorting or recycling infrastructure, and is limited to fossil GWP as the only impact category, due to data and budget constraints.

The main recommendations to the partners are to follow the waste hierarchy, prioritizing reuse over recycling over incineration; to sort out garments with high reuse potential for local reuse wherever feasible; where export is necessary, to work only with partners that can demonstrate transparent, traceable and responsible downstream handling; and to combine reuse with recycling of the remaining fractions for the best overall climate performance. Transport to regional sorting and treatment, including export, has only a minor influence on the results and is not a barrier to more centralized solutions, except for road transport to chemical recycling over very long distances.

# Abbreviations

EPR: Extended Producer Responsability

GWP: Global Warming Potential

LCA: Life Cycle Assessment

LHV: Lower heating value

MFA: Material Flow Analysis

NPA: The Northern Periphery and Arctic

PET: Polyethylene terephthalate

PP: Polypropylene

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# 1 Introduction

## 1.1 Background

Nordic municipalities operate within the EU waste-policy framework, while the detailed allocation of responsibilities between municipalities, producer-responsibility organizations, charities and private waste operators is set through national legislation. The overall legal direction is that textiles should be diverted from mixed residual waste and managed in accordance with the waste hierarchy. Prevention, reuse and preparation for reuse should be prioritized, followed by recycling, while incineration and disposal should be used only where higher-value options are not feasible.

The principal framework is the Waste Framework Directive (Directive 2008/98/EC, as amended), which establishes core definitions and principles for waste management, including the waste hierarchy, the polluter-pays principle and requirements for separate collection (The European Parliament and the Council of the European Union, 2008). From 1 January 2025, EU Member States have been required to ensure separate collection of textiles. For municipalities, this typically means providing, arranging or overseeing accessible collection systems and ensuring that textile waste enters authorized treatment routes (The European Parliament and the Coucil of the European Union, 2025).

The revised Waste Framework Directive introduces harmonized extended producer responsibility (EPR) requirements for textiles, textile-related products and footwear, which entered into force in October 2025. Under the forthcoming national EPR schemes, producers will be required to finance the end-of-life management of the products they place on the market. This includes costs related to separate collection, sorting, reuse, preparation for reuse, recycling and other treatment.

Historically, used-textile collection in the Nordic countries has often been organized through donation-based systems, frequently involving charities, municipalities and private collection operators. The revised framework might gradually change the role of municipalities. In the near term, municipalities remain key actors in enabling separate collection and securing lawful downstream management. In the longer term, EPR is expected to transfer a greater share of the financial responsibility for textile waste management to producers. Municipalities will nevertheless need to coordinate collection and treatment arrangements with producer-responsibility organizations, reuse actors and waste-management companies, while ensuring that local systems comply with national waste legislation and applicable rules for cross-border shipments.

## 1.2 Aim of the study

The purpose of the analysis is to evaluate the environmental footprint of the collection, sorting, and treatment of textile waste, from collection and sorting to potential recycling or disposal, in sparsely populated areas of the Norwegian, Swedish, and Finnish NPA, characterized by low waste volumes and long distances from viable sorting facilities. The results and recommendations will assist in decision-making by highlighting the impact of textile waste collected, sorting, and recycling within the NPA areas of Norway, Sweden, and Finland.

Life cycle assessment (LCA), interviews and desk research are used as a method for answering these questions.

## 1.3 Partners

The partners in this study are Trondheim municipality, Remiks Miljøpark in Tromsø, Åre municipality, Kiertokaari waste management in Oulu Finland, and Lumire miljøresurs in Luleå Sweden. The geographical location of the partners in this study is show in **Feil! Fant ikke referansekilden.**. The partners' common challenge is that they are characterized with low population density, long distances between services, regional hubs and urban areas. Consequently, the total volume of textile waste generated is low compared to urban areas and distances to potential facilities are longer.

The NPA area of Norway, Sweden and Finland have approximately 1,2 million inhabitants, 1,3 million inhabitants and 1,5 million inhabitants, respectively. This sums up to approximately 4 million inhabitants.

The calculated amounts of textiles vary with the various countries: in Norway, about 14kg textile waste is discarded per inhabitants in 2025 (de Sadeleer & Rubach, 2026) while this figure was 9kg for Sweden in 2025 (IVL, 2025), and 15,5 in Finland for 2019 (Helena Dahlbo, 2021).

Based on these assumptions, about 51 750 tons of textile waste are generated per year in the NPA area.




**Figure 1: The geographical location of the partners in this study; Remiks miljøpark in Tromsø, Trondheim municipality, Kiertokaari in Oulu, and Lumire in Luleå, and Åre municipality.**

Interviews with each partner were conducted to get an understanding of their textile waste flows and challenges, and their expectations for this project and potential scenarios for textile waste handling. The interviews were conducted as an online meeting with each partner separately. A short summary of the interviews is given below:

- **Trondheim municipality** is responsible for the textile waste in the Trondheim region in Norway, serving about 216 000 inhabitants. The textile waste handling system in Trondheim changed in 2025 to become a drop-off scheme in one stream (including both textile waste and reusable textiles) at two recycling stations. The collected textile waste is sorted in the sorting facility of Norwegian Re:Textile in several stream, for reuse, recycling and incineration. The facility intends to prioritize national reuse, but is required to send reusable textiles abroad due to a low national reuse demand. Historically, the textile waste generated was around 1400-1500 tonnes / year.
- **Remiks Miljøpark** in Tromsø manages the textile waste for Tromsø and Karlsøy municipality, serving about 85 000 inhabitants. The management system is based on drop-off scheme at their two recycling stations, where they separate in reusable and non-reusable textiles. In addition, mobile containers for smaller returns are located around the municipality. The textile classified as waste is incinerated at the recycling station. In 2025, the amount of textile waste was 153 tonnes. In addition, their local reuse shop Rebell collects reusable textiles for further sales.
- **Åre municipality** collects textile waste in four recycling stations, serving about 13 000 inhabitants. Most of the collected textiles were in 2025 incinerated (3,12 tonnes) while only a small fraction was deemed suitable for reuse. Separately, the municipality's second-hand store, Återbruket, sold 651 kg of textiles for reuse. These reused textiles were handed in directly to Återbruket and were not part of the textile waste collected at the waste collection centres. In addition, a picking analysis revealed that 6,7% of the residual waste stream consisted of textiles in 2023. Åre previously send their textile waste to sorting for reuse at Telge in Southern Sweden, but this came to a halt when the facility only wanted the garments with the highest quality, requiring Åre to sort the waste stream themselves. As a result, the municipality currently runs a pilot project for collecting reusable garments in bags with QR codes, incentivizing reuse of textiles locally.
- **Lumire miljø**, located in Luleå, collect textiles at designated recycling stations, where reusable and non-reusable textiles are sorted separately. Clean and reusable textiles are directed to second-hand reuse, charitable organizations, and local community initiatives, while damaged or soiled textiles are collected separately for appropriate recycling or disposal. This system prioritizes reuse whenever possible, with recycling as the next option for textiles that cannot be reused. Volumes were not obtained.
- **Kiertokaari** is a municipal waste management company in Finland serving nine municipalities with a total population of approximately 290 000 inhabitants. The largest city in its service area is Oulu. The company collects around 200 tonnes of textiles separately each year. Kiertokaari has experience with manual textile sorting. Finland was previously at the forefront of textile collection and the development of recycling solutions. However, since signals of a future EPR scheme for textiles emerged in 2023, much of this development has come to a halt. The last loads of sorted cellulosic fibres left Oulu in early 2025. Since then, Kiertokaari has focused more on textiles suitable for reuse and on developing a local market for recycled textile materials in craft products. Nevertheless, more than half of the separately collected textiles are sent for incineration.

## 1.4 Structure of the report

This report is divided into four parts.

The first part – Chapter 2 Understanding textile recycling - sets the scene by giving an introduction to available recycling technologies and the current European recycling sector.

In the second part – Chapter 3 LCA - the LCA is presented, following the methodological basis of LCA. The goal and scope of the study are presented (Chapter 3.1), followed by a description of the assessed scenarios (Chapter 3.2), and the data collection and inventory (Chapter 3.3). Details on the environmental impact assessment (Chapter 3.4) are then provided. Thereafter, the results of the LCA are presented for GWP fossil (Chapter 3.5) followed by a sensitivity analysis (Chapter 3.6).

The third part – Chapter 4 Costs of textile waste handling – gives indications of the costs for the alternative pathways of handling textile waste.

The fourth part provides a discussion of the three assessments (Chapter 5), and final recommendations for the partners (Chapter 6).

# 2 Understanding textile recycling

This chapter gives an overview of the textile recycling landscape in Europe as per 2026, describing the various technologies in use (chapter 2.1) and the main waste recyclers (chapter 2.2).

## 2.1 Overview of textile waste recycling technologies

Textile recycling technologies can be broadly grouped into mechanical, chemical, and thermo-mechanical/ chemical processes, each suited to different types of waste and recovery goals, see Figure 2. Together, these technologies form a layered system for handling textile waste, with each approach offering different advantages, and disadvantages, in terms of material quality, input flexibility, and end-use potential. A summarized description of each technology is provided in the following headings and the maturity of the recycling technologies.

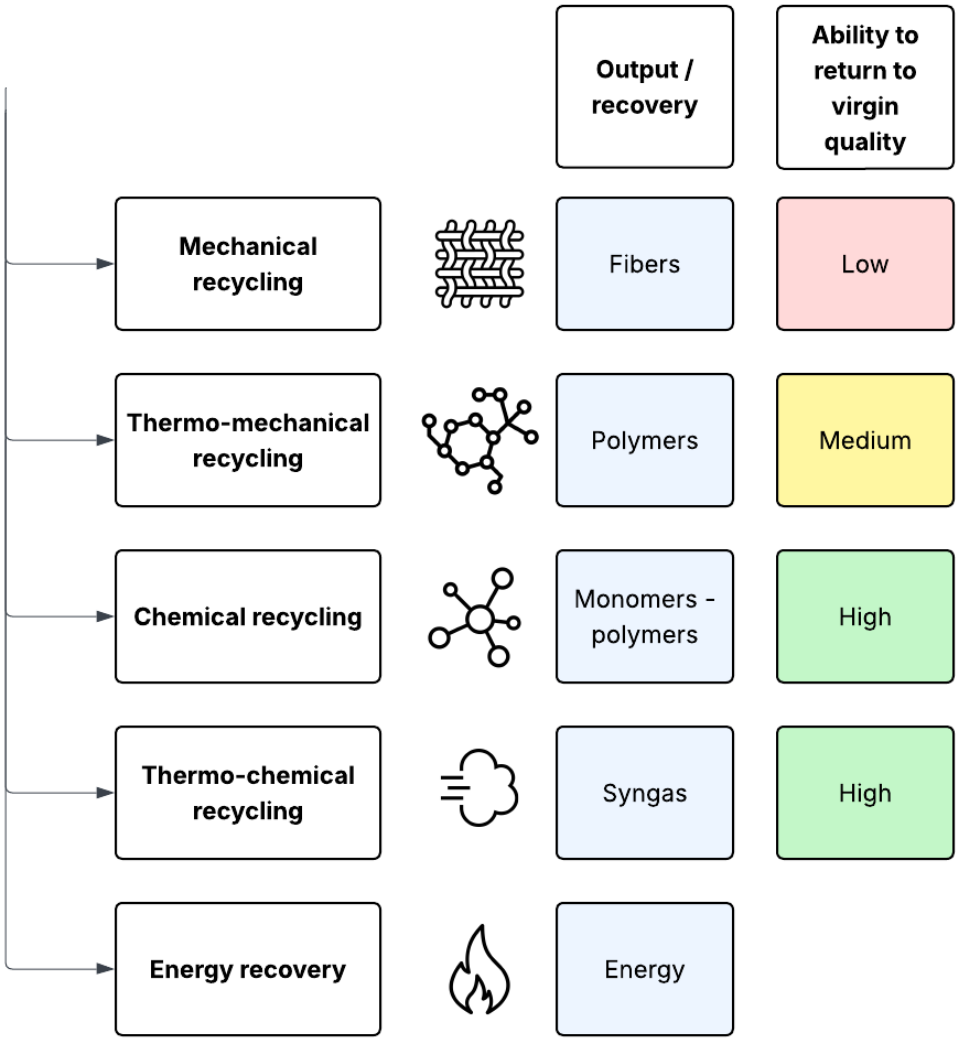



**Figure 2: The four main recycling technologies for textile waste in Europe. Adapted from McKinsley (2022)**

### 2.1.1 Mechanical recycling

Mechanical recycling of textiles is a process that uses physical force to break textile waste down into fibres. It can be used on its own or as a pre-treatment step before other recycling methods. In principle, it can handle many kinds of textile waste, including natural fibres, synthetics, blends, knitted fabrics, woven fabrics, and non-wovens. The best results come from clean, uniform, and uncontaminated input material, while mixed, coated, laminated, or heavily worn textiles are much harder to process and often produce lower-quality output (Tom Duhoux & Maarten Christis, 2021).

The process usually starts with pre-treatment, where textiles are dismantled, cut to size, and stripped of buttons, zippers, labels, and other unwanted parts. If the material is dirty, it may also be washed or cleaned before recycling. After that, the textile goes through mechanical opening or tearing machines that gradually separate the fibres. Extra steps such as blending, cleaning, and carding may be added to improve fibre quality and make the output more suitable for spinning. The exact machine setup depends on the type of textile and the desired end product (Tom Duhoux & Maarten Christis, 2021).

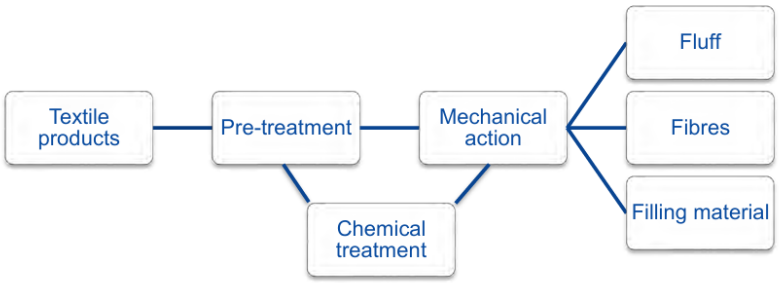



**Figure 3: Schematic representation of the mechanical recycling process. Source: Tom Duhoux and Maarten Christis (2021)**

The output is usually a mix of spinnable fibres, short fibres, fluff, dust, and other waste fractions. Only part of the recovered material is good enough to be spun into new yarn, so recycled fibres often need to be blended with virgin fibres. Much of the rest is used for non-wovens, insulation, filling materials, or technical applications, which means the process is often considered a form of downcycling. Mechanical recycling has advantages such as lower investment cost, lower resource use, and the ability to process many textile waste flows, but it also has clear limits because fibre quality drops, contaminants remain, and the final material can be difficult to standardize (Tom Duhoux & Maarten Christis, 2021).

### 2.1.2 Thermo-mechanical recycling

Thermo-mechanical recycling is a process that uses heat and mechanical treatment to melt thermoplastic textiles and recover polymers as fibres or regranulate. In principle, materials such as PET, polyamide, and polypropylene can be recycled, but the input must consist of a single polymer type or compatible polymers to ensure quality output. Even small amounts of incompatible materials or contaminants—such as dyes, coatings, or additives—can negatively affect processing and fibre properties. Therefore, well-sorted, clean, and known-origin materials, typically from production waste, are preferred over mixed post-consumer textiles (Tom Duhoux & Maarten Christis, 2021).

The process involves pre-treatment steps such as sorting, cleaning, drying, and shredding, followed by melt processing through extrusion and regranulation. The material is then converted into fibres via melt spinning,

where the molten polymer is extruded, cooled, and stretched into filaments. Maintaining polymer quality is a major challenge due to degradation from heat, mechanical stress, and environmental exposure. Techniques such as adding stabilizers, chain extenders, or blending with virgin material are used to improve viscosity and mechanical performance. Additional steps like melt filtration, vacuum degassing, and post-condensation (especially for PET) can further enhance output quality (Tom Duhoux & Maarten Christis, 2021).

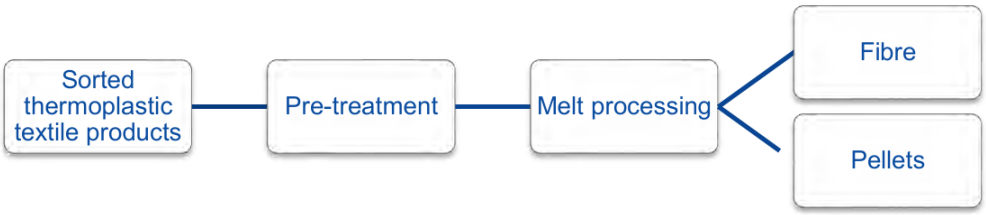



**Figure 4: Schematic representation of the thermo-mechanical recycling process. Source: Tom Duhoux and Maarten Christis (2021)**

Thermo-mechanical recycling is a cost-effective and established technology with relatively low emissions, capable of producing fibres for various textile applications. However, it has limitations, including degradation of material properties over multiple cycles, high sensitivity to contamination, and restrictions related to colour and chemical residues. The process is currently most suitable for industrial textile waste, with limited use of recycled content in final products. While the technology is approaching commercial maturity for certain applications, challenges remain in handling mixed materials and increasing the proportion of recycled content in high-quality fibres (Tom Duhoux & Maarten Christis, 2021).

### 2.1.3 Chemical recycling

Chemical recycling of textiles involves the use of chemical processes to break down materials into polymers or monomers that can be reused to produce new fibres. This includes monomer recycling (depolymerizing materials into basic building blocks), polymer recycling (recovering polymers without fully breaking them down), and technologies that separate and recover components from blended textiles such as polycotton. One key method is the chemical recycling of cotton through a pulping process, where cellulose is treated and regenerated into new fibres like viscose or lyocell. Although some steps resemble mechanical processing, the transformation into new fibres requires chemical treatment and is therefore classified as chemical recycling (Tom Duhoux & Maarten Christis, 2021).

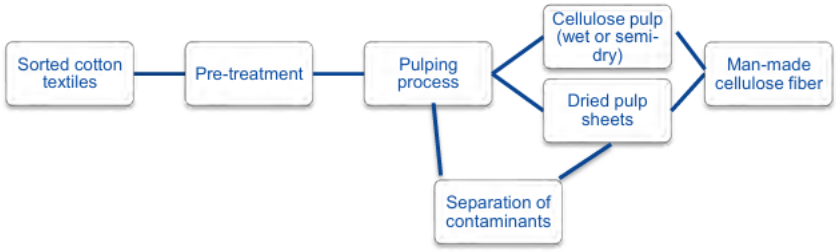



**Figure 5: Schematic representation of the chemical recycling process, here for cotton. Source: Tom Duhoux and Maarten Christis (2021)**

The pulping process for cotton begins with pre-treatment, where textiles are sorted, cleaned, and stripped of non-textile components. The material is then chemically processed into a cellulose pulp, during which dyes, finishes, and contaminants are removed, and the cellulose structure may be partially adjusted to improve processing. Additional steps can separate non-cellulosic fibres such as polyester. The resulting pulp can be used in fibre production or dried into sheets for storage and transport. The quality and efficiency of the process depend heavily on input purity, with high cotton content preferred, and many systems requiring blending with virgin wood pulp to achieve consistent fibre properties (Tom Duhoux & Maarten Christis, 2021).

The output of chemical recycling is regenerated cellulose fibres with properties comparable to those made from virgin raw materials, although repeated recycling can degrade fibre quality over time. The process generally produces limited waste, mainly from removed contaminants. While many technologies have reached a high level of maturity (TRL 7–9), challenges remain in scaling up operations and handling blended textiles economically. Future developments focus on improving separation technologies, increasing the share of recycled input, and optimizing environmentally friendly spinning methods, positioning chemical recycling as an important component of a circular textile system (Tom Duhoux & Maarten Christis, 2021).

### 2.1.4 Thermo-chemical recycling

Thermo-chemical recycling of textiles primarily involves processes such as gasification (and to a lesser extent pyrolysis), which differ from combustion by operating under limited or no oxygen to produce reusable chemical outputs rather than energy alone. Gasification typically occurs at high temperatures (about 700–1100°C) and converts carbon-based waste into syngas—a mixture of hydrogen and carbon monoxide—that can be used for energy or further refined into chemical intermediates. Unlike mechanical recycling, this method targets the molecular composition of materials, making it suitable for a wide range of textile and plastic waste, including mixed, contaminated, or complex materials (Tom Duhoux & Maarten Christis, 2021).

The process includes pre-treatment, gasification, and subsequent gas cleaning or purification. During pre-treatment, non-textile components are removed, and the material may be dried and size-reduced. In the gasification stage, controlled amounts of oxygen, air, or steam are introduced to initiate chemical reactions that produce gases, liquids (tars), and solid residues (ash). The resulting syngas must be purified to remove contaminants such as sulphur or nitrogen compounds before it can be used in chemical production. Depending on process conditions and input materials, outputs can vary and include fuels, chemical feedstocks such as methanol, or by-products like ash and tar (Tom Duhoux & Maarten Christis, 2021).




**Figure 6: Schematic representation of the thermos-chemical recycling process. Source: Tom Duhoux and Maarten Christis (2021)**

A key advantage of thermo-chemical recycling is its ability to handle heterogeneous and low-quality waste flows that are unsuitable for other recycling methods, producing high-purity, virgin-like chemical outputs. However, the process is energy-intensive and requires significant investment in gas cleaning and infrastructure. While it is considered a mature technology (TRL 9) for energy production, its application in

textile recycling—especially for producing chemical feedstocks—is still developing. Future progress is expected to improve efficiency and increase the share of outputs used for material recycling rather than fuel, making it a complementary solution within a broader circular textile system (Tom Duhoux & Maarten Christis, 2021).

## 2.2 Mapping the European textile waste recycling sector

A mapping of the European textile waste recycling sector was done to visualize the geographical distribution of recycling facilities across the continent, and the facilities status and relevant properties. The aim of this mapping was to gain knowledge on the status of European recycling of textile waste. The mapping was conducted through literature and market review, supplemented by internet searches to identify actors involved in textile recycling.

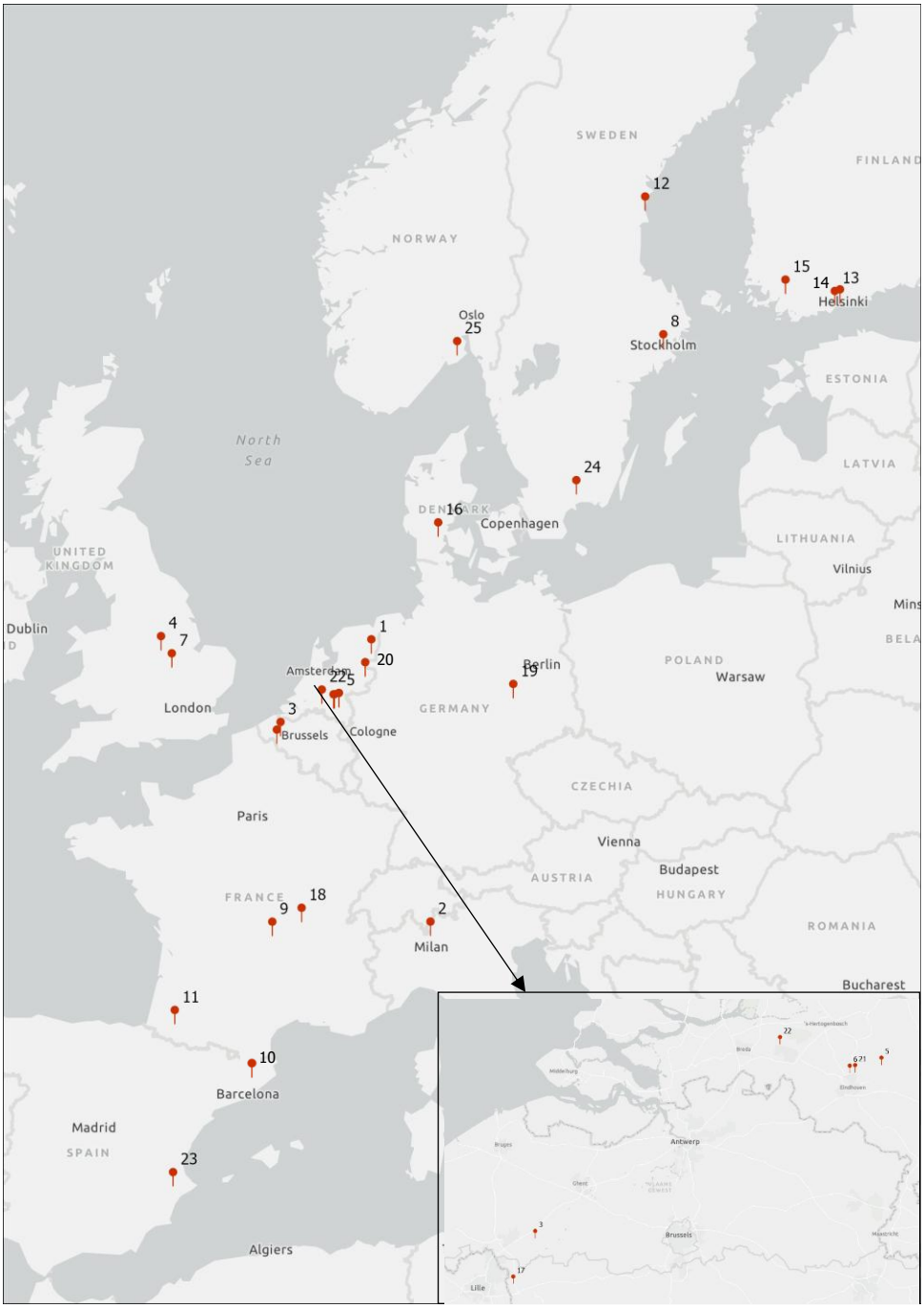
For each identified facility, the following facilities' properties were mapped:

- maturity level of these industries,
- recycling process technology,
- fibres processed,
- annual processing capacity in tons per year.

These properties are visualized respectively in maps and provide information on the facilities operations.

### 2.2.1 Textile recycling facilities in Europe

The relevant textile recycling facilities in Europe are shown in Figure 7. Under the market and literature review and internet searches, criteria for the facilities relevance where set. These criteria are based on capacity and fibres the facility can accept. Some facilities were small (< 1000 tons/ year) and only accepted one type of fibre such as cashmere, design material, leather etc, which have low volumes on the market. These were excluded from the analysis due to low relevance of the textile waste composition of the partners. The number of facilities, based on our criteria, is 25. However, this list may not be complete due to rapid advance and start-ups within the sector.




| ID: | Recycling facilities: |
|---|---|
| 1 | Cure |
| 2 | Gr3n |
| 3 | Purfi |
| 4 | worn again |
| 5 | DePoly |
| 6 | Re&Up |
| 7 | Project Re:Claim |
| 8 | Syre |
| 9 | Carbios |
| 10 | Antex |
| 11 | Reju |
| 12 | Circulose |
| 13 | Infinited Fibre company |
| 14 | Ioncell |
| 15 | Rester |
| 16 | Retextile |
| 17 | Procotex |
| 18 | ets h. Moncorge |
| 19 | SOEX Recycling Germany GmbH |
| 20 | Frankenhuis B.V. |
| 21 | Ioniqa |
| 22 | Wolkat |
| 23 | Recover |
| 24 | OnceMore |
| 25 | Norsk tekstilgjenvinning |

**Figure 7: Geographical distribution of relevant recycling facilities in Europe.**

The geographical distribution shows that the facilities are quite evenly spread across Europe. There are facilities from Scandinavia down to southern Spain, but with a clear concentration in central Europe around the Netherlands and Germany. In addition, several plants are in France, Belgium, Italy and Spain, forming a corridor of textile sorting and recycling capacity from the Benelux region towards the Mediterranean. In the Nordic region, facilities in countries such as Sweden and Finland complement this network, while Eastern and South-Eastern Europe currently appear less represented in terms of large-scale, industrial textile recycling sites. Overall, the pattern indicates that most of today's capacity is clustered in regions with strong existing textile value chains and logistics hubs, whereas more peripheral areas are mainly connected through export of collected textiles to these hubs.

## 2.2.2 Textile recycling sector maturity and capacity

**Textile recycling sector maturity and status**

The maturity and status of the facilities, ranging from the demonstration stage to commercial scale-up, are presented in **Feil! Fant ikke referansekilden.**. Entering and establishing a position in the textile recycling market is challenging and involves more than achieving technical maturity alone (MacKinsey, 2022). Market readiness also depends on economic viability, access to sufficient and suitable post-consumer textiles, and the ability to establish stable relationships across the textile value chain.




**Figure 8: The maturity and status of the facilities, ranging from the demonstration stage to commercial scale-up.**

The conditions required for effective scale-up remain uncertain, particularly regarding the collection, sorting, and continuous supply of post-consumer textiles. Large-scale recycling facilities require stable volumes of consistent feedstock, whereas the availability of separately collected and appropriately sorted textiles remains limited in many parts of Europe. Variations in material composition and quality may further increase the costs and complexity of collection and sorting, thereby affecting the economic viability of recycling operations. The ability to secure sufficient quantities of suitable feedstock may therefore represent a significant barrier to the further scaling of textile recycling.

The regulatory environment also plays a critical role in the transition towards textile recycling. European policies and forthcoming regulatory requirements may support market development by improving separate collection, increasing transparency and traceability, strengthening producer responsibility, and stimulating demand for recycled content. Overall, the transition from demonstration-scale facilities to fully commercial operations depend on a combination of technological, economic, regulatory, and organizational factors. Technological maturity is therefore only one dimension of market readiness and must be considered alongside feedstock availability, collection and sorting systems, the quality and marketability of recycled outputs, and the establishment of long-term partnerships throughout the textile value chain.

**Textile waste recycling capacity in Europe**

The mapped textile recycling facilities in Europe show a wide range of capacities, from small plants of only 500 tons per year to large industrial sites with capacities of up to 80,000 tons per year. Based on the available figures, the total mapped capacity amounts to nearly 500,000 tons per year across 25 facilities, with a median capacity of 10,000 tons per year. This suggests that the sector is characterized by a mix of small and medium-sized plants, alongside a smaller number of high-capacity hubs that account for a substantial share of the total throughput. The capacity distribution based on technology is broadly balanced between chemical and mechanical recycling, but mechanical recycling has a slightly higher total capacity.

Several of the facilities are planning scale-up, as seen in **Feil! Fant ikke referansekilden.**, which indicates that the current capacity is likely to increase further in the coming years as investments, technology development and policy pressure on textile waste handling.

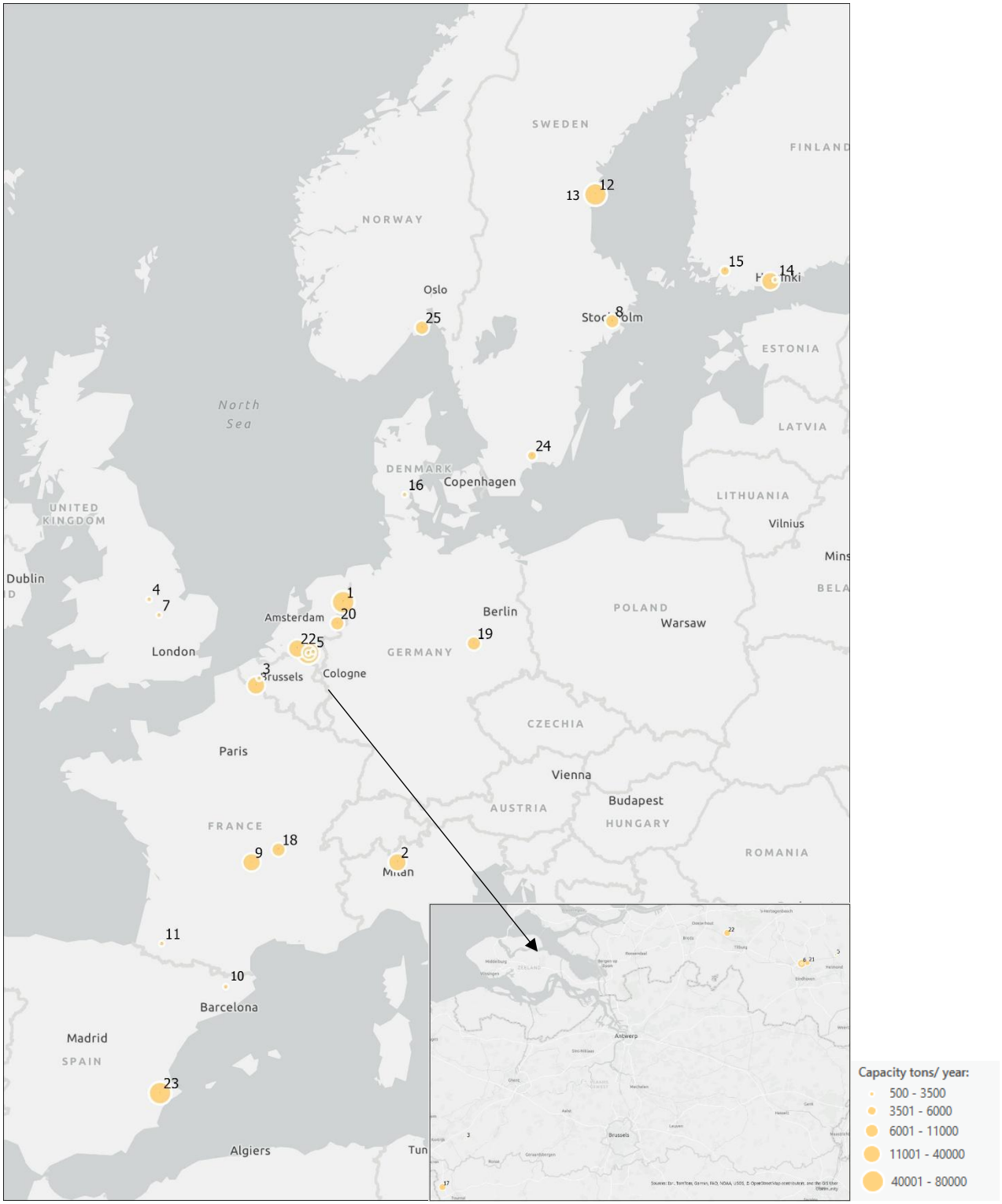



**Figure 9: The capacity of textile waste processed in tons/ year at the recycling facilities assessed.**

In Scandinavia there are seven recycling facilities (Syre, Circulose, Infinited Fibre Company, Rester, Retextile, OnceMore and Norsk Tekstilgjenvinning), and their gathered capacity is approx. 120 000 tons/ year of textile waste. Five out of these seven are at commercial size and scaling up, and the remaining at pilot stage. Consequently, there is great potential in recycling possibilities in Scandinavia, which also have the lowest transport distances to the partners' geographical location.

### 2.2.3 Recycling technology and fibre composition

**Recycling technology**

The textile recycling facilities included in the assessment use different recycling technologies and handle a range of fibre compositions. The facilities in the overview apply either mechanical recycling, chemical recycling, or a combination of mechanical and chemical processes. The distribution of technologies across the mapped facilities is relatively balanced, with 11 plants based on chemical recycling and 13 on mechanical recycling, see Figure 10. In addition, one facility combines mechanical and chemical steps. This indicates that both technological pathways are already present at an industrial scale in Europe. In Scandinavia, there is a majority of chemical recycling technologies (4 out of 6).

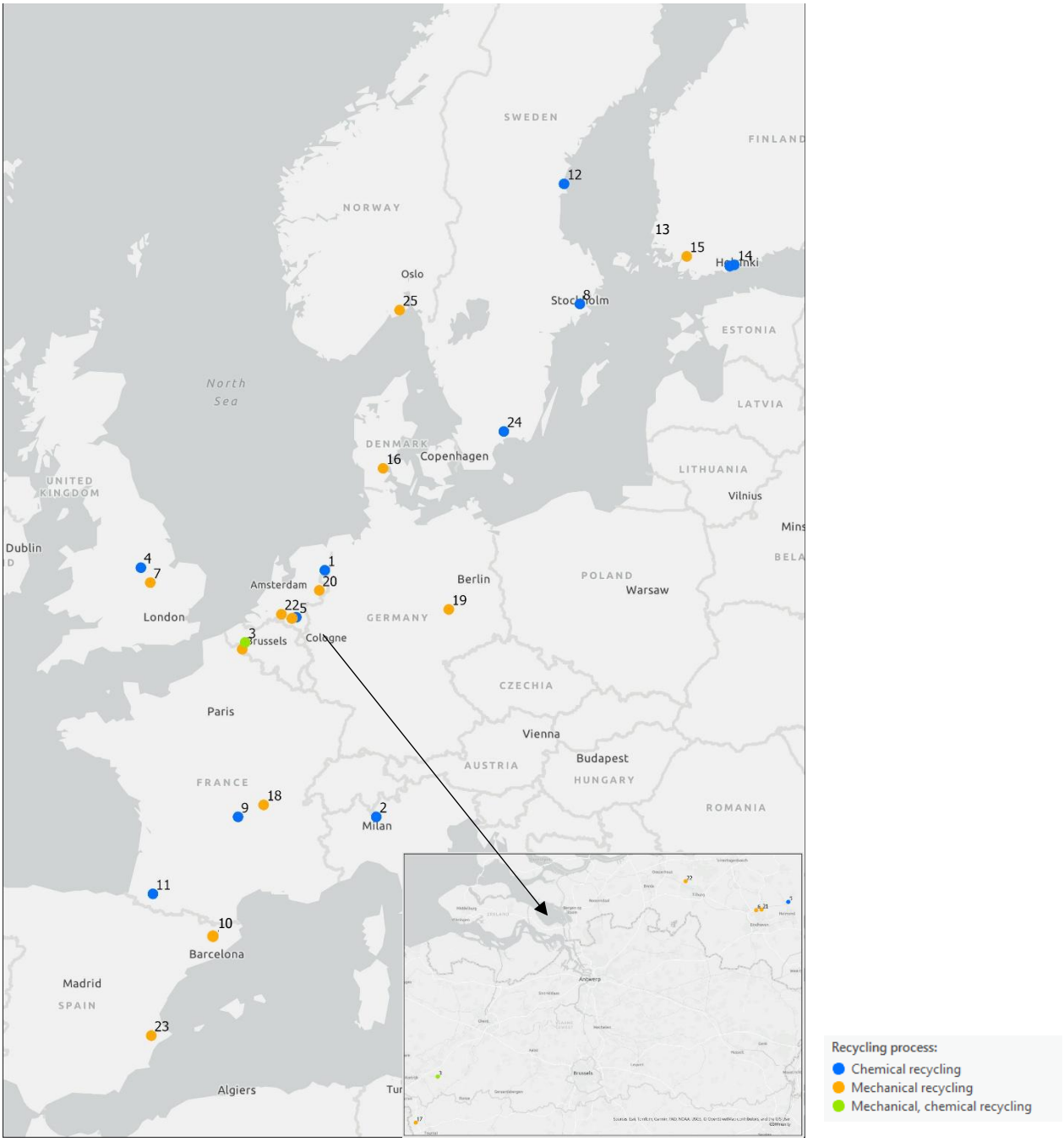



**Figure 10: European recycling facilities categorized after technology.**

**Fibre composition**

Textile waste is highly heterogeneous and may consist of natural fibres, such as cotton, wool, and linen, synthetic fibres, such as polyester, polyamide, and elastane, or blends combining several fibre types. In addition to fibre composition, the material may vary in terms of colour, construction, finishes, contamination, and previous use. The composition and fibre type of post-consumer textile waste are important factors influencing the maturity, performance, and scalability of recycling technologies. In

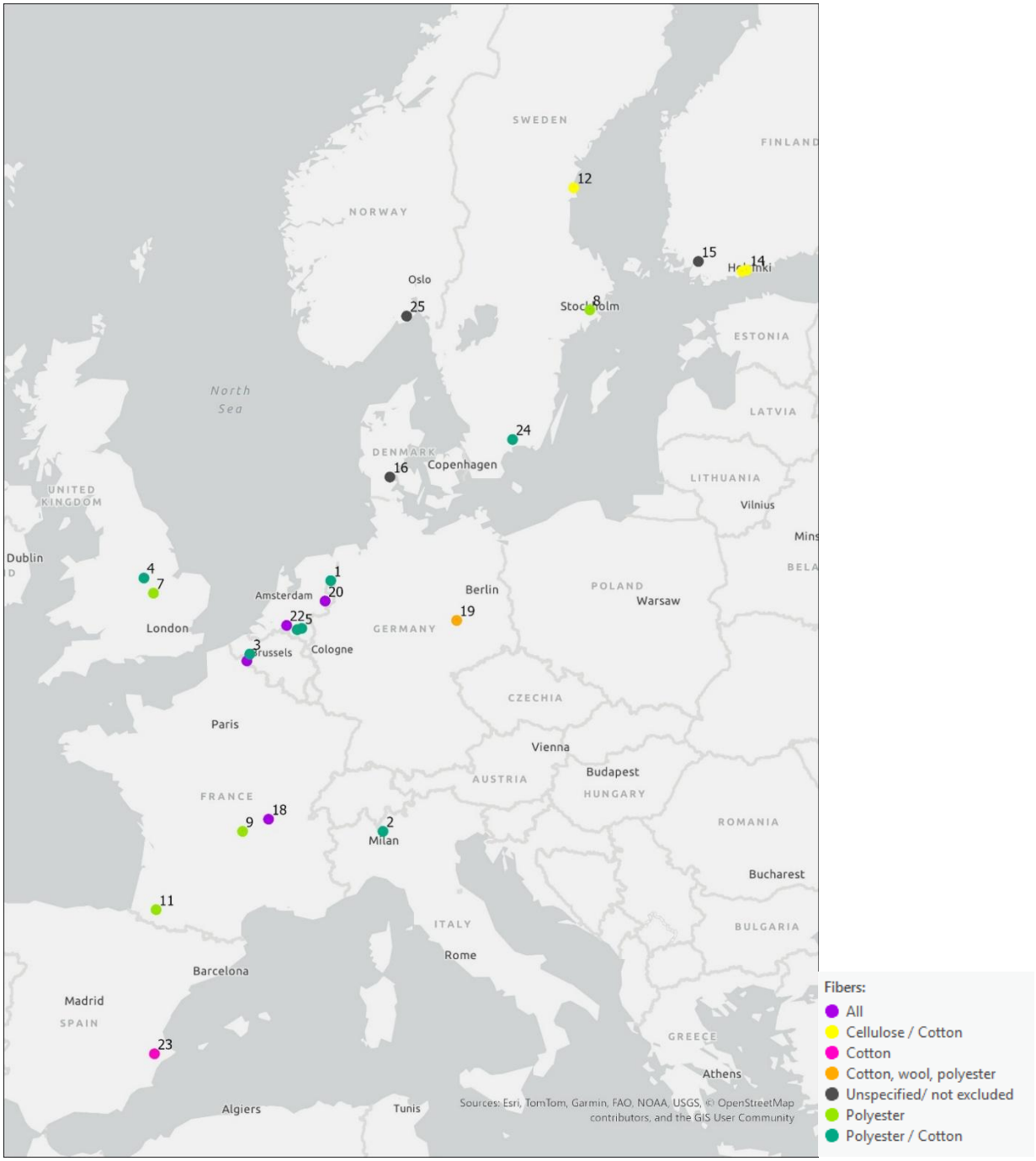



Figure 11, the fibre types processed at the textile recycling facilities are mapped and categorized. Several facilities are also categorized as accepting “all” fibre types or unspecified/ not excluded, indicating that their feedstock is not restricted to a single fibre category.

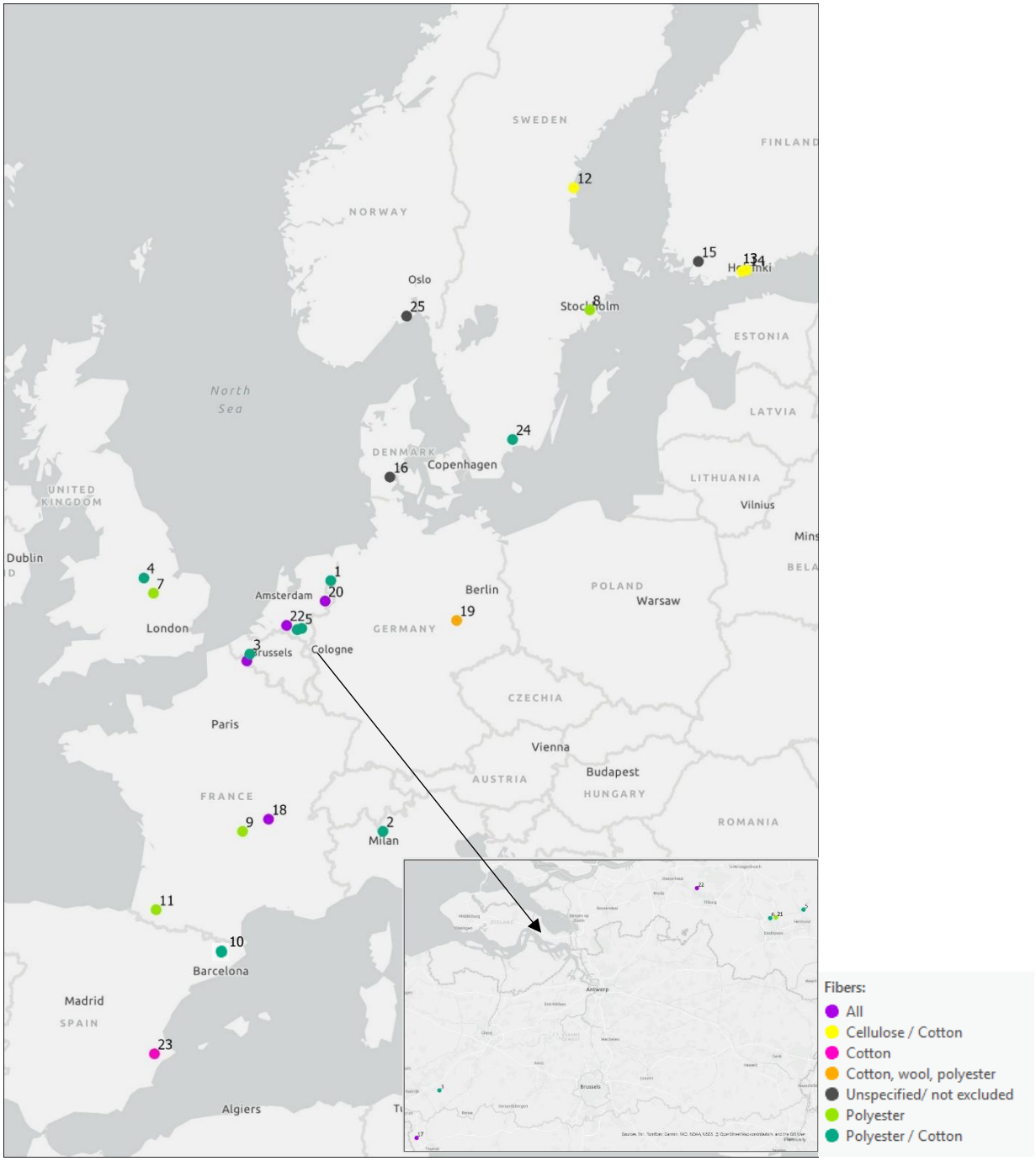



**Figure 11: The fibre composition of the textile waste processed at the facilities included in this assessment.**

Beyond fibre composition, there are several other factors influencing a textile's recyclability (sensitivity differs across recycling technologies), including product characteristics (for example, single versus multi-layers), hard parts (for example, buttons and zippers), soft parts (for example, labels and threads), heavy coatings or finishing, prints, colour (mostly relevant for mechanical recycling), fabric construction (for example, knitwear is easier for mechanical recycling than woven), and mold or oil stains (McKinsley, 2022). Variations in material composition, contamination, fibre blends, colour, and product quality can increase the complexity and cost of preparing textile waste for recycling. These factors may be particularly significant for technologies that require narrowly defined or highly homogeneous feedstock.

In Scandinavia, the seven facilities can process both polyester, cellulose, cotton and possibly all fibres in the unspecified/ not excluded facilities. The facilities with chemical recycling have specified fibres (polyester, cellulose/ cotton blends and polyester/ cotton blends), while the mechanical recycling can handle unspecified waste flows. When including capacity, maturity and status, these facilities can therefore be a resource for handling Scandinavian textile waste with mixed fibre composition.

# 3 LCA

In this chapter, the goal and scope of the study are presented (Chapter 3.1), followed by the data collection and inventory (Chapter 3.2), and a description of the assessed scenarios is given (Chapter 3.3). Details on the environmental impact assessment (Chapter 3.4) are then provided. Thereafter, the results of the LCA are presented for GWP fossil (Chapter 3.5) followed by a sensitivity analysis (Chapter 3.6).

## 3.1 Goal and scope definition

### 3.1.1 Functional unit

The following functional unit is used for this study "Treatment of one tonne of used textiles discarded by households and organizations, from the municipalities collection points until its final grave".

The fibre composition of the textile waste was unknown for most municipalities, therefore a generic composition (Table 1) was used based on literature values (Pettersen et al., 2026).

A recent Norwegian project conducted at the Norwegian University of Science and Technology sampled 16.464 clothes from donations and discards, which resulted in a recently published database over garment and fibre composition (Pettersen et al., 2026). This is, as far as the authors know, the most detailed data available for the Norwegian textile waste flows and is estimated representative for Swedish and Finnish conditions as well. Data on the main fibre type was extracted from the database for garments defined as textile waste, and classified into 6 categories: cotton, polycotton, polyester, other natural fibres, other synthetic fibres and soiled textiles. For the full list of main fibre fractions, see Appendix 1.

**Table 1: Fibre composition of the functional unit, based on (Pettersen et al., 2026)**

| Fibre type | Share of FU | In Mass |
|---|---|---|
| **Cotton** | 27,0 % | 0,27 t |
| **Polycotton** | 17,9 % | 0,18 t |
| **Polyester** | 17,2 % | 0,17 t |
| **Other natural fibres** | 8,0 % | 0,08 t |
| **Other syntetic fibres** | 5,9 % | 0,06 t |
| **Soiled textiles** | 23,8 % | 0,24 t |
| **SUM** | 100% | 1 t |

23,8% of the garments defined as textile waste were categorized as NaN in the database, meaning that their main fibre composition was unclear. In this study, this category is assessed as soiled textiles, which is a conservative estimation. However, the other fibre fractions can be seen as best-cases, as these are classified only based on their main fibre type (except for polycotton) and without impurities such as buttons, zipper, prints ect. The assumption that NaN is a soiled fraction, compensates for this.

This is a truncated view of the textile waste stream. Other sources have been reporting other fractions even in Norwegian studies (Wasted Textiles data, for instance), but the categorization of this database does not allow us the same overview. This categorization was chosen for mapping against the recycling technologies which currently exist, and for which inventories were found.

### 3.1.2 System boundaries

The system boundaries start at the municipal waste collection point and is generically visualized in Figure 12.

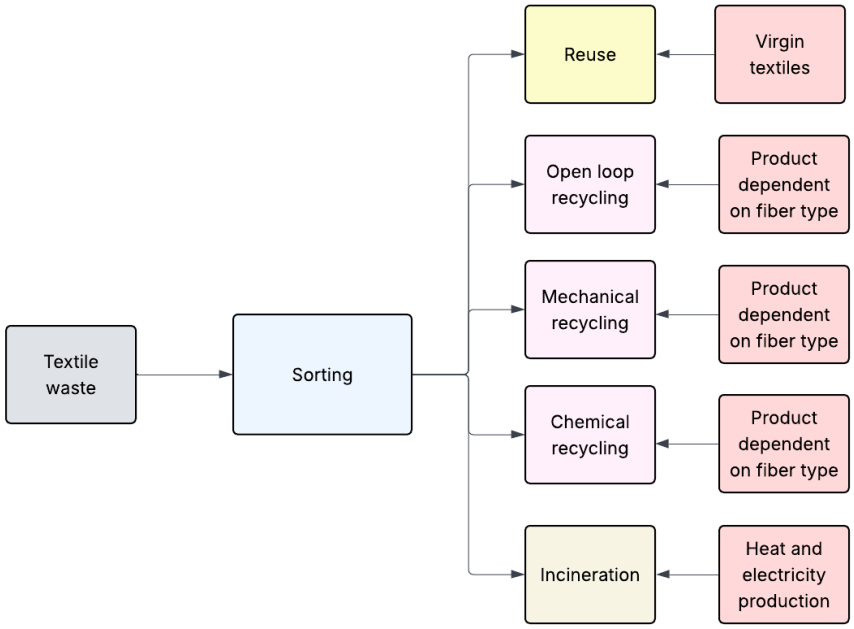



**Figure 12: Generic flowchart of the system under study**

Note that this analysis focuses on textile waste, and not on donated textiles for reuse, to charities for instance. The waste is being sorted, or not, and sent to various handling pathways (reuse, recycling or incineration), or to a combination of those.

A material recycling process represents a waste management process for a first product, but is also the material production process of a second product. According to Allacker et al. (Allacker et al., 2017), at least 11 different formulas have been identified as widely used and accepted methodologies for end-of-life allocation of burdens and credits of recycling process between different stages of product cascade systems, but there is no consensus which method to apply (Allacker et al., 2017; Bergsma & Sevenster, 2013; Ekvall et al., 2020). In a cut-off approach, also called recycled content and 100:0, recycling activities are allocated to the product using recycled material. Hence, the recycling process is defined as a production process and a system boundary (cut-off) is placed between the first and second product system. In a system expansion approach, also called substitution approach or 0:100, recycling activities are allocated to the product generating recycled material. Hence, the system is expanded by including avoided burdens from the substitution of virgin material. Different end-of-life modelling methods can give quite different results (Gala et al., 2015). The cut-off method provides incentives for the use of recycled material but is indifferent to the recyclability of products. In comparison, the system expansion approach promotes recycling but gives no incentive to use recycled material. Other modelling methods also exist for recycling, such as the European Commission's Circular Footprint Formula in the Product Environmental Footprint system, which combines benefits to the recycled materials and substitution effects.

This study applies a system expansion approach to address multifunctionality. A waste-management system has a primary function—treating a specified waste flow—but may also generate valuable co-products, such as secondary materials from recycling or electricity and heat from incineration. System expansion ensures that the compared systems are functionally equivalent by including these additional functions within the

system boundary. In practice, this is commonly implemented through substitution, avoided-burden modelling, or crediting: the waste-management system is credited for avoiding the production of the foreground or background process that is displaced by its recovered output (JRC, 2011).

For the scenarios having incineration as treatment option, this includes the avoidance of district heating. For recycling, the product generated from the recycling process is estimated avoided, often being raw materials such as pulp or plastic granulates. And in a reuse scenario, a final product is avoided if reused, for instance the production of a t-shirt, if a t-shirt is being reused.

Specific flowcharts for each scenario are presented in each scenario description, in chapters 3.2.1 - 3.2.4

## 3.2 Description of the scenarios analysed and material flow analysis

Given the diverse methods and previous experiences among the commissioning municipalities regarding textile waste management, generic scenarios have been developed so that each entity can identify the scenario corresponding to its current operations. Hence, the scenarios are not detailed per municipality.

We analyse four main scenarios:

1) Incineration,
2) Reuse,
3) Recycling,
4) A combination of reuse and recycling.

The scenarios vary in terms of sorting location, incineration location, reuse location, recycling location, recycling technology and the mass flows between the different processes. An overview of the scenarios analysed is given in Table 2.

**Table 2: Overview of the scenarios analysed**

| Scenario | Sorting location | Share to incineration | Incineration location | Reuse location | Recycling technology | Recycling location |
|---|---|---|---|---|---|---|
| **1a** | None | 100 % | Local | None | None | None |
| **1b** | None | 100 % | Regional | None | None | None |
| **2a** | Local | 73 % | Local | Local | None | None |
| **2b** | Regional | 73 % | Regional | Europe | None | None |
| **2c** | Regional | 73 % | Regional | Africa | None | None |
| **3a** | Regional | 38 % | Regional | None | Open loop | Europe |
| **3b** | Regional | 38 % | Regional | None | Mechanical | Scandinavia |
| **3c** | Regional | 54 % | Regional | None | Chemical | Scandinavia |
| **4a** | Regional | 31 % | Regional | Europe | Open loop | Europe |
| **4b** | Regional | 31 % | Regional | Europe | Mechanical | Scandinavia |
| **4c** | Regional | 45,8 % | Regional | Europe | Chemical | Scandinavia |

The Material flow analysis (MFA) shows how the different fibre fractions are diverted into various handling flows according to their properties, illustrated in the flowcharts of each scenario hereunder.

### 3.2.1 Incineration

The incineration scenario has two sub-scenarios: local incineration (scenario 1a) and regional incineration (scenario 1b) (Table 3). Local incineration depicts the current waste management option in most municipalities today, while 1b depicts the situation in Åre municipality specifically. These can hence be seen as reference scenarios, which the other results will be benchmarked against.

**Table 3: Overview of the altering parameters across the incineration scenarios**

| Scenario | Treatment | Incineration location | Share to incineration |
|---|---|---|---|
| **1a** | Incineration | Local | 100% |
| **1b** | Incineration | Regional | 100% |

#### Local incineration (1a)

In scenario 1a, as illustrated in Figure 13, all textile waste is being directly diverted to a local incineration plant. It is assumed that the waste is transported 25 km, with trucks fuelled on diesel. The heat and electricity produced by the incineration process in a combined heat and power plant replaces electricity and heat through district heating The substitution was modelled according to the LHV of the various fibre types and the efficiency of the incineration plant. The substitution was modelled according to the LHV of the various fibre fractions and the efficiency of the incineration plant.

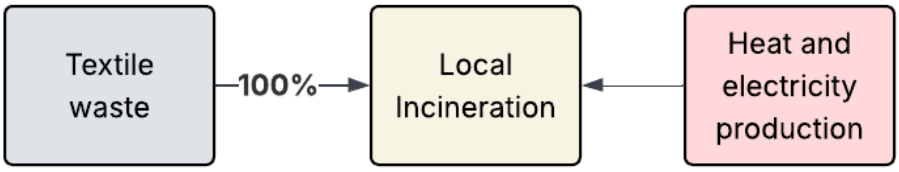



**Figure 13: Flowchart of the mass flows, for the local incineration scenario (1a)**

#### Remote incineration (1b)

Some municipalities must send the textile waste a certain distance for incineration, such as for Åre municipality. In scenario 1b, as illustrated in Figure 14, all textile waste is also being directly diverted to a regional incineration plant. The waste is transported over 300 km with trucks fuelled on diesel. The heat and electricity produced by the incineration process in a combined heat and power plant replaces electricity and heat through district heating The substitution was modelled according to the LHV of the various fibre types and the efficiency of the incineration plant.

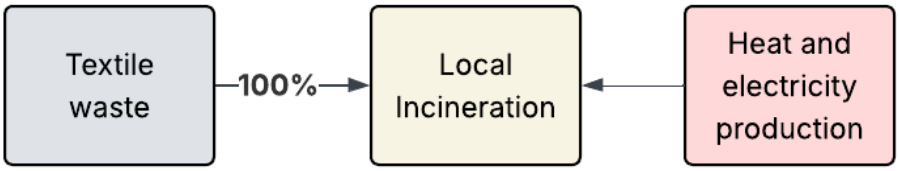



**Figure 14: Flowchart of the mass flows, for the remote incineration scenario (1b)**

### 3.2.2 Reuse

The reuse scenario has three sub-scenarios (Table 4), depending on where the textile stream is sorted and reused. The reuse potential differs across fibre types, with other natural fibres and other synthetic fibres having the highest reuse potential (Table 5).

**Table 4: Overview of the altering parameters across the reuse scenarios**

| Scenario | Treatment | Sorting location | Reuse location | Incineration location | Share incinerated |
|---|---|---|---|---|---|
| **2a** | Municipal sorting for local reuse | Local | Local reuse | Local | 73% |
| **2b** | Regional sorting for reuse | Regional | Regional reuse | Regional | 73% |
| **2c** | Regional sorting for reuse | Regional | Global reuse | Regional | 73% |

**Table 5: Fibre type categorization according to the reuse potential**

| Fibre type | Share of the F.U. | To reuse | To incineration |
|---|---|---|---|
| **Cotton** | 0,27 | 26 % | 74 % |
| **Polycotton** | 0,18 | 29 % | 71 % |
| **Polyester** | 0,17 | 32 % | 68 % |
| **Other natural fibres** | 0,08 | 49 % | 51 % |
| **Other synthetic fibres** | 0,06 | 45 % | 55 % |
| **Soiled textiles** | 0,24 | 0 % | 100 % |

#### Municipal sorting for local reuse (2a)

Most municipalities have a sorting system for extracting reusable garments, often for sale in local reuse shops. The data shows that there is a large potential for reuse in the textile waste flow, as a substantial share of the flow can be categorized as bright new clothing. According to NTNUs database (see description in Chapter 3.1.1 ), 27 % of the textile waste was classified as looking bright new (category 5 in the NTNU database, (see Appendix 2 for the categorization per fibre type and degree of wear).

This scenario hence focuses on a local sorting at the municipal level for extracting these volumes for local resale, while the remaining fraction is incinerated locally. It is assumed that the reused garments replace the production of new ones, and that the heat and electricity produced by the incineration process in a combined heat and power plant replaces electricity and heat through district heating. The substitution was modelled according to the LHV of the various fibre types and the efficiency of the incineration plant. This is a best-case scenario for reuse.

In scenario 2a, as illustrated in Figure 15, it was assumed that all reuse happens locally, and substitute the production of virgin cotton and polyester textile with a 0,4 ratio. The heat produced in the incinerator replaces heat and electricity through district heating.

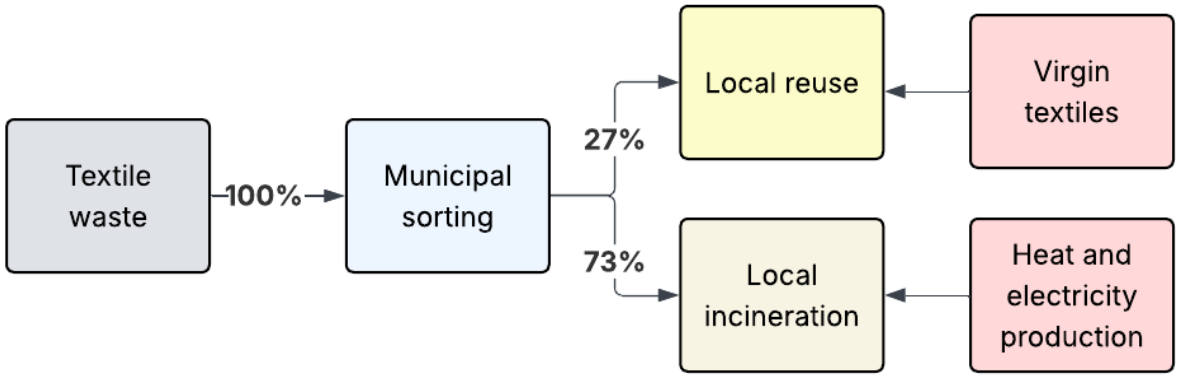



**Figure 15: Flowchart of the mass flows, for the local reuse scenario (2a)**

### Regional sorting for European reuse (2b)

In scenario 2b, as illustrated in Figure 16, it is assumed that the waste from the various municipalities is transported to a common regional sorting hubs in Kemi (Finland) and Trondheim (Norway), where it is sorted out for reuse in Europe.

It is assumed that the reused garments replace the production of new ones with a 0,4 ratio. The rest of the fraction sorted out in the Scandinavian sorting hubs, are incinerated regionally.

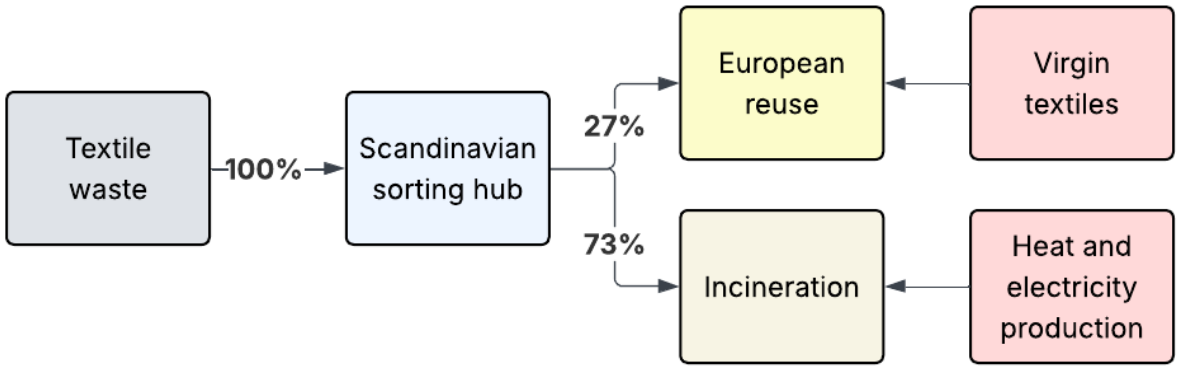



**Figure 16: Flowchart of the mass flows, for European reuse scenario (2b)**

### Regional sorting for African reuse (2c)

Actors in the textile reuse sector have said that the reuse potential in Scandinavia is relatively low. Currently, garments in the reuse segment are often shipped to Sub-Saharan Africa, where the market is larger.

In scenario 2c, as illustrated in Figure 17, the textile waste is diverted to sorting in Scandinavian sorting hubs in Kemi (Finland) and Trondheim (Norway). The reusable textile flow is further shipped to central sorting in Kenya, where the garments also are used. The rest of the fraction sorted out in the Scandinavian sorting hubs are incinerated regionally.

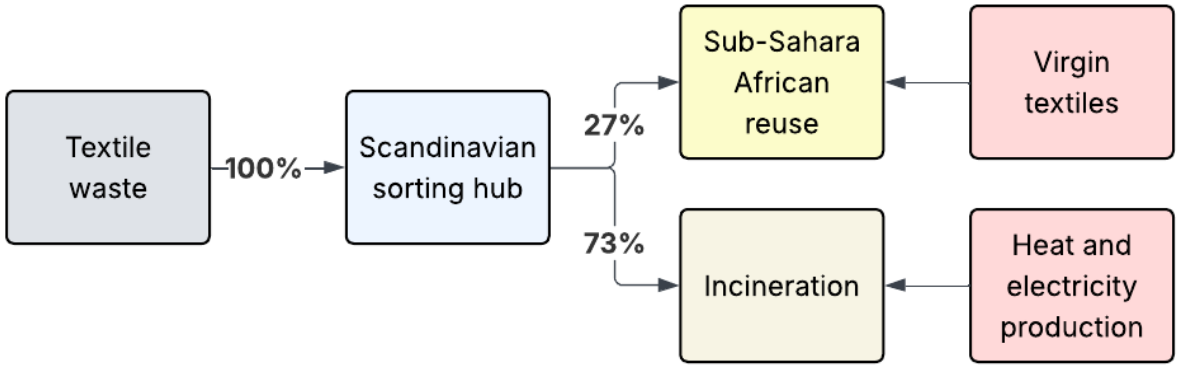



**Figure 17: Flowchart of the mass flows, for Sub-Saharan Africa reuse scenario (2c)**

### 3.2.3 Recycling

The recycling scenario has three sub-scenarios (Table 6), depending on the recycling technology and location. Table 7 presents the mass flows to the different treatment pathways, depending on the fibre types. See further explanations in the sections below.

**Table 6: Overview of the altering parameters across the recycling scenarios**

| Scenario | Treatment | Sorting location | Recycling location | Incineration location | Share incinerated |
|---|---|---|---|---|---|
| **3a** | Regional sorting for open loop recycling | Regional | Europe | Regional | 38 % |
| **3b** | Regional sorting for mechanical recycling | Regional | Scandinavia | Regional | 38 % |
| **3c** | Regional sorting for chemical recycling | Regional | Scandinavia | Regional | 54 % |

**Table 7: Fibre type categorization according to the recycling potential**

| Fibre type | Share of the F.U. | Open loop recycling | | Mechanical recycling | | Chemical recycling | |
|---|---|---|---|---|---|---|---|
| | | To recycling | To incineration | To recycling | To incineration | To recycling | To incineration |
| **Cotton** | 0,27 | 100 % | 0% | 100 % | 0% | 0,46 | 54 % |
| **Polycotton** | 0,18 | 100 % | 0% | 100 % | 0% | 0,65 | 35 % |
| **Polyester** | 0,17 | 100 % | 0% | 100 % | 0% | 0,35 | 65 % |
| **Other natural fibres** | 0,08 | 0% | 100 % | 0% | 100 % | 0% | 100 % |
| **Other synthetic fibres** | 0,06 | 0% | 100 % | 0% | 100 % | 0% | 100 % |
| **Soiled textiles** | 0,24 | 0 % | 100 % | 0 % | 100 % | 0 % | 100 % |

### Regional sorting for open loop recycling (3a)

This scenario presents sorting in the Finnish and Norwegian sorting hubs for all fibres which are not soiled to a mechanical open-loop recycling process, creating fibres, as illustrated in Figure 18. It is assumed that the open-loop recycling of cotton, polycotton and polyester substitutes wipers, insulation materials, and synthetic granulates, respectively. The remaining fraction, assumed as soiled textiles, is being incinerated locally. The heat and electricity produced by the incineration process in a combined heat and power plant replaces Scandinavian electricity and heat through district heating. The substitution was modelled according to the LHV of the various fibre types and the efficiency of the incineration plant. This is a best-case scenario for reuse.

Open loop recycling is currently commonly used, and represent hence an existing downcycling scenario. It is assumed that the open loop recycling facility is located in Switzerland.

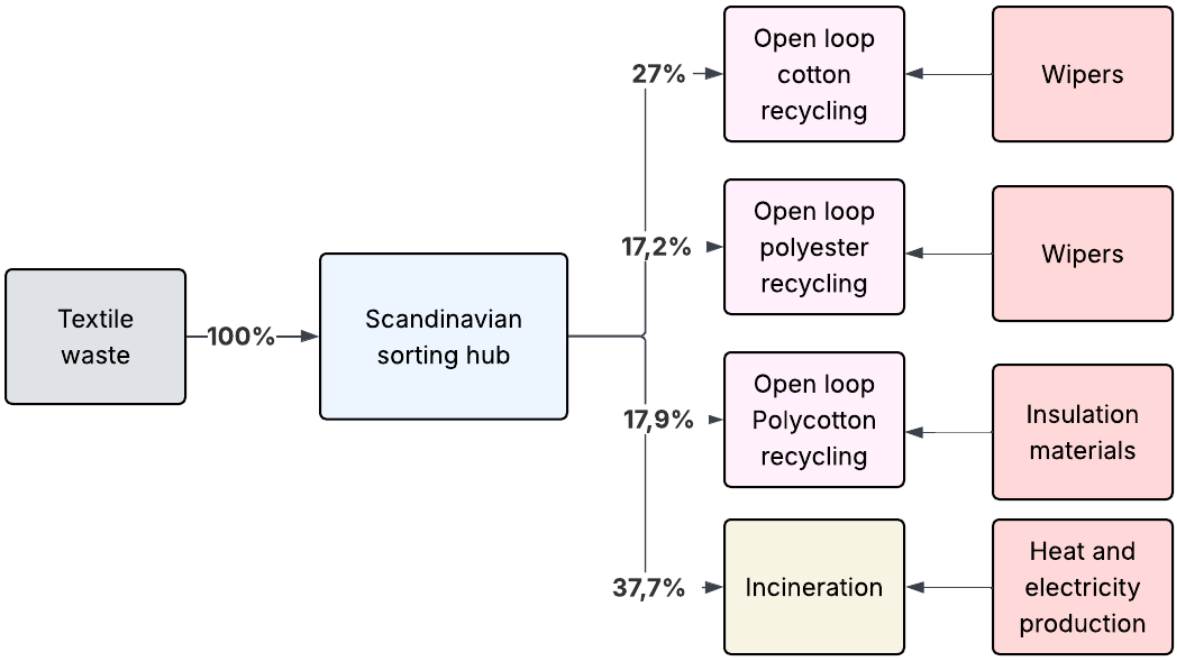



**Figure 18: Flowchart of the mass flows, for the open loop recycling scenario (3a)**

### Regional sorting for mechanical recycling (3b)

This scenario models a regional Scandinavian sorting facility, which sorts out all fibres which are not soiled to a mechanical recycling process located in the EU, creating fibres, as illustrated in Figure 19. It is assumed that the mechanical recycling of cotton, polycotton and polyester substitutes virgin fibres of each respective fraction. The remaining fraction, assumed as soiled textiles, is being incinerated locally. The heat and electricity produced by the incineration process in a combined heat and power plant replaces Scandinavian electricity and heat through district heating. The substitution was modelled according to the LHV of the various fibre types and the efficiency of the incineration plant. This is a best-case scenario for reuse. Mechanical recycling is currently commonly used, and represent hence an existing fibre-to-fibre recycling scenario.

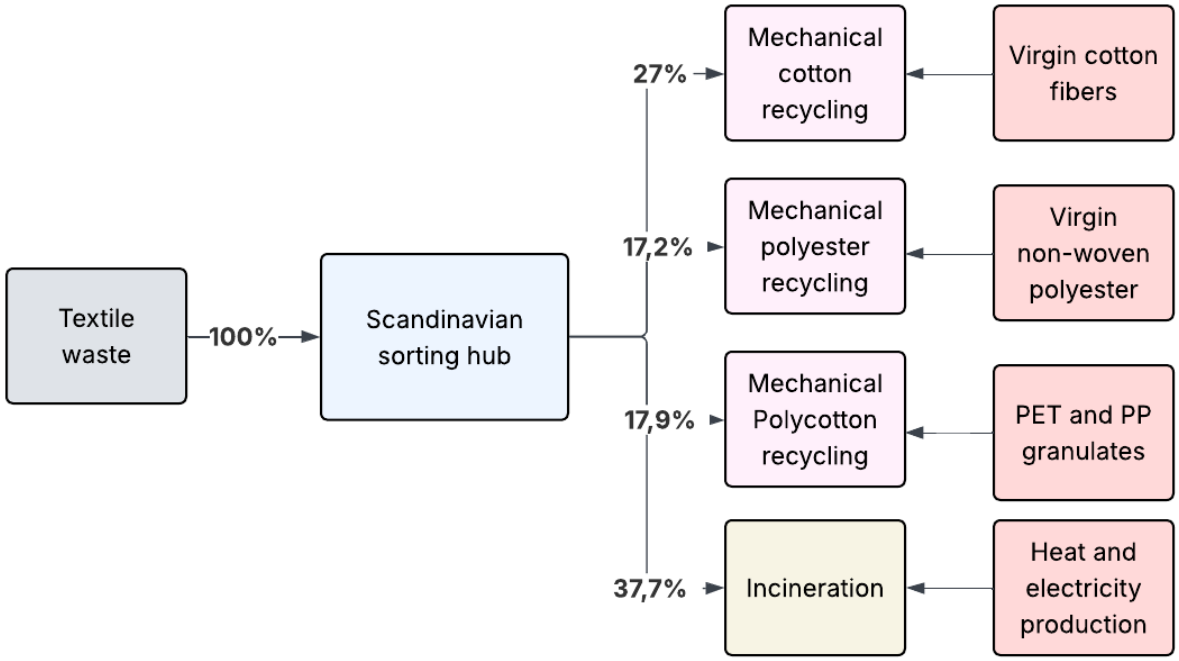



**Figure 19: Flowchart of the mass flows, for the mechanical recycling scenario (3b)**

### Regional sorting for chemical recycling (3c)

This scenario models a regional Scandinavian sorting facility, which sorts out fibres fit for chemical recycling, as illustrated in Figure 20. These are cotton, polycotton and polyester garments which have at least a fibre purity of 95%, which have no membranes nor prints, and that are not soiled. These are high requirements, and manipulation of the NTNU database shows that the following shares of the fibre types are fit for chemical recycling:

- 46% of the cotton flow
- 65% of the polycotton flow
- 35% of the polyester flow

This means that, in this scenario, larger volumes are being incinerated compared to the other recycling scenarios. The volumes for chemical recycling are sent facilities located in Scandinavia, using Infinite Fibre in Finland and Circulose om Sweden as recipient facilities for calculating transport distances from the sorting hubs.

It is assumed that the chemical recycling of cotton, polyester and polycotton substitutes virgin viscose fibres, virgin PET granulates and wood pulp and virgin polyester fibres, respectively.

The remaining volumes are being incinerated regionally. The heat and electricity produced by the incineration process in a combined heat and power plant replaces Scandinavian electricity and heat through district heating. The substitution was modelled according to the LHV of the various fibre types and the efficiency of the incineration plant. Chemical recycling is currently not commonly used, and represent hence a future scenario.

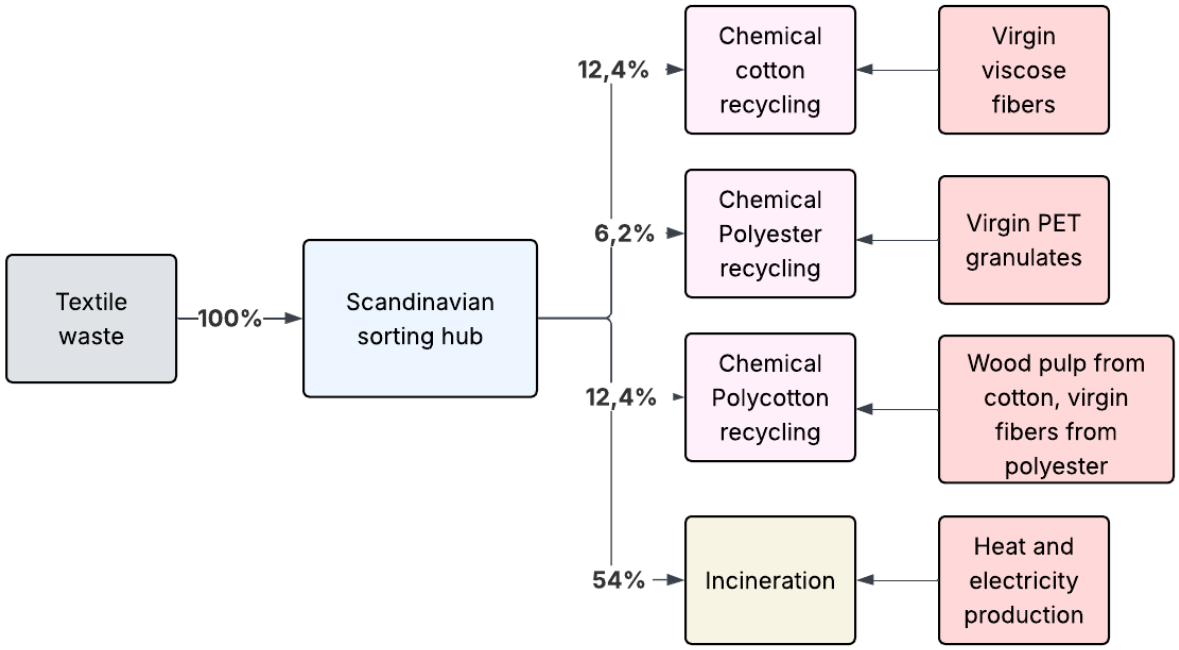



**Figure 20: Flowchart of the mass flows, for the chemical recycling scenario (3c)**

### 3.2.4 Combination of reuse and recycling

The reuse and recycling scenario has three sub-scenarios (Table 8), depending on the recycling technology and location. Because the fibre types differ in reuse potential, the pathways followed by the various fibre composition also change (Table 9).

**Table 8: Overview of the altering parameters across the reuse and recycling scenarios**

| Scenario | Treatment | Sorting location | Reuse location | Recycling location | Incineration location | Share incinerated |
|---|---|---|---|---|---|---|
| **4a** | Regional sorting for open loop recycling | Regional | Europe | Europe | Regional | 31 % |
| **4b** | Regional sorting for mechanical recycling | Regional | Europe | Scandinavia | Regional | 31 % |
| **4c** | Regional sorting for chemical recycling | Regional | Europe | Scandinavia | Regional | 45,8 % |

**Table 9: Fibre type categorization according to the reuse potential in the reuse and recycling scenarios**

| Fibre type | Share of the F.U. | Open loop and mechanical recycling | | | Chemical recycling | | |
|---|---|---|---|---|---|---|---|
| | | To reuse | To recycling | To incineration | To reuse | To recycling | To incineration |
| **Cotton** | 0,27 | 26 % | 74 % | | 26 % | 34 % | 40 % |
| **Polycotton** | 0,18 | 29 % | 71 % | | 29 % | 46 % | 25 % |
| **Polyester** | 0,17 | 32 % | 68 % | | 32 % | 24 % | 44 % |
| **Other natural fibres** | 0,08 | 49 % | | 51 % | 49 % | | 51 % |
| **Other synthetic fibres** | 0,06 | 45 % | | 55 % | 45 % | | 55 % |
| **Soiled textiles** | 0,24 | | | 100 % | | | 100 % |

### Regional sorting for reuse and open loop recycling (4a)

This scenario is a combination of scenario 2b and 3a. It models a regional Scandinavian sorting facility, which sorts out textiles for reuse, and thereafter textiles which are not soiled to an open loop recycling process located in the EU, creating different products. This is illustrated in Figure 21.

It is assumed that the open loop recycling of cotton, polyester and polycotton substitutes wipers and insulation materials. The remaining fraction, assumed as soiled textiles, is being incinerated regionally. The heat and electricity produced by the incineration process in a combined heat and power plant replaces Scandinavian electricity and heat through district heating. The substitution was modelled according to the LHV of the various fibre types and the efficiency of the incineration plant. This scenario represents a best-case scenario following the waste management hierarchy, starting with the recovery of usable textiles, and thereafter recycling for the textiles which are not in good condition.

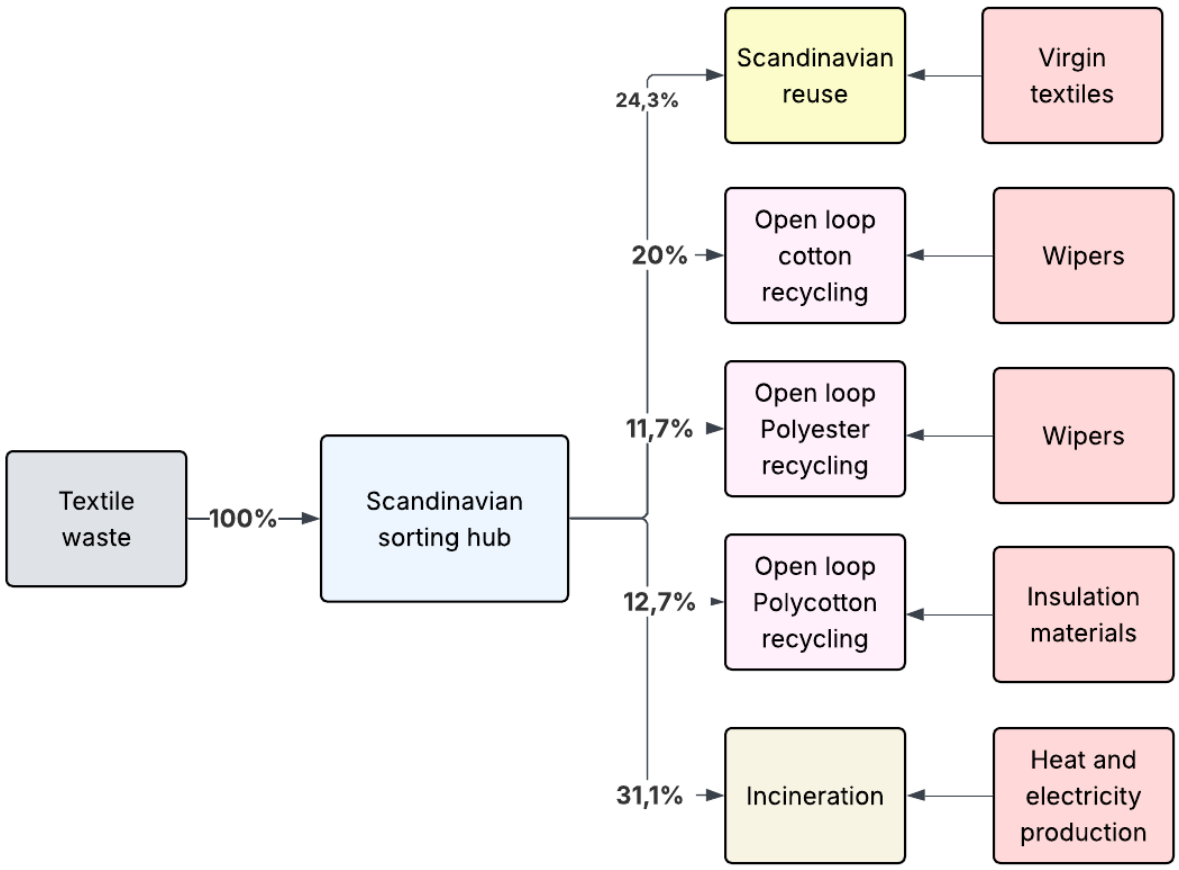



**Figure 21: Flowchart of the mass flows, for the reuse and open loop recycling scenario (4a)**

### Regional sorting for reuse and mechanical recycling (4b)

This scenario is a combination of scenario 2b and 3b. It models a regional Scandinavian sorting facility, which sorts out textiles for reuse, and thereafter textiles which are not soiled to a mechanical recycling process located in the EU, creating different products. This is illustrated in Figure 22.

It is assumed that the mechanical recycling of cotton, polyester and polycotton substitutes virgin cotton fibres, non-woven polyester fibres, and PET and PP granulates, respectively. The remaining fraction, assumed as soiled textiles, is being incinerated locally. The heat and electricity produced by the incineration process in a combined heat and power plant replaces Scandinavian electricity and heat through district heating. The substitution was modelled according to the LHV of the various fibre types and the efficiency of the incineration plant. This scenario represents a best-case scenario following the waste management hierarchy, starting with the recovery of usable textiles, and thereafter recycling for the textiles which are not in good condition.

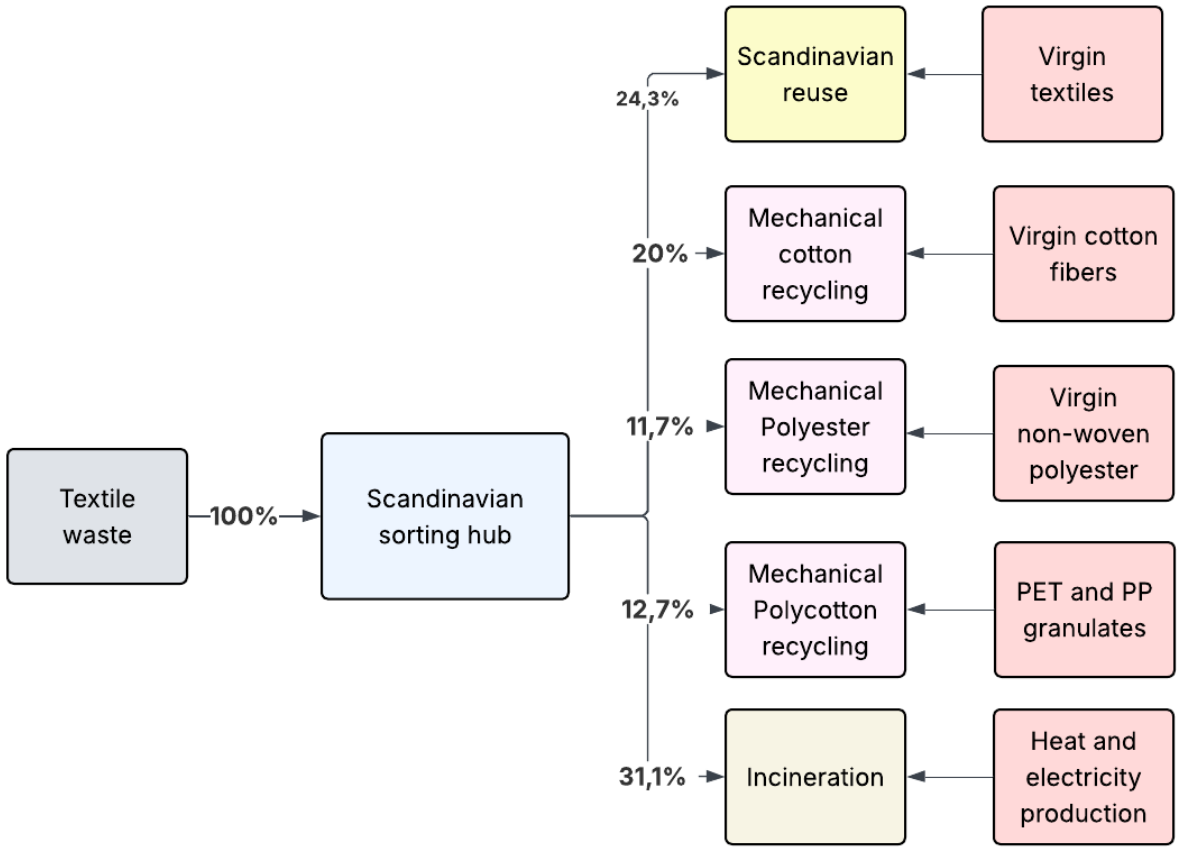



**Figure 22: Flowchart of the mass flows, for the reuse and mechanical recycling scenario (4b)**

### Regional sorting for reuse and chemical recycling (4c)

This scenario is a combination of scenario 2b and 3c.

This scenario models a regional Scandinavian sorting facility, which sorts out fibres fit for reuse in the EU, and for chemical recycling for the volumes which are left. This is illustrated in Figure 23.

These are cotton, polycotton and polyester garments which have at least a fibre purity of 95%, which have no membranes nor prints, and that are not soiled. These are high requirements, and manipulation of the NTNU database shows that the following shares of the fibre types are fit for chemical recycling:

- 46% of the cotton flow
- 65%  of the polycotton flow
- 35% of the polyester flow

This means that, in this scenario, larger volumes are being incinerated compared to the other recycling scenarios. The volumes for chemical recycling are sent facilities located in Scandinavia, using Infinite Fibre in Finland and Circulose om Sweden as recipient facilities for calculating transport distances from the sorting hubs.

It is assumed that the chemical recycling of cotton, polyester and polycotton substitutes virgin viscose fibres, virgin PET granulates and wood pulp and virgin polyester fibres, respectively.

The remaining volumes are being incinerated regionally. The heat and electricity produced by the incineration process in a combined heat and power plant replaces Scandinavian electricity and heat through district heating. The substitution was modelled according to the LHV of the various fibre types and the efficiency of the incineration plant. Chemical recycling is currently not commonly used, and represent hence a future scenario.

It models a regional Scandinavian sorting facility, which sorts out textiles for reuse, and thereafter textiles which are not soiled to a chemical recycling process located in the EU, creating different products. It is assumed that the chemical recycling of cotton, polyester and polycotton substitutes pulp wood, fossil feedstock and wood pulp, respectively. The remaining fraction, assumed as soiled textiles, is being incinerated locally, replacing Scandinavian heat and electricity production. This scenario represents a best-case scenario following the waste management hierarchy, starting with the recovery of usable textiles, and thereafter high-value recycling for the textiles which are not in good condition.

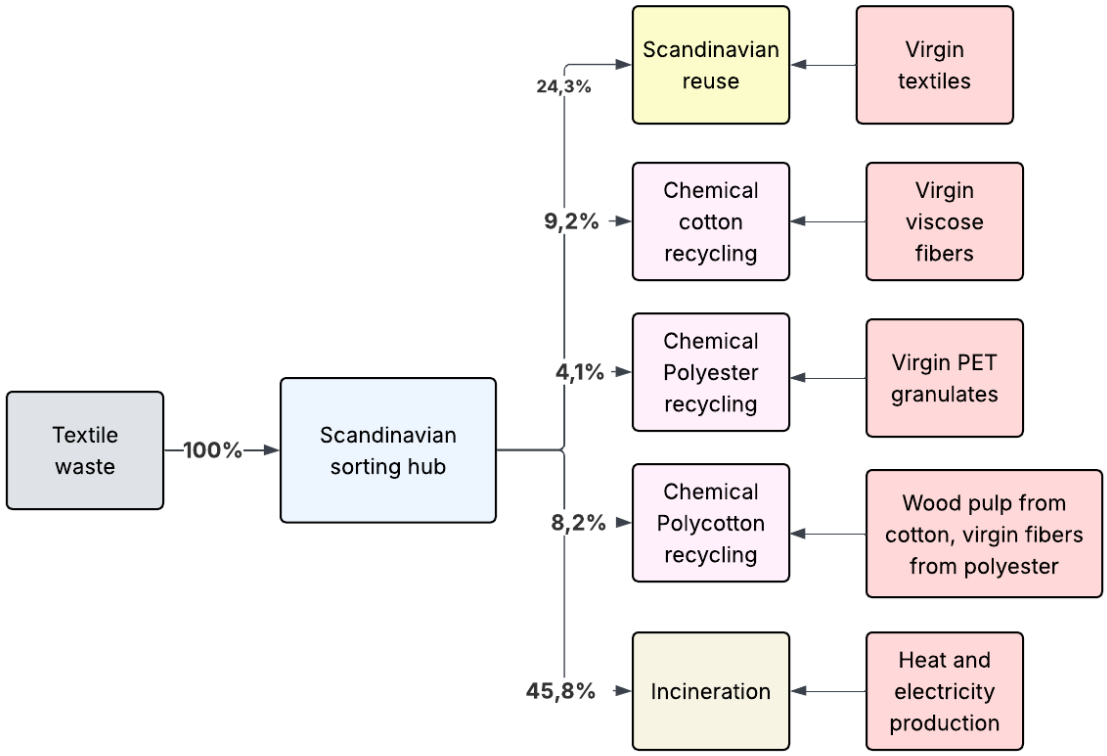



**Figure 23: Flowchart of the mass flows, for the reuse and chemical recycling scenario (4c)**

## 3.3 Data collection and inventory

### 3.3.1 Incineration

Specific datasets for incineration of various fibre types were not available. Therefore, ecoinvent proxies were used, as specified in Table 10. It is assumed that incinerating polyester gives the same emissions as plastics, and that incinerating cotton gives the same emissions as paperboard. The incineration of soiled textiles includes moisture and soil spills on the textiles. The results were comparable to the direct emissions of

incinerating cotton and polyester waste calculated by {POSTOLACHE, 2024 #7016}, which shows that the proxies are reliable.

**Table 10: Selected ecoinvent processes for incineration**

| Incineration of fibres | Ecoinvent process |
|---|---|
| **Cotton** | Waste paperboard {CH}\| treatment of waste paperboard, municipal incineration with fly ash extraction \| Cut-off, U |
| **Polyester** | Waste plastic, mixture {Europe without Switzerland}\| treatment of waste plastic, mixture, municipal incineration \| Cut-off, U |
| **Soiled textiles** | Waste textile, soiled {CH}\| treatment of waste textile, soiled, municipal incineration FAE \| Cut-off, U |

### 3.3.2 Sorting

We distinguish between municipal and regional sorting. With municipal sorting, we mean manual sorting, mainly for taking out reusable qualities from the waste flows. With regional sorting, we mean a bigger facility which can sort out either reusable textiles or specific fibres. Note that the literature reports a very large range of values for electricity consumption for sorting facilities, varying one order of magnitude. The inventory for the two processes is presented in Table 11.

**Table 11: Inventory of the sorting processes**

| Process | Inventory flow | Unit per tonne | Value | Source |
|---|---|---|---|---|
| **Municipal sorting** | Electricity | kWh | 16 | Solis et al. (2024). |
| **Regional sorting (Scandinavian sorting hub)** | Electricity | kWh | 100 | Personal Communication |

Two regional sorting hubs are identified based on the partner's geographical location and the existing, or planned, sorting facilities, as well as the textile waste volumes generated yearly (Figure 24). Trondheim is building a new sorting facility and is the area with greatest textile waste volumes generated yearly, as well as a natural midpoint for all partners included in this study. Trondheim is therefore the location for a regional sorting hub. In addition, in dialog with partners, a sorting hub for Luleå and Oulu in the port town Kemi was identified. Kemi is in Finland and has an easy access to textile waste facilities in Europe by ship. This town is therefore included as the second potential regional hub.




**Figure 24: Map of the study's sorting center locations**

### 3.3.3 Reuse

The inventory for the reuse scenarios covers sorting, which consumes electricity and heat (Table 12).

**Table 12: Inventory of the reuse system**

| Process | Inventory flow | Unit per tonne | Value | Source |
|---|---|---|---|---|
| **Municipal sorting hub** | Electricity | kWh | 16 | Solis et al. (2024) |
| | Heat | MJ | 30 | Solis et al. (2024) |
| **Central sorting in Europe and Africa** | Electricity | kWh | 250 | Solis et al. (2024) |
| | Heat | MJ | 30 | Solis et al. (2024) |
| | Water | 0,11 | l | Solis et al. (2024) |

### 3.3.4 Recycling

There exists a plenitude of different recycling technologies (see also section 0), but few of them have inventories that can be used in LCA calculations. Table 13 is a matrix of the recycling technologies that exist for each fibre types, represented with crosses. Note that this is a non-exhaustive list, based on (McKinsley, 2022).

The project mapped the main fibre types present in the waste composition with existing recycling technologies available on the market, for which there also exist inventory data, making an LCA analysis possible. The highlighted green cells in Table 13 show the technologies for which life cycle inventory data was found, which has been used in this study. Note that some LCA studies exist for other recycling

technologies than what has been used in this study, but they represent technologies at lab and pilot scale, and where therefore assessed as unfitted for this study.

**Table 13: Mapping of the available recycling technologies per fibre type, represented with crosses, and available life cycle inventory data, represented with green cells.**

| Recycling technologies | Output | Technology undertype | Fibres | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Cotton | MMCF | Polycotton | Polyester | Polyamide | Wool | Blends |
| **Mechanical** | Open-loop (fluff, fibre, filling materials) | | x | x | x | x | x | x | x |
| | to fibres | | x | | x | x | x | | |
| **Thermo-mechanical** | to polymer | | | | | x | x | | |
| **Thermo-chemical** | to monomer | | | | | x | x | | |
| **Chemical recycling** | to polymer | Pulping | x | x | x | | | | |
| | | solvent-based | | x | x | x | | | |
| | | Hydrothermal | | x | x | x | | | |
| | to monomer | Methanolysis | | | | x | | | |
| | | Glycolysis | | | | x | | | |
| | | Hydrolysis | | | | x | x | | |
| | | Enzymatic | | | x | x | | | |

Detailed inventories for recycling were found in the literature and used in the modelling of this study (Table 14). There are, in other words, technologies which exist and are currently operational for textile recycling, but which are not modelled due to a lack of inventory data. However, infrastructure (machines, buildings, ect) is not included in the inventory.

**Table 14: Inventory of the recycling processes**

| Process | Inventory flow | Unit per tonne | Value | Source |
|---|---|---|---|---|
| **Pre-treatment for mechanical recycling** | Electricity | kWh | 492,4 | SPATHAS (2017). European electricity mix was used. |
| **Mechanical processing, for open loop recycling of cotton, polyester and polycotton** | Electricity | kWh | 396,8 | Tom Duhoux and Maarten Christis (2021), from Solis et al. (2024). European electricity mix was used. |
| | Treatment of metal scrap (divided equally on copper, aluminium and iron) | t | 0,05 | Tom Duhoux and Maarten Christis (2021) |
| | Incineration of textile dust from the recycling process | t | 0,03 | Tom Duhoux and Maarten Christis (2021) |

| | | | | |
|---|---|---|---|---|
| **Mechanical processing of cotton, polyester and polycotton** | Electricity | kWh | 500 | Tom Duhoux and Maarten Christis (2021). European electricity mix was used. |
| | Water | l | 20 | Tom Duhoux and Maarten Christis (2021) |
| | Treatment of metal scrap (divided equally on copper, aluminium and iron) | t | 0,05 | Tom Duhoux and Maarten Christis (2021) |
| | Incineration of textile dust from the recycling process | t | 0,03 | Tom Duhoux and Maarten Christis (2021) |
| **Pre-treatment for chemical recycling** | Electricity | kWh | 93 | SPATHAS (2017). European electricity mix was used. |
| **Chemical recycling of cotton, by pulping** | Electricity | kWh | 412,2 | Solis et al. (2024). European electricity mix was used. |
| | Water | l | 3188 | Solis et al. (2024) |
| | Sodium Hydroxide | t | 0,0256 | Solis et al. (2024) |
| | Sulfuric acid | t | 0,0058 | Solis et al. (2024) |
| | Steam | t | 0,2918 | Solis et al. (2024) |
| | Treatment of metal scrap (divided equally on copper, aluminium and iron) | t | 0,05 | Tom Duhoux and Maarten Christis (2021) |
| **Chemical recycling of polycotton to polymers, for recovery of PE** | Electricity | kWh | 1307 | Solis et al. (2024). European electricity mix was used. |
| | Water | l | 272000 | Solis et al. (2024) |
| | Sodium Hydroxide | t | 0,0256 | Solis et al. (2024) |
| | Sulfuric acid | t | 0,0058 | Solis et al. (2024) |
| | Steam | t | 0,2918 | Solis et al. (2024) |
| | Solvent | t | 0,0011 | Solis et al. (2024) |
| | Treatment of metal scrap (divided equally on copper, aluminium and iron) | t | 0,05 | Tom Duhoux and Maarten Christis (2021) |
| **Chemical recycling of polycotton to polymer, for recovery of cotton** | Electricity | kWh | 3770 | Solis et al. (2024). European electricity mix was used. |
| | Water | l | 272000 | Solis et al. (2024) |
| | Sodium Hydroxide | t | 0,62 | Solis et al. (2024) |
| | Ethylene glycol | t | 0,14 | Solis et al. (2024) |
| | Chemicals, aromatic | t | 0,46 | Solis et al. (2024) |
| | Treatment of metal scrap (divided equally on copper, aluminium and iron) | t | 0,05 | Tom Duhoux and Maarten Christis (2021) |
| **Chemical recycling of polyester to monomers, by glycolysis** | Electricity | kWh | 2259,7 | Nordberg et al. (2026). European electricity mix was used. |
| | Water | l | 15071 | Nordberg et al. (2026) |
| | Diethyl ether | t | 30 | Nordberg et al. (2026) |
| | Iron sulphate | t | 1 | Nordberg et al. (2026) |

| | | | | |
|---|---|---|---|---|
| | methanol | t | 157 | Nordberg et al. (2026) |
| | Ethylene glycol | t | 490 | Nordberg et al. (2026) |
| | Potassium acetate | t | 20 | Nordberg et al. (2026) |
| | detergent | t | 11 | Nordberg et al. (2026) |
| | Treatment of metal scrap (divided equally on copper, aluminium and iron) | t | 0,05 | Nordberg et al. (2026) |

### 3.3.5 Transport

#### To incineration

Transport to the incineration facility is assumed to happen with diesel trucks (EURO6), travelling a distance of 25 km, based on the conducted interviews. In the remote incineration scenario, this distance is increased to 300 km. generic ecoinvent datasets were used, with average load factors.

#### To sorting

Average transport distances to the sorting hubs is presented in Table 15.

**Table 15: Average transport distances in kilometres (km) to the potential Scandinavian sorting hubs.**

| Municipality | Sorting hub 1: Kemi (FI) | Sorting hub 2: Trondheim (NO) |
|---|---|---|
| **Trondheim** | 740 | 0 |
| **Tromsø** | 910 | 1150 |
| **Åre** | 610 | 165 |
| **Luleå** | 120 | 820 |
| **Oulu** | 105 | 1070 |
| **Average** | 500 | 640 |

#### To reuse

The transport distances and modes to reuse vary in the three reuse scenarios modelled and presented in Table 16.

**Table 16: Transport inventory for the reuse scenarios**

| Scenarios | Reuse location | Transport distance | Transport mode and comments | Source |
|---|---|---|---|---|
| **2a** | Local | - | - | |
| **2b** | Europe | 2700 km | Maritime transport - Boat | From Kemi sorting hub to Rotterdam |
| | | 1300 km | Maritime transport - Boat | From Trondheim sorting hub to Rotterdam |
| | | 500 km | 16-32 tonne (EURO6) diesel truck | From Rotterdam to Frankfurt |
| **2c** | Sub-Saharan Africa | 1150 km | 16-32 tonne (EURO6) diesel truck | Trzepacz et al. (2023) |

| | | | |
|---|---|---|---|
| | 6282,83 km | Maritime transport - Boat to Kenya | Trzepacz et al. (2023) |
| | 441,97 km | 16-32 tonne (EURO3) truck | Trzepacz et al. (2023) |

### To recycling

The transport distances and modes to reuse vary in the three reuse scenarios modelled and presented in Table 17.

**Table 17: Transport inventory for the recycling scenarios**

| Scenarios | Recycling location | Transport distance | Transport mode | Comment |
|---|---|---|---|---|
| **3a** | Europe | 2700 km | Maritime transport - Boat | From Kemi sorting hub to Rotterdam |
| | | 1300 km | Maritime transport - Boat | From Trondheim sorting hub to Rotterdam |
| | | 800 km | 16-32 tonne (EURO6) diesel truck | Assuming that the open loop facility of TEXAID (Switzerland) is being used |
| **3b** | Scandinavia | 1000 km | 16-32 tonne (EURO6) diesel truck | Assuming that the mechanical facilities of Rester (Finland) and Norwegian Re:Textile (Norway) are being used |
| **3c** | Scandinavia | 700 km | 16-32 tonne (EURO6) diesel truck | Assuming that the chemical facilities of InfiniteFibre (Finland) and Circulose (Sweden) are being used |

## 3.3.6 Substitution

### From incineration

It is assumed that incineration replaces electricity and heat through substituting district heating. The electricity-generation efficiency was assumed to be 35%, and the utilization factor was set at 21.4%, based on figures from Raadal et al. (2009). This resulted in an energy recovery share of 7.49% for electricity. The correct national district heating fuel composition is modelled, as in Table 18.

**Table 18: Composition of the substituted district heating for Norway, Sweden and Finland.**

| | Norway | Sweden | Finland |
|---|---|---|---|
| **Natural gas** | 4 % | 0 % | 9 % |
| **Bioenergy** | 57 % | 87 % | 62 % |
| **Heat pumps** | 18 % | 0 % | 21 % |
| **Electricity** | 19 % | 11 % | 5 % |
| **Fossil oil** | 2 % | 2 % | 4 % |
| **Coal** | 0 % | 0 % | 6 % |
| **Source** | Fjernvarme (2026) | Energi Foretagen (2024) | Finnish Energy (2025) |
| **Year** | 2025 | 2025 | 2024 |

### From reuse

Woven cotton and polyester textiles are assumed to be replaced in the reuse scenarios. In a reuse context, it is of common understanding that the replacement rate for garments is not 1:1. Following the approach of Trzepacz et al. (2023) for B-grade t-shits, a replacement rate of 0,4 per garment is used.

It should be noted that this is a replacement rate for Nordic conditions, which was also applied in the African reuse scenario. However, it can be assumed that the replacement rate – which is highly defined by consumption patterns – would vary across countries and continents. More research is needed to confirm replacement rates for garments in different regions.

### From recycling

Table 19 presents a selection of treatment pathways provided by Solis et al. (2024), that has been used in this study.

It should be noted that these assumptions are important for the results. However, because the ecosystem for textile waste recycling is only at early stages, it is difficult to know with certainty which products are created from the various technologies, as they depend on the specific technology used, and differences between facilities. An approach based on using literature data was therefore followed. Solis et al. (2024)obtained the pathway-specific substitution factors from existing literature and experts' judgement at the stakeholder consultations.

For a future and more detailed and higher quality assessment, the products created from the different production facilities should be analysed, rather than using averages, as has been done here. For instance, it is likely that textile waste from the NPR area is sent to facilities nearby, such as CIRCULOSE in Sweden, who create an intermediate material, which can be used for several applications. It is difficult to say with certainty what would have been substituted with this recycling technology.

**Table 19: Substitution from the various recycling technologies.**

| Fibre type | Technology | Product | Avoided product | Substitution factor |
|---|---|---|---|---|
| **Cotton** | Open loop | Fluff | Wipers from woven cotton (40% recycled materials) | 0,6 |
| | Mechanical recycling | Fibres | Virgin cotton fibres, for textile production | 0,53 |
| | Chemical recycling | Cellulose pulp | Virgin viscose fibre, for textile production | 1 |
| **Polycotton** | Open loop | Fibres | Insulation materials (stone wool) | 0,67 |
| | Mechanical recycling | Fluff | PET and PP granulates | 0,25 PET granulate, 0,25 PP granulate |

| | | | | |
|---|---|---|---|---|
| | Chemical recycling (cotton) | Cellulose | Wood pulp | 1 |
| | Chemical recycling (polyester) | PET | Virgin fibres (non-woven polyester) | 0,53 |
| **Polyester** | Open loop | Fluff | Virgin polyester wipers (40% recycled materials) | 0,6 |
| | Mechanical recycling | Fibres | Virgin non-woven polyester | 0,53 |
| | Chemical recycling, glycolysis | PET | Virgin PET granulate | 1 |

## 3.4 Environmental Impact Assessment

SimaPro 10.3.0.4 and ecoinvent 3.12 (Wernet, 2016) were used to perform this study, using a cut-off approach. The results are presented for fossil Global Warming Potential (GWP) in a 100-year perspective (GWP100), using IPCC 2021. The results are expressed in $CO_2$ equivalents.

Ideally, the assessment would have included a broader set of environmental impact categories. However, limitations in data availability, together with the project's time and budget constraints, required the analysis to focus on global warming potential (GWP). This focus was considered the most feasible approach for providing a robust and comparable assessment within the scope of the study.

## 3.5 Results

The results chapter will first dive into each treatment alternative (3.5.1 -0), before summing them up and looking at the bigger picture (section 3.5.5 ).

### 3.5.1 Incineration scenarios

Figure 25 present the results for the incineration scenarios, split on the locations under study (Norway, Sweden, Finland). These results are the benchmarks that the remaining results will be seen against.

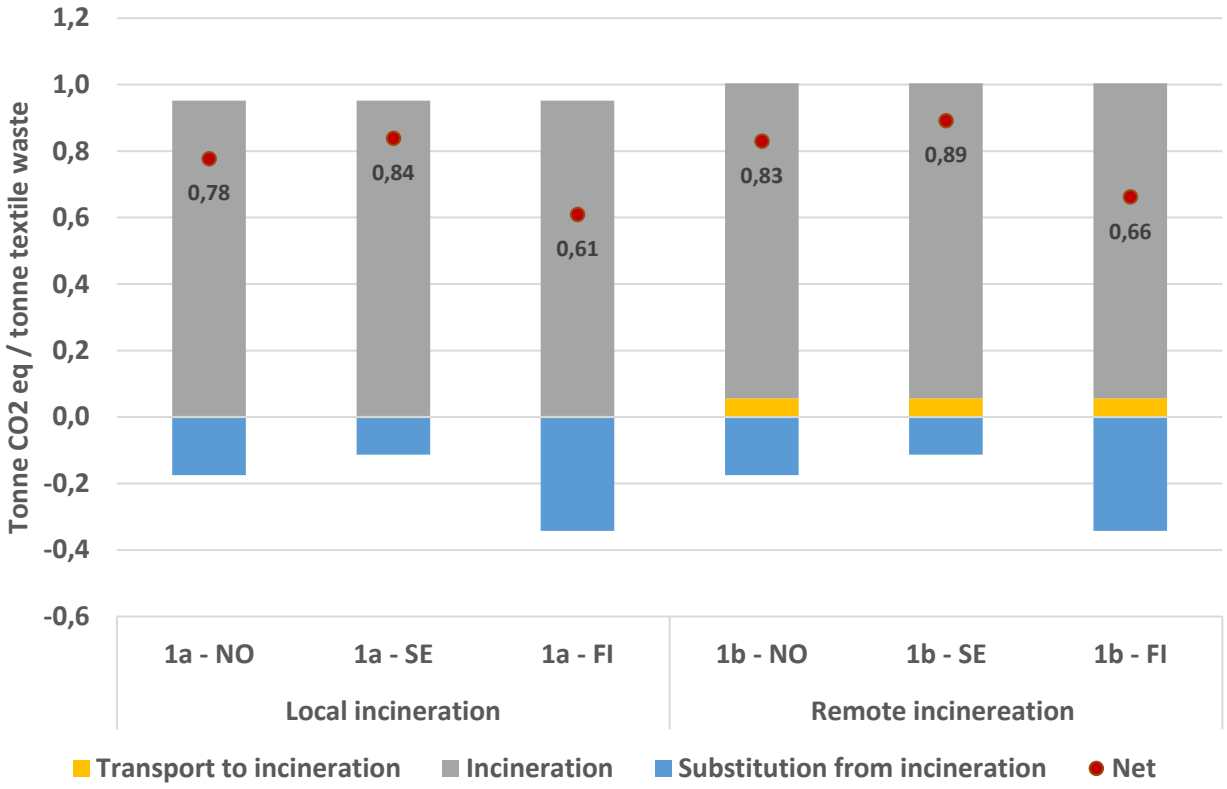



**Figure 25: Detailed results for local (1a) and remote (1b) incineration scenarios of textile waste, in Norway, Sweden and Finland.**

The results shows that the incineration of textile waste leads to potential global warming impacts, ranging between 0,61 and 0,89 tonne of $CO_2$ eq. per tonne textile waste handled (scenario 1a). Some heat and electricity are replaced, contributing to a small reduction in the net emissions. Because the fuels in the Norwegian, Swedish and Finnish district heating systems vary, the scenarios also replace different fuel types, which is the reason for which the substituted energy vary between the scenarios. The Finnish system is the most carbon intensive, which means that replacing its fuels leads to more negative emissions than for the two other countries. Transport has a minor contribution compared to the incineration process itself, also when the transport distances are increased from 25 km to 300 km (scenario 1b), only increasing the net emissions with 0,05 tonnes $CO_2$ eq.

### 3.5.2 Reuse scenarios

Figure 26 present the results for the reuse scenarios. The first scenario (2a) is split on the locations under study (Norway, Sweden, Finland) for local reuse. The second (2b) and third (2c) scenarios are split on the sorting hub localities (Kemi in Finland and Trondheim in Norway).

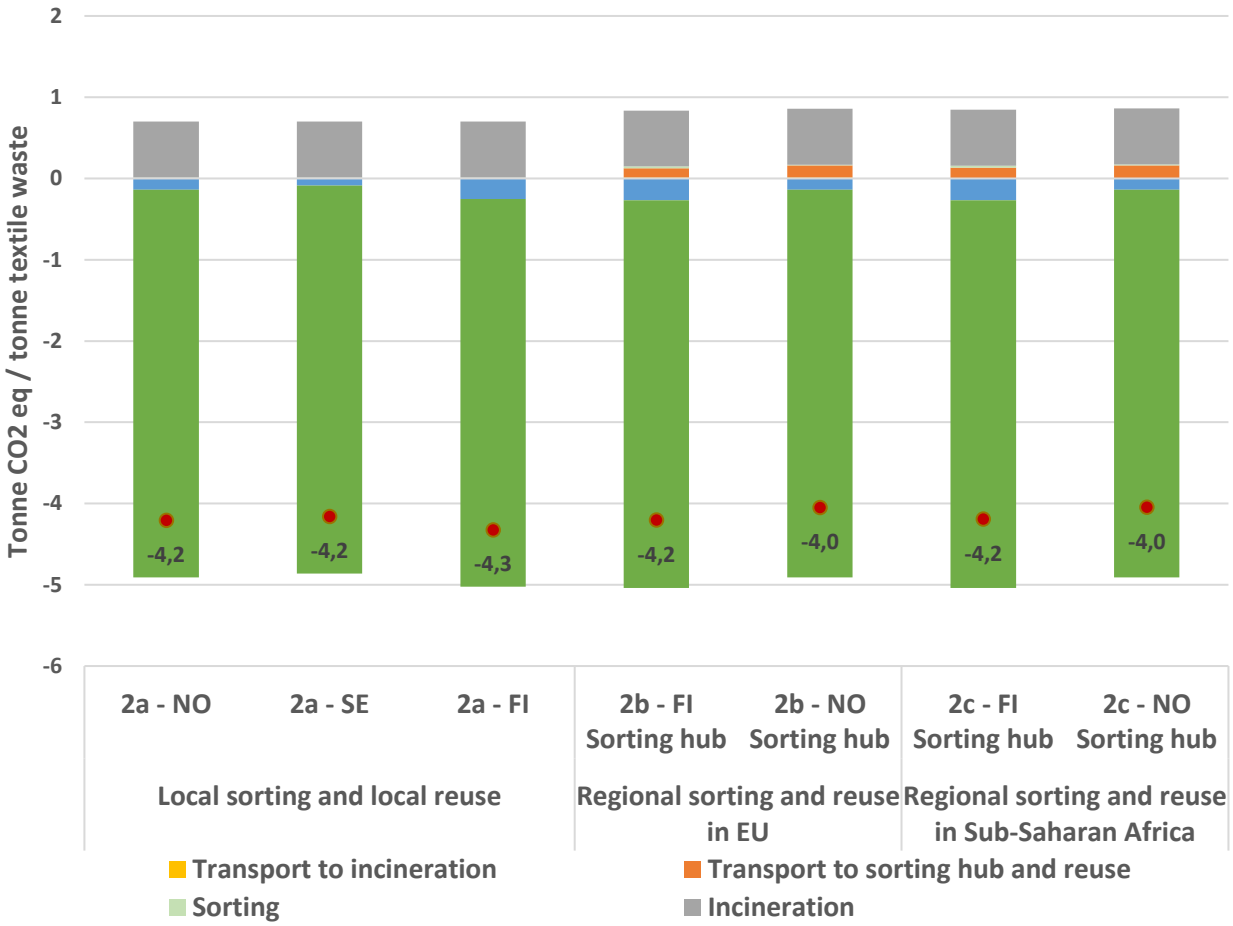



**Figure 26: Detailed results for local sorting and reuse (2a), regional sorting and European reuse (2b) and regional sorting for African reuse (2c)**

The results show that reuse scenarios give clear climate benefits, ranging between -4,0 and -4,3 tonne $CO_2$ eq. per tonne textile waste.

The benefits come from the replacement of virgin garments, using a replacement rate of 0,4. It must be remembered that these are best case scenarios, as they assume that the entire share of reusable textiles is actually replaced, which is most likely unrealistic. The results should be addressed with care. In fact, it is assumed that all garments classified with the highest reuse potential are being reused and replace partially new garments. However, the market for second-hand garments is known to be very low, especially in the Scandinavian countries. Hence, the local reuse scenarios are most likely difficult to achieve, as the marked is assumed not to be large enough. In addition, reuse of the waste flow might however be difficult to achieve. If textiles are collected in one flow, soiled textiles can for instance degrade the quality of the garments with high reuse potential.

Transport to the sorting hubs and the sorting itself make low contribution to the total results. Transport to Europe and to Africa, being mainly maritime transport, also has very little influence on the total results, contributing only minorly.

Incineration of the flow with no reuse potential leads to climate emissions, also partially offset by the replacement of heat and electricity.

### 3.5.3 Recycling scenarios

Figure 27 present the results for the recycling scenarios, all split on the sorting hub localities (Kemi in Finland and Trondheim in Norway). The first scenario (3a) represents open loop recycling, the second (3b) mechanical recycling and the third (3c) chemical recycling.

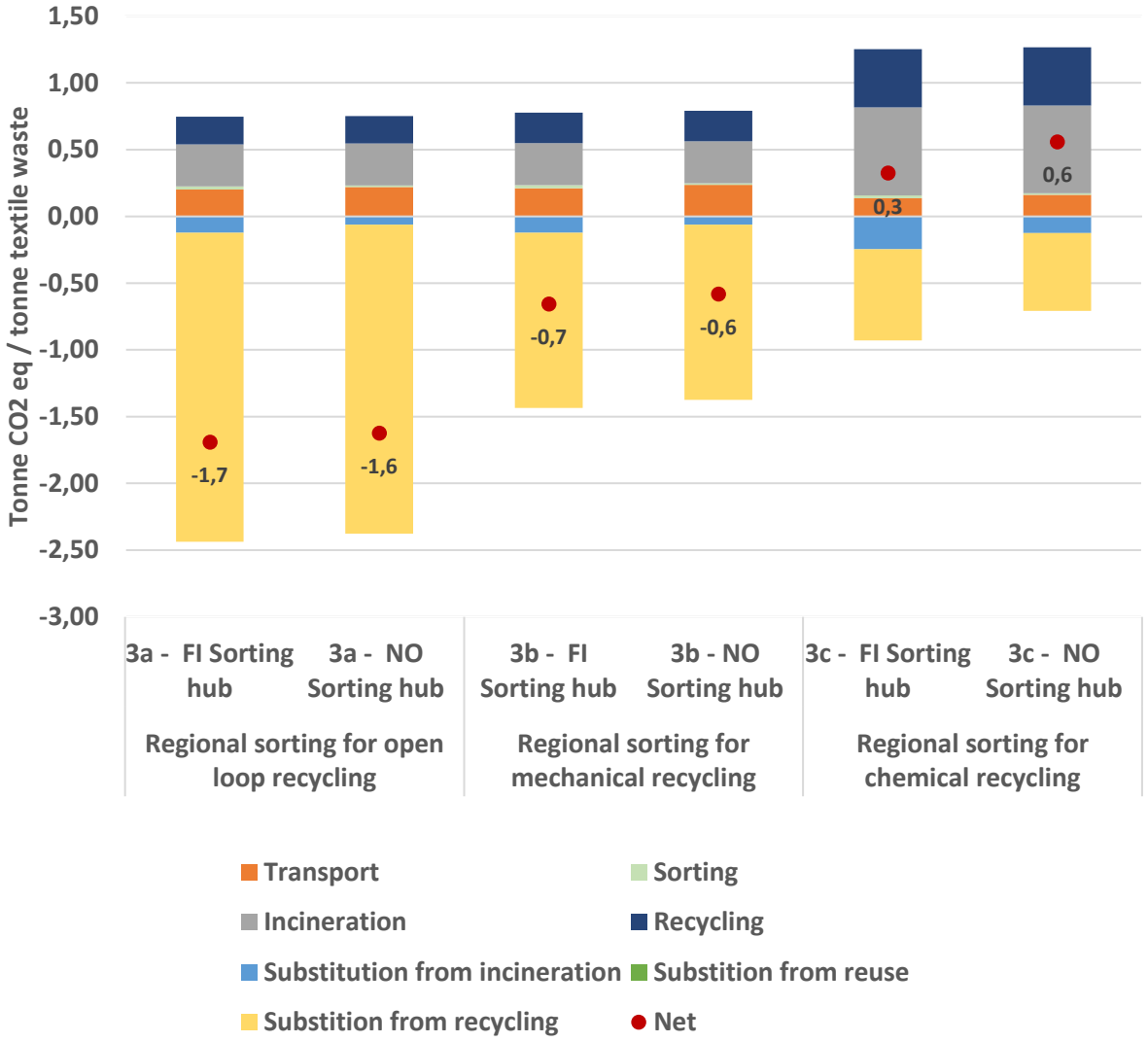



**Figure 27: Detailed results for open loop recycling (3a), mechanical recycling (3b), chemical recycling (3c).**

The results show that the open loop and mechanical recycling scenarios lead to climate benefits, while the chemical recycling leads to net climate impact (0,3 to 0,6 tonnes $CO_2$ eq. per tonne textile waste) – however still lower that the incineration benchmarks (Figure 25), and that open loop recycling leads to lower climate impact (-1,6 to -1,7 tonnes $CO_2$ eq. per tonne textile waste) than for mechanical recycling (-0,6 to -0,7 tonnes $CO_2$ eq. per tonne textile waste).

The offsetting of carbon emissions is larger when replacing wipers from open loop recycling, than for fibres or pulp and granulates from mechanical and chemical recycling, respectively. In open loop, a whole product is replaced, while in mechanical recycling, one moves higher up the value chain, replacing fibres, that the fabrics are made of. With chemical recycling, one moves even higher up the value chain, creating pulp and granulate, which the fibres are made of. This, however, only is true if the downstream market is not saturated. In fact, if all textile waste were downcycled, there might be created more wipers than what there

is demand for. In contrast, fibres and pulp/plastic granulates can be used for making a large range of products, being therefore more sought after and valuable products.

It must be remembered that these are best case scenarios, meaning that the results should be addressed with care. In the open loop and mechanical recycling scenarios, all the flow of cotton, polycotton and polyester are for instance assumed to be recycled, which is most likely an overestimation. However, no quality requirements were found for these recycling methods, which further research should dive deeper into, for instance by contacting operating facilities. The impacts from open loop and mechanical recycling especially are therefore likely to be higher than these results show.

### 3.5.4 Combination of reuse and recycling

Figure 28 present the results for the reuse and recycling scenarios, all split on the sorting hub localities (Kemi in Finland and Trondheim in Norway). The first scenario (4a) represents European reuse and open loop recycling, the second (4b) represents European reuse and mechanical recycling and the third (4c) represents European reuse and chemical recycling.

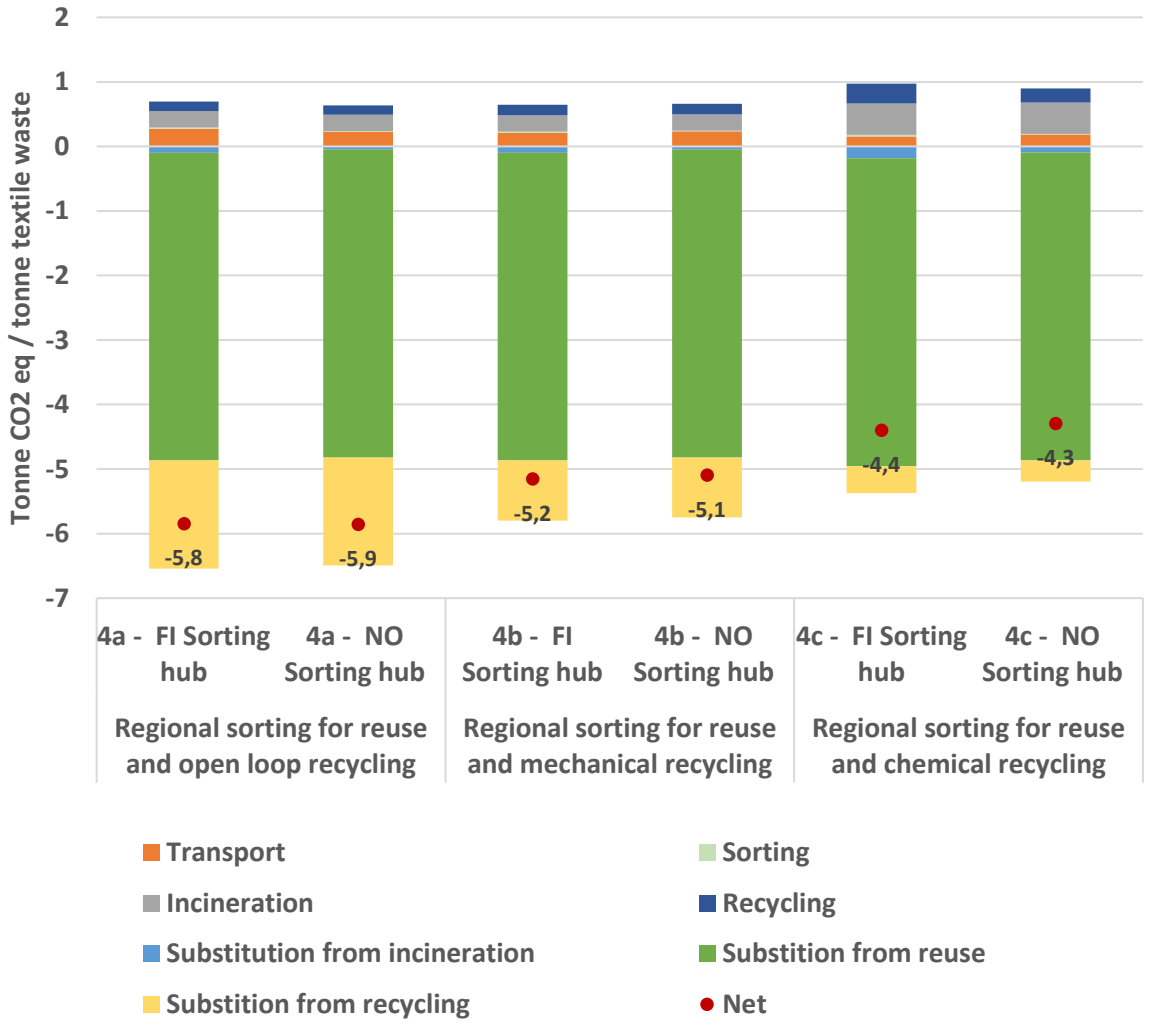



**Figure 28: Results for the scenarios combining reuse and the various recycling processes.**

The results show that all scenarios lead to negative net emissions, ranging between -5,9 to -4,3 tonne $CO_2$ eq per tonne textile waste.

The benefits come from the replacement of virgin garments, as detailed in section 3.5.2 . In addition, benefits are gained from substituting wipers, fibres and pulp/plastic granulates, as detailed in section 3.5.3 .

### 3.5.5 Overall results

For comparing the results across scenarios, it was chosen to take out the results for Norwegian conditions, presented in Figure 29.

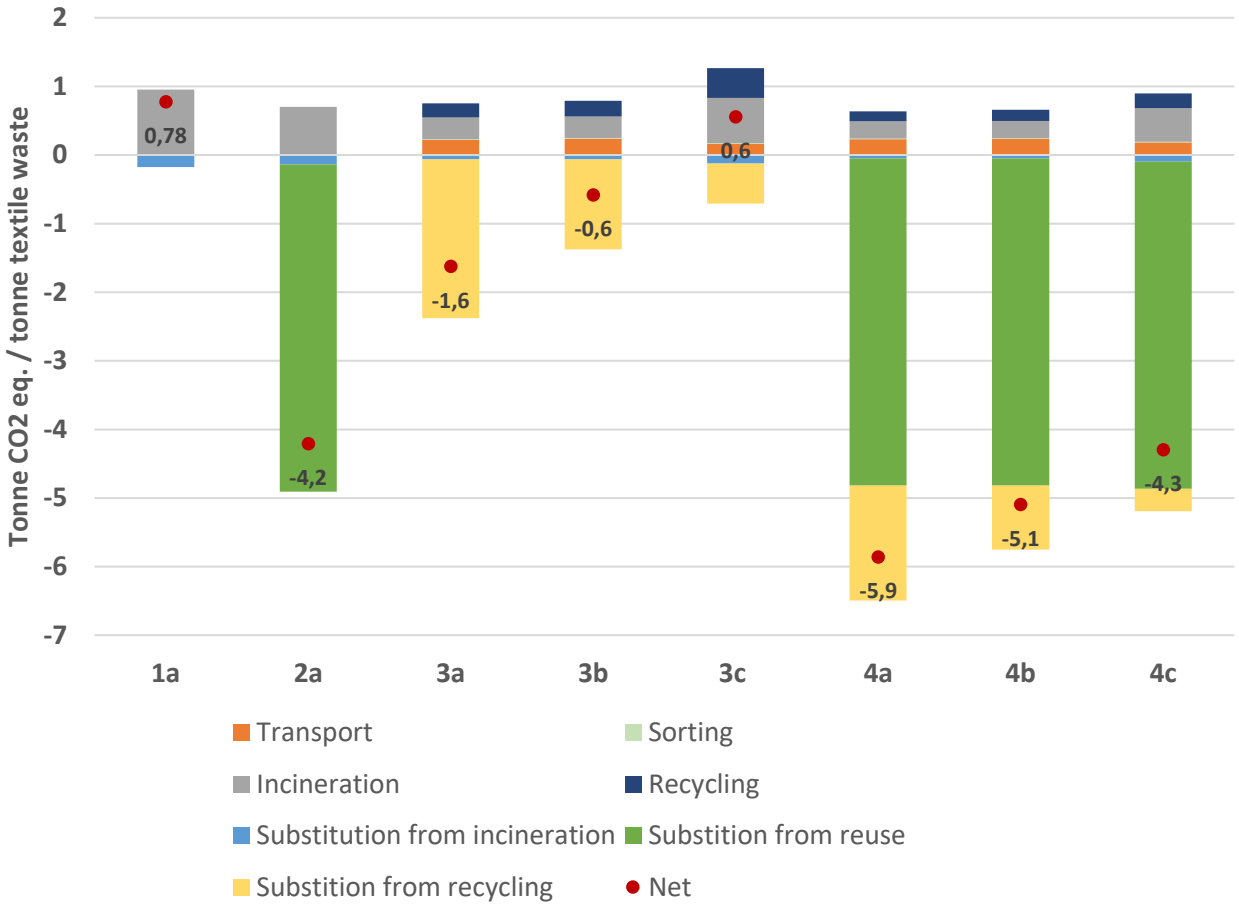



**Figure 29: Combination of results for scenarios for Norwegian conditions, in order to have a common ground for comparisons, benchmarked against the reference scenario (1a)**

The main conclusions that can be drawn from the analysis are the following:

- Incinerating textile waste leads to the highest carbon emissions, across all assessed scenarios, and is therefore the least preferred option.
- Sorting textile waste for reuse and recycling gives the largest climate benefits, especially when treated with open loop recycling.
- The system is very sensitive to what is being substituted. In all scenarios, some products or energy is being substituted, which creates a climate benefit (for fossil $CO_2$) in all scenarios.
- Substituting garments through reuse is what leads to the largest climate benefits.
- Substituting products through open loop recycling leads to higher environmental benefits than substituting fibres, created through mechanical recycling, which again leads to larger environmental benefits than substituting pulp/plastic granulates, created through chemical recycling.
- Transport-related emissions are relatively small compared to the rest of the system.

## 3.6 Sensitivity analysis

### 3.6.1 Transport

Because this project has an emphasis on transport distances, it was decided to assess even further the transport to sorting and handling. This was done by increasing the transport distances three-fold, which would still represent realistic scenarios – e.g. the municipality of Tromsø sending their waste to southern Norway, and the volumes therefrom sent to southern Europe for further treatment.

The results, presented in Figure 30; show that the conclusions presented in section 5.4. still hold.

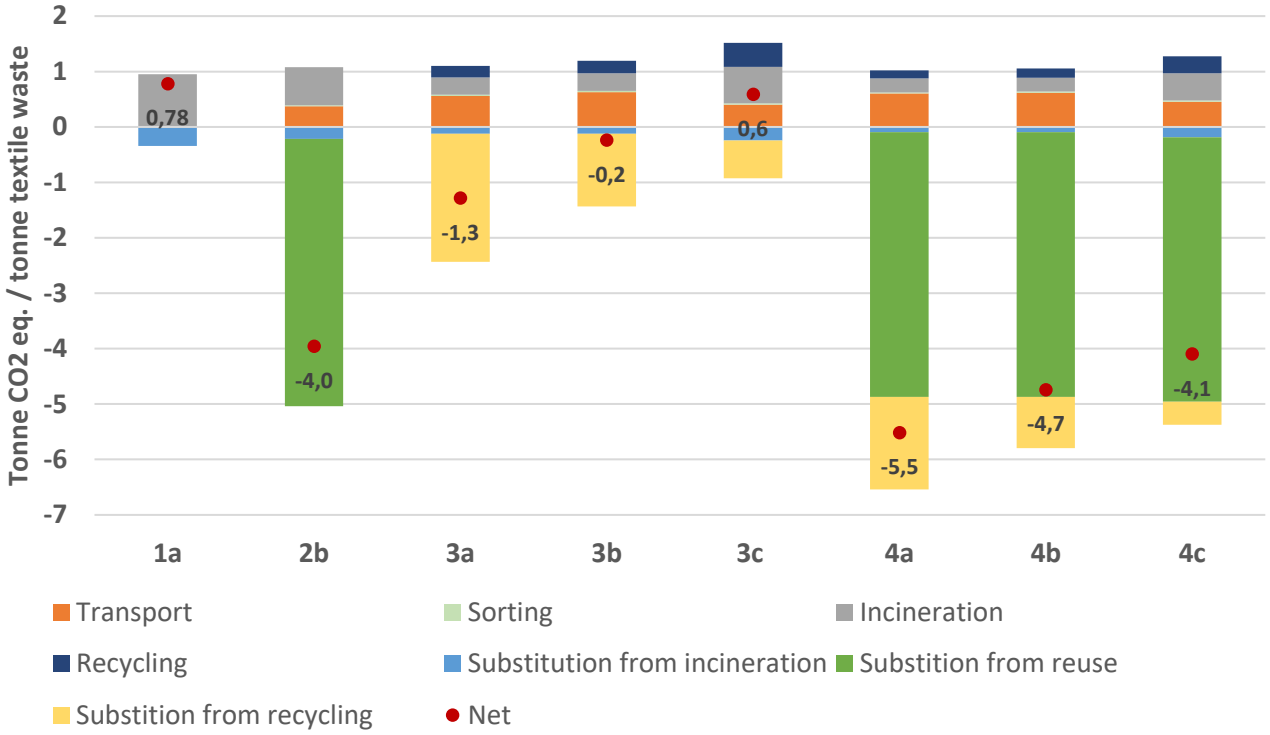



**Figure 30: Results of the sensitivity analysis for transport distances**

However, we can see that scenario 3c (chemical recycling) now leads to net climate emissions, when transport distances are increased three-fold, which leads to the conclusions that transport distances are relevant to monitor for this scenario.

Figure 31 further shows a trade-off analysis of transport distances against this scenario. A break-even point for the chemical recycling scenario is reached when road transport fuelled on diesel increases with:

- For Finland: 3500 km (Equals a distance between Oulu and Marseille).
- For Norway: 5500 km (Equals a distance between Tromsø and Madrid).
- For Sweden: 5900 km (Equals a distance between Luleå and Beyrouth).

This means that it would be more beneficial to incinerate the textile waste rather than sorting it out for chemical recycling.

Other transport modes, such as maritime and train transport, have a lower impact, about 25% and 5% of the climate burden per km, respectively, which means that this conclusion only is true if diesel trucks are used for transport.

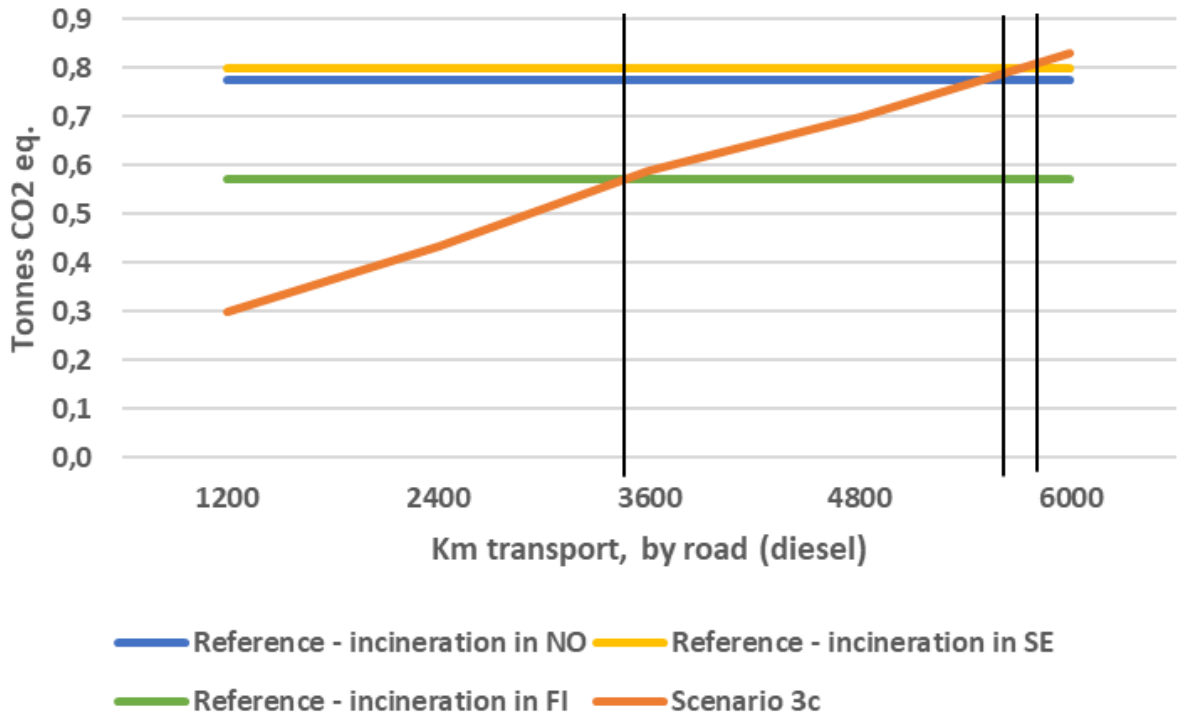



**Figure 31: Break-even points analysis for transport distances, for the chemical recycling scenario (3c) benchmarked against the reference scenario (1a)**

### 3.6.2 Composition of the functional unit

The results are determined by the composition of the waste. This parameter was tested by using values from Wasted Textiles (Table 21), altering the fibre composition of the functional unit.

**Table 20: Composition of textile waste by fibre type, according to the Wasted Textile project.**

| Data from wasted textiles, used for sensitivity analysis | Weight reusable | Weight Waste |
|---|---|---|
| **Mainly cotton** | 40,96 % | 49,82 % |
| **Mainly linen** | 0,03 % | 0,03 % |
| **Mainly silk** | 0,26 % | 0,27 % |
| **Mainly synthetic** | 13,19 % | 11,61 % |
| **Mainly wool** | 2,49 % | 2,16 % |
| **Mixed fibres (nothing over 60%)** | 41,48 % | 34,42 % |
| **Mainly other** | 0,02 % | 0,02 % |
| **Mainly viscose** | 1,58 % | 1,67 % |

Because the categories do not correspond directly to the composition of the functional unit used in this study, a mapping into the correct categories had to be performed (Table 21).

**Table 21: Mapping the fibre composition of the functional unit against data from the Wasted Textile project**

| | Mapping into the categories used in this study | Recycling | Reuse |
|---|---|---|---|
| **Cotton** | Mainly cotton | 0,50 | 0,41 |
| **Polycotton** | Mixed fibres (nothing over 60%) | 0,34 | 0,41 |
| **Polyester** | Mainly synthetic | 0,12 | 0,13 |
| **Other natural fibres** | Mainly linen + Mainly silk + Mainly wool + Mainly viscose | 0,04 | 0,04 |
| **Other synthetic fibres** | | | 0,00 |
| **Soiled textiles** | Mainly other | 0,0002 | |

Figure 32 presents the overall results, comparable to Figure 29, but with an altered fibre composition of the functional unit. The results show that the absolute values are altered, but that the ranking between the alternatives still hold, which strengthens the conclusions presented above.

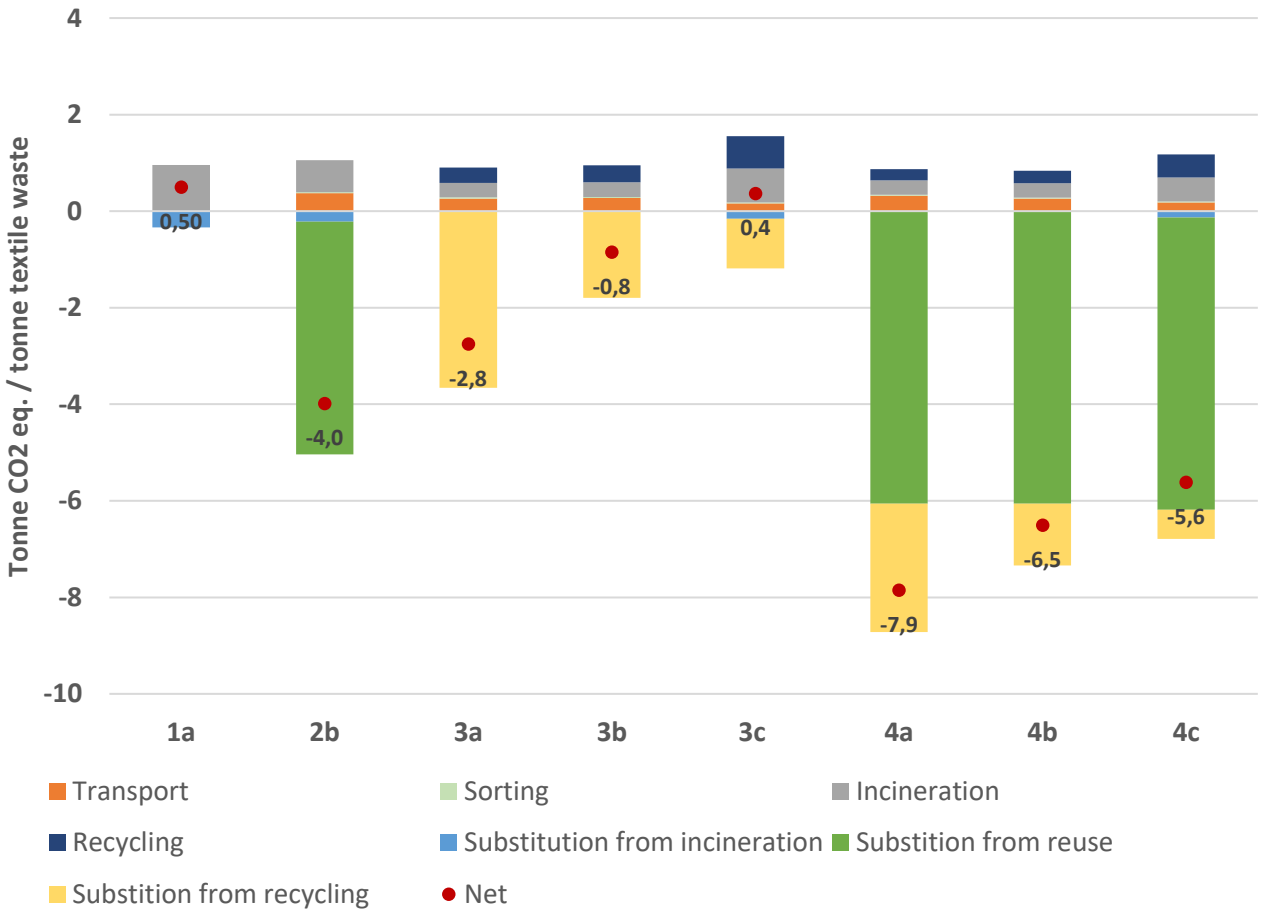



**Figure 32: Results of the sensitivity analysis of the composition of the functional unit**

# 4 Costs of textile waste handling

This chapter complements the environmental analysis with an overview of the economics of the different treatment pathways.

Costs are difficult to estimate precisely, as both recycling technologies and the market are evolving rapidly, and little data is publicly available. A literature review was conducted to gather available cost information, resulting in overview of estimates for costs and market prices of relevant processes and fractions. Information in this chapter is intended to support a rough understanding of the economics across pathways, not to serve as a basis for specific investment or policy decisions. For further and more precise information, processing facilities should be contacted directly, which was not in the scope of this project. In addition, the local costs between the countries vary according to wage levels for instance. Hence, a detailed economic assessment should be made for each country or each partner individually.

## 4.1 Incineration

The current default pathway, incineration, is a cost burden for the municipalities. Costs comprise largely two parts. First, the textile waste needs to be transported to the incineration facility. Depending on local arrangements, this transport is either outsourced to a waste handling company, or carried out using the municipality's own trucks, in which case the municipality covers fuel and driver costs directly. Second, a fee per tonne of textile waste is paid to the incineration facility for treatment. The price of incineration itself is often a part of mixed waste, and this will vary substantially with facility, contracts, transports and potential additional charges. Information from the project partners range this cost between 80 €/ton to 250 €/ton.

## 4.2 Reuse

Accessing the reusable fraction of textile waste requires a costly sorting process, as this involves facilities, equipment, energy and labour. A sorted reusable textile fraction generally has a positive value, which can vary greatly depending on quality and the market on which it is sold.

Top-quality fractions are on average sold for prices at €4.000 to €5.000 per ton in Western markets, while lower quality fractions sold on international second-hand export markets are sold for lower prices of €1.000 to €1.200 per ton (McKinsey, 2022).

Note that these prices reflected the situation in 2022 and have most likely been changing. In fact, after mandatory separate collection started in 2025, the European reuse market has been changing as the supply of reusable textiles to reuse actors has been expanded, but it has also made the reuse market more economically fragile because the additional material is generally of lower quality and more expensive to sort. However, the implementation of EPR schemes, through the revision of the Waste Framework Directive, will in the near future most likely again affect the reuse sector, and influence its prices.

## 4.3 Recycling

The recycling pathway also involves costs both in the sorting phase as well as in the recycling process itself. Table 22 presents the potential costs that the European Commission estimates will follow the introduction of the EPR scheme for collection. The table also includes the assessment that Menon Economics has done for the Norwegian Environmental Agency, on how these prices will be reflected on the Norwegian market (Menon Economics, 2026).

**Table 22: Costs. Source: Menon Economics, 2026**

| Value chain step | EU calculation for the EPR system | Implications for Nordic conditions |
|---|---|---|
| **Collection using textile bins, including transport** | 165 euro/tonne | Longer transport distances and higher transport costs are likely. |
| **Sorting and recycling** | 650 euro/tonne, based on chemical recycling of cotton. | Sorting: Feedback from relevant stakeholders point to the fact that costs of sorting in the Nordics might be slightly higher than in the EU. An economic cost will therefore depend on the sorting happening in the Nordic countries or aboard.<br><br>Recycling: the costs of handling will depend on the recycling location, but are expected to be slightly higher in the Nordics. |
| **Value of the downstream products** | Between 120 (open loop) - 230 (closed loop) euro/tonne | The value will depend on the type of fibre recycled, and its length. Natural fibres have a higher value than synthetics. |

It is expected that the costs of collection, sorting and recycling will be higher that the revenue of the downstream recycled products. This has to this point resulted in challenging business cases for recycling, as costs increase revenues. As an example, one of the project partners sorted out blended fibres for recycling into insulation materials. However, the end product did not cover the cost of sorting, and the initiative was ended. This might nonetheless be changing with the introduction of EPR.

In addition, costs for recycling vary greatly by type and technology, which nuances the analysis above. As estimated by McKinsley, the prices are ranging from €500 - €950 per tonne for (thermo)-mechanical recycling, to €1.570 - € 2.600 for chemical pulping, see Table 23. The more expensive the recycling process is to operate, the higher is also the income of the process.

**Table 23: Costs of textile recycling (Source: McKinsley 2022)**

| Technology | Type | Total costs (euro / ton treated) | Potential price per output |
|---|---|---|---|
| **Mechanical recycling** | **Open loop** | 280-560 | Low |
| | **Closed loop** | 500-900 | Medium |
| **Thermo-mechanical** | | 500 - 950 | High |
| **Chemical-polymer** | **Pulping** | 1570 - 2600 | High |
| | **Solvent-based** | 950 - 1500 | High |
| **Chemical-monomer** | **Methanolysis** | 1200 - 2300 | High |
| | **Glycolysis** | 1150 - 2200 | High |

It can also be noted that the price per ton for recycled materials are lower than what is estimated from the reuse fraction.

# 5 Discussion

This chapter discusses the three sections of this work: understanding the textile recycling industry in Europe (Chapter 5.1), the findings of the LCA (Chapter 5.2) and the costs (Chapter 5.3).

## 5.1 From functional unit to national scale

This LCA has taken 1 tonne of textile waste as functional unit, and has not analysed the system on a national scale. This would be needed for giving recommendations at a national level. For doing so, the reuse and recycling capacity should be factored in. This should be addressed by mapping national flows with their fibre fractions, with the capacity of the individual operating facilities, such as mapped in Figure 9.

The study now also assumes functioning markets, meaning that the products being sorted for reuse or being recycled, have a marked. However, we know that this is not necessarily true, illustrated by several European sorting and recycling facilities have gone bankrupt in the last years. However, this is critical for understanding the results, as they are so sensitive to which products are being replaced. If a facility recycles materials but the outcoming fibres are not being sold, there will only be additional burdens to the system.

The results show that the open loop recycling is the best option for recycling, because it replaces wipers, and is able to manage large volumes of textile waste. This, however, only is true if the downstream market is not saturated. In fact, if all textile waste were downcycled, there might be created more wipers than what there is a market for.

## 5.2 LCA

### 5.2.1 Overall results of the LCA study

This study has assessed different treatment pathways for textile waste. The scenarios depict potential future sorting facilities at a Scandinavian level, sorting for different fractions and treatment pathways. The results show that reuse is to be prioritized, followed by open loop recycling, mechanical recycling and chemical recycling. The most carbon intensive treatment pathway is incineration. However, a trade-off appears between chemical recycling and long transport distances, when these are longer than 3500 – 5900 km. The system is very sensitive to what the different scenarios substitute. The assumptions were based on available literature, but the substituted materials are likely to differ between operating facilities, and could be more nuanced than what appears in this study.

These results show the validity of the waste hierarchy, in line with results presented by former studies on the topic (Anders Schmidt, 2016; Solis et al., 2024).

Solis et al. (2024) provide in addition an assessment per fibre type, finding the following results: the largest net savings occurred for “preparing for reuse” for all textile waste fractions. The second largest net savings were provided by mechanical recycling for cotton, viscose, cotton polyamide; chemical recycling for polyester; and incineration for wool. Incineration incurred net burdens for all textile waste fractions except cotton and wool, due to the absence of fossil carbon in the material (Solis et al., 2024). This indicates that, even if this study did not perform specific assessments for each fibre types individually, the results are still in

line with other findings, prioritizing reuse, followed by mechanical recycling, chemical recycling and finally incineration.

### 5.2.2 Regional sorting facilities

The results show that the transport to a regional sorting facility does not influence the results in any significant manner. If reuse and recycling facilities are found with functioning downstream markets, it is beneficial in a carbon emission perspective to transport waste to a regional facility, for more homogenous flows to reuse and recycling with larger volumes.

### 5.2.3 Different technologies for different fibre types

Also, different scenarios could have been explored, such as certain fibre fractions being diverted to a specific recycling technology. Thus, other combinations of treatment pathways exist, which are not presented in this study. Other research has been analysing this, such as Yao et al. (2025). Their study, comparing different recycling technologies with each other, concludes that "*Based on environmental, economic, and technological trade-offs, it is hold that mechanical recovery is the most balanced option for waste cotton, physical recovery is the more stable solution for waste polyester, refuse derived fuel production is the optimal choice for mixed textile waste, and chemical recovery is more suitable for polyester-cotton"*. This however, is for a Chinese context, and further research should assess if these conclusions also hold for Scandinavian or European conditions. The study also highlights that "*selecting an optimal textile waste recovery method requires trade- offs among technological, economic, and environmental performance, which often conflicts with each other*".

### 5.2.4 Reuse

Reuse is not as easy as it sounds. In the Nordics especially, the reuse rate is very low, estimated at 1,4% I Norway in 2025 (de Sadeleer & Rubach, 2026), which means that the largest part of the reusable textiles is exported and traded on a global market. However, Europe's used-clothing trade is not closely monitored and regulations differ from country to country, making it difficult to enforce standards of cleanliness (Ricketts & Skinner, 2023).

In 2019, 46% of the EU textile flow was exported to Africa for reuse, which is driven by the demand for cheap clothing (EEA, 2023). However, a bale of sorted textiles to the African market, declared with toll number CN 6309 for used textiles, can also contain textile waste, even if the latter should be sorted out and classified as CN 6310 (Lingås et al., 2023).

The fraction which is not sold on local African markets has a high probability of being landfilled, dumped or incinerated. The EEA highlights that robust data is lacking for understanding the fate of exported discarded textiles to African countries (EEA, 2023).

Changing Market Foundation (2023) has investigated the case of the Kenyan reuse market, and document that the country's extensive second-hand clothing industry cannot deal with the volume of imported clothing. Nearly over 900 million items were sent to Kenya from around the globe in 2021. Out of these, nearly 112 million items came from the EU (Changing Markets Foundation, 2023). Estimates from those interviewed range from 20–50% of clothing bales being unusable, culturally or climatically unsuitable, size inappropriate, unsellable, soiled or damaged beyond repair (Changing Markets Foundation, 2023).

Even within Europe, cases of mismanaged reusable textiles have been documented (OCCRP, 2024).

The uncertainty related to the fate of exported reusable textiles makes it crucial to assess the results of scenarios 2b and 2c with care. The results show that reuse should be prioritized, but because the fate of exported textiles is uncertain, local reuse should be prioritized. More research is needed for how local reuse in the Nordic countries can be increased.

### 5.2.5 Limitations

There are several limitations to the study.

First, it must be remembered that this study is conceptual, because the reuse and recycling systems exist, but are not mature, or not scaled. These results must therefore be seen as indicative, and not as absolute results.

Second, these are best case scenarios, meaning that the results should be addressed with care. In the reuse scenarios, it is assumed that all garments classified with the highest reuse potential are being reused and partially replace new garments (with a 0,4 ratio). However, the market for second-hand garments is known to be very low, especially in the Scandinavian countries. Hence, the local reuse scenarios are most likely difficult to achieve, as the market is assumed not to be large enough. In addition, reuse of the waste flow might however be difficult to achieve. If textiles are collected in one stream, soiled textiles can for instance degrade the quality of the garments with high reuse potential. In the open loop and mechanical recycling scenarios, all the flow of cotton, polycotton and polyester are for instance assumed to be recycled, which is most likely an overestimation. However, no quality requirements were found for these recycling methods, which further research should dive deeper into, for instance by contacting operating facilities. The impacts from open loop and mechanical recycling especially are therefore likely to be higher than these results show.

Third, some aspects of the system were omitted from the analysis due to a lack of data: The bags used for the collection of used garments, and the sorting and recycling infrastructure. For the latter, only the heat and electricity needs were included, omitting the machines for sorting and recycling.

Fourth, it should be noted that we here present the results for fossil GWP. The actual impacts from incineration would have been higher if biogenic carbon had been included in the results, but because these are seen part of the carbon cycle they do count as zero. In addition, other impact categories should be further analysed for giving a broader environmental analysis.

## 5.3 Costs

The overview of the costs presented in Chapter 4 shows that the economics for incineration, reuse and recycling differ greatly. Incineration is a pure cost, with no revenue to offset it. Recycling and reuse become economically favourable when they generate lower net costs than the incineration pathway. This depends on whether sorting and treatment costs can be compensated enough for by the value of the resulting fractions, which in turn depends heavily on the quality of the incoming waste flow.

Following the sources reported in this chapter, reuse offers more value than recycling, and several recycling fractions can barely or not cover sorting costs. In terms of economics, the business case for recycling is currently particularly weak, but will be influenced with the introduction of the EPR scheme, where producers will be covering the costs of textile waste collection, sorting and handling.

# 6 Recommendations

The textile-waste management sector is undergoing significant change as regulatory requirements evolve. The introduction of mandatory separate collection, together with the forthcoming EPR schemes, is expected to reshape how textile waste is collected, sorted and treated. As producers will progressively assume financial responsibility for the collection, transport, sorting, preparation for reuse, recycling and other treatment of textiles placed on the market, the entire industry is expected to develop, including the costs of textile waste handling. These developments may create more stable funding for collection and treatment systems, support investment in sorting and recycling capacity, and strengthen markets for reusable textiles and secondary raw materials. At the same time, the eventual effects on treatment costs, contractual arrangements and the distribution of responsibilities between municipalities, producer-responsibility organizations and private operators will depend on how national EPR schemes are designed and implemented. The transition period is therefore likely to remain characterized by uncertainty, particularly for actors considering investments in new reuse, sorting or recycling facilities.

With this as a background, the following recommendations can be drawn from the LCA study:

- From an environmental perspective, actors should strive to follow the waste hierarchy when handling textile waste: reuse is to be preferred over recycling, which again is preferred over incineration. Even when accounting for transport, reuse and recycling remain clearly better for the climate: the relatively long distances needed to reach reuse and recycling facilities from the NPA region should not be a reason to choose incineration.
- Textile waste should be sorted either locally or at a dedicated regional sorting facility, in order to maximize the recovery of reusable items and recyclable material fractions. Effective sorting enables textiles to be directed to the most appropriate treatment route—prioritizing reuse and recycling where feasible—and thereby reduces the proportion of the collected flow that is sent to incineration. There is only a minimal difference in GWP between local and regional sorting, when transport is factored in.
- A Scandinavian sorting hub could consolidate textile volumes from several collection areas, thereby reducing unit sorting costs and improving operational efficiency. By pooling material flows, such a hub could produce larger, more consistent and homogeneous fractions for reuse and recycling. This would improve supply security for downstream actors and increase the potential for economies of scale, making investments in specialized sorting, reuse and recycling capacity more viable.
- A large number of discarded textiles are known to be in good condition, having a high reuse potential. It should be strived for sorting these garments out of the textile waste flow and incentivizing local reuse.
- Where local reuse is not feasible, reuse through export should be prioritized, provided that the receiving operator can demonstrate robust ethical and environmental practices. Export arrangements should prioritize organizations with transparent downstream traceability, credible quality-control procedures and documented end markets, to minimize the risk that exported garments are discarded, dumped or otherwise improperly managed in receiving countries.
- Textiles transported to treatment facilities further south should be moved using the lowest-emission logistics options that are practically available. Rail and maritime transport should therefore be prioritized over long-distance road transport using fossil fuels, as these modes have lower greenhouse-gas emissions per tonne-kilometre of freight.

- At present, mechanical and open-loop recycling should be prioritized over chemical recycling where they provide suitable and demonstrably beneficial treatment routes. These options are generally more technologically mature, have established processing capacity and markets for outputs such as insulation, non-wovens, filling materials and industrial wipes. Mechanical recycling also currently represents the larger share of identified textile-recycling capacity in Europe.
- Chemical recycling remains important for material flows that cannot be effectively treated through mechanical processes, particularly where it can enable higher-quality fibre recovery or manage challenging fibre compositions. However, many chemical recycling technologies are still being scaled up, and their commercial maturity, input specifications, costs and market demand are less established. Recycling-route decisions should therefore be based on the composition and quality of the textile fraction, the availability of reliable downstream markets, and a case-specific assessment of technical, economic and environmental performance.

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# Appendix 1

**Tabell 1: Fibre composition of donated textiles, textile waste and the combination of the two, based on data from a picking analysis from Norwegian waste management companies (Berg et al. 2026, in print)[1].**

| | Textile waste | |
|---|---|---|
| | Gram | % |
| **Acetate** | 912 | 0 % |
| **Acryl** | 350 | 0 % |
| **Acrylic** | 20358 | 1 % |
| **Alpaca** | 1235 | 0 % |
| **Angora** | 234 | 0 % |
| **Bamboo** | 15 | 0 % |
| **Cashmere** | 807 | 0 % |
| **Chlorofibre** | 2498 | 0 % |
| **Cotton** | 678769 | 41 % |
| **Cupro** | 309 | 0 % |
| **Eco cotton** | 162 | 0 % |
| **Elastane** | 1043 | 0 % |
| **Feather or down** | 355 | 0 % |
| **Fluorofibre** | | 0 % |
| **Leather** | 26 | 0 % |
| **Linen** | 12738 | 1 % |
| **Lyocell** | 3678 | 0 % |
| **Modacrylic** | | 0 % |
| **Modal** | 3518 | 0 % |
| **Mohair** | 415 | 0 % |
| **Nan** | 393013 | 24 % |
| **Other** | 2713 | 0 % |
| **Paper** | 235 | 0 % |
| **Polyamid** | | 0 % |
| **Polyamide or nylon** | 64897 | 4 % |
| **Polyester** | 347370 | 21 % |
| **Polyeurathane** | | 0 % |
| **Polylactide** | | 0 % |
| **Polypropylene** | 215 | 0 % |
| **Polypropylenee** | 603 | 0 % |
| **Polyurethane** | 6140 | 0 % |
| **Ramie** | 437 | 0 % |
| **Silk** | 2058 | 0 % |
| **Synthetic leather** | 76 | 0 % |

[1] DOI: 10.5281/zenodo.18821900.

| | | |
|---|---|---|
| **Viscose** | 53835 | 3 % |
| **Wool** | 52238 | 3 % |
| **Total** | 1651252 | 100 % |

# Appendix 2 Degree of wear for the collected textile waste

| Textile waste in degrees of wear (1=totally broken, 5=bright new) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | NaN | SUM |
| **acetate** | | | | 410 | 502 | | 912 |
| **acryl** | | | | 350 | | | 350 |
| **acrylic** | 91 | 1324 | 2104 | 8280 | 8559 | | 20358 |
| **alpaca** | | 390 | 180 | 365 | 300 | | 1235 |
| **angora** | | | 215 | | 19 | | 234 |
| **bamboo** | | | 15 | | | | 15 |
| **cashmere** | | | | | 807 | | 807 |
| **chlorofibre** | | 740 | 1758 | | | | 2498 |
| **Cotton** | 32351 | 59798 | 144336 | 264845 | 174847 | 2592 | 678769 |
| **cupro** | | | | | 309 | | 309 |
| **eco cotton** | | | 162 | | | | 162 |
| **elastane** | 75 | | 715 | | 253 | | 1043 |
| **feather or down** | | 355 | | | | | 355 |
| **leather** | | | | | 26 | | 26 |
| **linen** | 481 | 712 | 1182 | 7167 | 3196 | | 12738 |
| **lyocell** | 360 | 646 | | 768 | 1904 | | 3678 |
| **modal** | | | 428 | 1608 | 1482 | | 3518 |
| **mohair** | | 30 | | 210 | 175 | | 415 |
| **NaN** | 16806 | 45133 | 71355 | 115900 | 81691 | 62128 | 393013 |
| **other** | | | | 2713 | | | 2713 |
| **paper** | | | 120 | 115 | | | 235 |
| **polyamide or nylon** | 2495 | 5152 | 18826 | 24510 | 13914 | | 64897 |
| **polyester** | 12621 | 26833 | 63884 | 131064 | 112727 | 241 | 347370 |
| **polypropylene** | | | | | 215 | | 215 |
| **polypropylenee** | | | 157 | 240 | 206 | | 603 |
| **polyurethane** | | 1285 | 1500 | 1359 | 1996 | | 6140 |
| **ramie** | 205 | | | | 232 | | 437 |
| **silk** | | | 84 | 466 | 1508 | | 2058 |
| **synthetic leather** | | 35 | | 41 | | | 76 |
| **viscose** | 690 | 1988 | 8390 | 22069 | 20698 | | 53835 |
| **wool** | 2590 | 1848 | 10386 | 19858 | 17556 | | 52238 |
| **Totalsum** | **68765** | **146269** | **325797** | **602338** | **443122** | **64961** | **1651252** |

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