ISSN 1831-9424

European Commission

JRC SCIENCE FOR POLICY REPORT

Techno-scientific assessment of the management options for used and waste textiles in the European Union

Huygens, D., Foschi, J., Caro, D., Caldeira, C., Faraca, G., Foster, G., Solis, M., Marschinski, R., Napolano, L., Fruergaard Astrup, T., Tonini, D.

2023

Joint Research Centre

EUR 31750 EN

Contact information
Name: European Commission - Joint Research Centre
Email: JRC-WASTE-RESEARCH@ec.europa.eu
Tel.: +34 954 488 349

EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC134586

EUR 31750 EN

PDF ISBN 978-92-68-09692-5 ISSN 1831-9424 doi:10.2760/6292 KJ-NA-31-750-EN-N

Luxembourg: Publications Office of the European Union, 2023

How to cite this report: Huygens, D., Foschi, J., Caro, D., Caldeira, C., Faraca, G., Foster, G., Solis, M., Marschinski, R., Napolano, L., Fruergaard Astrup, T. and Tonini, D., *Techno-scientific assessment of the management options for used and waste textiles in the European Union.* Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/6292, JRC134586.

Contents

Abstract

The EU strategy for sustainable and circular textiles envisages “a circular textiles ecosystem that has sufficient capacities for innovative fibre-to-fibre recycling, while the incineration and landfilling of textiles is reduced to the minimum”. The general objective of this study is to summarise the techno-scientific knowledge base of different recycling, recovery and disposal options for waste textiles. First, it is indicated that post-consumer textile waste is the largest waste fraction, and that annually more than 8 million tonnes used and waste textiles are incinerated or landfilled, a much higher share than re-use, preparing for re-use and recycling together. Textile waste recycling is limited and currently dominated by transforming apparel and home textiles into cleaning rags and insulation materials, but closed-loop recycling facilities are emerging in the EU, particularly for post-industrial textile waste. Second, the life cycle assessment and cost analysis indicated that re-use and preparing for re-use are the most cost-effective options and have the best environmental performance. Whereas recycling is associated to greater costs than incineration and landfilling, it commonly brings supplementary environmental savings. Third, economic and non-economic barriers to recycling, particularly closed-loop recycling were identified. The information provided in this report may contribute to informing policy design and implementation on textile waste management.

Disclaimer

Acknowledgements

We are grateful to all experts who have contributed to the stakeholder consultations and provided information, data and comments on the draft version of this report. We thank Christoph Schuman, a Commission trainee (March to August 2023) for his contribution to the mapping of the recycling landscape in the EU (section 3.4.3.4) and reviewing this report.

Authors

HUYGENS Dries[(1)], FOSCHI Jacopo[(2)], CARO Dario[(1)], CALDEIRA Carla[(3)], FARACA Giorgia[(1)], FOSTER Gillian[(1)], SOLIS Martyna[(1,4)], MARSCHINSKI Robert[(1)], NAPOLANO Loredana[(3)], FRUERGAARD ASTRUP Thomas[(4)], TONINI Davide[(1)]

(1) European Commission, Joint Research Centre, Directorate B – Growth and Innovation, Circular Economy and Sustainable Industry unit (B5)
(2) External consultant, Ispra, Italy (work performed for the JRC)
(3) European Commission, Joint Research Centre, Directorate D – Sustainable Resources, Land Resources and Supply Chains Assessment unit (D3)
(4) Technical University of Denmark

Executive summary

Policy context and study objectives

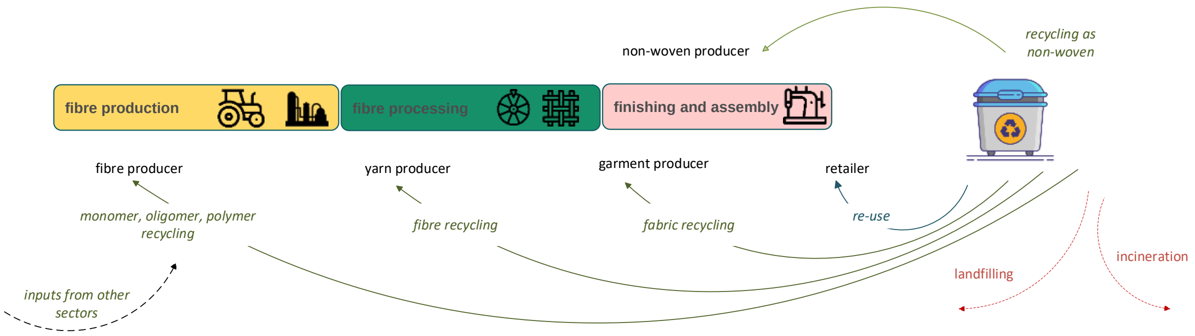
The European consumption of textiles has a major impact on environment, climate change as well as water and land use (EEA, 2022). With respect to textile waste management, the recently launched EU strategy for sustainable and circular textiles envisages "a circular textiles ecosystem that has sufficient capacities for innovative fibre-to-fibre recycling, while the incineration and landfilling of textiles is reduced to the minimum". The general objective of this study is to summarise the techno-scientific knowledge base of different recycling, recovery and disposal options for waste textiles. The specific objectives are to analyse textile material flows, waste management options for used and waste textiles and capacities for textile recycling, the environmental and techno-economic impacts of these management routes and existing barriers to recycling.

Background – textile end-of-life management in a circular economy

The textile value chain is comprised of all the activities that include the design, manufacturing, distribution, retail and consumption of a textile product (UN Environment Programme, 2020). It involves fibre production, fibre processing[1], and finishing and assembly steps, with environmental impacts being generated from each of these manufacturing steps (Roos et al., 2019) (Figure ES1).

End-of-life options, involving re-use[2], preparing for re-use[3] and recycling[4] are management options for used and waste textiles that are located at the higher echelons in the waste management hierarchy according to the Waste Framework Directive. In principle, they enable to extend the life cycle of textiles or building blocks thereof, and thus to displace incineration and landfilling as alternative waste management options (Figure ES1).

Figure ES1. End-of-life treatment options for used and waste textiles



Source: own work based on UN Environment Programme (2020) and Sanding and Peters (2018) (icons: Flaticon.com)

[1]Fibre processing is largely omitted for the production of non-woven textiles as alternative techniques (e.g spunbonding, heating) are applied instead of weaving or knitting techniques for apparel production.

[2]According to the definitions in the Waste Framework Directive, 're-use' means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived. 'Re-use' is not a waste management operation;

[3]'preparing for re-use' means checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing. In practice, a management operation for used textiles will classify, amongst other potential factors, as 're-use' or 'preparing for re-use' depending on the legal status of the separately collected textile material, currently varying across EU Member States. For simplicity, this report refers to 're-use' in the common sense of the word, and thus not necessarily in the legal sense of the word to circumvent terminology issues resulting from different schemes for waste status assignment for used textiles in EU Member States. The term 're-use' in this report may thus also encompass certain treatments that classify as 'preparing for re-use' in some EU Member States. A discussion on a consistent definition of 'textile waste' falls beyond the scope of this report.

[4]'recycling' means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes.

Main findings

Textile mass flows

We performed a mass flow analysis to estimate and track textile flows through the EU-27 textile production and consumption system for the reference year 2019 as well as for the year 2035 under forward-looking scenario in the absence of further policy change. It is noted that substantial uncertainties apply to the available data, and that official statistics and waste generation data were incomplete and only of limited use for this analysis. Therefore, the numbers presented in Figure ES2 are best estimates based on available techno-scientific data. Nevertheless, regardless of any quantitative deviations from the actual on-the-ground situation, the conclusions and ensuing problems identified from this assessment are believed to be robust.

The analysis for the reference year 2019 indicated that post-consumer waste, particularly from households, represents the greatest share of the textile waste generated (Figure ES2). Post-industrial and pre-consumer-waste were indicated to make up a smaller share of the total waste (11% and 3% of the total textile waste, respectively). Annually, more than 8 million tonnes (Mt) of post-consumer textile waste are being incinerated or landfilled in the EU. The separate collection of used and waste post-consumer textiles is estimated at 2.4 Mt yr^{-1}, whereas the sorting capacity is assessed to be lower at 1.8 Mt yr^{-1} (Figure ES2). Hence, it is indicated that a significant part of the separately collected textiles is exported to third countries for sorting, re-use and/or recycling. Export is also the dominant fate of sorted textiles; it is estimated that about 48% of the textiles are exported to third countries following sorting in the EU. In total about 1.8 Mt of textiles are exported to third countries annually (Figure ES2).

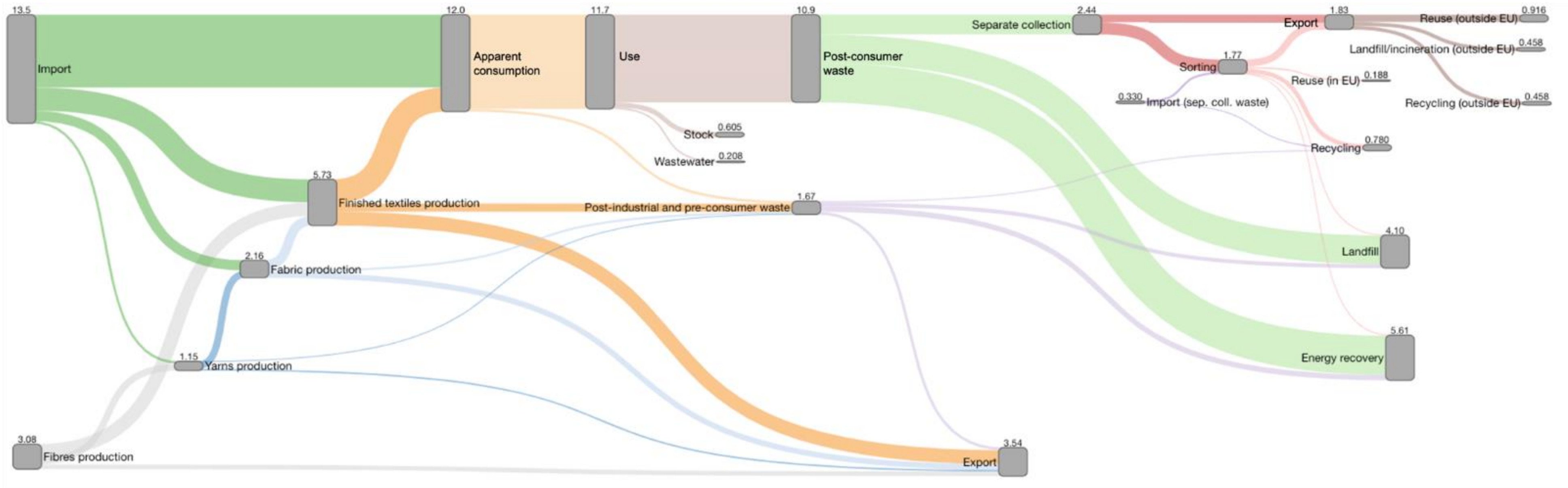
The final fate of exported textiles to third countries has been the focus of a recent report from the European Environment Agency (EEA, 2023). This study indicated that Africa and Asia are the main destinations for exported textiles. The main purpose of the textiles imported by African countries is re-use (EEA, 2023), but it is likely that a large share of the textiles is finally not re-usable and may contribute to adverse environmental and social impacts in the country of destination (Cobbing et al., 2022). Textiles sent to Asia are subject to a greater degree of sorting processing for re-use and recycling as industrial rags (EEA, 2023).

Along with export (~50% of the collected and sorted textiles), a small share of the sorted used and waste textiles in the EU is re-used locally within the EU (~10% of total collection) (Figure ES2). This is the so-called ‘cream’ fraction of the textiles discarded by their primary user. About 30% of the sorted textiles is sent to recycling operations (Figure ES2). A final share of about 10% of the collected and sorted textiles is not suitable for recovery operations and is thus directly sent to incineration or landfilling (Figure ES2).

With respect to textile composition, the analysis indicated that cotton (34%), polyester (29%) and polyamide (7%) were overall the main fibres used in textiles. A higher share of cotton is shown for apparel compared to textiles for industrial and commercial applications, typically having relatively more synthetic fibres.

In sum, the mass flow analysis points to two main problems with respect to waste management. At first, a small share of the used and waste textiles is actually collected in the EU, leading to a missed opportunity to recover valuable material after textile re-use, preparing for re-use or recycling out of the more than 9 million tonnes of textile waste being incinerated and landfilled. Secondly, a large share of the separately collected waste is sent to third countries, and possibly contributing to adverse environmental and social impacts in the country of destination. The forward-looking assessment for the year 2035 suggest that textile waste generation may further increase in the future due to increased textile consumption. Even though separately collected waste volumes may also grow, a large share of waste is still projected to be incinerated and, to a minor extent, landfilled.

Figure ES2. Mass Flow Analysis for textile production and waste management in the EU-27 for the reference year 2019. The mass flows in each node are expressed in Mt yr^{-1}, and represent best estimates based on available data.

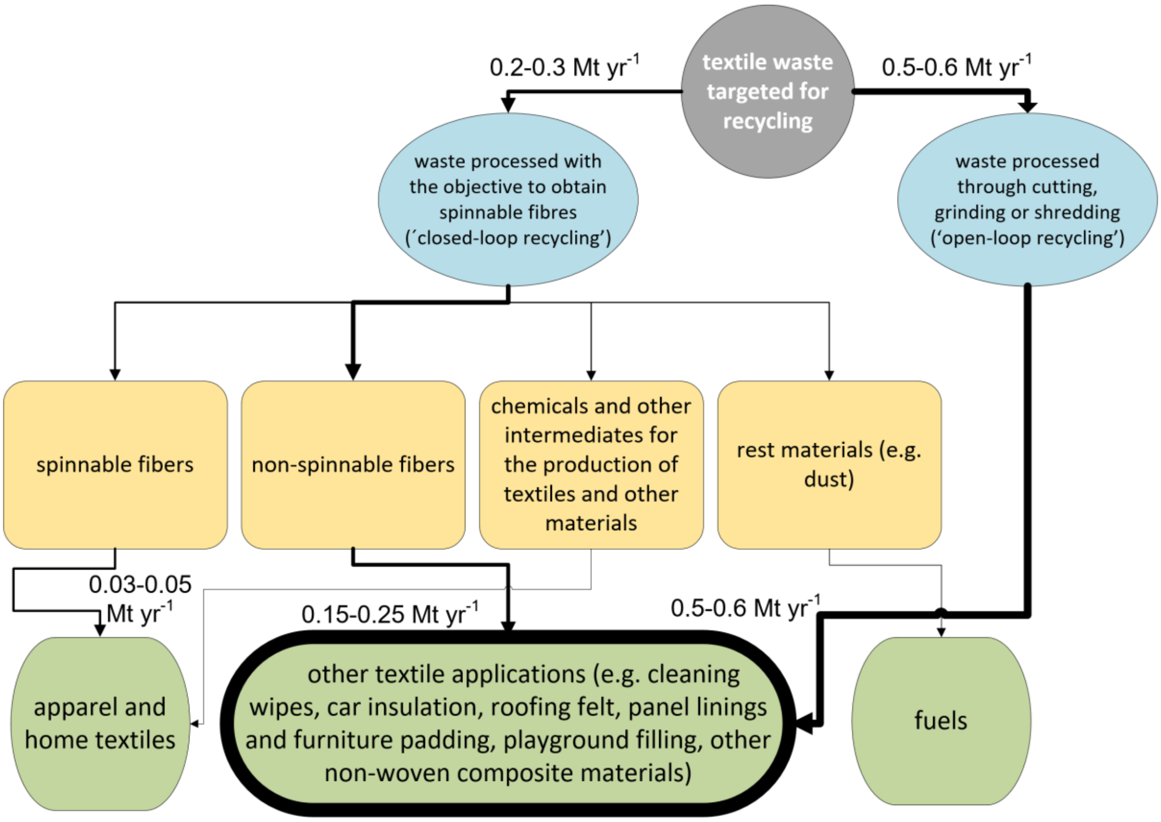


Source: own work.

Recycling techniques and capacities in the EU

Whereas the re-use of textiles is an established and well-known practice since long, less is known about textile recycling in the EU. To address the information gap, we have presented a non-exhaustive overview of the available technologies based on the recent work of Duhoux et al. (2021), and mapped technology providers active in textile recycling within the EU. Recycling technologies for textiles rely on mechanical, chemical and thermal material transformation pathways, but at present mainly mechanical and to a smaller extent chemical recycling is being operationally implemented in the EU at a relevant scale. Mechanical recycling involves actions that cut, shred, grind, open and tear textiles, whereas chemical recycling involves processes that deconstruct textile waste to chemical monomers or polymers that can be used for the production of fibres or plastics.

Figure ES3. Schematic overview of textile recycling processes grouped per share that is processed through 'closed-loop' mechanical, chemical or thermal processes (blue circle on the left) and 'open loop' processes (following cutting, grinding or shredding, blue circle on the right). The final use applications of the recovered materials are indicated in green, whereas intermediate materials from closed-loop recycling processes are depicted in yellow. The thickness of the arrow and the accompanying values approximately correspond to the estimated mass that is processed/generated through the pathway, indicating that at present most textiles are being recycling for applications other than apparel and home textiles.



Source: own work.

It is indicated that most recycling facilities rely on mechanical recycling that transform textile waste into cleaning wipes and non-woven materials (e.g. insulation materials for the construction or automotive sector) (Figure ES3). Whereas some of these recycling facilities tear and open textiles, they do not envisage applications of the output material as yarn-spinnable fibres for apparel application. The outputs from such recycling techniques mostly find further use as cleaning wipe or insulation material ('open-loop recycling'). Numerous other companies are active in closed-loop recycling processes that target applications of the output materials in the apparel or home textile sector ('closed-loop recycling'). Also at these recycling plants, mechanical recycling is most common, but a current limitation is that most technology providers only recover small shares of the input mass as long, yarn-spinnable fibres. Non-spinnable fibres for non-woven textile applications are thus also the most abundant output material for most technology providers. Such closed-loop mechanical techniques may also face technological challenges and barriers with respect to type of input materials they can process; currently the input is mostly limited to post-industrial waste textiles rich in a single fibre, of a homogeneous colour, and with removable non-textile parts (Jørgensen and Werner, 2022; van Duijn et al., 2022; Dahlbom et al., 2023). Chemical recycling for textile waste is still at its onset, but facilities are emerging that target the recycling of textiles rich in natural fibres to be recycled as man-made natural fibres, and textiles rich in certain polymers for monomer production. For current recycling techniques, with the exception of those that recycle chemical monomers, the output material is typically not equivalent to the 'virgin' counterpart, and requires partial blending with virgin materials to obtain a functionally equivalent material for use as a precursor in the apparel sector.

A total current recycling capacity of about 0.70-0.85 Mt yr^{-1} is estimated, with cleaning wipes and non-woven textiles as main outlets for the recycled materials (Figure ES3). Planned future capacities for the period 2030-2035 could mount up to 1.5 - 2.0 Mt yr^{-1}, though such capacity growth and upscaling would occur substantially faster compared to past efforts for the recycling of other secondary raw materials. Therefore, the future outlook is to be understood with the necessary caveats.

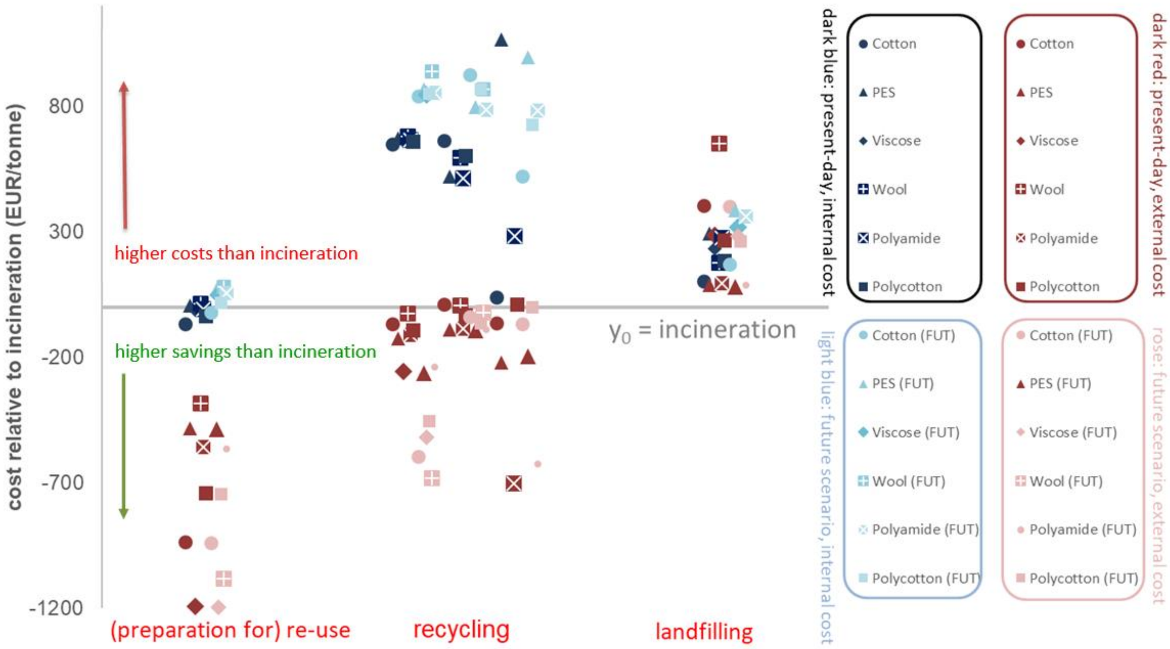
Environmental and techno-economic characterisation of waste management routes

The environmental benefits of moving textiles up in the waste management hierarchy to re-use, preparing for re-use and recycling acts upon two main mechanisms: (i) the avoidance of adverse impacts from waste management under the status quo situation, mainly textiles managed in the lower echelons of the waste management hierarchy, and (ii) the seizing of additional benefits from the substitution of "linear" textiles and their precursors in a more circular economy.

We performed a life cycle and life cycle costing assessment to respond to the two-pronged research question *'is the separate collection of used and waste textile a cost-beneficial practice? If so, does this also hold true for textiles and garments that have a low potential for re-use because they are worn-out or damaged?'*

To respond to this question, we used life cycle assessment models to compare the combined impact of separately collection, sorting, re-use and recycling versus the impacts from throwing textiles in mixed municipal solid waste for their incineration or landfilling. Both costs for private operators involved in waste management as well as environmental impacts were considered (Figure ES4).

Figure ES4. Overall summary of the internal (dark blue/pale blue) and external (red/rose) costs for textile waste management, relative to a baseline (y0) of textile waste incineration. The Figure reports findings for present (dark colours) and future (light colours) conditions for different textile waste management pathways and textile waste compositions (see legend on the right hand side). Recycling pathways group mechanical recycling (middle, points on the left hand side), open-loop recycling (middle, point in the centre) and chemical recycling (middle, points on the right hand side). Negative y-values represent greater savings compared to incineration as a baseline, whereas positive y-values indicate greater costs relative to incineration.



Source: adapted from Solis et al., in preparation.

The answer to the first part of the research question is mostly indicated for re-usable textiles, regardless of the fibre composition of the textile. Our results point to a neutral effect or minor savings for both private actors involved in textile end-of-first-life management, whereas re-use clearly shows a better environmental performance relative to incineration as a benchmark. In case the alternative scenario would involve landfilling, the benefits are even more clearly expressed. Re-use is associated to climate change and environmental benefits because emissions from all textile production steps can be displaced (fibre production, fibre processing and finishing assembly steps, all contributing to environmental impacts), and minimal impacts from waste management arise. When summing internal and external costs, overall societal savings are indicated for the re-use pathway. These results lend support to the up-scaling of re-use as a key strategy to accelerate a more sustainable textile management after its first use.

The answer to the second part of the research question on the benefits of recycling non-reusable textiles is more complex. Private costs are always higher for recycling than for incineration, and with the current technology outlook this seems likely to remain so in the future. The occurrence of environmental impacts basically depends on three main factors:

i. At first, it depends on the Member State where the textile is being handled, and more specifically, the treatment that (textile ending up in) mixed municipal solid waste receives. In case this were landfilling, recycling always provides environmental benefits, though mostly at higher (private) costs compared to this disposal treatment[5]. Relative to incineration, recycling generally provides environmental gains, but points (ii) and (iii) determine the overall outcome.

ii. At second, it depends on the input material - recycling technology configuration. For instance, the recycling of viscose or polyester is more environmentally beneficial than recycling cotton, a short-

[5]Note that this comparison is not directly visible from the Figure as here incineration is used for benchmark comparison. One would have to compare the recycling to landfilling (at the right hand side) for each individual textile fraction and composition.

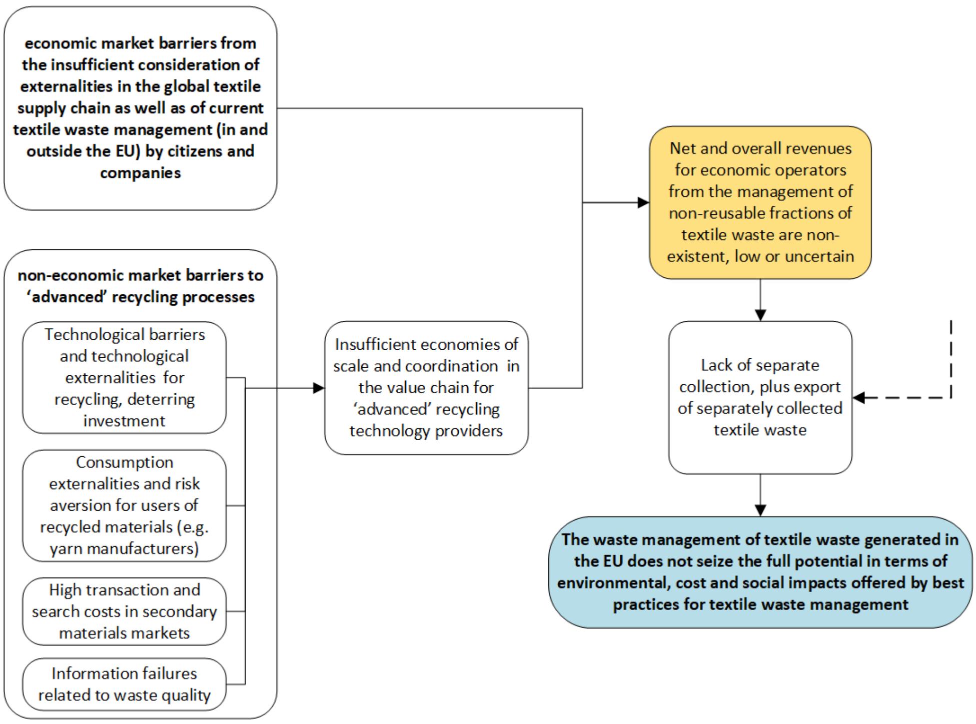
lived crop whose CO_2 emissions upon incineration are not counted towards global warming. Overall, the recycling of textiles may thus not necessarily lead to environmental benefits because the joint additional impacts from collection, transport, sorting, and recycling are not necessarily better than incineration.

iii. At third, it depends on the time and future technological progress. A more positive scenario with increased material recovery (e.g. greater amounts of long fibres recovered) from mechanical recycling may increase the environmental savings to levels that render the societal costs (private costs plus external cost) negative. Such scenario could even provide net monetary benefits to society because the additional private costs relative to recycling are offset by the environmental gains that could be obtained from the recycling process.

Economic and non-economic barriers to recycling

The EU Waste Framework Directive's waste management hierarchy ranks recycling as a better alternative than incineration and landfilling. In addition, a high demand for recycled materials by the apparel retail sector has been indicated (McKinsey & Company, 2022). Still, recycling is not sufficiently taking place, and the lack of a strong business case for recycling may even challenge the business model for the collection and sorting of used and waste textiles overall. Therefore, we performed an assessment to better understand the current market barriers that recycling is facing (Figure ES5).

Figure ES5. Overview of the problem tree indicating the interlinks between drivers considered to be barrier to a more extensive and performant textile waste recycling industry (yellow box), in turn contributing to the main problem observed outlined in the blue box.



Source: own work.

The overall low cost of products (fibres, yarns, fabrics, finished textiles) from primary raw materials on the market makes it challenging for products from recycled materials to compete. One of the explanations for the overall low cost of products on the market may relate to the adverse impacts from the 'linear' model on subpar working standards and textile waste management in the global supply chain. Hence, there is an insufficient internalisation of externalities in the global textile supply chain, which creates economic market barriers to recycling (Figure ES5).

A number of economic and non-economic market barriers hampers developing an 'economy of scale', particularly for closed-loop recycling (Figure ES5) (OECD, 2006). These barriers can include technological limitations (see above) and the design of non-recyclable textiles whose product design falls beyond the control of recycling companies (technological externalities), risk aversion from using recycled materials by the next value chain user (consumption externalities), and high transaction costs and challenges associated with determining the quality of input materials for recycling (high transaction and search costs combined with information failures) (Figure ES5).

Future outlook and conclusion

With an assumed increase in textile consumption, increased separate collection, and a potential re-orientation of currently exported textiles out of the EU, a well-functioning textile re-use and recycling market is more than ever a necessity in a sustainable and circular textile economy. Policy measures already proposed as part of the 2023 Waste Framework Directive revision (e.g. Extended Producer Responsibility (EPR)) and End-of-Waste criteria for textiles may help to address drivers of the problems observed for the current waste management of textiles.

References

Cobbing, M., Daaji, S., Kopp, M., Wohlgemuth, V., 2022. Poisoned Gifts From donations to the dumpsite: textiles waste disguised as second-hand clothes exported to East Africa. Available at: https://www.greenpeace.org/static/planet4-international-stateless/2022/04/9f50d3de-greenpeace-germany-poisoned-fast-fashi.

Dahlbom, M., Aguilar Johansson, I., Billstein, T., 2023. Sustainable clothing futures - Mapping of textile actors in sorting and recycling of textiles in Europe, Swedish Environmental Research Institute (IVL). Report number C736.

Duhoux, T., Maes, E., Hirschnitz-Garbers, M., Peeters, K., Asscherickx, L., Christis, M., Stubbe, B., Colignon, P., Hinzmann, M., Sachdeva, A., 2021. Study on the technical, regulatory, economic and environmental effectiveness of textile fibres recycling : final report. Commission, European Directorate-General for Internal Market Entrepreneurship and SMEs, Industry. Publications Office. doi:doi/10.2873/828412

EEA, 2023. EU exports of used textiles in Europe's circular economy. Available at: https://www.eea.europa.eu/publications/eu-exports-of-used-textiles/eu-exports-of-used-textiles.

EEA, 2022. Textiles and the environment: the role of design in Europe's circular economy. Available at: https://www.eea.europa.eu/publications/textiles-and-the-environment-the.

Jørgensen, P.E., Werner, A., 2022. Research and identification of textile plants globally - focusing on fiber-to-fiber recycling for the fashion & textile industry. Published by Lifestyle & Design Cluster Augut 2022, Second version. Available at: https://ldcluster.com/wp-content/uploads/si.

McKinsey & Company, 2022. Scaling textile recycling in Europe – turning waste into value.

OECD, 2006. Improving Recycling Markets. OECD Publishing, Paris, France.

Roos, S., Jönsson, C., Posner, S., Arvidsson, R., Svanström, M., 2019. An inventory framework for inclusion of textile chemicals in life cycle assessment. The International Journal of Life Cycle Assessment 24, 838–847. doi:10.1007/s11367-018-1537-6

Sandin, G., Peters, G.M., 2018. Environmental impact of textile re-use and recycling – A review. Journal of Cleaner Production 184, 353–365. doi:https://doi.org/10.1016/j.jclepro.2018.02.266

UN Environment Programme, 2020. Sustainability and Circularity in the Textile Value Chain - Global Stocktaking. Nairobi, Kenya.

van Duijn, H., Papú Carrone, N., Bakowska, O., Huang, Q., Akerboom, M., Rademan, K., Vellanki, D., 2022. Sorting for circularity Europe – An evaluation and commercial assessment of textile waste across Europe.

1 Study objectives and link to the ongoing revision of the Waste Framework Directive

The European consumption of textiles has a great impact on environment, climate change and water and land use (EEA, 2022a). The Commission already identified textiles in 2020 as a key value chain in the Circular Economy Action Plan. This points toward a need for a revised approach on how textiles are designed, used, and managed at the end of their life to ensure that waste is minimised and the resources used are kept in the EU economy for as long as possible.

With respect to waste management, the recently launched EU strategy for sustainable and circular textiles envisages "a circular textiles ecosystem that has sufficient capacities for innovative fibre-to-fibre recycling, while the incineration and landfilling of textiles would be reduced to the minimum". End-of-life options, involving re-use[6], preparing for re-use[7] and recycling[8] are management options for used and waste textiles that are located at the higher echelons in the waste management hierarchy according to the Waste Framework Directive. The Waste Framework Directive (2008/98/EC) states that Member States shall set up separate collection for textiles by 1 January 2025.

The JRC provides independent, evidence-based knowledge and science, supporting EU policies. The general objective of this study is to assess and summarise the techno-scientific knowledge base of different recycling, recovery and disposal options for waste textiles.

Specific objectives are to update and analyse available data on:

- Textile materials flows, including re-use rates, textiles discarded within and outside of the EU, including future estimates;
- The various waste management options for textile waste (collection, sorting, preparation for re-use, recycling, other recovery and disposal), the recycling/recovery processes currently available and the emerging techniques likely to play a role in the future and linked processing capacities;
- The composition of textiles;
- Actors in the recycling market, as well as current applications for recovered textiles;
- An environmental and techno-economic characterisation of the different recycling or other recovery routes and technologies;
- Drivers as well as economic and technological barriers with respect to the management and treatment options for textile waste, with a specific focus on recycling.

The information laid down in this report may support policy development on textile waste management.

[6] According to the definitions in the Waste Framework Directive, 're-use' means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived. 're-use' is not a waste management operation;

[7] According to the definitions in the Waste Framework Directive, 'preparing for re-use' means checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing. In practice, a management operation for used textiles will classify, amongst other potential factors, as 're-use' or 'preparing for re-use' depending on the legal status of the separately collected textile material, currently varying across EU Member States. For simplicity, this report refers to 're-use' in the common sense of the word, and thus not necessarily in the legal sense of the word to circumvent terminology issues resulting from different schemes for waste status assignment for used textiles in EU Member States. The term 're-use' may thus also encompass certain treatments that classify as 'preparing for re-use' in some EU Member States. A discussion on a consistent definition of 'textile waste' falls beyond the scope of this report.

[8] According to the definitions in the Waste Framework Directive, 'recycling' means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes.

2 The framework and structure of the report

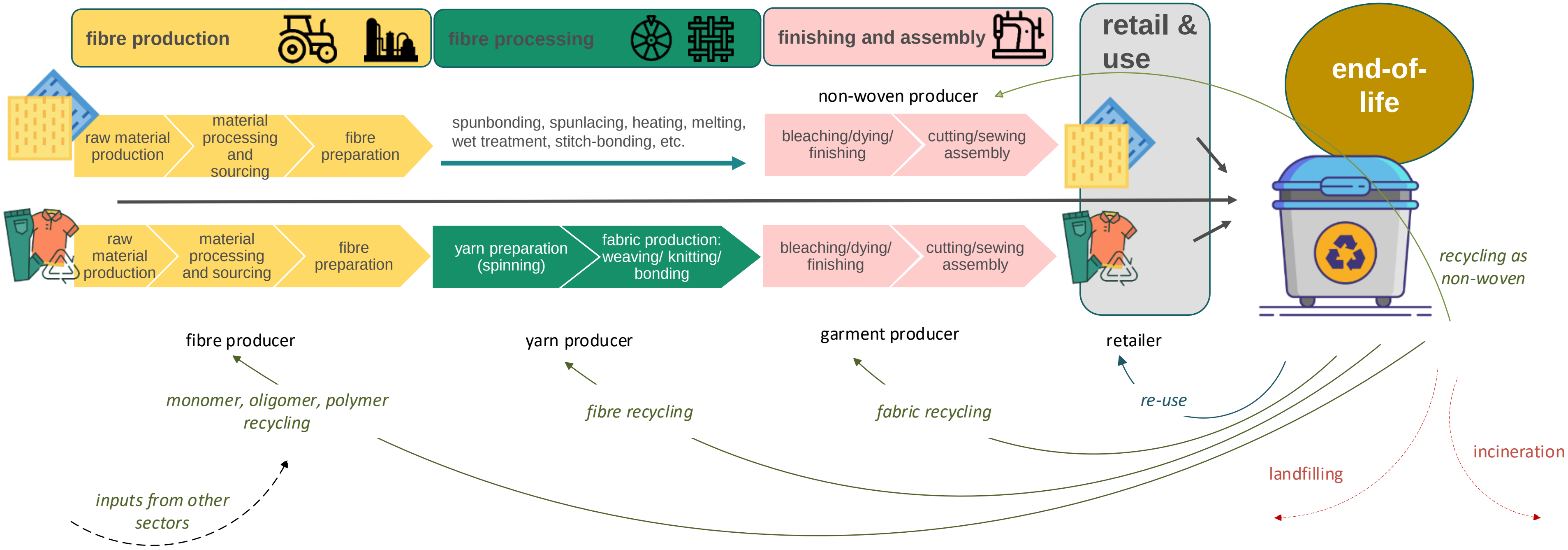
The textile value chain is comprised of all the activities that include the design, manufacturing, design, distribution, retail and consumption of a textile product (or providing the service that a textile product renders) (UN Environment Programme, 2020). It also includes the supply of raw materials, as well as the end-of-life stage of textiles (UN Environment Programme, 2020). For a textile product, the first step in the value chain is the production of a fibre (Figure 1). This involves agricultural activities that cultivate certain crops to extract natural fibres (e.g. cotton), or the extraction of fossil fuel materials to manufacture synthetic fibres (e.g. polyester), or a combination of both (UN Environment Programme, 2020). Subsequent manufacturing stages for woven textiles turn fibres into yarns (yarn spinning), after which these are knitted, weaved or bond into fabrics (Figure 1). The fabric is then processed chemically and/or mechanically to produce a textile with the desired properties. The final finishing step in the value chain involves cutting and sewing into finished product that is distributed and retailed (UN Environment Programme, 2020). Textiles can also be non-woven, with fibres bonded into fabric by chemical, mechanical or heat treatment (Figure 1). Non-woven fabrics are made directly from fibres, and their production process omits the yarn-spinning, weaving, and/or knitting. During the textile manufacturing process, textile-like materials (e.g. cutting leftover) are generated as residues that are either re-used or recycled (on-site or following transport to a different facility) or disposed (Figure 1). Textiles are placed on the market and used by households (e.g. garments, home textiles, cleaning products) as well as for industrial applications in the building and construction, automotive, medical, agricultural, and many other sectors. When reaching their end of life, the materials are subject to re-use or waste management (preparing for re-use, recycling, energy recovery or disposal) (Figure 1).

A mass flow and composition analysis of the apparent textile consumption and post-consumer waste in the EU-27 are provided in section 3 of the report. Section 4 focuses on reviewing the management options as well as the opportunities and technical limitations associated with the different management pathways, followed by an assessment of the environmental and techno-economic characterisation of impacts from the management of waste textiles (section 5). Based on this evidence and knowledge, this report brings forward an assessment of barriers observed to a sustainable textile waste management system, particularly for recycling (section 6). The conclusions of the report are provided in section 7.

A draft version of this report was shared for consultation with about ~150 stakeholder organisations, including Member States representatives, industry actors, non-profit organisations, academics and non-governmental organisations, in April 2023. Feedback on this draft report was received orally and in written during a stakeholder workshop (18-19 April) and an associated questionnaire.

Note that this report has a waste management perspective and aims at researching and comparing different waste management options for used and waste textiles, and that an explicit evaluation of the added value and environmental benefits of using recycled fibres in textiles products placed on the market falls beyond the scope of this study.

Figure 1. Overview of the textile life cycle for woven and non-woven textile products, including the end-of-life management of textiles



Source: own work based on UN Environment Programme (2020) and Sanding and Peters (2018)(icons: Flaticon.com)

3 Textile flows and composition of waste textiles

3.1 Textile flows

3.1.1 Terminology for textiles

As per Regulation (EU) No 1007/2011, 'textile product' means any raw, semi-worked, worked, semi-manufactured, manufactured, semi-made-up or made-up product which is composed for at least 80% of textile fibres, regardless of the mixing or assembly process employed. A 'textile fibre' means then either of the following: (i) a unit of matter characterised by its flexibility, fineness and high ratio of length to maximum transverse dimension, which render it suitable for textile applications; (ii) a flexible strip or tube, of which the apparent width does not exceed 5 mm, including strips cut from wider strips or films, produced from certain substances used for the manufacture of the fibres (listed in Table 2 of Annex I of the Regulation) and suitable for textile applications. Some categories of products that have a variable share of textiles (e.g. footwear) were also considered as textiles in the recent Commission proposal for a targeted revision of the Waste Framework Directive[9]. Waste is generated at different stages in the life cycle of textiles, and consequently defined as:

— Post-industrial waste: Waste generated during the manufacturing of textile products and their precursors;

— Pre-consumer waste: Waste generated at retail stages (e.g. unsold textiles).

— Post-consumer waste: Textiles that have been disposed of after consumption and use by the citizen or end-users of commercial and industrial activities (hotel, care, automotive, etc.), commonly referred to household and commercial post-consumer textile waste, respectively.

It is noted that residues from textile production are classified here as "post-industrial waste", but that the legal status of these materials may vary and may also include materials that classify as "by-products" in some countries and regions. At present, separately collected post-consumer textiles classify differently across EU Member States. In line with the Commission proposal for a targeted revision of the Waste Framework Directive, this section considers used and waste textiles, textile-related and footwear products as waste upon collection.

Three main categories of post-consumer waste products can be discerned:

- Apparel: trousers, t-shirts, sweaters, coats, footwear[10], dresses, apparel accessories such as scarves, handkerchiefs, etc.)
- Home textiles (curtains, bed linen, carpets, etc.);
- Used textiles from professional textile applications: automotive applications, medical textile, agro textile, protective equipment, etc.

Note that technical textiles, meaning any textile product manufactured for non-aesthetic purpose where instead function is the primary design criterion (automotive applications, medical textile, agro textile, protective equipment, etc.), are distributed amongst both household and professional applications.

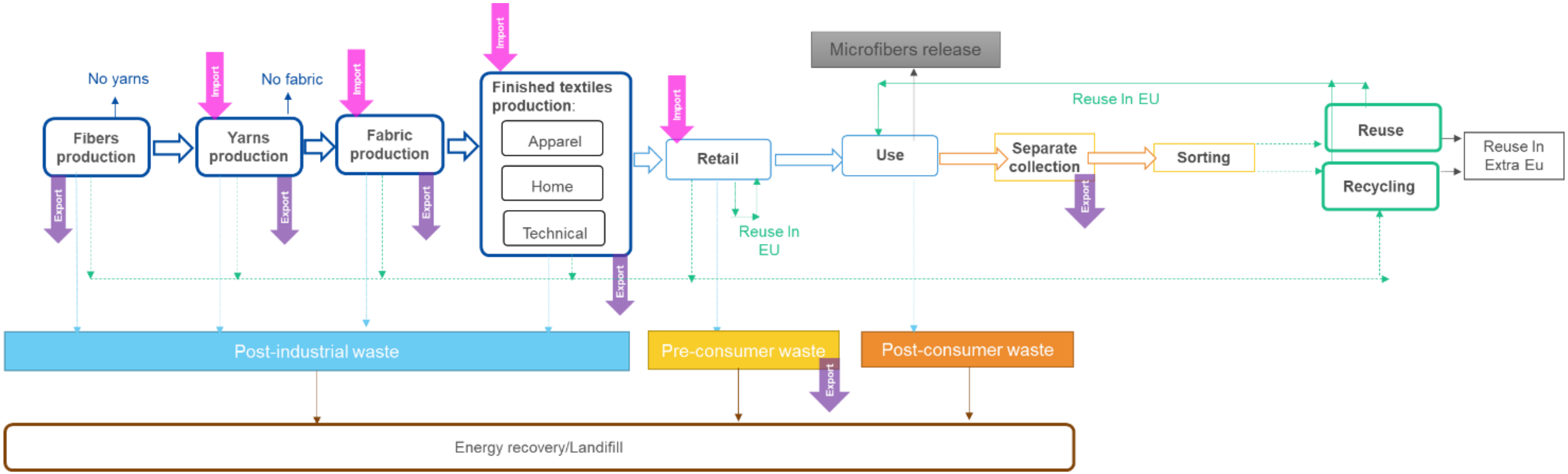
3.1.2 Methods and assumptions

To map textile flows, including waste management options for textiles, a Mass Flow Analysis (MFA) was performed. This study builds upon available evidence of recent studies (EEA, 2019; Köhler et al., 2021), but further expands the boundaries to textiles other than apparel and household textiles (including e.g. non-woven and technical textiles) and other stages of the life cycle (including waste generated during the production and retail life stage of textiles). The MFA thus details the amounts of fibres, yarns, fabrics, and finished products flowing along the textiles value chain (post-industrial waste), as well as pre- and post-consumer waste (Figure 2). Imports and exports of textiles are likewise considered (Figure 2). Waste flows undergoing separate collection and sorting, re-use, recycling, landfilling and energy recovery are estimated, in order to highlight priority areas to improve in textile waste management system.

[9] https://environment.ec.europa.eu/publications/proposal-targeted-revision-waste-framework-directive_en

[10] Footwear and accessories may or may not contain >80% by weight of textiles and may thus fall in the scope of the Textiles Labelling Regulation. All footwear has been included in this assessment as they are separately collected together with textiles in the some EU Member States.

Figure 2. System boundaries considered in the MFA of EU textiles.



Source: own work.

Moreover, flows composition in terms of product type (clothing, household and technical textiles) and fibre type (e.g., acrylic, polyester, cotton, wool etc.) have been also added to the model. The MFA was conducted for the whole value chain of textile in the EU-27 with 2019 as reference year. In addition, considering that uncertainty is associated with many flows and parameters (e.g. finished products life expectancy, share of separate collection,) an uncertainty analysis of MFA results has been also conducted.

A total of 342 products were considered in the scope of this study, covering fibre production, yarns production, fabrics production and finished textile production (Annex 1 of section 8.1.2).

Further details on the methodological approach applied for the development of the MFA are given in section 8. The sections below focus on the assessment and budgeted flows, principally in relation to textile waste management.

3.1.2.1 Post-industrial and pre-consumer waste

The total amount of losses during the manufacturing processes of textiles was estimated using default loss coefficients found in scientific literature.

3.1.2.2 Retail and use

"Apparent consumption" means domestic retail and textiles placed on the market for business-to-business applications. It is calculated as the sum of EU production plus imports minus exports of finished textiles. "Use" indicates the use of textile products by consumers for apparel, household, and technical purposes, and takes into consideration that a share of the retail is unsold. For further details, please consult section 8.1.3.

3.1.2.3 Post-consumer waste

Post-consumer textile waste was estimated according to a dynamic-MFA approach, thus considering the average textiles life time and waste generation after they are placed on the market[11]. Post-consumer waste in the MFA reference year was estimated as the sum of products reaching the end of their life expectancy in MFA reference year, according to the following steps:

- Life expectancy is assigned to each product, according to Laitala et al. (2018) and the International Fair Claims Guide for Consumer Textiles Products (Drycleaning Institute of Australia Ltd, 2015). The assumed life expectancies are reported in section 8.
- Flow of textiles products put on the market from 1995 to 2021 is calculated using Prodcom database[12] for each year. Life expectancy is summed to the year of product placement on the market to obtain an estimate of the year it becomes waste.
- The sum of flows of products becoming waste in the MFA reference year corresponds to the post-consumer waste flow.

By using the above methodology, textiles products are considered as durable goods which can become waste years after they are put on the market (according to their lifetime). Hence, the amount of post-consumer textile waste presented in the Figures does not correspond to the amount of textile products put on the market in 2019.

3.1.2.4 Stock

The stock represents the textiles that are preserved by consumers during their use phase. Stock is calculated as the mass difference between the flow of textiles placed on the market, post-consumer waste and microfibres release (see section 8.1.4.5) during the use phase. It is referred to section 8.1.4.3 for more details.

3.1.2.5 Waste treatment

It is referred to the report Annexes (section 8) for all assumptions to budget textile waste management in the EU, including separate collection as well as downstream options to re-use, recycle, recover or dispose textile

[11] Example: the average life time of bed linen is 3 years (Annex 3 of section 8). Bed linens put on the market in the year 2017 (calculated from prodcom database) is wasted in the year 2019 (MFA reference year)

[12] https://ec.europa.eu/eurostat/web/prodcom

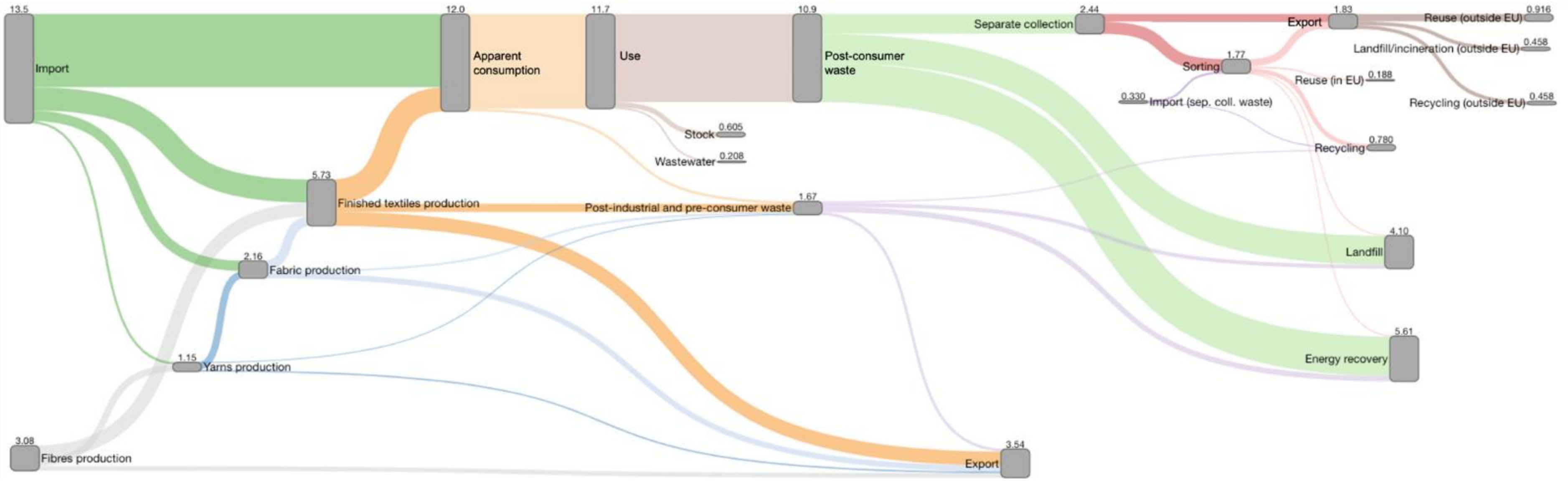
waste. In the MFA model, waste treatment flows for re-use, recovery and disposal operations are calculated as shares of total post-consumer waste, assuming coefficients found through a literature review. For recycling, the input of the assessment of recycling capacities for textile waste in the EU was also considered. The list of considered references and coefficients is presented in Annex 4 of section 8. Energy recovery and landfilling are reported as an aggregated flow, i.e., a single coefficient is assumed to calculate sum flows going to the two destinations, both in case of not separately collected and not sorted. This aggregated flow was then broken down into specific sub-flows going to energy recovery and landfill, assuming a ratio between energy recovered and total landfilled and energy recovered flow equal to 0.51, calculated using 2019 Eurostat data on municipal waste[13]. Import of separately collected waste was considered as additional input flow to sorting. Data on such flow were retrieved from Comext dataset (Eurostat, 2022a), assuming that all textile waste imported from extra-EU countries comes from separate collection.

3.1.3 Findings

Flows of textile product and waste in the EU in 2019 as estimated by the MFA model are illustrated as a Sankey plot (Figure 3). Note that the Figure and text below refers to fixed numbers, but that substantial uncertainties apply to the flows, as outlined in the Supplementary Information (uncertainty analysis, section 8.1.5). Values of each mass flow are reported in Annex 8 of section 8. The total textile waste is estimated at 12.6 Mt yr^{-1} of which post-consumer waste was the dominant fraction, corresponding to 87% of all textile waste (10.9 Mt yr^{-1}, with an uncertainty range of 10.2 -11.5 Mt yr^{-1}).

[13] https://ec.europa.eu/eurostat/databrowser/view/ENV_WASMUN/default/table?lang=en

Figure 3. Mass Flow Analysis for textile production and waste management in the EU-27 for the reference year 2019 ("status quo scenario"). The mass flows in each node are expressed in Mt yr-1, and represent best estimates characterised by further uncertainties as outlined in section 8.1.5



Source: own work.

3.1.3.1 Production, placing on the market, and use of finished textiles

A total of about 12 Mt yr^{-1} of textiles are placed on the EU market. Only about 33% of all textiles placed on the EU market originate from domestic production (Figure 3). The import of fibres, yarns, fabrics and particularly finished products jointly corresponds to 13.5 Mt yr^{-1}. It is noted that the total amount of textile waste presented in this study is larger than in previous studies (e.g. Köhler et al., 2021) because of the extensive scope of the study. In contrast to other studies, this study expands the boundaries to post-industrial, pre-consumer and post-consumer waste from commercial and industrial sectors (thus including non-woven and technical textiles, and waste generated during the production and retail life stage of textiles).

Post-industrial waste (1.3 Mt yr^{-1}; 11% of all textile waste) and pre-consumer waste (0.33 Mt yr^{-1}; 3% of all textile waste) constitute a smaller fraction of the total waste. In addition, it is indicated that 0.21 Mt yr^{-1} of microfibres are emitted during the life stage of textiles. The results also suggest that the in-use textiles in the EU increased in 2019 (supplementary stock of 0.6 Mt yr^{-1}) because of the rising textile consumption in the years preceding to the 2019 reference year.

Post-industrial waste was assumed to be 37%, where 8%, 13%, and 20% are attributed to Yarns, Fabrics, and Finished textiles productions, respectively (Sadowski et al., 2021). The estimated manufacturing losses are in line with the information reported in the EU textile strategy, where it is reported that in factories 25-40% of all fabric used is either leftover or becomes waste (Aus et al., 2021). Pre-consumer waste was assumed to be 4%, with 70% of unsold products exported outside EU, and the remaining 30% re-inputted into EU retail market (McKinsey, 2022). The available information in techno-scientific literature on the topic is limited, and individual publications point to a high degree of local variations in waste generation and treatment in Europe[14]. An assessment of post-industrial waste in Lithuania indicated that the amount of cutting waste reaches 20-25% of the total quantity of materials used for production (Dobilaite et al., 2017). It was found that cutting waste corresponded to about 20% of the produced textiles, and that waste is not sorted in Lithuanian clothing enterprises and is disposed in landfills in most cases, notwithstanding the positive tendencies of recycling of waste observed (Dobilaite et al., 2017). Roos et al. (2019) estimated post-industrial waste during the fabric manufacturing stage at 15-20% for garments. A study performed for the Swiss textile industry indicated that yarn and fabric residues equalled 9.5% of the total textile production (Schmutz and Som, 2022). Incineration was the most used end-of-life treatment (37%, mostly containing mixed fibres), whereas re-use (36%), open-loop recycling (21%), and closed-loop recycling (5%) where more common options for unmixed natural and synthetic materials. Hence, the few available information indicates that significant amounts of textile residues are being generated during the manufacturing process, and that residues may not necessarily be managed in line with the waste management hierarchy, especially in regions with no availability of textile recycling infrastructure.

Even though the recycling of the post-industrial waste is upscaled and the preferred feedstock for certain recycling operators, the masses that are actually recycled are still low (see section 4.3.4). Based on the data presented in the latter section, it is estimated that at present 0.17 Mt yr^{-1} of the total generated post-industrial (mostly yarns and fabrics waste) and pre-consumed textile waste is recycled. The remaining waste is assumed to be split between incineration with energy recovery and landfilling (in line with the weighted EU average for mixed municipal waste).

3.1.3.2 Post-consumer textile waste management

The separate collection of post-consumer textiles is the dominant textile waste fraction making up a total of 10.9 Mt yr^{-1} (Figure 3). The separate collection of textile waste is calculated based on the estimated share of textile waste collected for apparel and home textiles (together representing 57% of the post-consumer textile waste; see section 3.2). Both materials are commonly within the scope of national separate collection systems for used textiles and textile waste. The values documented in literature, for apparel and home textiles only (section 8, Annex 4), indicate an average value of 38%, resulting in about 2.4 Mt of used textiles and textile waste that is annually collected for further processing. This value is aligned to other studies documenting separate collection from 2.1 Mt yr^{-1} (Köhler et al., 2021) to 2.8 Mt yr^{-1} (EURATEX, 2021). The amount of separate collection of used textiles and textile waste represents about 22% of the post-consumer waste.

[14] The 27 EU countries, extended to European Economic Area (EEA) and European Economic Area (EFTA) countries in this assessment

This implies that a significant share (8.5 Mt yr^{-1}) of the textile waste generated is not separately collected and thus largely being diverted to incineration or landfill (recovery and disposal operations) (Figure 3). This number may be slightly overestimated in case some other textile waste fractions are subject to supplementary collection at the municipal level or business-to-business waste transactions for recycling. However, based on the overview of current recycling capacities (section 4.3.4), it seems unlikely that at EU-level a substantial share of the textile waste is recycled in this manner. Therefore, it is likely that more than 8 Mt yr^{-1} of textile waste is effectively going to incineration with energy recovery or disposal (landfilling) operations.

It is estimated that the current capacity in the EU for the sorting of separately collected waste is 1.5 -2.0 Mt yr^{-1}, based on findings documented by Köhler et al. (2021), McKinsey (2022) and EURATEX (2021) (Figure 3). Most sorting presently takes place manually. Sorting may also take place in a different Member State; particularly Germany has a sorting capacity that is significantly below the levels of separate collection (Watson et al., 2020b; Van Duijn et al., 2022). In addition, some separately collected textile fractions (about 0.3 Mt yr^{-1}) are imported from countries outside the EU, mainly the UK and Turkey (Eurostat, 2022a). This may involve separately collected textile waste fractions for further sorting and processing at EU facilities, as well as textile fractions that are directly sent to recycling operators[15].

Hence, it is suggested that a substantial share of the separately collected waste is shipped from within the EU to third countries without prior sorting (~50% of the total exports or 0.5-1.0 Mt yr^{-1}; Figure 3)), other than sorting out non-textile fractions. This can be mainly attributed to the lower cost of the (manual) sorting process in these third countries. In addition, export is the most common fate of separately collected textile waste sorted in the EU (0.85 Mt yr-1; 48% of the total collected). Together, this means that annually a total of 1.35 – 1.85 Mt yr^{-1} of used and waste textiles is exported from the EU to third countries. This flow is aligned to the data flow of about 1.7 Mt yr^{-1} documented in trade databases for the same reference year (UN Comtrade, 2023). A recent EEA report (EEA, 2023) points out that Asian and African countries are the main destinations for these textiles (jointly receiving close to 90% of the EU exports). The exports to Asia are mostly subject to sorting and processing in the country of destination, and then recycled locally (mostly for the production of industrial rags or filling materials), or re-exported to other (mostly African) countries (EEA, 2023). The import of used textiles seems to be mainly meant for local re-use in Africa, but it is likely that a substantial share of this material is ultimately non-re-usable. Hence, the management of unsorted textile waste in certain receiving countries is not necessarily socially and environmentally sound because of the insufficient quality of this material for re-use (only 58% is deemed suitable for re-use after sorting of similar fractions in the EU), a potential lack of aptness for re-use in country different than the country of origin, and the absence of a good recycling and disposal infrastructure in the receiving countries (Cobbing et al., 2022).

Re-use[16] within the EU of separately collected waste is estimated at about 10% of the separately collected waste, or 0.18 Mt yr^{-1} (Figure 3). Re-use within the EU, either in the same country of collection or following shipment to other EU regions, is the so-called 'cream' fraction within the collected material and generates an important share of the revenues for the sorters (Nørup et al., 2019a).

The fraction after sorting that does not meet the quality requirements for (preparing for) re-use is mostly recycled, and low amounts of waste for energy recovery or disposal (5-10%) are generated after the sorting process (Figure 3) (Nørup et al., 2019a; Watson et al., 2020a; Le Relais, 2023). Watson et al. (2020b) report that 32% of the separately collected waste is recycled. If these results are extrapolated to the total sorted fraction, this would correspond to 0.55-0.60 Mt yr^{-1} (Figure 3). Most of this fraction is mechanically recycled for further use as cleaning rags or non-woven materials for the non-woven textile sector and other industrial applications (e.g. insulation material for construction or automotive sector), either in or outside the EU (see section 4.3.4). The share that is actually recycled for further applications as apparel is low, as recently reported by the Fashion for Goods report (Van Duijn et al., 2022). Together with the recycled share of post-industrial and pre-consumer waste, the total mass that is effectively entering textile recycling plants, corresponds to the estimated recycling capacity in the EU (0.70 – 0.85 Mt yr^{-1}) as outlined in section 4.3.4 of this report. Hence, triangulated independent data supports the conclusions of our assessment on recycling and by extension management of separately collected textile waste.

[15] See section 4.3.4 on the mapping of recycling operators. Some of the entities document the intake of specific pre-sorted textile fractions (e.g. wool) for recycling and the manufacturing of recycled fibres and apparel.

[16] Including preparing for re-use

Importantly, waste management and treatment derived in this MFA study are based on data representative of the whole EU, so they might differ from Member States specific values, since municipal and country textile waste management strategies can change significantly (Amsterdam University of Applied Sciences, 2020; Dahlbo et al., 2021; Kjellsdotter Ivert, 2022). Austrian Environment Agency[17] reports higher share of textile waste sent to energy recovery consistently to Eurostat data on municipal waste treatment, which indicates a dominant fraction of residual household waste sent to incineration. Dahlbo et al. (2021) and Kjellsdotter Ivert et al. (2022) report higher shares of separate collection for Denmark and Finland, respectively, which can be explained by a longer and better-established textile waste management practice in comparison to the EU average.

Further information and a full uncertainty assessment of the Mass Flow Analysis results are presented in section 8.

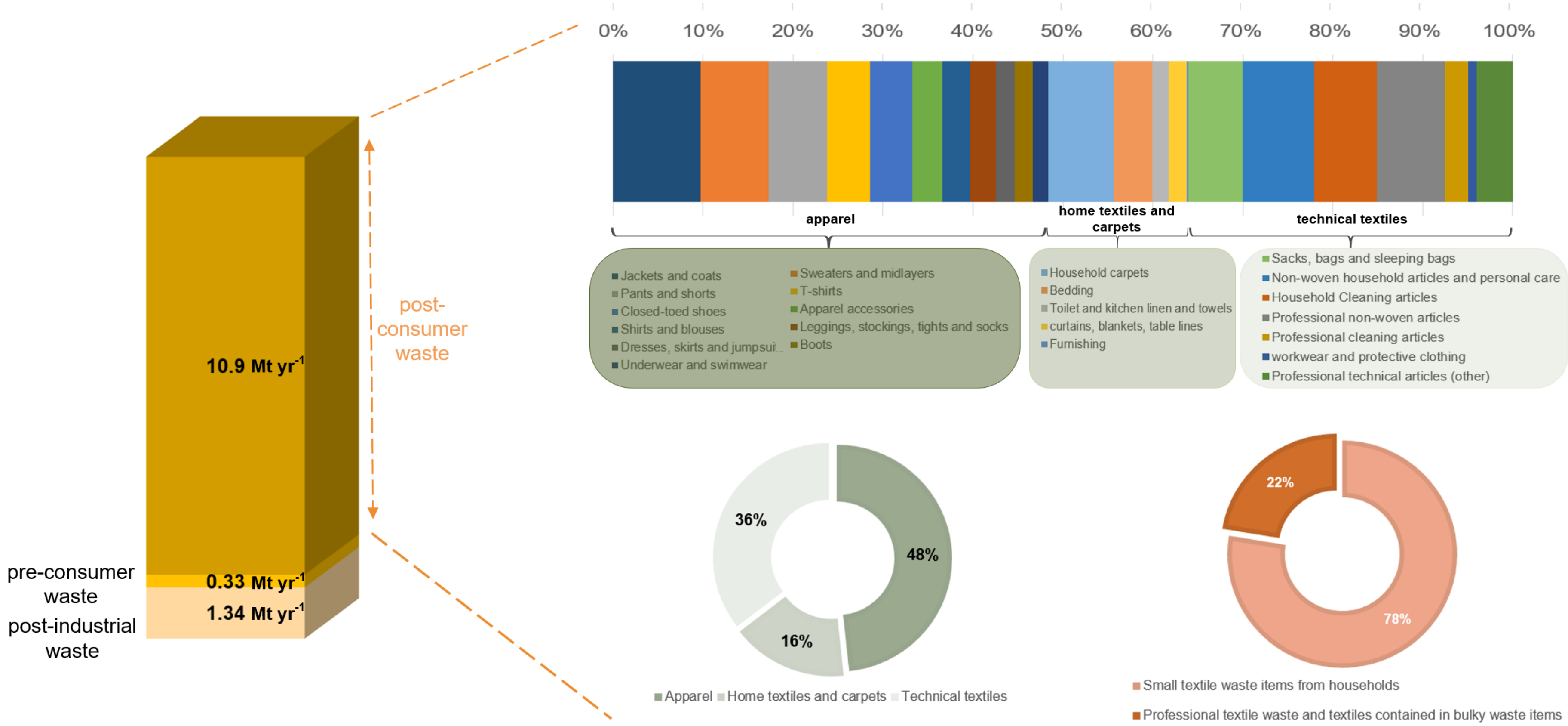
[17] https://www.umweltbundesamt.at/en/news220207en

3.2 Composition of textile waste

3.2.1 Composition in terms of textile categories

The textile waste consists of different fractions, potentially having a different potential for (preparing for) re-use and recycling (Figure 4).

Figure 4. Overview of the textile waste composition in terms of material categories, with a particular focus on post-consumer waste (10.9 Mt yr-1). The exact values for material categories as well as the assumed split up between 'small textile waste items from households' and 'professional textile waste and textiles contained in bulky waste items' are provided in Annex 9 of section 8.



Source: own work.

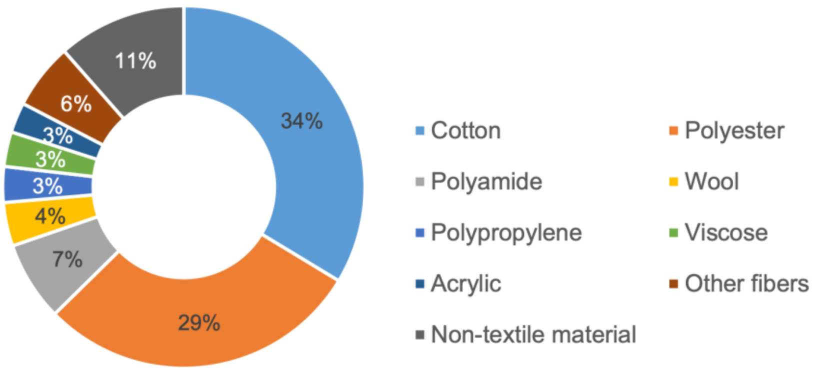
It shows that apparel is the dominant fraction that accounts for 48% (5.2 Mt yr^{-1}) of the total post-consumer textile waste, whereas home textiles and carpets make up another 16% of the total used textiles and textile waste. Technical textiles cover a variety of materials that are used by households and professional users, and represent 36% of the textile waste. Jackets and coats, sweaters and midlayers, pants and shorts, and T-shirts are the dominant apparel fractions (>50% of all apparel waste) (Figure 4).

A different manner of assessing textile waste stream is to estimate how much waste can theoretically be collected using collection systems for small household items (e.g. bring banks, street containers; see section 4.1), as opposite to collection schemes for textiles contained in bulky items and textile waste from professional users. Such assessment was performed by allocating certain textile fractions to their determined collection systems (e.g. apparel, workwear), and estimating the share of textile materials that find outlets for both types of collections (e.g. splitting items such as non-wovens and cleaning articles between households and professional users) (see section 8). It suggests that 78% of the post-consumer textile waste could theoretically be collected via collection systems for small households. This involves apparel (48%, split up between clothes (41.6%) and footwear (6.6%)), home textiles (8%, excluding non-woven textiles) and technical textiles used by households (sacks and bags, non-woven households items, cleaning articles for households; together 21%). It is, however, noted that not all items are recyclable (e.g. non-woven household items include disposable items such as absorbent hygiene products). Still, 60-70% of all post-consumer used and waste textiles originates from households and can (theoretically) be collected for re-use or recycling using already established separate collection systems in EU Member States. This involves not only apparel, home textiles but also sacks and bags, and cleaning articles (of a low degree of contamination). Less than 25% of the total post-consumer waste originates from professional applications or involves bulky items (e.g. carpets, non-woven industrial products).

3.2.2 Fibre composition

Cotton (34%), polyester (29%) and polyamide (7%) make up together 70% of the fibres contained in post-consumer waste fraction (Figure 5). Other fibres (including wool, polypropylene, acrylic) have a small share in the overall waste composition. Finally, non-textile materials (leather, metals in zippers, etc.) make up 11% of the total textile waste mass (Figure 5).

Figure 5. Fibres contained in the post-consumer textile waste fraction.



Source: own work.

It is also relevant to assess the typical composition at the levels of the individual textile pieces collected (e.g. a single garment, and home textile). Detailed information on the typical composition is available in Annex 7 of section 8. It shows that clothing is a textile waste fraction that contains more cotton and natural fibres compared to home textiles and technical textiles. Particular items with a high cotton content and/or wool content are T-shirts, shirts and blouses, pants and shorts, dresses, skirts, jumpsuits, linen and towels, and cleaning articles that contain commonly 45-70% cotton. Textiles rich in polyester and other synthetic fibres are blankets, curtains, carpets, non-woven articles and technical textiles, each of them having shares of >30-40% polyester, often polycotton.

Information on the composition of individual textile items is available from two European studies: Van Duijn et al. (2022) and Refashion (2023). They focused on measuring the non-reusable fraction of separately collected textile waste to assess its suitability for recycling purposes (current situation, study performed in selected countries). It was documented that cotton (43-52%) was the dominant fibre, followed by polyester (19-21%). Hence, the share of cotton is higher in their study, likely due to the fact that the study focused on the textile waste fraction that is currently collected, dominated by apparel. Another relevant outcome of the study is also that 31% to 37% of potential recyclable fractions analysed are contained in fibre mixes, often polycotton blends. The actual share is likely even higher, given that elastane may also be present in the fractions classified as 'pure' in the report due to analytical limitations. The Fashion-for-Goods report (Van Dujin et al., 2022) also provide data on share of specific textile fibres in apparel and home textiles which are part of blends (see Annex 9 for further estimates on blended fibre shares).

More information on the fitness of fibres in terms of their potential for recycling is given in section 4.

3.3 Preliminary outlook on textile flows

3.3.1 Textile sector growth

The present analysis attempts to develop a consensus on the future evolution and growth forecast of recycling capacity for Europe's waste textiles from the current literature.

At first, this section reviews five publicly available studies (scientific and grey literature) that offer future scenarios and market forecasts for the market for textiles, textile waste, and recycling capacity (Table 1). They were selected because their analyses of the market for textiles were carried out in the context of sustainability and/or circular economy (reduction, re-use, recycling).

This review of the literature offers a cross-cutting understanding of how industry stakeholders and academics assess each of the following topics, which are important for policy analysis of the future of textile recycling industries in the EU:

- future growth trends;
- methods for assessing the industry, given data availability;
- realistic time frames for forecasts / scenarios;
- key drivers in the industry.

The summary establishes the order of magnitude for the expectations of industry stakeholders and academics rather than a precise forecast. This is a consequence also of the fact that the reviewed literature cannot be directly compared. The literature's scenarios and forecasts vary in detail and insight into their underlying variables and methodologies in several respects.

First, the scope of the textile products analysed, and the unit of measurement applied. The scope of textiles analysed can be all textiles, clothing, home textiles, industrial textiles, apparel, or footwear. The unit of measurement is at different points in the value chain. For example, volume of textiles as production capacity in kilograms or tons, or the unit of measure can be monetary (i.e., revenue / turnover in US dollars or Euros).

Second, the timeframes of the sources' original data vary. When there is sufficient annual data available in the original source, a simple time series forecast is applied to adjust the data to the 2030 and/or 2050 timeframe used in many of the analyses.

Third, the analyses were carried out before, during, and after the global Corona pandemic, so include differing insights based on the pandemic's perceived impact. The summary of the literature presented in Table 1.

Table 1. Summary of literature estimating textile recycling industries' capacity growth in Europe. Scope of textiles analysed: all textiles, clothing, home textiles, industrial textiles, apparel, or footwear. Unit of measurement: volume (i.e., production capacity in kg or tonnes, consumption in tonnes, disposal of textile waste in tonnes) or the unit of measure can be monetary (i.e., revenue / turnover in US dollars or Euros).

Study (title, author, year)	Main focus of the study	Timeframe and results of the study	Key drivers identified
"EU-27 Textile Recycling Industry Market Research Report", Maia Consulting, 2023	All textiles Measured in monetary units Revenue in US dollars and measured in volume	2021-2028 15% growth Compound Annual Growth Rate (CAGR) 2.3% 2021 – 2030 18% Growth CAGR 2.3% (inferred) 2021-2050 40% CAGR 1.78% (inferred)	Less durable clothing / fast fashion, high disposable income, population growth
"Pulse of the Fashion Industry", Global Fashion Agenda and Boston Consulting Group, 2017	Apparel and footwear Consumption reported, measured in volume	2015 – 2030 63% CAGR 3%	Population, items per capita, growth of retail
"Fashion on climate", Mckinsey & Global Fashion Agenda, 2020	Apparel Consumption reported, Measured in volume and measured in monetary units	2030 CAGR 2.1% with circular business models at 20% or at current low level of circularity CAGR 2.7%	Population and scenarios for sharing/renting and post-consumer recovery
"A new textiles economy: Redesigning fashion's future", The Ellen McArthur Foundation, 2017	Clothing and textile industry production Measured in volume	2015-2050 CAGR 3.5%	Projected volumes of materials (e.g., cotton, plastic-based fibres)
"Scaling textile recycling in Europe—turning waste into value", McKinsey Apparel, Fashion & Luxury Group, 2022	Clothing and home textile Waste Measured in volume -- Recycling capacity demand based on post-consumer clothing and home textile waste volume available for recycling	2020 -2030 Post-consumer household waste 18% growth CAGR 2% (inferred) base case is 50%, of waste recycled "upside" case is 80% by 2030)	Consumption trends, waste trends, post-consumer collection rate scenarios derived from French curve

Source: own work.

Having acknowledged these boundary conditions, the literature review of the scenarios and forecasts suggests the following conclusions:

— Textile waste volumes and textile recycling industry capacity is expected to grow in the EU and globally by 2030 and 2050. None of the sources foresee a decrease in overall textile waste from today's levels;

— There is a general lack of robust data in the sector, consequently the need to incorporate a number of assumptions, which leads to significant uncertainty;

— The average compound annual growth rate (CAGR) is 1.8 – 3.5% for the five sources;

— The main observed key drivers in the literature are: demographic trends (population and disposable income); consumption trends, particularly apparel; and post-consumer textile collection rates.

The studies indicate that the textile industry is expected to generate more waste in the short-term and long-term, even with stronger regulation/guidance regarding apparel durability and the emergence of new circular business models designed to prevent product waste. When surveyed by the JRC, roughly 67% of 48 stakeholders responded that 2.5% CAGR was a reasonable estimate. Roughly 14% chose higher than 2.5% and 19% of respondents believed lower or no growth was likely.

3.3.2 Baseline projection for the year 2035 on textile waste management

Parameters of the MFA described in section 3.1 are projected in 2035 according to a baseline scenario, which assumes business-as-usual economic and technological trends, considering only policies already in place before 2023. Assumptions of the baseline scenario involve future production, import and export of manufactured products, separate collection, re-use rate, recycling capacity, import and export of discarded textiles and energy recovery and landfill rate as summarised below.

3.3.2.1 Apparent consumption

The projection of import, domestic production and export (and then, apparent consumption) of textile products is estimated assuming a Compound Annual Growth Rate (CAGR) equal to 3%.

This value is aligned to the Strategy for Sustainable and Circular Textiles. In addition, this number is in line with the data provided in the JRC 2023 report (Joint Research Centre, 2023). During the JRC workshop on textile waste[18], stakeholders confirmed that a 3% compound annual growth rate is a realistic outlook for the EU.

The value of each indicator (import, domestic production or export) of a product in 2035 is calculated as:

$$I_{2035} = I_{2021}(1 + CAGR)^{\Delta t}$$

Where:

- I_{2035}: is the value of the indicator in 2035.
- I_{2021}: is the value of the indicator in 2021.
- $CAGR = 0.03$.
- $\Delta t = 14$, being the time (in years) between 2021 and 2035.

Note that projections are made starting from the year when we have the most recent observation (2021).

3.3.2.2 Recycling of post-industrial and pre-consumer waste

Post-industrial and pre-consumer waste generation are estimated as 37% of the textiles produced in the EU, with losses assumed from the production of yarns, fabrics, and finished textiles equivalent to 8%, 13%, and 20% of their total production, respectively (Sadowski et al., 2021). Pre-consumer waste was assumed to be 3% of the textile placed on the market (McKinsey & Company, 2022). It is assumed that these shares do not change in comparison with the status quo scenario (reference year 2019).

The recycling of post-industrial and pre-consumer textile waste is assumed as a constant share of the total recycling capacity estimated. It is assumed that the ratio of (post-industrial plus pre-consumer waste sent to recycling)/total textile waste sent to recycling) remains equal to status quo scenario, at 33%.

The projection is thus based on two following assumptions:

— future total recycling capacity in 2035 of 1.3 Mt yr^{-1} (see below);

— as for the 2019 status quo scenario, 1/3 of total recycled textile mass is assumed to come from post-industrial waste.

Recycled post-industrial and pre-consumer waste in 2035 is then projected as:

[18] Workshop organised by JRC on 18-19 April 2023 to discuss a draft version of their report (Joint Research Centre, 2023). More than 150 organisations, including industry organisations active in the textile sector, participated in this workshop.

$$\frac{1.3}{3} = 0.43\ \frac{Mt}{yr}$$

Note that this 0.43 Mt will include a minor share of post-industrial waste which is imported in EU (data retrieved from Comext database) and assumed to go directly to recycling.

3.3.2.3 Separate collection

Based on historical year-on-year improvements in countries/regions that have made strong efforts to increase collection rates through target setting, communication and an emphasis on collection of the non-reusable collection waste (France, Flanders and Netherlands), Köhler et al. (2021) estimate that the annual collection will increase by a further 65 000 to 90 000 tonnes annually in coming years as Member States begin to adjust or roll out supplementary collection systems to implement the provisions on separate collection of textiles in the Waste Framework Directive. This would further increase the separately collected textile volume by 0.8 – 1.1 Mt in 2035, to a total of 3.2 – 3.6 Mt yr-1. The upper bound is preferred since separate collection is low in many EU countries and is likely to increase significantly before 2035. Based on these assumptions, the best estimate for separately collected textiles in baseline scenario is assumed 3.6 Mt yr^{-1}.

3.3.2.4 Export of unsorted separately collected textiles

Relative to the 2019 quo scenario, a relative decrease in the exports to third countries of unsorted textile waste is expected because:

(i) At present, approximately 96% of the textiles are exported to non-OECD countries (EEA, 2023). In the Commission proposal for a revised Waste Shipment Regulation, environmental sound waste management practices and the demonstration thereof is proposed for textile waste shipped to non-OECD countries;

(ii) In addition, receiving countries may set stricter quality requirements on the amounts and types of textiles that they import. Some of the countries have already banned import of used clothes (e.g. Nigeria, Zimbabwe), whereas others (e.g. Kenya, Zambia) have introduced a levy to prevent competition with local industries.

At present, no data are available to estimate the impact of such revised settings on the export of unsorted waste, but it seems likely that some of the exports may continue to take place to third countries, whereas a different share of the fraction may be rerouted to the EU for domestic sorting. The impact assessment of the Commission proposal for a revised Waste Shipment Regulation, estimated that the exports of waste to non-OECD countries may overall decrease by 25-50% (average 37.5%). We assumed that (i) sorted textiles suitable for re-use will not be affected in the future as it will be shipped as a good, rather than waste, after compliance with End-of-Waste criteria; (ii) exports of unsorted textile waste to OECD countries will continue to take place at the same order of magnitude, and (iii) exports of unsorted textile waste to non-OECD countries will decrease by 37.5%.

3.3.2.5 Textile re-use and export after sorting in EU

Uncertainties apply with respect to the quality of the additional textiles collected when shifting towards increased separate collection. It seems intuitive that textiles with the lowest re-use potential are more prevalent in the textile fraction of mixed municipal waste, but the few available research findings are inconclusive. Nørup et al. (2019b) and Hultén et al. (2016) found similar or only marginally higher shares of re-usable and recyclable waste in separately collected textiles compared to residual waste in Sweden (containing 60-70% re-usable clothing and home textiles). This stands in contrast with findings from Watson et al. (2018). In this study, it was indicated that 23% of the textiles separated from mixed household waste would have been reusable and 26% recyclable. The re-usable share is similar to values reported by a Norwegian study (Laitala et al., 2012) indicating that only 28% of the textiles disposed as mixed municipal solid waste can be re-used. No information is available from studies performed in other geographic EU regions with a lower consumer expenditure on textiles.

A lower quality in the separately collected textiles, and subsequent reductions in the fraction that is re-usable, could be expected in case increased separate collection circumvents certain (worn-out or damaged) textiles from ending up in mixed municipal solid waste. It can be assumed that this value decreases to 42% for the supplementary collected apparel and home textiles (average value of studies listed in the paragraph above). Re-use share of sorted textiles is then projected in 2035 as the weighted average of the re-usability of currently separately collected textiles (2.44 Mt yr^{-1}) and the future fraction that will be separately collected (1.16 Mt yr-1), as follows:

$$Reuse\ [\%] = \left(\frac{2.44}{3.6}0.57 + \frac{3.6 - 2.44}{3.6}0.42\right) \times 100 = 52\%$$

Where:

- 2.44 Mt yr-1 is the mass of separately collected textiles in current-state scenario.
- 0.57 is the share of "high-quality" textiles going to re-use (in and outside EU) after sorting.
- 3.6 Mt yr-1 is the mass of separately collected textiles in baseline scenario.
- 0.42 is the share of "lower quality" (additionally collected) textiles going to re-use (in and outside EU) after sorting.

The exports involve both textiles that are destined for re-use as well as further sorting in the third country of destination.

Similar to the status quo scenario, it is assumed that re-use in the EU of the separately collected waste is only a small fraction of the total fraction of the separately collected waste (~8%).

3.3.2.6 Recycling of post-consumer textile waste (after sorting)

The current recycling capacity for the year 2023 is estimated in the EU at 0.75-0.80 Mt yr-1. In case we assume an average compound annual growth rate that is similar to historic capacity developments for the recycling of other secondary raw materials (paper and cardboard, packaging waste (with a compound annual growth rate of 3%-5.5%)), the total textile waste recycling capacity in 2035 would grow to approx. 1.3 Mt yr-1. Assuming that, similar to the status quo scenario, about 66% of this capacity is being used to process post-consumer waste, the total recycling of post-consumer waste would be projected as:

$$1.3 \times 0.66 = 0.87 \frac{Mt}{yr}$$

It is noted that any restrictions on chemicals present in recycled materials could possibly limit recycling. In the absence of a sound assessment the matter, this aspect has however not been considered in this assessment.

3.3.2.7 Incineration and landfill rate

The mass of discarded textile not separately collected, selected for re-use or recycling or exported, was sent to energy recovery or landfill, based on proportions found in data on mixed waste treatment in Eurostat. In case of current-state scenario, this proportion was calculated based on Eurostat data for 2019. In case of baseline scenario, the proportion for 2035 was projected by means of linear regression over time.

3.3.2.8 Import of textile waste

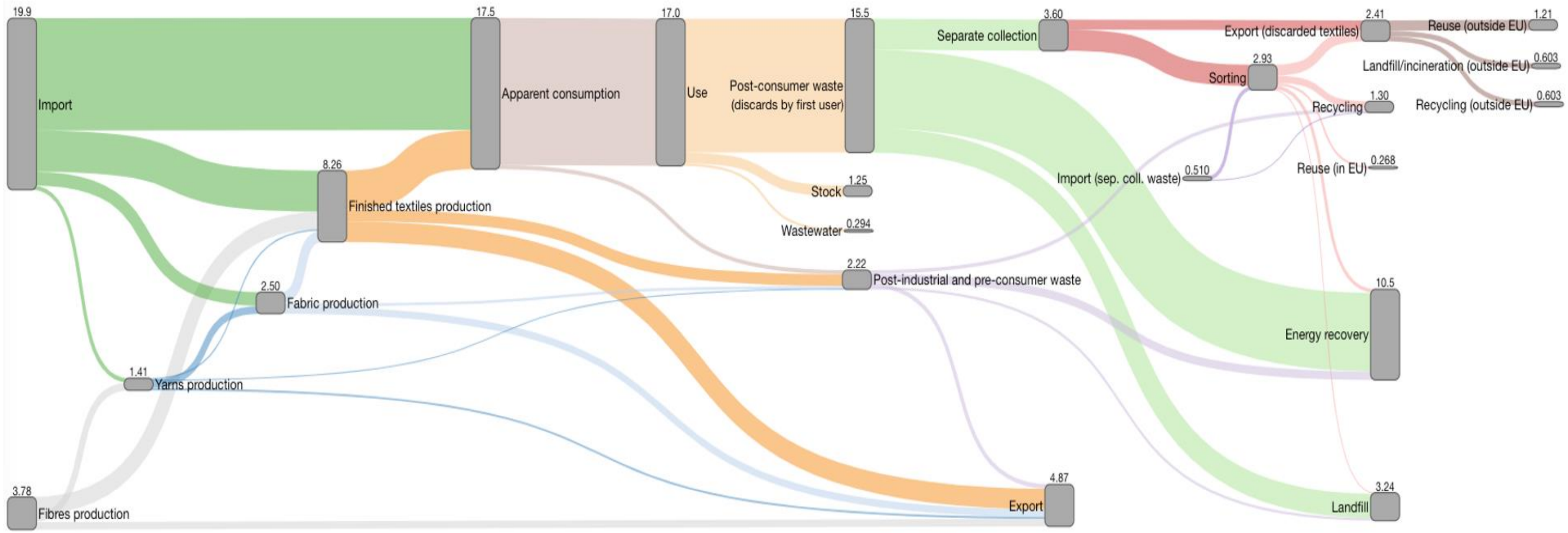
The mass of imported textile was estimated based on data from Comext database. For current-state scenario, data referred to 2019 were used. In case of baseline scenario, imported textile waste in 2015 was projected by means of linear regression over time.

3.3.2.9 Outcome

The baseline scenario for the reference year 2035 is mainly driven by a significant increase in import and production, due to the expected increase in apparent textile consumption (Figure 6; see Annex 8 for numerical values). Textiles placed on the EU market in the baseline scenario are approximately 30% more than the current state scenario of (about 17 Mt yr-1). As in the 2019 scenario, only about 35% of all textiles placed on the EU market originate from domestic production and the import of fibres, yarns, fabrics and, particularly, finished products jointly corresponds to 20 Mt yr-1. Increase in mass of manufactured products determines a proportional increase in both post-industrial waste and total discarded textiles after consumption. Post-industrial waste increased by 25% (2.22 Mt), still representing a smaller fraction (13%) of the total waste, similarly to the 2019 scenario. 0.3 Mt yr-1 of microfibres[19] are emitted during washing of textiles. The overall share of separately collected discarded textiles is substantially the same in 2035, estimated as 23%. This is due to an expected annual increase in flow of discarded textiles which basically equals growth of separate collection, as consequence of the increase in consumption. As a result of baseline scenario assumptions, more textiles are sorted in the EU, due to a reduction of textiles exported after being separately collected. An increase in recycling capacity, both for post-industrial and sorted textiles, is projected. Importantly, the other main difference of baseline scenario with respect to 2019 lays in the share of textile waste sent to energy recovery, which drastically increased (from 39% to 59%), with a consequent decrease of landfilled waste. Flow of discarded textile not separately collected and sent to energy recovery is approximately 9.09 Mt yr-1 in the baseline scenario and 4.33 Mt yr-1 in 2019. Such increase was projected due to the observed increase in the share of incinerated textile waste observed in historical data. Uncertainty analysis results for the baseline scenario are summarised in Annexes 10 and 11.

[19] Textiles are a major source of microplastic pollution. Microplastics are ubiquitous, persistent, very mobile and virtually impossible to capture once released into the environment.

Figure 6. Projected Mass Flow Analysis for textile production and waste management in the EU-27 for the reference year 2035 ("baseline scenario"). The mass flows in each node are expressed in Mt yr-1, and represent best estimates characterised by uncertainties as outlined in Annex 10 and 11.



Source: own work.

3.4 Summary of stakeholders' feedback on draft report

A draft version of this report was shared for consultation with about ~150 stakeholder organisations, including Member States representatives, industry actors, non-profit organisations, academics and non-governmental organisations, in April 2023. Feedback on this draft report was received orally and in written during a stakeholder workshop (18-19 April) and an associated questionnaire (hereafter "stakeholder consultation").

3.4.1 General overview

Feedback on the draft report was mainly provided by industry (52% of the total), Member States representatives and non-profit organisation (both 14%), research organisation (10%) and local Authority and non-governmental organisations (both 5%). 28% of the received stakeholder feedbacks are related to the specific section 3 on textile material flows. Comments addressed scope definition (24%), discrepancies with stakeholders' data (29%), doubts on the methodology (19%) and provided additional references and data sources (29%). A general overview of the comments is provided below:

- Clarification on scope definition: most comments suggested to improve some descriptive parts in text and figures, such as the definition of the MFA model structure and the difference between textile waste and second hand and reusable textiles;
- Discrepancies with stakeholders' data: most comments were provided to complement data on waste generation and management activities, highlighting differences with previous studies and technical reports. Several key references and data were provided to complement MFA data;
- Clarifications on the methodology: comments suggested to better clarify the methodologies followed for the development of the MFA.

3.4.2 Main changes compared to draft report

Main changes compared to the draft report are as follows:

Comment addressed	**Short description of review**
Clarification of scope definition	— Figure 2 of the report has been updated for including a better distinction between textile waste and second hand and reusable textiles. A clarification has been also added in the Terminology for textiles (section 3.1.1). Figure 2 also includes two extra boxes for fibres that do not become yarns and yarns that do not become fabrics. — Mass of yarns not becoming fabrics is estimated as = to the mass of ropes, cordage and net products produced in the EU. Within this mass, share of imported yarns is estimated as = to the overall share of imported yarns (considering all kind of yarns). This is required since we do not have specific information on yarn products used for net, ropes and cordages. — Flow of fibres directly going to fabrics is estimated and represented in results. — Fraction of blended fibres was calculated (but prevalence of specific blends is missing). A comment on this was added in section on composition and some additional results were added in Annex 9. — Description of MFA methodology (calculation and assumption of domestic production, import and export of fibres, yarns, fabrics and finished textile products) was updated in section 8.1.2.
Discrepancies with stakeholder	All stakeholder inputs/references have been analysed and compared to the MFA results, and relevant additional references have been included in the bibliography. The received inputs are related both to the EU and single member state. These inputs and references

data	generally validated the information and assumptions reported in the MFA. However, some discrepancies are present and discussed in the report: — Waste management and treatment shares included in the MFA are retrieved from the literature and they are representative of the whole EU, so they might differ from Member States specific values, since municipal and textile waste management strategies can change significantly for each country (clarification added in section 8.1.1); — The total amount of textile waste presented in this study is larger than in previous studies because of the extensive scope of the study. In contrast to other studies, this study expands the boundaries to textiles other than apparel and home textiles, including non-woven and technical textiles, and textile waste management, including waste generated during the production and retail life stage of textiles. Indeed, this study covers post-industrial, pre-consumer and post-consumption waste from textiles used by both citizens and commercial sectors (clarification added in section 3.1.3.1). — Waste composition calculation (clarification added in sections 3.1.3.2 and 3.2.2 and annex 9) — Better explanation on the methodology adopted for the calculation of post-consumer waste in section 3.1.2.3, including an example in the footnote 6. — Better explanation of the calculation of separate collection of post-consumer textiles share in section 3.1.3.2
Clarification of methodology	Better explanation have been added in the report on the following aspects: — Methodology (Dynamic MFA) adopted for the calculation of post-consumer waste in section 3.1.2.3, including an example in the footnote. — Estimation of total amount of textile waste (the amount presented in this study is larger than in previous studies because of the extensive scope of the study; clarification added in section 3.1.3.1). — Estimation of the re-use fraction outside the EU (section 3.1.2.5)

4 Management options for used and waste textiles

4.1 Separate collection

Separate collection of waste fractions diverts recyclable materials from the residual or mixed municipal solid waste and thus provides opportunities to make more value out of valuable resources that would otherwise be landfilled and incinerated (Albizzati et al., 2023). This is particularly important for textiles as this stream is a small part of the total waste generated (estimated to be at around 3-6% of mixed municipal households waste), and textile intermingling of this fraction would reduce possibilities for recycling (e.g. due to moistening and associated quality loss of the material). Therefore, the Waste Framework Directive (Article 12b of Directive (EU) 2018/851) obliges Member States to set up separate collection for textiles. Main collection strategies for dry recyclables and textiles typically consist of pick-up schemes and drop-off schemes (bring points, including civic amenity sites) (Commission et al., 2015; Albizzati et al., 2023) (Table 2).

Table 2. Main collection strategies for textiles

Collection type	Features
Pick up schemes	Pick-up schemes include door-to-door and kerbside collection, where collection rounds on the territory are typically organised for the most voluminous and common waste streams, referring to bio-waste, dry recyclables and residual waste
Drop-off schemes (or bring banks/points)	Drop-off/bring schemes include road and underground containers with a number of containers placed on public areas, where households or businesses can deliver waste. For textiles in particular, retailers can also set up take back systems where citizens can dispose their used textiles. Civic amenity sites also accept a wider range of waste streams, including large voluminous waste such as bulky waste (furniture, bulky garden waste, etc.) or hazardous streams (such as paints, etc.) and waste from electrical and electronic equipment, etc.

Source: own work

Note that Member States have different schemes for the target textile materials for separate collection, both in relation to physical fractions as well as to the acceptance of non-re-usable textiles. In some countries such as Italy and the Netherlands, all textiles collected via containers are labelled as waste. In other Member States, the legal status depends on whether the (majority) of the collected textiles are re-used or not (ECAP, 2018). Finally, in certain municipalities (e.g. in Sweden), there are two bins at the curbside; one belonging to a charity organisation for high-quality textiles or targeted re-use, and one belonging to the recycling company for (worn out, broken and damaged) waste textiles (Ragn-Sells, 2013). Collection of reusable textiles over the counter in second-hand shops or other manned collection points is not classified as waste collection, since the receiver has had the chance to inspect items to check suitability for re-use (Köhler et al., 2021).

4.1.1 Post-industrial and pre-consumer waste

Post-industrial textile residues are generated during the manufacturing process (e.g. cut-off leftovers), and their management is controlled by the textile manufacturer. It may involve on-site recycling, posterior management by an industrial waste management as a third-party (business-to-business), or disposal. Post-industrial waste is usually clean and undamaged and of a well-known chemical composition, and can thus often be recycled without any additional cleaning or sorting. Therefore, it is a preferred source for mechanical recycling processes (see section 4.3.4). Unsold textile goods are labelled as pre-consumer waste and their management is generally unclear. In some cases, they are rebranded and sold in outlet shops, donated to charity organisations and/or exported to other EU or extra-EU countries (Granum, 2013). In other cases, unsold goods are destroyed by companies.

4.1.2 Post-industrial waste from households

In the EU, municipalities, charities, social enterprises, second-hand shops and retail companies (via take-back schemes) play a varying role in the collection of post-consumer textile waste. The organisations involved in separate collection are typically also responsible for sorting the collected textile material.

4.1.2.1 Municipalities

Routinely, municipalities are in charge of handling the citizens' waste, and have moreover the power to decide on who may set up the collection infrastructure. For example, in Estonia, due to legal obligations, municipalities carry out 37% of all collection, and in Lithuania they have a 30% share (Watson et al., 2020a). Germany has developed a draft revision of the German waste legislation that places the responsibility for the collection of textile waste from households on municipalities, provided that the treatment of these waste quantities is technically and economically feasible (Köhler et al., 2021). Similarly, in Denmark and in Italy, municipalities are required to carry out the separate collection of textile waste since the beginning of 2022, and Spanish municipalities from 2025 (Gazzetta Ufficiale, 2020; Watson et al., 2020b; Boletín Oficial del Estado, 2022). It seems that Finland will also place the responsibility on municipalities (Watson et al., 2020b).

Collection via drop-off schemes is reported to be the dominant form of used textile collection in many European countries. For example, in France, 78-83 % of collection is via bring banks, of which three quarters are placed on streets and other public ground, and the remainder on private ground, while 88 % of collection in Germany is via bring banks (EcoTLC, 2020a; Van Duijn et al., 2022). Bring banks are often placed on streets, private areas and at civic amenity centres on streets (Watson et al., 2020b). It is important to mention that the quality of the collected textile waste is thought to be linked to whether the collection system is manned or unmanned. Especially if the municipality collects textile waste for re-use purposes only, an unmanned collection system typically implies that 20-30% of the collected textile waste are suitable for recycling but not for re-use (Köhler et al., 2021).

Kerbside collection is another way of collecting textiles, yet it is significantly less prevalent, in part due to higher costs but also due to risk of theft (EcoTLC, 2020a). Currently, it comprises only 1.8% of collection in France and 3% in Germany. In Austria, kerbside collection via special textile waste bags is carried out by a small number of municipalities but has become rarer in recent years. A handful of municipal waste companies have begun kerbside collection of textiles waste in Denmark, the Netherlands and Sweden, generally using bags that are sealed and placed with other dry recyclables (Watson et al., 2020a). There is no kerbside collection in the Baltic States (Watson et al., 2020b).

4.1.2.2 Charity organisations

Charity organisations have historically been the main actors involved in the collection of used textiles, and they still are (Köhler et al., 2021). Charity organisations collect used textiles via bring banks (containers), or over the counter in the charity organisations shops. Containers can be located in civic amenity sites (also named recycling stations in some countries) or on the streets. In some cases, e.g. in The Netherlands, charities are asked to pay a fee to the municipalities for the textiles they collect via containers in public space (ECAP, 2018). Following collection via bring banks, textiles are then collected and transported to central sorting or bagging locations for either local second hand or exported to sorting companies. Textiles are sorted into different qualities which are usually directed to different markets. This kind of collection gives an average quality of collected textiles, with less quality than in-store collection, but likely more efficiency in terms of quantity of textiles collected (Schmidt et al., 2016a). Charities' collection can also happen over the counter at second hand shops, which makes the quality of textiles for re-use higher than collection via containers, since the collection is carefully monitored by the shop's personnel (Palm et al., 2014). In this case, used clothes are sold directly in the charity's shop, without the need of transport to a sorting facility. Kerbside collection by charities is very rare, although some charities offer on-demand pick-up services, usually in return for a fee.

The main aim of charitable organisations is normally to sell used textiles for direct re-use, without any type of repair or mending. Therefore, charitable collectors in most countries tend to make it clear on their bring banks that they only wish to receive clean and reusable textiles (and footwear), often due to the negative impact that collecting non-reusable textiles have on their economies (Köhler et al., 2021). Some organisations then carry out sorting into different streams completely "in-house"; others sort a part of the collected textiles internally (usually differentiating between textile for domestic re-use vs textiles for treatment in other EU or non-EU countries), and sell another part unsorted (Palm, 2014). However, the collection system by charity organisations usually does not address textile material for recycling outside the portion of collected textiles that is not suitable for re-use and that is sold as unsorted stream to other countries/actors.

Currently, charity organisations are by far the main actors for the collection of used textiles in many EU countries, especially the Nordic countries (Denmark, Norway, Sweden, Finland and Iceland), but also globally (Palm et al., 2014: Watson et al., 2020a). For example, charities accounted for 87% of the collection of used textiles in 2013 in Sweden (Elander et al., 2014). In fact, charity organisations have often preferential treatment in that they are the only ones allowed by the municipalities to set up collection containers.

However, these organisations have been recently joined by a number of other actors, such as second-hand shops, social enterprises and on-line platforms for the sale and exchange of clothes. For example, in the Netherlands the collection share of used textiles managed by charities has dropped from nearly 100% in 2000 to 55% in 2013 (ECAP, 2018). In some countries like the Netherlands, charitable organisations create dedicated private companies to carry out the textile collection, sorting and sales operations with the revenues returned to the charitable part of the organisation (Watson et al., 2020a). In the Baltic countries, separate collection is relatively evenly split between charitable organisations, commercial/private collectors and municipalities/contracted waste companies (Watson et al., 2020b). In Italy, where collection of textiles via bring banks is considered as waste, there is a complex interaction of companies and cooperatives active in the sector of separate collection of textile waste, managed at national level by a large association (Unicircular, 2018). The sole country where charity organisations are less involved is France, where household textile waste is managed through an Extended Producer Responsibility (EPR) scheme, and the collection is managed by an accredited Producer Responsibility Organisation (PRO) (Köhler et al., 2021). However, charities can register as official collectors under the EPR scheme (ECAP, 2018). Some countries collect both reusable and non-reusable textiles, building thus a centralised system for all textiles.

Large charity organisations active in the collection of used textiles are Oxfam and Caritas, and are characterised by having at least a share of the workers not receiving a full salary when supporting the organisation.

4.1.2.3 Social enterprises or organisations

Social enterprises involved in the collection of textiles partly differ from charities in that their employees are not volunteers, they normally have a social or environmental goal, and can be for-profit or non-profit. Social enterprises can organise textile collection via kerbside, drop-off or in-store systems. In the EU there are many examples of social entities that collect used textiles or textile waste. In the Netherlands, Flanders and Austria, socio-economic re-use organisations under the HERWIN and RepaNet networks specialise in receiving used goods including textiles across the counter for processing and repair in the shop (ECAP, 2018). These national networks are all part of the European RRE-USE network[20], an international non-profit network of social enterprises. In 2021, RRE-USE had 31 members across 29 countries. As of 2021, 341 000 tonnes of textiles were collected by RRE-USE members, of which 39 000 were re-used locally (RRE-USE, 2022). Other social enterprises include the Red Cross in the Nordic Countries, Humana in several countries such as Lithuania, Spain, Italy and Sweden, and Komosie in Belgium.

4.1.2.4 Second-hand shops

Second-hand shops have recently increased their role in the handling of used textiles, although they are usually not estimated to represent a significant share of total used textiles collection. It is challenging to estimate the used textiles volumes that are handled through second-hand shops, particularly given the recent popularity of online platforms for direct consumer-to-consumer sale or exchange (e.g. Vinted, Vestiaire Collection). Collection of reusable textiles over the counter in second-hand shops is not classified as waste collection in Europe, since the receiver has had the chance to inspect items to check suitability for re-use. Indoor collection in second-hand shops is estimated to represent 13% of total collection in France, and 4% in Germany, while it is not thought to represent a significant share of the textile flows in the Baltic States and in the Nordic countries (Köhler et al., 2021).

Similar to the case of charities, the main aim of second-hand shops is re-use, or reselling, therefore only textiles in very good quality are accepted at the counter, and the focus is almost exclusively on apparel and apparel accessories. Second-hand shops are normally run by private actors, that retain a part or the total of the price at which second-hand textiles are sold.

4.1.2.5 Retail companies

Circular business models (CBM) aim at creating added value "to reduce the extraction and use of natural resources and the generation of industrial and consumer wastes", according to the definition of CBM given by the OECD (OECD, 2019). In the textile sector, CBMs aim to exploit resource values by maintaining or restoring the function of textile products as long as possible, amongst others based on sound waste management (CTP,

[20] https://rre-use.org/work-areas/environmental-and-circular-policies/

2015). Brands such as Patagonia, Zara, and H&M have already introduced their own take-back scheme. Some brands have established brand mail-back systems, i.e. users are asked to mail their unwanted clothes back to brands[21]. Some other brands opted for retailer drop-off containers, where users bring their garments at the retailers' shops[22]. For example, H&M's Recycle Your Clothes initiative collected 18 800 tonnes in 2020 via drop-off containers at their shops (H&M Group, 2020). In some cases, in-store collection is incentivised by rewarding citizens with a voucher with which they can immediately get money off a new purchase in exchange of their used textiles (Palm et al., 2014). Other companies decided to keep their main role as producers, but committed to improving textiles recycling by initiating take-back schemes or separate collection of used textiles by bring banks placed directly in their shops. Take-back systems can also be part of a broader EPR scheme.

4.1.3 Non-household and bulky post-consumer waste

Generally little information is available for technical textiles used for industrial applications, and only information on workwear could be retrieved (ECAP, 2017). Workwear garments are unlikely to reach the end of their functional life before being discarded, making them suitable for re-use if technical and security issues can be overcome (ECAP, 2017). The collection systems for workwear comprise three principles routes: commercial recycling (and re-use) collections, take-back and commercial collections, and household waste disposal. Estimating the proportions for these routes is not possible although case studies, e.g. City of Herning in Denmark and Welsh NHS Trust nurses' uniforms, noted that the leakage of workwear such as uniforms into the household waste collection system was significant (ECAP, 2017). If separately collected, the majority of workwear is bulked with home textiles and clothing, and delivered to sorting stations.

It seems likely that disposal together with other waste streams is a common management route for other technical textiles, often designed for very specific applications, being contaminated or subject to wear and contamination during first use (e.g. medical, cleaning and agricultural textiles) and/or being intimately intermingled with other materials (e.g. construction and automotive applications). For instance, most textile products placed on the healthcare market are currently incinerated or sent to landfill because of the contamination with drugs, body fluids and blood during use (Das et al., 2021). Cars and car parts including textiles are increasingly being dismantled, but incineration with energy recovery or other use outside the textile sector for the textile fraction is common[23]. Agricultural textiles may also be designed to biodegrade after use (Sharma et al., 2022).

Textiles in carpets, mattresses and furniture are bulky waste streams that may contain a variable share of textiles. Such materials are typically collected via kerbside or in civic amenity sites. Alternatively, the company that sells new products or an appointed recycler may pick up the used mattress, carpet or piece of furniture from the customer.

4.2 Textile recognition and sorting techniques

Increasing collection quantities should go hand in hand with establishing or scaling-up sorting and recycling processes at the same time, in order to improve the opportunity to capture value from collected materials. The sorting of post-consumer-textiles is a critical process for assessing its re-use potential and recycling potential (Dahlbom et al., 2023). The assessment of textile sorting is limited to small post-consumer waste items from households and bulky waste items containing textiles. Post-industrial and pre-consumer waste are not sorted as separately collected fractions will have a well-identified composition and quality, but customer returns may undergo a quality check. Bulky waste is typically separated in different fractions, textiles and non-textiles. The textile fraction of these materials may be separated during material-specific dismantling process by specialised recyclers, for instance for mattresses[24] or carpets[25]. The obtained materials may then be recycled using mechanical, chemical or thermal techniques.

[21] Examples are Patagonia (http://www.patagonia.com/recycling.html) and Eileen Fisher (https://www.fisherfound.com)

[22] Examples are H&M (https://about.hm.com/en/sustainability/get-involved/recycle-your-clothes.html) and Zara (https://www.zara.com/uk/en/info/join-life/clothes-collecting-c861007.html)

[23] See example on the uses of textiles following car dismantling: https://www.recycleaid.co.uk/car-and-vehicle-recycling/1221/

[24] See for instance, https://cefic.org/a-solution-provider-for-sustainability/chemistrycan/driving-the-circular-economy/giving-new-life-to-old-mattresses/

4.2.1 Manual sorting of post-consumer waste from households

At present, most of the revenues for organisations involved in textile sorting are the result of sales to different re-use markets, pointing towards the value of assessing the re-use potential of separately collected textiles, mostly apparel and footwear. This involves a quality control on the textiles for damage, stains, puncture or signs of discoloration, loss of quality, and other defects (e.g. pilling). In manual sorting the need for highly trained staff is crucial to sort the textiles rapidly in categories based on type, size, style, and quality. Many sorting facilities sort the textiles in over several hundred different categories, mostly for re-use in different markets (Nørup et al., 2019a). A lot of the manual sorting of European textile waste is carried out outside the EU (see section 3.1.3), or in the Baltic States and Eastern Europe, where the labour cost is lower than in western Europe (Nørup et al., 2019a; Watson et al., 2020b).

4.2.2 Automated sorting

Textiles for recycling need to have a known fibre composition, since there are requirements and limitations of fibre composition on the input material going to recycling processes (Watson et al., 2020b; Dahlbom et al., 2023). Automatic sorting technologies are faster and more precise compared to manual sorting to assess fibre composition (900-4500 kg per hour versus 100-150 kg per person per hour for manual sorting) (Dahlbom et al., 2023). The most promising technology is spectroscopy that analyses the material composition via electromagnetic waves, and interactions and measurements of the wave and chemical structures. A spectrum is created which represents the sample's chemical structure, enabling to discern categories such as pure material (100 percent cotton), mix of material (40/60% cotton/polyester) or material families (cellulose fibres). The most common spectroscopic approach is near infrared light (NIR) (Dahlbom et al., 2023).

At least a few operational plants have started to implement automated sorting based on NIR as part of their activities. Siptex[26] is an automatic textile sorting facility in Malmö, Sweden. It is a result of a Swedish research project and today operated by the municipality-owned waste management company Sysav. The sorting capacity is 24 000 tonnes per year at a maximum, and presently 8000 tonnes per year are already sorted automatically. Another example is the Coleo Recycling[27] textile facility in A Coruña, Spain, with a current capacity of 2 200 tonnes per year, relying on NIR and Artificial Intelligence techniques of the PICVISA[28] technology provider. Also, the NewRetex[29] textile sorting facility in Denmark makes use of NIR technology and aims at upscaling its automated sorting capacity to 40 000 tonnes in 2025 (Dukovska-Popovska et al., 2023). In some other sorting plants (Boer Group[30], LSJH[31]) hand scanners with NIR technology[32] are already used to identify the products' fibre composition and upscaling to automated sorting is planned for the near future (Dahlbom et al., 2023). Also other technology providers for manual, semi-automatic and integrated sorting systems for textiles based on NIR technology are emerging (e.g. Fibresort[33]). Some limitations to automated sorting apply (e.g. when assessing the composition of dark-colored textiles, or separating fibres with a similar chemical composition). NIR spectra can also be further processed using Artificial Intelligence (AI) to improve the classification or to sort out specific materials (e.g. of a specific shape). Near infrared remains relatively inexpensive, with a CAPEX of about 150 000 – 200 000 EUR for an optical sorting machine (EcoTLC, 2020b; throughput capacity not reported, but likely a few kilotonnes per year), for integrated solutions with a high sorting capacity. This means that the return on investment could be high when a demand for sorted bales for recycling processes exist.

Another promising methodology to improve sorting, and particularly sorting for recycling relates to the digital product passports initiative, part of the proposed Ecodesign for Sustainable Products Regulation and listed as one of the actions in the EU strategy for sustainable and circular textiles. Use of digital information carriers (e.g. RFID tags; Radio Frequency IDentification) integrated in garments have the potential to greatly increase

---

[25] See for instance, https://www.vanheede.com/en/our-treatment/carpet-recycling/ and http://www.tarkett-carpetrecycling.com/news/
[26] https://www.sysav.se/en/
[27] https://coleo.es/en/
[28] https://picvisa.com/en/ecosort-textil/
[29] https://newretex.dk
[30] https://boergroup.eu/
[31] https://www.lsjh.fi/en/jatteiden-abc/textile/
[32] E.g. https://trinamixsensing.com/textiles
[33] https://www.fibresort.com/

future traceability throughout the supply chain and facilitate subsequent sorting processes prior to recycling. Implementing such passports requires the adoption of uniform standards and concensus amongst actors involved in the textile and waste sector.

4.2.3 Outlook on sorting

High-quality sorting of separately collected textiles from households is a prerequisite for the re-use and recycling of textiles. Although still in the initial stages (<1% of post-consumer textiles are subject to automated sorting), it seems likely that in a near future automated sorting could become complementary or partially replace the sorting of textiles that are destined for recycling. This will particularly hold true when increasing amounts of textiles are being collected and recycling technologies continue to rely on composition-specific feedstocks. At the same time, manual sorting might remain highly relevant to evaluate textile quality, particularly when assessing re-use potential for client markets. To the best of our knowledge, no automated technologies are currently available that could take over actions other than assessments of fibre and colors. However, artificial intelligence may in a future help to progress in recognition techniques. Given the high cost of manual sorting by trained and skilled personnel, it seems likely that manual process may continue to take place to a significant extent in countries with low labor costs, inside or outside the EU.

4.3 Textile repair and recycling

4.3.1 Removal of non-textile parts and disruptors for recycling as a pre-treatment step

Pre-treatment and the removal of (hard) non-textile parts is a pre-requisite for many repair and recycling processes, and therefore this section lists promising developments to facilitate this process steps. Several disintegration technologies to facilitate textile disassembly are currently under development. Wear2Go is a patented sewing thread (Wear2®)[34] combined with innovative microwave technology to disassemble end-of-life clothing and other textile products. Various types of textile and accessories including logos, tags, labels, zippers, buttons, high visibility tape, etc. can be separated quickly (<1 minute) without damaging the components. The Wear2 yarn and industrial microwave for assembly and disassembly is being further developed to TRL 7 in the Circtex project (2019-2022). Resortecs[35] is a melting stitching thread combined with industrial disassembling ovens to facilitate straightforward disassembling on an industrial scale, for posterior recycling and repair.

In addition to novel sewing/stitching yarns to facilitate textile disassembly, technologies for the removal of coatings and laminated layers are available. Current technological developments at varying levels of technological readiness level include selective polymer dissolution, triggerable smart polymers, reversible crosslinking-decrosslinking systems, and supramolecular polymer adhesives (Duhoux et al., 2021).

4.3.2 Repair services

"Preparing for re-use" means checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing. Textile repair services are traditionally done at the customer's home or as a professional service. Integrating repair services into a company's operations, as well as including product care guidance, are emerging in a more circular economy. Patagonia's s 15-year-old product longevity initiative, 'Worn Wear', extends from detailed product care guides to free-repair truck tours across the US, Europe and South America. Starting in 2017, the Worn Wear site[36] sells repaired and refurbished Patagonia clothing. Amongst others, Nudie Jeans and Finisterre offer repairs and have dedicated repair services[37]. Zara, part of the multinational Inditex, is to launch pilot repair services in the UK[38], whereas H&M offers repair instructions on its website[39]. Finally, online repair services are emerging, both for customers and brands (e.g. clothes doctor[40]).

---

[34] https://wear2.com/en/
[35] https://resortecs.com/technology/
[36] https://wornwear.patagonia.com/
[37] https://www.nudiejeans.com/free-repairs/
[38]https://elpais.com/economia/2022-10-21/zara-entra-en-la-ropa-de-segunda-mano-con-un-servicio-de-reventa-arreglos-y-donacion.html
[39] https://www2.hm.com/en_gb/hm-sustainability/take-care.html
[40] https://clothes-doctor.com/

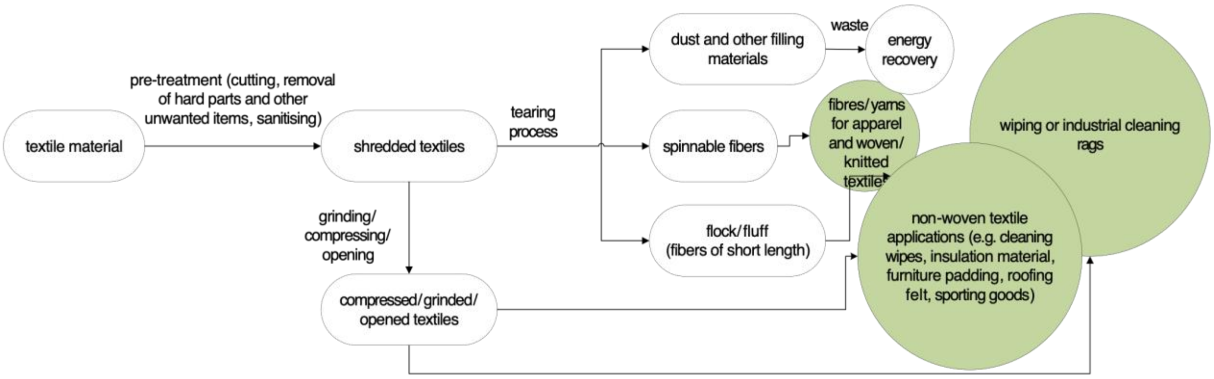
4.3.3 Recycling technologies

According to the Waste Framework Directive, 'recycling' means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.

This report summarises the main findings of the study of Dehoux et al., published in December 2021. Duhoux et al. (2021) identified 78 identified technology providers, and inventoried information collected from 32 entities through questionnaires and interviews. The study groups recycling in mechanical, thermal and (bio)chemical technologies. The sections below are thus directly referencing and quoting the work of Duhoux et al. (2021), but further own insights and additional references are added (see additional citations).

4.3.3.1 Mechanical recycling

Figure 7. Overview of mechanical recycling processes and applications of the resulting end-material (green circles, with their size being indicative for the shares currently being used for the application)



Source: own work, based on Duhoux et al. 2021.

4.3.3.1.1 Process description

Textile material is pre-treated manually or semi-automated to remove unwanted non-textile components (if possible; e.g. labels, buttons, zipper) and sanitised (if needed; following industrial cleaning/washing). Alternatively, non-textile components can be removed after mechanical processing. The textiles are shredded or cut into smaller pieces.

Closed-loop recycling processes include mechanical action through a sequential tearing process (e.g. rotating cylinders or drums, covered with saw wires or steel pins) to open up and release the individual fibres (Duhoux et al., 2021). The output material obtained following tearing consists of yarn-spinnable fibres of variable fibre length, shorter fibres that cannot be respun (so called flock or fluff), and dust (Duhoux et al., 2021). Throughout the report, such technology will be referred to as "advanced mechanical recycling".

An important share of the shredded textiles are used directly for certain industrial applications, outside the retail apparel sector e.g. as wiping rags. Rest fractions from the cutting are sent to incineration or further processed into non-woven materials. The rags can also be further processed after a textile opening process that exclusively generates short fibres and fluffy material, afterwards bond into non-wovens (e.g. insulation materials or acoustic in automotive applications). Hence, there are in fact great similarities between the 'advanced mechanical recycling processes' and this 'other' process because presently 'advanced' techniques only generate a minor amount of long fibres that can be yarn-spinned, particularly for cotton (see below). The difference mainly relates to the use of a technologically advanced opening equipment, and the interest to target a different market for the generated output materials. Throughout the report, such technology will be referred to as "open-loop recycling".

Practically any textile waste stream (material and structure) can be processed via open-loop recycling. Any chemicals and impurities present in the input material are retained in the end materials of the process (Duhoux et al., 2021). Sorting is, however, required and fabrics should be first sorted into different fibre blends. The fibre limitations on input materials are not very stringent when the output material is used for wiping rags or insulation materials, and fibre mixes can be tolerated (a common requirement is >50% cotton to ensure adsorptive properties, but no strict requirement apply). In case of 'advanced' unravelling, the fabric should ideally consist of a single fibre (Duhoux et al., 2021). In case of fibre blends, the unravelled output is an inconsistent mix of fibres with different properties, limiting further applications, particularly for the retail apparel sector (Duhoux et al., 2021). For some fibres, it may be possible to combine mechanical recycling process with chemical dissolution to selectively retain fibres of interest (Duhoux et al., 2021).

4.3.3.1.2 Output materials and applications

Some textiles are re-used as wiping or industrial cleaning rags, after the removal of hard components such as eyelets, straps, hooks and zippers. Cleaning rags made from sorted out textile waste commonly comply with the textile standard DIN 61650 (titled "Putzlappen" in German). This standard specifies which requirements the used clothing must meet; they must be dominantly made of cotton, viscose or semi-linen, and must be clean, firm and dry. Such textiles are then cut into manageable irregular pieces of at least 20 x 30 cm and packed. Cutting waste is, however, been generated during this process. In addition, textile waste can also be further shredded, opened and compressed for further use in car insulation, roofing felt, panel linings and furniture padding. This application is most common at present.

Spinnable fibres are the targeted output material when advanced fibre-to-fibre recycling is envisaged. However, in case of natural fibres, commonly only between 5%–20% of a good quality textile inputs can be recovered as good-quality spinnable fibres, though greater amounts (25%-55%) can be used when synthetic fibres are used as input material for the recycling process (Duhoux et al., 2021). Fibre blending can be used in order to ensure an input of high-quality fibres of minimum length and strength so that the quality of the output is more consistent (thus resulting in yarns of varying thicknesses and qualities) (Duhoux et al., 2021). The ability to process recycled fibres is dependent on the textile product and its production process (open end versus ring spinning, weaving versus knitting). For instance, a greater amount of recycled fibres can be used in the production of jeans than in the manufacturing process for blouses). Recycled fibres are also particularly suitable for the manufacturing of carded yarns.

When the fibre length has become too short following tearing, respinning will be impossible, and fluff or flock is obtained. The majority of the recovered fibres (i.e. about 80-95% for cotton) are currently not respun into yarn but processed into non-wovens instead (Duhoux et al., 2021). The short fibres can be used as filling material or to produce non-woven cleaning rags, insulation material or technical nonwovens for the automotive industry (Duhoux et al., 2021).

Also dust and other filling materials are produced, particularly from heavily worn textiles, which are either sent as waste to incineration or used as a filling material (Duhoux et al., 2021).

4.3.3.1.3 Technological advantages, limitations and progress

- Relatively simple and straightforward technology process, requiring a relatively low investment cost.
- Mechanical recycling processes that target wiping rags or insulation materials (following removal of hard parts and cutting) are well-established, and currently already implemented at great scale. The production of a clean material is sufficient for the envisaged application, and the presence of colouring dyes is not considered problematic for the envisaged application. Within limitations and knowledge on the approximate fibre composition (e.g. dominant fibres), a relative high tolerance to the input materials in terms of fibre heterogeneity exists. Still, a main share of the cutting waste cannot be recycled.
- More advanced mechanical recycling following the unravelling of textile waste is subject to greater limitations (Duhoux et al., 2021). Whereas in principle fibre blends can be unravelled, the composition of the output material will reflect the composition of the input material used for the mechanical recycling process. Any blends will thus result in a mixture of fibres of a variable and inconsistent composition, possibly limiting further uses in the retail apparel sector (Duhoux et al., 2021). Also textiles with a high elastane content may be still problematic, although certain (chemical) pre-treatment process may help to overcome the issue (Phan et al., 2023). Advanced mechanical recycling of laminated, coated, printed or contaminated (e.g. pain stains) input will not result into spinnable fibres.
- The mass shares of the input textile that results in high-quality spinnable fibres following unravelling is currently low (<20% for cotton) (Duhoux et al., 2021). Alternatively, fibres of a shorted length can be mixed in smaller amounts with virgin (long) fibres, to make carded yarns for e.g. technical applications. Some technology holders claim to be able to recover 80-90% of spinnable fibre in

specific cases of cotton waste (e.g. Recovertex process[41]). This is due to the use of larger pieces of textile, improved technology and better performing machinery. Such technologies are, however, not yet widespread, and even the technology holders indicate 100% commercial viability, they also acknowledge that the quality of the recovered yarns is not equivalent to virgin quality. In addition, the technology holder indicates that mechanical recycling can only be repeated "2-3 times, but likely more depending on product performance needs" before open-loop recycling technologies need to be applied due to the technical limitations (shorter fibres).

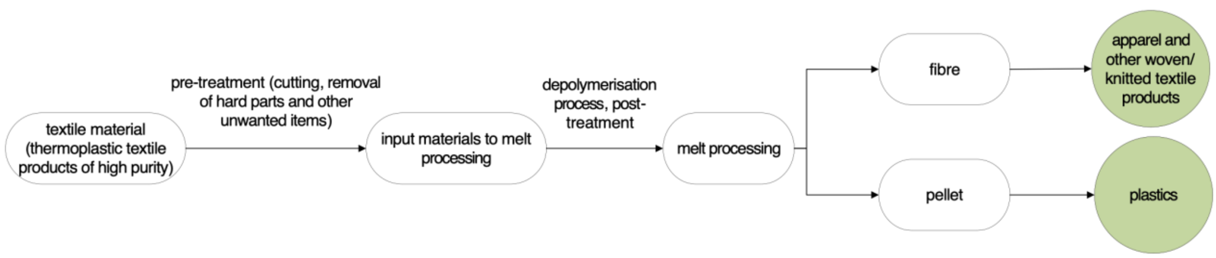
- For apparel applications, the remaining of impurities and colorants results, even after colour-sorting, may be a challenge when targeting colour-consistent recycling outputs (Duhoux et al., 2021; Van Duijn et al., 2022). The same holds true when multi-coloured textiles are used as input material for the process (Duhoux et al., 2021). Bleaching could be considered but it depends on the colorant if this is possible and even if it would be possible, it would probably damage the fibre too much. Alternatively, different processes can be set up for color-sorted waste.
- Contaminants that are resulting from the textile use phase will be retained in the output material (Duhoux et al., 2021).

4.3.3.1.4 Status and outlook

Mechanical recycling is often stated to have a technological readiness level (TRL) of 9 (Duhoux et al., 2021). This particularly holds true when the resulting end material of the recycling process is used outside the retail apparel sector. Important hurdles and technological barriers remain to be overcome before mechanical recycling can contribute to placing on the market spinnable fibre volumes that mirror a large shares of the textile waste volumes generated. At present it is estimated that about 20% of the separately collected textiles have a homogeneous fibre composition, mostly pure cotton materials, and have no or removable disruptors (Van Duijn et al., 2022). In addition, using the current state-of-technology and machinery, at maximum ~25% of this material can be turned into high-quality spinnable fibres e.g. in terms of length and strength. Furthermore, possible issues on colour and contaminant quality requirements may apply in a future more mature market for recycled fibres. The impact of multiple mechanical recycling cycles on output quality remains elusive. This implies that, with the current state of technology, the greatest field of applications for the output of mechanically recycled fibres lies in textile applications outside the apparel sector. Particularly, non-woven textiles and composite materials are main applications for the materials resulting from mechanical recycling. The implementation and upscaling of new developments that are currently at TRL 7-9, focused on increasing the amount of spinnable fibre and improving the quality of the fibres, may further increase the technological potential of mechanical recycling to contribute to recycling for apparel applications. It is concluded that mechanical recycling is a proven and scalable technique, but that additional technological hurdles need to be surmounted before mechanical recycling can play a central role in converting textile waste into new textiles at scale for the retail apparel sector.

4.3.3.2 Thermo-mechanical recycling

Figure 8. Overview of the thermo-mechanical recycling process for thermoplastic textile waste and the possible application of the resulting end-material. Note that these processes have not yet reached full technological maturity.



Source: own work, based on Duhoux et al. 2021.

[41] https://www.commonobjective.co/article/insider-series-recover-turns-textile-waste-into-valuable-yarn

4.3.3.2.1 Process description

Thermoplastic textile waste is processed via compounding and regranulation techniques (Duhoux et al., 2021). Examples of thermoplastic materials include PET, PA6, PA6,6, and PP. The pre-treatment step involves the removal of non-textile parts, washing/cleaning, drying and shredding/grinding to fibres. Afterwards, reprocessing into a granulate occurs followed by melt spinning or other processing techniques to generate fibres (Duhoux et al., 2021). Melt filtration is typically applied to remove small quantities of contaminants and impurities (such as wood, paper, cellulose fibres, chemicals, rubbers, and higher melting polymers) from the polymer melt (Duhoux et al., 2021).

Thermo-mechanical recycling thus recovers polymers in the form of regranulate or fibres (Duhoux et al., 2021).

4.3.3.2.2 Applications

The output are fibres that can be used in various textile applications, depending on the quality. Similar to outputs from mechanical recycling, blending with virgin counterparts (polymers in this case) can take place. Thermoplastic polymer pellets (regranulate) can also be used for other applications in case fibre spinning is not targeted or technically possible (Duhoux et al., 2021).

4.3.3.2.3 Technological advantages, limitations and progress

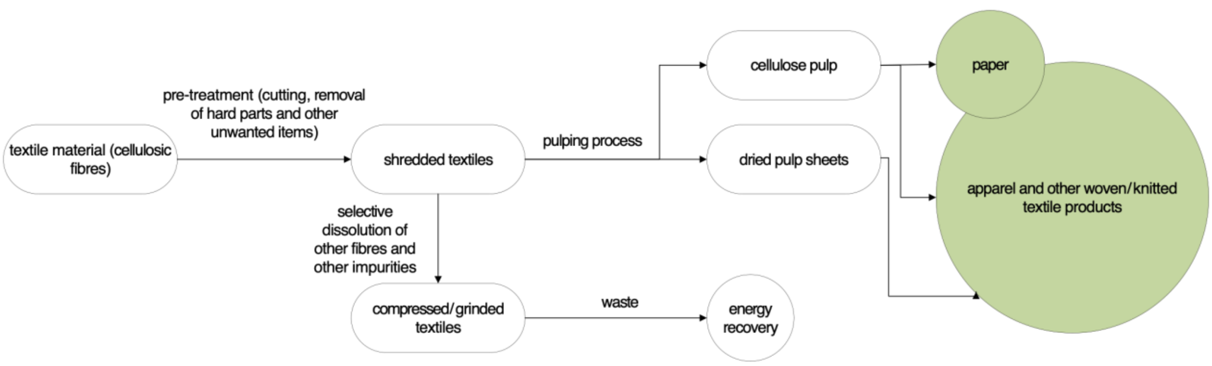
- Similarities with production process (melt processing) for virgin materials.
- The input material should consist of only one polymer type or of compatible polymer types (Duhoux et al., 2021). Due to the high risk of contamination, post-consumer waste is generally not considered as a suitable feedstock (Duhoux et al., 2021).
- Contaminants such as pigments, dyes and other chemicals are transferred to the output material. The output colour is thus dependent on the colours of the input materials and process conditions that degrade colour dyes (Duhoux et al., 2021).
- The polymer/fibre properties deteriorate after each cycle and specialised equipment or components are required to ensure a well-functioning recycling process (Duhoux et al., 2021).
- The addition of virgin material is to obtain functional output materials. One of the technology holders blends 20% of recycled polyester with virgin material (Duhoux et al., 2021).

4.3.3.2.4 Status and outlook

One of the technology holders by Duhoux et al. (2021) processes about 5000 tonne yr-1, and is about to reach TRL 7 for post-industrial textile waste (Duhoux et al., 2021).

4.3.3.3 Chemical recycling – cotton polymer recycling via a pulping process

Figure 9. Overview of cotton polymer recycling via a pulping process and applications of the resulting end-material (green circles, with their size being indicative for the shares currently being used for the application).



Source: own work, based on Duhoux et al. 2021.

4.3.3.3.1 Process description

A pretreatment is required to remove any hard parts from the textile waste and the material is shredded/grinded. The textiles are then suspended in a liquid with chemicals and depolymerised, transformation the input into pulp ("dissolving pulp") (Duhoux et al., 2021). A chemical treatment is commonly applied to remove dyes and finishes as well as a bleaching step, similar to the traditional wood pulp production process (Duhoux et al., 2021). Some technology holders implement an additional stage for the removal of impurities and non-target fibres (polyester, elastane, etc.) (Duhoux et al., 2021). The output is commonly blended with wood pulp and processed in traditional or custom spinning processes for man-made cellulosic fibres, though some technology holders process 100% waste (Duhoux et al., 2021). A low amount of waste is generated in case of use of cotton-rich input material (Duhoux et al., 2021).

This process can be categorized as polymer recycling, as the cellulose chain is not broken down to monomer level (i.e., glucose), although it can be partially degraded (Duhoux et al., 2021).

Textiles dominantly composed of cellulosic fibres are used as input material for the process, but the pulping process or pre-treatment is specific to the fibre composition. At present, cotton is mostly used as an input material for the process (Duhoux et al., 2021). Technology holders prefer textile waste with a cotton content of at least 50%, preferably as high as possible (Duhoux et al., 2021). Some technologies can separate PET from cotton, but most are still working on the recovery of PET and currently only the cellulosic fraction of blends can be recycled (see also section 4.3.3.5).

4.3.3.3.2 Applications

The regenerated cellulose or viscose is used as yarn for woven or knitted fabrics or for paper production.

4.3.3.3.3 Technological advantages, limitations and progress

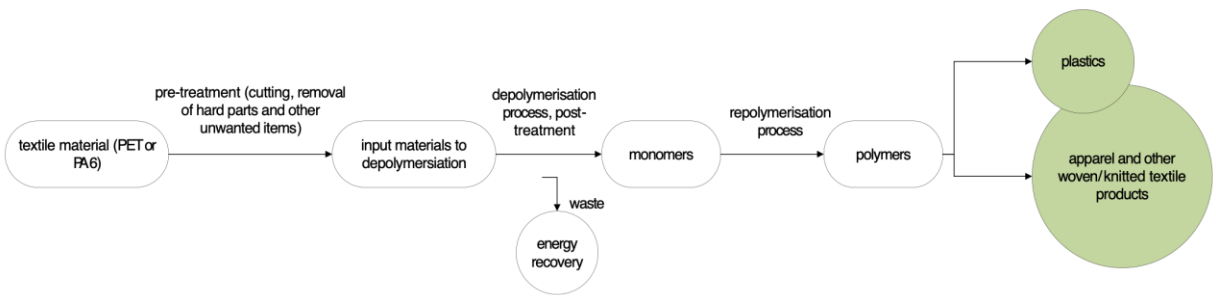
- The tolerance to dyed textiles and contaminants depends on the process, but most technologies include a decolouring, bleaching and/or purification steps, although with varying efficiencies (Duhoux et al., 2021).
- The mass shares of cotton-rich input textiles of high purity, and with no or removable hard parts, is currently low. In case a certain degree of impurities could be acceptable, volumes might increase as cotton is a dominant fibre, particularly in apparel.
- Theoretically the cellulose recovery process can be repeated several times, however the polymer chain degrades with each repetition (Duhoux et al., 2021).

4.3.3.3.4 Status and outlook

At present, most technologies have already reached a high TRL of 7 to 9, at least for pure or cotton-rich textiles as input material. Facilities that apply this technology are already operational at high scale. The TRL 7-8 technologies are expected to reach TRL 9 by 2025 at the latest (Duhoux et al., 2021).

4.3.3.4 Chemical recycling – monomer recycling of PET and PA6

Figure 10. Overview of chemical recycling process (monomer recycling) of PET and PA6 and the applications of the resulting end-material (green circles, with their size being indicative for the shares currently being used for the application).



Source: own work, based on Duhoux et al. 2021.

4.3.3.4.1 Process description

A pretreatment to remove any hard parts from the textile waste and separating non-target materials is required. Pre-treatment can also include shredding/grinding, washing, granulation and/or pelletising steps. The PA6 or PET materials are depolymerized, some after first dissolving the polymer, via different technologies and various reaction conditions (temperatures/ pressures/ time/catalysts) (Duhoux et al., 2021). PA6 is generally depolymerized via hydrolysis, via acid hydrolysis and super-heated steam, or via glycolysis. For PET, hydrolysis methanolysis and glycolysis are used for depolymerisation, with glycolysis being the most common technique (Duhoux et al., 2021). Recently also enzymatic depolymerisation has become available as a bio-chemical alternative (Duhoux et al., 2021). Post-treatment steps are applied for purification (not strictly necessary, but enabling the removal of contaminants and colorants), separation (e.g. solvent removal), and drying (Duhoux et al., 2021). The output includes para-terephthalic acid (PTA) and Mono Ethylene Glycol (MEG) as the traditional monomers obtained from PET, but alternatives are possible dependent on reagent used (Duhoux et al., 2021). These monomers can be depolymerised to obtain high purity, virgin grade PET. Concerning PA6 recycling, the output is caprolactam which can be repolymerised to virgin grade PA6 (Duhoux et al., 2021).

Chemical recycling via depolymerisation implies that the polymer chains are completely broken down into monomers and is thus classified as monomer recycling (Duhoux et al., 2021). These monomers are separated and typically purified before entering the polymerization process again to produce new virgin-quality polymers. Hence, no quality degradation occurs during the recycling process.

Knowledge of the composition and adequate sorting of the input textile waste is of great importance. Most technology holders request a minimum of 80-90% PET or PA6 content for economic reasons (Duhoux et al., 2021). In theory many polymers can be depolymerized, but presently only recycling of PA6-rich and PET-rich textile waste is under development on a commercial scale (Duhoux et al., 2021).

4.3.3.4.2 Applications

The recycled chemicals have similar applications as their equivalents derived from fossil fuels as primary raw materials. Most caprolactam is used for the production of PA6 and textile applications, but it can also be used as a high-strength precursor for industrial uses (e.g. automotive sector). Recycled PET can be used for textiles as well as other PET applications, such as packaging (Duhoux et al., 2021).

4.3.3.4.3 Technological advantages, limitations and progress

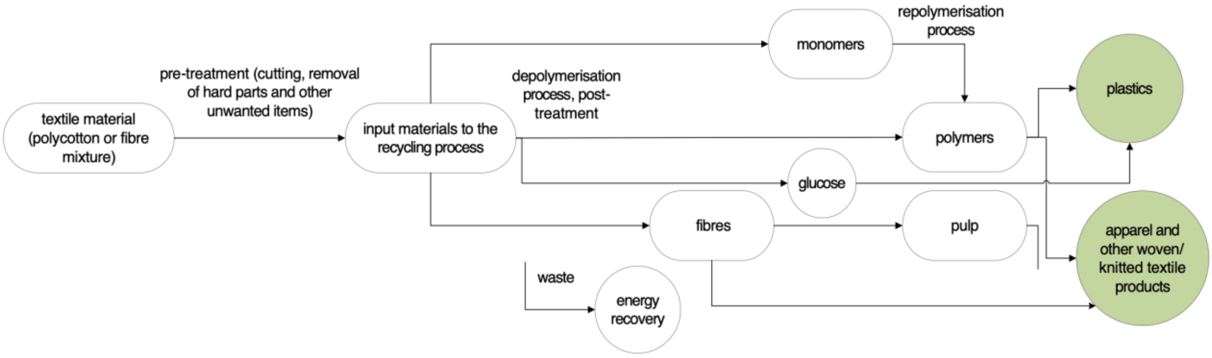
- Potential to remove contaminants and achieve homogeneous colours in the recycled material, and to obtain textile fibres with high and consistent mechanical properties.
- Just like the pulping process of cellulose fibres, the efficiency of the chemical recycling of synthetic fibres depends highly on the purity of the input material. The waste that is generated is a non-PET/PA6 solid residue or sludge consisting of other synthetic or natural fibres, dyes, chemicals from finishings/coatings/prints, etc. depending on the input composition.
- The mass shares of polyester-rich and PA6-rich input textiles of high purity, and with no or removable hard parts, is currently low.

4.3.3.4.4 Status and outlook

Chemical recycling of PA6 textiles via depolymerisation is already an established technology at TRL 9 for more than a decade. For PET recycling from textiles, the technology is not yet mature, and TRL levels vary from 4 up to 7 (Duhoux et al., 2021).

4.3.3.5 ***Chemical recycling – polymer or monomer recycling of fibre blends***

Figure 11. Overview of chemical recycling process for textiles of a mixed fibre composition and the envisaged application of the resulting end-material. Note that, with the exception of wool recycling, the processes have not yet reached full technological maturity.



Source: own work, based on Duhoux et al. 2021.

4.3.3.5.1 Process description

Several technologies focus on the recycling of cotton, wool and PET from polycotton blends via different approaches. Some of these technologies maintain fibres, others do not affect polymer chains and are thus classified as polymer recycling, whereas a third share breaks textiles down to monomers.

Most technologies can deal with a certain percentage of contamination with other materials (nylon, acrylic, wool, elastane…), however non-textile accessories such as zippers and buttons and generally also coatings must be removed. Sorting of textiles waste is required as knowledge of the composition is often required for a good process efficiency.

- Color-sorted wool- or cashmere-rich textile recycling are subject to hydrochloric acid vapors, which break down the cellulose and synthetic residues/fibres, whereas animal fibres remain intact. The fibrous material preserves the fibre length and the initial characteristics of the fabric, dried, and used as an input to the carding process.
- Cotton and PET polymer recycling via a dissolution process: PET and cotton are both dissolved, each with a different solvent. The PET pathway includes dye-removal, polymer solvent separation, purification and polymer restoration steps. PET polymers are kept largely intact, but the final process step is meant to increase the molecular weight and achieve virgin quality (Duhoux et al., 2021). The output of the cotton pathway is cellulose pulp for man-made cellulose fibre production.
- Hydrothermal recycling processes: Textiles are treated with water containing one or more acids (e.g., an organic acid or sulphuric acid) and without organic solvents, under increased temperature and pressure (Duhoux et al., 2021). Some technologies result in the decomposition of cotton which is recovered as powdered cellulose. In a next step, the polyester fibres are separated via filtration, retaining as such the quality of the fibres. The fibres can also be melted, extruded and pelletised, and additional chemical processing can be used to obtain virgin quality PET pellets (Duhoux et al., 2021). Other hydrothermal technologies work inversely; PET is depolymerised to PTA and MEG, and subsequently the cellulose fraction is recovered via a dissolution process. The different processes can include a colour removal/bleaching step as well (Duhoux et al., 2021).
- Enzymatic recycling process: A fungus is grown onto the textile waste, and its enzymes are recovered for use in textile waste hydrolysis. Cotton is hydrolysed into cellulose and soluble glucose, while PET and/or other non-biodegradable material remains chemically unaltered and can be filtrated as fibre (Piribauer et al., 2019). The cotton hydrolysate is then further purified to obtain a glucose-rich pulp, whereas the PET is re-spun into yarns (Duhoux et al., 2021).

4.3.3.5.2 Applications

At present, the state of technology is insufficient to assess applications. In principle, the recovered materials are similar to these of the individual processes described for chemical recycling above, thus implying similar fields of application.

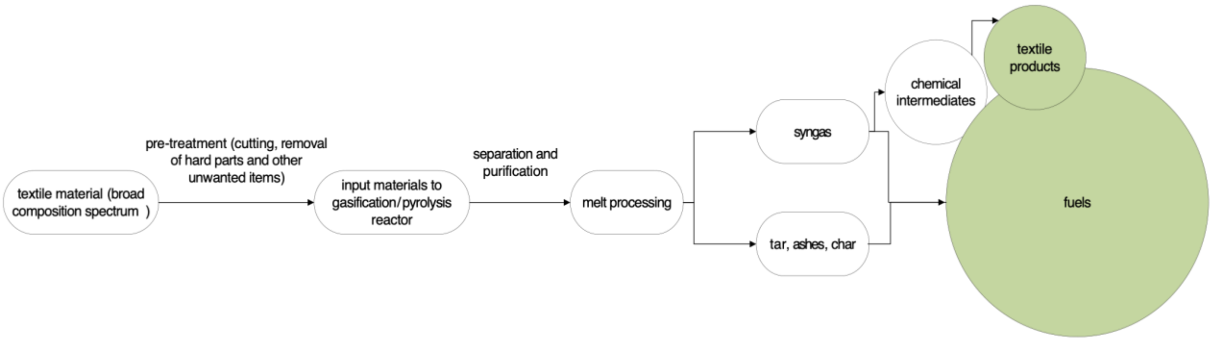
4.3.3.5.3 Status and outlook

The main advantage is that the recycled material can be obtained from mixed fibre mixtures (Duhoux et al., 2021). Wool recycling using hydrochloric acid has since decades been a tradition and operation practice in the Italian Prato district. The solvent-based dissolution and filtration technology is currently at TRL 5-6. The different hydrothermal technologies are at TRL 6-7, while the enzymatic approach is at TRL 5 (Duhoux et al., 2021).

4.3.3.6 Thermo-chemical recycling

The thermo-chemical recycling processes pyrolysis and gasification differ from one another and from combustion in several ways. Combustion is performed at temperatures in between 800 and 1200°C with sufficient oxygen in order to completely oxidize the material and is mainly used to generate steam for electricity production or for heating. Hence, in such case it would not be considered a recycling/material recovery process. Gas and oil output products from gasification and pyrolysis can be used for heat and power production or be converted into chemical intermediates for the chemical industry (Roos, 2010; Duhoux et al., 2021).

Figure 12. Overview of the thermo-chemical recycling process and the envisaged application of the resulting end-material, mostly fuels.



Source: own work, based on Duhoux et al. 2021.

4.3.3.6.1 Process description

Non-textile parts such as metal buttons are removed as they can cause problems during processing. Drying is performed for wet input material with a view to reduce energy input, and homogenizing and compacting the input textiles may also be required (Duhoux et al., 2021). The actual gasification or pyrolysis step entails heating the waste to temperatures of 400 to 1100°C with a controlled amount of oxygen, air, oxygen enriched air and/or steam. During the process a series of complex endothermic chemical reactions occur, resulting in the production of pyrolysis oil, volatiles (i.e. gases and tars) and a solid residue (i.e. char or ash). A series of traps/separators each collect a fraction of the reaction products. The specific outputs of the process and their relative shares depend on the input waste, the reactor type and process parameters (temperature, heating rate, residence time, etc.). The obtained fractions are mostly used as a fuel, but can also serve as a feedstock for the chemical industry following upgrading. In order for the syngas to meet the requirements for the production of chemical intermediates (e.g. methanol), components containing sulfur, halogens, nitrogen, etc. need to be removed (Duhoux et al., 2021).

4.3.3.6.2 Technological advantages, limitations and progress

- The main advantage of the process relates to its ability to process more complex, heterogeneous waste streams, including fibres and blends of fibres that can’t be recycled by any other technology. The process does not need high-quality, sorted textile waste and may even include materials from different industries (e.g. biomass, plastics). It is also more tolerant to contaminants compared to thermo-mechanical or chemical recycling technologies and therefore does not require thorough cleaning and decontamination pre-treatment of the input textiles (Duhoux et al., 2021).

- The technology leads to pure, uncontaminated, virgin-like monomers, offering possibilities to be used for the production of textiles and other materials of high-quality (Duhoux et al., 2021).
- The process of thermo-chemical recycling is energy consuming due to the high temperatures needed. The additional cleaning steps to obtain chemical intermediates increase investment and operational costs (Duhoux et al., 2021).
- The output materials are mostly used as a fuel, rather than for the production of new textile products.

4.3.3.7 Summary overview of recycling processes

The summary of the main features (input and output materials, barriers to recycling, and technological readiness level) of the different recycling processes are summarised in Table 3 so as to facilitate a technology comparison.

Table 3. Summary of different recycling technologies for textile waste.

Technology	Feedstock	Main output	Potential to process textiles of a mixed fibre composition	Potential to address impurities involving non-textile parts, multi-coloured and/or contaminated input materials	Technological maturity	Other limitations and comments
Advanced mechanical recycling	Any textiles with a high share of a dominant natural or synthetic fibre. Mostly textiles rich in cotton or other natural fibres are used.	Yarn-spinnable fibres, short fibres for the production of non-woven textiles	Limited	No, non-textile materials can or need to be removed before or during the recycling process. Contaminants and colours will be transferred from input to output materials. This may, depending on the application of the output material, require a need for colour sorting or use in multi-coloured textiles.	High, but current technologies mostly generate a low amount of yarn-spinnable fibres. Technologies that target longer and stronger fibres for use in apparel production is at a lower level of technological readiness.	Yarn-spinnable materials that are the targeted output material is of a lower quality than virgin equivalents. Therefore, fibres should be blended with virgin fibres, and possibly be used for the used for the production of carded yarns. Uncertainty on potential for multiple recycling cycles, likely limited to ~3.
Open-loop recycling	Any textiles. For the production of cleaning rags, textiles of a greater dimension (e.g. home textiles) are preferred.	Short fibres for the production of non-woven textiles	In principle yes, depending on the application area of the output material	No, non-textile materials can or need to be removed before or during the recycling process. Other contaminants and colours remain in the output material but given their targeted applications (e.g. insulation materials for construction of automotive sector), this is not considered a main hurdle.	High and fully mature, with a long history as the dominant recycling technique for textile waste.	When rags are further processed through opening, grinding or cutting, the process is very similar than 'advanced' mechanical recycling, with the difference that no yarn-spinnable fibres are targeted as output. Non-woven materials are therefore the main application area for materials generated through this process.
Thermochemical recycling	Typically thermoplastic textiles of high purity.	Polymers in the form of regranulate or fibres	No, with the exception of mixtures of compatible polymer types of high purity.	No, non-textile materials can or need to be removed before or during the recycling process. Contaminants such as pigments, dyes and other chemicals remain in the output material.	Intermediate, technology readiness level of ~7.	A deterioration of polymer/fibre properties occurs following the recycling process. Therefore, fibres should be blended with virgin fibres.

Chemical recycling for natural fibres ("cotton polymer recycling via a pulping process")	Textiles dominantly composed of cellulosic fibres, but impurities in terms of other fibres can reasonably be accepted.	Man-made cellulosic pulp. The regenerated cellulose or viscose is used as yarn for woven or knitted fabrics or for paper production.	Yes, typically an additional stage for the removal of impurities and non-target fibres (polyester, elastane, etc).	Partly, disruptors can or need to be removed before or during the recycling process. Commonly a chemical treatment removes dyes and finishes as well as a bleaching step of which the latter is similar to the traditional wood pulp production process.	Most technologies have already reached a high TRL of 7 to 9, at least for pure cotton textiles as input material.	The regenerated cellulose or viscose is used as yarn for woven or knitted fabrics or for paper production.
Chemical recycling for synthetic fibres ("monomer recycling of PET and PA6")	Different polymers can be depolymerized, but presently only recycling of PA6-rich textile waste.	Chemical monomers	Most technology holders request a minimum of 80-90% PET or PA6 content	Partly, non-textile materials can or need to be removed before or during the recycling process. Potential to remove contaminants and achieve homogeneous colours in the recycled material.	For PA-6 available at operational scale since long. For PET textiles the TRL-levels vary from 4 up to 7.	-
Chemical recycling for textiles with fibre mixtures ("polymer or monomer recycling of fibre blends")	Several technologies focus on the recycling of cotton, wool and PET from polycotton blends	Depending on the process, can be natural fibres, polymers, monomers.	Most technologies can deal with a certain percentage of contamination with other materials (nylon, acrylic, wool, elastane…),	Disruptors and generally also coatings must be removed. Colour removal can be performed and a bleaching step as well.	Wool recycling using hydrochloric acid is a tradition and operation practice in the Italian Prato district. The solvent-based dissolution and filtration technology is currently at TRL 5-6. The different hydrothermal technologies are at TRL 6-7, while the enzymatic approach is estimated by Duhoux et al. (2021) at TRL 5.	-
Thermo-chemical recycling	The process does not need high-quality, sorted textile waste and may even include materials from different industries (e.g. biomass, plastics).	Syn gas, oil, tar and char, can also be converted into chemical intermediates and therefore serve as feedstock for the chemical industry	Yes	Yes, though non-textile parts such as metal buttons are typically removed as they can cause problems during processing	Pyrolysis has already been implemented as industrial plants (TRL 9), but unknown scaled up applications for textile waste.	The main advantage relates to its ability to process more heterogeneous waste streams, including fibres and blends of fibres that can't be recycled by any other technology. Some studies claim a higher energy use compared to other recycling technologies due to external heat requirements of the process.

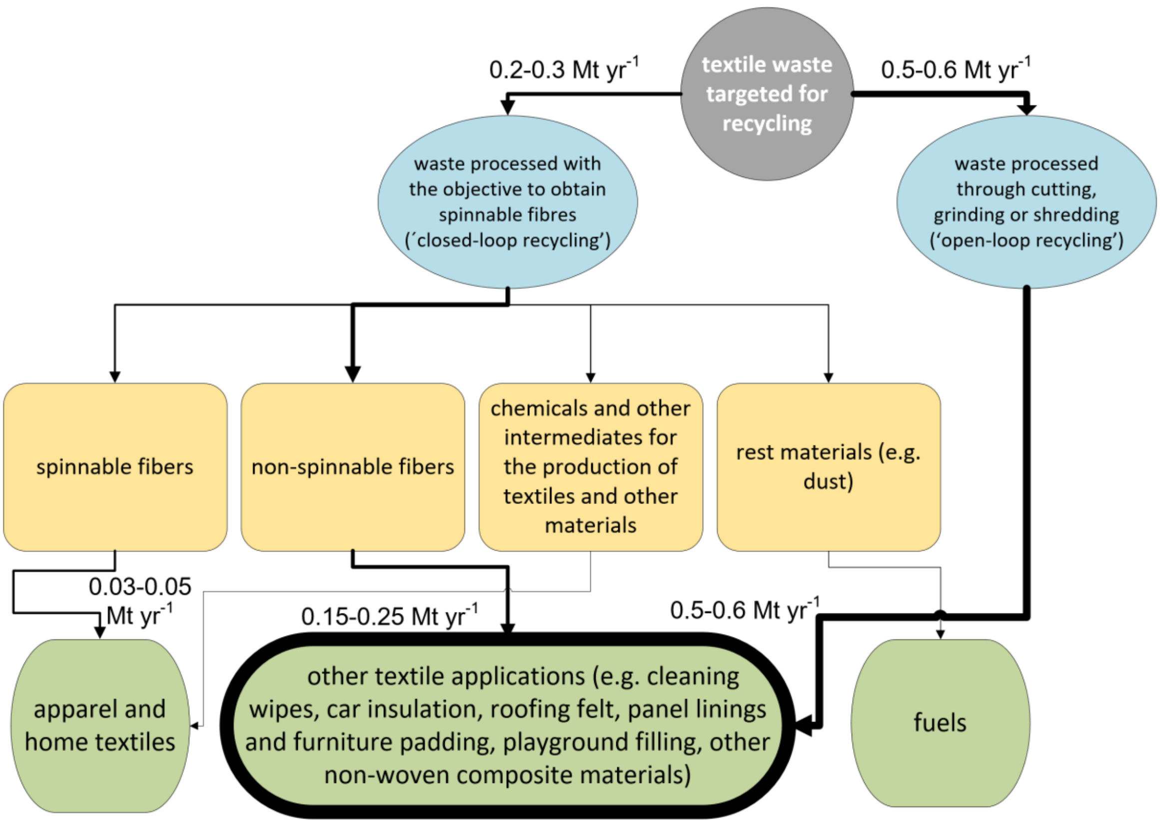
Source: Own work based on the work of Duhoux et al. (2021).

4.3.4 Mapping the current textile recycling market landscape in the EU and applications of recycled materials

The mapping of textile recycling plants is based on a review of recent literature, involving recently published key studies from Fashion for Good (Van Duijn et al., 2022), the Swedish Environmental Research Institute (Dahlbom et al., 2023) and Lifestyle & Design Cluster (Jørgensen and Werner, 2022). In addition, also a market study on textile recycling was taken into account (MaiaConsulting, 2023). The review was complemented by checking cross-references from existing techno-scientific publications during the development of this report and internet searches. A draft list has been reviewed and complemented based on the feedback from experts active in the field of textile recycling on a first draft of this report. Publically available information from the websites of each of the companies was reviewed and inventoried. The review of the consulted sources is believed to provide a good overview of the structure of the recycling market, but cannot be considered as complete and non-identified additional actors in the market are certainly existent. This holds extensively true for recycling processes that do not involve final applications for the apparel sector.

In the context of this study, the scope of recycling is aligned with the definition in the Waste Framework Directive, and thus includes recycling techniques that process textile waste through cutting and shredding for further uses ('open-loop mechanical recycling'; see section 4.3.3.1). This scope is broader than most studies that exclusively focus on recycling for potential applications in the apparel and home textile sector. Materials that find an application that is different than the original product (e.g. apparel transformed into industrial cleaning wipes) are classified as recycling because only products and components of products which are being re-used for their original purpose can be considered to be 're-used' or 'prepared for re-use', in line with the definition under the Waste Framework Directive.

Figure 13. Schematic overview of textile recycling processes grouped per share that is processed through 'closed-loop' mechanical, chemical or thermal processes (blue circle on the left) and 'open loop' processes (following cutting, grinding or shredding, blue circle on the right). The final use applications of the recovered materials are indicated in green, whereas intermediate materials from closed-loop recycling processes are depicted in yellow. The thickness of the arrow and the accompanying values approximately correspond to the estimated mass that is processed/generated through the pathway, indicating that at present most textiles are being recycling for applications other than apparel and home textiles.



Source: own work.

It is noted that feedstocks and output material of recycling processes are subject to substantial trade on the international market. Hence, EU companies active in textile waste recycling often import textiles (often rags, not always labelled as waste) from third countries, whereas textile sorting companies in the EU often export waste to third countries for recycling abroad. Also the recycled fibers from plants located in the EU find outlets in EU countries or international markets, including countries located in the Americas.

4.3.4.1 Recycling processes for potential applications of end-materials in the apparel retail sector

The summed capacity of the different operators applying 'closed-loop' recycling processes for potential applications of end-materials in the apparel retail sector is at present estimated at about 0.2 - 0.3 Mt yr^{-1}. Note that this Figure is based on the present-day (year 2023) capacity, and does not take into account any forward looking capacity upgrades (see also section 4.3.5 for the assessment of outlook and future markets). In total, around 40-50 companies were identified that are grouped into 11 larger players (individual companies or grouped entities that are active in the same region and market niche) with an identified processing capacity of more than 5 kilotonnes (kt) per year (together processing an estimated waste textile mass of about 0.15 Mt yr^{-1}), and 36 players with either an unknown capacity or small current capacity (estimated to have a joint capacity of about 0.05 – 0.15 Mt yr^{-1}).

The feedstock materials used by these companies mostly involve textiles made of a dominant fibre (e.g. > 95% cotton).

The recycled fibres are then further used by yarn and fabric manufacturers and retailers that place textiles made from recycled fibres on the market. Examples of such companies are Chemosvit Fibrochem[42], Loop a Life[43], Noverpluma[44], Pure Waste[45], Rohdex[46], Sodra[47], Purfi[48], and WeTurn[49].

4.3.4.1.1 Large economic entities

It is observed that main players are mainly located in South, West and to a smaller extent in Northern Europe, thus largely aligned to the location of the main textile producers (mostly active in Italy, France, Germany, Spain and Portugal) (Table 4).

About more than one third of the recycling facilities (based on capacity, 50-60 kt yr^{-1} out of 150 kt yr^{-1}) exclusively accepts post-industrial, pre-consumer and post-consumer waste from industrial applications (Table 4). Some plants (SOEX, Wolkat, together processing 20 kt yr-1 of textile waste) exclusively accept post-consumer waste, mainly from households. The remaining recycling facilities accept textile waste from all origins, though facilities that mainly target uses in the apparel retail sector only accept certain fibres like cotton, viscose or wool. Overall, it is assumed that at least 50% of the input materials to closed-loop recycling plants involve post-industrial and pre-consumer waste. Hence, it is indicated that proportional to the waste mass generated, post-industrial waste is subject to a greater relative degree of recycling than post-consumer waste in closed-loop recycling plants, likely because of a greater homogeneity and increased information on fibre composition as well as the reduced challenges to recycling (e.g. no wear from use phase, potential contamination).

Mechanical recycling is clearly the dominant technology being used (~135 out of 155 kt yr^{-1} of textile input to the recycling process) over chemical recycling (15 kt yr^{-1} of textile input) (Table 4). No thermal recycling plants of great capacity (> 5 kt yr^{-1}) have been found in this literature review. With the current state of technology, mechanical recycling mainly results in fibres of a relatively short length (see section 4.3.3.1). This observation explains the fact that the applications of the output materials mainly involves uses as cleaning wipes,

[42] www.fibrochem.sk
[43] https://loopalife.com/
[44] http://www.neokdun.com/
[45] https://purewastetextiles.com/
[46] http://rohdex.com/
[47] https://www.sodra.com/en/
[48] https://purfi.com/
[49] https://weturn.eco/

insulations materials in the automotive and construction sector, rather than uses in the apparel retail sector. Hence, the properties of the fibres generated (see section 4.3.3.1; in general <20% for cotton that is the most common fibre in the input material) limit further uses of apparel and other applications equal to their original use purpose. One notable exception to this general trend observed involve the Recover (mechanical recycling) and Renewcell (chemical recycling) plants that mainly target applications for the apparel retail sector as part of an effort to upscale recycling for further use aligned to their original purpose.

Other applications of the end materials of the recycling process include use as fuels (e.g. rest materials that cannot be valorised in the recycling process, e.g. dust or very short fibres). The output products of chemical recycling processes are currently used for the manufacturing of apparel and other woven/knitted textile products.

Table 4. Overview of the main economic organisations located in the different EU Member States (MS) active in the processing of textile waste through advanced mechanical (following the unravelling of textiles), chemical or thermal processes.

	Process type	MS	Capacity estimate (kt yr^{-1})	Input materials	Output application
Altex Textil Recycling **https://www.altex.de/en**	Mechanical	DE	25	Mostly post-industrial and pre-consumer waste. Post-consumer waste is less than 20% of the total input. Interest to take in all types of textiles	insulation, automotive, geotextiles, non-woven
Aquafil (Econyl) **https://www.econyl.com/**	Chemical, polyamide (Nylon 6) recycling	IT	Estimate <5 of textile waste, even though total feedstock processing is about 50 kt yr^{-1}.	Only a small share (< 5 kt) originates form fabric scraps (post-industrial waste). The main input materials are old fishing nets, fabric scraps, used plastic, and other types of ocean waste.	fabrics, clothing
Associazione Tessile Riciclato Italiana **https://astrirecycling.it/en**	Mechanical (wool and cashmere)	IT	22	Post-industrial and post-consumer waste rags rich in wool and cashmere.	clothing
ETS H. Moncorgé http://divi-extra.com/en/	Mechanical	FR	5-10	Management of scraps and textile production waste, but also certain post-consumer textiles can be processed.	automotive, clothing, geotextiles, home textiles, other industry products
Frankenhuis B.V. (Boer Group) **https://www.frankenhuisbv.nl/**	Mechanical	NL	9	Post-industrial waste, workwear and post-consumer waste	automotive, non-woven, insulation, fabrics, other industry products
Procotex **https://en.procotex.com**	Mechanical	BE	25	Post-industrial waste and post-consumption of textiles from industrial applications	automotive, mattress, insulation, non-woven, geotextiles
Recover **https://www.recovertex.com/**	Mechanical	ES	20	Post-industrial, pre-consumer and post-consumer waste. Exclusive focus on cotton and cotton-rich blends	clothing, home textiles

Renewcell **https://www.renewcell.com/en/section/our-technology/**	Chemical – pulping of waste with high cellulosic content	SE	10	Textile production waste with high cellulosic content, like cotton or viscose. Currently post-industrial waste is mainly used.	Dissolving pulp cellulose that can be used for the production of man-made cellulosic fibres (approx. 68% of the output is Circulose®)
Rester **https://rester.fi/en/**	Mechanical	FI	12	Used technical textiles and textile production waste. Received material fractions are at the moment cotton, polyester, cotton-polyester, wool, polypropylene and mixed materials.	nonwovens, technical, automotive & geo-textiles, insulation, yarn, fabric for apparel etc
SOEX Recycling Germany GmbH **https://www.soex.de/en/services/recycling/**	Mechanical	DE	11	Post-consumer waste	Mostly insulation material for the automotive and construction industries. Certified recycled fibres from previously defined material compositions and colors are produced
Wolkat **https://www.wolkat.com/en**	Mechanical	NL, MA[50]	9 (~ 30 kt processed per year, of which ~30% recycled)	Post-consumer waste (cotton, polyester, acrylic, synthetics, other blends, polycotton blends, wool blends)	Yarns, knitted or woven end products and also non-woven fabrics.
Total	Mechanical (11 plants) and chemical (2 plants)	MS in S/W/N EU	~ 150-160	See text	See text

Source: own work.

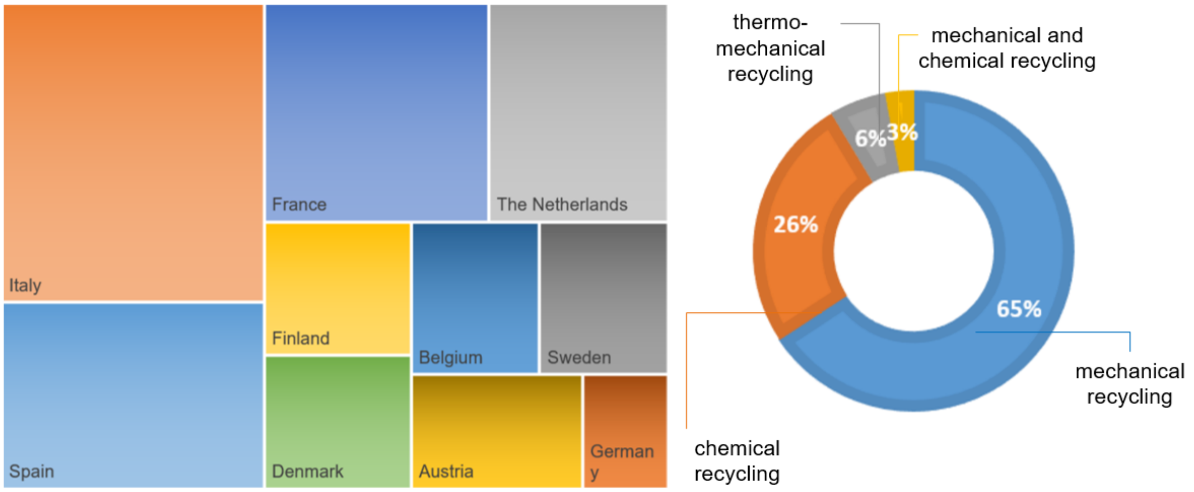
4.3.4.1.2 Economic entities of unknown capacity or small current capacity

These economic entities involve a mixture of pilot plants (start-ups/scale-ups), including also a few more established operational/commercial plants (Table 5). Textile recycling organisation of unknown capacity or small current capacity are also located in South, West or North Europe (Figure 14), similar to the larger economic entities. A main difference compared to the larger economic entities lies in a more diversified technology field, covering not only mechanical recycling (23 operators), but also chemical recycling (9 operators) as dominant processing pathways. In addition, thermochemical processing (one operators) and a combination of mechanical and chemical processing (2 operators) are observed (Figure 14). For these processes, cotton-, polyester-, polyamide, and wool-rich materials are main input materials. Also textiles containing feathers and down are an important input materials, dominantly for well-established economic operators. Both post-industrial and post-consumer waste are used as dominant input materials, with 64% and 58% of the operators accepting these input materials, respectively. Pre-consumer waste is less common as input material, with only 19% of the plants stating its acceptance.

A remarkable difference with the larger established economic operators is that the main output materials of these facilities, particularly emerging players, involve (envisaged) uses in the apparel sector.

[50] Headquarters are located in the NL, but the actual recycling process is performed in Morocco.

Figure 14. Overview of the economic entities of unknown capacity or small current capacity active in the recycling market with a treemap for the geographic location of the plant (left hand Figure), as well as an overview of the type of recycling



applied at the different facilities (right hand pie chart).

Source: own work.

Table 5. Overview of economic entities of unknown capacity or small current capacity (estimated < 5 kt yr-1) active in textile recycling in the EU.

Organisation name	Website	Type of activity	MS	input material class* and fibre type		output application
Antex (EcoAntex)	https://antex.net/	Thermo-mechanical	Spain	PM	Polyester, PP, PBT, PTT, PLA	Yarn
Belda Lloréns (EcoLife)	https://www.ecolifebybelda.com/home-english/	Mechanical	Spain	PM	Cotton, man-made cellulosics (MMC)	Yarn
Carbios	https://www.carbios.com/en/enzymatic-recycling/	Chemical	France	PreC, PM,PC	Polyester, Polycotton blends	Resin
Cardato	http://www.cardato.it/en/brand-cardato-recycled/	Mechanical	Italy	PI, PC	Wool	Yarn
COM.I.STRA	https://www.comistra.com/	Mechanical	Italy	PC	Wool	Yarn
CuRe Technology	https://curetechnology.com/	Chemical	Netherlands	PM,PC,PreC	Polyester, Polycotton blends	Fibre, resin
Eastman	https://www.eastman.com/en	Chemical	France	PI, PC	polyester	Monomers for fibre and others
European Spinning Group	https://www.esg-group.eu/en/collections/green	Mechanical	Belgium	PC	Cotton, denim, polyester	Yarn
Fast Feet Grinded	https://www.fastfeetgrinded.eu	Mechanical	Netherlands	PC	Rubber	Rubber, foam, fibre
Filatures du Parc	http://filatures-du-parc.com/NotreEntreprise_EN.htm	Mechanical	France	PI, PC	Wool	Yarn
Fulgar (Q-NOVA)	https://www.fulgar.com/eng/products/q-nova	Mechanical	Italy	PreC	Polyamide (Nylon 6.6), Polyamide	Fibre
Hivesa Textil SL	http://www.hivesa.com/inuestraempresa.html	Mechanical	Spain	PM	Cotton, Wool, Polyester, Polyamide, Acrylic, MMC	Fibre, yarn, non-woven
Infinited Fiber	https://infinitedfiber.com	Chemical	Finland	PM,PC	Cotton	Yarn
JSC Neaustima	https://neaustima.lt/en/	Mechanical	Latvia	PI	Polyester, cotton, wool, hemp, flax, acrylic and mixed fiber blends.	
Lenzing AG (Refibra)	https://www.tencel.com/de/refibra	Chemical	Austria	PM,PC	Cotton, MMC	Pulp
Manteco Spa (MWool)	https://manteco.com/mwool/	Mechanical	Italy	PreC, PC	Wool	Fabric
Marchi & Fildi (Ecotec TM)	http://www.ecotecproject.com/english.html	Mechanical	Italy	PM,PC	Cotton, Wool, Wool/Acrylic blends	Yarn
MPO Recycling	https://www.mporecycling.nl/producten/	Mechanical	Netherlan	PM	Cotton, Wool, Polyester,	Fibre, granulates

			ds		Polyamide, PP, Jute, MMC	
Nurel (RecoNylon)	https://nurelfibers.com/en	Chemical	Spain	PM	Polyamide	Fibre, yarn
Pure Loop	https://www.pureloop.com/en/plastic-recycling-material/	Mechanical	Austria	PI, PC	LDPE, PP, PE	Pellets
Radici Group (Renycle)	https://www.radicigroup.com/en	Mechanical	Italy	PM	Polyamide (Nylon 6), Polyamide	Yarn
Re:Down	https://www.re-down.com/down-recycling-our-processes	Mechanical	France	PC	Down	Down
Re:Mix	http://mistrafuturefashion.com/wp-content/uploads/2017/11/Remix.pdf	Chemical	Sweden	PM,PC	Polyamide,Elastane	Fibre, flakes, chips or pellets
Re.Verso	http://www.re-verso.com/en/info/chi-siamo	Mechanical	Italy	PM	Wool, cashmere	Yarn, fabric, farment
Really	https://reallycph.dk/products	Mechanical	Denmark	PM,PC	Cotton, Wool, Polyester	Non-woven
Robert Levy	http://www.textile-alsace.com/fr/	Mechanical	France	PM	Cotton, Aramid	Fibre
SaXcell B.V.	http://saxcell.nl/	Chemical	Netherlands	PI, PC	Cotton	Yarn, fibre
Spinnova	https://spinnova.com/	Mechanical	Finland	PM, PreC, PC	Cotton-rich materials	Fibre, pulp
Sysav - Siptex	https://www.sysav.se/en/	Chemical and mechanical	Sweden	PI, PC	Blends, various	Fibre and yarn
Tesma Cashmere	http://www.tesmacashmere.com/	Mechanical	Italy	PC	Cashmere	Yarn
Textile Change	https://textilechange.com/	Chemical	Denmark	PI, PC	Cotton, polyester	Fibre
Velener Textil GmbH (WECYCLED)	https://wecycled.de	Mechanical	Germany	PM	Cotton	Yarn
Vicente Barber Belda	http://www.vbmateriastextiles.com/productos/	Mechanical	Spain	PreC	Cotton, Polyester, Acrylic	Fibre
Vanotex	https://www.vanotex.be/	Mechanical	Belgium	PM, PReC	PP, Polyester (PES), carpet waste, needle felt, mattress ticking, wool, sisal, PA6, PA, cotton,	Construction, fibre, agricultural sector

*PI: post-industrial waste, PreC: pre-consumer waste, PC: post-consumption waste

Source: own work.

4.3.4.2 Recycling following cutting, grinding, or shredding of textiles for potential applications of end-materials outside the apparel retail sector

The most common recycling process for separately collected post-consumer textiles involves their shredding and reprocessing into cleaning rags, either in the EU or third countries (often located in Asia). After opening and transformation of the fibres into a fluffy fibrous state, the rags can be further transformed into non-woven and/or garnetted products for industrial applications (e.g. insulation materials). This process bypasses both yarn-spinning and weaving/knitting, and is therefore able to rely exclusively on short fibres and fluffy material, and remaining colours in the output materials are generally not considered as problematic. Altogether, a best estimate suggests that about 0.5 - 0.6 Mt yr^{-1} of textiles are processed in this manner in the EU, thus a much higher mass compared to the textile waste shares that are processed through more advanced techniques that aim at recovering precursors for the apparel retail industry (see section 4.3.4.1).

The market players that are active in this field (Table 6, non-exhaustive list) are typically more established companies, active since longer in the textile recycling market, compared to the entities involved in closed-loop recycling processes. Often the recycling activity is only a part of the company's activities that typically also involve collection and sorting for re-use and export to other entities in or outside the EU. The likely reason for this business structure is that high revenues are obtained from re-use that can compensate for the net cost of the recycling activities. Although textile waste rich in natural fibres are preferred, in principle all types of textiles can be processed. Therefore, the companies indicate that the textile fraction that is not suitable as input material for such recycling processes and effectively goes to incineration with energy recovery and/or landfill is very low (<5-10%), indicating a high efficiency of the recycling process and ability to process a broad range of materials. However, further process losses occur during the recycling process e.g. in the form of cutting losses that are then used as fuel or subject to disposal operations.

This 'open-loop recycling' mainly takes place directly at large sites that process separately collected textile waste in Germany, France, and Poland and Hungary (Table 6). For Germany alone, it is indicated that of the approx. 1 million tonnes of textile waste annually collected, about 21% (212 kt) is recycled as cleaning rags, and 17% (172 kt) further transferred into non-woven textile products for applications as e.g. insulation materials (Watson et al., 2020b; Striebel Textil, 2023). Similarly, a dominant (55%) share of the non-reusable separately collected textile waste in France is processed in this manner by the company Le Relais[51]. Other organisations that were inventoried as part of this study are located in Hungary, Poland, Italy, and Slovakia (Table 6). Compared to the identified closed-loop recycling techniques, it is likely that the overview of economic operators active is noticeably less complete, and that a main share of the recycling takes place in third countries.

It is indicated that the operators identified mainly focus on the management of (sorted) separately collected post-consumer waste, rather than the processing of post-industrial or pre-consumer waste. The feedstock for these recycling processes is subject to a minor of limitations compared to recycling processes that focus on applications for the apparel sector.

Table 6. Non-exhaustive overview of textile recycling facilities that apply cutting, grinding, or shredding of textiles for potential applications of end-materials outside the apparel retail sector.

Organisation	Website	Member State
Ecotex	https://ecotexgroup.com/	Germany, Poland
Hotex recycling	https://www.hotex-recycling.de/	Germany
Le Relais	https://www.lerelais.org/index.php	France
Pistoni srl	https://www.texile-plastic-materials-recycling.com/index.php	Italy
Re Textil DE	https://www.re-textil.de/en/home/	Germany

[51] See https://www.lerelais.org/decouvrir.php?page=collecte_et_valorisation_textile

Remitex	https://remitex.de/en/	Germany
SK-tex	https://sk-tex.com/	Slovakia
Striebel Textil	https://www.striebel-textil.de/	Germany
Texaid	https://www.texaid.ch/en/products-and-services/recycling.html	Hungary/Germany
Textrade	https://textradekft.hu/en/	Hungary
VIVE textile recycling	https://www.vivetextilerecycling.pl/?lang=en	Poland

Source: own work.

4.3.4.3 Summary of recycling pathways

Based on the inventory of the recycling capacities, it is estimated that a total of 0.70 – 0.85 Mt yr^{-1} of textile waste is annually recycled in the EU. Most recycling takes place following the cutting, grinding and shredding of textiles into rags for further use as cleaning wipes or non-woven textiles for industrial applications (Figure 13).

4.3.5 Present-day barriers and outlook on textile recycling

4.3.5.1 Present-day barriers to recycling

The technology overview (section 4.3.3) combined with the mapping of recycling facilities (section 4.3.4) indicates that present-day recycling process experience technology hurdles that limit their potential to process an important share of the textile waste generated in the EU in a 'closed loop' where output materials can be used for the production of e.g. garments for the apparel industry:

- The feedstock applied are mostly textiles of a homogeneous composition, e.g. pure cotton or wool;
- Mostly, processes rely on post-industrial waste as its composition is well-known and informed by the supplier. Moreover, the material is clean and has not been subject to wear;
- Due to the strong limitations on input materials, feedstock for recycling facilities in the EU does not only originate from the EU, but also from imports from industrial plants located outside the EU;
- The output from mechanical recycling plants, the dominant technology providers in the EU, is mostly not used for the production of apparel because it is not fully equivalent to primary raw materials. Short fibres ('fluff') is an important output material from the mechanical recycling process. If spinnable fibres are produced, they are mostly used in the manufacturing process of a limited set of textiles (e.g. home linen) or intermixed with virgen fibres in textiles made from carded yarns.

4.3.5.2 Technology outlook

Recycling processes, particularly mechanical recycling processes that turn textile waste into industrial rags and fluff that can be used for the production of non-woven textiles, are prevalent and technologically mature. No or negligible technological limitations apply to these technologies.

However, a more diverse recycling market that generates output materials that can also be used in other industrial applications (e.g. for apparel production) is desirable under future scenario of market diversification. Mckinsey (2022) assumes, based on interviews with technology providers, that current technological limitations can be overcome in the short term and that up to 70% of the textile waste can technically be recycled in 2030 for posterior use in apparel. This would mainly involve textiles with a high content of a single fibre, and assuming that a certain degree of fibres other than the main fibre can be accepted and other current challenges (presence of non-textile parts, such as hard non-textile parts) can be overcome.

4.3.5.3 Outlook on recycling capacities in the EU

The available literature (Dahlbom et al., 2023) and outlooks from identified several actors in the EU recycling market (section 4.3.4, as listed on their websites) suggest that substantial capacity upgrades have been planned in the near future, particularly for closed-loop recycling technologies.

Dahlbom et al. (2023) indicate that the planned total capacity (mass of feedstock entering the recycling plant) from 17 closed-loop recycling actors would increase to 1.3 million tons per year[52]. Most of the future capacity would be for mechanical recycling (1000 kt yr^{-1}), and lower capacities are claimed by chemical recycling operators (250 kt yr^{-1}). Hence, this would involve an increase of about 1 million tonne per year in just a few years of time. Main growth is projected and claimed by a limited set of economic entities (e.g. Renewcell 250 kt yr^{-1}, Recover 200 kt yr^{-1}, Spinnova 150 kt yr^{-1}, Carbios 40 kt yr^{-1}), indicating that a certain degree of caution is required to ascertain that industry claims can actually be realised in practice. Together with open-loop recycling processes growing at a slower pace (currently 0.5 – 0.6 Mt yr^{-1}; subject to a 2.3% compounds annual growth rate for this sector as projected by MaiaConsulting (2023)), textile recycling capacity would grow to roughly 2.0 Mt yr^{-1} in 2035. This would equal an overall compounds annual growth rate of 8.5% to accommodate an absolute capacity growth of about 1.25 Mt yr^{-1} over a time span of 12 years.

Schumpeter (1942) distinguishes three stages in the process by which a new technology develops (OECD and IEA, 2023), invention, innovation and diffusion. However, technical capacity development is not a linear process, but a cyclical process based on feedback loops between market experience and technical development (OECD and IEA, 2023). Comparing the compound annual growth rate to that of other processes and sectors may provide an alternative estimate of how capacity development may evolve with time. Projecting forward using the evolution of dissimilar technologies is unwarranted since the technological and policy tools, including investment subsidies and legal requirements, may be different. Still, within broader limits, the concept may be partially useful to compare and project immature technologies such as textile recycling. The recycling capacities for the EU beverage industry (1991- 2005) for paper and board collected and recycled increased during the phase of exponential growth by an average rate of 5.5% per year (CEFIC, 2020), whereas packaging waste recycling capacity during the period 1998 – 2006 in the EU-15 increased at an average compounds annual growth rate of 3.2% (EEA, 2008). Hence, the projected capacity growth is predicted based on pledged future recycling capacities seems only possible if compounds annual growth rates are significantly higher than these observed for open-loop recycling technologies in the past.

Altogether, our best estimate is an increase of average compound annual growth rate that is similar to historic capacity for other secondary raw materials (4.25% compounds annual growth until 2035). This value would increase the total textile waste recycling capacity in the EU for the reference year 2035 to approx. 1.3 Mt yr-1.

4.4 Summary of stakeholder feedback on the draft report

A draft version of this report was shared for consultation with about ~150 stakeholder organisations, including Member States representatives, industry actors, non-profit organisations, academics and non-governmental organisations, in April 2023. Feedstock on this draft report was received orally and in written during a stakeholder workshop (18-19 April) and an associated questionnaire (hereafter “stakeholder consultation”).

[52] For 2025 as reference year. Given the claim of annual recycling growth rate that are substantially higher in the next years compared earlier time periods, and due to delays observed in upscaling to industry pledged capacities for recycling in other areas (e.g. Kahlert and Bening, 2022), it is assumed that this number also applies to the 2035 reference year.

4.4.1.1 General overview

About 25-30 responses were received on questions related to this section, mostly from recycling and sorting organisations, with following general observations:

- Most organisations and recyclers, except three to four, were already listed in the draft report and had thus previously been;
- Recycling technologies, agreed on the importance of currently listed technologies. Most referred to chemical and mechanical methods, some refer to thermal techniques. A shift towards chemical recycling (lyocell, viscose, polyester recycling into monomers) is indicated relative to the present situation;
- Most recyclers indicated only the intake of pure materials and do not take in apparel of a mixed fibre composition, unless they are focused on making materials for non-apparel applications (insulation materials, cleaning rags). Most focus on cotton, polyester and polyamide, from different waste types (post-industrial and post-consumer);
- On volumes, most actors seem to confirm the information that we have collected from their websites. Some additional information was received from specific organisations on present and future outlook.
- Organisations flagged the international market of feedstocks for recycling processes, particularly due to the very specific nature and purity requirements for input facilities. Bales of e.g. pure cotton often originate from Pakistan, Dubai or US, and or often production that are shipped as (by-)products rather than waste.

4.4.1.2 Main changes compared to draft report

Text parts were revised to account for the new information. Minor updates to the Tables that document recycling entities, and their current and future capacity estimates on recycling capacity were performed.

5 Environmental and techno-economic characterisation of the different recycling or other recovery routes and technologies

5.1 Methodology

This section describes the life-cycle-based methods used in the study to quantify the potential environmental and economic impacts (savings or burdens/costs) of textile waste re-use, recycling, incineration or landfilling, based on Life Cycle Assessment (LCA) (Section 5.1.1), Environmental Life Cycle Costing (ELCC) and full Environmental Life Cycle Costing (fELCC) (Section 5.2).

5.1.1 Potential environmental impacts (LCA)

The quantification of potential environmental impacts was carried out following established practice for waste management LCA (see literature (Finnveden, 1999; Clift et al., 2000; Joint Research Centre, 2012) and in accordance with the guidelines of the ISO 14040/14044 standards (ISO, 2006a, 2006b). Specific methodological and modelling rules of the Environmental Footprint (EF) Method (European Commission, 2021) relevant to the goal and scope of the study were also applied. These regard, notably, the selection of impact categories and Life Cycle Impact Assessment (LCIA) methods. For the modelling of background activities and processes involved in the investigated waste management pathways and scenarios (e.g. electricity use, transport and capital goods), we relied on Ecoinvent 3.8 datasets. Further detail is provided in Sections 5.1.5 (life cycle impact assessment) and 5.1.6 (life cycle inventory).

5.1.2 Goal, scope and Functional Unit

The goal of this study is assessing and comparing the impacts associated with the treatment of a selected waste material fraction (e.g. cotton-rich textile waste) via selected technology pathways and their combinations, i.e. re-use, mechanical and chemical recycling[53] as well as incineration and landfilling. Since the main purpose of this study is to assess the impact **of the treatment of 1 metric tonne in different technology scenarios**, we assume in the re-use and recycling scenarios that the separate collection rate by household/services is 100% (all waste generated is collected). Note that assuming a separate collection rate less than 100% would just cloud the performance of the downstream sorting and recycling technologies, which is instead the main goal of this LCA[54].

The geographical scope of the study is the European Union, represented by the entirety of its Member States, i.e., EU-27. As for the temporal scope, the study reflects current conditions (year 2023). This applies both to the foreground system including all activities associated with the specific waste management scenario, and to the background system including all ancillary activities such as energy and material supply.

In this study, the functional unit (FU) is “management and treatment of 1 metric tonne of a selected textile waste material fraction, wet weight including impurities from collection”. The material fractions that are prioritized (reported in the interim reporting) are those that together make up more than 80% of the total EU-27 textile waste by weight: 1) cotton, 2) polyester, 3) wool, 4) polyamide, 5) viscose, and 6) mixed polycotton.

5.1.3 System boundary and supporting software

The boundary starts from the waste collected in households or businesses and ends with the final recovery (e.g. into new products, materials, substances or fuels/energy) or disposal in landfill of the studied material. Since the main purpose of this study is to assess the impact of the treatment of 1 metric tonne in different technology scenarios, we do not consider the source-separation inefficiencies (no mass losses at separate collection stage). Energy consumptions, labour, and costs for collection operations (both for separate and mixed collection) are included in the assessment.

The processes included are: collection, sorting, recycling (including pre-treatment), energy recovery via incineration, and landfilling. The system ends with the final recovery (e.g. into new products, materials,

[53] See section 5.1.4 for technologies considered. Recycling includes both ‘advanced’ mechanical recycling that target spinnable fibres as well as open-loop recycling technologies that transform i) natural fibres to secondary wipers, ii) synthetic fibres to PP granulate and iii) mixed fibres to insulation material based on Faraca et al. (2019).

[54] In a full impact assessment, one should also include the rate of separate collection at source, as not all the generated waste is captured by separate collection schemes.

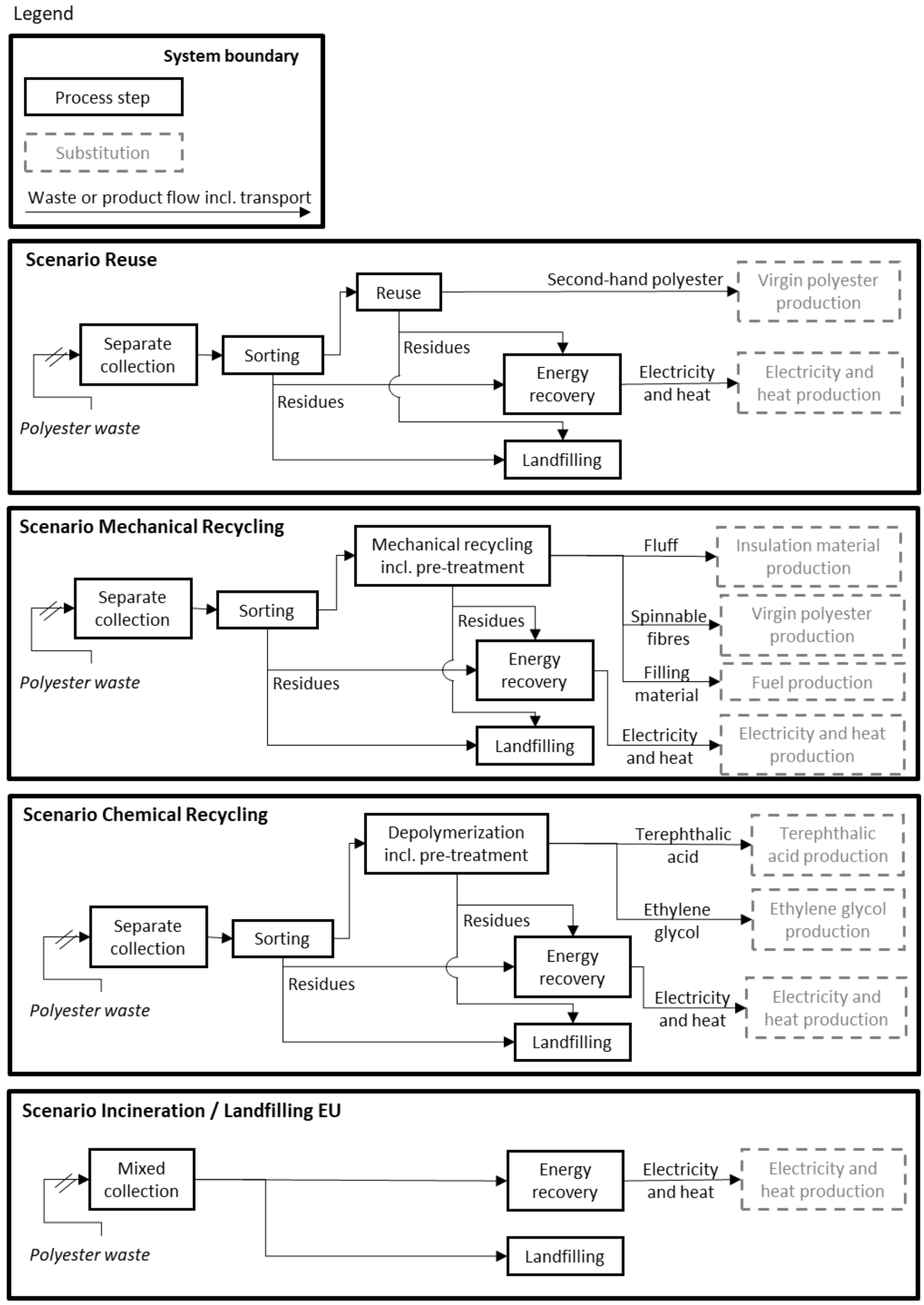
substances or fuels/energy) or disposal in landfill of the material, i.e. with the end of its ‘first life’, and any impacts from a possible ‘second life’ of re-used and recycled materials is considered through LCA crediting (see below). The system boundary of each LCA scenario includes all the operations involved in the management of the waste through the specific technology, i.e.: i) transport; ii) collection and sorting; iii) processing of the waste material; iv) handling of separated non-recyclable material fractions, residues and losses from recycling and residues from energy recovery processes; as well as v) substitution of market materials, products and/or energy from the recovered materials/products and/or energy.

System expansion is performed to account for the multi-functionalities of waste management systems where additional products are generated alongside the main service required, which is treating the waste. Thus, any flow of secondary material or energy generated from the waste management system is credited via system expansion by assuming the replacement of corresponding primary material or energy in the EU market (Figure 15). To this end, marginal[55] background processes are used to describe the replaced production processes (or supply process when transport needs to be included too). While marginal processes were used for this specific exercise, the model has been set up to accommodate switches from marginal to average processes and vice versa.

Incineration residues (bottom ash after metal separation and air pollution control residues) are each sent to a specific treatment and fate, i.e. re-use as construction material and disposal in underground deposits, respectively. In case of chemical recycling, any required mechanical pre-treatment of the input-waste is also included (if not already covered by the inventory data applied).

[55] Marginal processes are those processes that are expected to change as a result of an increased/decreased demand, normally consisting of suppliers that are able to respond to a market demand increase/decrease. In LCA, this is an alternative approach to using average market processes, which instead normally consist of the weighted average of the market suppliers for a certain good or service.

Figure 15. Graphical representation of technical pathway scenarios including system boundary, waste and product flows as well as both induced (continuous-black lines) and avoided processes (dotted-grey lines). The illustrative example is for the case of polyester (PES), but can as well be extended to the remaining textile waste fractions. Note that, since the focus of this study is on the impact of the treatment of 1 metric tonne in different technology scenarios, we consider a separation rate of 100%, i.e. no losses at separate collection stage.



Source: adapted from Solis et al., in preparation.

The input-waste is assumed to carry no environmental burdens from the respective upstream life cycle, following the common "zero-burden" assumption applied in waste management LCA (see, for instance, Ekvall et al. (2007); Finnveden (1999)), as the impacts occurring before the waste is generated would be exactly the same across the alternative management scenarios herein compared.

The assessment of the investigated waste management scenarios and technologies is conducted with the support of the LCA software EASETECH v3.4.4 (Astrup et al., 2012; Clavreul et al., 2014) specifically developed to assess waste management technologies and systems. This tool is applied to model the different waste management activities and processes included in each scenario, and to calculate the respective potential environmental impacts, environmental life cycle costs and full environmental life cycle costs.

5.1.4 Scenarios definition

The assessment considers comparison among different waste management scenarios relying on alternative pathways and technologies for treatment of specific textile waste streams, see Table 7 for the overview. Not all technologies described in section 4.3.3 are addressed in this section. For instance, thermo-mechanical and thermo-chemical technologies are not included in this assessment due to a lack of data and implementation in operational plants at high technology readiness level.

Note that although this study compares fibre-sorted feedstock/technology combinations, sorting was assumed to take place for re-use and recycling operations as this operation would take place on (mixed) separately collected used and waste textiles. This enables a fair comparison amongst management routes for used and waste textiles, and allows to present impact of the entire waste management chain, including sorting.

5.1.5 Life cycle impact assessment

The following 16 environmental impact categories - included in the currently recommended EU Environmental Footprint (EF) methods (European Commission, 2021) - were considered in this study: Climate Change (CC), Ozone Depletion (ODP), Human Toxicity, cancer (Htox_c), Human Toxicity, non-cancer (Htox_nc), Particulate Matter (PM), Ionising Radiation (IR), Photochemical Ozone Formation (POF), Acidification (AC), Eutrophication, terrestrial (TEU), Eutrophication, freshwater (FEU), Eutrophication, marine (MEU), Ecotoxicity, freshwater (Ecotox), Land Use (LU), Water Use (WU), Resource Use, minerals and metals (MRU), and Resource Use, fossils (FRU). Notice that MRU is mostly affected by the consumption or recovery of critical minerals and metals (e.g. gold, silver, antimony, lithium, indium), while FRU by the consumption or avoided use, via energy recovery from waste, of fossil resource (gas, coal, oil, peat, uranium, etc.). The EF 3.0 Life Cycle Impact Assessment (LCIA) method, as implemented in the LCA software used to model the investigated waste management scenarios (EASETECH v3.4.4), was applied to calculate the potential environmental impacts of each scenario in these impact categories. Notice that the categories LU and WU are not regionalised in EASETECH v3.4.4 and therefore their results are to be considered as an indication of the tendency of these impacts rather than an accurate figure.

5.1.6 Life cycle inventory modelling

The life cycle inventory data consist of foreground and background data. Foreground data refer to input/output technology data (e.g., consumption of electricity and chemicals as well as outputs produced to treat 1 unit of input waste, which here corresponds to the reference flow that fulfils the functional unit). These were developed based on scientific and technical literature as well as data obtained from the previous JRC´s projects. Table 7 provides an overview of the technologies and processes involved in each management scenario investigated. To describe the technologies and processes, uncertainty ranges were used to cover the data variation when multiple studies (or players) provide data on a similar or same technology. Background data refer to processes that are input to the foreground system but that are (typically) not affected by choices operated on the foreground system (e.g., by policy makers or operators). These were covered with external datasets (ecoinvent database). Where needed, these data were complemented with specific assumptions. It is referred to section 5.3 for more information and data.

5.1.6.1 Recovered products/materials/substances and substitution of primary production

Recovered products/materials/substances (e.g. recycled secondary wipers) as well as recovered energy or fuels (e.g. electricity and heat from incineration) were identified as those process outputs that can be directly sold on the market and used, as such or after further external processing/conversion, to replace virgin textile materials, chemical intermediates (e.g. monomers) or feedstock (e.g. naphtha), and/or conventional fuels or energy (e.g. electricity and heat from the grid).

According to the applied methodological approach and system boundary (Section 5.1.3), recycled and recovered products/co-products were assumed to replace equivalent primary products on the market, obtained from primary or conventional production routes. Specific substitution factors were applied, where relevant, to account for any real or potential difference between the quality of recycled and replaced primary products, as detailed in Table 8. The substitution factor thus intends to reflect a quality ratio, i.e. how well the secondary material is able to fulfil the same function of its virgin counterpart, for an intended market application. A substitution 1:1 means that the secondary material/product/substance is fully equivalent to its virgin counterpart.

Regarding energy substitution, recovered electricity was assumed to replace electricity from the EU grid, represented by the marginal EU electricity grid mix for the period 2015-2020 (0% nuclear, 32% natural gas, 0% hard coal, 15% hydro & marine, 42% wind, 0% biomass, 0% oil and 11% solar (KERAMIDAS et al., 2021)). The choice of a past period was determined by focus on showcasing reality to as high degree as possible. For thermal energy, we distinguish between space and industrial heating. The space heating mix is represented by the marginal space heating mix for EU27 for the period 2015-2020 (8% natural gas, 7% oil, 9% hard coal, 10% electricity, 66% biomass). The industrial heating mix is represented by the marginal industrial heating mix for EU27 for the period 2015-2020 (48% natural gas, 28% oil, 8% hard coal, 16% biomass).

Table 7. Overview of the waste management scenarios and technologies assessed for each textile waste stream and details of the technology applied and main products obtained in each scenario. CHP: combined heat and power; COT: cotton waste; CR: chemical recycling; EG: ethylene glycol; EN: enzymatic recycling; EU: current distribution of municipal solid waste management in EU between incineration and landfilling (we use 54% incineration and 46% landfilling based on (Albizzati et al., 2023); IN: incineration; LA: landfilling; MR: mechanical recycling; MSW: municipal solid waste; OR: open-loop recycling (mechanical processing to products that are different and used for different purposes than the material from which the waste has originated); PA: polyamide waste PC: polycotton waste; PES: polyester; RU: re-use; TPA: terephthalic acid; VIS: viscose waste; WOL: wool waste.

Input-waste	Functional unit	Scenario name	Type of treatment	Main technology	Main products	Other products
Cotton waste	Management of 1 tonne of cotton waste	COT-RU	Re-use/preparing for re-use	Cutting and sewing	Second-hand textiles	N/A
		COT-MR	Mechanical recycling, closed-loop (see section 4.3.3.1)	Shredding, separation of impurities, washing, density separation, drying	Spinnable fibres	Fluff, filling material, metals, dust
		COT-OR	Open-loop recycling (see section 4.3.3.1)	Shredding, washing, density separation, drying	Cleaning rags/ secondary wipers	N/A
		COT-CR	Chemical recycling (see section 4.3.3.3)	Pulping	Pulp	N/A
		COT-EU	Energy recovery and landfilling (54%/46%)	Incineration (MSW) with CHP generation, controlled landfilling with gas and leachate collection system and gas utilization	Electricity and heat	N/A
		COT-IN	Energy recovery	Incineration (MSW) with CHP generation	Electricity and heat	N/A
		COT-LA	Landfilling	Controlled landfilling with gas and leachate collection system and gas utilization	N/A	N/A
Polyester waste	Management of 1 tonne of polyester waste	PES-RU	Re-use	Cutting and sewing	Second-hand textiles	N/A
		PES-MR	Mechanical recycling (see section 4.3.3.1)	Shredding, separation of impurities, washing, density separation, drying	Spinnable fibres	Fluff, filling material, metals, dust
		PES-OR	Open-loop recycling (see section 4.3.3.1)	Shredding, washing, density separation, drying	Non-virgin grade fibres	N/A
		PES-CR	Chemical recycling (see section 4.3.3.4)	Depolymerization	TPA, EG, PES	Sodium sulphate
		PES-EU	Energy recovery and landfilling (54%/46%)	Incineration (MSW) with CHP generation, controlled landfilling with gas and leachate collection system and gas utilization	Electricity and heat	N/A
		PES-IN	Energy recovery	Incineration (MSW) with CHP generation	Electricity and heat	N/A
		PES-LA	Landfilling	Controlled landfilling with gas and leachate collection system and gas utilization	N/A	N/A
Wool waste	Management of 1 tonne of wool waste	WOL-RU	Re-use	Cutting and sewing	Second-hand textiles	N/A
		WOL-OR	Open-loop recycling (see section 4.3.3.1)	Shredding, washing, density separation, drying	Non-virgin grade fibres	N/A
		WOL-EU	Energy recovery and landfilling	Incineration (MSW) with CHP generation, controlled	Electricity and heat	N/A

			(54%/46%)	landfilling with gas and leachate collection system and gas utilization		
		WOL-IN	Energy recovery	Incineration (MSW) with CHP generation	Electricity and heat	N/A
		WOL-LA	Landfilling	Controlled landfilling with gas and leachate collection system and gas utilization	N/A	N/A
Polyamide waste	Management of 1 tonne of polyamide waste	PA-RU	Re-use	Cutting and sewing	Second-hand textiles	N/A
		PA-MR	Mechanical recycling (see section 4.3.3.1)	Shredding, separation of impurities, washing, density separation, drying	Spinnable fibres	Fluff, filling material, metals, dust
		PA-OR	Open-loop recycling (see section 4.3.3.1)	Shredding, washing, density separation, drying	Non-virgin grade fibres	N/A
		PA-EU	Energy recovery and landfilling (54%/46%)	Incineration (MSW) with CHP generation, controlled landfilling with gas and leachate collection system and gas utilization	Electricity and heat	N/A
		PA-IN	Energy recovery	Incineration (MSW) with CHP generation	Electricity and heat	N/A
		PA-LA	Landfilling	Controlled landfilling with gas and leachate collection system and gas utilization	N/A	N/A
Viscose waste	Management of 1 tonne of viscose waste	VIS-RU	Re-use	Cutting and sewing	Second-hand textiles	N/A
		VIS-MR	Mechanical recycling (see section 4.3.3.1)	Shredding, separation of impurities, washing, density separation, drying	Spinnable fibres	Fluff, filling material, metals, dust
		VIS-EU	Energy recovery and landfilling (54%/46%)	Incineration (MSW) with CHP generation, controlled landfilling with gas and leachate collection system and gas utilization	Electricity and heat	N/A
		VIS-IN	Energy recovery	Incineration (MSW) with CHP generation	Electricity and heat	N/A
		VIS-LA	Landfilling	Controlled landfilling with gas and leachate collection system and gas utilization	N/A	N/A
Poly-cotton waste	Management of 1 tonne of polycotton waste	PC-RU	Re-use	Cutting and sewing	Second-hand textiles	N/A
		PC-MR	Mechanical recycling (see section 4.3.3.1)	Shredding, separation of impurities, washing, density separation, drying	Spinnable fibres	Fluff, filling material, metals, dust
		PC-OR	Open-loop recycling (see section 4.3.3.1)	Shredding, washing, density separation, drying	Non-virgin grade fibres	N/A
		PC-CR	Chemical recycling	Dissolution of cotton and recovery of polyester	Recovered cellulose, PET resins	N/A
		PC-CR*	Chemical recycling	Dissolution of polyester and recovery of cotton	Cellulosic fibre, TPA, EG	N/A
		PC-EU	Energy recovery and landfilling (54%/46%)	Incineration (MSW) with CHP generation, controlled landfilling with gas and	Electricity and heat	N/A

				leachate collection system and gas utilization		
		PC-IN	Energy recovery	Incineration (MSW) with CHP generation	Electricity and heat	N/A
		PC-LA	Landfilling	Controlled landfilling with gas and leachate collection system and gas utilization	N/A	N/A

Source: adapted from Solis et al., in preparation.

Table 8. Main assumptions related to the modelling of the substitution of primary market products by products obtained from the investigated recycling scenarios: substituted products and corresponding substitution factors. CR: chemical recycling; EN: enzymatic recycling; MR: mechanical recycling; OR: open-loop recycling (mechanical processing to products that are different and used for different purposes than the material from which the waste has originated); PET: polyethylene terephthalate; RU: re-use; TPA: terephthalic acid.

Input waste	Tech-nology	Re-used or recycled product	Substituted product	Substitution factor	Source
Cotton	RU	Second-hand textiles	Virgin fibres	1:0.725	(Farrant et al., 2010)
	MR	Fluff	Insulation material	1:0.8	(Faraca et al., 2019; Duhoux et al., 2021)
		Spinnable fibres	Virgin fibres	1:0.525	(Schmidt et al., 2016b; Rittfors, 2020; Duhoux et al., 2021; Textile Exchange, 2021)
	OR	Non-virgin grade fibres	Secondary wipers	1:0.8	(Faraca et al., 2019)
	CR	Pulp	Wood-based pulp	1:1	Stakeholder consultation
Poly-ester	RU	Second-hand textiles	Virgin fibres	1:0.725	(Farrant et al., 2010)
	MR	Fluff	Insulation material	1:0.8	(Faraca et al., 2019; Duhoux et al., 2021)
		Spinnable fibres	Virgin fibres	1:0.525[6]	(Schmidt et al., 2016b; Rittfors, 2020; Duhoux et al., 2021; Textile Exchange, 2021)
	OR	Non-virgin grade fibres	Synthetic granulate	1:0.8	(Faraca et al., 2019)
	CR	Terephthalic acid (TPA)	TPA from virgin fossil-based feedstock	1:1	(Garcia-Gutierrez et al., 2023)
		Ethylene glycol (EG)	EG from virgin fossil-based feedstock	1:1	(Garcia-Gutierrez et al., 2023)
		Polyester (PES) polymers	Virgin PES	1:1	(Garcia-Gutierrez et al., 2023)
Wool	RU	Second-hand textiles	Virgin fibres	1:0.725	(Farrant et al., 2010)
	OR	Non-virgin grade fibres	Secondary wipers	1:0.8	(Faraca et al., 2019)
Polyami de	RU	Second-hand textiles	Virgin fibres	1:0.725	(Farrant et al., 2010)
	MR	Fluff	Insulation material	1:0.8	(Faraca et al., 2019; Duhoux et al., 2021)
		Spinnable fibres	Virgin fibres	1:0.525[6]	(Schmidt et al., 2016b; Rittfors, 2020; Duhoux et al., 2021; Textile Exchange, 2021)
	OR	Non-virgin grade fibres	Synthetic granulate	1:0.8	(Faraca et al., 2019)
Viscose	RU	Second-hand textiles	Virgin fibres	1:0.725	(Farrant et al., 2010)
	MR	Fluff	Insulation material	1:0.8	(Faraca et al., 2019; Duhoux et al., 2021)
		Spinnable fibres	Virgin fibres	1:0.525[6]	(Schmidt et al., 2016b; Rittfors, 2020; Duhoux et al., 2021; Textile Exchange, 2021)

Polycotton	RU	Second-hand textiles	Virgin fibres	1:0.725	(Farrant et al., 2010)
	MR	Fluff	Insulation material	1:0.8	(Faraca et al., 2019; Duhoux et al., 2021)
		Spinnable fibres	Virgin fibres	1:0.525[6]	(Schmidt et al., 2016b; Rittfors, 2020; Duhoux et al., 2021; Textile Exchange, 2021)
	OR	Non-virgin grade fibres	Insulation material	1:0.8	(Faraca et al., 2019)
	CR	Recovered cellulose	Wood-based pulp	1:1	Stakeholder consultation
	CR*	Terephthalic acid (TPA)	TPA from virgin fossil-based feedstock	1:1	(Peterson et al., 2022)
		Ethylene glycol (EG)	EG from virgin fossil-based feedstock	1:1	(Peterson et al., 2022)
	EN	PET fibres	Virgin fibres	1:0.525	(Duhoux et al. 2021; Textile Exchange, 2021)
		Glucose syrup	Virgin syrup	1:1	Duhoux et al., 2021

Source: adapted from Solis et al., in preparation.

5.2 Environmental life cycle costing and full environmental life cycle costing

An Environmental LCC[56] (ELCC) focusing on internal costs (budget costs and transfers related to environmental taxes that are already internalised, e.g. landfill and incineration taxes paid by operators) and reflecting a traditional financial assessment was performed. The ELCC adhered to state-of-the-art methodology as presented in Hunkeler et al. (2008) and Martinez-Sanchez et al. (2015). The ELCC and LCA share the same object, scope, functional unit, and system boundaries. The cost assessment includes internal costs (budget costs and transfers); strictly defined, budget costs are costs incurred by the different actors involved in the management chain of the waste (collectors, operators, transporters, etc.), while transfers refer to money redistributed among stakeholders (taxes, subsidies, value added tax - VAT, and fees). In our analysis, for the purpose of simplicity and the resolution of the data obtained, we will refer only to the aggregated internal costs in general reported as operational expenditures and capital expenditures (sum of OPEX and CAPEX), i.e. we will not report budget costs and transfers separately. The ELCC was carried out with the software EASETECH v3.4.4 (Astrup et al., 2012; Clavreul et al., 2014).

Full Environmental Life Cycle Costing (fELCC) accounts for the internal costs after subtraction of environmental taxes (covered in ELCC) and external costs, striving to take perspective of the entire costs borne by society. The external costs are not covered by current market prices (i.e. not internalised in the current products and/or services price paid by consumers). To price environmental externalities we here used the shadow prices of environmental emissions by de Bruyn (2018) as suggested by the official EC guidelines for impact assessment studies (European Commission, 2023). The CO_2 price was corrected to 100 EUR/t based on a recent update and recommendation by DG ENV and CLIMA (van Essen et al., 2019), which is more in line with current ETS prices. Notice that only the externalities associated with environmental emissions to soil/water/air are included in de Bruyn (2018) while other external costs mainly related to social aspects (e.g. time spent by citizens to sort their waste, children labour to produce textile product, gender or other inequality issues, and all the other social effects that one may think of) are here not accounted for. It should be noticed that the term fELCC precisely refers to the fact that only environmental externalities are considered in the assessment while social aspects are not. In previous studies, also from the same authors, the term Societal LCC was used in place of fELCC. Both ELCC and fELCC followed the state-of-the-art methodology as defined and presented in Martinez-Sanchez et al., (2015) and Albizzati (2021).

[56] This is different from a full environmental LCC (where environmental externalities are monetised and summed to the internal costs, all expressed as shadow prices) or from a societal LCC (where environmental and social externalities are monetised and summed to the internal costs, all expressed as shadow prices) that strive to quantify the total cost carried by the society, thus reflecting a socio-economic or welfare assessment.

As previously, the fELCC and LCA share the same object, scope, functional unit, and system boundaries. The fELCC was carried out with the software EASETECH v3.4.4 (Astrup et al., 2012; Clavreul et al., 2014).

5.3 Inventory data

This section summarises the main data used for the assessment and relates sources. While our choice is not to show the detailed technology and process inventories in this report, detailed information (i.e. input-output data used in terms of amount of energy, fuel, chemicals consumption per unit of waste treated, product yields out of one unit of waste treated, etc.) will be prepared and made available under request[57].

The foreground data (consumptions, emissions, yields, etc.) to describe the waste treatment technologies were taken from previous JRC studies or the recent literature. For cotton, RU was based on (Farrant et al., 2010; Schmidt et al., 2016b; Faraca et al., 2019), MR on (Schmidt et al., 2016b; Rittfors, 2020; Duhoux et al., 2021; Textile Exchange, 2021), OR on (Faraca et al., 2019), and CR on (Schmidt et al., 2016b; Spathas, 2017; Duhoux et al., 2021; stakeholder consultation); incineration was modelled based on Garcia-Gutierrez et al. (2023), which performed a similar exercise on plastic waste, while landfilling on (Cruz and Barlaz, 2010; Kabir et al., 2013; Olesen and Damgaard, 2014; Chamas et al., 2020; Jin et al., 2022; Shoaf, 2022).

For polyester, RU, MR and OR were based on same sources as for cotton, CR on (Schmidt et al., 2016b; Spathas et al., 2017; Duhoux et al., 2021; Garcia-Gutierrez et al., 2023). Incineration and landfilling were modelled similarly to cotton, but the emissions are specific to the polyester following the waste-specific logic of the EASETECH software (Clavreul et al., 2014).

For viscose RU and MR were based on same sources as for previous textile fractions. Incineration and landfilling were modelled similarly to cotton, but the emissions are specific to the viscose following the waste-specific logic of the EASETECH software (Clavreul et al., 2014).

For polycotton CR was based on (Peterson et al., 2022), whereas EN was based on Duhoux et al. (2021). Incineration and landfilling were modelled similarly to cotton, but the emissions are specific to the polycotton following the waste-specific logic of the EASETECH software (Clavreul et al., 2014).

The background data describing the input to the foreground system (e.g. electricity supply, fuels, chemicals, ancillary materials) are represented with datasets from the ecoinvent 3.8 database. With respect to prices (e.g. for consumption of chemicals, electricity, heat, fuels but also for recovered products, chemicals, etc.), most data were taken from previous studies (Torres-Rivas et al., 2018; Nørup et al., 2019a; Duhoux et al., 2021; Bassi et al., 2022; Hilde van Duijn et al., 2022; McKinsey & Company, 2022; Albizzati et al., 2023; Garcia-Gutierrez et al., 2023). While the specific background data are available in a separate document upon request, the following unit-cost (cost of treating 1 t input to the unit treatment) are especially important for understanding the LCC results: landfilling cost (OPEX and CAPEX): 69.5 EUR/t; landfill tax 43 EUR/t; incineration cost (OPEX and CAPEX): 125 EUR/t; incineration tax: 21 EUR/t; separate collection cost (OPEX and CAPEX): 181 EUR/t; mixed waste collection cost (OPEX and CAPEX): 106 EUR/t; transport cost: 0.0057 EUR/t/km; depolymerization cost (OPEX and CAPEX): 47 EUR/t; sorting cost (OPEX and CAPEX): 418 EUR/t; mechanical recycling (OPEX and CAPEX): 234 EUR/t.; price of EG: 775 EUR/t; price of TPA: 725 EUR/t; price of second-hand textiles: 1100 EUR/t; price of spinnable fibres: 535 EUR/t; price of secondary wipers: 125 EUR/t, price of synthetic granulate: 525 EUR/t; price of insulation material: 796 EUR/t; price of pulp: 1411 EUR/t; price of electricity: 0.18 EUR/kWh; price of heat (assumed as natural gas heating): 0.024 EUR/MJ. Both electricity and heat prices are for the first semester of 2022 based on Eurostat data for EU27. More details may be found in the studies abovementioned or upon request.

5.4 Addressing uncertainty

In this assessment, the uncertainty is mainly associated with i) data inputs (data parameter uncertainty), ii) framework conditions assumptions (such as the energy mix used for EU-27 or other similar assumptions), iii) model uncertainty (related to the equations and constants used to represent physico-chemical processes) and iv) impact assessment uncertainty, which refer to the uncertainty of the characterization factors used to represent the impact of an emission (e.g. methane has an impact of 28 kg $CO_{2\text{-eq}}$/kg methane on Climate Change following IPCC methodology). We will address the point (i) and (ii), while points (iii) and (iv) are out of the scope.

[57] One of the reasons is that some of the data used are protected by non-disclosure-agreements.

To cover point (i), we performed analytical propagation of the parameter uncertainty for all the (data) parameters used in the model. The methodology to propagate the error analytically is based on the classic Taylor's error propagation theory and has been thoroughly detailed elsewhere (Bisinella et al., 2016). By doing so, we are also able to identify the most uncertain (data). The results of the uncertainty propagation analysis are reported as traditional 'error bars' around the 'default' net results in section 5.5. Together, we also briefly point out to the most uncertain (data) parameter.

To cover point (ii), we performed a dedicated sensitivity analysis on future technology and framework conditions to illustrate how the evolution of recycling technology, in terms of recovery yields, and the evolution of the EU energy system, in terms of energy supply sourcing, will impact on our default results. To do this, the following modifications were done on the input-data used in the model:

- The EU electricity supply mix was based on the growing suppliers (i.e. marginal suppliers) for the period 2030-2040 based on the EU Commission GECO report (KERAMIDAS et al., 2021) (i.e. 0% coal, 0% natural gas, 5% natural gas with CCS[58], 0% oil, 25% biomass and waste, 2% biomass and waste with CCS, 13% nuclear, 0% hydro, 27% wind and 28% solar). Notice that this affects both energy consumption (e.g. by the waste treatment technologies) and recovery (e.g. via incineration).
- The EU heat supply was based on the growing suppliers (i.e. marginal suppliers) for the period 2030-2040 based on the EU Commission GECO report (KERAMIDAS et al., 2021) (i.e. for industrial heat: 27% coal, 10% natural gas, 21% oil, 5% biomass and 37% hydrogen; for space heat: 35% natural gas, 1% oil, 5% coal, 58% electricity, 0% biomass and 2% hydrogen). Notice that this affects both energy consumption (e.g. by the waste treatment technologies) and recovery (e.g. via incineration).
- For mechanical recycling of cotton, we assumed that the yield of spinnable fibre would increase from approximately 12% (average of reported 5-20% interval (Duhoux et al., 2021)) to 85% based on data from Recover[59], while simultaneously decreasing the yield of fluff from 40% ((Duhoux et al., 2021)) to 7% based on the reporting from frontrunners. The yield of filling materials which was previously replacing fuel was diverted to fluff instead and therefore replacing insulation material. The residual 8% (100%-(85%+7%)) to close mass balance is assumed to be incinerated.
- For mechanical recycling of polyester and viscose, we assumed that the yield of spinnable fibre would increase from 40% (average of reported 25-55% interval (Duhoux et al., 2021)) to the maximal value in that interval namely 55%, and the yield of fluff increased from 26% ((Duhoux et al., 2021)) to 37%. Just as in case of cotton, the yield of filling materials which was previously replacing fuel was diverted to fluff instead and therefore replacing insulation material.
- For chemical recycling of cotton and polyester, we did not assume any change, as the data seem already in the higher range of achievable yields.
- For incineration, across all waste material fractions, we assumed an increased electricity recovery efficiency from 15% to 23.2% based on (Danish Energy Agency, 2023). Heat recovery efficiency was kept to 35%, as in the default calculations.
- For landfilling, across all waste material fractions, we assumed no technology changes as landfilling is anyway expected to be phased out, conforming to EU legislation.
- For prices, we assumed no changes as our intention is to illustrate the effect of increased recovery yields (e.g. for spinnable fibres) and of increased decarbonisation of the EU energy system (for both heat and electricity), maintaining current prices.

Notice that we assume that the primary production of fibres and non-woven textile takes place outside EU, therefore it is not affected by the decarbonisation of the EU energy system (point i and ii above). The results of the future scenario analysis are reported in section 5.8.

[58] CCS stands for Carbon Capture and Storage

[59] Textile Exchange interviews Alfredo Ferre, CEO of Hilaturas Ferre & Recovertex. Available at: https://www.commonobjective.co/article/insider-series-recover-turns-textile-waste-into-valuable-yarn

5.5 Results - present-day situation

In the following sections, the potential environmental impacts of the investigated scenarios are presented for a subset of impact categories, namely: Climate Change, Resource Use - fossils, Human toxicity - cancer and Water Use. These impact categories were selected because of their relevance in the context of textile waste management. Environmental life cycle costs of the investigated scenarios are also presented (Section 5.6), as well as the full environmental life cycle costs (Section 5.7). The remaining impact categories results are reported in the annexes.

5.5.1 Life cycle assessment of re-use, recycling, incineration, and landfilling scenarios

This section presents the results of the environmental life cycle assessment, which are expressed per functional unit, i.e. management of one tonne (1t = 1000 kg, wet weight) of textile waste input to each of the compared set of scenarios including impurities. Positive impact contributions represent burdens to the environment, while negative impact contributions represent savings to the environment. The net impact of the management of the waste at the level of the individual scenarios is calculated as the difference between the burdens of the management pathway and the savings from the substituted products and co-products arising from that pathway, and it is referred to as "net" in the discussion of the results. The "net" impact is thus a 'net saving' when negative or a 'net burden' when positive. The results regarding potential impacts on Climate Change, Resource Use, fossils, Human toxicity, cancer and Water Use, with a breakdown of the contribution of each sub-process/activity, are presented herein. Note that the textile waste input was considered to enter each scenario as "burden-free", i.e. free of any upstream environmental impact, as the upstream impacts of generating the waste would be the same across all the scenarios handling such waste. The impact contributions were aggregated into eight clusters, representing the main processes and activities of the investigated scenarios: collection and transport, sorting, re-use, recycling, incineration, landfilling, material recovery and energy recovery. The cluster 'material recovery' includes the savings associated with the recovery of second-hand textiles, spinnable fibres, non-spinnable fibres (e.g. fluff), chemicals (i.e. terephthalic acid, ethylene glycol and hydrotreated pyrolysis oil), and pulp. The cluster 'energy recovery' includes the savings associated with the recovery of electricity and heat from incinerating the waste as well as from landfilling, via gas capture and utilisation.

Across all the recycling scenarios investigated (Figure 17, 19, 21, 23), the following general and recurrent observations apply:

- For the recycling scenarios, the most important contribution to the burdens is the recycling itself (processing in terms of use of energy and chemicals) and the treatment of the residues generated within the processing itself (via incineration or landfilling). The most important contribution to the savings is substitution of materials via recycling and other forms of recovery. In selected recycling pathways substitution of energy via energy recovery also becomes important owing to the significant mass loss during recycling and the consequent diversion to incineration of a significant portion of the input-waste treated.

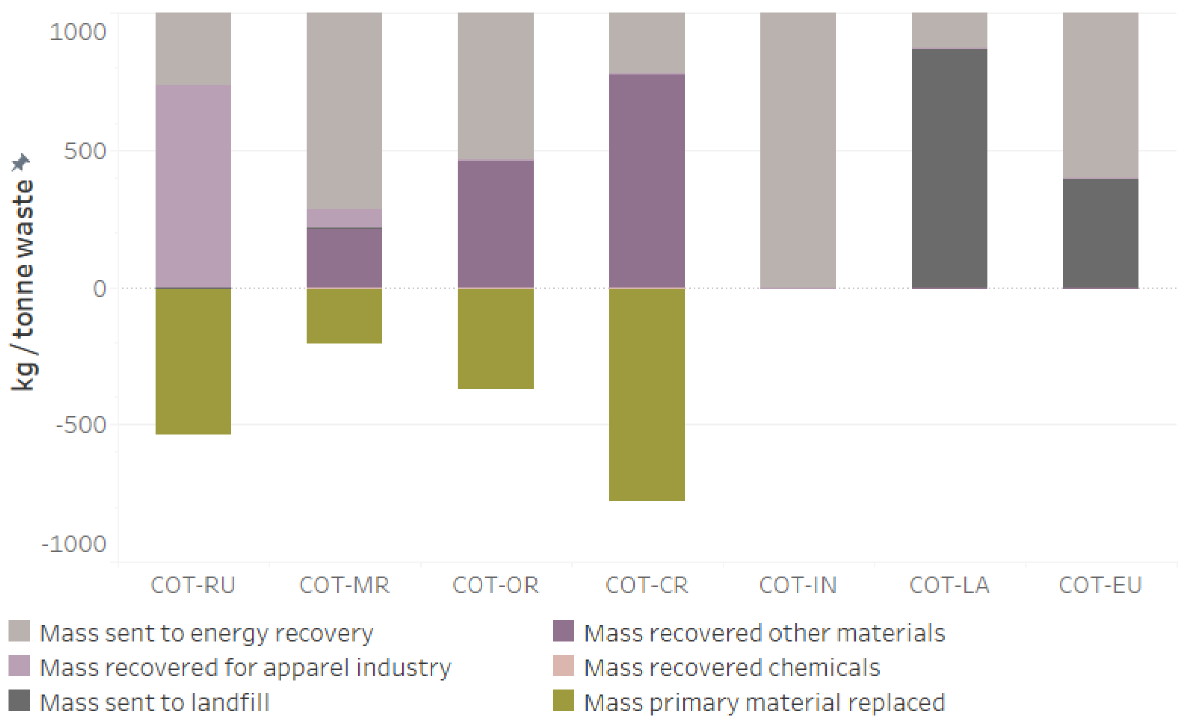
- For the direct incineration scenarios, the most important contribution to the burdens is the incineration process itself (combustion and related emissions), while the most important contribution to the savings is energy substitution. Notice that for Climate Change, the burdens from direct incineration (scenario namely IN) are always larger than the savings obtained via energy recovery and substitution (i.e. incineration burdens are much larger than energy substitution savings, leading to a net burden on Climate Change) for synthetic or mixed textiles (polyester, viscose and polycotton; PES, VIS, and PC). This is not the case for natural fibres like cotton (COT) given that the material is not originating from fossil fuels, but is short-lived biomass. This trend does not apply to the remaining environmental impact categories where typically the energy substitution savings are larger than the direct burdens from incineration. This is a known result in environmental assessment of waste management and it is due to the fact that flue-gas cleaning in EU incinerators has stricter emission limits than the EU average mix of energy (power or heat) plants. This means that currently, other than for CO_2 for which no emission control exists, air emissions are typically lower at the average EU incinerator relative to the average mix of EU (power or heat) plants, per kWh or MJ produced.

5.5.1.1 Cotton waste

Figure 16 showcases the mass balance resulting from the management of 1 tonne of cotton waste. Textile material recovery is maximised in re-use (RU) and mechanical recycling (MR) due to yields of second-hand textiles and spinnable fibres that could potentially replace virgin textiles and be used in the apparel or home textile sector, compared to the open-loop processes where such material quality is not recovered. However, open-loop recycling (OR) and chemical recycling (CR) achieve higher mass recovery overall.

The mass of primary material replaced is the highest in re-use, followed by open-loop recycling and chemical recycling, both with comparable results. Notice that, even though the products from mechanical recycling have a higher quality than those from open-loop recycling or chemical recycling, the mass of primary material replaced is lower for mechanical recycling due to the combined effect of: i) lower yield of spinnable fibres compared with secondary wipers in OR and pulp in CR and ii) lower potential to substitute virgin counterparts (substitution factors, estimated to 0.525 for spinnable fibres from MR, vs 0.8 for wipers and insulation-like recovered material in OR and CR, respectively; see Table 8).

Figure 16. Overview of mass balances and substitution potential of management pathways for used and waste textiles, in the investigated scenarios for the management of 1 tonne of cotton waste (COT) via re-use (RU), mechanical recycling (MR), open-loop recycling (OR: production of secondary wipers), chemical recycling via pulping (CR), incineration (IN), landfilling (LA) and combination of the last two (EU) (it is referred to Table 7 for a description of the different treatment scenarios and technologies). The data presented on the positive Y-axis indicate the mass partitioning of the textile material that is used as input materials for a management pathway. The number presented on the negative Y-axis indicates the amount of primary material that can be replaced, taken into consideration the material(s) generated at the output of the management pathway as well as its quality and potential to displace primary (virgin) materials. The category mass recovered textiles for apparel includes re-used textiles and spinnable fibres from mechanical recycling that could potentially be used in the apparel retail industry and contribute to avoiding production of virgin textiles. The category mass recovered other materials includes short fibres and other products (e.g., pulp, secondary wipers) that can replace other materials such as e.g., virgin cleaning cloths.



Source: adapted from Solis et al., in preparation.

Figure 17 shows that the management of cotton waste results in:

Climate Change: Net savings for re-use, mechanical recycling, open-loop recycling, chemical recycling, and incineration scenarios with re-use achieving by far the highest net saving. Among the recycling scenarios, mechanical recycling to fibers is preferred over open-loop recycling to secondary wipers and comparable to chemical recycling to pulp. Net burdens for landfilling and the EU average treatment scenario (mixed waste treatment) scenario. The uncertainties are about ±10-to-30% around the default value, depending upon scenario. Mechanical and chemical recycling pathways largely overlap.

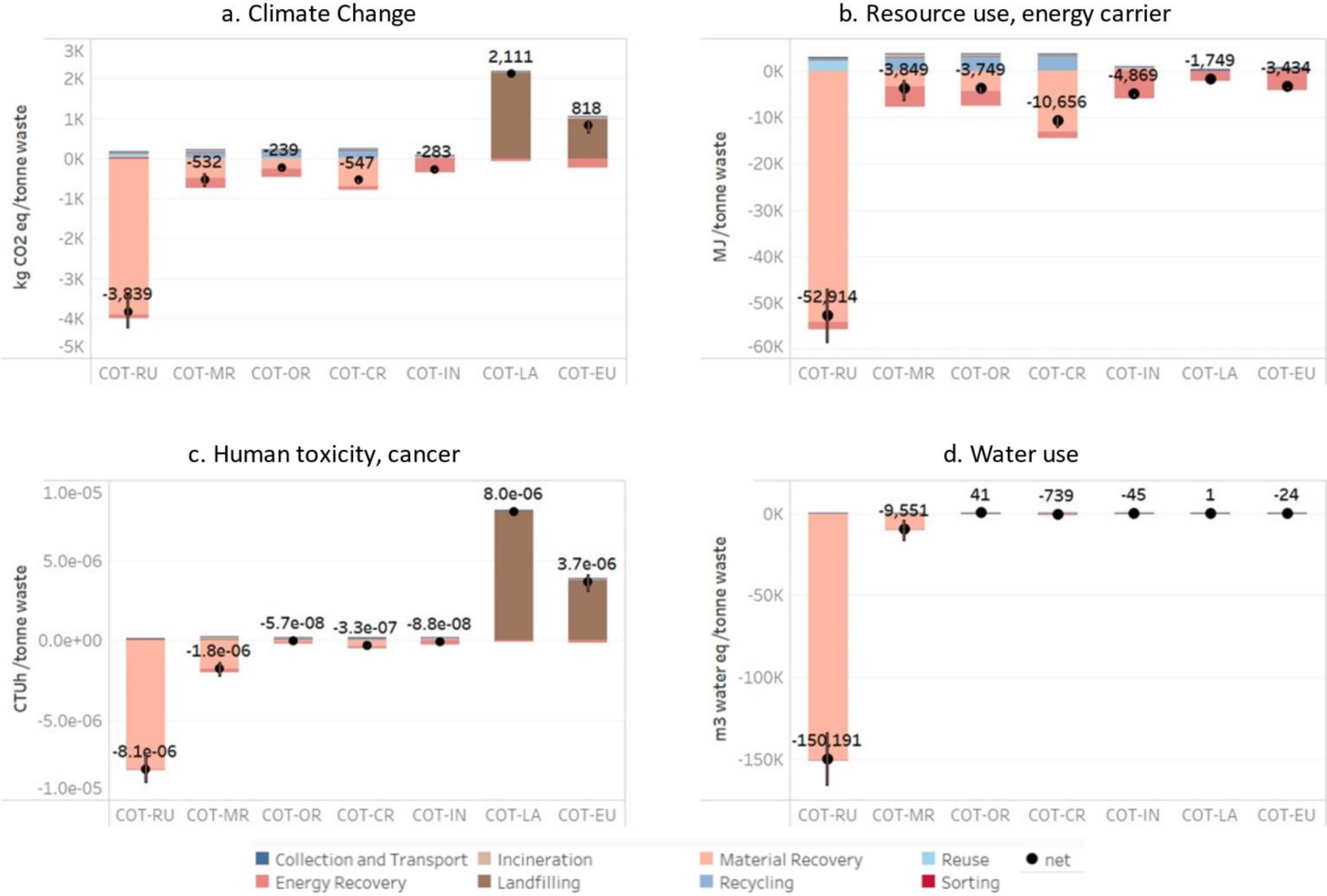
Resource Use, energy carrier: Net savings for all investigated scenarios. Re-use achieves incomparably the highest net saving. In this case direct incineration achieves slightly higher savings than mechanical and open-loop recycling thanks to energy recovery. The uncertainties are about ±2-to-60% around the default value, depending upon scenario.

Human toxicity, cancer: The trend follows results for Climate Change impact category. Net savings for re-use, recycling scenarios (mechanical recycling is best among the three recycling scenarios) and incineration, with re-use achieving by far the highest net saving. The remaining scenarios incur net burden with landfilling showing the highest one. The uncertainties are about ±10-to-35% around the default value, depending upon scenario.

Water Use: Net savings for all scenarios investigated except for open-loop recycling via production of secondary wipers. Re-use achieves by far the highest net saving followed by mechanical recycling. Savings from the remaining scenarios are of significantly lower order of magnitude compared to re-use and mechanical recycling. The uncertainties are about ±10-to-20% around the default value, depending upon scenario.

In general, across all impact categories the (data) parameters contributing the most to the total uncertainty are identified in substitution factors, shares of sorted waste sent to different treatment pathways, technology performance, and yields of most desirable products from the treatment pathways.

Figure 17. Management of 1 tonne of cotton waste (COT) via re-use (RU), mechanical recycling (MR), Open-loop recycling (OR: production of secondary wipers), chemical recycling via pulping (CR), incineration (IN), landfilling (LA) and combination of the last two (EU): Climate Change, Resource use, energy carrier, Human Toxicity, cancer, and Water use impact indicators. Negative values represent savings, while positive ones represent burdens. The error bar represents ± the standard deviation around the default value. See Table 7 for description of the different treatment scenarios and technologies.



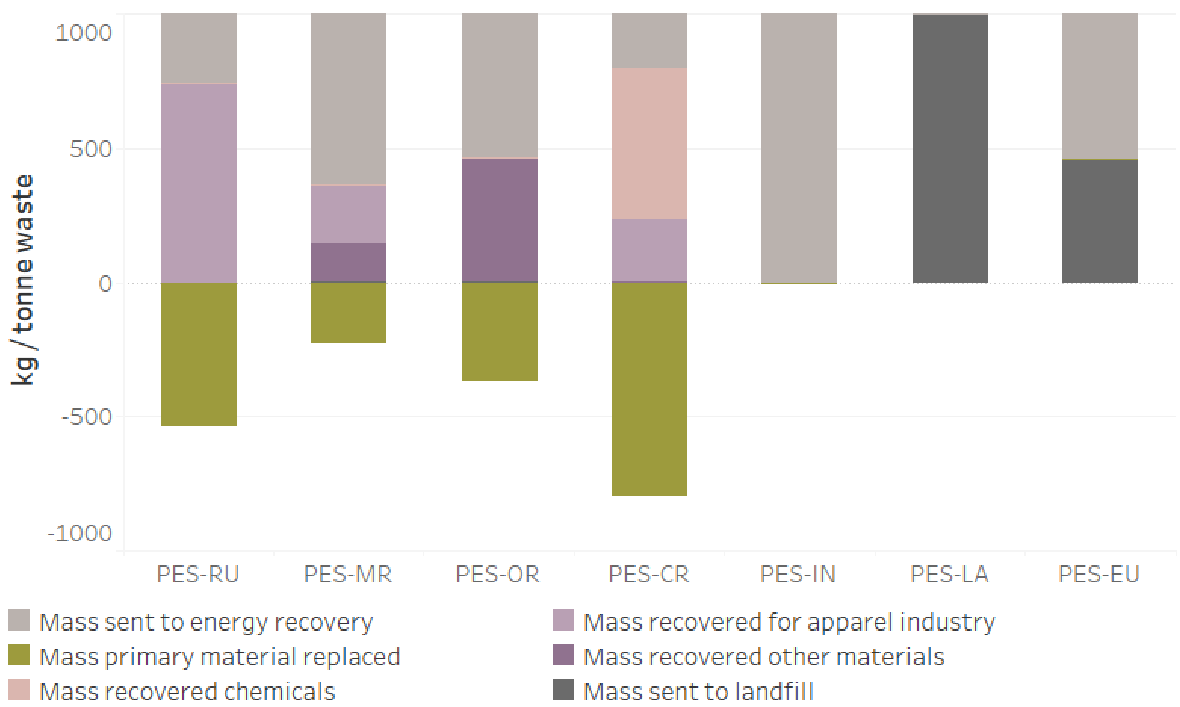
Source: adapted from Solis et al., in preparation.

5.5.1.2 Polyester waste

Figure 18 showcases the mass balance resulting from the management of 1 tonne of polyester waste. Textile material recovery is maximised in re-use and chemical recycling, due to yields of second-hand textiles and spinnable fibres that could potentially replace virgin textiles and be used in the apparel or home textile sector, compared to the open-loop recycling processes where such material quality is not recovered. Overall material recovery is maximised in re-use and chemical recycling followed by open-loop recycling and mechanical recycling.

The mass of primary material replaced is maximised in chemical recycling scenario, which suggests that the products from the process have the highest quality and thus the highest potential to replace their virgin counterparts.

Figure 18. Overview of mass balances and substitution potential of management pathways for used and waste textiles, in the investigated scenarios for the management of 1 tonne of polyester waste (PES) via re-use (RU), mechanical recycling (MR), Open-loop recycling (OR: production of synthetic granulate), chemical recycling via depolymerization (CR), incineration (IN), landfilling (LA) and combination of the last two (EU) (it is referred to Table 7 for a description of the different treatment scenarios and technologies). The data presented on the positive Y-axis indicate the mass partitioning of the textile material that is used as input materials for a management pathway. The number presented on the negative Y-axis indicates the amount of primary material that can be replaced, taken into consideration the material(s) generated at the output of the management pathway as well as its quality and potential to displace primary (virgin) materials. The category mass recovered textiles for apparel includes re-used textiles and spinnable fibres from mechanical recycling that could potentially be used in the apparel retail industry and contribute to avoiding production of virgin textiles. The category mass recovered other materials includes short fibres and other products (e.g., pulp, secondary wipers) that can replace other materials such as e.g., virgin cleaning cloths.



Source: adapted from Solis et al., in preparation.

Figure 19 shows that the management of 1 tonne of polyester waste results in:

Climate Change: Net savings for re-use and chemical recycling. Mechanical and open-loop recycling achieve net burdens because of lower material recovery yields relative to chemical recycling, which imply higher loss of material that is sent to incineration, incurring CO_2 emissions and related impacts. Incineration, landfilling, and the EU average (mixed waste treatment) scenario result in net burdens. The uncertainties are about ±2-to-80% around the default value, depending upon scenario.

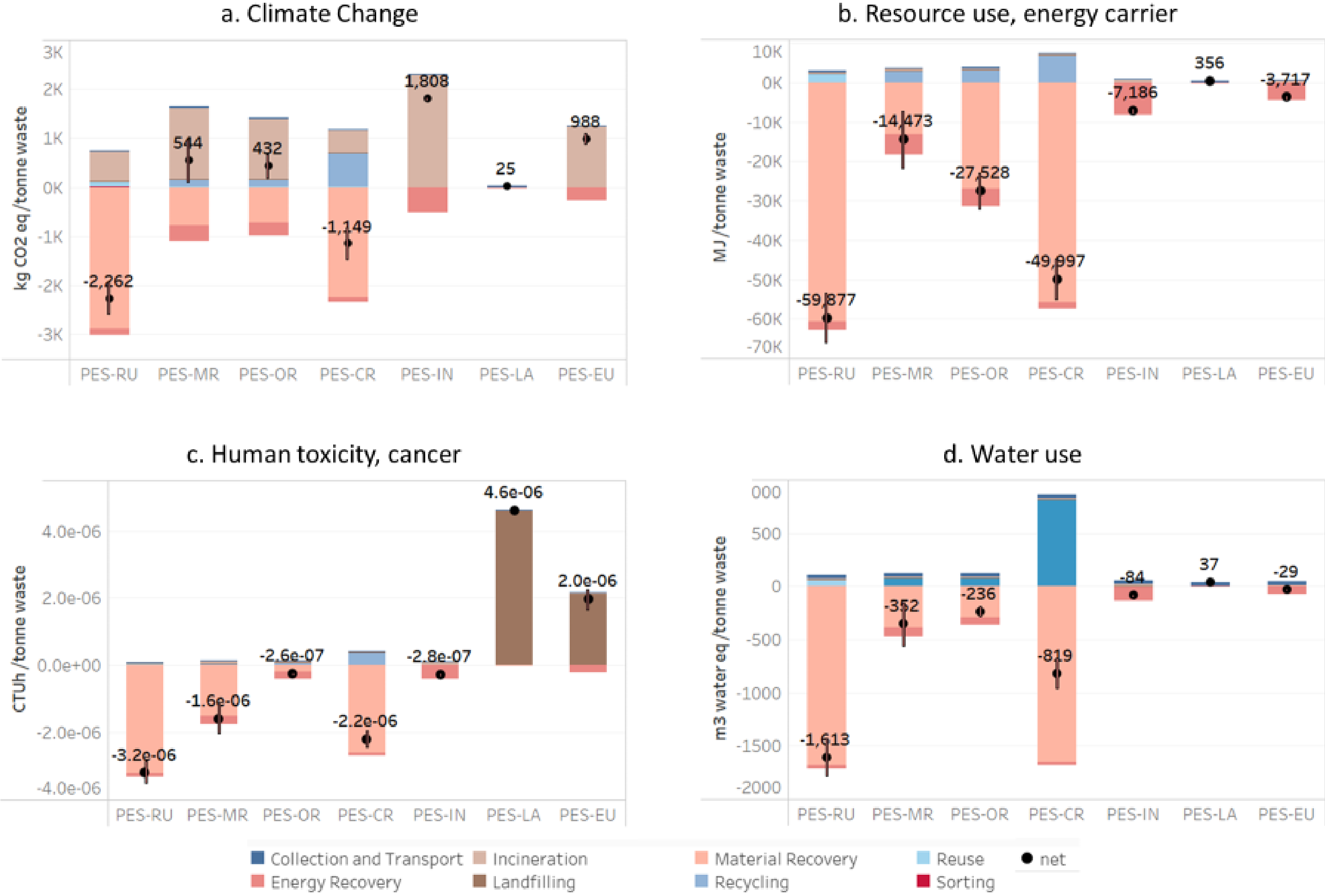
Resource Use, energy carrier: Net savings for all scenarios except for landfilling. Chemical recycling and re-use result in the highest net savings, with a similar order of magnitude, followed by open-loop recycling and mechanical recycling. The uncertainties are about ±10-to-50% around the default value, depending upon scenario.

Human toxicity, cancer: Net savings for re-use, all recycling pathways and incineration. Re-use and chemical recycling achieve the highest net savings. Landfilling incurs the highest burden, followed by the EU average (mixed waste treatment) scenario and incineration. The uncertainties are about ±10-to-30% around the default value, depending upon scenario.

Water Use: Net savings for all scenarios analysed except for landfilling. Re-use results in the highest net saving, followed by chemical recycling, mechanical and open-loop recycling. The uncertainties are about ±10-to-50% around the default value, depending upon scenario.

In general, across all impact categories the (data) parameters contributing the most to the total uncertainty are identified in substitution factors, shares of sorted waste sent to different treatment pathways, technology performance, and yields of most desirable products from the treatment pathways.

Figure 19. Management of 1 tonne of polyester waste (PES) via re-use (RU), mechanical recycling (MR), open-loop recycling (OR: production of synthetic granulate), chemical recycling via depolymerization (CR), incineration (IN), landfilling (LA) and combination of the last two (EU): Climate Change, Resource use, energy carrier, Human Toxicity, cancer, and Water use impact indicators. Negative values represent savings, while positive ones represent burdens. The error bar represents ± the standard deviation around the default value. See Table 7 for description of the different treatment scenarios and technologies.



Source: adapted from Solis et al., in preparation.

5.5.1.3 Wool waste

Figure 20 showcases the mass balance resulting from the management of 1 tonne of wool waste. Textile material recovery is maximised in re-use due to yields of second-hand textiles that could potentially replace virgin textiles and be used in the apparel and home textile sector, compared to the open-loop recycling processes where such material quality is not recovered. Overall material recovery and mass of primary material replaced are maximised in re-use followed by open-loop recycling.

Figure 20. Overview of mass balances and substitution potential of management pathways for used and waste textiles, in the investigated scenarios for the management of 1 tonne of wool waste (WOL) via re-use (RU), open-loop recycling (OR: production of secondary wipers), incineration (IN), landfilling (LA) and combination of the last two (EU) (it is referred to Table 7 for a description of the different treatment scenarios and technologies). The data presented on the positive Y-axis indicate the mass partitioning of the textile material that is used as input materials for a management pathway. The number presented on the negative Y-axis indicates the amount of primary material that can be replaced, taken into consideration the material(s) generated at the output of the management pathway as well as its quality and potential to displace primary (virgin) materials. The category mass recovered textiles for apparel includes re-used textiles and spinnable fibres from mechanical recycling that could potentially be used in the apparel retail industry and contribute to avoiding production of virgin textiles. The category mass recovered other materials includes short fibres and other products (e.g., pulp, secondary wipers) that can replace other materials such as e.g., virgin insulation.

Source: adapted from Solis et al., in preparation.

Figure 21 shows that the management of 1 tonne of wool waste results in:

Climate Change: Net savings for re-use, open-loop recycling, and incineration with re-use achieving by far the highest net saving. Net burdens for landfilling and the EU average treatment scenario (mixed waste treatment) scenario with landfilling incurring the highest net burden. The uncertainties are about ±10-to-20% around the default value, depending upon scenario.

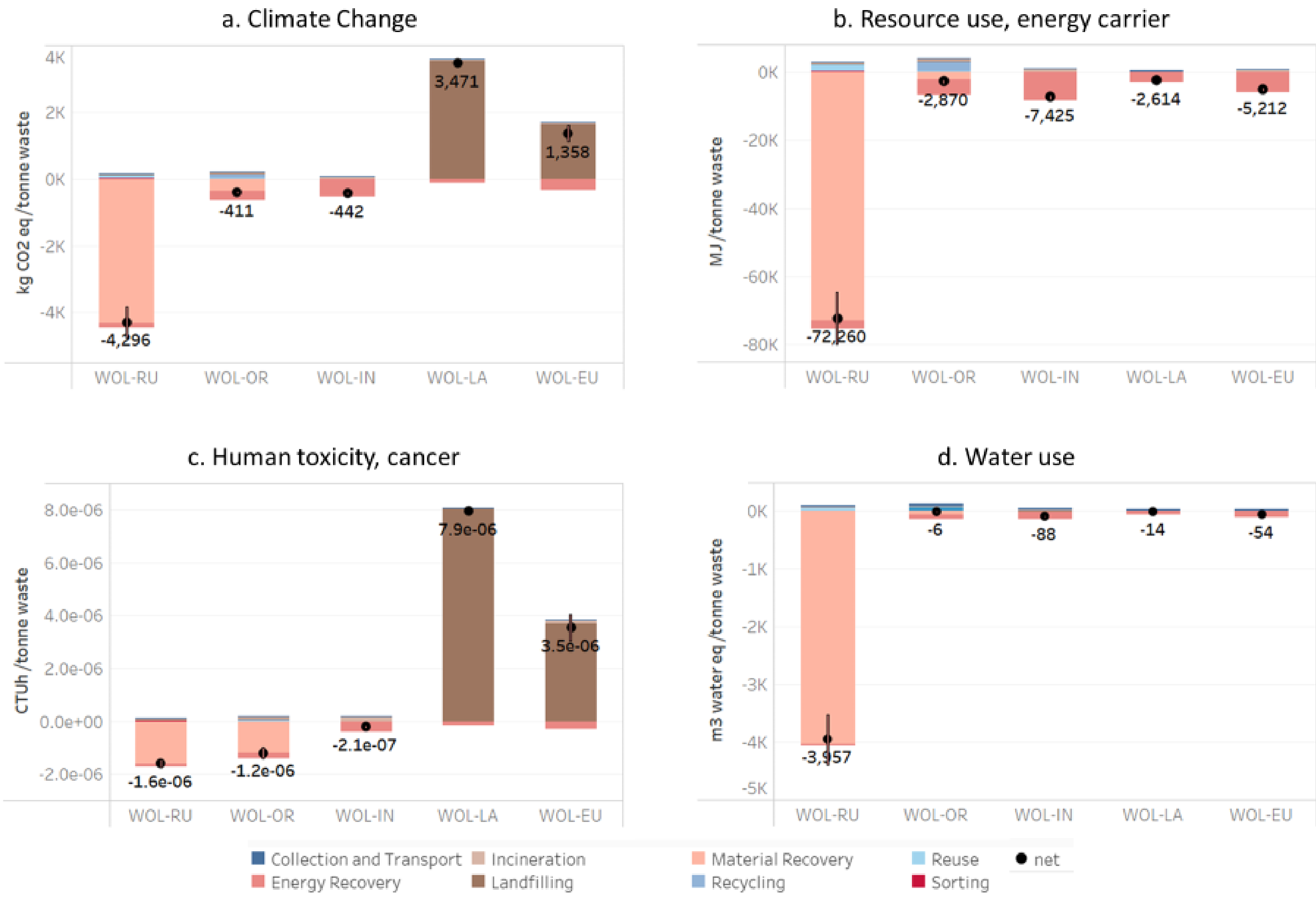
Resource Use, energy carrier: Net savings for all scenarios. Re-use result in by far the highest net savings, followed by incineration and open-loop recycling with results relatively close to 0. The uncertainties are about ±1-to-20% around the default value, depending upon scenario.

Human toxicity, cancer: Net savings for re-use, open-loop recycling, and incineration. Re-use achieves the highest net savings, closely followed by open-loop recycling. Landfilling incurs the highest burden, followed by the EU average (mixed waste treatment) scenario. The uncertainties are about ±10-to-20% around the default value, depending upon scenario.

Water Use: Net savings for all scenarios analysed. Re-use results in the highest net saving, all the other scenarios offer significantly lower savings with similar order of magnitude. The uncertainties are about ±10-to-15% around the default value, depending upon scenario.

In general, across all impact categories the (data) parameters contributing the most to the total uncertainty are identified in substitution factors, shares of sorted waste sent to different treatment pathways, technology performance, and yields of most desirable products from the treatment pathways.

Figure 21. Management of 1 tonne of wool waste (WOL) via re-use (RU), open-loop recycling (OR: production of secondary wipers), incineration (IN), landfilling (LA) and combination of the last two (EU): Climate Change, Resource use, energy carrier, Human Toxicity, cancer, and Water use impact indicators. Negative values represent savings, while positive ones represent burdens. The error bar represents ± the standard deviation around the default value. See Table 7 for description of the different treatment scenarios and technologies.

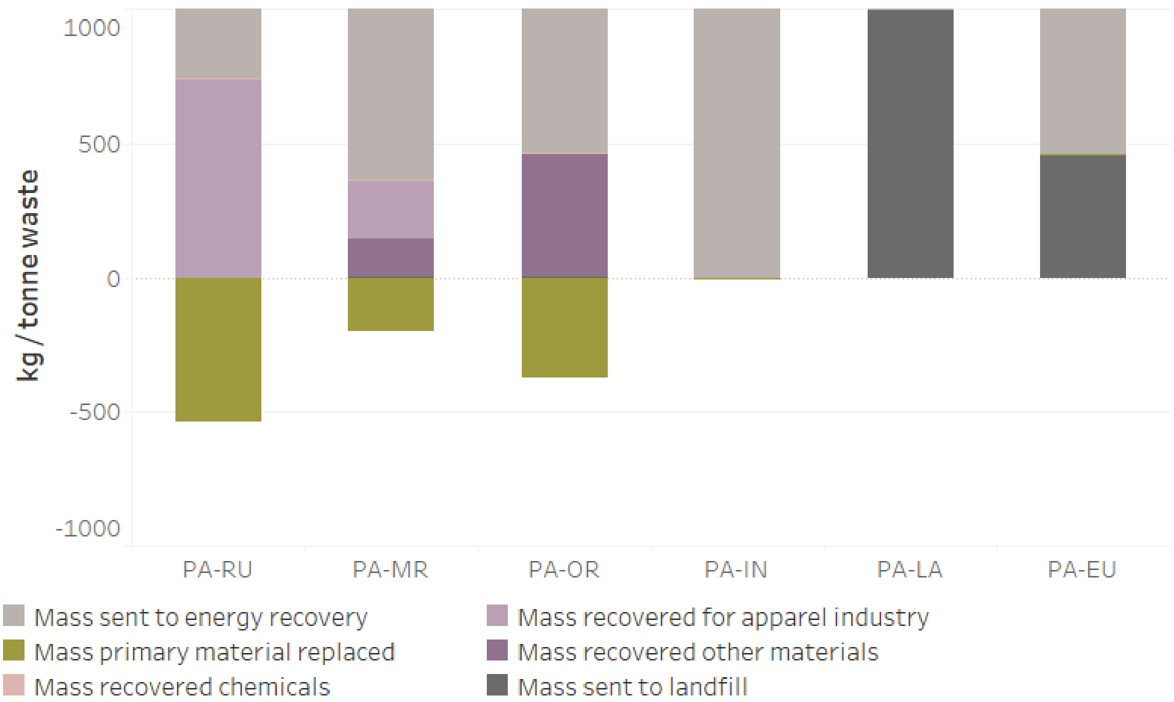


Source: adapted from Solis et al., in preparation.

5.5.1.4 Polyamide waste

Figure 22 showcases the mass balance resulting from the management of 1 tonne of polyamide waste. Textile material recovery is maximised in re-use and mechanical recycling due to yields of second-hand textiles and spinnable fibres that could potentially replace virgin textiles and be used in the apparel and home textile sector, compared to the open-loop recycling processes where such material quality is not recovered. Overall material recovery and mass of primary material replaced are maximised in re-use followed by open-loop recycling.

Figure 22. Overview of mass balances and substitution potential of management pathways for used and waste textiles, in the investigated scenarios for the management of 1 tonne of polyamide waste (PA) via re-use (RU), mechanical recycling (MR), open-loop recycling (OR: production of synthetic granulate), incineration (IN), landfilling (LA) and combination of the last two (EU) (it is referred to Table 7 for a description of the different treatment scenarios and technologies). The data presented on the positive Y-axis indicate the mass partitioning of the textile material that is used as input materials for a management pathway. The number presented on the negative Y-axis indicates the amount of primary material that can be replaced, taken into consideration the material(s) generated at the output of the management pathway as well as its quality and potential to displace primary (virgin) materials. The category mass recovered textiles for apparel includes re-used textiles and spinnable fibres from mechanical recycling that could potentially be used in the apparel retail industry and contribute to avoiding production of virgin textiles. The category mass recovered other materials includes short fibres and other products (e.g., pulp, secondary wipers) that can replace other materials such as e.g., virgin insulation.



Source: adapted from Solis et al., in preparation

Figure 23 shows that the management of 1 tonne of polyamide waste results in:

Climate Change: Net savings only for re-use. The lowest net burden for mechanical recycling followed by open-loop recycling. Incineration and the EU average treatment scenario (mixed waste treatment) scenario incur net burdens. The uncertainties are about ±10-to-145% around the default value, depending upon scenario.

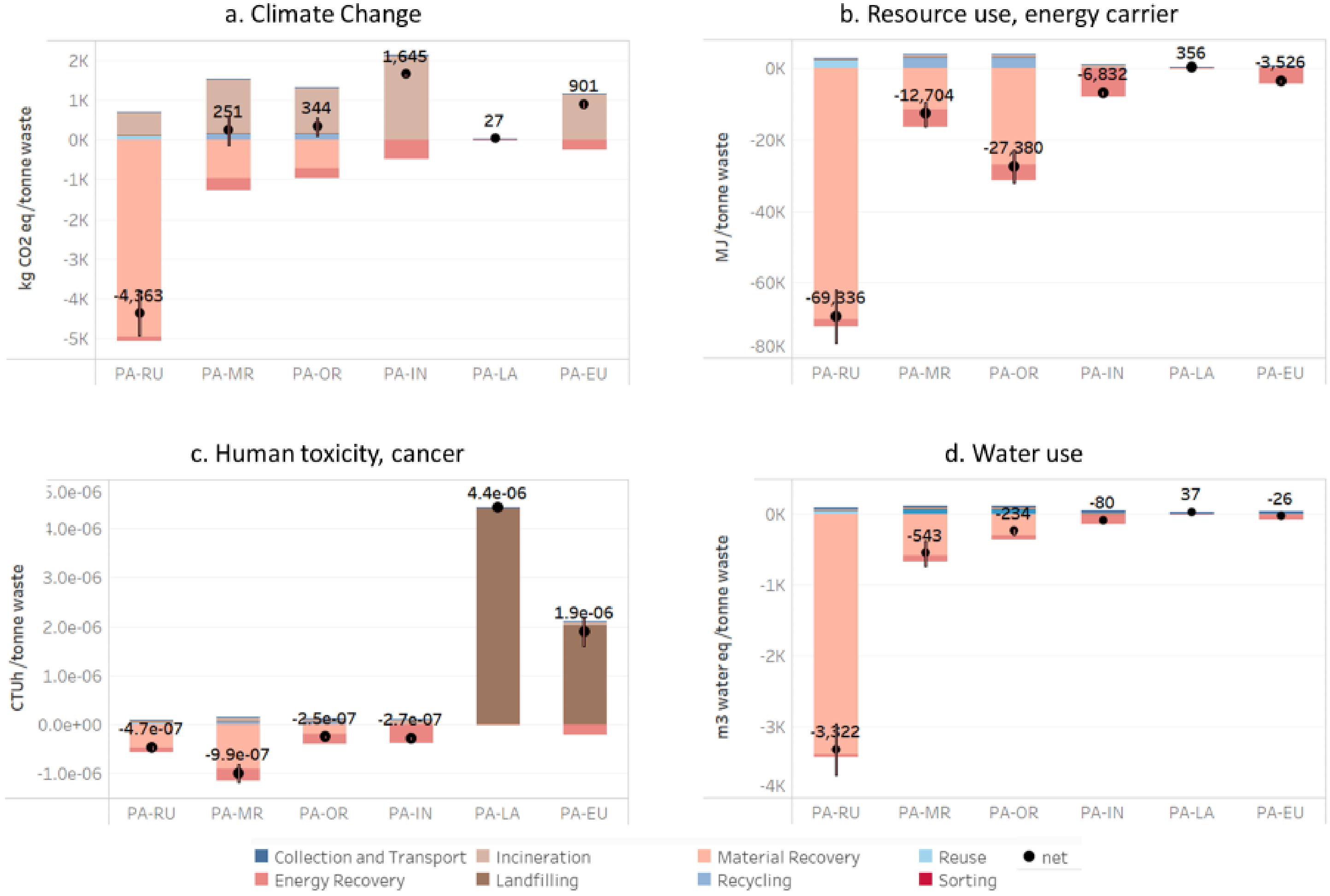
Resource Use, energy carrier: Net savings for all scenarios except for landfilling. Re-use results in by far the highest net savings, followed by open-loop, mechanical recycling, incineration, and EU average treatment scenario (mixed waste treatment). The uncertainties are about ±10-to-30% around the default value, depending upon scenario.

Human toxicity, cancer: Net savings for re-use, all recycling pathways, and incineration. Mechanical recycling achieves the highest net savings, followed by re-use. Landfilling incurs by far the highest burden, followed by the EU average (mixed waste treatment) scenario. The uncertainties are about ±10-to-20% around the default value, depending upon scenario.

Water Use: Net savings for all scenarios except for landfilling. Re-use results in the highest net saving, followed by mechanical and open-loop recycling. Incineration and the EU average (mixed waste treatment) scenario offer similar net savings, relatively close to 0. The uncertainties are about ±10-to-20% around the default value, depending upon scenario.

In general, across all impact categories the (data) parameters contributing the most to the total uncertainty are identified in substitution factors, shares of sorted waste sent to different treatment pathways, technology performance, and yields of most desirable products from the treatment pathways.

Figure 23. Management of 1 tonne of polyamide waste (PA) via re-use (RU), mechanical recycling (MR), Open-loop recycling (OR: production of synthetic granulate), chemical recycling via depolymerization (CR), incineration (IN), landfilling (LA) and combination of the last two (EU): Climate Change, Resource use, energy carrier, Human Toxicity, cancer, and Water use impact indicators. Negative values represent savings, while positive ones represent burdens. The error bar represents ± the standard deviation around the default value. See Table 7 for description of the different treatment scenarios and technologies.

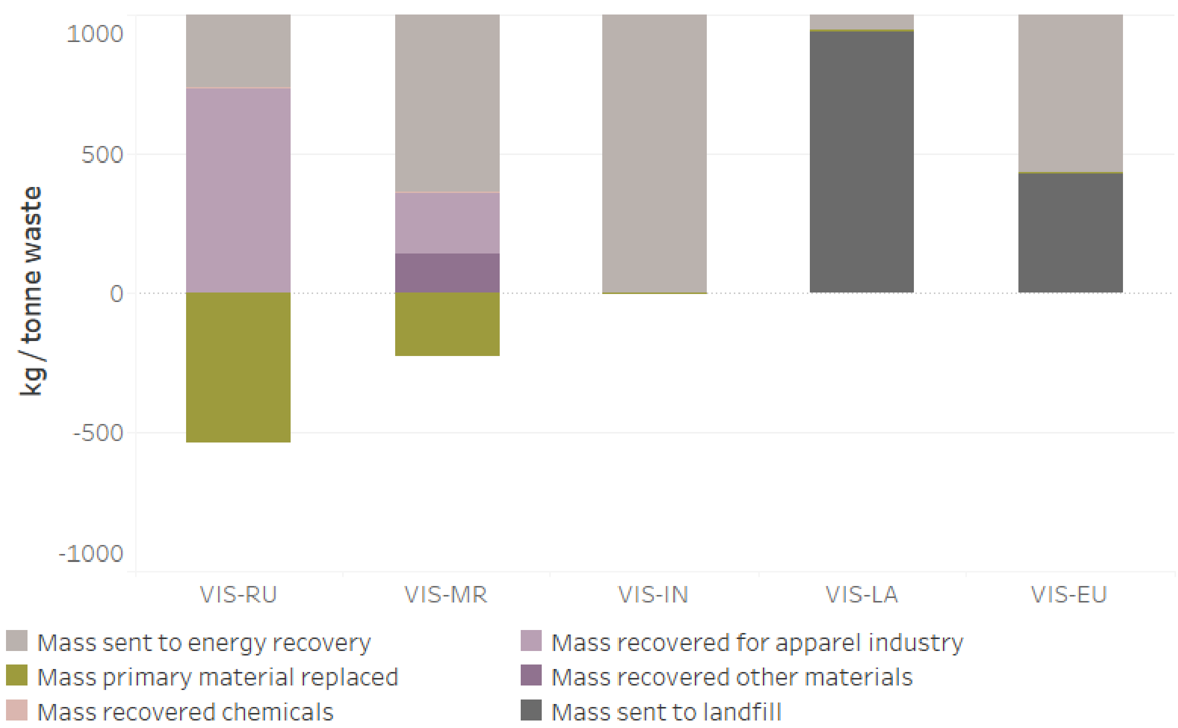


Source: adapted from Solis et al., in preparation.

5.5.1.5 Viscose waste

Figure 24 showcases the mass balance resulting from the management of 1 tonne of viscose waste. Textile material recovery is maximised in re-use and mechanical recycling due to yields of second-hand textiles and spinnable fibres that could potentially replace virgin textiles and be used in the apparel and home textile sector, compared to the open-loop recycling processes where such material quality is not recovered. The overall material recovery and the mass of primary material replaced are maximised in the re-use and mechanical recycling scenarios.

Figure 24. Overview of mass balances and substitution potential of management pathways for used and waste textiles, in the investigated scenarios for the management of 1 tonne of viscose waste (VIS) via re-use (RU), mechanical recycling (MR), incineration (IN), landfilling (LA) and combination of the last two (EU) (it is referred to Table 7 for a description of the different treatment scenarios and technologies). The data presented on the positive Y-axis indicate the mass partitioning of the textile material that is used as input materials for a management pathway. The number presented on the negative Y-axis indicates the amount of primary material that can be replaced, taken into consideration the material(s) generated at the output of the management pathway as well as its quality and potential to displace primary (virgin) materials. The category mass recovered textiles for apparel includes re-used textiles and spinnable fibres from mechanical recycling that could potentially be used in the apparel retail industry and contribute to avoiding production of virgin textiles. The category mass recovered other materials includes short fibres and other products (e.g., pulp, secondary wipers) that can replace other materials such as e.g., virgin insulation



Source: adapted from Solis et al., in preparation.

Figure 25 shows that the management of 1 tonne of viscose waste results in:

Climate Change: Net savings for re-use and mechanical recycling. Net burdens incurred by incineration (i.e. burden due to waste incineration exceeds savings from energy recovery; notice than viscose material contains a significant share of fossil carbon together with the biogenic one) the EU average treatment scenario (mixed waste treatment) scenario as well as landfilling. Notice that the degradation of viscose was assumed as for mixed textile waste and comparable to cellulosic/paper/cardboard materials[60]. The uncertainties are about ±2-to-80% around the default value, depending upon scenario.

Resource Use, energy carrier: Net savings for all scenarios analysed. Re-use results achieves by far the highest net savings, followed by mechanical recycling and incineration. Landfilling incurs the lowest net saving. The uncertainties are about ±10-to-50% around the default value, depending upon scenario.

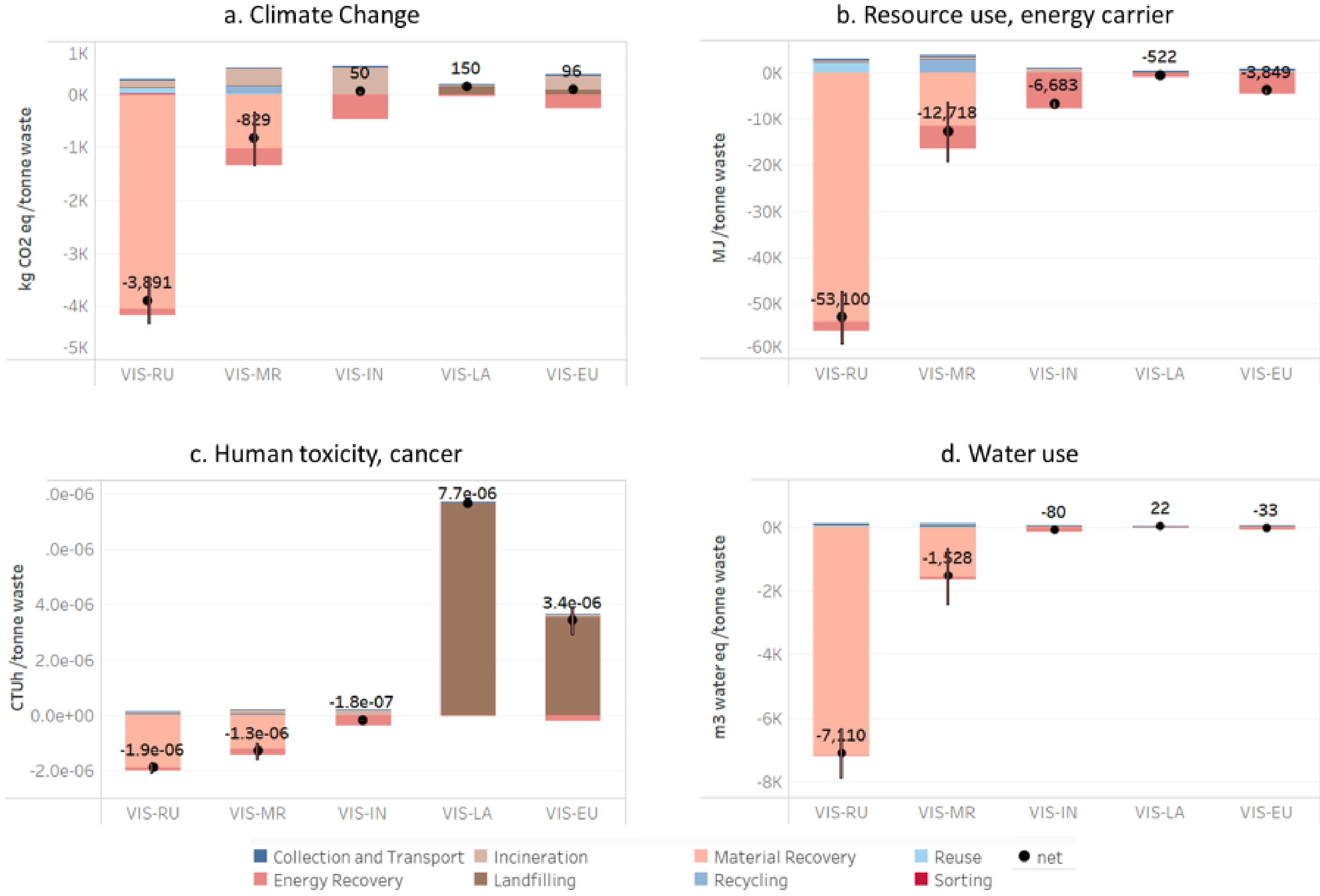
Human toxicity, cancer: Net savings for re-use, mechanical recycling, and incineration. Re-use results in the highest net savings followed by mechanical recycling and incineration. Landfilling results the highest net burden. The uncertainties are about ±10-to-25% around the default value, depending upon scenario.

Water Use: Net savings for all scenarios analysed except for landfilling. Re-use results in by far the highest net savings, followed by mechanical recycling and incineration which offer significantly lower savings than re-use. The uncertainties are about ±10-to-30% around the default value, depending upon scenario.

In general, across all impact categories the (data) parameters contributing the most to the total uncertainty are identified in substitution factors, shares of sorted waste sent to different treatment pathways, technology performance, and yields of most desirable products from the treatment pathways.

[60] The k-rate was 0.021 y^{-1} based on several studies by (Cruz and Barlaz, 2010), the report 'US EPA (2011) Final Background Information Document for Life-Cycle Inventory Landfill Process Model. U.S. Environmental Protection Agency, Air Pollution Prevention and Control Division, Office of Research and Development' provides decay rates (k rate as $year^{-1}$) for individual waste material fractions disposed in landfill, considering a time-horizon of 100y, for use in LCI.

Figure 25. Management of 1 tonne of viscose waste (VIS) via re-use (RU), mechanical recycling (MR), incineration (IN), landfilling (LA) and combination of the last two (EU): Climate Change, Resource use, energy carrier, Human Toxicity, cancer, and Water use impact indicators. Negative values represent savings, while positive ones represent burdens. The error bar represents ± the standard deviation around the default value. See Table 7 for description of the different treatment scenarios and technologies.

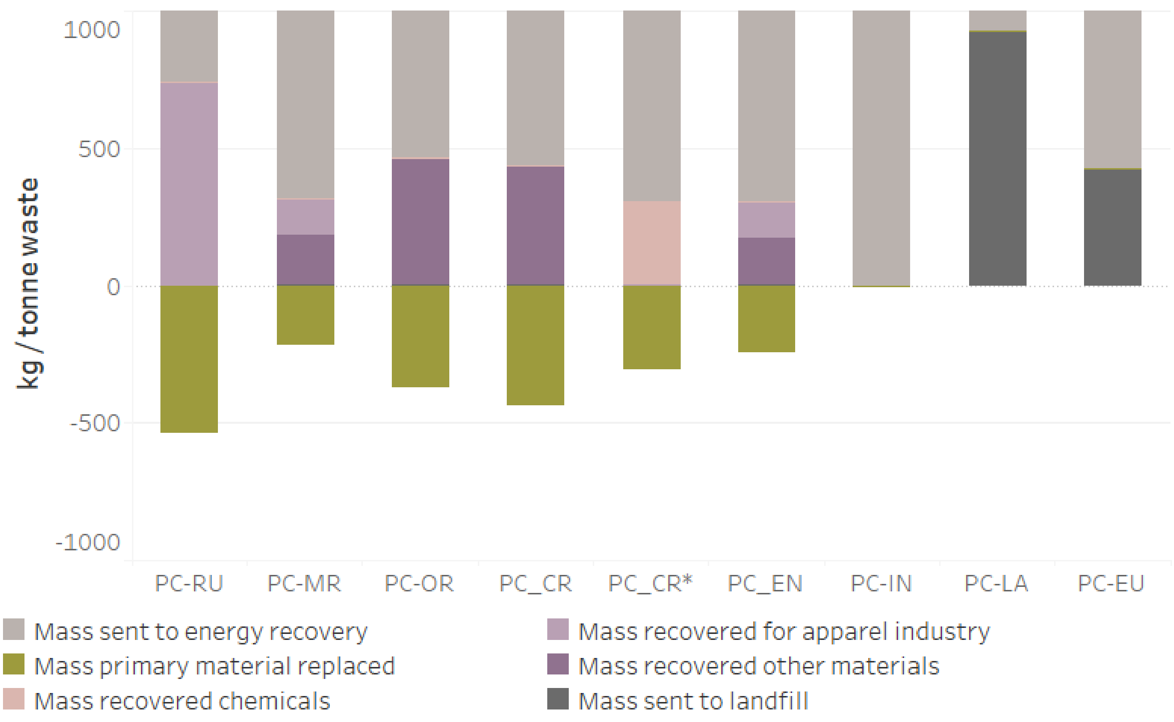


Source: adapted from Solis et al., in preparation.

5.5.1.6 Polycotton textile waste

Figure 26 showcases the mass balance resulting from the management of 1 t of polycotton waste. Textile material recovery is maximised in re-use and mechanical recycling due to yields of second-hand textiles and spinnable fibres that could potentially replace virgin textiles and be used in the apparel and home textile sector, compared to the open-loop recycling processes where such material quality is not recovered. The overall material recovery and the mass of primary material replaced are maximised in the re-use and dissolution (CR) scenarios.

Figure 26. An overview of mass balances in the investigated scenarios for the management of 1 tonne of polycotton waste (PC) via re-use (RU), mechanical recycling (MR), open-loop recycling (OR: production of insulation material), dissolution in two variants: 1) dissolution of cotton and recovery of polyester (CR) and 2) dissolution of polyester and recovery of cotton (CR*), enzymatic recycling (EN), incineration (IN), landfilling (LA) and combination of the last two (EU) (it is referred to Table 7 for a description of the different treatment scenarios and technologies). The category mass recovered textiles for apparel includes re-used textiles and spinnable fibers from mechanical recycling that could potentially be used in the apparel retail industry and contribute to avoiding production of virgin textiles. The category mass recovered other materials includes short fibers and other products (e.g. insulation material) that can replace other materials such as e.g. virgin insulation. The category mass primary material replaced shows to what extent the products from the selected scenarios can replace their virgin counterpart.



Source: adapted from Solis et al., in preparation.

Figure 27 shows that the management of 1 tonne of polycotton waste results in:

Climate Change: Net burdens for all analysed scenarios except for re-use and mechanical recycling with the highest net saving for re-use. The main burden in the open-loop recycling and dissolution (CR) scenarios stems from incineration of the losses originated from the low chemical recycling yield. These are sent to incineration together with the portion of polyester present in the mix, incurring GHG emissions but also savings via energy recovery (however GHG emissions >> GHG savings because of the large amount of synthetic textile incinerated). The burdens incurred by the dissolution* (CR*) and enzymatic recycling are significantly larger than from dissolution (CR) and are the highest from all scenarios. This is mainly due to high impact from recycling processes as they are energy intensive. Incineration incurs lower net burden than dissolution* and enzymatic recycling scenarios and results in the lowest net burden compared with the EU average treatment scenario (mixed waste treatment) scenario which has a similar result to dissolution (CR) and landfilling. The uncertainties are about ±5-to-300% around the default value, depending upon scenario.

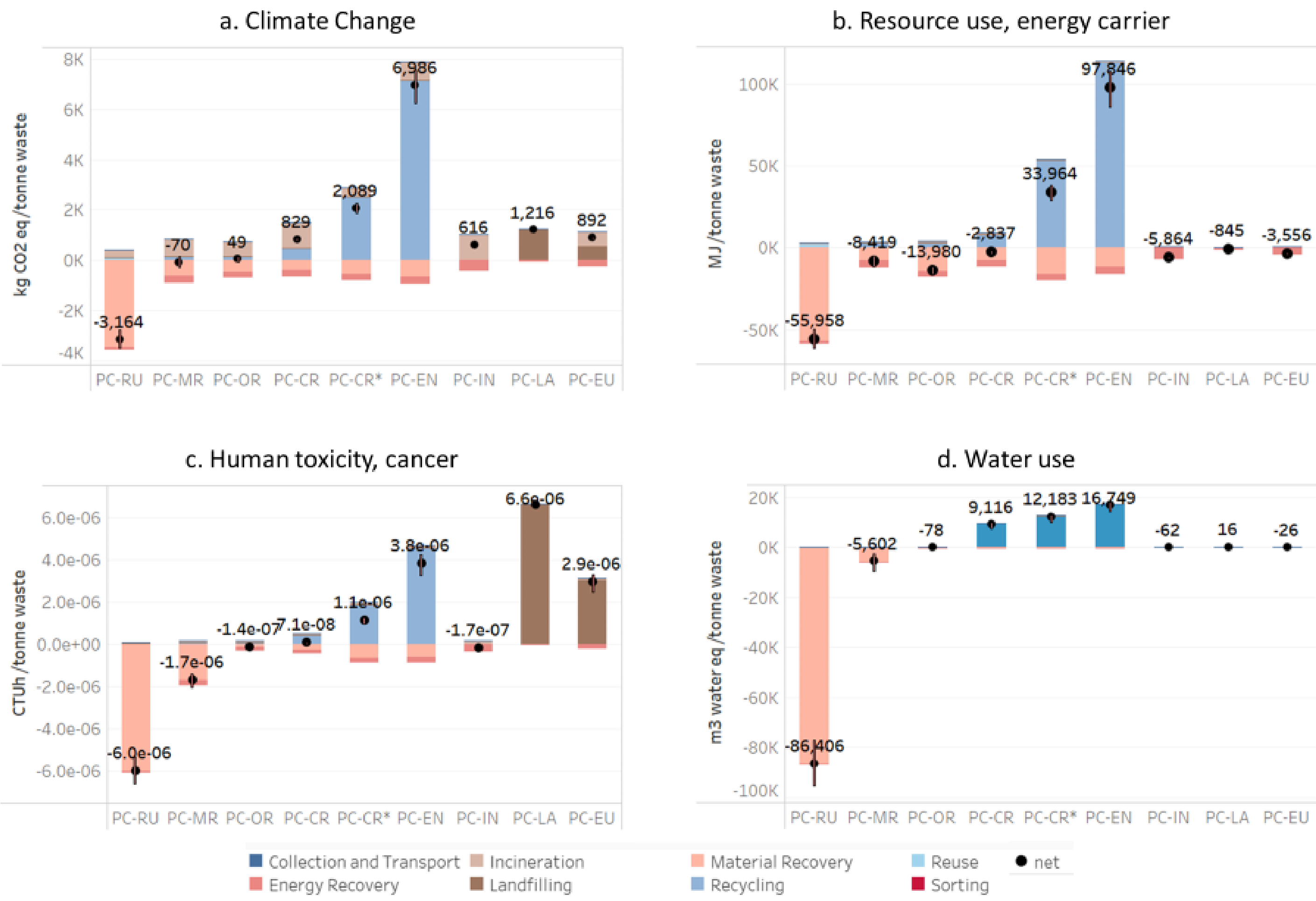
Resource Use, energy carrier: Net savings for all scenarios except for dissolution* (CR*) and enzymatic recycling. Enzymatic recycling incurs the highest net burden. The uncertainties are about ±10-to-40% around the default value, depending upon scenario.

Human toxicity, cancer: Re-use, mechanical recycling, open-loop recycling and incineration achieve net savings with re-use achieving by far the highest level. Landfilling incurs the highest net burden followed by enzymatic recycling, with the EU average treatment scenario (mixed waste treatment) scenario and dissolution* (CR*). The uncertainties are about ±10-to-70% around the default value, depending upon scenario.

Water Use: Net savings for re-use, mechanical recycling, open-loop recycling, incineration, and the EU average treatment scenario (mixed waste treatment) scenario. The highest net burden for enzymatic recycling followed by dissolution* (CR*) and dissolution (CR). Landfilling incurs a significantly lower net burden, relatively close to 0. The uncertainties are about ±10-to-400% around the default value, depending upon scenario.

In general, across all impact categories the (data) parameters contributing the most to the total uncertainty are identified in substitution factors, shares of sorted waste sent to different treatment pathways, technology performance, and yields of most desirable products from the treatment pathways.

Figure 27. Management of 1 tonne of polycotton waste (PC) through re-use (RU), mechanical recycling (MR), open-loop recycling (OR: production of insulation material), dissolution in two variants: 1) dissolution of cotton and recovery of polyester (CR) and 2) dissolution of polyester and recovery of cotton (CR*), enzymatic recycling (EN), incineration (IN), landfilling (LA) and combination of the last two (EU): Climate Change, Resource use, energy carrier, Human Toxicity, cancer, and Water use impact indicators. Negative values represent savings, while positive ones represent burdens. The error bar represents ± the standard deviation around the default value. See Table 7 for the description of the different treatment scenarios and technologies.



Source: adapted from Solis et al., in preparation.

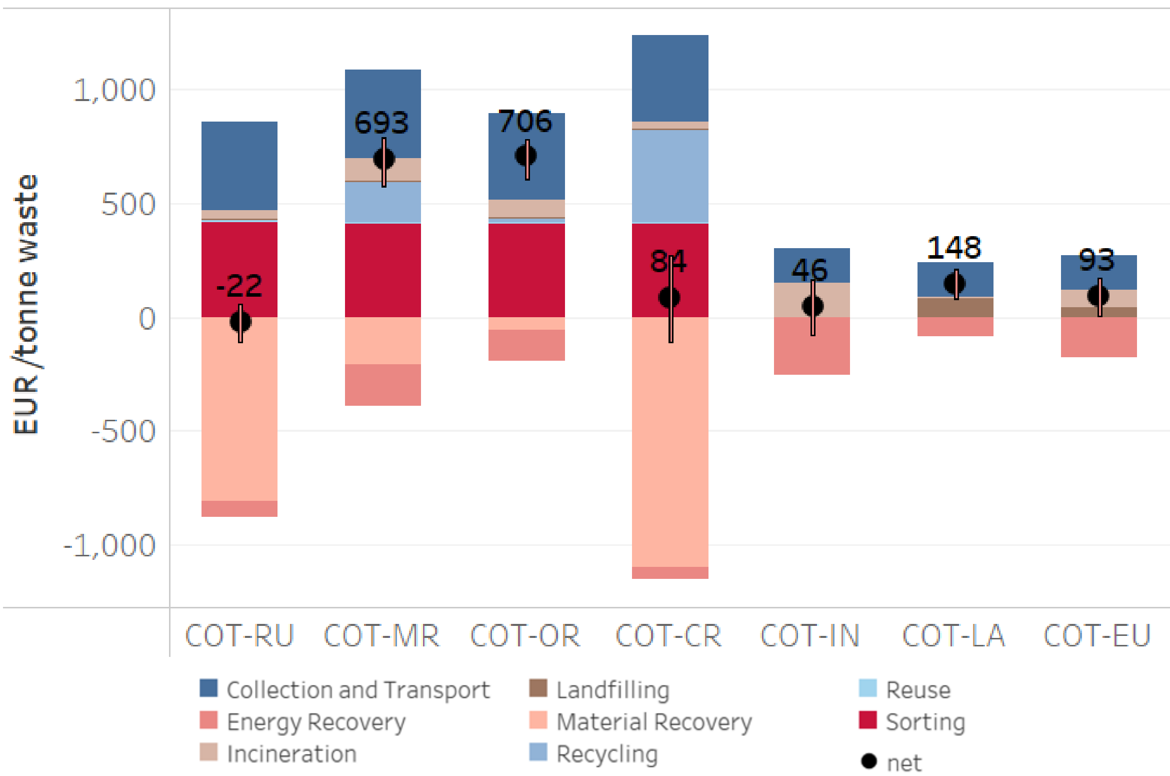
5.5.2 Life cycle costing of re-use, recycling, incineration, and landfilling scenarios

This section presents the preliminary results of the environmental life cycle costing (ELCC), which are expressed in EUR (€) per functional unit, i.e., one tonne of textile waste managed. The result at the scenario level is calculated as the difference between the sum of the costs associated to the management pathway and the revenues obtained from selling any products and co-products arising from that pathway. This is referred to as "net" in the discussion of the results. Cost contributions were aggregated into eight clusters, representing the main processes and activities of the investigated scenarios: collection and transport, sorting, re-use, recycling, incineration, landfilling, material recovery and energy recovery. Each category includes all the costs associated with CAPEX, OPEX and labour cost from a given process.

5.5.2.1 Cotton waste

Highlights: Re-use is the only scenario where revenues are higher than costs, i.e. a net income is achieved (Figure 28). All the remaining scenarios have net costs, i.e. revenues < management costs. Incineration, thanks to the revenues from energy recovery, and chemical recycling, because of high revenue from material recovery, are the cheapest scenarios. The mechanical and open-loop recycling scenarios achieve comparable costs in the range 693-706 EUR/tonne., with mechanical recycling slightly less expensive because of the higher revenues.

Figure 28. Environmental life cycle costs for the management of 1 tonne of cotton waste (COT) via re-use (RU), mechanical recycling (MR), open-loop recycling (OR: production of secondary wipers), chemical recycling via pulping (CR), incineration (IN) and landfilling (LA) as well as combination of the two last ones according to the EU average management of residual mixed (not separately collected) municipal waste (EU). The error bar represents ± the standard deviation around the default value. It is referred to Table 7 for a description of the different treatment scenarios and technologies.



Source: adapted from Solis et al., in preparation.

Key Cost Contributions: Collection and transport, recycling, incineration, and sorting are the most important contributions to the costs. Separate collection is about 1.5 time the cost of mixed collection (ca. 225 vs 150 EUR/tonne). Sorting, which is an additional step in separate collection relative to mixed collection, has a cost around 419 EUR/tonne, while recycling costs 20-408 EUR/tonne waste (notice that values are here reported per one tonne put into the process) depending upon the specific recycling technology. The most important contributions to the revenues are material and energy recovery. As indicated in

Figure 28, energy recovery revenues are significant even in recycling scenarios owing to the material losses during the process.

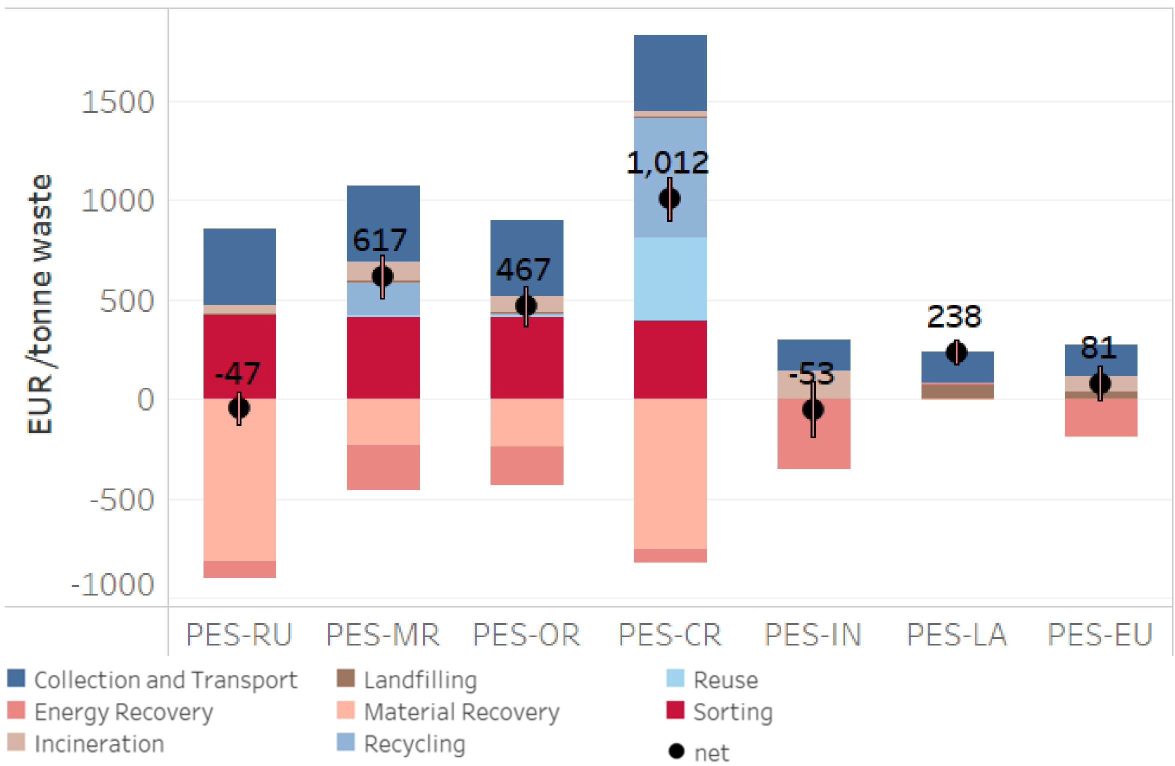
5.5.2.2 Polyester waste

Highlights: Re-use (RU) and incineration (IN) are the only scenarios where revenues are higher than costs (Figure 29). All the remaining scenarios have net costs, i.e. revenues < management costs. As for the recycling scenarios, open-loop recycling (OR) achieves the lowest net cost because of relatively low management cost. Landfilling (LA) is a net cost, though still lower than mechanical (MR) and open-loop recycling (OR).

Key Cost Contributions: Collection and transport, recycling, incineration, and sorting are the most important contributions to the costs. Separate collection is about 1.5 time the cost of mixed collection (ca. 225 vs 150 EUR/tonne). Sorting, which is an additional step in separate collection relative to mixed collection, has a cost around 419 EUR/tonne, while recycling costs 20-610 EUR/tonne (notice that values are here reported per one tonne put into the process) depending upon the specific recycling technology. The most important contributions to the revenues are material and energy recovery. As indicated in

Figure **29**, energy recovery revenues are significant even in recycling scenarios owing to the material losses during the process. For chemical recycling via depolymerization, the revenues from TPA and EG recovery are significant compared to the revenues from material recovery in the other recycling pathways. This is a result of higher yields and unit-price taken for the material sale.

Figure 29. Environmental life cycle costs for the management of 1 tonne of polyester waste (PES) via re-use (RU), mechanical recycling (MR), open-loop recycling (OR: production of synthetic granulate), chemical recycling via depolymerization (CR), incineration (IN) and landfilling (LA) as well as combination of the two last ones according to the EU average management of EU average management of residual mixed (not separately collected) municipal waste (EU). The error bar represents ± the standard deviation around the default value. It is referred to Table 7 for a description of the different treatment scenarios and technologies.



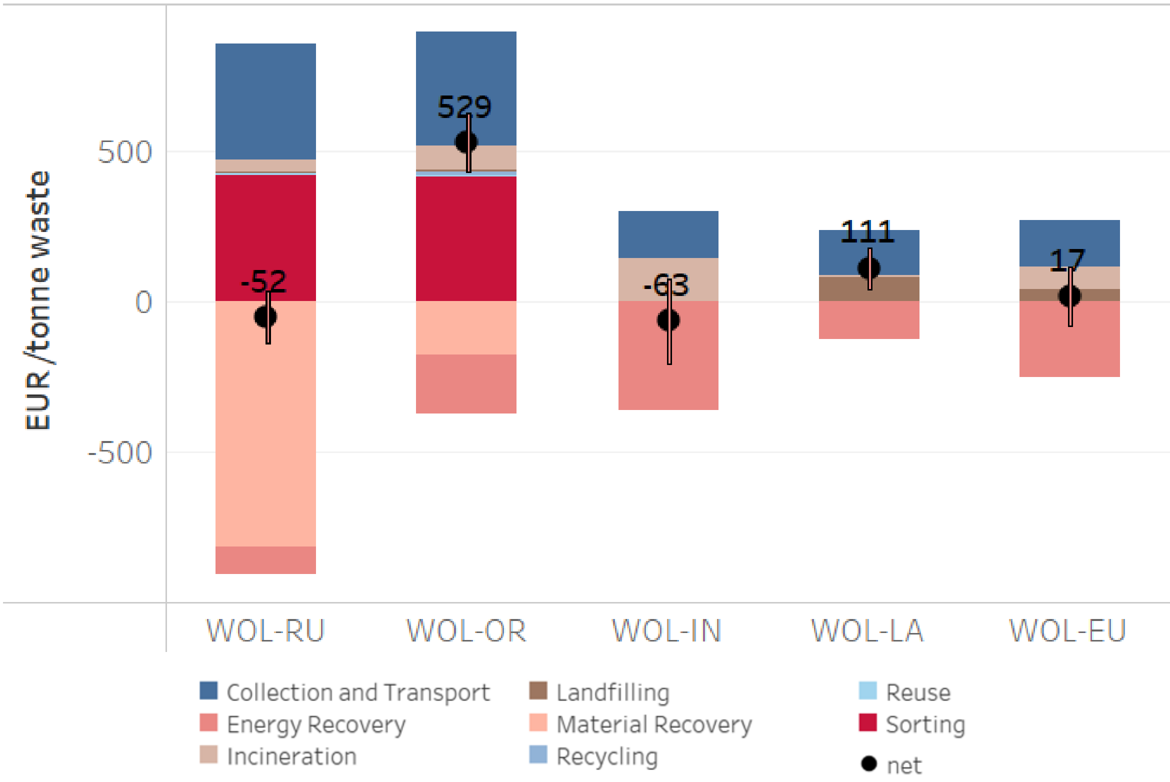
Source: adapted from Solis et al., in preparation.

5.5.2.3 Wool waste

Highlights: Re-use (RU) and incineration (IN) are the only scenarios where revenues are higher than costs (Figure 30). All the remaining scenarios have net costs, i.e. revenues < management costs. As for the recycling scenarios, open-loop recycling (OR) has higher net cost (almost 5 times) than landfilling (LA).

Key Cost Contributions: Collection and transport, recycling, incineration, and sorting are the most important contributions to the costs. Separate collection is about 1.5 time the cost of mixed collection (ca. 225 vs 150 EUR/tonne). Sorting, which is an additional step in separate collection relative to mixed collection, has a cost around 419 EUR/tonne, while open-loop recycling costs around 20 EUR/tonne (notice that values are here reported per one tonne put into the process). The most important contributions to the revenues are material and energy recovery (Figure 30).

Figure 30. Environmental life cycle costs for the management of 1 tonne of wool waste (WOL) via re-use (RU), open-loop recycling (OR: production of secondary wipers), incineration (IN) and landfilling (LA) as well as combination of the two last ones according to the EU average management of residual mixed (not separately collected) municipal waste (EU). The error bar represents ± the standard deviation around the default value. It is referred to Table 7 for a description of the different treatment scenarios and technologies.



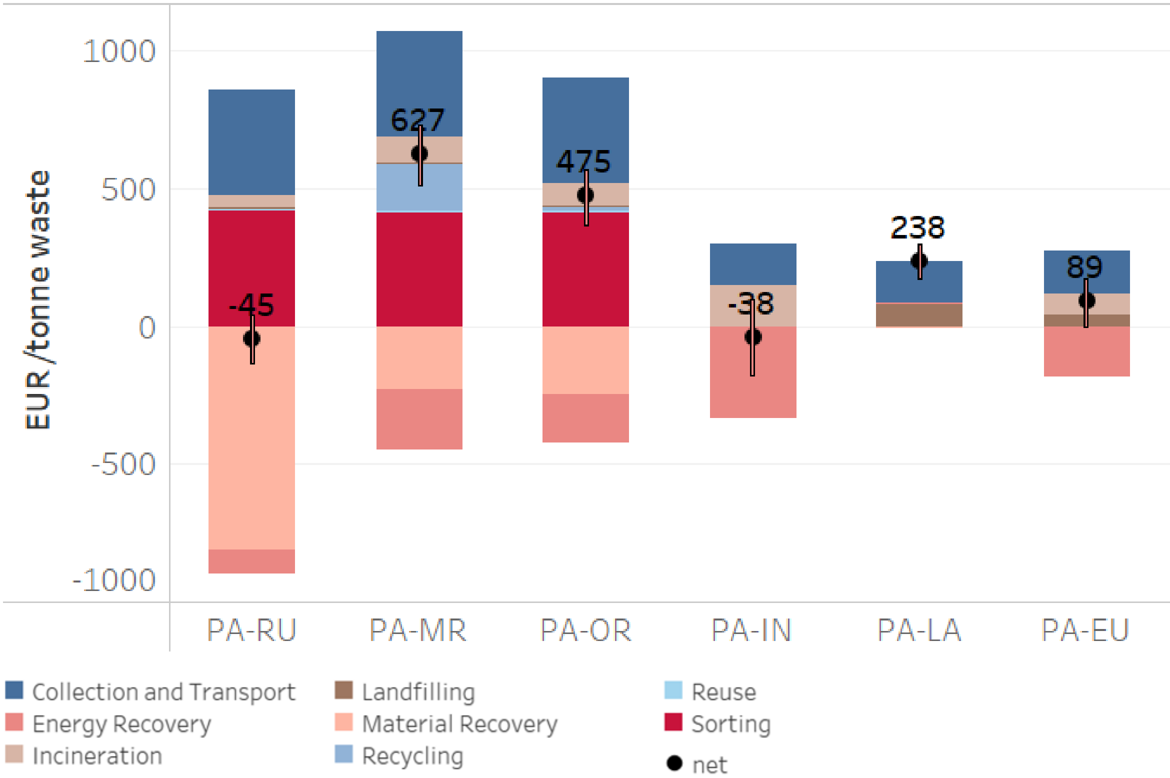
Source: adapted from Solis et al., in preparation.

5.5.2.4 Polyamide waste

Highlights: Re-use (RU) and incineration (IN) are the only scenarios where revenues are higher than costs (Figure 31). All the remaining scenarios have net costs, i.e. revenues < management costs. As for the recycling scenarios, mechanical (MR) and open-loop recycling (OR) have higher net cost (about 2.5 and 2 times respectively) than landfilling (LA).

Key Cost Contributions: Collection and transport, recycling, incineration, and sorting are the most important contributions to the costs. Separate collection is about 1.5 time the cost of mixed collection (ca. 225 vs 150 EUR/tonne). Sorting, which is an additional step in separate collection relative to mixed collection, has a cost around 419 EUR/tonne, while mechanical recycling costs around 177 EUR/tonne (notice that values are here reported per one tonne put into the process). The most important contributions to the revenues are material and energy recovery. Energy recovery revenues are significant even in the mechanical recycling scenario owing to the material losses during the process (Figure 31).

Figure 31. Environmental life cycle costs for the management of 1 tonne of polyamide waste (PA) via re-use (RU), mechanical recycling (MR), open-loop recycling (OR: production of synthetic granulate), incineration (IN) and landfilling (LA) as well as combination of the two last ones according to the EU average management of residual mixed (not separately collected) municipal waste (EU). The error bar represents ± the standard deviation around the default value. It is referred to Table 7 for a description of the different treatment scenarios and technologies.



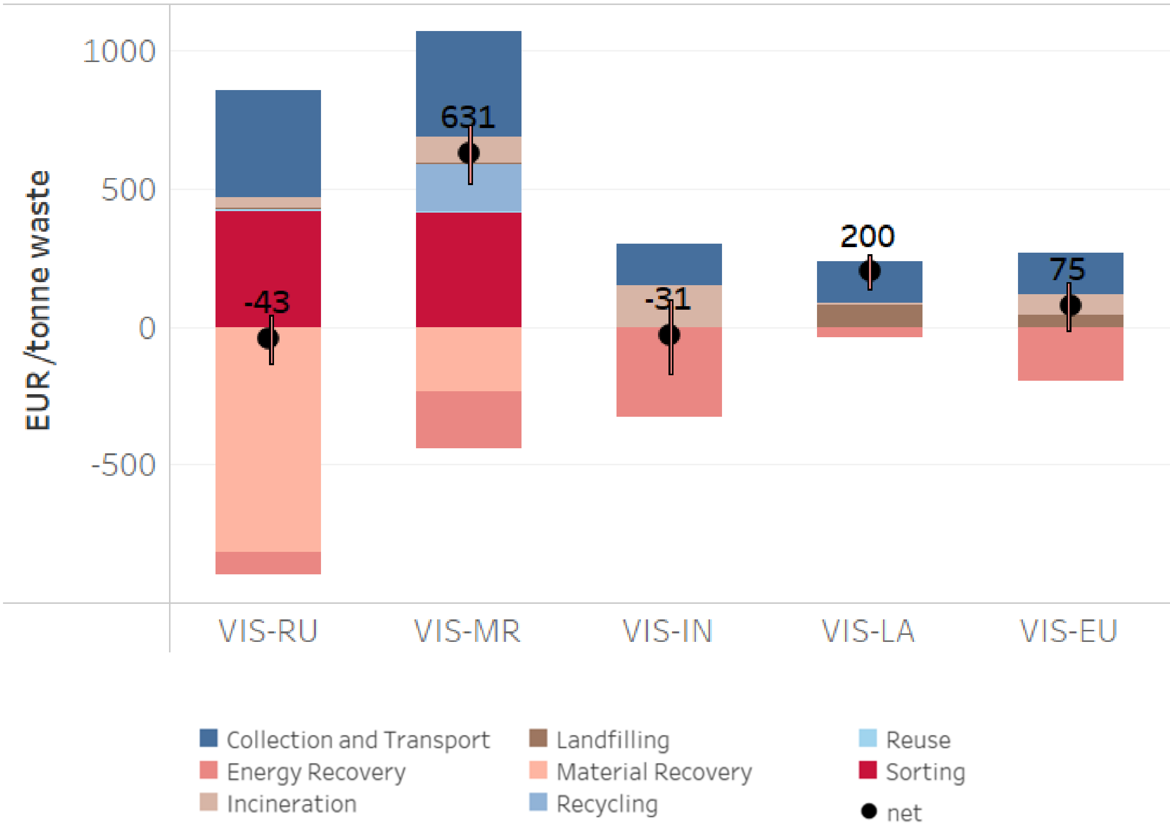
Source: adapted from Solis et al., in preparation.

5.5.2.5 Viscose waste

Highlights: Re-use (RU) and incineration (IN) are the only scenarios where revenues are higher than costs (Figure 32). All the remaining scenarios have net costs, i.e. revenues < management costs. As for the recycling scenarios, mechanical recycling (MR) has higher net cost (about 3 times) than landfilling (LA).

Key Cost Contributions: Collection and transport, recycling, incineration, and sorting are the most important contributions to the costs. Separate collection is about 1.5 time the cost of mixed collection (ca. 225 vs 150 EUR/tonne). Sorting, which is an additional step in separate collection relative to mixed collection, has a cost around 419 EUR/tonne, while mechanical recycling costs around 177 EUR/tonne (notice that values are here reported per one tonne put into the process). The most important contributions to the revenues are material and energy recovery. As indicated in Figure 32, energy recovery revenues are significant even in the mechanical recycling scenario owing to the material losses during the process.

Figure 32. Environmental life cycle costs for the management of 1 tonne of viscose waste via re-use (RU), open-loop recycling (OR: production of synthetic granulate), incineration (IN) and landfilling (LA) as well as combination of the two last ones according to the EU average management of residual mixed (not separately collected) municipal waste (EU). The error bar represents ± the standard deviation around the default value. It is referred to Table 7 for a description of the different treatment scenarios and technologies.



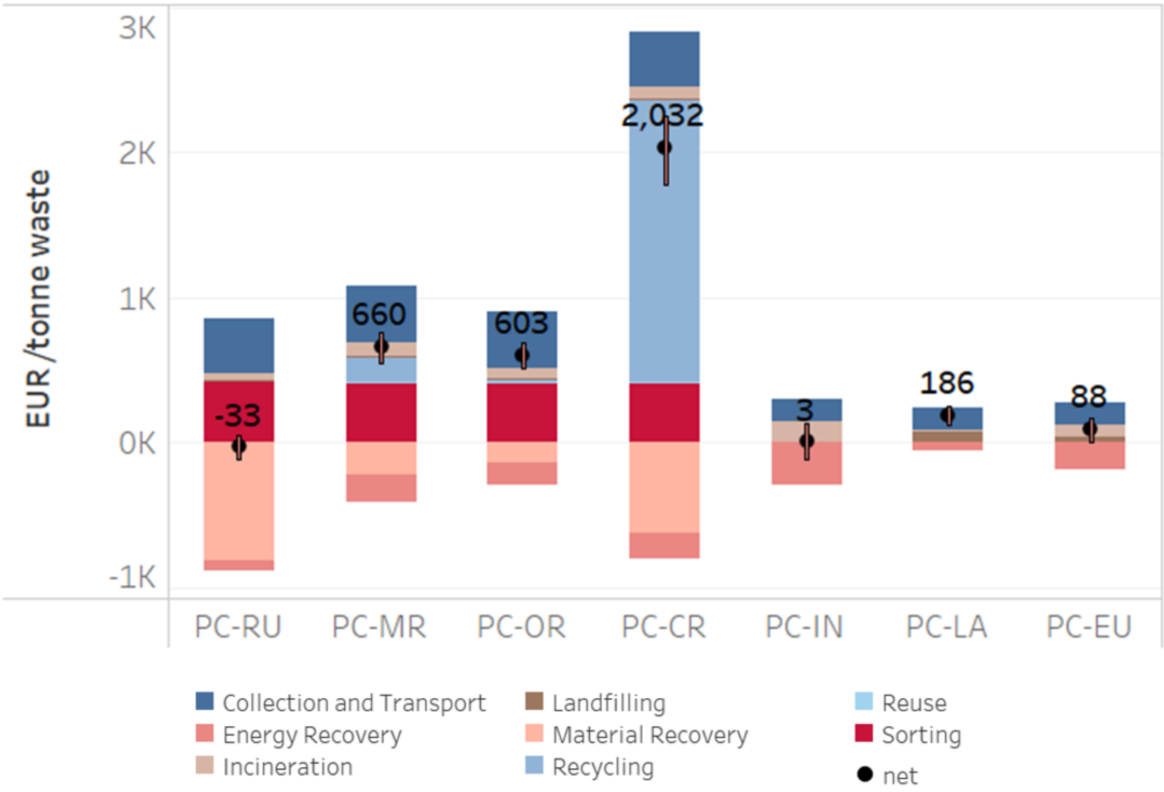
Source: adapted from Solis et al., in preparation.

5.5.2.6 Polycotton waste

Highlights: Only re-use (RU) in net cost savings (Figure 33), i.e. revenues are higher than the costs. Incineration (IN) achieves the lowest net cost (slightly above zero), while enzymatic recycling (EN) results in the highest net cost, about 327-fold the cost of landfilling (LA).

Key Cost Contributions: Collection and transport, recycling, incineration, and sorting are the most important contributions to the costs. Separate collection is about 1.5 time the cost of mixed collection (ca. 225 vs 150 EUR/tonne). Sorting, which is an additional step in separate collection relative to mixed collection, has a cost around 419 EUR/tonne, while chemical recycling around 60 500 EUR/tonne (notice that values are here reported per one tonne put into the process). The most important contributions to the revenues are material and energy recovery. As indicated in Figure 33, energy recovery revenues are significant even in the recycling scenario owing to the material losses during the process.

Figure 33. Environmental life cycle costs for the management of 1 tonne of polycotton waste (PC) through re-use (RU), mechanical recycling (MR), open-loop recycling (OR: production of insulation material), dissolution of cotton and recovery of polyester (CR) incineration (IN) and landfilling (LA) as well as combination of the two last ones according to the EU average management of residual mixed (not separately collected) municipal waste (EU). The error bar represents ± the standard deviation around the default value. It is referred Table 7 for a description of the different treatment scenarios and technologies. (Source: adapted from Solis et al., in preparation). Note that dissolution of polyester and recovery of cotton (CR*, EUR 3 628) and enzymatic recycling (EN, EUR 60 858) are not represented in the Figure because out of scale.



Source: adapted from Solis et al., in preparation.

5.5.3 Full environmental life cycle costing of re-use, recycling, incineration, and landfilling scenarios

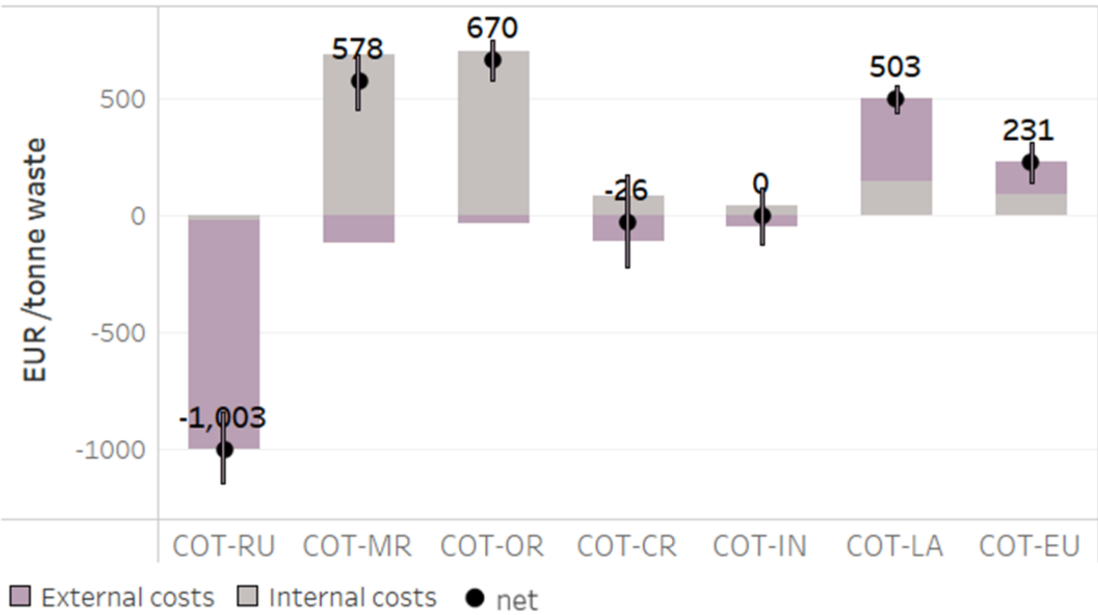
This section presents the preliminary results of the full environmental life cycle costing (fELCC), which are expressed in EUR (€) per functional unit, i.e., one tonne (t) of textile waste input including impurities. Positive contributions reflect induced costs, while negative contributions reflect revenues and avoided external costs. The result at the scenario level is calculated as the difference between the sum of the (internal and external) costs associated to the management pathway and the sum of the revenues and avoided external costs. This is referred to as "net" in the discussion of the results. Notice also that internal and external costs are herein illustrated as aggregated (e.g. the internal cost reported in the figures herein represents the total sum of internal costs and revenues, minus taxes, for that pathway). This also means that, e.g. when the internal costs (blue stack) are negative, a net income is expected for that management scenario. This approximately[61] corresponds to the 'net' reported for ELCC in section 5.6.

5.5.3.1 Cotton waste

Highlights: Re-use (RU) and chemical recycling (CR) incur net savings (revenues > costs) (Figure 34). Incineration (IN) shows net cost equal to zero which means that revenues = costs. Mechanical (MR) and open-loop recycling (OR) recycling scenarios incur net costs as the net internal costs are not sufficiently compensated by the (avoided) externalities from (avoided) primary production. The full environmental cost of landfill (LA) is the highest and, relative to the ELCC, is significantly increased because of the external costs related to fugitive (mainly methane) emissions.

Key Cost Contributions: The detailed breakdown of the internal costs has been described in section 5.6. The external costs are driven by CO_2 emissions to a large extent. Notice that the cost of landfilling also includes the landfill tax, which is therefore here considered in addition to the environmental emissions externalities (in purple).

Figure 34. Full environmental life cycle costs for the management of 1 tonne of cotton waste via re-use (RU), mechanical recycling (MR), open-loop recycling (OR: production of secondary wipers), chemical recycling via pulping (CR), incineration (IN) and landfilling (LA) as well as combination of the two last ones according to the EU average management of residual mixed (not separately collected) municipal waste (EU). The error bar represents ± the standard deviation around the default value. It is referred to Table 7 for a description of the different treatment scenarios and technologies.



Source: adapted from Solis et al., in preparation.

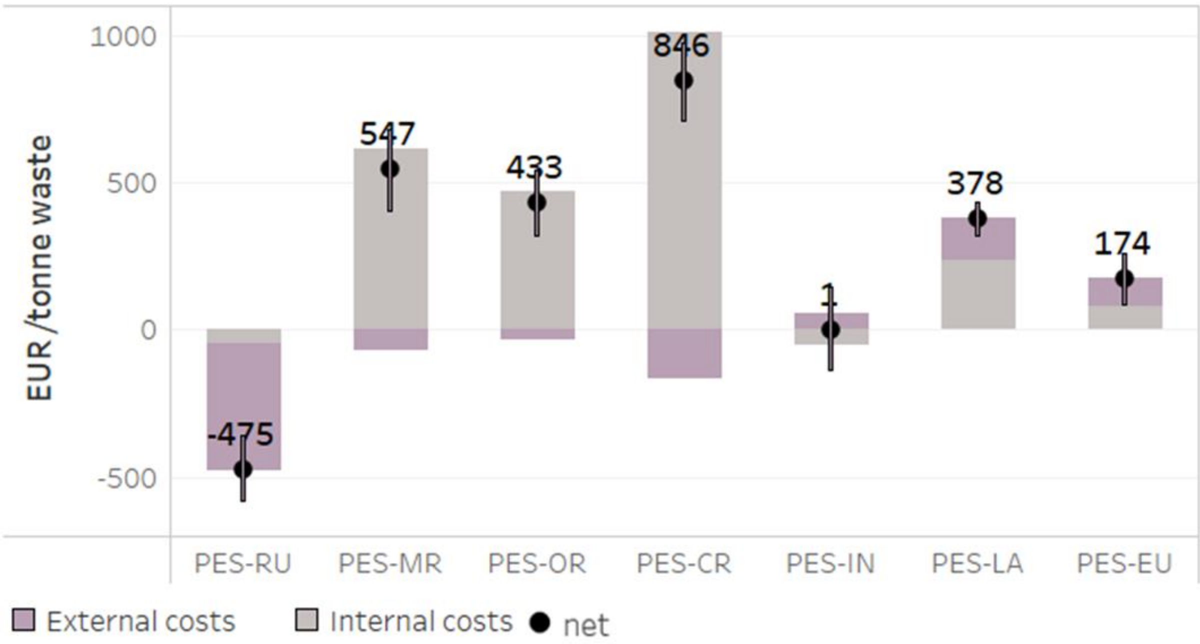
[61] 'Approximately' because in the fELCC the internal costs are corrected by removing the environmental taxes.

5.5.3.2 *Polyester waste*

Highlights: Re-use (RU) incurs net savings because the internal costs incur a net income (revenues > costs) and because of the further (avoided) external costs (Figure 35). The remaining scenarios incur net costs as the net internal costs are not sufficiently compensated by the (avoided) externalities from (avoided) primary material or energy production. The full environmental cost of chemical recycling (CR) is the highest.

Key Cost Contributions: The detailed breakdown of the internal costs has been described in section 5.6. The external costs are driven by CO_2 emissions to a large extent. Note that the cost of landfill includes also the landfill tax, which is therefore here considered in addition to the environmental emissions externalities (in purple).

Figure 35. Full environmental life cycle costs for the management of 1 tonne of polyester waste via re-use (RU), mechanical recycling (MR), open-loop recycling (OR: production of synthetic granulate), chemical recycling via depolymerization (CR), incineration (IN) and landfilling (LA) as well as combination of the two last ones according to the EU average management of residual mixed (not separately collected) municipal waste (EU). The error bar represents ± the standard deviation around the default value. It is referred to Table 7 for a description of the different treatment scenarios and technologies.



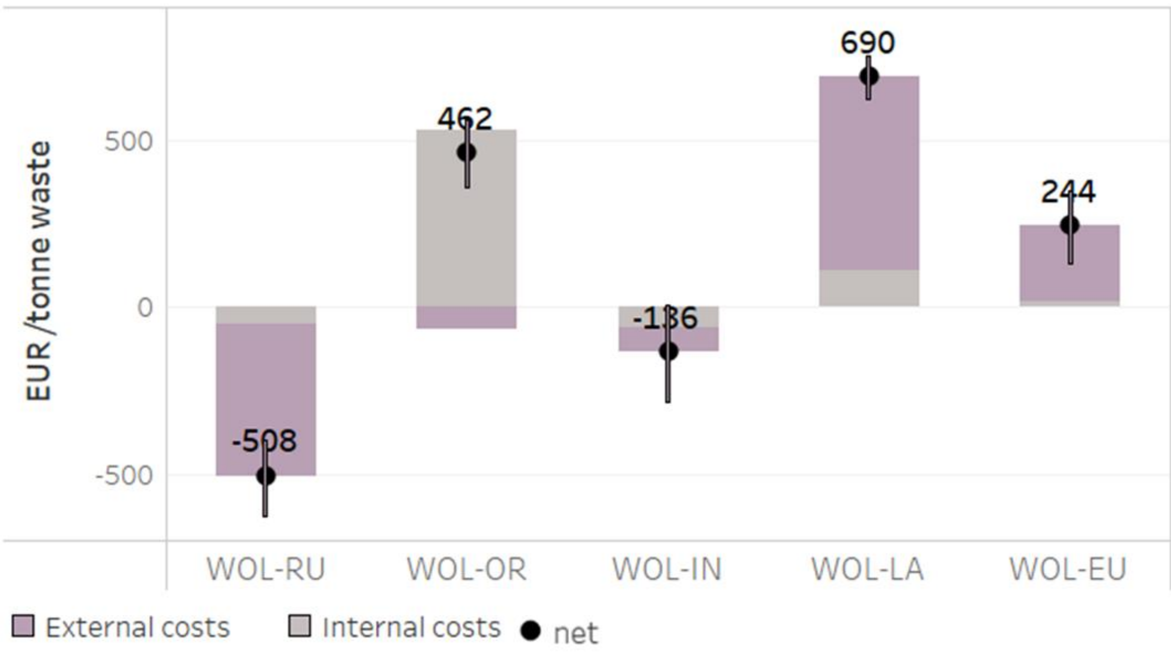
Source: adapted from Solis et al., in preparation.

5.5.3.3 *Wool waste*

Highlights: Re-use (RU) incurs net savings because the internal costs incur a net income (revenues >> costs) and because of the further (avoided) external costs (Figure 36). Incineration also incurs savings thanks to the net income from the sum of internal costs and the (avoided) externalities related to the energy recovery and substitution of electricity and heat in the market. Open-loop recycling (OR) incurs net costs as the net internal costs are not sufficiently compensated by the (avoided) externalities from (avoided) primary production. The cost of landfilling (LA) is the highest and, relative to the ELCC, is significantly increased because of the external costs related to fugitive (mainly methane) emissions.

Key Cost Contributions: The detailed breakdown of the internal costs has been described in section 5.6. The external costs are driven by CO_2 emissions to a large extent. Note that the cost of landfill also includes the landfill tax, which is therefore here considered in addition to the environmental emissions externalities (in purple).

Figure 36. Full environmental life cycle costs for the management of 1 tonne of wool waste (WOL) via re-use (RU), open-loop recycling (OR: production of secondary wipers), incineration (IN) and landfilling (LA) as well as combination of the two last ones according to the EU average management of residual mixed (not separately collected) municipal waste (EU). The error bar represents ± the standard deviation around the default value. It is referred to Table 7 for a description of the different treatment scenarios and technologies.



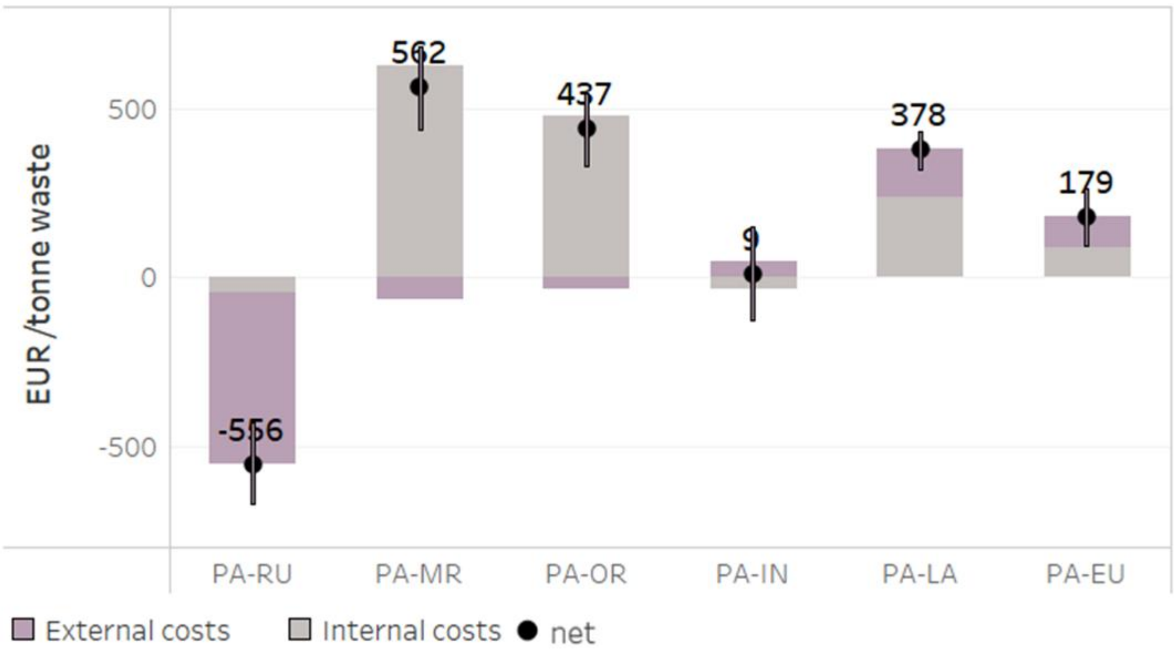
Source: adapted from Solis et al., in preparation.

5.5.3.4 Polyamide waste

Highlights: Re-use (RU) is the only scenario that incurs net savings because the internal costs incur a net income (revenues >> costs) and because of the further (avoided) external costs (Figure 37). The rest of scenarios incur net costs as the net internal costs are not sufficiently compensated by the (avoided) externalities from (avoided) primary production, with mechanical recycling (MR) resulting in the highest net cost. The full environmental cost of landfill, relative to the ELCC, is significantly increased because of the external costs related to fugitive (mainly methane) emissions.

Key Cost Contributions: The detailed breakdown of the internal costs has been described in section 5.6. The external costs are driven by CO_2 emissions to a large extent. Notice that the cost of landfill also includes the landfill tax, which is therefore here considered in addition to the environmental emissions externalities (in purple).

Figure 37. Full environmental life cycle costs for the management of 1 tonne of polyamide waste (PA) via re-use (RU), mechanical recycling (MR), open-loop recycling (OR: production of synthetic granulate), incineration (IN) and landfilling (LA) as well as combination of the two last ones according to the EU average management of residual mixed (not separately collected) municipal waste (EU). The error bar represents ± the standard deviation around the default value. It is referred to Table 7 for a description of the different treatment scenarios and technologies.



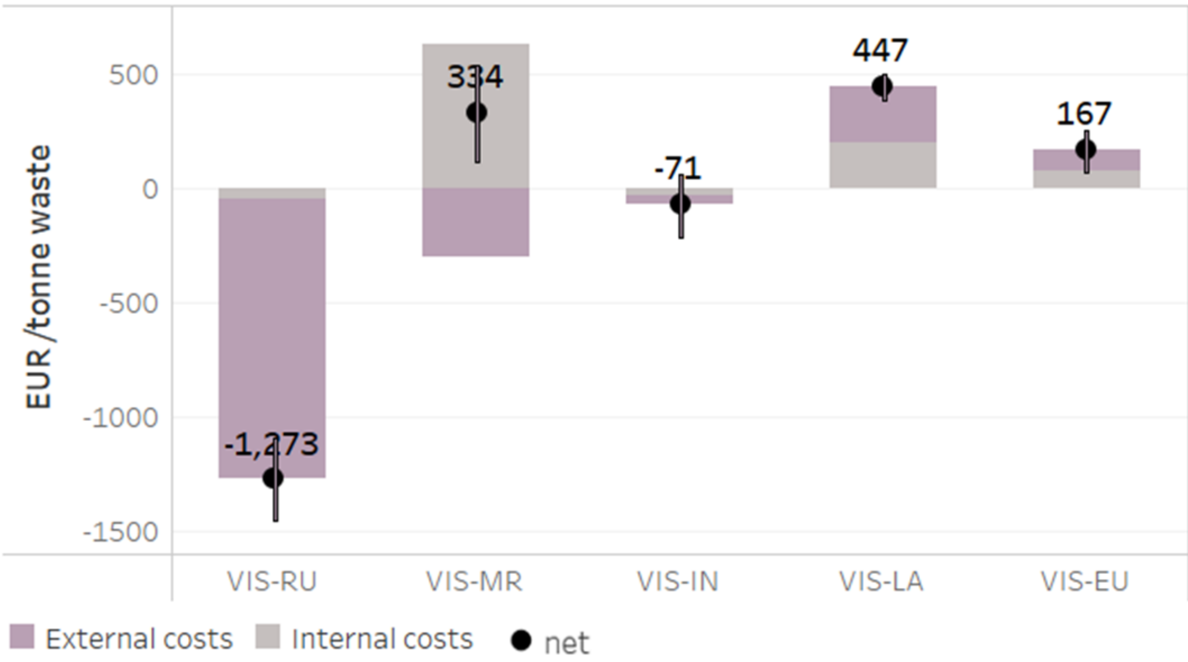
Source: adapted from Solis et al., in preparation.

5.5.3.5 Viscose waste

Highlights: Re-use (RU) incurs net savings because the internal costs incur a net income (revenues >> costs) and because of the further (avoided) external costs (Figure 38). Incineration also incurs savings thanks to the net income from the sum of internal costs and the (avoided) externalities related to the energy recovery and substitution of electricity and heat in the market. Mechanical recycling (MR) incurs the highest net costs as the net internal costs are not sufficiently compensated by the (avoided) externalities from (avoided) primary production. The cost of landfill (LA) relative to the ELCC, is higher increased because of the external costs related to fugitive (mainly methane) emissions.

Key Cost Contributions: The detailed breakdown of the internal costs has been described in section 5.6. The external costs are driven by CO_2 emissions to a large extent. Notice that the cost of landfill also includes the landfill tax, which is therefore here considered in addition to the environmental emissions externalities (in purple).

Figure 38. Full environmental life cycle costs for the management of 1 tonne of viscose waste via re-use (RU), mechanical recycling (MR), incineration (IN) and landfilling (LA) as well as combination of the two last ones according to the EU average management of residual mixed (not separately collected) municipal waste (EU). The error bar represents ± the standard deviation around the default value. It is referred to Table 7 for a description of the different treatment scenarios and technologies.



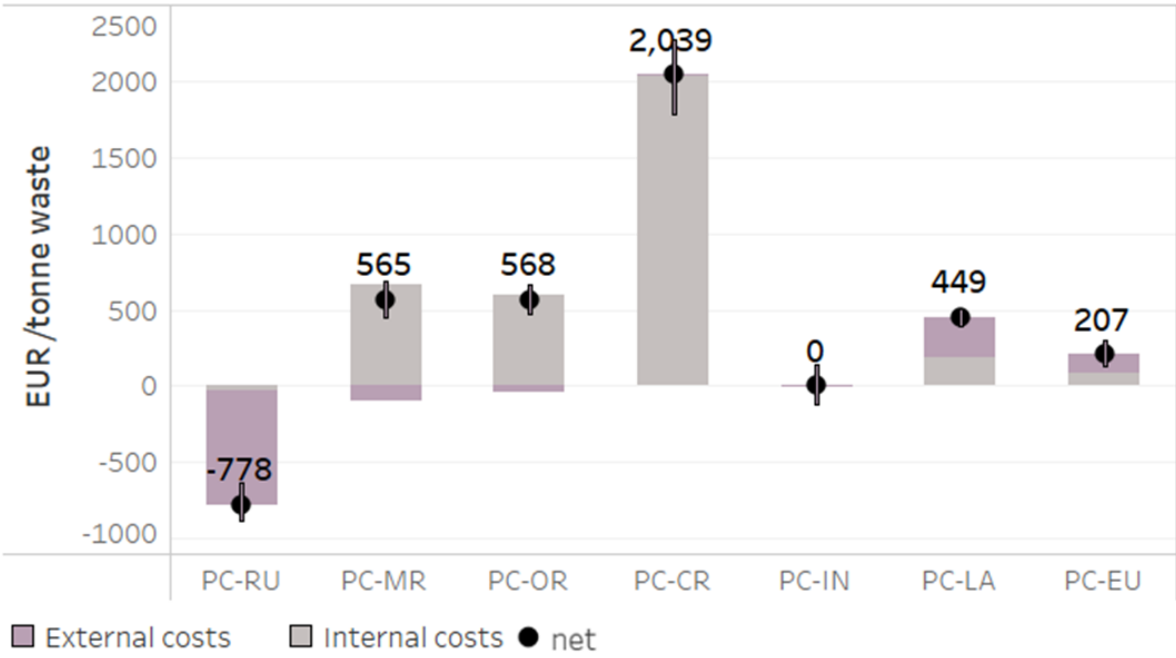
Source: adapted from Solis et al., in preparation.

5.5.3.6 Polycotton waste

Highlights: Re-use (RU) incurs net savings because the internal costs incur a net income (revenues >> costs) and because of the further (avoided) external costs (Figure 39). Incineration (IN) incurs net zero costs thanks to net income from the sum of internal costs and the (avoided) externalities related to the energy recovery and substitution of electricity and heat in the market. All recycling scenarios incur net costs because the net internal costs are not sufficiently compensated by the (avoided) externalities from (avoided) primary production. The cost of enzymatic recycling (EN) is the highest (data not shown in Figure because of selected scale). The cost of landfill (LA) relative to the ELCC, is significantly increased because of the external costs related to fugitive (mainly methane) emissions.

Key Cost Contributions: The detailed breakdown of the internal costs has been described in section 5.6. The external costs are driven by CO_2 emissions to a large extent. Notice that the cost of landfill also includes the landfill tax, which is therefore here considered in addition to the environmental emissions externalities (in purple).

Figure 39. Full environmental life cycle costs for the management of 1 tonne of polycotton waste (PC) through re-use (RU), mechanical recycling (MR), open-loop recycling (OR: production of insulation material), dissolution in two variants: 1) dissolution of cotton and recovery of polyester (CR) and 2) dissolution of polyester and recovery of cotton (CR*), enzymatic recycling (EN), incineration (IN) and landfilling (LA) as well as combination of the two last ones according to the EU average management of residual mixed (not separately collected) municipal waste (EU). The error bar represents ± the standard deviation around the default value. It is referred to Table 7 for a description of the different treatment scenarios and technologies. Note that dissolution of polyester and recovery of cotton (PC-CR*, EUR 4 037) and enzymatic recycling (PC-EN, EUR 62 089) are not represented in the Figure because out of scale.



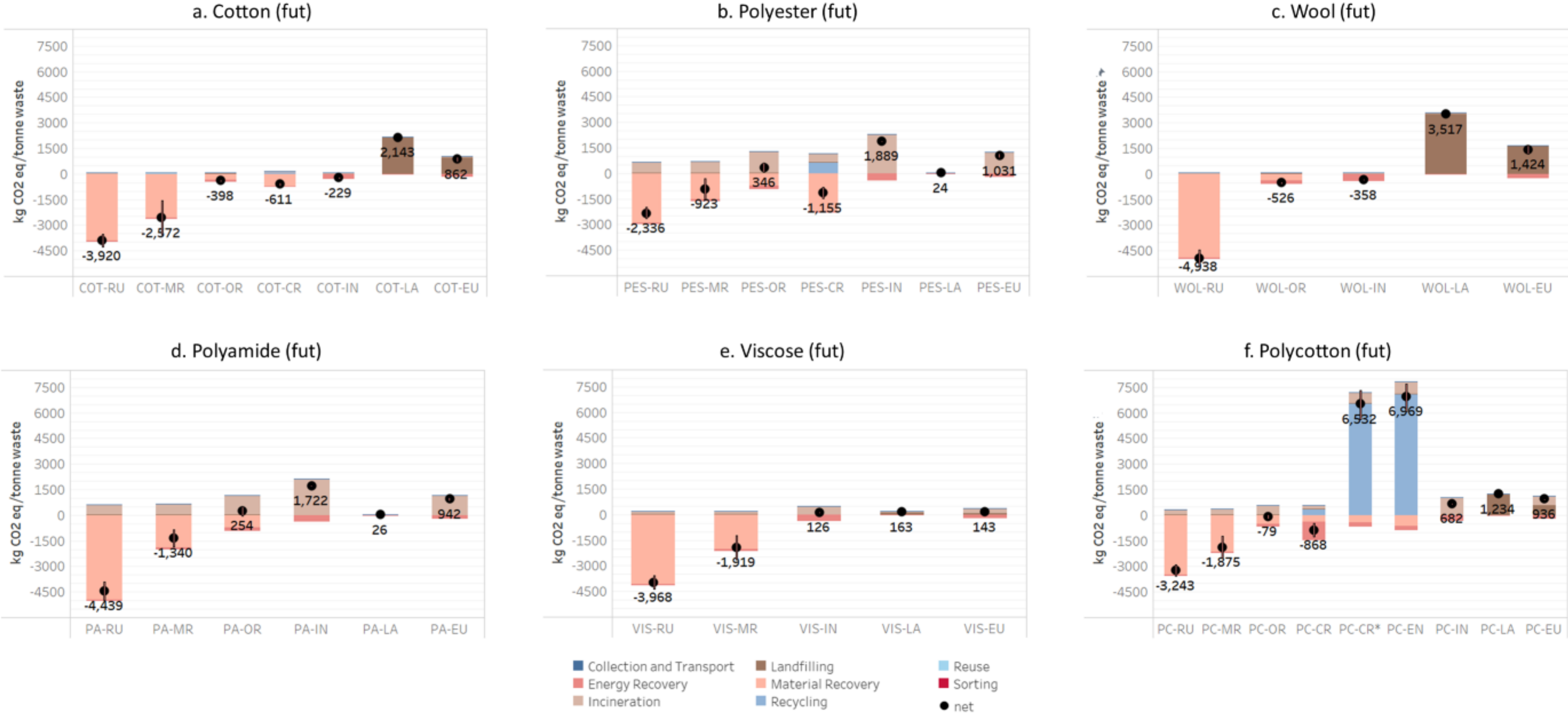
Source: adapted from Solis et al., in preparation.

5.6 Technology outlook – future scenario

The results of the sensitivity analysis on future scenario are illustrated for the category Climate Change (Figure 40) and Environmental and full Environmental Life Cycle Costs (Figure 41 and Figure 42, respectively). For Climate Change, we observe that mechanical recycling now becomes clearly preferred to incineration and other recycling scenarios for all investigated textile waste streams except for polyester. This is a result of two simultaneous and additional future effects: i) increased material recovery via recycling technology improvement, ii) decarbonisation of the EU energy mix, which makes energy-recovery oriented technologies less environmentally preferable (e.g. for carbon, there are less GHG credits for unit of energy recovered). For polyester, mechanical recycling clearly improves its performance compared with the 'default' scenario and it is clearly preferred to incineration but has still higher impact than chemical recycling, under the assumptions taken.

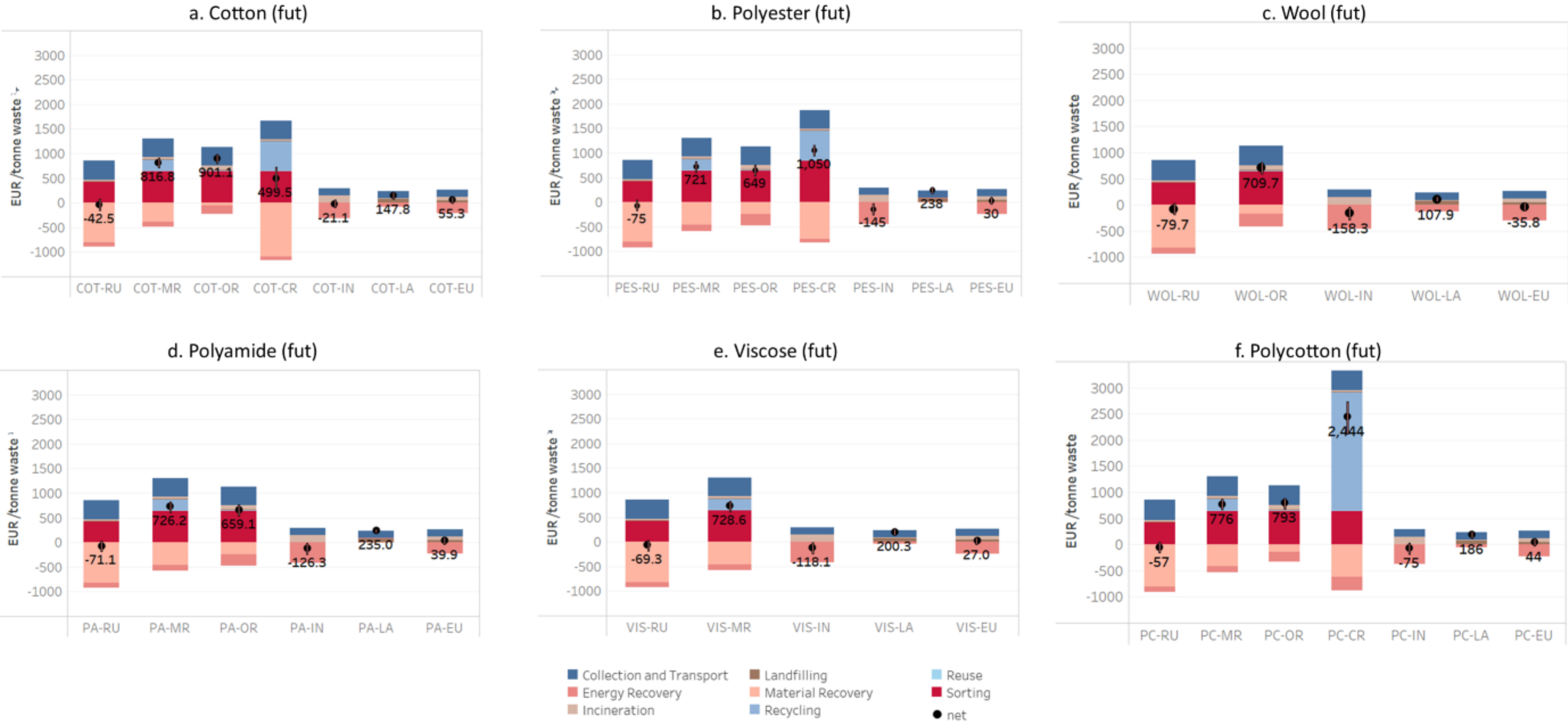
The environmental life cycle costs (Figure 41) pinpoint that recycling scenarios are always significantly more expensive than direct incineration or landfilling (often by an order of magnitude) due to the additional costs related to separate collection, sorting and processing which are not fully counterbalanced by the revenues associated with material (and to some extent energy) sale. However, costs are significantly lower compared with the 'default' scenario owing to the increased technology efficiency assumed in the future scenario. Note that the future costs are not discounted for economic savings resulting from potential increases in scale of recycling because the challenge associated to such estimation. Hence, the future cost have not benefited from an "economies of scale" discount.

Figure 40. Future scenario analysis - Climate Change impact for the management of 1 tonne of cotton (COT), polyester (PES), wool (WOL), polyamide (PA), viscose (VIS) and polycotton (PC) waste via re-use (RU), mechanical recycling (MR), open-loop recycling (OR), chemical recycling (CR), enzymatic recycling (EN), incineration (IN) and landfilling (LA) as well as combination of the two last ones according to the EU average management of residual mixed (not separately collected) municipal waste (EU). The error bar represents ± the standard deviation around the default value. It is referred to Table 7 for a description of the different treatment scenarios and technologies.



Source: adapted from Solis et al., in preparation.

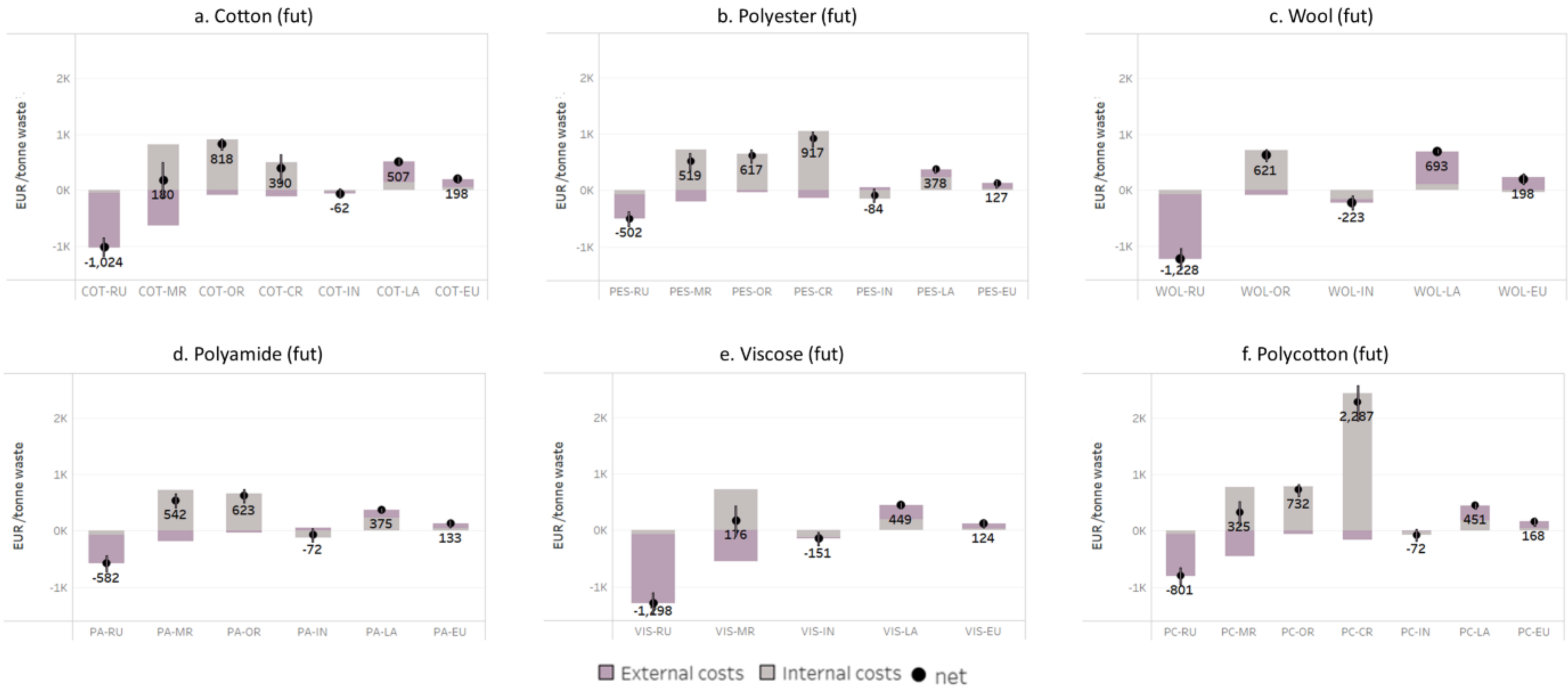
Figure 41. Future scenario analysis - Environmental life cycle costs for the management of 1 tonne of cotton (COT), polyester (PES), wool (WOL), polyamide (PA), viscose (VIS) and polycotton (PC) waste via re-use (RU), mechanical recycling (MR), open-loop recycling (OR), chemical recycling (CR), enzymatic recycling (EN), incineration (IN) and landfilling (LA) as well as combination of the two last ones according to the EU average management of residual mixed (not separately collected) municipal waste (EU). The error bar represents ± the standard deviation around the default value. It is referred to Table 7 for a description of the different treatment scenarios and technologies. Note that for polycotton, dissolution of polyester and recovery of cotton (PC-CR*, EUR 5 577) and enzymatic recycling (PC-EN, EUR 61 235) are not represented in the Figure because out of scale.



Source: adapted from Solis et al., in preparation.

While the full environmental costs (Figure 42) are significantly affected by the internal costs (grey stack), the contribution of the externalities (purple stack) is significant for recycling scenarios, and often leads the full environmental cost to be negative and smaller than incinerating or landfilling the waste. Notably, for all investigated textile waste streams, we observe that mechanical recycling continues to incur higher full environmental costs than incineration. This is because higher revenues due to the higher material recovery yield expected in the future scenario, do not counterbalance higher external cost savings (because of more primary material displacement). The most expensive management options from an environmental point of view are open-loop recycling for cotton and polyamide, chemical recycling for polyester, landfilling for viscose and wool as well as enzymatic recycling for polycotton.

Figure 42. Future scenario analysis – Full environmental life cycle costs for the management of 1 tonne of cotton (COT), polyester (PES), wool (WOL), polyamide (PA), viscose (VIS) and polycotton (PC) waste via re-use (RU), mechanical recycling (MR), open-loop recycling (OR), chemical recycling (CR), enzymatic recycling (EN), incineration (IN) and landfilling (LA) as well as combination of the two last ones according to the EU average management of residual mixed (not separately collected) municipal waste (EU). The error bar represents ± the standard deviation around the default value. It is referred to Table 7 for a description of the different treatment scenarios and technologies. Note that for polycotton, dissolution of polyester and recovery of cotton (PC-CR*, EUR 6 698) and enzymatic recycling (PC-EN, EUR 62 469) are not represented in the Figure because out of scale.



Source: adapted from Solis et al., in preparation.

5.7 Summary of stakeholders' feedback

A draft version of this report was shared for consultation with about ~150 stakeholder organisations, including Member States representatives, industry actors, non-profit organisations, academics and non-governmental organisations, in April 2023. Feedstock on this draft report was received orally and in written during a stakeholder workshop (18-19 April) and an associated questionnaire (hereafter "stakeholder consultation"). In addition, a follow up meeting with experts in the field, including representatives from different recycling companies, was organised by JRC on 30 May to discuss data used for the LCA/LCC assessment.

The main feedback and changes made to the draft report are summarised as follows, and mainly relate to the cost of sorting and data for a specific recycling process:.

Item/process	**Feedback received on draft report**	**Action taken for final report**
Scope and boundary of the study	Requests for clarifications were received regarding scope, FU, boundary of the LCA and substitution factors. Particularly, stakeholders required clarifying that re-use & recycling also avoids landfilling or the current management in place (e.g. incineration/export to third countries).	We clarified in the scope, discussion and conclusions that recycling & re-use also have the consequence of avoiding alternative landfill or incineration of textile. However, we did not change the results figures as we aim to compare management options, rather than the shift from one management pathway to another. In addition, results show the difference between these pathways (i.e. the net 'delta' can be derived simply by comparing two alternative pathways).
Sorting	Sorting for re-use is greater than assumed in the draft report (OPEX: 350-400 EUR/tonne). In addition, future costs assuming partial automated sorting to analyse the composition of the textiles sent to recycling may further increase sorting costs (70-130 EUR/tonne for OPEX & 400-700 EUR/tonne for CAPEX). Sorting yield loss for future automated sorting are to be set at 20%	Sorting for re-use OPEX was changed to 400 EUR/tonne (range 350-450), while CAPEX was maintained to 18.6 EUR/tonne. The sorting for recycling cost for the future scenario was set in line with the expert suggestions accordingly: (OPEX: 100 (70-130); CAPEX: 550 (400-700). Sorting loss was maintained at 15%, as it similar to the suggested 20%.
Chemical recycling (pulping process)	Substitution factor cotton pulp-to-wood pulp=1:1, In addition, the technical substitution is to be based on the *alpha cellulose* content, which is actually slightly higher in cotton-derived pulp in comparison to wood-derived pulp (98% against 91-96%), indicating a substitution equal or > 1. The limiting factor is the low supply of recyclate, not a technical	The substitution factor cotton pulp-to-wood pulp was increased to 1:1. The price of recycled cotton pulp was set to 1411 EUR/tonne for 2021 and recalculated according to our reference year in this study

	limitation *per se.* The sales price of recycled cotton pulp was indicated to be 1411 EUR/tonne (2021)	

5.8 Limitations and perspectives for further work

The results should be cautiously interpreted, bearing in mind the following limitations or assumptions of the study:

i. Scope and objective: this work aims at comparing the different management options, based on hypothetical scenarios. In real-world situations, textile waste is distributed over different management options. For instance, recycling is part of a management pathway that involves separate collection, sorting and partial re-use of separately collected fraction for which sorting and collection could be attributed to re-use as the main intention of this route rather than to recycling. Under such assumption (i.e. that collection of non-reusable textiles would occur anyway), the environmental impacts and particularly the cost of recycling would be reduced relative to incineration or landfill. This is because also the incineration and landfill pathways would require separate collection and sorting prior to final incineration or landfilling under the assumption that non-reusable textiles would be collected separately anyways.

ii. The substitution factors (Table 8) used to reflect how much of the primary material can be replaced with the secondary (recycled) material, thus their quality, are based on literature, authors' judgement and have been discussed with stakeholders. On top, we accounted for uncertainty around the 'default' value used. Notwithstanding these efforts, it is acknowledged that little technical information is available on these aspects and that future research is needed to obtain more detailed information on the quality of recycled products.

iii. The inventory data used for chemical recycling via depolymerisation of polyester (PES) waste are based on previous JRC reports on chemical recycling of PET waste; although, chemically PES=PET, the two waste flows may have different impurities and challenges for management; therefore, future research is desirable to obtain specific information for chemical recycling of textile polyester waste specifically and confirm that yields and processing costs are comparable to those of PET.

iv. Data for costs of waste treatment technologies and materials/products derived from them are subject to significant variations due to market fluctuations and should be considered as representative of 2021 conditions only.

v. The LCA and LCC do not take into account the separate collection rate (i.e. the efficiency of source separation of the textile waste), thus the results are valid only under the assumption that 100% of the generated waste is properly source separated by the citizens/services. Notice that lower collection rate would obviously decrease the benefits of 'recycling pathways' relative to incineration or landfilling.

Notice that point (i) and (v) will be addressed in a next stage of the JRC work that takes into consideration the actual mass flows of textile waste, with its proportional allocation to the different processes and stages in the life cycle. Several broad scenario analyses will be performed on the entire EU textile waste management system, encompassing all material fractions and all management stages. Such analyses will account for the entire system efficiency (including the separate collection rate).

5.9 Conclusions

5.9.1 Climate Change

Re-use stands out as the least impactful management option for all the waste fractions investigated. Recycling performs better or for some compositions equivalent to incineration, whereas landfilling is the management option associated to the greatest burden. For cotton, a dominant fibre type fraction, mechanical, and chemical recycling show a better performance than open-loop recycling. For polyester as the other dominant fibre type, a contrasting trend is observed, with chemical recycling showing the best performance.

5.9.2 Other environmental impact categories

Re-use stands out as the best management option for all the waste fractions investigated across all impact categories considered. Mechanical and chemical recycling pathways, except for polycotton waste, generally perform better than incineration and it is always better than landfilling (or the EU average treatment scenario, namely 'EU' in the figures). For polycotton waste, specifically, incineration in many categories performs better than chemical recycling due to the low material yield in the chemical recycling process.

5.9.3 Environmental and full environmental costs

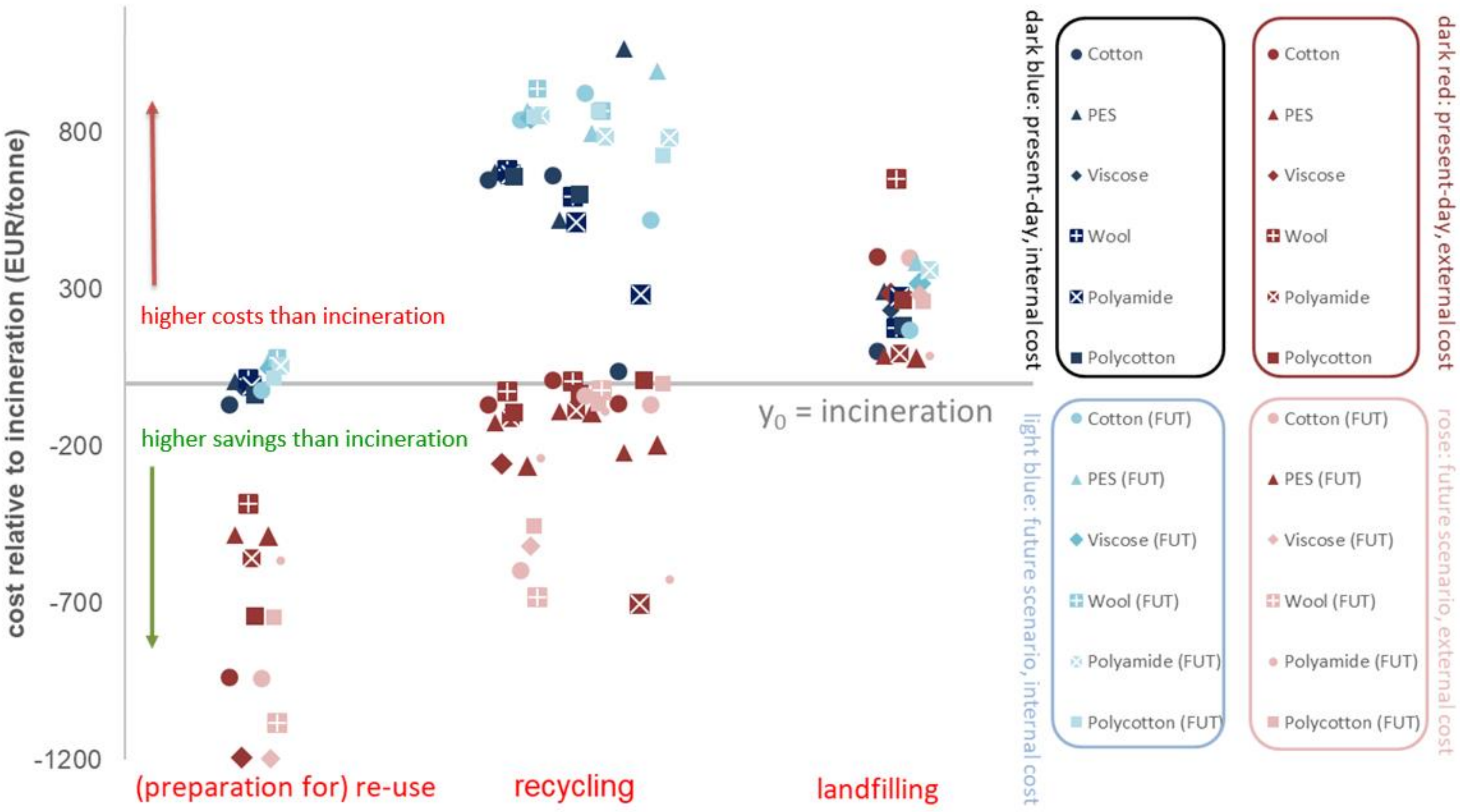
Re-use is a management pathway with net income for all the material fractions, i.e. revenues > costs (throughout the entire management life cycle). Direct incineration is also a net income (i.e. revenues > costs) for polyester and viscose or close to a break-even (i.e. revenues ≈ costs) for cotton and polycotton. For incineration, the costs of collection and processing are compensated by the revenues from energy recovery, which depend upon the calorific value of the material fraction incinerated (e.g. higher for polyester and viscose, being fossil-based materials). The cost of the recycling scenarios is always higher than landfilling or incineration taken individually (or the mix of them, namely 'EU'), except for the case of chemical recycling of cotton (pulping) for which the high revenues incurred reduce the management costs, ultimately making this pathway comparable to direct incineration or to the EU average treatment scenario. As for the recycling of the other material fractions, life cycle costs are higher than direct incineration or landfilling, as costs of separate collection, sorting, and recycling (with eventual preparation for) are not sufficiently counterbalanced by the revenues from material sales. These results should however be taken with care in the light of the uncertainties reported.

The full environmental costs follow very closely the trend observed for the environmental costs, as the full environmental cost (sum of internal costs, minus environmental taxes, plus external costs) is largely dominated by the internal costs. Under a future scenario, the external costs for mechanical recycling could further decrease relative to incineration, pointing towards increased environmental benefits relative to incineration. For such pathways, full environmental costs would be lower or similar to incineration.

Notice that when we refer to costs, we account for all the costs throughout the management life cycle including collection, transport, and sorting (not only the final recycling, incineration, or landfilling). However, the individual breakdown of the costs provided in this study also allows to see the specific cost of each individual stage (e.g. incineration alone, which can be compared to the cost of e.g. recycling alone).

The overall internal and external costs are depicted in Figure 43.

Figure 43. Overall summary of the internal (dark blue/pale blue) and external (red/rose) costs for textile waste management, relative to a baseline (y0) of textile waste incineration. The Figure reports findings for present (dark colours) and future (light colours) conditions for different textile waste management pathways and textile waste compositions (see legend on the right hand side). Recycling pathways group mechanical recycling (middle, points on the left hand side), open-loop recycling (middle, point in the centre) and chemical recycling (middle, points on the right hand side). Negative y-values represent greater savings compared to incineration as a baseline, whereas positive y-values indicate greater costs relative to incineration.



Source: adapted from Solis et al., in preparation.

5.9.4 Future outlook

Assuming improved performances of the technology and a cleaner EU energy mix expected for the decade 2030-2040, the results and the conclusions for the impact categories Climate Change and full environmental costs would change significantly, in particular for cotton and viscose waste.

When looking into the evolution of technology (improved material recovery efficiency) and EU energy system (low carbon-intensity; higher shares of renewables), mechanical recycling of cotton and viscose waste becomes increasingly superior to the alternative options, notably incineration, in terms of impacts on Climate Change. This is also reflected in lower environmental and full environmental costs because of the higher revenues from material recovery and the associated higher external costs avoided (because more primary production will be displaced, thanks to increased material recovery).

6 Drivers and barriers to a sustainable and circular management of waste textiles

6.1 Current opportunities and barriers to recycling

6.1.1 Moving textile waste up in the waste management hierarchy

Based on current and future technology settings, the environmental impact assessment points to environmental benefits when textile waste would be moved up in the waste management hierarchy. Re-use leads to the clear benefits for all types of textiles considered. To a smaller extent, selected recycling pathways show a better performance over landfilling and incineration, even though this observation is not sustained for all input material-recycling pathway combinations when comparing recycling to incineration. Particularly under a future scenario of further technological development and a further greening of the EU energy mix, environmental benefits could be reaped.

From a cost perspective, revenues from the re-use of used textile waste offset costs for collection and sorting and is thus a profitable activity today. The internal and full environmental costs for the recycling of textile waste are typically greater than the incineration or the landfilling of textile waste.

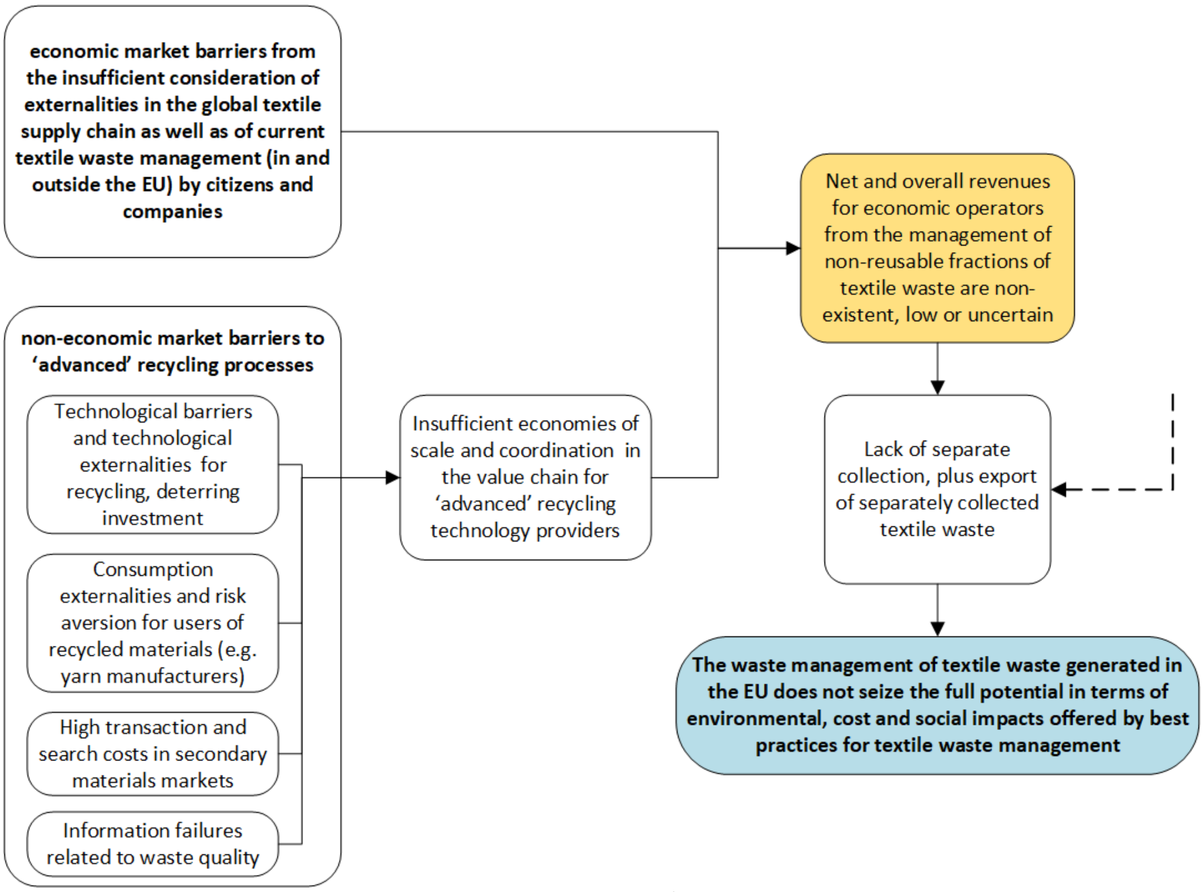
The assessment indicates that the cost-benefit ratio for the re-use of used and waste textiles is better compared to incineration and landfilling as alternative management options. For recycling, the picture is more complex with some recycling pathways showing greater benefits at higher costs compared to incineration, but others showing a higher cost than incineration without a clear occurrence of overall environmental benefits. Future technological evaluation may further improve the cost-benefit ratio of recycling pathways, but the path of further technological progress for some recycling technology – input material combinations remains unclear.

6.1.2 Problems and drivers

Despite the requirement to manage textile waste aligned to the waste management hierarchy, the main share of textile waste is currently being incinerated and landfilled, thus managed according to the lower levels of the hierarchy. The textile waste proportion that is actually re-used and recycled is minor compared to the total textile waste that is being generated and recovered (incineration) or disposed (landfilled). Hence, the main problem is that the current implementation of textile waste management is not aligned with the Waste Framework Directive and does not seize the full potential in terms of environmental and cost savings offered by best practices for textile waste management.

A full problem tree on problems and drivers observed in relation to textile waste (e.g. including waste generation) falls beyond the scope of this study. Instead, this work mainly focuses on identifying the main barriers to a more extensive and environmentally performant recycling industry, particularly for closed-loop technologies that may offer greater environmental benefits compared to incineration and landfilling (Figure 44).

Figure 44. Overview of the problem tree indicating the interlinks of drivers considered to be barrier to a more extensive and performant textile waste recycling industry (yellow box), in turn contributing to the main problem observed outlined in the blue box. A main barrier is the insufficient internalisation of externalities. Market barriers, other than the consideration of externalities in the global textile supply chain, particularly relevant for closed-loop recycling processes are discussed in section 6.1.4.



Source: own work.

The business model for the separate collection and sorting of textile waste is driven by the revenues generated from the re-usable fraction that off-set gross costs from separate collection, sorting, and the management of non-re-usable textile fractions (mostly sent to incineration or landfilling) (Watson et al., 2016). At present, the overall net cost (expenses - revenues) for the recycling of the non-reusable fraction is positive, thus the small revenues from the sales of this fraction do not cover the net expenses from the collection and separation of this fraction (see section 5.6).

In addition, the business model for the management of separately collected textile waste, based on revenues from re-use, is currently being challenged by the decreasing prices for re-usable textile fractions that are mostly sent to countries outside the EU (See section 3 on MFA; EEA, 2023).

In sum, these two observations explain why a substantial share of the separately collected textile waste is being exported without prior sorting, and also contributes to adverse environmental and social impacts generated by used and waste textiles in countries outside the EU (see section 3).

The lack of a net positive income from the recycling processes is attributed to both economic and non-economic barriers. These economic and non-economic market barriers are not evident for the more established re-use markets.

6.1.3 Insufficient consideration of externalities in the global textile supply chain

Studies suggest that there is an insufficient internalisation of externalities in the global textile supply chain, which creates economic barriers to recycling. The majority of stakeholders answering the survey (68%) agreed that the very low prices of primary raw materials prevents the recycling industry from growing. The 'primary' textile supply chain is characterised by actual and potential adverse impacts on human rights (e.g.

low wages, unhealthy working conditions) and the environment (Greenpeace, 2016; European Parliament, 2019; Niinimäki et al., 2020; UN Environment Programme, 2020; Amicarelli and Bux, 2022). This is one of the explanations for the overall low cost of primary products (fibres, yarns, fabrics, finished textiles) on the market. There is concern about the safeguarding of workers' safety and social rights in several of the developing countries where many textiles imported to the EU are manufactured. The relocation of supply chains to manufacturing centers outside of the EU has decreased the price of finished textile products and their precursors (fibres, yarns, fabrics) placed on the EU market over the last decades. Therefore, recycling processes in the EU that comply with EU environmental and social standards face a competitive disadvantage, as the revenues they make from their recycled fibres, yarns or fabrics are determined by the low – or too low - market prices for primary products. The distortion of the level playing field is further corroborated by the competitive environment in the textile industry, characterised by "globalisation and internet-based technologies in a market dominated by low prices, cheap imports and international sub-contracting" as main features (Leal Filho et al., 2019). In addition, textile waste that is subject to unsound management, either in the EU or following export (e.g. exported textiles brought to open landfills or other dumping sites) is associated with greater external costs than textile recycling processes (see section 5.2). This distorts the markets in a manner that has negative consequences for textile recovery processes (Scheffer, 2011; Leal Filho et al., 2019).

6.1.4 Insufficient economies of scale and coordination in the value chain for closed-loop recycling

Critical scale and coordination across the value chain is required to provide sufficient feedstock (following collection and sorting) to closed-loop recycling technologies, and to allow recycling technologies to become more profitable by operating at a larger scale (Piribauer et al., 2019; McKinsey & Company, 2022). This may be particularly the case for chemical and thermal recycling facilities that require high initial investments. For the collection and sorting stage the same argument holds, but here the driver is not the absolute size of single installations or the overall market, but rather the fragmented business environment that lacks a well-working connection between the different collection, sorting and recycling actors (Riemens et al., 2021). As overall impact, the recycling industry might be prevented from reaching a critical size that would make it cost-competitive vis-a-vis the primary material industry, even though the market equilibrium with a critical-size recycling industry would be preferable from an economic, environmental and social perspective to the one without. This cause of market imperfection seems particularly relevant for 'closed-loop recycling' processes (generating precursors for apparel production) that may potentially have a high (future) potential to be cost-competitive, rather than for recycling processes that turn textile waste into cleaning rags and non-woven industrial products. Still, the implementation and upscaling of such technologies face a set of technological market barriers as discussed in section 6.1.4. Market power in primary and secondary markets is not relevant for textiles according to our analysis, although it is a common market barrier for recyclables[62].

The sections below are based on the review and expansion of non-economic market barriers in recycling markets as identified and quoted by the OECD (2006). These have been evaluated, considering a specific focus on recycled market for textiles.

6.1.4.1 Technological barriers and technological externalities to recycling processes, deterring investment

The Fashion for Goods report indicates that only 16% of the non-reusable separately collected textile waste is suitable for mechanical recycling because the technology cannot handle fibre mixes, multi-layered or multi-coloured textiles, or textiles with non-removable non-textile parts (Van Duijn et al., 2022) (see section 4 for technological challenges; also suggested in literature by Leal Filho et al., 2019; Piribauer et al., 2019). Hence, mechanical recycling is most effective with high-quality, relatively clean sorted waste, but may experience limitations such as restricted availability of appropriate feedstock and resulting material properties that may limit end-market applications. Chemical recycling has a greater potential to handle a wider variety of textiles, but still limitations apply to current technologies.

---

[62] Market power would be of relevance if a few large textile firms would dominate the market for textiles and textiles recycling, and thereby manage to limit other innovative firms oriented towards textile recycling from entering the market. Given that in the literature the textile industry is typically characterised as the opposite, namely as fragmented (see section 4.3.4), this potential source of market inefficiency is not deemed to be relevant.

With the current state of newly emerging technologies and types of textiles placed on the market, a well-functioning value chain for closed-loop recycling would require a continuous supply of textile waste materials of a specific and well-defined nature (e.g. fibre composition, uniform colours, absence of disruptors) (see section 4). Automated sorting (e.g. based on spectroscopic techniques) may facilitate the grouping of textile waste, but still has technological limitations (e.g. when assessing coated or loosely knitted fabrics) (Cura et al., 2021). Also, large amounts of feedstock for sorting centres are required to achieve sizable output for different fibre-colour combination classes.

Still, for many processing technology combinations that use textile waste feedstock, the current state of technology recovers only a low amount of materials with high economic value (e.g. yarn-spinnable fibres, chemical monomers) due to the technical processes' inability to produce yarn-spinnable fibres and losses during the recycling process when processing fibre blends. Moreover, the environmental benefits from the current recycling processes for mixed-fibre textile waste relative to energy recovery are modest or not always clear-cut (see section 5). In the future, better technologies and design for recycling may increase environmental and cost benefits from the recycling process (see section 5).

A current problem is also that technological externalities may exist that complicate the development of an efficient market. According to OECD (2006), a technological externality exists "when the production function of one agent enters another agent's production or utility function, without the latter being compensated (Kolstad, 2000); technological externalities arise when one firm manufactures a product in such a way which increases the cost of recycling for the downstream processor, but for institutional reasons there is no means by which the potential waste recovery facility can provide the manufacturer with the incentives to change their product design (Calcott and Walls, 2000; Porter, 2002)". This barrier is identified for textile recycling by Hole et al. (2020). An illustrative example involves the placing of the market of a coloured, multi-layered textile of low quality with non-removable components that is of not sufficient quality for re-use and challenging to recycle, leading to significant costs for textile waste operators (Greenpeace, 2016; Leal Filho et al., 2019; Piribauer et al., 2019; Candido, 2021). Most survey respondents (73%), agreed with the statement "Producers of textiles, especially of clothing, do not take the recyclability of their products sufficiently into account at the design phase". This strong response signals the need for ecodesign criteria.

Hence, the ongoing technology evolution combined with market uncertainty might discourage investors. Investors and technology holders could wait for the market to consolidate to a more mature technology potentially accompanied by a cost drop (second-mover advantage). This could particularly hold true for recycling technologies that require large investments (e.g. chemical recycling). Most stakeholders disagreed with the statement that the lack of investment is the only barrier recycling processes in the EU that aim at recovering materials for apparel products. This means that stakeholders recognise that the non-economic barriers are not easily solved, regardless of economic incentives. Therefore, understanding the drivers of non-economic barriers is critical in this sector.

6.1.4.2 Consumption externalities and risk aversion of users of recycled materials (e.g. yarn manufacturers)

Spinnable fibres from closed-loop recycling are not perfect substitutes for primary raw materials in all cases, for instance due to the decreased fibre length or strength compared to primary materials or potential presence of contaminants in recycled products. When some textile products derived from recycled textiles are not (or are not perceived as) equal to those from virgin material, the next actor (e.g. yarn or fabric manufacturers) may become hesitant to alter their value chain and prefer to wait for others to move first and 'demonstrate' the equivalence. This leads to a reduced diffusion of textiles from secondary materials in the market (OECD, 2006). Consumption externalities may thus slow down the uptake of recycled materials, and even perceived risks can have strong adverse impacts on the emerging market (OECD, 2006).

6.1.4.3 High transaction and search costs in secondary material markets

The fact that textile waste is generated in many locations and from many sources (post-industrial, pre-consumer, post-consumer) and that it is heterogeneous in terms of material (cotton, polyesters, elastane, and blends) and quality (reusable for original purpose, suitable for rags or insulation, or suitable for chemical recycling) contributes to a high incidence of 'transaction' and 'search' costs for recycling (OECD, 2006; Payne, 2015). According to OECD (2006), transaction costs arise "when there is friction in the market – i.e. market transactions are not undertaken costlessly". Such costs could be the result of investing resources in the detection of reference prices for required process inputs or to detect suitable trade partners ("search costs"). For textile recycling, transaction and search costs are high because of the lack of international or national reference prices for recyclable textiles and the absence of 'organised' trade markets (EEA, 2022b). Another point of friction in the market raised by stakeholders is the potential presence of substances of concern and other contaminants in collected textiles. Resellers and recyclers find it costly to rule out vintage clothing that might contain "vintage" contaminants. Another challenge in an emerging market that requires very specific ("fibre-pure") input materials for the recycling process, is that a geographically disperse market with many smaller and unknown players has to be explored. Hence, recycling companies often perform "unique" transactions in an emerging market that involve a learning investment and cost.

6.1.4.4 Information failures related to waste quality

Information failures may originate from the absence or incompleteness of the waste quality characteristics (OECD, 2006). Hence, recyclers may buy certain textile waste fractions, but may require performance tests to gain better knowledge on detailed composition and its consistency over time of the material they receive. This concerns wear-out and material composition, including the presence of hazardous chemicals. Possibly, the quality of textile waste must be determined for each individual batch. In addition, the willingness to pay a fair price for waste materials may be low due to the additional need to verify quality in an imperfect market (OECD, 2006). Some companies may take advantage of testing by the buyer to put low quality material out on the market, as such further contributing to a negative feedback loop (OECD, 2006). Note that part of this problem is interlinked with technological barriers (section 6.1.4.1). These information failures may cause a sub-optimal fit between feedstock characteristics and recycling technology.

6.2 Demand for recycled textiles

This study has mainly looked at the supply side, evaluating the potential of textile recycling industries to manufacture recycled fibres that can be used as components of new textile and other products. However, it is also important to evaluate the demand for the uptake of these recycled materials to ensure well-functioning markets where supply and demand is aligned. Chicken-and-egg problems may occur if recyclers produce few recycled textile precursors because direct consumers are perceived as not demanding them ("missing markets"; OECD, 2006), and potential buyers, such as yarn manufacturers, do not use recycled products because they are not widely available on markets (OECD, 2006).

To the best of our knowledge, at present no evidence points towards a lack of uptake of the produced secondary raw materials in finished textile products. However, it is noted that production volumes of recycled materials, especially yarn-spinnable fibres for apparel production, are negligible, and that recycle content in finished products is typically low. Hence, the market for recycled textile materials is still a niche-market. Demand may also be driven by the added value for customers in terms of reputational and cost benefits from green claims.

McKinsey (2022) reported that almost half of the European brand executives (apparel and home textile sector) surveyed for the development of the McKinsey study indicated that more than 30-70%[63] of their products should come from recycled fibres in a future, more mature recycling market. In such case, the EU demand for recycled fibres in finished textile produced in the EU would correspond to 1.2 - 2.7 Mt yr^{-1} [64], indicating that market demands could be largely aligned to maximum supply of recycled fibres under future legislative settings, assumed no technological or capacity issues that may limit actual supply. The demand of 1.2 - 2.7 Mt yr^{-1} also corresponds roughly to the envisaged future capacity for recycling based on the planned recycling capacity (see section 4.3.5.2).

These manufacturers form part of an extensive supply chain[65]. Hence, it would be important to better grasp the willingness of all actors in the value chain, and to better understand their needs based on the challenges and uncertainties faced by all actors in the textile value chain.

Ecodesign criteria for textiles could be targeted to demand-side issues, including recycled content standards, tradeable credits for recycled content, public procurement preferences for goods made from recycled

[63] minimum and maximum for 2025 and 2035 reference year, respectively

[64] Presently, 2.9 Mt yr-1 of finished textiles are being produced in the EU, leading to estimated EU production volumes of 3.9 Mt yr-1 under a scenario of 2.5% compounds annual growth rate, and equal shares of textiles placed on the market produced in the EU.

[65] For example, H&M does business "with over 605 commercial product suppliers who manufacture products for our brands in over 1183 factories in Europe, Asia and Africa". The company groups their supplier in different Tiers that are under their direct control (Tier 1; "companies we do business with"), "Companies working with component production and processing" (Tiers 2 to 4), and "Raw material producers" (Tiers 4 to 6). See https://hmgroup.com/sustainability/leading-the-change/transparency/supply-chain/

materials, eco-labels related to recycled material content, and support for research and development for use of recyclable materials (OECD, 2006). Each of these measures may provide incentives to increase demand for recycled materials but should be carefully evaluated to reduce unintended adverse impacts. Such measures could potentially be covered under the Ecodesign for Sustainable Products Regulation.

6.3 Future problem evolution

6.3.1 Will the problem persist in the future?

From the outlook sections in different parts of the report (on flows, technologies, and capacities), it is clear that without any further policy measures many problems will persist. Two main issues are expected for the future:

(i) more textile waste to be separately collected, potentially including fractions that have a reduced aptness for re-use, and

(ii) a reduced potential to export unsorted textile waste to countries that do not manage waste in an environmentally sound manner and potential further price drops for (exported) re-usable textile fractions.

These two issues challenge the existing business models for the sorting, re-use, and recycling of used and waste textiles. The current management of separately collected textiles may become non-viable if the future joint revenues for re-usable and recyclable textile products may no longer off-set the expenses (e.g. for collection and sorting). Hence, there is a possibility that used and waste textiles management systems would require additional economic support from public authorities in charge of waste management and taxpayers, in the absence of other policy measures. Member States may set up alternative financing systems (e.g. EPR schemes), but risk setting up such systems in a non-harmonised manner (different scopes, fees, etc.) that could result in additional market distortion and would not fully address current economic and non-economic market barriers to textile collection and sorting for recycling.

6.3.2 Key measures of the envisaged revision of the Waste Framework Directive

The Commission has developed a legislative proposal to amend the Waste Framework Directive[66]. This is a targeted revision to address food and textile waste – two resource intensive sectors.

One of the key measures for textiles that is being assessed as part of the impact assessment is the mandate to set up national extended producer responsibility (EPR) schemes for textiles to close the investment gap for collection, sorting, and recycling. The organisational and operational modalities of the EPR scheme are also considered in view of ensuring a high level of harmonisation and consistency with the Delegated Act under the Eco-design for Sustainable Product Regulation. This is important to ensure consistency of the design signals as well as to reduce administrative burden.

The proposal for textile waste also considered as part of the accompanying Impact Assessment Report the setting waste performance targets for the precursors to recycling, for example limiting waste generation, preparation for re-use, separation collection. However, setting the level of those targets was considered challenging because of a lack of consistent and robust data on textile waste generation and management. Therefore, the initiative also considers measures to harmonise the definitions and indicators for data on textiles.

In 2021, the Commission conducted a scoping study with the aim of identifying top candidate streams for the development of EU-wide end-of-waste or by-product criteria. The work on the development of end-of-waste criteria for textile waste has been launched in 2023.

[66] https://environment.ec.europa.eu/publications/proposal-targeted-revision-waste-framework-directive_en

6.3.3 Which problem drivers are already addressed by proposed measures under the WFD revision?

Extended Producer Responsibility (EPR) is a key measure in the proposal. The OECD[67] defines EPR as "an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle". It aims to ensure that economic entities who place textile products on the market finance the costs of the collection, sorting and recycling of waste textiles. Also, costs for expanding R&D efforts could be covered under EPR schemes. Hence, EPR schemes foster a cost-competitive market where recycled materials can effectively compete with textiles and textile precursors from primary materials. EPR fee modulation is the modification of fees paid by producers in a collective producer responsibility scheme based on measurable product characteristics (e.g. durability, recyclability). Fee-modulation of the EPR schemes are intended to address technological externalities related to the recovery, recycling, and re-use of secondary materials and encourage "design for recycling".

The development of end-of-waste criteria partly seeks to provide incentives for market participants to comply with a minimum quality for waste-derived materials. This increases transparency in the market, and fosters efforts to meet quality requirements so secondary raw materials can better compete with primary materials in terms of quality (OECD, 2006). These end-of-waste criteria could receive significant support from the industry as they help to reduce business risks related to subpar quality and safety for recyclers. Altogether, end-of-waste criteria partly address information gaps, and may help to mitigate consumption externalities and risk aversion for recyclers. The combination of both measures, together with greater harmonisation of the definitions and robustness of data on textiles, thus aim to address key problem drivers observed.

[67] see https://www.oecd.org/environment/extended-producer-responsibility.htm

7 Conclusion

The main problems observed for textile waste management relate to the lack of separate collection and the export of non-sorted fractions to non-OECD countries where they can create negative environmental and social impacts due to the low quality and re-usability of this exported material. Both management pathways are not aligned to the waste management hierarchy as they involve the incineration and, worse, the landfilling, and dumping of textile waste.

The available evidence indicates that following the waste management hierarchy leads to the best possible environmental outcomes, but exceptions may apply as certain recycling pathways do not show a superior performance over incineration. It is shown that re-use clearly results in the greater environmental and economic benefits than recycling, and is always associated with net gains for the involved economic actors. Promoting re-use and preparing for re-use remains critical, but a further focus on textile recycling is justified as many textiles that are separately collected cannot be re-used. The business model for the sorting of textiles may be challenged if an increasing share of textiles with an overall lower potential for re-use is collected.

Currently, operators that manage separately collected waste typically rely on recycling as the preferred option to manage non-reusable waste over incineration and energy recovery. Most of the recycled materials are used as cleaning rags or for the production of non-woven textiles, such as insulation material ('open-loop recycling'). Emerging developments in recycling technologies focus on generating output materials that can be used for applications in the apparel industry, with potentially higher economic benefits for operators and environmental performance, as compared to the currently employed recycling technologies. These 'advanced' technologies rely on specific feedstocks, mostly textiles dominantly composed by a single natural or synthetic fibre, and are currently still implemented at small scale and with a low recovery of input mass that can actually be used for apparel production. These low performances hinder their potential environmental and economic benefits.

The capacity for textile recycling is growing, and a demand for the use of recycled materials in apparel applications appears to exist. However, upscaling recycling is hampered by significant economic and non-economic market barriers, including technical limitations. Barriers to textile waste recycling may persist in the future, and policy intervention may be desirable to overcome them.

References

AISE, 2023. AISE - Market and economic data. Available at: https://www.aise.eu/our-industry/market-and-economic-data-2292.aspx.

Albizzati, P., Cristobal Garcia, J., Antonopoulos, I., Egle, L., Foster, G., Gaudillat, P., Marschinski, R., Pierri, E., Tonini, D., 2023. Harmonised labelling of waste receptacles with matching product labels. Publications Office of the European Union, Luxembourg (Luxembourg). doi:10.2760/09021 (online)

Albizzati, P.F., 2021. Sustainability Assessment of Food Waste Management Paola Federica Albizzati PhD Thesis. Technical University of Denmark.

Amicarelli, V., Bux, C., 2022. Quantifying textile streams and recycling prospects in Europe by material flow analysis. Environmental Impact Assessment Review 97, 106878. doi:https://doi.org/10.1016/j.eiar.2022.106878

Amsterdam University of Applied Sciences, 2020. Measuring the Dutch clothing mountain. Available at: https://www.hva.nl/binaries/content/assets/subsites/kc-fdmci/fashion/measuring-the-dutch-clothing-mountain_final-report-1.pdf?1589295592841.

Astrup, T.F., Turconi, R., Tonini, D., Damgaard, A., Clavreul, J., Christensen, T.H., Boldrin, A., 2012. Easetech Energy: Advanced Life Cycle Assessment of Energy from Biomass and Waste, in: Fourth International Symposium on Energy from Biomass and Waste.

Athanasopoulos, P., Zabaniotou, A., 2022. Post-consumer textile thermochemical recycling to fuels and biocarbon: A critical review. Science of the Total Environment 834, 155387. doi:10.1016/j.scitotenv.2022.155387

Aus, R., Moora, H., Vihma, M., Unt, R., Kiisa, M., Kapur, S., 2021. Designing for circular fashion: integrating upcycling into conventional garment manufacturing processes. Fashion and Textiles 8, 34. doi:10.1186/s40691-021-00262-9

Bassi, S.A., Tonini, D., Saveyn, H., Astrup, T.F., 2022. Environmental and Socioeconomic Impacts of Poly(ethylene terephthalate) (PET) Packaging Management Strategies in the EU. doi:10.1021/acs.est.1c00761

Boletín Oficial del Estado, 2022. Ley 7/2022, de 8 de abril, de residuos y suelos contaminados para una economía circular (in Spanish). Available at: https://www.boe.es/buscar/act.php?id=BOE-A-2022-5809.

Bisinella, V., Conradsen, K., Christensen, T.H., Astrup, T.F., 2016. A global approach for sparse representation of uncertainty in Life Cycle Assessments of waste management systems. International Journal of Life Cycle Assessment 21, 378–394.

Calcott, P., Walls, M., 2000. Policies to Encourage Recycling and 'Design for Environment': What to Do When Market are Missing, RFF Discussion Paper 00-30, RFF, Washington, D.C.

Candido, R.G., 2021. Recycling of textiles and its economic aspects. In Fundamentals of natural fibres and textiles (pp. 599-624). Woodhead Publishing.

Cañete Vela, I., Maric, J., Seemann, M., 2019. Valorisation of textile waste via steam gasification in a fluidized bed reactor. Proceedings - HERAKLION 2019 - 7th International Conference on Sustainable Solid Waste Management.

Carpets Closeouts, 2019. Ways to Determine the Quality of a Carpet. Available at: https://www.azcarpetcloseouts.com/ways-to-determine-the-quality-of-a-carpet/.

CEFIC, 2020. MONITORING REPORT 2020 - European Declaration on Paper Recycling 2016-2020.

Chamas, A., Moon, H., Zheng, J., Qiu, Y., Tabassum, T., Jang, J.H., Abu-Omar, M., Scott, S.L., Suh, S., 2020. Degradation Rates of Plastics in the Environment. ACS Sustainable Chemistry and Engineering 8, 3494–3511. doi:10.1021/acssuschemeng.9b06635

Clavreul, J., Baumeister, H., Christensen, T.H., 2014. An environmental assessment system for environmental technologies. Environ. Modell. Softw. 60, 18–30. doi:10.1016/j.envsoft.2014.06.007

Clift, R., Doig, A., Finnveden, G., 2000. The Application of Life Cycle Assessment to Integrated Solid Waste Management: Part 1—Methodology. Process Safety and Environmental Protection 78, 279–287. doi:https://doi.org/10.1205/095758200530790

Cobbing, M., Daaji, S., Kopp, M., Wohlgemuth, V., 2022. Poisoned Gifts From donations to the dumpsite: textiles waste disguised as second-hand clothes exported to East Africa. Available at: https://www.greenpeace.org/static/planet4-international-stateless/2022/04/9f50d3de-greenpeace-germany-poisoned-fast-fashi.

Commission, E., Environment, D.-G. for, Weißenbacher, J., Dollhofer, M., Herczeg, M., Bakas, I., McKinnon, D., Seyring, N., 2015. Assessment of separate collection schemes in the 28 capitals of the EU : final report. Publications Office. doi:doi/10.2779/49194

Cruz, F.B.D. La, Barlaz, M.A., 2010. Estimation of waste component-specific landfill decay rates using laboratory-scale decomposition data. Environmental Science and Technology 44, 4722–4728. doi:10.1021/es100240r

CTP, 2015. Service-based BM & circular strategies in the textiles sector. Available at: https://s3-eu-west-1.amazonaws.com/stjm/20160330092502/Service-based-business-models-and-circular-strategies-for-textiles-2015-SITRA-STJM.pdf.

Cura, K., Rintala, N., Kamppuri, T., Saarimäki, E., Heikkilä, P., 2021. Textile Recognition and Sorting for Recycling at an Automated Line Using Near Infrared Spectroscopy. Recycling. doi:10.3390/recycling6010011

Dahlbo, H., Rautiainen, A., Savolainen, H., Oksanen, P., Nurmi, P., Virta, M., Pokela, O., 2021. Textile flows in Finland 2019. Available at: https://julkaisut.turkuamk.fi/isbn9789522167873.pdf.

Dahlbom, M., Aguilar Johansson, I., Billstein, T., 2023. Sustainable clothing futures - Mapping of textile actors in sorting and recycling of textiles in Europe, Swedish Environmental Research Institute (IVL). Report number C736.

Danish Energy Agency, 2023. https://ens.dk/en/our-services/projections-and-models/technology-data.

Das, S.K., Chinnappan, A., Jayathilaka, W.A.D.M., Gosh, R., Baskar, C., Ramakrishna, S., 2021. Challenges and Potential Solutions for 100% Recycling of Medical Textiles. Materials Circular Economy 3, 13. doi:10.1007/s42824-021-00023-5

de Bruyn, S., Ahdour, S., Bijleveld, M., de Graaff, L., Schep, E., Schroten, A., Vergeer, R., 2018. Environmental prices handbook 2017 - methods and numbers for valuation of environmental impacts. CE Delft, Delft.

Dobilaite, V., Mileriene, G., Juciene, M., Saceviciene, V., 2017. Investigation of current state of pre-consumer textile waste generated at Lithuanian enterprises. International Journal of Clothing Science and Technology 29, 491–503. doi:10.1108/IJCST-08-2016-0097

Drycleaning Institute of Australia Ltd, 2015. International Fair Claims Guide for consumer textiles products.

Duhoux, T, Maes, E., Hirschnitz-Garbers, M., Peeters, K., Asscherickx, L., Christis, M., Stubbe, B., Colignon, P., Hinzmann, M., Sachdeva, A., 2021. Study on the technical, regulatory, economic and environmental effectiveness of textile fibres recycling : final report. Commission, European Directorate-General for Internal Market Entrepreneurship and SMEs, Industry. Publications Office. doi:doi/10.2873/828412

Dukovska-Popovska, I., Kjellsdotter Ivert, L., Jónsdóttir, H., Carin Dreyer, H., Kaipia, R., 2023. The supply and demand balance of recyclable textiles in the Nordic countries. Waste Management 159, 154–162. doi:https://doi.org/10.1016/j.wasman.2023.01.020

ECAP, 2018. USed textile collection in European cities. LIFE14 ENV/UK/00257.

ECAP, 2017. European Textiles & Workwear Market - The role of Public Procurement in making textiles circular.

ECHA, 2020. Committee for Risk Assessment (RAC) Committee for Socio-economic Analysis (SEAC) Opinion on an Annex XV dossier proposing restrictions on intentionally added microplastics. https://echa.europa.eu/restrictions-under-consideration/-/substance-rev/22921/term.

EcoTLC, 2020a. Annual Report 2019. Available at: https://refashion.fr/pro/sites/default/files/fichiers/ECO_TLC_EN_BD.pdf.

EcoTLC, 2020b. Technical monitoring on optical sorting and textile recognition technologies at a European level.

Edana, 2023. Nonwoven Markets, Facts and Figures. Available at: https://www.edana.org/nw-related-industry/nonwovens-markets.

EEA, 2023. EU exports of used textiles in Europe's circular economy. Available at: https://www.eea.europa.eu/publications/eu-exports-of-used-textiles/eu-exports-of-used-textiles.

EEA, 2022a. Textiles and the environment: the role of design in Europe's circular economy. Available at: https://www.eea.europa.eu/publications/textiles-and-the-environment-the.

EEA, 2022b. Investigating Europe's secondary raw material markets.

EEA, 2022c. Microplastics from textiles: towards a circular economy for textiles in Europe. Available at: https://www.eea.europa.eu/publications/microplastics-from-textiles-towards-a.

EEA, 2021. Progress towards preventing waste in Europe — the case of textile waste prevention. https://doi.org/10.2800/494502.

EEA, 2019. Textiles in Europe's circular economy. Available at: https://www.eea.europa.eu/publications/textiles-in-europes-circular-economy.

EEA, 2008. Generation and recycling of packaging waste. Available at: https://www.eea.europa.eu/data-and-maps/indicators/generation-and-recycling-of-packaging-waste/generation-and-recycling-of-packaging-1.

Ekvall, T., Assefa, G., Björklund, A., Eriksson, O., Finnveden, G., 2007. What life-cycle assessment does and does not do in assessments of waste management. Waste Management 27, 989–996. doi:10.1016/j.wasman.2007.02.015

Elander, M., Sorme, L., Dun, O., Stare, M., Allerup, J., 2014. Konsumtion och återanvändning av textilier. SMED report nr. 149. Commissioned by Naturvårdsverket, Stockholm http://www.smed.se/wp-content/uploads/2014/06/Slutrapport.pdf.

EURATEX, 2021. ReHubs - A joint initiative for industrial upcycling of textile waste streams & circular materials.

European Commission, 2023. Better regulation toolbox [WWW Document].

European Commission, 2021. Commission recommendation of 16.12.2021 on the use of the Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and organisations, COM (2021) 9332.

European Parliament, 2019. Environmental impact of the textile and clothing industry, European Parliamentary Research Service, European Parliament, January 2019. https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2019)633143.

Eurostat, 2022a. EU trade since 1988 by HS2-4-6 and CN8 (DS-045409). Available at: http://epp.eurostat.ec.europa.eu/newxtweb/setupdimselection.do.

Eurostat, 2022b. Overview - Prodcom - statistics by product - Eurostat. Available at: https://ec.europa.eu/eurostat/web/prodcom.

Faraca, G., Edjabou, V.M., Boldrin, A., Astrup, T., 2019. Combustible waste collected at Danish recycling centres : Characterisation , recycling potentials and contribution to environmental savings. Waste Management 89, 354–365. doi:10.1016/j.wasman.2019.04.007

Farrant, L., Olsen, S.I., Wangel, A., 2010. Environmental benefits from reusing clothes. International Journal of Life Cycle Assessment 15, 726–736. doi:10.1007/s11367-010-0197-y

Finnveden, G., 1999. Methodological aspects of life cycle assessment of integrated solid waste management systems. Resources, Conservation and Recycling 26, 173–187. doi:https://doi.org/10.1016/S0921-3449(99)00005-1

Gabel Group, 2022. Home - GABEL GROUP. 2022. Available at: https://www.gabelgroup.com/.

Garcia-Gutierrez, P., Amadei, A.M., Klenert, D., Nessi, S., Tonini, D., Tosches, D., Ardente, F., Saveyn, H., 2023. Environmental and economic assessment of plastic waste recycling. Publications Office of the European Union, Luxembourg, 2023. doi:10.2760/0472

Gazzetta Ufficiale, 2020. DECRETO LEGISLATIVO. 3 Sept. 2020, n. 116. Available at: https://www.gazzettaufficiale.it/eli/id/2020/09/11/20G00135/sg.

Grand View Research, 2018. Europe Carpet Market Size Analysis Report By Product. Available at:

https://www.grandviewresearch.com/industry-analysis/europe-carpet-market-analysis.

Granum, C.R., 2013. Granum, C. R. (2013). Klær til overs. En undersøkelse av hva som skjer med overflødige tekstiler fra norske kleskjeder (Clothes left over. An examination of what happens to the overflow textiles from Norwegian clothing chains). Framtiden i våre hender. Ra.

Greenpeace, 2016. Timeout for fast fashion https://www.greenpeace.org/international/Global/international/briefings/toxics/2016/Fact-Sheet-Timeout-for-fast-fashion.pdf.

H&M Group, 2020. Annual Report 2020. https://hmgroup.com/wp-content/uploads/2021/04/HM-Annual-Report-2020.pdf.

Hann, S., Sherrington, C., Jamieson, O., Hickman, M., Kershaw, P., Bapasola, A., 2018. Investigating options for reducing releases in the aquatic environment of microplastics emitted by (but not intentionally added in) products Final Report. www.icf.com.

Hole, G., Hole, A.S., 2020. Improving recycling of textiles based on lessons from policies for other recyclable materials: A minireview. Sustainable Production and Consumption 23, 42–51. doi:https://doi.org/10.1016/j.spc.2020.04.005

Huggard Consulting Group, 2016. The Household Care and Professional Cleaning and Hygiene Products Industry – A Socio-economic Analysis.

Hultén, J., Johansson, M., Dunsö, O., Jensen, C., 2016. Plockanalyser av textilier i hushållens restavfall- En kartläggning av mängder och typ av kläder, hemtextilier och skor (in Swedish), Sveriges Meteorologiska och Hydrologiska Institut, 601 76 Norrköping, ISSN: 1653-8102.

Hunkeler, D., Lichtenvort, K., Rebitzer, G., 2008. Environmental Life Cycle Costing. CRC Press, Boca Raton.

IKEA, 2022. Textiles - Home Textiles - IKEA. Available at: https://www.ikea.com/gb/en/cat/textiles-tl001/.

ISO, 2006a. ISO 14040 - Environmental management -- Life cycle assessment -- Principles and framework [WWW Document].

ISO, 2006b. ISO 14044 - Environmental management -- Life cycle assessment -- Requirements and guidelines [WWW Document].

Jin, W., Dai, Z., Wang, L., Cai, F., Song, C., Liu, G., Chen, C., 2022. Recycling different textile wastes for methane production: Morphological and microstructural changes and microbial community dynamics. Waste Management 151, 154–162. doi:10.1016/j.wasman.2022.07.018

Joint Research Centre, I. for E. and S., 2012. Supporting environmentally sound decisions for waste management : a technical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) for waste experts and LCA practitioners. Publications Office. doi:doi/10.2788/52632

Jørgensen, P.E., Werner, A., 2022. Research and identification of textile plants globally - focusing on fibre-to-fibre recycling for the fashion & textile industry. Published by Lifestyle & Design Cluster Augut 2022, Second version. Available at: https://ldcluster.com/wp-content/uploads/si.

Kabir, M.M., Forgács, G., Sárvári Horváth, I., 2013. Enhanced methane production from wool textile residues by thermal and enzymatic pretreatment. Process Biochemistry 48, 575–580. doi:10.1016/j.procbio.2013.02.029

Kahlert, S., Bening, C.R., 2022. Why pledges alone will not get plastics recycled: Comparing recyclate production and anticipated demand. Resources, Conservation and Recycling 181, 106279. doi:https://doi.org/10.1016/j.resconrec.2022.106279

Kawecki, D., Scheeder, P.R.W., Nowack, B., 2018. Probabilistic Material Flow Analysis of Seven Commodity Plastics in Europe. Environmental Science & Technology 52, 9874–9888. doi:10.1021/acs.est.8b01513

KERAMIDAS, K., FOSSE, F., DIAZ VAZQUEZ, A., DOWLING, P., GARAFFA, R., DESPRÉS, J., RUSS, H.P., SCHADE, B., SCHMITZ, A., SORIA RAMIREZ, A., VANDYCK, T., WEITZEL, M., TCHUNG-MING, S., DIAZ RINCON, A., REY LOS SANTOS, L., WOJTOWICZ, K., 2021. Global Energy and Climate Outlook 2021 : Advancing towards climate neutrality. doi:10.2760/410610

Khalifa, T.F., 2012. Technical Textile - Design & Methodology.

Kjellsdotter Ivert, L., 2022. Towards a sustainable circular system of textiles in the Nordics. Swedish National

Road and Transport Research Institute (VTI).

Köhler, A., Watson, D., Trzepacz, S., Löw, C., Liu, R., Danneck, J., Konstantas, A., Donatello, S., Faraca, G., 2021. Circular Economy Perspectives in the EU Textile sector, EUR 30734 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-38646-9, doi:10.2760/858144, JRC125110.

Kolstad, C.D., 2000. Environmental Economics Oxford University Press, Oxford.

Laitala, K., Klepp, I.G., Henry, B., 2018. Does Use Matter? Comparison of Environmental Impacts of Clothing Based on Fibre Type. Sustainability. doi:10.3390/su10072524

Laitala, K., Klepp, I.G., Morley, N., Meistad, T., Chapman, A., Chen, W., Hebrok, M., Daae, J., Austgulen, M.H., 2012. Potensiale for økt materialgjenvinning av tekstilavfall og andre avfallstyper (papir/papp, metall og glass) (in Norwian) Rapport TA -2994, Statens institutt for forbruksforskning (SIFO) Grensesvingen 7, 0661 Oslo.

Le Relais, 2023. Comment ça marche Du don à la valorisation : le circuit des TLC en images. Available at: https://www.lerelais.org/commentcamarche.php.

Leal Filho, W., Ellams, D., Han, S., Tyler, D., Boiten, V.J., Paço, A., Moora, H., Balogun, A.-L. %J J. of cleaner production, 2019. A review of the socio-economic advantages of textile recycling 218, 10–20.

MaiaConsulting, 2023. EU-27 Textile Recycling Industry Market Research Report.

Martinez-Sanchez, V., Kromann, M.A., Astrup, T.F., 2015. Life cycle costing of waste management systems: Overview, calculation principles and case studies. Waste Manage. 36, 343–355. doi:https://doi.org/10.1016/j.wasman.2014.10.033

McKinsey, 2022. Scaling textile recycling in Europe-turning waste into value. Available at: https://www.mckinsey.com/industries/retail/our-insights/scaling-textile-recycling-in-europe-turning-waste-into-value.

McKinsey & Company, 2022. Scaling textile recycling in Europe – turning waste into value.

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., Gwilt, A., 2020. The environmental price of fast fashion. Nature Reviews Earth & Environment 1, 189–200. doi:10.1038/s43017-020-0039-9

Nørup, N., Pihl, K., Damgaard, A., Scheutz, C., 2019a. Evaluation of a European textile sorting centre: Material flow analysis and life cycle inventory. Resources, Conservation and Recycling 143, 310–319. doi:https://doi.org/10.1016/j.resconrec.2019.01.010

Nørup, N., Pihl, K., Damgaard, A., Scheutz, C., 2019b. Quantity and quality of clothing and household textiles in the Danish household waste. Waste Management 87, 454–463. doi:https://doi.org/10.1016/j.wasman.2019.02.020

OECD, 2022. Global Plastics Outlook. Global Plastics Outlook. https://doi.org/10.1787/AA1EDF33-EN.

OECD, 2019. Business Models for the Circular Economy. Opportunities and Challenges from a Policy Perspective. Available at: https://www.oecd.org/environment/business-models-for-the-circular-economy-g2g9dd62-en.htm.

OECD, 2006. Improving Recycling Markets. OECD Publishing, Paris, France.

OECD and IEA, 2023. Technology Innovation, Development and Diffusion. COM/ENV/EPOC/IEA/SLT(2003)4.

Olesen, A., Damgaard, A., 2014. Landfill modelling in EASETECH - Data collection and modelling of the landfill modules in EASETECH. Technical University of Denmark, Lyngby, Denmark 45.

Payne, A., 2015. Open-and closed-loop recycling of textile and apparel products. In Handbook of life cycle assessment (LCA) of textiles and clothing (pp. 103-123). Woodhead Publishing.

Peterson, A., Wallinder, J., Bengtsson, J., Idström, A., Bialik, M., Jedvert, K., de la Motte, H., 2022. Chemical Recycling of a Textile Blend from Polyester and Viscose, Part I: Process Description, Characterization, and Utilization of the Recycled Cellulose. Sustainability (Switzerland) 14. doi:10.3390/su14127272

Phan, K., Ügdüler, S., Harinck, L., Denolf, R., Roosen, M., O'Rourke, G., De Vos, D., Van Speybroeck, V., De Clerck, K., De Meester, S., 2023. Analysing the potential of the selective dissolution of elastane from mixed fibre textile waste. Resources, Conservation and Recycling 191, 106903. doi:https://doi.org/10.1016/j.resconrec.2023.106903

Piribauer, B., Bartl, A. %J W.M., Research, 2019. Textile recycling processes, state of the art and current developments: A mini review 37, 112–119.

Porter, R., 2002. The Economics of Waste, Resources for the Future, Washington, D.C.

Quantis, 2021. Measuring Fashion: Insights from the Environmental Impact of the Global Apparel and Footwear Industries. Available at: https://quantis.com/report/measuring-fashion-report/.

Ragn-Sells, 2013. Pressmeddelande. http://www.ragnsells.se/Omforetaget/Press/Pressmeddelande-2013-04-17/.

Refashion, 2023. Characterisation study of the incoming and outgoing streams from sorting facilities. Available at: https://refashion.fr/pro/sites/default/files/rapport-etude/Synth%C3%A8se_Caract%C3%A9risation_Refashion_2023_EN.pdf.

Riemens, J., Lemieux, A.-A., Lamouri, S., Garnier, L. %J S., 2021. A Delphi-Régnier Study Addressing the Challenges of Textile Recycling in Europe for the Fashion and Apparel Industry 13, 11700.

Rittfors, J., 2020. Thermochemical textile recycling Investigation of pyrolysis and gasification of cotton and polyester 64.

Roos, C.J., 2010. Clean Heat and Power Using BiomassGasification for Industrial and Agricultural Projects. U.S. Department of Energy.

Roos, S., Jönsson, C., Posner, S., Arvidsson, R., Svanström, M., 2019. An inventory framework for inclusion of textile chemicals in life cycle assessment. The International Journal of Life Cycle Assessment 24, 838–847. doi:10.1007/s11367-018-1537-6

RRE-USE, 2022. RRE-USE Member Impact 2021. Available at: https://rre-use.org/wp-content/uploads/2022/12/rre-use-impact-infographic-2021-new.pdf.

Sadowski, M., Perkins, L., McGarvey, E., 2021. Roadmap to net zero: delivering science-based targets in the apparel sector." World Resources Institute. https://doi. org/10.46830/wriwp 20 (2021).

Scheffer, M.R., 2011. In-depth assessment of the situation of the textile and clothing sector in the EU and prospects. FINAL REPORT ENTR/2010/16 PREPARED FOR EUROPEAN COMMISSION ENTERPRISE AND INDUSTRY DG, NOVEMEBR 2011.

Schmidt, A., Watson, D., Roos, S., Askham, C., Poulsen, P.B., 2016a. Gaining benefits from discarded textiles : LCA of different treatment pathways, TemaNord NV - 2016:537. Nordisk Ministerråd, Copenhagen. doi:10.6027/TN2016-537

Schmidt, A., Watson, D., Roos, S., Askham, C., Poulsen, P.B., 2016b. Gaining benefits from discarded textiles.

Schmutz, M., Som, C., 2022. Identifying the potential for circularity of industrial textile waste generated within Swiss companies. RESOURCES CONSERVATION AND RECYCLING 182. doi:10.1016/j.resconrec.2021.106132

Schumpeter, J., 1942. Capitalism, Socialism and Democracy, Harper, New York, N.Y.

Sharma, N., Allardyce, B., Rajkhowa, R., Adholeya, A., Agrawal, R., 2022. A Substantial Role of Agro-Textiles in Agricultural Applications. Frontiers in Plant Science 13. doi:10.3389/fpls.2022.895740

Shoaf, T.J., 2022. A STUDY TO ASSESS METHANE POTENTIAL OF PLANT BASED TEXTILES THROUGH ANAEROBIC DIGESTION.

Sleep Foundation, 2023. How Heavy Should a Weighted Blanket Be? Available at: https://www.sleepfoundation.org/bedding-information/weighted-blanket-weight-chart.

Spathas, T., 2017. The Environmental Performance of High Value Recycling for the Fashion Industry LCA for four case studies 33–43.

Striebel Textil, 2023. Gute Gründe für Textilrecycling mit Striebel Textil. Available at: http://f2594702.td-fn.net/index.php?Gute-Gruende-fuer-Textilrecycling.

Textile Exchange, 2021. Textile Exchange Guide to Recycled Inputs.

Torres-Rivas, A., Palumbo, M., Haddad, A., Cabeza, L.F., Jiménez, L., Boer, D., 2018. Multi-objective optimisation of bio-based thermal insulation materials in building envelopes considering condensation risk. Applied Energy 224, 602–614. doi:10.1016/j.apenergy.2018.04.079

UN Comtrade, 2023. Database'.Available at: https://comtrade.un.org/data.

UN Environment Programme, 2020. Sustainability and Circularity in the Textile Value Chain - Global Stocktaking. Nairobi, Kenya.

Unicircular, 2018. http://www.unicircular.org/index.php/unicircular/settori/unirau (Accessed 20.07.2022).

van Duijn, H., Papú Carrone, N., Bakowska, O., Huang, Q., Akerboom, M., Rademan, K., Vellanki, D., 2022. SORTING FOR CIRCULARITY EUROPE - AN EVALUATION AND COMMERCIAL ASSESSMENT OF TEXTILE WASTE ACROSS EUROPE.

van Essen, H., Fiorello, D., El Beyrouty, K., Bieler, C., van Wijngaarden, Lisanne Schroten, A., Parolin, R., Brambilla, M., Sutter, D., Maffii, S., Fermi, F., 2019. Handbook on the External Costs of Transport, European Commission.

Vassilenko, E., Watkins, M., Chastain, S., Mertens, J., Posacka, A.M., Patankar, S., Ross, P.S., 2021. Domestic laundry and microfibre pollution: Exploring fibre shedding from consumer apparel textiles. PLOS ONE 16, e0250346.

Watson, D., Hvass, K.K., Moora, H., Martin, K., Nausėdė, V., Gurauskiene, I., Akule, D., 2020a. Post-consumer textile circularity in the Baltic countries : Current status and recommendations for the future, TemaNord NV - 2020:526. Nordisk Ministerråd, Copenhagen. doi:10.6027/temanord2020-526

Watson, D., Palm, D., Brix, L., Amstrup, M., Syversen, F., Nielsen, R., 2016. Exports of Nordic Used Textiles - Fate, benefits and impacts. TemaNord 2016:558.

Watson, D., Trzepacs, S., Pedersen, O.G., 2018. Mapping of textile flows in Denmark. Environmental Project No. 2025.

Watson, D., Trzepacz, S., Lander Svendsen, N., Wittus Skottfelt, S., Kiørboe, N., Elander, M., Nordin, L.., 2020b. Towards 2025: Separate collection and treatment of textiles in six EU countries, Miljøstyrelsen.

List of abbreviations and definitions

AC	Acidification
CAGR	Compound Annual Growth Rate
CAPEX	Capital expenditure
CBAM	Circular business models
CC	Climate Change
CHP	combined heat and power
COT	cotton waste
CR	chemical recycling
Ecotox	Ecotoxicity, freshwater
EG	ethylene glycol
ELCC	Environmental life cycle costing
fELCC	Full environmental life cycle costing
EN	enzymatic recycling
EPR	Extended Producer Responsibility
EU	European Union
FEU	Eutrophication, freshwater
FRU	Resource Use, fossils
FU	functional unit
Htox_c	Human Toxicity, cancer
Htox_nc	Human Toxicity, non-cancer
IN	incineration
IR	Ionising Radiation
JRC	Joint Research Centre
kt	kilotonnes
LA	landfilling
LCA	Life Cycle Assessment
LCC	Life cycle costing

LCIA	Life Cycle Impact Assessment
LU	Land Use
MEG	Mono Ethylene Glycol
MEU	Eutrophication, marine
MFA	Mass Flow Analysis
MR	Resource Use, minerals and metals
MR	mechanical recycling
MSW	municipal solid waste
Mt	Million tonnes
NIR	Near infrared
ODP	Ozone Depletion
OPEX	Operational expenditure
OR	open-loop recycling (mechanical processing to products that are different and used for different purposes than the material from which the waste has originated)
PA	polyamide waste
PA6	Polyamide 6 (Nylon 6)
PA6,6	Polyamide 6.6
PC	polycotton waste
PES	polyester
PET	Polyethylene
PM	Particulate Matter
POF	Photochemical Ozone Formation
PP	Polypropylene
PRO	Producer Responsibility Organisation
PTA	Para-terephthalic acid
RFID	Radio Frequency IDentification
RU	re-use
TEU	Eutrophication, terrestrial
TPA	terephthalic acid

VIS	viscose waste
WOL	wool waste
WU	Water Use

List of figures

List of tables

Annexes

8 Supplementary data on the Mass Flow Analysis

8.1 Methodology

8.1.1 Scope and system boundaries

The system boundaries cover the value chain of textile, starting from fibres production to the end-of-life of textile products, including fibres, yarns, fabric and finished textiles production, import and export (described in section 8.1.2). The modelling assumption in relation to 'apparent consumption and use' are described in section 8.1.3, whereas the generation and management of waste flows and emissions (post-industrial waste, pre- and post-consumer waste, and microfibre release) are described in section 8.1.4.

Prodcom database on manufactured products was used to estimate domestic production, import and export of fibres, yarns, fabrics and finished articles and derive mass of textiles put on the market in the reference year, as further detailed in sections 8.1.2 and 8.1.3. A literature review was performed to collect data on manufacturing losses, textile waste export and treatment shares (separate collection, recycling, re-use) and shedding of microfibres during washing (more details in section 8.1.4). Such review was performed through a search on the Scopus® database aimed at gathering documents related to material flow assessment at level of sectors in the EU. Several keywords were considered for screening the literature documents (titles and abstracts), such as: "mass flow model textile"; "textile Europe"; "textile flows"; "textile waste"; "pre-consumer textile waste"; "post-consumer textile waste" "microfibre releases" etc. The temporal scope of the search was 2010-2022 and EU-based studies or studies providing sector-specific information were prioritized.

8.1.2 Domestic production, import and export of fibres, yarns, fabrics and finished textile products

Textile manufacturing is a high complexity system, which, in case of this MFA model, was schematised into four main points of textiles manufacturing that were considered: fibres production, yarns production, fabrics production and finished textiles production. Fibre production stage involves both extraction of natural fibres from plants and animals and production of man-made synthetic fibres. Yarn production corresponds to the process of spinning fibres into yarns, which are then transformed into fabrics mainly by weaving and knitting. Finally, fabrics are used to produce finished products to be placed on the market. Non-woven textiles products, namely textile products which are not produced by weaving or knitting, were also considered in the MFA scope. Production of non-woven textiles was considered as part of the finished textiles production step since it involves direct transformation of fibers into finished products, by-passing intermediate manufacturing stages. Production of cordage, ropes and nets involves direct transformation of yarns in finished products, thus by-passing the fabric production stage. Flows of domestic production, import and export of fibres, yarns, fabrics and finished textiles were estimated using Prodcom database (Eurostat, 2022b), which contains data on domestic production of manufactured goods and related external trade for EU. A total of 342 products were considered in the scope of this study, falling in the NACE categories reported in Table 9, where they are mapped to each manufacturing stage. Each NACE category, identified by a single 4-digit NACE code, includes several products identified by 8-digit codes. When the same NACE category is mapped to more than one manufacturing stage, different 8-digit product codes are used to calculate flows related to each of those stages. More details on products considered in the MFA study are given in Annex 1. In case no data were available for import and export, data from Comext dataset were used. In addition, in case of some Prodcom products considered in the scope, quantities are originally expressed in pairs (e.g., footwear, gloves), number of items (many clothing products) or m2 (fabrics). Clothing and footwear products mass expressed as pairs or number items was converted into kg applying conversion factors assumed in Quantis (2021) for subcategories of products. Household products expressed as pieces were converted based on coefficients found on online sources (Carpets Closeouts, 2019; Sleep Foundation, 2023). Conversion factors assumed for all units are reported in Annex 2. In case of cordage, ropes and nets Prodcom products description of yarns product does not allow to identify mass flows of yarns specifically dedicated to the production of such finished products. Mass of yarns directly flowing from yarns production to finished products production for manufacturing of cordage, ropes and nets is estimated as equal to the mass of domestically manufactured products of such kind (which is available in Prodcom). Then, shares of import and domestic production of the estimated mass are assumed as equal to the overall shares of import and domestic production of the total production of all other type of yarns.

Table 9. NACE categories of Prodcom products considered in the Mass Flow Analysis

MFA manufacturing stage	4-digit code	NACE category
Fibres production	1310	Preparation and spinning of textile fibres
	2060	Manufacture of man-made fibres
Yarns production	1310	Preparation and spinning of textile fibres
	2060	Manufacture of man-made fibres
	1399	Manufacture of other textiles n.e.c.
	1396	Manufacture of other technical and industrial textiles
Fabrics production	1391	Manufacture of knitted and crocheted fabrics
	1320	Weaving of textiles
	1399	Manufacture of other textiles n.e.c.
	1396	Manufacture of other technical and industrial textiles
Finished Textiles production	1392	Manufacture of carpets and rugs
	1520	Manufacture of footwear
	1413	Manufacture of other outerwear
	1412	Manufacture of workwear
	1419	Manufacture of other wearing apparel and accessories
	1414	Manufacture of underwear
	1439	Manufacture of other knitted and crocheted apparel
	1431	Manufacture of knitted and crocheted hosiery
	1394	Manufacture of cordage, rope, twine and netting
	1396	Manufacture of other technical and industrial textiles

	1399	Manufacture of other textiles n.e.c.
	1395	Manufacture of non-wovens and articles made from non-wovens, except apparel

8.1.3 Apparent consumption and Use

Apparent consumption (AC) means domestic retail, namely all retail activities selling finished textile products in EU. “Use” indicates the use of textile products by consumers for clothing, household, and technical purposes. Input flow of the retail node was calculated as:

$$AC_{in} = Import_{fin.prod.} + Production_{fin.prod.} - Export_{fin.prod.}$$

where $Import_{fin.prod.}$, $Production_{fin.prod.}$ and $Export_{fin.prod.}$ are import, domestic production and export of finished textiles products, respectively. Output flows of the AC node are the input flow to the use node, namely the flow of finished textiles put in the EU market, and the flow of export of unsold products. They are calculated as:

$$Export_{unsold} = \alpha AC_{in}$$

$$Use_{in} = AC_{in} - Export_{unsold}$$

where $Export_{unsold}$ is the export of unsold products (i.e., pre-consumer waste) and α is the share of products which remain unsold and is then exported. α was calculated assuming that 4% of AC_{in} is unsold and 70% of unsold products are exported outside EU, with remaining 30% re-inputted into EU retail market (McKinsey, 2022). Output flows of the Use node are post-consumer waste and stock. These flows are detailed in section 8.1.4.

8.1.4 Textile waste

8.1.4.1 Post-industrial waste

It is referred to the main text, section 3.1.2.1. Coefficients of generation of textile waste from manufacturing processes were obtained from Sadowski et al. (2021).

8.1.4.2 Post-consumer waste

It is referred to the main text, section 3.1.2.3.

The calculation of Post-Consumer Waste (PCW) is calculated as follows assuming an average life time expectancy:

$$y_w = y_r + LE$$

$PCW = \sum_i Use_{in,i,y_w}$ where $y_w = MFAreferenceyear$

Where:

y_w is the year when a given product becomes waste, i.e., it is discarded by the user.

y_r is the year when a given product is put on the EU market, either because it was imported or produced in the EU.

LE is life expectancy of a given product.

Use_{in,i,y_w} is the mass flow input to the Use node (i.e., put on the EU market) of product i which is discarded in year y_w.

8.1.4.3 Stock

Difference between the flow of textiles put on the market (Use_{in}, see section 8.1.3) post-consumer waste and microfibres release go into Stock, representing the variation of textile mass stored in EU.

8.1.4.4 Waste treatment

It is referred to section 3.1.2.5 of the main text and Annex 4 of this section for all assumptions on the modelling of textile waste flows.

Microfibres release

It was estimated that at global level washing synthetics releases 0.5 million tons of microfibres into the ocean, accounting for 35% of primary microplastics released into the environment (EEA, 2022c). A single laundry load of polyester clothes can discharge 700.000 microplastic fibres that can end up in the food chain. However, the overall quantity of microplastics released by textile into the environment varies across different publications. Indeed, the final estimated range for the microplastics generated from the washing of synthetic clothing ranges between 13.000—40.000 tons per year (Hann et al., 2018; ECHA, 2020; OECD, 2022). In this study, along with the estimation of microfibres (MF) released by the washing of synthetic textiles, also the release due to the washing of natural textiles has been calculated by means of the following formula:

$MF = \alpha_i Use_{in} \beta_i w$

Where:

$\alpha_i(\frac{mg}{kg*wash})$: shedding fibre coefficient for fibre type i. (see Annex 5)

β_i: content of fibre type i of input flow to use node.

w: number of washes per year (Hann et al., 2018).

As can be understood from the above-described formula, only washing of new textile products starting to be used in the MFA reference year is considered in the calculation of microfibres shedding, while washing of older products (starting to be used at least one year earlier than MFA reference year) is neglected, since an estimate of total mass of textiles in use in EU was not found for any year. Also, the fact that not all textile products in use in the EU have the same usage rate is not considered. Since it is likely that newer products are the most used, being purchased for immediate needs and pushed by latest fashion trends, consumption of new products was anyway considered a good proxy of products undergoing washing in MFA reference year, in lack of more precise data.

8.1.4.5 Composition

Composition of flows of finished products put and sold on the EU market (Use_{in}, see section 8.1.3) and post-consumer waste was estimated at the level of categories, subcategories, and fibres, as described in sections 8.1.4.7, 8.1.4.8 and 8.1.4.9.

8.1.4.6 Categories

As often assumed in literature (EEA, 2019; Euratex, 2021; EC-JRC, 2021), textiles products were categorised as: clothing and footwear, home textiles, and technical textiles, in line with EEA (2019), EURATEX (2021) and Köhler et al. (2021). In this analysis, this last category includes ropes, cordage, twines, netting, sails, parachutes, textile hose piping, tents, tarpaulins, sunblinds, labels and badges, and conveyor belts. The assignment of each product to categories was based on the description of NACE category and Prodcom code (see section 8.1.1 for details on Prodcom dataset use and processing).

8.1.4.7 Subcategories

Considered products were assigned to subcategories with higher level of detail, as summarised in Annex 6. Clothing and footwear products subcategories defined in Quantis (2021) were assumed, which already classifies most of relevant Prodcom product codes, assigning 6-digits Prodcom codes to each sub-category. Since 6-digit Prodcom codes can include a group of several products identified by 8-digit code, same 6-digit code is sometimes assigned to multiple subcategories in Quantis (2021). In such cases, in this work 6-digit codes were assigned to subcategories representing most of single products within the group. Products within this work scope which were not classified in Quantis (2021) were assigned to sub-categories based on

Prodcom description of product. Household products subcategories were assigned to products based on description of Prodcom NACE codes and 8-digit codes. Since only a smaller number of technical textiles were included in the work's scope, they were not divided into subcategories. This was assumed since only generic fibres composition (and not specifically for group of products) of technical textiles was found in the literature, as further detailed in section 8.1.4.9. Prodcom data on mass flows belonging to subcategories "carpets", "cleaning articles" and "non-woven articles" were assumed as including both household and technical articles. In such cases, mass was allocated to "small textile waste items from households" and "professional textile waste and textiles contained in bulky waste" categories (see section 8.1.4.7 and Annex 6) based on shares derived from literature data (Huggard Consulting Group, 2016; Grand View Research, 2018; AISE, 2023; Edana, 2023).

8.1.4.8 Fibres

Composition by type of textile fibre was estimated by assigning a representative composition to each sub-category. Sub-category compositions from Quantis (2021) for clothing and footwear category were assumed. Compositions of household sub-categories were estimated based on composition data on products from two selected representative manufacturing companies (Gabel Group, 2022; IKEA, 2022). Technical textile products composition reported in Khalifa (2012) was assumed for all products within the category. Compositions assumed for all subcategories are reported in Annex 7. As can be noticed, some shares of non-textile materials are included in composition of a few subcategories (particularly in case of clothing and footwear) and they were removed from the MFA flows, since they represent non-textiles parts of products (e.g., rubber in footwear soles, leather, fur and metal parts in clothing, glass fibres in technical textiles).

8.1.5 Uncertainty analysis

Uncertainty assessment was done using Monte Carlo simulation for the following parameters:

Life Expectancy parameter: Minimum and maximum values are provided for each product according to Laitala et al. (2018). Then, two data points are considered for the analysis.

Separate collection share: five data points for textile waste that can be separately collected are considered.

Recycling: five data points for textile waste that can be recycled (i.e. for non-fibre to fibre applications or wipers) are considered.

Export of separately collected waste: three data points for separately collected textile waste that are exported (the other amount goes to sorting) are considered.

Re-use (in and outside EU): four data points for sorted textile waste that are re-used in and outside EU are considered.

Share of domestic re-use: two data points, (calculated from data reported in Annex 4 for the share of domestic re-use (i.e., re-use in EU)) are considered.

Microfibre release: Standard deviation for each shedding coefficient is measured.

Besides standard descriptive statistics, relative uncertainty was calculated on results of Monte Carlo simulations, as done in previous research on probabilistic MFA (Kawecki et al., 2018). Relative uncertainty is defined as the standard deviation divided by the mean of the mass distributions and is here used as a measure of the spread of results distribution, normalised by its mean value.

8.2 Supplementary results

8.2.1 Annexes to the Mass Flow Analysis

Annex 1 Textile products considered in the analysis

Following table reports complete inventory of Prodcom textile products considered in MFA scope.

Prodcom 8-digit code	Product description

13104030	Yarn spun from silk waste, n.p.r.s.
13921450	Woven toilet linen and kitchen linen, of textiles (excluding terry towelling or similar terry fabrics of cotton)
13931100	Knotted carpets and other knotted textile floor coverings
13931200	Woven carpets and other woven textile coverings (excluding tufted or flocked)
13931300	Tufted carpets and other tufted textile floor coverings
13931930	Needlefelt carpets and other needlefelt textile floor coverings (excluding tufted or flocked)
13931990	Carpets and other textile floor coverings (excluding knotted, woven, tufted, needlefelt)
13102100	Raw silk (not thrown)
13102200	Wool, degreased or carbonised, not carded or combed
13102300	Noils of wool or fine animal hair
13102400	Wool or animal hair, carded or combed (including wool tops)
13102500	Cotton, carded or combed
13102600	Jute and other textile fibres (except flax, true hemp and ramie), processed but not spun
13102900	Other vegetable textile fibres, processed but not spun
13103100	Synthetic staple fibres, carded, combed or otherwise processed for spinning
13103200	Artificial staple fibres, carded, combed or otherwise processed for spinning
13104010	Silk yarn, n.p.r.s. (excluding spun from silk waste)
13104050	Silk yarn and silk waste yarn, p.r.s.; silk-worm gut
13105010	Yarn of carded wool or fine animal hair, n.p.r.s.
13105030	Yarn of combed wool or fine animal hair, n.p.r.s.
13105050	Yarn of wool or fine animal hair, p.r.s.
13106132	Yarn of uncombed cotton, n.p.r.s., for woven fabrics (excluding for carpets and floor coverings)
13106133	Yarn of uncombed cotton, n.p.r.s., for knitted fabrics and hosiery
13106135	Yarn of uncombed cotton, n.p.r.s., for other uses (including carpets and floor coverings)
13106152	Yarn of combed cotton, n.p.r.s., for woven fabrics (excluding for carpets and floor coverings)

13106153	Yarn of combed cotton, n.p.r.s., for knitted fabrics and hosiery
13106155	Yarn of combed cotton, n.p.r.s., for other uses (including carpets and floor coverings)
13106160	Cotton yarn, p.r.s. (excluding sewing thread)
131061Z1	Cotton yarn of uncombed fibres, n.p.r.s.
131061Z2	Cotton yarn of combed fibres, n.p.r.s.
13106200	Cotton sewing thread
13107110	Flax yarn, n.p.r.s.
13107120	Flax yarn, p.r.s.
13107200	Yarn of vegetable or bast fibres (excluding flax); paper yarn
13108110	Multiple or cabled synthetic filament yarn, n.p.r.s.
13108130	Multiple or cabled yarn of artificial filaments, n.p.r.s. (excluding sewing thread)
13108150	Man-made filament yarn, p.r.s. (excluding sewing thread)
13108210	Yarn (other than sewing thread) containing >= 85 % by weight of synthetic staple fibres, n.p.r.s.
13108250	Yarn (other than sewing thread) containing >= 85 % by weight of synthetic staple fibres, p.r.s.
13108320	Yarn containing < 85 % by weight of polyester staple fibres (other than sewing thread), mixed with artificial fibres, n.p.r.s.
13108333	Yarn containing < 85 % by weight of synthetic staple fibres (other than sewing thread) mixed with carded wool or fine animal hair, n.p.r.s.
13108336	Yarn containing < 85 % by weight of synthetic staple fibres, mixed with combed wool or fine animal hair, n.p.r.s.
13108340	Yarn containing < 85 % by weight of synthetic staple fibres (other than sewing thread), mixed with cotton, n.p.r.s.
13108380	Other yarns, containing < 85 % by weight of synthetic staple fibres (other than sewing thread), n.p.r.s., n.e.c.
13108390	Yarn containing < 85 % by weight of synthetic staple fibres (other than sewing thread), p.r.s.
131083Z0	Yarn of synthetic staple fibres mixed with wool, n.p.r.s
13108410	Yarn (other than sewing thread) of artificial staple fibres, n.p.r.s.
13108430	Yarn (other than sewing thread) of artificial staple fibres, p.r.s.
13108510	Sewing thread of man-made filaments
13108550	Sewing thread of man-made staple fibres

13201100	Woven fabrics of silk or silk waste
13201230	Woven fabrics of carded wool or carded fine animal hair
13201260	Woven fabrics of combed wool or combed fine animal hair; woven fabrics of coarse animal hair
13201330	Woven fabrics of flax, containing >= 85 % by weight of flax
13201360	Woven fabrics of flax, containing < 85 % by weight of flax
13201400	Woven fabrics of jute or of other textile bast fibres (excluding flax, true hemp, ramie)
13201900	Woven fabrics of true hemp, ramie or other vegetable textile fibres (excluding flax, jute, other textile bast fibres); paper yarn
13202014	Woven fabrics of cotton, not of yarns of different colours, weighing <= 200 g/m², for clothing
13202017	Woven fabrics of cotton, not of yarns of different colours, weighing <= 200 g/m², for household linen or home furnishing textiles
13202019	Woven fabrics of cotton, not of yarns of different colours, weighing <= 200 g/m², for technical or industrial uses (excluding gauze, medical gauze)
13202020	Woven fabrics of cotton weighing <= 100 g/m², for medical gauzes, bandages and dressings
13202031	Woven fabrics of cotton of yarns of different colours, weighing <= 200 g/m², for shirts and blouses
13202042	Woven fabrics of cotton, not of yarns of different colours, weighing > 200 g/m², for clothing
13202044	Woven fabrics of cotton, not of yarns of different colours, weighing > 200 g/m², for household linen or home furnishing textiles
13202049	Woven fabrics of cotton, not of yarns of different colours, weighing > 200 g/m², for technical or industrial uses
13202060	Woven fabrics of denim cotton weighing > 200 g/m² (including denim other than blue)
13202072	Woven fabrics of cotton of yarns of different colours, for other clothing
13202074	Woven fabrics of cotton of yarns of different colours, for household linen or home furnishing textiles
13202079	Woven fabrics of cotton of yarns of different colours, for technical or industrial uses
132020Z1	Cotton fabrics, <= 200 g/m² (excluding gauze and coloured yarns)
132020Z2	Cotton fabrics, > 200 g/m² (excluding coloured yarns)
132020Z3	Woven fabrics of cotton of yarns of different colours (excluding denim)
13203130	Woven fabrics of man-made filament yarns obtained from high tenacity yarn, strip or the like (including nylon, other polyamides, polyester, viscose rayon)
13203150	Woven fabrics of synthetic filament yarns (excluding those obtained from high tenacity yarn or strip and the like)
13203170	Woven fabrics of artificial filament yarns (excluding those obtained from high tenacity yarn)

13203210	Woven fabrics of synthetic staple fibres, containing 85 % or more by weight of synthetic staple fibres
13203220	Woven fabrics of synthetic staple fibres, containing less than 85 % by weight of such fibres, mixed mainly or solely with cotton (excluding fabrics of yarns of different colours)
13203230	Woven fabrics of synthetic staple fibres, containing less than 85 % by weight of such fibres, mixed mainly or solely with cotton, of yarns of different colours
13203240	Woven fabrics of synthetic staple fibres mixed mainly or solely with carded wool or fine animal hair
13203250	Woven fabrics of synthetic staple fibres mixed mainly or solely with combed wool or fine animal hair
13203290	Woven fabrics of synthetic staple fibres mixed other than with wool, fine animal hair or cotton
13203330	Woven fabrics of artificial staple fibres, not of yarns of different colours
13203350	Woven fabrics of artificial staple fibres, of yarns of different colours
13204100	Warp and weft pile fabrics; chenille fabrics (excluding terry towelling and similar woven terry fabrics of cotton, tufted textile fabrics, narrow fabrics)
13204200	Terry towelling and similar woven terry fabrics of cotton
13204300	Terry towelling and similar woven terry fabrics (excluding of cotton)
13204400	Gauze (excluding medical gauze, narrow woven fabrics)
13204500	Tufted textile fabrics (excluding tufted carpets and other textile floor coverings)
13204600	Woven fabrics of glass fibre (including narrow fabrics, glass wool)
13911100	Pile fabrics, terry fabrics, knitted or crocheted
13911910	Knitted or crocheted fabrics (excluding pile fabrics)
13921130	Blankets and travelling rugs of wool or fine animal hair (excluding electric blankets)
13921150	Blankets and travelling rugs of synthetic fibres (excluding electric blankets)
13921190	Blankets (excluding electric blankets) and travelling rugs of textile materials (excluding of wool or fine animal hair, of synthetic fibres)
13921230	Bed linen of knitted or crocheted textiles
13921253	Bed linen of cotton (excluding knitted or crocheted)
13921255	Bed linen of flax or ramie (excluding knitted or crocheted)
13921259	Bed linen of woven textiles (excluding of cotton, of flax or ramie)
13921270	Bed linen of non-woven man-made fibres (excluding knitted or crocheted)
13921330	Table linen of knitted or crocheted textiles

13921353	Table linen of cotton (excluding knitted or crocheted)
13921355	Table linen of flax (excluding knitted or crocheted)
13921359	Table linen of woven man-made fibres and of other woven or non-woven textiles (excluding of cotton, of flax)
13921370	Table linen of non-woven man-made fibres
13921430	Toilet linen and kitchen linen, of terry towelling or similar terry fabrics of cotton
13921470	Toilet linen and kitchen linen, of non-woven man-made fibres
13921530	Curtains and interior blinds, curtain or bed valances, of knitted or crocheted materials
13921550	Curtains and interior blinds, curtain or bed valances, of woven materials
13921570	Curtains and interior blinds, curtain or bed valances, of non-woven materials
13921620	Hand-woven tapestries of the type Gobelins, Flanders, Aubusson, Beauvais, and needle-worked tapestries (including petit point, cross-stitch) whether or not made up
13921640	Bedspreads (excluding eiderdowns)
13921660	Furnishing articles including furniture and cushion covers as well as cushion covers, etc. for car seats (excluding blankets, travelling rugs, bed linen, table linen, toilet linen, kitchen linen, curtains, blinds, valances and bedspreads)
13922130	Sacks and bags, of cotton, used for packing goods
13922150	Sacks and bags, of knitted or crocheted polyethylene or polypropylene strip, used for packing goods
13922170	Sacks and bags, of polyethylene or polypropylene strip, used for packing goods (excluding knitted or crocheted)
13922173	Sacks and bags, of polyethylene or polypropylene strip, weighing <= 120 g/m2, used for packing goods (excluding knitted or crocheted)
13922175	Sacks and bags, of polyethylene or polypropylene strip, weighing > 120 g/m2, used for packing goods (excluding knitted or crocheted)
13922190	Sacks and bags, used for packing goods (excluding of cotton, polyethylene or polypropylene strip)
13922210	Tarpaulins, awnings and sunblinds (excluding caravan awnings)
13922230	Tents (including caravan awnings)
13922250	Sails
13922300	Parachutes and rotochutes, parts and accessories (including dirigible parachutes)
13922430	Sleeping bags
13922493	Articles of bedding of feathers or down (including quilts and eiderdowns, cushions, pouffes, pillows) (excluding mattresses, sleeping bags)

13922499	Articles of bedding filled other than with feathers or down (including quilts and eiderdowns, cushions, pouffes, pillows) (excluding mattresses, sleeping bags)
13922953	Floor-cloths, dish-cloths, dusters and similar cleaning cloths, of non-woven textiles
13922957	Floor-cloths, dish-cloths, dusters and similar cleaning cloths (excluding knitted or crocheted, articles of non-woven textiles)
13922990	Floor-cloths, dish-cloths, dusters and similar cleaning cloths, knitted or crocheted; life-jackets, life-belts and other made up articles
13922993	
13922997	
13922998	Floor-cloths, dish-cloths, dusters and similar cleaning cloths, knitted or crocheted; life-jackets, life-belts and other made up articles (excluding protective face masks, sanitary towels and napkins and similar articles)
13922999	Floor-cloths, dish-cloths, dusters and similar cleaning cloths, knitted or crocheted; life-jackets, life-belts and other made up articles (excluding sanitary towels and napkins and similar articles)
13941130	Twine, cordage, rope or cables, of sisal or other textile fibres of 'agave', of jute or other textile bast fibres and hard leaf fibres (excluding binder or baler twine)
13941133	Twine, cordage, rope or cables, of sisal or other textile fibres of 'agave' measuring >100,000 decitex, of jute or other textile bast fibres and hard leaf fibres (excluding binder or baler twine)
13941135	Twines of sisal measuring <= 100,000 decitex (10 g/m) (excluding binder or baler twine)
13941153	Sisal binder or baler (agricultural) twines
13941155	Polyethylene or polypropylene binder or baler (agricultural) twines
13941160	Cordage, ropes or cables of polyethylene, polypropylene, nylon or other polyamides or of polyesters measuring > 50 000 decitex, of other synthetic fibres (excluding binder or baler twine)
13941170	Twines of polyethylene or polypropylene, of nylon or other polyamides or polyesters measuring <= 50 000 decitex (5 g/m) (excluding binder or baler twine)
13941190	Twines, cordage, rope and cables of textile materials (excluding jute and other textile bast fibres, sisal, abaca or other hard leaf fibres, synthetic fibres)
13941233	Made-up fishing nets from twine, cordage or rope of man-made fibres (excluding fish landing nets)
13941235	Made-up fishing nets from yarn of man-made fibres (excluding fish landing nets)
13941253	Made-up nets from twine, cable or rope of nylon or other polyamides (excluding netting in the piece produced by crochet, hairnets, sports and fishing nets)
13941255	Made-up nets of nylon or other polyamides (excluding netting in the piece produced by crochet, hairnets, sports and fishing nets, those made from twine, cable or rope)
13941259	Knotted netting of textile materials (excluding made-up fishing nets of man-made textiles, other made-up nets of nylon or other polyamides)
13941280	Articles of twine, cordage, rope or cables
13951010	Non-wovens of a weight <= 25 g/m² (including articles made from non-wovens) (excluding articles of apparel, coated or covered)

13951020	Non-wovens of a weight of > 25 g/m² but <= 70 g/m² (including articles made from non-wovens) (excluding articles of apparel, coated or covered)
13951030	Non-wovens of a weight of > 70 g/m² but <= 150 g/m² (including articles made from non-wovens) (excluding articles of apparel, coated or covered)
13951050	Non-wovens of a weight of > 150 g/m² (including articles made from non-wovens) (excluding articles of apparel, coated or covered)
13951070	Non-wovens, coated or covered (including articles made from non-wovens) (excluding articles of apparel)
13961100	Metallised yarn or metallised gimped yarn
13961300	Rubber thread and cord, textile covered; textile yarn and strip impregnated, coated, covered or sheathed with rubber or plastics
13961400	Textile fabrics, impregnated, coated or covered n.e.c.
13961500	Tyre cord fabrics of high tenacity yarn, of nylon, other polyamides, polyesters or viscose rayon
13961620	Textile hosepiping and similar textile tubing, whether or not impregnated or coated, with or without lining, armour or accessories of other materials
13961650	Textile wicks, conveyor belts or belting (including reinforced with metal or other material)
13961680	Textile fabrics and felts, for paper-making machines or similar machines (including for pulp or asbestos-cement)
13961730	Narrow woven fabrics other than labels, badges and other similar articles
13961750	Labels, badges and similar articles in textile materials (excluding embroidered)
13961770	Braids in the piece; tassels and pompons, ornamental trimmings (excluding knitted or crocheted)
13991130	Tulles and other net fabrics (excluding woven, knitted or crocheted)
13991150	Machine-made lace in the piece, in strips or in motifs
13991170	Hand-made lace in the piece, in strips or in motifs
13991230	Embroidery (without visible ground) in the piece, in strips or in motifs
13991250	Cotton embroidery in the piece, in strips or in motifs (excluding embroidery without visible ground)
13991270	Embroidery of textiles in the piece, in strips or in motifs (excluding without visible ground, cotton)
13991300	Felt, whether or not impregnated, coated, covered or laminated, n.e.c.
13991400	Textile flock and dust and mill neps
13991500	Gimped yarn and gimped strip and the like, of man-made textile materials of an apparent width <= 5 mm; chenille yarn; loop wale-yarn
13991600	Quilted textile products in the piece (excluding embroidery)
13991900	

14121120	Men’s or boys’ ensembles, of cotton or man-made fibres, for industrial and occupational wear
14121130	Men’s or boys’ jackets and blazers, of cotton or man-made fibres, for industrial and occupational wear
14121240	Men’s or boys’ trousers and breeches, of cotton or man-made fibres, for industrial or occupational wear
14121250	Men’s or boys’ bib and brace overalls, of cotton or man-made fibres, for industrial or occupational wear
14122120	Women’s or girls’ ensembles, of cotton or man-made fibres, for industrial or occupational wear
14122130	Women’s or girls’ jackets and blazers, of cotton or man-made fibres, for industrial or occupational wear
14122240	Women’s or girls’ trousers and breeches, of cotton or man-made fibres, for industrial or occupational wear
14122250	Women’s or girls’ bib and brace overalls, of cotton or man-made fibres, for industrial or occupational wear
14123013	Men’s or boys’ other garments, of cotton or man-made fibres, for industrial or occupational wear
14123023	Women’s or girls’ other garments, of cotton or man-made fibres, for industrial or occupational wear
14131110	Men’s or boys’ overcoats, car-coats, capes, cloaks and similar articles, of knitted or crocheted textiles (excluding jackets and blazers, anoraks, wind-cheaters and wind-jackets)
14131120	Men’s or boys’ waistcoats, anoraks, ski-jackets, wind-cheaters, wind-jackets and similar articles, of knitted or crocheted textiles (excluding jackets and blazers)
14131230	Men’s or boys’ jackets and blazers, of knitted or crocheted textiles
14131260	Men’s or boys’ suits and ensembles, of knitted or crocheted textiles
14131270	Men’s or boys’ trousers, breeches, shorts, bib and brace overalls, of knitted or crocheted textiles
14131310	Women’s or girls’ overcoats, car-coats, capes, cloaks and similar articles, of knitted or crocheted textiles (excluding jackets and blazers)
14131320	Women’s or girls’ waistcoats, anoraks, ski-jackets, wind-cheaters, wind-jackets and similar articles, of knitted or crocheted textiles (excluding jackets and blazers)
14131430	Women’s or girls’ jackets and blazers, of knitted or crocheted textiles
14131460	Women’s or girls’ suits and ensembles, of knitted or crocheted textiles
14131470	Women’s or girls’ dresses, of knitted or crocheted textiles
14131480	Women’s or girls’ skirts and divided skirts, of knitted or crocheted textiles
14131490	Women’s or girls’ trousers, breeches, shorts, bib and brace overalls, of knitted or crocheted textiles
14132110	Men’s or boys’ raincoats
14132115	Men’s or boys’ raincoats, overcoats, car-coats, capes, etc.

14132120	Men's or boys' overcoats, car-coats, capes, etc
14132130	Men's or boys' waistcoats, anoraks, ski-jackets, wind-jackets and similar articles (excluding jackets and blazers, knitted or crocheted, impregnated, coated, covered, laminated or rubberised)
14132200	Men's or boys' suits & ensembles (excluding knitted or crocheted)
14132210	Men's or boys' suits (excluding knitted or crocheted)
14132220	Men's or boys' ensembles (excluding knitted or crocheted)
14132300	Men's or boys' jackets and blazers (excluding knitted or crocheted)
14132442	Men's or boys' trousers and breeches, of denim (excluding for industrial or occupational wear)
14132444	Men's or boys' trousers, breeches and shorts, of wool or fine animal hair (excluding knitted or crocheted, for industrial or occupational wear)
14132445	Men's or boys' trousers and breeches, of man-made fibres (excluding knitted or crocheted, for industrial or occupational wear)
14132448	Men's or boys' trousers and breeches, of cotton (excluding denim, knitted or crocheted)
14132449	Men's or boys' trousers, breeches, shorts and bib and brace overalls (excluding of wool, cotton and man-made fibres, knitted or crocheted)
14132455	Men's or boys' bib and brace overalls (excluding knitted or crocheted, for industrial or occupational wear)
14132460	Men's or boys' shorts, of cotton or man-made fibres (excluding knitted or crocheted)
14133110	Woman's or girls' raincoats
14133115	Woman's or girls' raincoats and overcoats, etc
14133120	Woman's or girls' overcoats, etc
14133130	Women's or girls' waistcoats, anoraks, ski-jackets, wind-jackets and similar articles (excluding jackets and blazers, knitted or crocheted, impregnated, coated, covered, laminated or rubberised)
14133200	Women's or girls' suits & ensembles (excluding knitted or crocheted)
14133210	Women's or girls' suits (excluding knitted or crocheted)
14133220	Women's or girls' ensembles (excluding knitted or crocheted)
14133330	Women's or girls' jackets and blazers (excluding knitted or crocheted)
14133470	Women's or girls' dresses (excluding knitted or crocheted)
14133480	Women's or girls' skirts and divided skirts (excluding knitted or crocheted)
14133542	Women's or girls' trousers and breeches, of denim (excluding for industrial or occupational wear)

14133548	Women's or girls' trousers and breeches, of cotton (excluding denim, for industrial or occupational wear)
14133549	Women's or girls' trousers and breeches, of wool or fine animal hair or man-made fibres (excluding knitted or crocheted and for industrial and occupational wear)
14133551	Women's or girls' bib and brace overalls, of cotton (excluding knitted or crocheted, for industrial or occupational wear)
14133561	Women's or girls' shorts, of cotton (excluding knitted and crocheted)
14133563	Women's or girls' bib and brace overalls, of wool or fine animal hair and man-made fibres (excluding cotton, knitted or crocheted, for industrial or occupational wear) and women's or girls' shorts, of wool or fine animal hair (excluding knitted or crocheted)
14133565	Women's or girls' shorts, of man-made fibres (excluding knitted or crocheted)
14133569	Women's or girls' trousers, breeches, bib and brace overalls, of textiles (excluding cotton, wool or fine animal hair, man-made fibres, knitted or crocheted)
14141100	Men's or boys' shirts, knitted or crocheted
14141220	Men's or boys' underpants and briefs, of knitted or crocheted textiles (including boxer shorts)
14141230	Men's or boys' nightshirts and pyjamas, of knitted or crocheted textiles
14141240	Men's or boys' dressing gowns, bathrobes and similar articles, of knitted or crocheted textiles
14141310	Women's or girls' blouses, shirts and shirt-blouses, of knitted or crocheted textiles
14141420	Women's or girls' briefs and panties, of knitted or crocheted textiles (including boxer shorts)
14141430	Women's or girls' nighties and pyjamas, of knitted or crocheted textiles
14141440	Women's or girls' negligees, bathrobes, dressing gowns and similar articles, of knitted or crocheted textiles
14141450	Women's or girls' slips and petticoats, of knitted or crocheted textiles
14142100	Men's or boys' shirts (excluding knitted or crocheted)
14142220	Men's or boys' underpants and briefs (including boxer shorts) (excluding knitted or crocheted)
14142230	Men's or boys' nightshirts and pyjamas (excluding knitted or crocheted)
14142240	Men's or boys' singlets, vests, bathrobes, dressing gowns and similar articles (excluding knitted or crocheted)
14142300	Women's or girls' blouses, shirts and shirt-blouses (excluding knitted or crocheted)
14142430	Women's or girls' nightdresses and pyjamas (excluding knitted or crocheted)
14142450	Women's or girls' slips and petticoats (excluding knitted or crocheted)
14142460	Women's or girls' singlets and other vests, briefs, panties, negligees, bathrobes, dressing gowns, housecoats and similar articles of cotton (excluding knitted or crocheted)

14142480	Women's or girls' negligees, bathrobes, dressing gowns, singlets, vests, briefs and panties (including boxer shorts), of man-made fibres (excluding knitted or crocheted)
14142489	Women's or girls' singlets, vests, briefs, panties, negligees, bathrobes, dressing gowns and similar articles, of textiles (excluding cotton, man-made fibres, knitted or crocheted)
14142530	Brassieres
14142550	Girdles, panty-girdles and corselettes (including bodies with adjustable straps)
14142570	Braces, suspenders, garters and similar articles and parts thereof
14143000	T-shirts, singlets and vests, knitted or crocheted
14191100	Babies' garments and clothing accessories, knitted or crocheted including vests, rompers, underpants, stretch-suits, gloves or mittens or mitts, outerwear (for children of height <= 86 cm)
14191210	Track-suits, of knitted or crocheted textiles
14191230	Ski-suits, of knitted or crocheted textiles
14191240	Men's or boys' swimwear, of knitted or crocheted textiles
14191250	Women's or girls' swimwear, of knitted or crocheted textiles
14191290	Other garments, knitted or crocheted (including bodies with a proper sleeve)
14191300	Gloves, mittens and mitts, of knitted or crocheted textiles
14191930	Shawls, scarves, mufflers, mantillas, veils and the like, of knitted or crocheted textiles
14191960	Clothing accessories and parts thereof, of knitted or crocheted textiles (excluding gloves, mittens, shawls, scarves, mufflers, mantillas and veils)
14192100	Babies' clothing and accessories, of textiles, not knitted or crocheted (for children of height <= 86 cm) including vests, rompers, underpants, stretch-suits, napkins, gloves, mittens and outerwear
14192150	Babies clothing and accessories, of textiles, not knitted or crocheted (for children of height <= 86 cm) including vests, rompers, underpants, stretch-suits, gloves, mittens and outerwear (excluding sanitary towels and napkins and similar articles)
14192210	Other men's or boys' apparel n.e.c., including tracksuits and jogging suits (excluding waistcoats, ski-suits, knitted or crocheted)
14192220	Other women's or girls' apparel n.e.c., including tracksuits and jogging suits (excluding waistcoats, ski-suits, knitted or crocheted)
14192230	Ski-suits (excluding of knitted or crocheted textiles)
14192240	Men's or boys' swimwear (excluding of knitted or crocheted textiles)
14192250	Women's or girls' swimwear (excluding of knitted or crocheted textiles)
14192310	Handkerchiefs
14192333	Shawls, scarves, mufflers, mantillas, veils and the like (excluding articles of silk or silk waste, knitted or crocheted)

14192338	Shawls, scarves, mufflers, mantillas, veils and the like, of silk or silk waste (excluding knitted or crocheted)
14192353	Ties, bow ties and cravats (excluding articles of silk or silk waste, knitted or crocheted)
14192358	Ties, bow ties and cravats, of silk or silk waste (excluding knitted or crocheted)
14192370	Gloves, mittens and mitts (excluding knitted or crocheted)
14192393	Clothing accessories of textiles (excluding shawls, scarves and mufflers, mantillas and veils, ties, bow-ties and cravats, gloves, mittens and mitts, knitted or crocheted)
14192395	Parts of garments or of clothing accessories, of textiles (excluding bras, girdles and corsets, braces, suspenders and garters, knitted or crocheted)
14192396	Clothing accessories, parts of garments or of clothing accessories, of textiles, n.e.c. and parts thereof, (excluding shawls, scarves and mufflers, mantillas and veils, ties, bow-ties and cravats, gloves, mittens and mitts and parts thereof; bras, girdles and corsets, braces, suspenders and garters
14193180	Belts and bandoliers, of leather or composition leather
14193190	Clothing accessories of leather or composition leather (excluding gloves, mittens and mitts, belts and bandoliers)
14193200	Garments made up of felt or non-wovens, textile fabrics impregnated or coated
14194130	Hat-forms, hat bodies and hoods, plateaux and manchons of felt (including slit manchons) (excluding those blocked to shape, those with made brims)
14194150	Hat-shapes, plaited or made by assembling strips of any material (excluding those blocked to shape, those with made brims, those lined or trimmed)
14194230	Felt hats and other felt headgear, made from hat bodies or hoods and plateaux
14194250	Hats and other headgear, plaited or made by assembling strips of any material
14194270	Hats and other headgear, knitted or crocheted or made-up from lace, felt or other textile fabric in the piece (but not in strips); hair-nets of any material
14194300	Other headgear (except headgear of rubber or of plastics, safety headgear and asbestos headgear); headbands, linings, covers, hat foundations, hat frames, peaks and chinstraps, for headgear
14311033	Panty hose and tights, of knitted or crocheted synthetic fibres, measuring per single yarn < 67 decitex
14311035	Panty hose and tights, of knitted or crocheted synthetic fibres, measuring per single yarn >= 67 decitex
14311037	Pantyhose and tights of textile materials, knitted or crocheted (excl. graduated compression hosiery, those of synthetic fibres and hosiery for babies)
14311050	Women's full-length or knee-length knitted or crocheted hosiery, measuring per single yarn < 67 decitex
14311090	Knitted or crocheted hosiery and footwear (including socks; excluding women's full-length/knee-length hosiery, measuring <67decitex, panty-hose and tights, footwear with applied soles)
14391031	Men's or boys' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of wool or fine animal hair (excluding jerseys and pullovers containing >= 50 % of wool and weighing >= 600 g)
14391032	Women's or girls' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of wool or fine animal hair (excluding jerseys and pullovers containing >= 50 % of wool and weighing >= 600 g)

14391033	Jerseys and pullovers, containing >= 50 % by weight of wool and weighing >= 600 g per article
14391053	Lightweight fine knit roll, polo or turtle neck jumpers and pullovers, of cotton
14391055	Lightweight fine knit roll, polo or turtle neck jumpers and pullovers, of man-made fibres
14391061	Men's or boys' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of cotton (excluding lightweight fine knit roll, polo or turtle neck jumpers and pullovers)
14391062	Women's or girls' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of cotton (excluding lightweight fine knit roll, polo or turtle neck jumpers and pullovers)
14391071	Men's or boys' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of man-made fibres (excluding lightweight fine knit roll, polo or turtle neck jumpers and pullovers)
14391072	Women's or girls' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of man-made fibres (excluding lightweight fine knit roll, polo or turtle neck jumpers and pullovers)
14391090	Jerseys, pullovers, sweatshirts, waistcoats and cardigans, of textile materials (excluding those of wool or fine animal hair, cotton, man-made fibres)
15201100	Waterproof footwear, with uppers in rubber or plastics (excluding incorporating a protective metal toecap)
15201210	Sandals with rubber or plastic outer soles and uppers (including thong-type sandals, flip flops)
15201231	Town footwear with rubber or plastic uppers
15201237	Slippers and other indoor footwear with rubber or plastic outer soles and plastic uppers (including bedroom and dancing slippers, mules)
15201330	Footwear with a wooden base and leather uppers (including clogs) (excluding with an inner sole or a protective metal toe-cap)
15201351	Men's town footwear with leather uppers (including boots and shoes; excluding waterproof footwear, footwear with a protective metal toe-cap)
15201352	Women's town footwear with leather uppers (including boots and shoes; excluding waterproof footwear, footwear with a protective metal toe-cap)
15201353	Children's town footwear with leather uppers (including boots and shoes; excluding waterproof footwear, footwear with a protective metal toe-cap)
15201361	Men's sandals with leather uppers (including thong type sandals, flip flops)
15201362	Women's sandals with leather uppers (including thong type sandals, flip flops)
15201363	Children's sandals with leather uppers (including thong type sandals, flip flops)
15201370	Slippers and other indoor footwear with rubber, plastic or leather outer soles and leather uppers (including dancing and bedroom slippers, mules)
15201380	Footwear with wood, cork or other outer soles and leather uppers (excluding outer soles of rubber, plastics or leather)
15201444	Slippers and other indoor footwear (including dancing and bedroom slippers, mules) with uppers of textile materials
15201445	Footwear with rubber, plastic or leather outer soles and textile uppers (excluding slippers and other indoor footwear, sports footwear)
15201446	Footwear with textile uppers (excluding slippers and other indoor footwear as well as footwear with outer soles of rubber, plastics, leather or composition leather)

15202100	Sports footwear with rubber or plastic outer soles and textile uppers (including tennis shoes, basketball shoes, gym shoes, training shoes and the like)
15202900	Other sports footwear, except snow-ski footwear and skating boots
15203120	Footwear (including waterproof footwear), incorporating a protective metal toecap, with outer soles and uppers of rubber or of plastics
15203150	Footwear with rubber, plastic or leather outer soles and leather uppers, and with a protective metal toe-cap
15203200	Wooden footwear, miscellaneous special footwear and other footwear n.e.c.
20601110	Aramids staple, not carded, combed or otherwise processed for spinning
20601120	Other polyamide tow and staple, not carded, combed or otherwise processed for spinning
20601130	Polyester tow and staple, not carded, combed or otherwise processed for spinning
20601140	Acrylic tow and staple, not carded, combed or otherwise processed for spinning
20601150	Polypropylene synthetic tow and staple not carded, combed or otherwise processed for spinning
20601190	Other synthetic tow and staple not carded, combed or otherwise processed for spinning
20601220	High-tenacity filament yarn of aramids (excluding sewing thread and yarn put up for retail sale)
20601240	High-tenacity filament yarn of nylon or other polyamides (excluding sewing thread, yarn put up for retail sale and high-tenacity filament yarn of aramids)
20601260	High-tenacity filament yarn of polyesters (excluding that put up for retail sale)
20601310	Polyamide textile filament yarn, n.p.r.s. (excluding sewing thread)
20601320	Polyamide carpet filament yarn, n.p.r.s. (excluding sewing thread)
20601330	Polyester textile filament yarn, n.p.r.s. (excluding sewing thread)
20601340	Polypropylene filament yarn, n.p.r.s. (excluding sewing thread)
20601350	Elastomeric filament yarn, n.p.r.s.
20601390	Other synthetic filament yarn, n.p.r.s. (excluding sewing thread)
20601420	Polypropylene monofilament of >= 67 decitex and with a cross-sectional dimension of <= 1 mm (excluding elastomers)
20601440	Synthetic monofilament of >= 67 decitex and with a cross-sectional dimension of <= 1 mm (excluding polypropylene monofilament); strip and the like (for example, artificial straw), of synthetic textile materials, of an apparent width <= 5 mm
20602120	Artificial filament tow and staple fibres (not carded, combed or otherwise processed for spinning), of viscose rayon
20602140	Artificial filament tow, of acetate
20602150	Artificial filament tow and staple fibres (not carded, combed or otherwise processed for spinning, excluding the ones of acetate)

20602190	Other artificial filament tow and staple fibres (not carded, combed or otherwise processed for spinning)
20602200	High tenacity filament yarn of viscose rayon, n.p.r.s. (excluding sewing thread)
20602320	Yarn of viscose rayon filament, including monofilament of < 67 decitex, single, n.p.r.s. (excluding sewing thread and high-tenacity yarn)
20602340	Filament yarn of cellulose acetate, including monofilament of < 67 decitex, single, n.p.r.s. (excluding sewing thread and high-tenacity yarn)
20602390	Other artificial filament yarn, including artificial monofilament of < 67 decitex, single, n.p.r.s. (excluding sewing thread)
20602400	Artificial monofilament of >= 67 decitex and of which the cross-sectional dimension <= 1 mm; strip and the like of artificial textile materials of an apparent width <= 5 mm

Annex 2 Conversion factor

Following table report conversion factors from “number of items”, “pairs” and “m^2” assumed for textile products.

Prodcom code	Product description	Prodcom unit	Conversion factor to kg
13931100	Knotted carpets and other knotted textile floor coverings	m2	1.6
13931200	Woven carpets and other woven textile coverings (excluding tufted or flocked)	m2	1.6
13931300	Tufted carpets and other tufted textile floor coverings	m2	1.38
13931930	Needlefelt carpets and other needlefelt textile floor coverings (excluding tufted or flocked)	m2	1.6
13931990	Carpets and other textile floor coverings (excluding knotted, woven, tufted, needlefelt)	m2	1.6
13201100	Woven fabrics of silk or silk waste	m2	0.25
13201230	Woven fabrics of carded wool or carded fine animal hair	m2	0.25
13201260	Woven fabrics of combed wool or combed fine animal hair; woven fabrics of coarse animal hair	m2	0.25
13201330	Woven fabrics of flax, containing >= 85 % by weight of flax	m2	0.25
13201360	Woven fabrics of flax, containing < 85 % by weight of flax	m2	0.25
13201400	Woven fabrics of jute or of other textile bast fibres (excluding flax, true hemp, ramie)	m2	0.25
13201900	Woven fabrics of true hemp, ramie or other vegetable textile fibres (excluding flax, jute, other textile bast fibres); paper yarn	m2	0.25
13202014	Woven fabrics of cotton, not of yarns of different colours, weighing <= 200 g/m², for clothing	m2	0.25
13202017	Woven fabrics of cotton, not of yarns of different colours, weighing <= 200 g/m², for household linen or home furnishing textiles	m2	0.25
13202019	Woven fabrics of cotton, not of yarns of different colours, weighing <= 200 g/m², for technical or industrial uses (excluding gauze, medical gauze)	m2	0.25
13202020	Woven fabrics of cotton weighing <= 100 g/m², for medical gauzes, bandages and dressings	m2	0.25
13202031	Woven fabrics of cotton of yarns of different colours, weighing <= 200 g/m², for shirts and blouses	m2	0.25
13202042	Woven fabrics of cotton, not of yarns of different colours, weighing > 200 g/m², for clothing	m2	0.25
13202044	Woven fabrics of cotton, not of yarns of different colours, weighing > 200 g/m², for household linen or home furnishing textiles	m2	0.25
13202049	Woven fabrics of cotton, not of yarns of different colours, weighing > 200 g/m², for	m2	0.25

	technical or industrial uses		
13202060	Woven fabrics of denim cotton weighing > 200 g/m^2 (including denim other than blue)	m2	0.25
13202072	Woven fabrics of cotton of yarns of different colours, for other clothing	m2	0.25
13202074	Woven fabrics of cotton of yarns of different colours, for household linen or home furnishing textiles	m2	0.25
13202079	Woven fabrics of cotton of yarns of different colours, for technical or industrial uses	m2	0.25
132020Z1	Cotton fabrics, <= 200 g/m^2 (excluding gauze and coloured yarns)	m2	0.25
132020Z2	Cotton fabrics, > 200 g/m^2 (excluding coloured yarns)	m2	0.25
132020Z3	Woven fabrics of cotton of yarns of different colours (excluding denim)	m2	0.25
13203130	Woven fabrics of man-made filament yarns obtained from high tenacity yarn, strip or the like (including nylon, other polyamides, polyester, viscose rayon)	m2	0.25
13203150	Woven fabrics of synthetic filament yarns (excluding those obtained from high tenacity yarn or strip and the like)	m2	0.25
13203170	Woven fabrics of artificial filament yarns (excluding those obtained from high tenacity yarn)	m2	0.25
13203210	Woven fabrics of synthetic staple fibres, containing 85 % or more by weight of synthetic staple fibres	m2	0.25
13203220	Woven fabrics of synthetic staple fibres, containing less than 85 % by weight of such fibres, mixed mainly or solely with cotton (excluding fabrics of yarns of different colours)	m2	0.25
13203230	Woven fabrics of synthetic staple fibres, containing less than 85 % by weight of such fibres, mixed mainly or solely with cotton, of yarns of different colours	m2	0.25
13203240	Woven fabrics of synthetic staple fibres mixed mainly or solely with carded wool or fine animal hair	m2	0.25
13203250	Woven fabrics of synthetic staple fibres mixed mainly or solely with combed wool or fine animal hair	m2	0.25
13203290	Woven fabrics of synthetic staple fibres mixed other than with wool, fine animal hair or cotton	m2	0.25
13203330	Woven fabrics of artificial staple fibres, not of yarns of different colours	m2	0.25
13203350	Woven fabrics of artificial staple fibres, of yarns of different colours	m2	0.25
13204100	Warp and weft pile fabrics; chenille fabrics (excluding terry towelling and similar woven terry fabrics of cotton, tufted textile fabrics, narrow fabrics)	m2	0.25
13204200	Terry towelling and similar woven terry fabrics of cotton	m2	0.25
13204300	Terry towelling and similar woven terry fabrics (excluding of cotton)	m2	0.25

13204400	Gauze (excluding medical gauze, narrow woven fabrics)	m2	0.25
13204500	Tufted textile fabrics (excluding tufted carpets and other textile floor coverings)	m2	0.25
13921130	Blankets and travelling rugs of wool or fine animal hair (excluding electric blankets)	p/st	0.5
13921150	Blankets and travelling rugs of synthetic fibres (excluding electric blankets)	p/st	0.5
13921190	Blankets (excluding electric blankets) and travelling rugs of textile materials (excluding of wool or fine animal hair, of synthetic fibres)	p/st	0.5
13921530	Curtains and interior blinds, curtain or bed valances, of knitted or crocheted materials	m2	0.25
13921550	Curtains and interior blinds, curtain or bed valances, of woven materials	m2	0.25
13921570	Curtains and interior blinds, curtain or bed valances, of non-woven materials	m2	0.25
13921640	Bedspreads (excluding eiderdowns)	p/st	0.5
13922430	Sleeping bags	p/st	0.5
13922493	Articles of bedding of feathers or down (including quilts and eiderdowns, cushions, pouffes, pillows) (excluding mattresses, sleeping bags)	p/st	0.5
13922499	Articles of bedding filled other than with feathers or down (including quilts and eiderdowns, cushions, pouffes, pillows) (excluding mattresses, sleeping bags)	p/st	0.5
13961400	Textile fabrics, impregnated, coated or covered n.e.c.	m2	0.25
13961500	Tyre cord fabrics of high tenacity yarn, of nylon, other polyamides, polyesters or viscose rayon	m2	0.25
13991600	Quilted textile products in the piece (excluding embroidery)	m2	0.25
13991900	Powder-puffs and pads for the application of cosmetics or toilet preparations	p/st	0.5
14111000	Articles of apparel of leather or of composition leather (including coats and overcoats) (excluding clothing accessories, headgear, footwear)	p/st	0.9
14121120	Men's or boys' ensembles, of cotton or man-made fibres, for industrial and occupational wear	p/st	0.5
14121130	Men's or boys' jackets and blazers, of cotton or man-made fibres, for industrial and occupational wear	p/st	0.95
14121240	Men's or boys' trousers and breeches, of cotton or man-made fibres, for industrial or occupational wear	p/st	0.45
14121250	Men's or boys' bib and brace overalls, of cotton or man-made fibres, for industrial or occupational wear	p/st	0.45
14122120	Women's or girls' ensembles, of cotton or man-made fibres, for industrial or occupational wear	p/st	0.5

14122130	Women's or girls' jackets and blazers, of cotton or man-made fibres, for industrial or occupational wear	p/st	0.95
14122240	Women's or girls' trousers and breeches, of cotton or man-made fibres, for industrial or occupational wear	p/st	0.45
14122250	Women's or girls' bib and brace overalls, of cotton or man-made fibres, for industrial or occupational wear	p/st	0.45
14123013	Men's or boys' other garments, of cotton or man-made fibres, for industrial or occupational wear	p/st	0.5
14123023	Women's or girls' other garments, of cotton or man-made fibres, for industrial or occupational wear	p/st	0.5
14131110	Men's or boys' overcoats, car-coats, capes, cloaks and similar articles, of knitted or crocheted textiles (excluding jackets and blazers, anoraks, wind-cheaters and wind-jackets)	p/st	0.95
14131120	Men's or boys' waistcoats, anoraks, ski-jackets, wind-cheaters, wind-jackets and similar articles, of knitted or crocheted textiles (excluding jackets and blazers)	p/st	0.95
14131230	Men's or boys' jackets and blazers, of knitted or crocheted textiles	p/st	0.95
14131260	Men's or boys' suits and ensembles, of knitted or crocheted textiles	p/st	0.5
14131270	Men's or boys' trousers, breeches, shorts, bib and brace overalls, of knitted or crocheted textiles	p/st	0.45
14131310	Women's or girls' overcoats, car-coats, capes, cloaks and similar articles, of knitted or crocheted textiles (excluding jackets and blazers)	p/st	0.95
14131320	Women's or girls' waistcoats, anoraks, ski-jackets, wind-cheaters, wind-jackets and similar articles, of knitted or crocheted textiles (excluding jackets and blazers)	p/st	0.95
14131430	Women's or girls' jackets and blazers, of knitted or crocheted textiles	p/st	0.95
14131460	Women's or girls' suits and ensembles, of knitted or crocheted textiles	p/st	0.5
14131470	Women's or girls' dresses, of knitted or crocheted textiles	p/st	0.3
14131480	Women's or girls' skirts and divided skirts, of knitted or crocheted textiles	p/st	0.25
14131490	Women's or girls' trousers, breeches, shorts, bib and brace overalls, of knitted or crocheted textiles	p/st	0.45
14132115	Men's or boys' raincoats, overcoats, car-coats, capes, etc.	p/st	0.5
14132130	Men's or boys' waistcoats, anoraks, ski-jackets, wind-jackets and similar articles (excluding jackets and blazers, knitted or crocheted, impregnated, coated, covered, laminated or rubberised)	p/st	0.95
14132200	Men's or boys' suits & ensembles (excluding knitted or crocheted)	p/st	0.5
14132300	Men's or boys' jackets and blazers (excluding knitted or crocheted)	p/st	0.95

14132442	Men's or boys' trousers and breeches, of denim (excluding for industrial or occupational wear)	p/st	0.45
14132444	Men's or boys' trousers, breeches and shorts, of wool or fine animal hair (excluding knitted or crocheted, for industrial or occupational wear)	p/st	0.45
14132445	Men's or boys' trousers and breeches, of man-made fibres (excluding knitted or crocheted, for industrial or occupational wear)	p/st	0.45
14132448	Men's or boys' trousers and breeches, of cotton (excluding denim, knitted or crocheted)	p/st	0.45
14132449	Men's or boys' trousers, breeches, shorts and bib and brace overalls (excluding of wool, cotton and man-made fibres, knitted or crocheted)	p/st	0.45
14132455	Men's or boys' bib and brace overalls (excluding knitted or crocheted, for industrial or occupational wear)	p/st	0.45
14132460	Men's or boys' shorts, of cotton or man-made fibres (excluding knitted or crocheted)	p/st	0.45
14133115	Woman's or girls' raincoats and overcoats, etc	p/st	0.5
14133130	Women's or girls' waistcoats, anoraks, ski-jackets, wind-jackets and similar articles (excluding jackets and blazers, knitted or crocheted, impregnated, coated, covered, laminated or rubberised)	p/st	0.95
14133200	Women's or girls' suits & ensembles (excluding knitted or crocheted)	p/st	0.5
14133330	Women's or girls' jackets and blazers (excluding knitted or crocheted)	p/st	0.95
14133470	Women's or girls' dresses (excluding knitted or crocheted)	p/st	0.3
14133480	Women's or girls' skirts and divided skirts (excluding knitted or crocheted)	p/st	0.25
14133542	Women's or girls' trousers and breeches, of denim (excluding for industrial or occupational wear)	p/st	0.45
14133548	Women's or girls' trousers and breeches, of cotton (excluding denim, for industrial or occupational wear)	p/st	0.45
14133549	Women's or girls' trousers and breeches, of wool or fine animal hair or man-made fibres (excluding knitted or crocheted and for industrial and occupational wear)	p/st	0.45
14133551	Women's or girls' bib and brace overalls, of cotton (excluding knitted or crocheted, for industrial or occupational wear)	p/st	0.45
14133561	Women's or girls' shorts, of cotton (excluding knitted and crocheted)	p/st	0.45
14133563	Women's or girls' bib and brace overalls, of wool or fine animal hair and man-made fibres (excluding cotton, knitted or crocheted, for industrial or occupational wear) and women's or girls' shorts, of wool or fine animal hair (excluding knitted or crocheted)	p/st	0.45
14133565	Women's or girls' shorts, of man-made fibres (excluding knitted or crocheted)	p/st	0.45
14133569	Women's or girls' trousers, breeches, bib and brace overalls, of textiles (excluding cotton, wool or fine animal hair, man-made fibres, knitted or crocheted)	p/st	0.45

14141100	Men's or boys' shirts, knitted or crocheted	p/st	0.25
14141220	Men’s or boys’ underpants and briefs, of knitted or crocheted textiles (including boxer shorts)	p/st	0.08
14141230	Men’s or boys’ nightshirts and pyjamas, of knitted or crocheted textiles	p/st	0.15
14141240	Men’s or boys’ dressing gowns, bathrobes and similar articles, of knitted or crocheted textiles	p/st	0.3
14141310	Women’s or girls’ blouses, shirts and shirt-blouses, of knitted or crocheted textiles	p/st	0.25
14141420	Women’s or girls’ briefs and panties, of knitted or crocheted textiles (including boxer shorts)	p/st	0.08
14141430	Women’s or girls’ nighties and pyjamas, of knitted or crocheted textiles	p/st	0.15
14141440	Women’s or girls’ negligees, bathrobes, dressing gowns and similar articles, of knitted or crocheted textiles	p/st	0.3
14141450	Women’s or girls’ slips and petticoats, of knitted or crocheted textiles	p/st	0.5
14142100	Men’s or boys’ shirts (excluding knitted or crocheted)	p/st	0.25
14142220	Men’s or boys’ underpants and briefs (including boxer shorts) (excluding knitted or crocheted)	p/st	0.08
14142230	Men’s or boys’ nightshirts and pyjamas (excluding knitted or crocheted)	p/st	0.15
14142240	Men’s or boys’ singlets, vests, bathrobes, dressing gowns and similar articles (excluding knitted or crocheted)	p/st	0.3
14142300	Women’s or girls’ blouses, shirts and shirt-blouses (excluding knitted or crocheted)	p/st	0.25
14142430	Women’s or girls’ nightdresses and pyjamas (excluding knitted or crocheted)	p/st	0.3
14142450	Women’s or girls’ slips and petticoats (excluding knitted or crocheted)	p/st	0.5
14142460	Women’s or girls’ singlets and other vests, briefs, panties, negligees, bathrobes, dressing gowns, housecoats and similar articles of cotton (excluding knitted or crocheted)	p/st	0.08
14142480	Women's or girls' negligees, bathrobes, dressing gowns, singlets, vests, briefs and panties (including boxer shorts), of man-made fibres (excluding knitted or crocheted)	p/st	0.08
14142489	Women’s or girls’ singlets, vests, briefs, panties, negligees, bathrobes, dressing gowns and similar articles, of textiles (excluding cotton, man-made fibres, knitted or crocheted)	p/st	0.08
14142530	Brassieres	p/st	0.05
14142550	Girdles, panty-girdles and corselettes (including bodies with adjustable straps)	p/st	0.5
14143000	T-shirts, singlets and vests, knitted or crocheted	p/st	0.17

14191210	Track-suits, of knitted or crocheted textiles	p/st	0.5
14191230	Ski-suits, of knitted or crocheted textiles	p/st	0.5
14191240	Men's or boys' swimwear, of knitted or crocheted textiles	p/st	0.12
14191250	Women's or girls' swimwear, of knitted or crocheted textiles	p/st	0.12
14191300	Gloves, mittens and mitts, of knitted or crocheted textiles	pa	0.1
14191930	Shawls, scarves, mufflers, mantillas, veils and the like, of knitted or crocheted textiles	p/st	0.1
14192210	Other men's or boys' apparel n.e.c., including tracksuits and jogging suits (excluding waistcoats, ski-suits, knitted or crocheted)	p/st	0.5
14192220	Other women's or girls' apparel n.e.c., including tracksuits and jogging suits (excluding waistcoats, ski-suits, knitted or crocheted)	p/st	0.5
14192230	Ski-suits (excluding of knitted or crocheted textiles)	p/st	0.5
14192240	Men's or boys' swimwear (excluding of knitted or crocheted textiles)	p/st	0.12
14192250	Women's or girls' swimwear (excluding of knitted or crocheted textiles)	p/st	0.12
14192310	Handkerchiefs	p/st	0.5
14192333	Shawls, scarves, mufflers, mantillas, veils and the like (excluding articles of silk or silk waste, knitted or crocheted)	p/st	0.15
14192338	Shawls, scarves, mufflers, mantillas, veils and the like, of silk or silk waste (excluding knitted or crocheted)	p/st	0.15
14192353	Ties, bow ties and cravats (excluding articles of silk or silk waste, knitted or crocheted)	p/st	0.15
14192358	Ties, bow ties and cravats, of silk or silk waste (excluding knitted or crocheted)	p/st	0.15
14192370	Gloves, mittens and mitts (excluding knitted or crocheted)	pa	0.1
14193175	Gloves, mittens and mitts, of leather or composition leather (excluding for sport, protective for all trades)	pa	0.1
14193180	Belts and bandoliers, of leather or composition leather	p/st	0.1
14193200	Garments made up of felt or non-wovens, textile fabrics impregnated or coated	p/st	0.1
14194130	Hat-forms, hat bodies and hoods, plateaux and manchons of felt (including slit manchons) (excluding those blocked to shape, those with made brims)	p/st	0.1
14194150	Hat-shapes, plaited or made by assembling strips of any material (excluding those blocked to shape, those with made brims, those lined or trimmed)	p/st	0.1
14194230	Felt hats and other felt headgear, made from hat bodies or hoods and plateaux	p/st	0.1

14194250	Hats and other headgear, plaited or made by assembling strips of any material	p/st	0.1
14194270	Hats and other headgear, knitted or crocheted or made-up from lace, felt or other textile fabric in the piece (but not in strips); hair-nets of any material	p/st	0.1
14311033	Panty hose and tights, of knitted or crocheted synthetic fibres, measuring per single yarn < 67 decitex	p/st	0.07
14311035	Panty hose and tights, of knitted or crocheted synthetic fibres, measuring per single yarn >= 67 decitex	p/st	0.07
14311037	Pantyhose and tights of textile materials, knitted or crocheted (excl. graduated compression hosiery, those of synthetic fibres and hosiery for babies)	p/st	0.07
14311050	Women's full-length or knee-length knitted or crocheted hosiery, measuring per single yarn < 67 decitex	pa	0.01
14311090	Knitted or crocheted hosiery and footwear (including socks; excluding women's full-length/knee-length hosiery, measuring <67decitex, panty-hose and tights, footwear with applied soles)	pa	0.07
14391031	Men's or boys' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of wool or fine animal hair (excluding jerseys and pullovers containing >= 50 % of wool and weighing >= 600 g)	p/st	0.5
14391032	Women's or girls' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of wool or fine animal hair (excluding jerseys and pullovers containing >= 50 % of wool and weighing >= 600 g)	p/st	0.5
14391033	Jerseys and pullovers, containing >= 50 % by weight of wool and weighing >= 600 g per article	p/st	0.3
14391053	Lightweight fine knit roll, polo or turtle neck jumpers and pullovers, of cotton	p/st	0.5
14391055	Lightweight fine knit roll, polo or turtle neck jumpers and pullovers, of man-made fibres	p/st	0.5
14391061	Men's or boys' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of cotton (excluding lightweight fine knit roll, polo or turtle neck jumpers and pullovers)	p/st	0.5
14391062	Women's or girls' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of cotton (excluding lightweight fine knit roll, polo or turtle neck jumpers and pullovers)	p/st	0.5
14391071	Men's or boys' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of man-made fibres (excluding lightweight fine knit roll, polo or turtle neck jumpers and pullovers)	p/st	0.5
14391072	Women's or girls' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of man-made fibres (excluding lightweight fine knit roll, polo or turtle neck jumpers and pullovers)	p/st	0.5
14391090	Jerseys, pullovers, sweatshirts, waistcoats and cardigans, of textile materials (excluding those of wool or fine animal hair, cotton, man-made fibres)	p/st	0.5
15111030	Tanned or dressed whole furskins, not assembled, of rabbit, hare or lamb	p/st	0.5
15112100	Chamois leather and combination chamois leather	m2	0.25
15112200	Patent leather; patent laminated leather and metallised leather	m2	0.25

15114150	Sheep or lamb skin leather without wool on, parchment-dressed or prepared after tanning (excluding chamois, patent, patent laminated leather and metallised leather)	m2	0.25
15114250	Goat or kid skin leather without hair on, parchment-dressed or prepared after tanning (excluding chamois leather, patent leather, patent laminated leather and metallised leather)	m2	0.25
15114350	Leather of swine without hair on; parchment-dressed or prepared after tanning (excluding patent leather; patent laminated leather and metallised leather)	m2	0.25
15115200	Composition leather with a basis of leather or leather fibre, in slabs, sheets or strips	m2	0.25
15121210	Trunks, suitcases, vanity cases, briefcases, school satchels and similar containers of leather, composition leather, patent leather, plastics, textile materials, aluminium or other materials	p/st	0.5
15121220	Handbags of leather, composition leather, patent leather, plastic sheeting, textile materials or other materials (including those without a handle)	p/st	0.5
15121270	Travel sets for personal toilet; sewing; or shoe or clothes cleaning (excluding manicure sets)	p/st	0.5
15121300	Watch straps, bands, bracelets and parts thereof (including of leather, composition leather or plastic; excluding of precious metal, metal or base metal clad/plated with precious metal)	p/st	0.01
15201100	Waterproof footwear, with uppers in rubber or plastics (excluding incorporating a protective metal toecap)	pa	0.9
15201210	Sandals with rubber or plastic outer soles and uppers (including thong-type sandals, flip flops)	pa	0.5
15201231	Town footwear with rubber or plastic uppers	pa	0.9
15201237	Slippers and other indoor footwear with rubber or plastic outer soles and plastic uppers (including bedroom and dancing slippers, mules)	pa	0.35
15201330	Footwear with a wooden base and leather uppers (including clogs) (excluding with an inner sole or a protective metal toe-cap)	pa	0.9
15201351	Men’s town footwear with leather uppers (including boots and shoes; excluding waterproof footwear, footwear with a protective metal toe-cap)	pa	0.9
15201352	Women’s town footwear with leather uppers (including boots and shoes; excluding waterproof footwear, footwear with a protective metal toe-cap)	pa	0.9
15201353	Children’s town footwear with leather uppers (including boots and shoes; excluding waterproof footwear, footwear with a protective metal toe-cap)	pa	0.9
15201361	Men’s sandals with leather uppers (including thong type sandals, flip flops)	pa	0.5
15201362	Women’s sandals with leather uppers (including thong type sandals, flip flops)	pa	0.5
15201363	Children’s sandals with leather uppers (including thong type sandals, flip flops)	pa	0.5
15201370	Slippers and other indoor footwear with rubber, plastic or leather outer soles and leather uppers (including dancing and bedroom slippers, mules)	pa	0.35

15201380	Footwear with wood, cork or other outer soles and leather uppers (excluding outer soles of rubber, plastics or leather)	pa	0.9
15201444	Slippers and other indoor footwear (including dancing and bedroom slippers, mules) with uppers of textile materials	pa	0.35
15201445	Footwear with rubber, plastic or leather outer soles and textile uppers (excluding slippers and other indoor footwear, sports footwear)	pa	0.9
15201446	Footwear with textile uppers (excluding slippers and other indoor footwear as well as footwear with outer soles of rubber, plastics, leather or composition leather)	pa	0.9
15202100	Sports footwear with rubber or plastic outer soles and textile uppers (including tennis shoes, basketball shoes, gym shoes, training shoes and the like)	pa	0.9
15202900	Other sports footwear, except snow-ski footwear and skating boots	pa	0.9
15203120	Footwear (including waterproof footwear), incorporating a protective metal toecap, with outer soles and uppers of rubber or of plastics	pa	0.9
15203150	Footwear with rubber, plastic or leather outer soles and leather uppers, and with a protective metal toe-cap	pa	0.9
15203200	Wooden footwear, miscellaneous special footwear and other footwear n.e.c.	pa	0.9
22292920	Outer soles and heels of plastics	p/st	0.1

Annex 3 Life expectancy of textile products

Following table reports minimum, average and maximum values assumed for life expectancy (in years) of finished textile products considered in MFA scope.

Prodcom 8-digit code	Product description	Min	Average	Max	Source
13931100	Knotted carpets and other knotted textile floor coverings	5	5	5	Fair Claims Guide
13931200	Woven carpets and other woven textile coverings (excluding tufted or flocked)	5	5	5	Fair Claims Guide
13931300	Tufted carpets and other tufted textile floor coverings	5	5	5	Fair Claims Guide
13931930	Needlefelt carpets and other needlefelt textile floor coverings (excluding tufted or flocked)	5	5	5	Fair Claims Guide
13931990	Carpets and other textile floor coverings (excluding knotted, woven, tufted, needlefelt)	5	5	5	Fair Claims Guide
13961650	Textile wicks, conveyor belts or belting (including reinforced with metal or other material)	10	10	10	Fair Claims Guide
13921130	Blankets and travelling rugs of wool or fine animal hair (excluding electric blankets)	10	10	10	Fair Claims Guide
13921150	Blankets and travelling rugs of synthetic fibres (excluding electric blankets)	5	5	5	Fair Claims Guide
13921190	Blankets (excluding electric blankets) and travelling rugs of textile materials (excluding of wool or fine animal hair, of synthetic fibres)	5	5	5	Fair Claims Guide
13921230	Bed linen of knitted or crocheted textiles	3	3	3	Fair Claims Guide
13921253	Bed linen of cotton (excluding knitted or crocheted)	3	3	3	Fair Claims Guide
13921255	Bed linen of flax or ramie (excluding knitted or crocheted)	3	3	3	Fair Claims Guide
13921259	Bed linen of woven textiles (excluding of cotton, of flax or ramie)	3	3	3	Fair Claims Guide
13921270	Bed linen of non-woven man-made fibres (excluding knitted or crocheted)	3	3	3	Fair Claims Guide
13921330	Table linen of knitted or crocheted textiles	2	2	2	Fair Claims Guide
13921353	Table linen of cotton (excluding knitted or crocheted)	3	3	3	Fair Claims Guide
13921355	Table linen of flax (excluding knitted or crocheted)	2	2	2	Fair Claims Guide
13921359	Table linen of woven man-made fibres and of other woven or non-woven textiles (excluding of cotton, of flax)	2	2	2	Fair Claims Guide
13921370	Table linen of non-woven man-made fibres	2	2	2	Fair Claims Guide
13921430	Toilet linen and kitchen linen, of terry towelling or similar terry fabrics of cotton	3	3	3	Fair Claims Guide
13921450	Woven toilet linen and kitchen linen, of textiles (excluding terry towelling or similar terry fabrics of cotton)	2	2	2	Fair Claims Guide

13921470	Toilet linen and kitchen linen, of non-woven man-made fibres	3	3	3	Fair Claims Guide
13921530	Curtains and interior blinds, curtain or bed valances, of knitted or crocheted materials	4	4	4	Fair Claims Guide
13921550	Curtains and interior blinds, curtain or bed valances, of woven materials	4	4	4	Fair Claims Guide
13921570	Curtains and interior blinds, curtain or bed valances, of non-woven materials	4	4	4	Fair Claims Guide
13921620	Hand-woven tapestries of the type Gobelins, Flanders, Aubusson, Beauvais, and needle-worked tapestries (including petit point, cross-stitch) whether or not made up	4	4	4	Fair Claims Guide
13921640	Bedspreads (excluding eiderdowns)	3	3	3	Fair Claims Guide
13921660	Furnishing articles including furniture and cushion covers as well as cushion covers, etc. for car seats (excluding blankets, travelling rugs, bed linen, table linen, toilet linen, kitchen linen, curtains, blinds, valances and bedspreads)	3	3	3	Fair Claims Guide
13922130	Sacks and bags, of cotton, used for packing goods	1	1	1	Fair Claims Guide
13922150	Sacks and bags, of knitted or crocheted polyethylene or polypropylene strip, used for packing goods	1	1	1	Fair Claims Guide
13922170	Sacks and bags, of polyethylene or polypropylene strip, used for packing goods (excluding knitted or crocheted)	1	1	1	Fair Claims Guide
13922173	Sacks and bags, of polyethylene or polypropylene strip, weighing <= 120 g/m2, used for packing goods (excluding knitted or crocheted)	1	1	1	Fair Claims Guide
13922175	Sacks and bags, of polyethylene or polypropylene strip, weighing > 120 g/m2, used for packing goods (excluding knitted or crocheted)	1	1	1	Fair Claims Guide
13922190	Sacks and bags, used for packing goods (excluding of cotton, polyethylene or polypropylene strip)	1	1	1	Fair Claims Guide
13922210	Tarpaulins, awnings and sunblinds (excluding caravan awnings)	4	4	4	Fair Claims Guide
13922230	Tents (including caravan awnings)	4	4	4	Fair Claims Guide
13922250	Sails	3	3	3	Fair Claims Guide
13922300	Parachutes and rotochutes, parts and accessories (including dirigible parachutes)	10	10	10	Fair Claims Guide
13922430	Sleeping bags	5	5	5	Fair Claims Guide
13922493	Articles of bedding of feathers or down (including quilts and eiderdowns, cushions, pouffes, pillows) (excluding mattresses, sleeping bags)	5	5	5	Fair Claims Guide
13922499	Articles of bedding filled other than with feathers or down (including quilts and eiderdowns, cushions, pouffes, pillows) (excluding mattresses, sleeping bags)	5	5	5	Fair Claims Guide
13922953	Floor-cloths, dish-cloths, dusters and similar cleaning cloths, of non-woven textiles	2	2	2	Fair Claims Guide
13922957	Floor-cloths, dish-cloths, dusters and similar cleaning cloths (excluding knitted or crocheted, articles of non-woven textiles)	2	2	2	Fair Claims Guide
13922990	Floor-cloths, dish-cloths, dusters and similar cleaning cloths, knitted or crocheted; life-jackets, life-belts and	2	2	2	Fair Claims Guide

	other made up articles				
13922993	Sanitary towels, tampons and similar article of textile materials (excluding wadding)	2	2	2	Fair Claims Guide
13922997	Napkins and napkin liners for babies and similar article of textile materials (excluding wadding)	1	1	1	Fair Claims Guide
13922998	Floor-cloths, dish-cloths, dusters and similar cleaning cloths, knitted or crocheted; life-jackets, life-belts and other made up articles (excluding protective face masks, sanitary towels and napkins and similar articles)	2	2	2	Fair Claims Guide
13922999	Floor-cloths, dish-cloths, dusters and similar cleaning cloths, knitted or crocheted; life-jackets, life-belts and other made up articles (excluding sanitary towels and napkins and similar articles)	2	2	2	Fair Claims Guide
13941130	Twine, cordage, rope or cables, of sisal or other textile fibres of 'agave', of jute or other textile bast fibres and hard leaf fibres (excluding binder or baler twine)	10	10	10	Fair Claims Guide
13941133	Twine, cordage, rope or cables, of sisal or other textile fibres of 'agave' measuring >100,000 decitex, of jute or other textile bast fibres and hard leaf fibres (excluding binder or baler twine)	10	10	10	Fair Claims Guide
13941135	Twines of sisal measuring <= 100,000 decitex (10 g/m) (excluding binder or baler twine)	10	10	10	Fair Claims Guide
13941153	Sisal binder or baler (agricultural) twines	10	10	10	Fair Claims Guide
13941155	Polyethylene or polypropylene binder or baler (agricultural) twines	10	10	10	Fair Claims Guide
13941160	Cordage, ropes or cables of polyethylene, polypropylene, nylon or other polyamides or of polyesters measuring > 50 000 decitex, of other synthetic fibres (excluding binder or baler twine)	10	10	10	Fair Claims Guide
13941170	Twines of polyethylene or polypropylene, of nylon or other polyamides or polyesters measuring <= 50 000 decitex (5 g/m) (excluding binder or baler twine)	10	10	10	Fair Claims Guide
13941190	Twines, cordage, rope and cables of textile materials (excluding jute and other textile bast fibres, sisal, abaca or other hard leaf fibres, synthetic fibres)	10	10	10	Fair Claims Guide
13941233	Made-up fishing nets from twine, cordage or rope of man-made fibres (excluding fish landing nets)	10	10	10	Fair Claims Guide
13941235	Made-up fishing nets from yarn of man-made fibres (excluding fish landing nets)	10	10	10	Fair Claims Guide
13941253	Made-up nets from twine, cable or rope of nylon or other polyamides (excluding netting in the piece produced by crochet, hairnets, sports and fishing nets)	10	10	10	Fair Claims Guide
13941255	Made-up nets of nylon or other polyamides (excluding netting in the piece produced by crochet, hairnets, sports and fishing nets, those made from twine, cable or rope)	10	10	10	Fair Claims Guide
13941259	Knotted netting of textile materials (excluding made-up fishing nets of man-made textiles, other made-up nets of nylon or other polyamides)	10	10	10	Fair Claims Guide
13941280	Articles of twine, cordage, rope or cables	10	10	10	Fair Claims Guide
13951010	Non-wovens of a weight <= 25 g/m² (including articles made from non-wovens) (excluding articles of apparel, coated or covered)	4	4	4	Fair Claims Guide
13951020	Non-wovens of a weight of > 25 g/m² but <= 70 g/m² (including articles made from non-wovens) (excluding articles of apparel, coated or covered)	4	4	4	Fair Claims Guide
13951030	Non-wovens of a weight of > 70 g/m² but <= 150 g/m² (including articles made from non-wovens) (excluding articles of apparel, coated or covered)	4	4	4	Fair Claims Guide

13951050	Non-wovens of a weight of > 150 g/m² (including articles made from non-wovens) (excluding articles of apparel, coated or covered)	4	4	4	Fair Claims Guide
13951070	Non-wovens, coated or covered (including articles made from non-wovens) (excluding articles of apparel)	4	4	4	Fair Claims Guide
13961620	Textile hosepiping and similar textile tubing, whether or not impregnated or coated, with or without lining, armour or accessories of other materials	10	10	10	Fair Claims Guide
13961750	Labels, badges and similar articles in textile materials (excluding embroidered)	1	1	1	Fair Claims Guide
13961770	Braids in the piece; tassels and pompons, ornamental trimmings (excluding knitted or crocheted)	1	1	1	Fair Claims Guide
13991230	Embroidery (without visible ground) in the piece, in strips or in motifs	2	2	2	Fair Claims Guide
13991250	Cotton embroidery in the piece, in strips or in motifs (excluding embroidery without visible ground)	2	2	2	Fair Claims Guide
13991270	Embroidery of textiles in the piece, in strips or in motifs (excluding without visible ground, cotton)	2	2	2	Fair Claims Guide
13991600	Quilted textile products in the piece (excluding embroidery)	2	2	2	Fair Claims Guide
13991900	Powder-puffs and pads for the application of cosmetics or toilet preparations	1	1	1	Fair Claims Guide
14111000	Articles of apparel of leather or of composition leather (including coats and overcoats) (excluding clothing accessories, headgear, footwear)	5	5	5	Fair Claims Guide
14121120	Men's or boys' ensembles, of cotton or man-made fibres, for industrial and occupational wear	8.7	8.7	8.7	Laitala et. 2018
14121130	Men's or boys' jackets and blazers, of cotton or man-made fibres, for industrial and occupational wear	4	6.8	11.5	Laitala et. 2018
14121240	Men's or boys' trousers and breeches, of cotton or man-made fibres, for industrial or occupational wear	2.5	2	6.2	Laitala et. 2018
14121250	Men's or boys' bib and brace overalls, of cotton or man-made fibres, for industrial or occupational wear	2.5	4.7	6.2	Laitala et. 2018
14122120	Women's or girls' ensembles, of cotton or man-made fibres, for industrial or occupational wear	4.5	4.6	4.7	Laitala et. 2018
14122130	Women's or girls' jackets and blazers, of cotton or man-made fibres, for industrial or occupational wear	4	6.8	11.5	Laitala et. 2018
14122240	Women's or girls' trousers and breeches, of cotton or man-made fibres, for industrial or occupational wear	2.5	4.7	6.2	Laitala et. 2018
14122250	Women's or girls' bib and brace overalls, of cotton or man-made fibres, for industrial or occupational wear	2.5	4.7	6.2	Laitala et. 2018
14123013	Men's or boys' other garments, of cotton or man-made fibres, for industrial or occupational wear	4.7	4.7	4.7	Laitala et. 2018
14123023	Women's or girls' other garments, of cotton or man-made fibres, for industrial or occupational wear	2.4	3.1	4.4	Laitala et. 2018
14131110	Men's or boys' overcoats, car-coats, capes, cloaks and similar articles, of knitted or crocheted textiles (excluding jackets and blazers, anoraks, wind-cheaters and wind-jackets)	4	6.8	11.5	Laitala et. 2018
14131120	Men's or boys' waistcoats, anoraks, ski-jackets, wind-cheaters, wind-jackets and similar articles, of knitted or crocheted textiles (excluding jackets and blazers)	4	6.8	11.5	Laitala et. 2018
14131230	Men's or boys' jackets and blazers, of knitted or crocheted textiles	4	6.8	11.5	Laitala et. 2018

14131260	Men’s or boys’ suits and ensembles, of knitted or crocheted textiles	8.7	8.7	8.7	Laitala et. 2018
14131270	Men’s or boys’ trousers, breeches, shorts, bib and brace overalls, of knitted or crocheted textiles	2.5	4.7	6.2	Laitala et. 2018
14131310	Women’s or girls’ overcoats, car-coats, capes, cloaks and similar articles, of knitted or crocheted textiles (excluding jackets and blazers)	4	6.8	11.5	Laitala et. 2018
14131320	Women’s or girls’ waistcoats, anoraks, ski-jackets, wind-cheaters, wind-jackets and similar articles, of knitted or crocheted textiles (excluding jackets and blazers)	4	6.8	11.5	Laitala et. 2018
14131430	Women’s or girls’ jackets and blazers, of knitted or crocheted textiles	4	6.8	11.5	Laitala et. 2018
14131460	Women’s or girls’ suits and ensembles, of knitted or crocheted textiles	8.7	8.7	8.7	Laitala et. 2018
14131470	Women’s or girls’ dresses, of knitted or crocheted textiles	4.5	4.6	4.7	Laitala et. 2018
14131480	Women’s or girls’ skirts and divided skirts, of knitted or crocheted textiles	4.1	6.9	5.2	Laitala et. 2018
14131490	Women’s or girls’ trousers, breeches, shorts, bib and brace overalls, of knitted or crocheted textiles	2.5	4.7	6.2	Laitala et. 2018
14132110	Men's or boys' raincoats	4	7	11.6	Laitala et. 2018
14132115	Men’s or boys’ raincoats, overcoats, car-coats, capes, etc.	4	7	11.6	Laitala et. 2018
14132120	Men's or boys' overcoats, car-coats, capes, etc	4	7	11.6	Laitala et. 2018
14132130	Men’s or boys’ waistcoats, anoraks, ski-jackets, wind-jackets and similar articles (excluding jackets and blazers, knitted or crocheted, impregnated, coated, covered, laminated or rubberised)	4	6.8	11.5	Laitala et. 2018
14132200	Men’s or boys’ suits & ensembles (excluding knitted or crocheted)	8.7	8.7	8.7	Laitala et. 2018
14132210	Men's or boys' suits (excluding knitted or crocheted)	8.7	8.7	8.7	Laitala et. 2018
14132220	Men's or boys' ensembles (excluding knitted or crocheted)	8.7	8.7	8.7	Laitala et. 2018
14132300	Men’s or boys’ jackets and blazers (excluding knitted or crocheted)	4	6.8	11.5	Laitala et. 2018
14132442	Men’s or boys’ trousers and breeches, of denim (excluding for industrial or occupational wear)	2.5	3.5	4.3	Laitala et. 2018
14132444	Men’s or boys’ trousers, breeches and shorts, of wool or fine animal hair (excluding knitted or crocheted, for industrial or occupational wear)	2.5	4.7	6.2	Laitala et. 2018
14132445	Men’s or boys’ trousers and breeches, of man-made fibres (excluding knitted or crocheted, for industrial or occupational wear)	2.5	4.7	6.2	Laitala et. 2018
14132448	Men’s or boys’ trousers and breeches, of cotton (excluding denim, knitted or crocheted)	2.5	2	6.2	Laitala et. 2018
14132449	Men’s or boys’ trousers, breeches, shorts and bib and brace overalls (excluding of wool, cotton and man-made fibres, knitted or crocheted)	2.5	4.7	6.2	Laitala et. 2018
14132455	Men’s or boys’ bib and brace overalls (excluding knitted or crocheted, for industrial or occupational wear)	2.5	4.7	6.2	Laitala et. 2018

14132460	Men’s or boys’ shorts, of cotton or man-made fibres (excluding knitted or crocheted)	2.5	4.7	6.2	Laitala et. 2018
14133110	Woman's or girls' raincoats	4	7	11.6	Laitala et. 2018
14133115	Woman’s or girls’ raincoats and overcoats, etc	4	7	11.6	Laitala et. 2018
14133120	Woman's or girls' overcoats, etc	4	7	11.6	Laitala et. 2018
14133130	Women’s or girls’ waistcoats, anoraks, ski-jackets, wind-jackets and similar articles (excluding jackets and blazers, knitted or crocheted, impregnated, coated, covered, laminated or rubberised)	4	6.8	11.5	Laitala et. 2018
14133200	Women’s or girls’ suits & ensembles (excluding knitted or crocheted)	8.7	8.7	8.7	Laitala et. 2018
14133210	Women's or girls' suits (excluding knitted or crocheted)	8.7	8.7	8.7	Laitala et. 2018
14133220	Women's or girls' ensembles (excluding knitted or crocheted)	8.7	8.7	8.7	Laitala et. 2018
14133330	Women’s or girls’ jackets and blazers (excluding knitted or crocheted)	4	6.8	11.5	Laitala et. 2018
14133470	Women’s or girls’ dresses (excluding knitted or crocheted)	4.5	4.6	4.7	Laitala et. 2018
14133480	Women’s or girls’ skirts and divided skirts (excluding knitted or crocheted)	4.1	6.9	5.2	Laitala et. 2018
14133542	Women’s or girls’ trousers and breeches, of denim (excluding for industrial or occupational wear)	2.5	3.5	4.3	Laitala et. 2018
14133548	Women’s or girls’ trousers and breeches, of cotton (excluding denim, for industrial or occupational wear)	2.5	4.7	6.2	Laitala et. 2018
14133549	Women’s or girls’ trousers and breeches, of wool or fine animal hair or man-made fibres (excluding knitted or crocheted and for industrial and occupational wear)	2.5	4	6.2	Laitala et. 2018
14133551	Women’s or girls’ bib and brace overalls, of cotton (excluding knitted or crocheted, for industrial or occupational wear)	2.5	4.7	6.2	Laitala et. 2018
14133561	Women’s or girls’ shorts, of cotton (excluding knitted and crocheted)	2.5	4.7	6.2	Laitala et. 2018
14133563	Women's or girls' bib and brace overalls, of wool or fine animal hair and man-made fibres (excluding cotton, knitted or crocheted, for industrial or occupational wear) and women's or girls' shorts, of wool or fine animal hair (excluding knitted or crocheted)	2.5	4.7	6.2	Laitala et. 2018
14133565	Women’s or girls’ shorts, of man-made fibres (excluding knitted or crocheted)	2.5	4.7	6.2	Laitala et. 2018
14133569	Women’s or girls’ trousers, breeches, bib and brace overalls, of textiles (excluding cotton, wool or fine animal hair, man-made fibres, knitted or crocheted)	2.5	4.7	6.2	Laitala et. 2018
14141100	Men's or boys' shirts, knitted or crocheted	3.3	4.8	7.2	Laitala et. 2018
14141220	Men’s or boys’ underpants and briefs, of knitted or crocheted textiles (including boxer shorts)	2.4	3.1	4.4	Laitala et. 2018
14141230	Men’s or boys’ nightshirts and pyjamas, of knitted or crocheted textiles	2.4	3.1	4.4	Laitala et. 2018
14141240	Men’s or boys’ dressing gowns, bathrobes and similar articles, of knitted or crocheted textiles	2.4	3.1	4.4	Laitala et. 2018

14141310	Women's or girls' blouses, shirts and shirt-blouses, of knitted or crocheted textiles	3.3	4.8	7.2	Laitala et. 2018
14141420	Women's or girls' briefs and panties, of knitted or crocheted textiles (including boxer shorts)	2.4	3.1	4.4	Laitala et. 2018
14141430	Women's or girls' nighties and pyjamas, of knitted or crocheted textiles	2.4	3.1	4.4	Laitala et. 2018
14141440	Women's or girls' negligees, bathrobes, dressing gowns and similar articles, of knitted or crocheted textiles	2.4	3.1	4.4	Laitala et. 2018
14141450	Women's or girls' slips and petticoats, of knitted or crocheted textiles	2.4	3.1	4.4	Laitala et. 2018
14142100	Men's or boys' shirts (excluding knitted or crocheted)	3.3	4.8	7.2	Laitala et. 2018
14142220	Men's or boys' underpants and briefs (including boxer shorts) (excluding knitted or crocheted)	2.4	3.1	4.4	Laitala et. 2018
14142230	Men's or boys' nightshirts and pyjamas (excluding knitted or crocheted)	2.4	3.1	4.4	Laitala et. 2018
14142240	Men's or boys' singlets, vests, bathrobes, dressing gowns and similar articles (excluding knitted or crocheted)	2.4	3.1	4.4	Laitala et. 2018
14142300	Women's or girls' blouses, shirts and shirt-blouses (excluding knitted or crocheted)	3.3	4.8	7.2	Laitala et. 2018
14142430	Women's or girls' nightdresses and pyjamas (excluding knitted or crocheted)	2.4	3.1	4.4	Laitala et. 2018
14142450	Women's or girls' slips and petticoats (excluding knitted or crocheted)	2.4	3.1	4.4	Laitala et. 2018
14142460	Women's or girls' singlets and other vests, briefs, panties, negligees, bathrobes, dressing gowns, housecoats and similar articles of cotton (excluding knitted or crocheted)	2.4	3.1	4.4	Laitala et. 2018
14142480	Women's or girls' negligees, bathrobes, dressing gowns, singlets, vests, briefs and panties (including boxer shorts), of man-made fibres (excluding knitted or crocheted)	2.4	3.1	4.4	Laitala et. 2018
14142489	Women's or girls' singlets, vests, briefs, panties, negligees, bathrobes, dressing gowns and similar articles, of textiles (excluding cotton, man-made fibres, knitted or crocheted)	2.4	3.1	4.4	Laitala et. 2018
14142530	Brassieres	3	3.5	4.4	Laitala et. 2018
14142550	Girdles, panty-girdles and corselettes (including bodies with adjustable straps)	3	3.5	4.4	Laitala et. 2018
14142570	Braces, suspenders, garters and similar articles and parts thereof	3	3.5	4.4	Laitala et. 2018
14143000	T-shirts, singlets and vests, knitted or crocheted	3.3	4.6	6.8	Laitala et. 2018
14191100	Babies' garments and clothing accessories, knitted or crocheted including vests, rompers, underpants, stretch-suits, gloves or mittens or mitts, outerwear (for children of height <= 86 cm)	2.4	3.1	4.4	Laitala et. 2018
14191210	Track-suits, of knitted or crocheted textiles	3.7	5.4	7.1	Laitala et. 2018
14191230	Ski-suits, of knitted or crocheted textiles	8.7	8.7	8.7	Laitala et. 2018
14191240	Men's or boys' swimwear, of knitted or crocheted textiles	2	2	2	Laitala et. 2018
14191250	Women's or girls' swimwear, of knitted or crocheted textiles	2	2	2	Laitala et. 2018

14191290	Other garments, knitted or crocheted (including bodies with a proper sleeve)	4.7	4.7	4.7	Laitala et. 2018
14191300	Gloves, mittens and mitts, of knitted or crocheted textiles	1	1	1	Laitala et. 2018
14191930	Shawls, scarves, mufflers, mantillas, veils and the like, of knitted or crocheted textiles	2	2	2	Laitala et. 2018
14191960	Clothing accessories and parts thereof, of knitted or crocheted textiles (excluding gloves, mittens, shawls, scarves, mufflers, mantillas and veils)	1	1	1	Fair Claims Guide
14192100	Babies' clothing and accessories, of textiles, not knitted or crocheted (for children of height <= 86 cm) including vests, rompers, underpants, stretch-suits, napkins, gloves, mittens and outerwear	2.4	3.1	4.4	Laitala et. 2018
14192150	Babies clothing and accessories, of textiles, not knitted or crocheted (for children of height <= 86 cm) including vests, rompers, underpants, stretch-suits, gloves, mittens and outerwear (excluding sanitary towels and napkins and similar articles)	2.4	3.1	4.4	Laitala et. 2018
14192210	Other men's or boys' apparel n.e.c., including tracksuits and jogging suits (excluding waistcoats, ski-suits, knitted or crocheted)	3.7	5.4	7.1	Laitala et. 2018
14192220	Other women's or girls' apparel n.e.c., including tracksuits and jogging suits (excluding waistcoats, ski-suits, knitted or crocheted)	3.7	5.4	7.1	Laitala et. 2018
14192230	Ski-suits (excluding of knitted or crocheted textiles)	8.7	8.7	8.7	Laitala et. 2018
14192240	Men's or boys' swimwear (excluding of knitted or crocheted textiles)	2	2	2	Fair Claims Guide
14192250	Women's or girls' swimwear (excluding of knitted or crocheted textiles)	2	2	2	Fair Claims Guide
14192310	Handkerchiefs	2	2	2	Fair Claims Guide
14192333	Shawls, scarves, mufflers, mantillas, veils and the like (excluding articles of silk or silk waste, knitted or crocheted)	2	2	2	Fair Claims Guide
14192338	Shawls, scarves, mufflers, mantillas, veils and the like, of silk or silk waste (excluding knitted or crocheted)	2	2	2	Fair Claims Guide
14192353	Ties, bow ties and cravats (excluding articles of silk or silk waste, knitted or crocheted)	1	1	1	Fair Claims Guide
14192358	Ties, bow ties and cravats, of silk or silk waste (excluding knitted or crocheted)	1	1	1	Fair Claims Guide
14192370	Gloves, mittens and mitts (excluding knitted or crocheted)	1	1	1	Fair Claims Guide
14192393	Clothing accessories of textiles (excluding shawls, scarves and mufflers, mantillas and veils, ties, bow-ties and cravats, gloves, mittens and mitts, knitted or crocheted)	1	1	1	Fair Claims Guide
14192395	Parts of garments or of clothing accessories, of textiles (excluding bras, girdles and corsets, braces, suspenders and garters, knitted or crocheted)	1	1	1	Fair Claims Guide
14192396	Clothing accessories, parts of garments or of clothing accessories, of textiles, n.e.c. and parts thereof, (excluding shawls, scarves and mufflers, mantillas and veils, ties, bow-ties and cravats, gloves, mittens and mitts and parts thereof; bras, girdles and corsets, braces, suspenders and garters	1	1	1	Fair Claims Guide
14193175	Gloves, mittens and mitts, of leather or composition leather (excluding for sport, protective for all trades)	1	1	1	Fair Claims Guide
14193200	Garments made up of felt or non-wovens, textile fabrics impregnated or coated	4.7	4.7	4.7	Laitala et. 2018

14194130	Hat-forms, hat bodies and hoods, plateaux and manchons of felt (including slit manchons) (excluding those blocked to shape, those with made brims)	2	2	2	Fair Claims Guide
14194150	Hat-shapes, plaited or made by assembling strips of any material (excluding those blocked to shape, those with made brims, those lined or trimmed)	2	2	2	Fair Claims Guide
14194230	Felt hats and other felt headgear, made from hat bodies or hoods and plateaux	2	2	2	Fair Claims Guide
14194250	Hats and other headgear, plaited or made by assembling strips of any material	2	2	2	Fair Claims Guide
14194270	Hats and other headgear, knitted or crocheted or made-up from lace, felt or other textile fabric in the piece (but not in strips); hair-nets of any material	2	2	2	Fair Claims Guide
14194300	Other headgear (except headgear of rubber or of plastics, safety headgear and asbestos headgear); headbands, linings, covers, hat foundations, hat frames, peaks and chinstraps, for headgear	2	2	2	Fair Claims Guide
14311033	Panty hose and tights, of knitted or crocheted synthetic fibres, measuring per single yarn < 67 decitex	1.8	2.6	3.6	Laitala et. 2018
14311035	Panty hose and tights, of knitted or crocheted synthetic fibres, measuring per single yarn >= 67 decitex	1.8	2.6	3.6	Laitala et. 2018
14311037	Pantyhose and tights of textile materials, knitted or crocheted (excl. graduated compression hosiery, those of synthetic fibres and hosiery for babies)	1.8	2.6	3.6	Laitala et. 2018
14311050	Women's full-length or knee-length knitted or crocheted hosiery, measuring per single yarn < 67 decitex	2.4	3.1	4.4	Laitala et. 2018
14311090	Knitted or crocheted hosiery and footwear (including socks; excluding women's full-length/knee-length hosiery, measuring <67decitex, panty-hose and tights, footwear with applied soles)	1.8	2.6	3.6	Laitala et. 2018
14391031	Men's or boys' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of wool or fine animal hair (excluding jerseys and pullovers containing >= 50 % of wool and weighing >= 600 g)	3.7	5.4	7.1	Laitala et. 2018
14391032	Women's or girls' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of wool or fine animal hair (excluding jerseys and pullovers containing >= 50 % of wool and weighing >= 600 g)	3.7	5.4	7.1	Laitala et. 2018
14391033	Jerseys and pullovers, containing >= 50 % by weight of wool and weighing >= 600 g per article	3.7	5.4	7.1	Laitala et. 2018
14391053	Lightweight fine knit roll, polo or turtle neck jumpers and pullovers, of cotton	3.7	5.4	7.1	Laitala et. 2018
14391055	Lightweight fine knit roll, polo or turtle neck jumpers and pullovers, of man-made fibres	3.7	5.4	7.1	Laitala et. 2018
14391061	Men's or boys' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of cotton (excluding lightweight fine knit roll, polo or turtle neck jumpers and pullovers)	3.7	5.4	7.1	Laitala et. 2018
14391062	Women's or girls' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of cotton (excluding lightweight fine knit roll, polo or turtle neck jumpers and pullovers)	3.7	5.4	7.1	Laitala et. 2018
14391071	Men's or boys' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of man-made fibres (excluding lightweight fine knit roll, polo or turtle neck jumpers and pullovers)	3.7	5.4	7.1	Laitala et. 2018
14391072	Women's or girls' jerseys, pullovers, sweatshirts, waistcoats and cardigans, of man-made fibres (excluding lightweight fine knit roll, polo or turtle neck jumpers and pullovers)	3.7	5.4	7.1	Laitala et. 2018
14391090	Jerseys, pullovers, sweatshirts, waistcoats and cardigans, of textile materials (excluding those of wool or fine animal hair, cotton, man-made fibres)	3.7	5.4	7.1	Laitala et. 2018
15201100	Waterproof footwear, with uppers in rubber or plastics (excluding incorporating a protective metal toecap)	4.7	4.7	4.7	Laitala et. 2018

15201210	Sandals with rubber or plastic outer soles and uppers (including thong-type sandals, flip flops)	4.7	4.7	4.7	Laitala et. 2018
15201231	Town footwear with rubber or plastic uppers	4.7	4.7	4.7	Laitala et. 2018
15201237	Slippers and other indoor footwear with rubber or plastic outer soles and plastic uppers (including bedroom and dancing slippers, mules)	4.7	4.7	4.7	Laitala et. 2018
15201330	Footwear with a wooden base and leather uppers (including clogs) (excluding with an inner sole or a protective metal toe-cap)	4.7	4.7	4.7	Laitala et. 2018
15201351	Men's town footwear with leather uppers (including boots and shoes; excluding waterproof footwear, footwear with a protective metal toe-cap)	4.7	4.7	4.7	Laitala et. 2018
15201352	Women's town footwear with leather uppers (including boots and shoes; excluding waterproof footwear, footwear with a protective metal toe-cap)	4.7	4.7	4.7	Laitala et. 2018
15201353	Children's town footwear with leather uppers (including boots and shoes; excluding waterproof footwear, footwear with a protective metal toe-cap)	4.7	4.7	4.7	Laitala et. 2018
15201361	Men's sandals with leather uppers (including thong type sandals, flip flops)	4.7	4.7	4.7	Laitala et. 2018
15201362	Women's sandals with leather uppers (including thong type sandals, flip flops)	4.7	4.7	4.7	Laitala et. 2018
15201363	Children's sandals with leather uppers (including thong type sandals, flip flops)	4.7	4.7	4.7	Laitala et. 2018
15201370	Slippers and other indoor footwear with rubber, plastic or leather outer soles and leather uppers (including dancing and bedroom slippers, mules)	4.7	4.7	4.7	Laitala et. 2018
15201380	Footwear with wood, cork or other outer soles and leather uppers (excluding outer soles of rubber, plastics or leather)	4.7	4.7	4.7	Laitala et. 2018
15201444	Slippers and other indoor footwear (including dancing and bedroom slippers, mules) with uppers of textile materials	4.7	4.7	4.7	Laitala et. 2018
15201445	Footwear with rubber, plastic or leather outer soles and textile uppers (excluding slippers and other indoor footwear, sports footwear)	4.7	4.7	4.7	Laitala et. 2018
15201446	Footwear with textile uppers (excluding slippers and other indoor footwear as well as footwear with outer soles of rubber, plastics, leather or composition leather)	4.7	4.7	4.7	Laitala et. 2018
15202100	Sports footwear with rubber or plastic outer soles and textile uppers (including tennis shoes, basketball shoes, gym shoes, training shoes and the like)	4.7	4.7	4.7	Laitala et. 2018
15202900	Other sports footwear, except snow-ski footwear and skating boots	4.7	4.7	4.7	Laitala et. 2018
15203120	Footwear (including waterproof footwear), incorporating a protective metal toecap, with outer soles and uppers of rubber or of plastics	4.7	4.7	4.7	Laitala et. 2018
15203150	Footwear with rubber, plastic or leather outer soles and leather uppers, and with a protective metal toe-cap	4.7	4.7	4.7	Laitala et. 2018
15203200	Wooden footwear, miscellaneous special footwear and other footwear n.e.c.	4.7	4.7	4.7	Laitala et. 2018
15204020	Leather uppers and parts thereof of footwear (excluding stiffeners)	4.7	4.7	4.7	Laitala et. 2018
15204050	Uppers and parts thereof of footwear (excluding stiffeners, of leather)	4.7	4.7	4.7	Laitala et. 2018

15204080	Parts of footwear (excluding uppers) other materials	4.7	4.7	4.7	Laitala et. 2018

Annex 4 References and shares used to calculate treatment flows of post-consumer waste

Following tables report references and shares used to calculate treatment flows of post-consumer and separately collected textile waste and from sorting and of exported separately collected waste.

References	Shares of post-consumer waste treatment		Shares of separately collected waste management	
	Separate collection*	Landfill and Energy recovery	Export	Sorting
(Amicarelli and Bux, 2022)	0.37	0.63	-	1
(Van Duijn et al., 2022)	0.38	0.62	-	1
(McKinsey, 2022)	0.31	0.69	0.40	0.60
(EEA, 2021)	0.33	0.67	-	1
(EURATEX, 2021)	0.41	0.59	0.34	0.66
(Watson et al., 2020b)	-	-	0.41	0.59

*Note: only textile waste that is commonly subject to separate collection schemes (apparel, home textiles) are considered for the determination of textile waste that is separately collected. The average value of separate collection (approximately 38%) is calculated as weighted average by the population.

References	Sorting						Exported separately collected waste		
	Fibre-to-fibre for apparel applications	Non fibre-to-fibre for use in textiles other than apparel	Landfill and Energy recovery	Re-use (In and extra EU)	Re-use (in EU)	Re-use (extra EU)	Recycling	Landfill and Energy recovery	Re-use
(Van Duijn et al., 2022)	0.02	0.24	0.19	-	0.10	0.45	-	-	-
(McKinsey, 2022)	0.01	0.29	0.10	-	0.10	0.50	-	-	-
(EEA, 2021)	0.005	0.20	0.15	0.65	-	-	-	-	-
(EURATEX, 2021)	-	0.35	0.12	0.54	-	-	-	-	-
(Watson et al., 2020b)	-	0.35	0.12	-	0.53	-	(0.32)*	(0.06)*	0.62

*Note: the share that is recycled has been calculated taken into consideration the existing recycling capacity in the EU. Landfill and energy recovery has been calculated as the difference between separate collection and re-use plus recycling. However, the outcome of such assessment is largely aligned to the values provided in the Table.

Annex 5 Shedding fibre coefficients used for the microfibre release calculation

Fibre	Vassilenko et al. (2021)	Hann et al. (2018)	Unit
Cotton	177	-	mg/kg x wash
Wool	129	-	mg/kg x wash
Polyester	112.75	246	mg/kg x wash
Nylon	23.5	198	mg/kg x wash
Viscose	-	261	mg/kg x wash
Acrilyc	-	205	mg/kg x wash
Polypropylene	-	82	mg/kg x wash

Annex 6 Categories and subcategories assumed for products

Category	Sub-category
Clothing and footwear	Apparel accessories Boots Closed-toed shoes Dresses, skirts and jumpsuits Jackets and coats Leggings, stockings, tights and socks Pants and shorts Shirts and blouses Sweaters and midlayers Swimwear T-shirts Underwear

Household	Bedding Blankets Carpets Cleaning articles Curtains Furnishing Non-woven articles Personal care Sacks and bags Sleeping bags Table linen Toilet and kitchen linen and towels
Technical	Carpets Cleaning articles Mixed technical textiles Non-woven articles

Annex 7 Subcategories composition for clothing and footwear and for household and technical textiles

Fibre type	Clothing and footwear												
	T-shirts	Shirts and blousers	Sweaters and midlayers	Jackets and coats	Pants and shorts	Dresses, skirts and Jumpsuits	Leggings,stockings, tights, socks	Underwear	Swimwear	Apparel accessories	Open-toed shoes	Closed-toed shoes	Boots
Acrylic	-	-	0.05	0.11	-	-	0.07	-	-	0.16	-	-	-
Cashmere and camel hair	-	-	0.04	0.009	-	-	-	-	-	-	-	-	-
Cork	-	-	-	-	-	-	-	-	-	-	0.05	-	-
Cotton	0.7	0.55	0.34	0.15	0.47	0.54	0.22	0.705	-	0.15	-	0.03	-
Duck down	-	-	-	0.009	-	-	-	-	-	-	-	-	-
Elastane	-	-	-	-	0.04	-	0.09	0.07	0.09	-	-	-	-
EVA	-	-	-	-	-	-	-	-	-	-	0.28	0.07	-
Fur	-	-	-	0.003	-	-	-	-	-	-	-	-	-
Leather	-	-	-	0.009	0.01	-	-	-	-	0.07	0.17	0.11	0.21
Linen	-	0.05	-	-	0.04	-	-	-	-	-	-	-	-
Metal	-	-	-	-	-	-	-	-	-	-	-	-	0.02
Polyamide	-	-	0.02	0.15	0.07	0.04	0.27	0.1	0.51	0.04	-	-	-

Polyamide recycled	-	-	-	-	-	-	0.04	0.02	-	-	-	-	-
Polyester and other synthetics	0.213	0.232	0.217	0.356	0.309	0.245	0.188	0.051	0.376	0.303	0.03	0.26	0.13
Polyester recycled	0.02	0.03	0.04	0.04	0.03	0.02	0.02	-	0.02	-	-	0.03	0.02
Polypropylene	-	-	-	-	-	-	-	-	-	-	-	-	-
Polyurethane	-	-	-	-	-	-	-	-	-	-	-	-	-
PTFE	-	-	-	0.018	-	-	-	-	-	-	0.08	0.06	0.1
PVC	-	-	-	-	-	-	-	-	-	-	0.06	0.06	0.14
Rubber natural	-	-	-	-	-	-	-	-	-	-	0.13	0.08	0.05
Rubber synthetic	-	-	-	-	-	-	-	-	-	-	0.19	0.16	0.11
Silk	-	-	-	-	-	-	-	-	-	0.01	-	-	-
Thermoplastic polyurethane	-	-	-	-	-	-	-	-	-	-	-	0.03	0.14
Trims	0.007	0.008	0.003	0.016	0.011	0.005	0.002	0.004	0.004	0.007	0.01	0.02	0.03
Viscose	0.06	0.13	0.05	0.04	0.02	0.13	0.08	0.05	-	-	-	0.02	-
Wood-based non-woven	-	-	-	-	-	-	-	-	-	-	-	-	0.02
Wool	-	-	0.24	0.09	-	0.02	0.02	-	-	0.26	-	0.04	-

Other cellulosic	-	-	-	-	-	-	-	-	-	-	-	-	-
Polyolefin	-	-	-	-	-	-	-	-	-	-	-	-	-
Glass	-	-	-	-	-	-	-	-	-	-	-	-	-
Aramic and carbon	-	-	-	-	-	-	-	-	-	-	-	-	-
Jute	-	-	-	-	-	-	-	-	-	-	-	-	-

Subcategories composition for clothing and footwear and for home and technical textiles (continue from Annex 7)

Fibre type	Home textiles												Techincal textiles
	Bedding	Blankets	Curtains	Carpets	Furnishing	Cleaning articles	Personal care	Non-woven articles	Sacks and bags	Sleeping bags	Table linen	Toilet and kitchen linen and towels	
Acrylic	0.06	0.12	-	-	-	-	-	0.02	0.02	0.02	-	-	-
Cashmere and camel hair	-	-	-	-	-	-	-	-	-	-	-	-	-
Cork	-	-	-	-	-	-	-	-	-	-	-	-	-
Cotton	0.38	0.27	0.33	-	0.48	0.73	1	0.5	0.5	0.5	0.5	0.83	0.07
Duck down	0.05	-	-	-	-	-	-	0.01	0.01	0.01	-	-	-
Elastane	-	-	-	-	-	-	-	-	-	-	-	-	-
EVA	-	-	-	-	-	-	-	-	-	-	-	-	-
Fur	-	-	-	-	-	-	-	-	-	-	-	-	-
Leather	-	-	-	-	-	-	-	-	-	-	-	-	-
Linen	0.15	-	-	-	0.08	0.04	-	0.04	0.04	0.04	-	0.06	-
Metal	-	-	-	-	-	-	-	-	-	-	-	-	-
Polyamide	-	0.04	0.04	0.33	-	-	-	0.05	0.05	0.05	-	-	0.07
Polyamide recycled	-	-	-	-	-	-	-	-	-	-	-	-	-
Polyester and other synthetics	0.28	0.53	0.62	0.33	0.44	0.21	-	0.33	0.33	0.33	0.5	0.09	0.25
Polyester recycled	-	-	-	-	-	-	-	-	-	-	-	-	-
Polypropylene	-	-	-	0.33	-	-	-	0.04	0.04	0.04	-	-	-
Polyurethane	-	-	-	-	-	-	-	-	-	-	-	-	-
PTFE	-	-	-	-	-	-	-	-	-	-	-	-	-
PVC	-	-	-	-	-	-	-	-	-	-	-	-	-

Rubber natural	-	-	-	-	-	-	-	-	-	-	-	-	-
Rubber synthetic	-	-	-	-	-	-	-	-	-	-	-	-	-
Silk	-	-	-	-	-	-	-	-	-	-	-	-	-
Thermoplastic polyurethane	-	-	-	-	-	-	-	-	-	-	-	-	-
Trims	-	-	-	-	-	-	-	-	-	-	-	-	-
Viscose	0.09	-	-	-	-	0.02	-	0.02	0.02	0.02	-	0.03	0.03
Wood-based non-woven	-	-	-	-	-	-	-	-	-	-	-	-	-
Wool	-	0.04	-	-	-	-	-	0	0	0	-	-	-
Other cellulosic	-	-	-	-	-	-	-	-	-	-	-	-	0.03
Polyolefin	-	-	-	-	-	-	-	-	-	-	-	-	0.25
Glass	-	-	-	-	-	-	-	-	-	-	-	-	0.15
Aramic and carbon	-	-	-	-	-	-	-	-	-	-	-	-	0.01
Jute	-	-	-	-	-	-	-	-	-	-	-	-	0.14

Annex 8 Results of MFA

Following table reports results from MFA on mass flows (in Mt) linking each node considered in the project scope (EU 27, 2019 and 2035).

From:	To:	Mass flow, 2019 [Mt]:	Mass flow, 2035 [Mt]:
Apparent consumption	Post-industrial and pre-consumer waste	0.33	0.48
Apparent consumption	Use	11.67	16.95
Export (discarded textiles)	Landfill/incineration (outside EU)	0.46	0.60
Export (discarded textiles)	Recycling (outside EU)	0.46	0.60
Export (discarded textiles)	Re-use (outside EU)	0.92	1.21
Fabric production	Export	0.7	0.86
Fabric production	Finished textiles production	1.2	1.32
Fabric production	Post-industrial and pre-consumer waste	0.26	0.32
Fibres production	Export	0.57	0.87
Fibres production	Finished textiles production	1.67	1.99
Fibres production	Yarns production	0.84	0.91
Finished textiles production	Apparent consumption	2.98	4.52
Finished textiles production	Export	1.73	2.39
Finished textiles production	Post-industrial and pre-consumer waste	1.02	1.36
Import	Apparent consumption	9.02	13.00
Import	Fabric production	1.27	1.59

Import	Finished textiles production	2.86	4.76
Import	Yarns production	0.31	0.50
Import (sep. coll. waste)	Recycling	0.07	0.04
Import (sep. coll. waste)	Sorting	0.26	0.47
Post-consumer waste	Energy recovery	4.86	9.09
Post-consumer waste	Landfill	3.55	2.81
Post-consumer waste	Separate collection	2.44	3.60
Post-industrial and pre-consumer waste	Energy recovery	0.67	0.98
Post-industrial and pre-consumer waste	Export	0.34	0.51
Post-industrial and pre-consumer waste	Landfill	0.49	0.30
Post-industrial and pre-consumer waste	Recycling	0.17	0.43
Separate collection	Export (discarded textiles)	0.94	1.14
Separate collection	Sorting	1.5	2.46
Sorting	Energy recovery	0.08	0.43
Sorting	Export (discarded textiles)	0.89	1.27
Sorting	Landfill	0.06	0.13
Sorting	Recycling	0.54	0.83
Sorting	Re-use (in EU)	0.19	0.27
Use	Post-consumer waste	10.86	15.50

Use	Stock	0.6	1.25
Use	Wastewater	0.21	0.29
Yarns production	Export	0.2	0.24
Yarns production	Fabric production	0.89	0.91
Yarns production	Post-industrial and pre-consumer waste	0.07	0.07

Annex 9 Estimated composition of flows at category, subcategory and fibres level

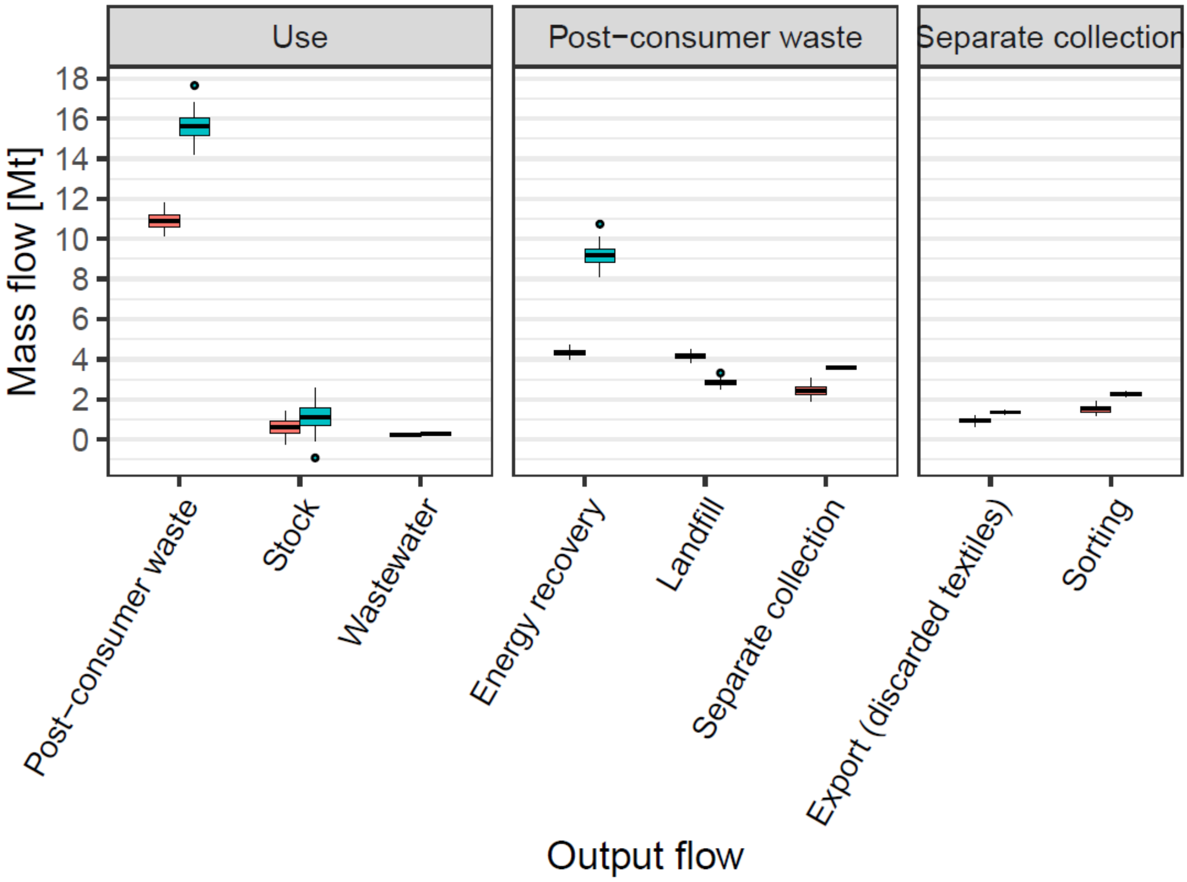
Category	Subcategory	Consumption of new textile products		Post-consumer waste	
		(%)		(%)	
		Category share	Subcategory share	Category share	Subcategory share
Apparel	Jackets and coats	49.13%	11.71%	48.20%	9.73%
	Sweaters and midlayers		7.61%		7.60%
	Pants and shorts		6.52%		6.46%
	T-shirts		4.76%		4.80%
	Closed-toed shoes		4.24%		4.64%
	Apparel accessories		3.04%		3.39%
	Shirts and blouses		2.64%		3.09%
	Leggings, stockings, tights and socks		2.46%		2.80%
	Dresses, skirts and jumpsuits		2.32%		2.17%
	Boots		1.94%		2.00%
	Underwear		0.97%		0.91%
	Swimwear		0.92%		0.80%
Home textiles	Carpets	16.01%	7.66%	15.72%	7.23%
	Bedding		4.11%		4.34%
	Toilet and kitchen linen and towels		1.69%		1.81%
	Curtains		1.07%		0.93%
	Blankets		0.56%		0.61%
	Table linen		0.44%		0.42%

	Furnishing		0.36%		0.26%
	Other personal care		0.08%post		0.08%
	Sleeping bags		0.04%		0.04%
Technical textiles - households	Non-woven articles	19.38%	7.15%	20.81%	7.81%
	Cleaning articles		6.88%		7.05%
	Sacks and bags		5.35%		5.95%
Technical textiles - Professional use	Non-woven articles	15.49%	7.64%	15.07%	7.53%
	Mixed technical articles		4.88%		3.54%
	Cleaning articles		2.48%		2.61%
	workwear and protective clothing		2.48%		0.90%
	Carpets		0.49%		0.50%

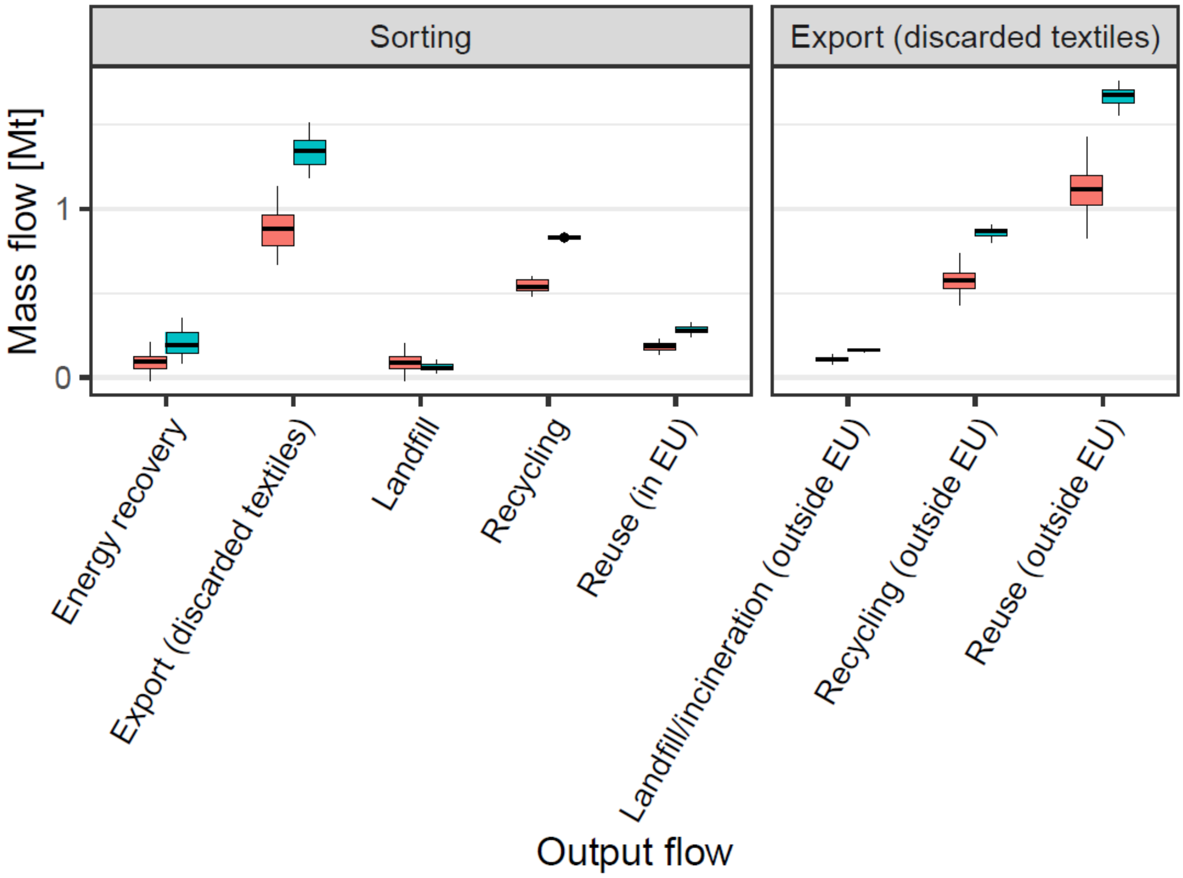
Fibre type	Share of blended fiber	Fibre content [%]			
		Consumption of new textile products (Use_{in})		Post-consumer waste (PCW)	
		Total content	Blended	Total content	Blended
Cotton	23.1%	33.3%	7.7%	33.7%	7.8%
Polyester	42.9%	29.3%	12.6%	29.0%	12.4%
Polyamide	66.7%	7.3%	4.9%	7.1%	4.7%
Wool	50.0%	3.9%	1.9%	3.9%	1.9%
Polypropylene	n/a	3.1%	n/a	3.2%	n/a
Viscose	42.9%	3.1%	1.3%	3.1%	1.3%
Acrylic	37.5%	2.8%	1.0%	2.7%	1.0%
Other fibres	n/a	6.0%	n/a	5.9%	n/a
Non-textile material	-	11.0%	-	11.5%	-

Annex 10 Uncertainty analysis results of output flows from selected nodes for current state (orange bars) and baseline (blue bars) MFA scenarios. a) Use, post-consumer waste nodes and separate collection; b) Sorting and export nodes

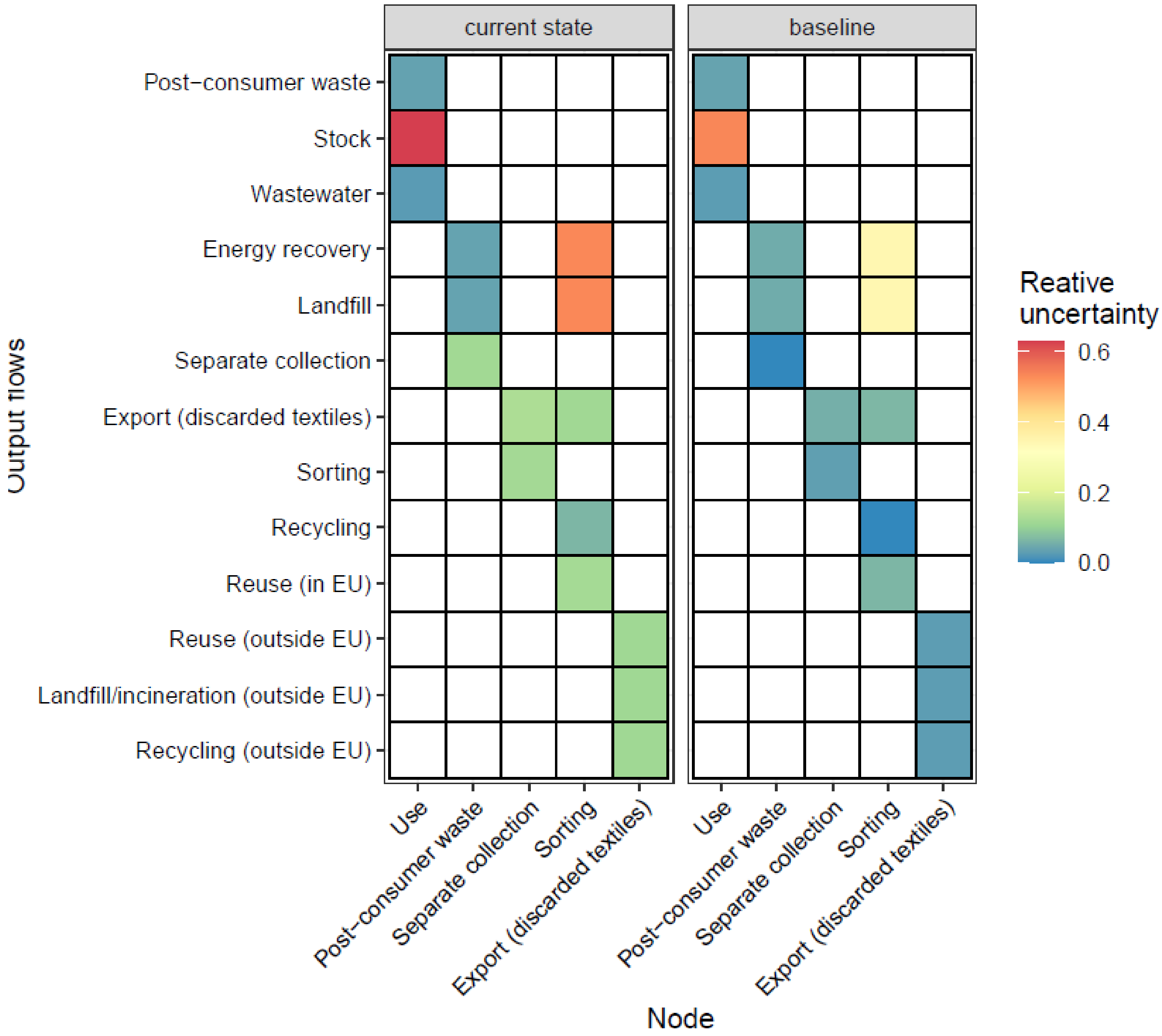
(a)



(b)


Sorting
Export (discarded textiles)
Mass flow [Mt]
1
0
Energy recovery
Export (discarded textiles)
Landfill
Recycling
Reuse (in EU)
Landfill/incineration (outside EU)
Recycling (outside EU)
Reuse (outside EU)
Output flow

Annex 11 Heatmap of relative uncertainty of current state and baseline MFA results.



Science for policy

The Joint Research Centre (JRC) provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society

EU Science Hub
joint-research-centre.ec.europa.eu

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

@eu_science

Publications Office
of the European Union