January 2023

# LCA-based assessment of the management of European used textiles


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# EXECUTIVE SUMMARY

The quantities of used textiles collected in Europe are increasing, while the proportion of high-quality reusable garments is decreasing. Towards 2030, the amount of separately collected textiles might reach 8.5 – 9 million tons. Currently, around 50-75 % of the collected textiles are reused, whereas 10-30 % is recycled. Towards 2030 however, it is expected that a smaller portion will be suitable for reuse, and that more will be fit for recycling. This is because the requirement of separately collected textiles is expected to divert textiles from mixed waste which are likely not fit for reuse, as well as a general trend of falling quality.

Today, the premium quality clothing textiles, called “crème”, constitute around 5 % of the total collected volume, and are sold to the Western European markets. The remining reusable textiles are sold to wholesalers for detailed sorting and are then exported on the global market. Second-grade textiles (also called “B-grade”) are typically sold to Eastern Europe and the Middle East, the lowest qualities are sold to Asian markets, and a special grade called “Tropical mix” (lightweight garments) are often sold to sub-Saharan Africa.

The part which is not considered reusable is sent for recycling, and the same is suspected to happen to a large portion of the lowest qualities. Mostly, recycling signifies mechanical recycling into industry wipes, bedding, or insulation products, but mechanical recycling can also be used to produce new yarn, a process termed “fibre-to-fibre” recycling. There is a mature and growing industry of mechanical recyclers, but there are challenges in terms of specific feedstock-requirements and that for each recycling round, the fibres are shortened and will ultimately not create strong enough yarn. New technologies using chemical processes to extract valuable components to produce new fibres are arising and are expected to speed-up the fibre-to-fibre recycling in the coming years.

The EU Strategy for Sustainable Textiles aims to strengthen both reuse and recycling in Europe, according to the waste hierarchy which clearly states that reuse should be prioritised over recycling, even when the reuse occurs in other global regions. However, as the portion of non-reusable garments is expected to increase and the field and capacity of the textile recycling sector in Europe is rapidly changing, this study has investigated through two comparative LCA’s 1) The environmental benefit of reuse compared to a new product and 2) The environmental impact of reuse globally compared to recycling within the EU.

The lifecycle impact assessment of reuse compared to a new product confirms that the environmental impact of reuse is significantly lower than the production of a new garment, for all three qualities. For both the crème and the B-grade t-shirt, the new garment is responsible for almost 70 times more overall environmental impact than a reused t-shirt, and in terms of $CO_2$-equivalents, the reuse of both types of garments saves more than 3 kg $CO_2$. The impact from a new garment primarily comes from the production of fibres as well as the production in itself, whereas the little impact connected with reuse comes from transportation to point of sales. But the latter is comparably trivial to the impact of the production of a new garment, that the study supports the existence of a global market for reuse, despite the connected transportation.

The lifecycle impact assessment of reuse compared to recycling in Europe, shows that reuse avoids more than recycling, and is therefore environmentally beneficial for all three qualities. However, if the reuse does not to a large degree replace the production of new garments, recycling can be slightly more environmentally beneficial.

# BACKGROUND AND OBJECTIVES

Approximately 5.4 million tonnes of textiles were placed on the EU-27 market in 2019. Somewhere between 1.7 and 2.1 million tonnes of post-consumer textiles are collected separately each year primarily for reuse[1]. This is expected to increase towards and beyond 2025, as countries implement the requirement for separate collection of textile waste in the Waste Framework Directive. By 2030, this annual gross textile waste figure could rise to 8.5 million to 9 million tons, corresponding to just below 20 kilograms per person for EU-27 and Switzerland[2] [3]

Current collection focuses on reusable clothing for second-hand markets and, depending on the country, somewhere between 50% and 75% of collected textiles are reused. Much of the reuse takes place on global markets[4]. Since a fair share of the additional collected textiles diverted from mixed waste after 2025 is expected to comprise non-reusable textiles, there will be a need for new recycling facilities and technologies.

The EU Strategy for Sustainable Textiles includes actions to boost textile reuse and recycling in Europe[5]. The waste hierarchy is clear that reuse should be prioritised over recycling, and studies that have been carried out to date indicate that reuse indeed provides greater environmental and economic benefits than both newly produced items and recycling, even where reuse occurs in other global regions[6]. With this project EuRIC Textiles wishes to explore the scale of environmental benefits derived from reuse and recycling of clothing at various levels of *quality*[7]. With a further aim to use the findings to inform stakeholders in the rapidly changing landscape of the used textiles industry.

The report starts with a qualitative overview of the market surrounding used textiles both in Europe and globally. This includes a presentation of current and future collection and sorting practices in Europe, the share and fate of various qualities, including both reuse and recycling, and projected volumes, fates and composition of collected textiles post 2025. Then, the two comparative lifecycle assessments are presented. First, the LCA of imported new garments vs imported second-hand garments, and then the LCA comparison of exported reused textiles vs. recycling in Europe. Each LCA includes the following parts: 1) Goal and scope, 2) Life cycle inventory analysis, 3) Life cycle impact assessment, 4) Interpretation, 5) Limitations and 6) Conclusion. Lastly, the report presents a set of recommendations based on the findings.

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[1] Køhler et al (2021) Circular Economy Perspectives in the EU Textile sector. For Joint Research Centre
[2] McKinsey & Company. (2022). Scaling textile recycling in Europe–turning waste into value.
[3] Data about Switzerland is not included in this report however these numbers are included as they are the most updated numbers, and it is assumed that even though they include Switzerland, they still give a sufficient indication of the amount of textile waste which is expected towards 2030.
[4] Watson et al (2020) Towards 2025: separate collection and treatment of textiles in 6 EU countries. For Danish EPA
[5] Directorate-General for Environment. (2022). EU strategy for sustainable and circular textiles.
[6] e.g. Schmidt et al (2016) Gaining benefits from discarded textiles: LCA of different treatment pathways. For Nordic Council of Ministers
[7] **'Qualities'** refer to different fibre compositions of different garments, such as 100 % cotton, a mix of polyester and cotton, and 100 % polyester. The report investigates the environmental impact of different qualities, as due to the different fibres their environmental impact might be different.

# 1 COLLECTION AND SORTING OF USED TEXTILES IN EUROPE

## 1.1 Textile collection practices

There is currently no legislation in Europe forcing the separate collection of post-consumers used textiles, but by 2025 all EU Member States will be obliged to separately collect used household textiles for reuse or recycling. However, many Member States have already established an infrastructure for the separate collection and sorting of used textiles. Textiles are either collected via a) Outside bring banks[8], b) Indoor bring banks and over the counter in second-hand shops and retailers, or c) Kerbside. Outside bring banks are by far the most dominant practice across Europe, with bring banks typically located on streets or at public ground[9]. Kerbside collection is less prevalent[10]. Furthermore, there are concerns of the quality and condition of items received in countries where the kerbside collection is undertaken by the local waste collection scheme instead of charity door-to-door clothing collections and donations.

> Box 1: Definition of 'textiles'
>
> Textiles are defined by the European Parliament and the Council (2011) as "any raw, semi -worked, worked, semi-manufactured, manufactured, semi-made-up or made-up product, which is exclusively composed of textile fibres, regardless of the mixing or assembly process employed". Products 'containing at least 80% by weight of textile fibres' are also referred to as textile products. In this report used textiles are mostly referring to as used clothing, as this is what most of the data refers to. However, some data also includes non-clothing household textiles, technical textiles, shoes and bags.

There are no European requirements for reporting on which collection methods have been applied for the textiles collected separately, but some data can be found across countries (on a project basis, or due to national targets as in France (see box 2))[11]:

- In France, being the only country with official numbers, 83 % of the collection is via bring banks; 15,5 % indoor bring banks/over the counter; and 1.5 % through kerbside[12].
- In Germany, it is estimated that 75,6 % of textiles are collected through bring banks; 20,4 % via recycling Centres; 2,1 % via street collection (kerbside); 0,5 % through door-to-door-collection; and 0,7 % via indoor collection by retail[13].
- In UK, 48 % of all textiles is collected over the counter at second-hand shops managed by charities, 37 % through bring banks, 9% is collected door-to-doors and the remaining 6% is collected through various schemes, in-store, and others[14].

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8 Bring banks refer to local collection points for used textiles, typically closed containers placed in places with high foot fall.

9 JRC (2021) Circular Economy Perspectives in the EU Textile sector

10 EcoTLC (2019). Annual Report 2018: https://www.ecotlc.fr/ressources/Documents_site/EcoTLC_2018-Annual-Report_web.pdf

11 The data on separate collection of textiles are most often collected through survey data sent to collection organisations and interpolated depending on the response rate. In Germany, volume of separate collection of textiles is calculated by taking the consumption of textiles minus the textiles found in mixed household waste (a picking analysis from 2006) and minus lint loss

12 EcoTLC (2020). Annual Report 2019: https://refashion.fr/pro/sites/default/files/fichiers/ECO_TLC_EN_BD.pdf

13 Wagner, J., Kösegi, N., Hoyer, S., Steinmetzer, S., Theophil, L., Streus, A.-S. (2022). Evaluation der Erfassung und Verwertung ausgewählter Abfallströme zur Fortentwicklung der Kreislaufwirtschaft. Umweltbundesamt (Hrsg.). [pdf] available under: https://www.umweltbundesamt.de/sites/default/files/medien/479/publikationen/texte_312022_evaluation_der_erfassung_und_verwertung_ausgewaehlter_abfallstroeme_zur_fortentwicklung_der_kreislaufwirtschaft.pdf

14 WRAP (2019). Textiles – market situation report 2019: https://wrap.org.uk/sites/default/files/2021-03/WRAP-textiles-market-situation-report-2019.pdf

Box 2: National targets for separate collection of textiles

France adopted an EPR scheme in 2007, where producers can choose to organise their own collection of textiles waste, reuse and recycling system or contribute to the accredited Producer Responsibility Organisation, ReFashion, whose mandate is negotiated with the French government. France aimed that by 2019, 95% of all collected textiles were to be reused, recycled, or used for energy recovery, and only 2% were to be land-filled. The new mandate includes updating the targets. The volume of collected textiles almost quadrupled between 2006 – 2019 resulting from the enforcement of the EPR scheme, going from 65,000 tonnes to 249,000 tonnes[15] .

Collection of textiles is carried out either by charities, commercial actors, or municipal waste companies, with charities and commercial actors being the most dominant actors. However, the landscape of actors involved in textile collection and sorting is changing. With the enforcement of the Waste Framework Directive requirement to set up an infrastructure for textile collection, municipal waste companies are expected to plan an increasingly important role in the countries where textiles are currently only collected by charities and commercial actors[16]. However, in countries like The Netherlands where commercial collectors and charities have been handling textile collection under responsibility of the cities and municipalities, the playing field will shift due to the upcoming introduction of EPR for textiles. Consequently, an increasing number of textile retailers are expected to scale up their existing textile (in-store) collection schemes or introduce new ones, alongside the existing infrastructure for collection of used textiles.

## 1.2 Volumes of separately collected textiles

Approximately 5.4 million tonnes of textiles were placed on the EU-27 market in 2019 and between 1.7-2.1 million tonnes of post-consumer textiles were collected (primarily) for reuse in the EU-27[17]. Additional approximately 620,000 tonnes of textiles were collected in the United Kingdom[18].

On average between countries, 38% of the textiles placed on the EU market are separately collected for reuse, recycling, or other waste treatment. The 38% collection rate corresponds to approximately 2.1 million tonnes[19]. The differences in consumption of new textiles (kg/person) between Member States are due to variation in average income and cultural differences in consumption patterns (some differences in the consumption figures can also be assigned variation in calculation method and data acquisition[20]).

[15] EcoTLC (2020). Annual Report 2019: https://refashion.fr/pro/sites/default/files/fichiers/ECO_TLC_EN_BD.pdf and Bukhari, M., et al. (2018). Developing a national programme for textiles and clothing recovery. Waste Management and Research Vol 36, Issue 4, 2018.: https://journals.sagepub.com/doi/full/10.1177/0734242X18759190
[16] JRC (2021) Circular Economy Perspectives in the EU Textile sector
[17] Köhler et al (2021) Circular Economy Perspectives in the EU Textile sector. For Joint Research Centre
[18] WRAP (2019) Textiles Market Situation Report 2019
[19] This estimate is calculated by taking the average collection rate for the member states (representing 63% of EU) where separate collection rates are currently available, as presented in JRC (2021) Circular Economy Perspectives in the EU Textile sector
[20] JRC (2021) Circular Economy Perspectives in the EU Textile sector

Table 1: Separate collection of used textiles in tons, kg/person, and as a share of new textiles placed on the market in the same year[21] [22]

| Country code (data year) | | AT (2018) | CZ (2013) | DE (2018) | DK (2016) | EE (2018) | FI (2012) | Fla. (2019) | FR (2019) | IT (2018) | LT (2018) | LV (2018) | NL (2018) | SE (2013) | UK[23] (2017) | ES[24] (2019) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Consumption of new textiles** | **K-tonnes** | --- | 69 | 1715 | 85 | 16 | 72 | ---- | 648 | 1383 | 19 | 12 | 305 | 121 | 1040 | 890 |
| | ***Kg/ person*** | --- | *6.6* | *20.7* | *15* | *12.4* | *13.2* | ---- | *9.7* | *22.8* | *7.0* | *6.1* | *17.7* | *12.6* | *15,7* | *19.0* |
| **Separate collection of used textiles** | **K-tonnes** | 38 | 20 | 1271 | 37 | 4.8 | 16 | 55 | 249 | 146 | 2.1 | 0.5 | 136 | 23 | 620 | 108 |
| | ***Kg/ person*** | *4.3* | *1.9* | *15.3* | *6.4* | *3.7* | *3.0* | *8.3* | *3.7* | *2.4* | *0.8* | *0.3* | *7.9* | *2.4* | *9.4* | *2,3* |
| **Collection rate*** | **%** | --- | 30% | --- | 43% | 30% | 23% | ---- | 38% | 11 % | 11 % | 4.5% | 45% | 19% | 60 % | 12 |

The volumes of separately collected textiles are growing and expected to grow even more rapidly towards 2025, as Member States implement separate collection of textiles waste to fulfil the obligations of the revised Waste Framework Directive.

[21] JRC (2021) Circular Economy Perspectives in the EU Textile sector
[22] WRAP (2019). Textiles – market situation report 2019. 66M has been applied to calculate pr. capita
[23] 1.7M textiles were consumed in 2017, and 620.000m were separately collected. WRAP (2019). Textiles – market situation report 2019. 66M has been applied to calculate pr. capita
[24] MODA RE- (2021) Analisis de la recogida de la ropa usada en España

## 1.3 Sorting of separately collected textiles

Once post-consumer textiles are collected, they are either sorted in-country or exported for sorting elsewhere. Manual sorting is most prevalent in Europe. Sorting facilities vary in size and capacity.

Non textiles are removed, and reusable textiles are sorted into different 2nd hand products. The sorting process is an item-based quality assessment of the condition, the style, the fabric etc. The concrete sorting categories depend on the demand. It takes half a year for a person to fully learn how to sort textiles for reuse. Sector representatives do not foresee this can be done automatically soon. However, semi-automatised sorting is conducted in some sorting plants.

## 1.4 Use of sorted textiles

On average across seven European countries, 50-75% of separately collected textiles (constituting 38 % of the total amounts of post-consumer textiles) are reused, 10-30% are recycled, and the remaining is used for energy recovery or landfilled as illustrated in Figure 1 below[25]. The bulk of post-consumer disposed textiles (62%) ends up in the general household waste and will therefore be incinerated or landfilled directly. There are currently no countries where textiles are removed from general household waste for recycling, although some initiatives are arising to pilot such interventions.

Box 3: The destiny of UK used textiles (numbers are estimates and subject to methodological limitations)[26]

Among those textiles separately collected, 32% is reused through charity shops and 2% through commercial second-hand outlets, 3% is recycled, 5% is landfilled or energy recovered, and the remaining 60% is exported, principally for sorting for reuse

55% of all textiles, corresponding to 921,000 tonnes of textile products, ended in the residual waste stream in 2017, thus being destined for landfill or incineration[27].

Textile sorters primarily sell the premium quality clothing textiles – also called the “crème”, constituting around 5% of the total collected volume – on Western European markets. The remaining textiles suitable for second-hand markets are sold to wholesalers for detailed sorting and/or for sale on Eastern European or global markets. The destination of these exported textiles depends on their fit with local market demands[28]. Second-grade textiles are typically exported to Eastern Europe and the Middle East, while the lowest qualities end up in Asian markets. A special grade called ‘tropical mix’ consisting of lightweight garments are often sold in sub-Saharan African markets. Some sorting centres sell up to 20% of the collected volumes on the European markets, with second grade textiles sold on the Eastern European markets being the largest part of this. If the garment is not considered saleable on global markets, the textile product is sent to recycling, where it is most often either recycled to industry wipes, bedding or insulation products or incinerated[29]. There is an inherent economic incentive for textile recyclers to follow the waste hierarchy in terms of reuse over recycling, recovery, and disposal.

[25] Much of the data stems from wholesalers, who are not formally obliged to report data, and who are not always aware of where textiles end up, leaving the data with a certain level of uncertainty. JRC (2021) Circular Economy Perspectives in the EU Textile sector
[26] WRAP (2019). Textiles – market situation report 2019: https://wrap.org.uk/sites/default/files/2021-03/WRAP-textiles-market-situation-report-2019.pdf
[27] ibid.
[28] Illustrated by the research conducted in Kenya, showing the demand for used textiles in such countries of destination. Available at: https://ieakenya.or.ke/download/the-state-of-second-hand-clothes-and-footwear-trade-in-kenya/
[29] JRC (2021) Circular Economy Perspectives in the EU Textile sector

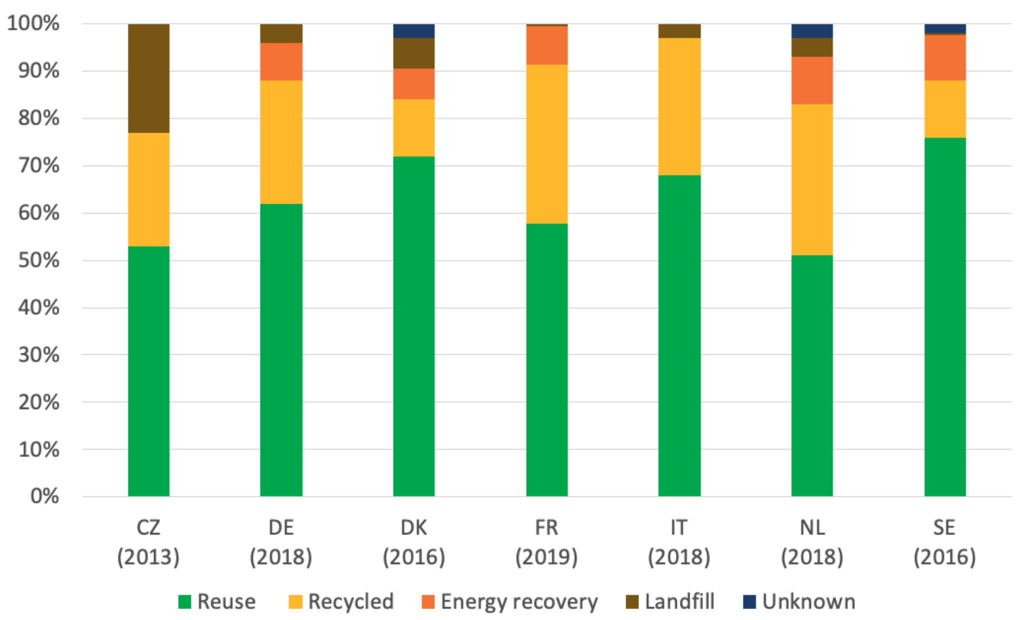


Figure 1: Global treatment pathways* for separately collected post-consumer textiles in countries with available data

*Note that the treatment is global. For example, 71% of all textiles collected separately in Denmark are reused either within Denmark or on global reuse markets. Source: JRC (2021). Circular Economy Perspectives in the EU Textile sector

There is no uniform classification of used textiles. In some EU Member States, such as Austria, Germany and the Netherlands, all textiles collected via bring banks are classified as waste as waste, but the collector is obliged to state that they only want to receive reusable textiles, therefore the textiles handed tend to be of better quality[30]. Figure 2 below shows the destination of Nordic exported textiles of various quality and value, demonstrating that 46 % of the textiles (of next best quality) end up in Europe, Africa, and the Middle East[31]. All future destinations of sorted textiles are described in more detail in the next chapter.

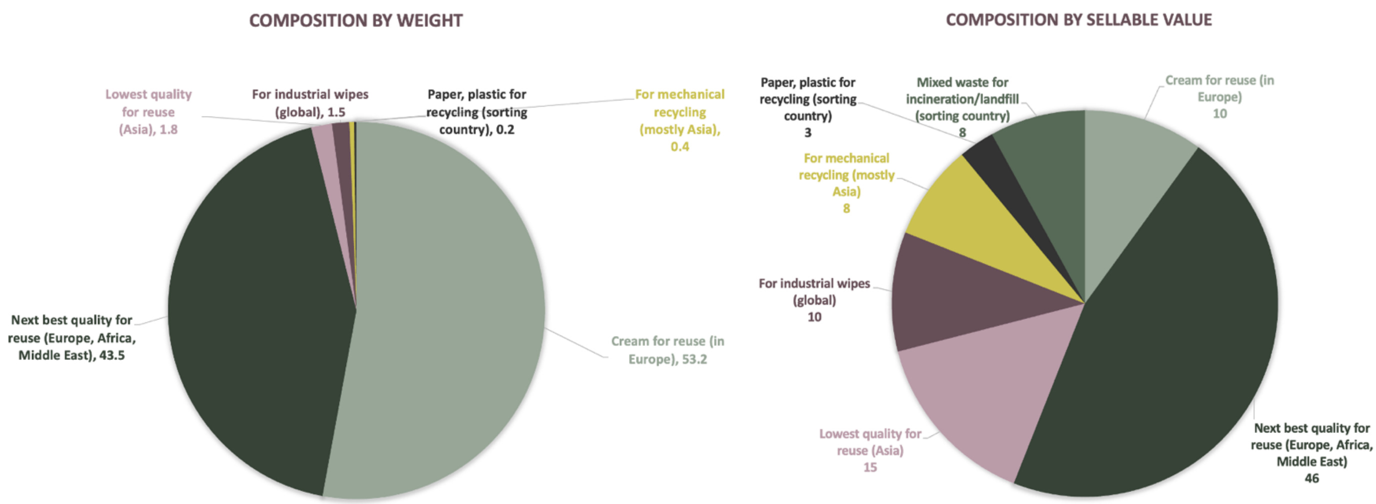


**Figure 2: Typical post-sorted composition of Nordic textiles, in per cent**[32]
(with eventual destinations in brackets)

[30] Ibid.
[31] Ibid.
[32] Watson, D., Palm, D., Brix, L., Amstrup, M., Syversen, F., & Nielsen, R. (2016). *Exports of Nordic used textiles: fate, benefits and impacts*. Nordic Council of Ministers.

# 2 SHARE AND FATE OF VARIOUS QUALITIES OF PRODUCTS

Textile-items are considered of different qualities, based on garment construction and material. In this report, 'quality' refers solely to the material. For instance, a shirt can be made of 100 % cotton (considered high quality material), a mix between polyester and cotton, and 100 % polyester (considered lower quality).

## 2.1 Reuse: domestic markets

The share of re-wearable textiles fit for the domestic or European market (this 'quality' is referred to as 'Crème') fluctuates depending on the consumption and disposal behaviour of a country's citizen as well as the collection methods used. Whilst Nordic countries report a share of 'Crème' products of 10 % to 15 % of the total volume collected, other countries estimate the share of 'Crème' at around 5 %.

## 2.2 Reuse: destinations and value of used textiles

European sorters are very dependent on the global market for sales of separated collected used textiles. Over the last decades, the global market is characterised by an increase in used textiles supply, while the demand over time has shown signs of a stabilising, although there are yearly fluctuations. Figure 3 below shows how EU's export of textiles has increased from 400,000 tonnes in 2003 to 1.3 million tonnes in 2019, whilst the value of exported materials followed a different trend[33].

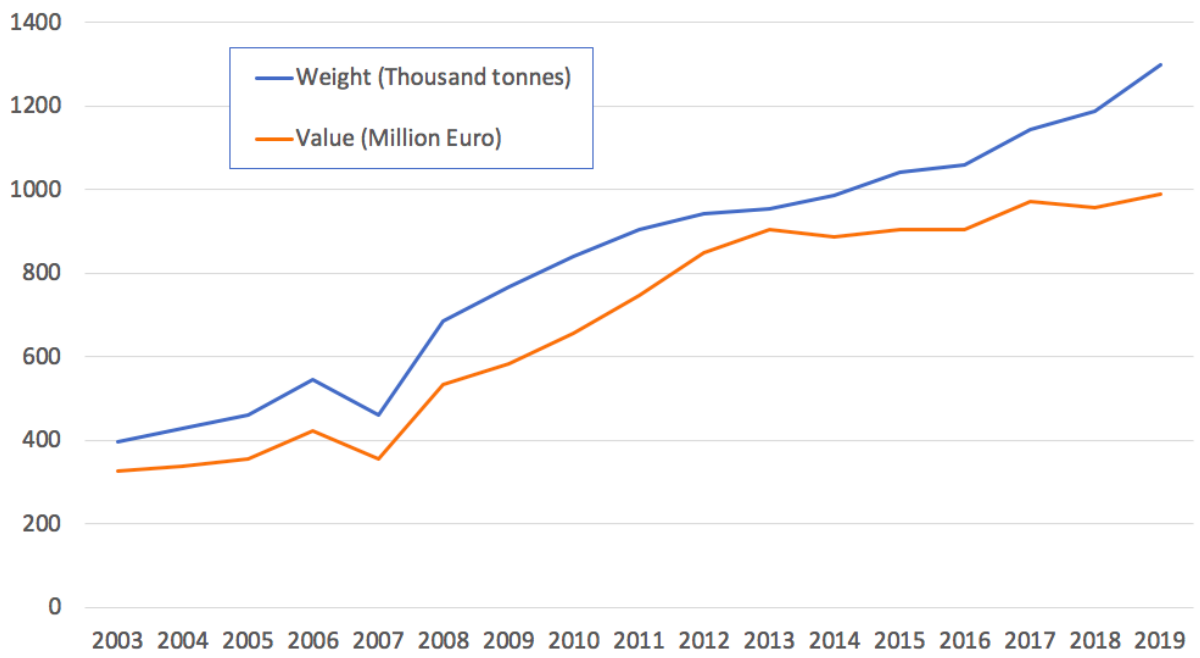


**Figure 3: Data from Eurostat Comtrade database EU-27-extra exports for code CN 6309**

Due to increase in supply at the global market and a stabilisation of demand, the price of used textiles is falling: From €0.95 per kg of textiles in 2013 to €0.70 in 2020[34], making business less profitable for second-hand garment traders. In addition to the increased amounts, the price fall is also due to a

[33] JRC (2021) Circular Economy Perspectives in the EU Textile sector
[34] UNCOMTRADE database

general fall in the quality of the textiles, because of fast fashion (thus low-quality products) and the trend that consumers increasingly sell their highest quality textiles independently at C2C second-hand platforms. In particular, the demand for lower quality garment is decreasing, and some of the qualities[35] – which were reused before – are now recycled[36]. If this becomes an increasingly common practice, this could have further implications on the path for used textiles.

In 2020 the main country of export for the EU-countries was Pakistan (accounting for 14.5% of the total volume exported), followed by the United Arab Emirates (11.6%) and Tunisia (8.3%). Whilst these countries absorb over one third of the exported volume, they only accounted for less than 14% of the value of exported used textiles. When considering the value of exported textiles, the ranking of top destinations looks completely different. Out of the non-EU-27 countries the Russian Federation absorbs the most expensive textiles at an average value of € 2.26 per kilo, followed by Ukraine (€ 1.28 per kilo) and Cameroon (€ 0.99 per kilo). The top 10 exporting countries ranked by annual export volume (table 2) and average export value (table 3) are shown below[37]. It should be noted that the export data does not distinguish between textiles exported as second-hand garments or recycling fractions.

Table 2: Top ten importing countries by volume and value, ranked according to volume

| | | **Export volume** (tonnes in 2020) | **Export value** (euro/kilo) |
|---|---|---|---|
| | World | 1,234,405 | €0.70 |
| 1 | Pakistan | 179,385 | €0.17 |
| 2 | UAE | 143,590 | €0.33 |
| 3 | Tunisia | 102,862 | €0.39 |
| 4 | Cameroon | 71,419 | €0.99 |
| 5 | Ukraine | 59,917 | €1.28 |
| 6 | Turkey | 55,087 | €0.40 |
| 7 | Togo | 53,384 | €0.44 |
| 8 | Ghana | 48,849 | €0.89 |
| 9 | India | 39,378 | €0.13 |
| 10 | Russian Federation | 36,138 | €2.26 |

Table 3: Top ten importing countries by volume and value, ranked according to value

[35] 'Quality' refers to the fibre composition of the material, such as 100 % cotton, a mix of polyester and cotton, and 100 % polyester.
[36] Ljungkvist, H., Watson, D., & Elander, M. 2018. Developments in global markets for used textiles and implications for reuse and recycling. Report for Mistra Future Fashion. Available at: http://mistrafuturefashion.com/wp-content/uploads/2018/05/Mistra-Future-Fashion-2018-4H.-LjungkvistD.3.3.4.1.pdf
[37] Based on trade data available in the UNCOMTRADE database, for product code 6309 (Textiles; worn clothing and other worn articles). Available at: https://comtrade.un.org/data/ - data collected from the database in February 2022.

| | | Export volume (tonnes in 2020) | Export value (euro/kilo in 2020) |
|---|---|---|---|
| | World | 1,234,405 | €0.70 |
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| 9 | Pakistan | 179,385 | €0.17 |
| 10 | India | 39,378 | €0.13 |

## 2.3 Recycling: mature and emerging technologies

10-30% of the textiles being separately collected are recycled, most often as industry wipes (approximately 20% of all textiles collected[38]), padding, or insulation material[39]. The textiles used as secondary raw material for manufacturing of these products typically stem from a mechanical recycling process (being the most prevalent recycling technology) which tends to degrade the textile through cutting, tearing, and needling.

Mechanical recycling can also recover a garment to produce new yarn, a process termed "fibre-to-fibre" recycling. There is a mature and growing industry of mechanical recyclers, mostly using wool-, cotton- and acrylic-rich textiles as their feedstock[40]. Whilst mechanical recycling is a valuable destination for some of the non-re-wearable collected textiles, most of these textiles do not meet the feedstock specifications the recyclers require. To maximise the quality of their outputs, mechanical recyclers firstly remove non-textile contamination, and also restrict the composition of textiles they take in (high content of wool, cotton or acrylic, no presence of synthetic fibres like elastane) and the presence of disruptors (like haberdashery or care labels).

New technologies using chemical processes to extract valuable components to produce new fibres are arising. These technologies can process pure cotton or polyester, and/or blends of both fibre types, and polyamide into new textile fibres. Whilst some of these technologies focus on pure materials, others can process a wider variety of material types. These innovative fibre-to-fibre chemical recycling technologies are emerging, which expectedly will speed-up the fibre-to-fibre recycling in the coming years.

Technical challenges for fibre-to-fibre recycling relate to shortening of fibre lengths, separation of fibre types in blends, and persistent chemicals in specialised products. Ensuring sufficient volumes of recyclable textiles is another challenge[41].

[38] Kösegi, N. (2018). *Applications and markets for post-consumer textiles*
[39] Inventories amongst textile sorters in the context of the JRC report, the Fibersort project and the EigenDraads initiative in Rotterdam
[40] Van Duijn, H., Papú Carrone, N. 2020. Recycled post-consumer textiles: an industry perspective. Report for the Interreg NWE Fibersort project. Available at: https://www.nweurope.eu/media/9453/wp-lt-32-fibersort-end-markets-report.pdf
[41] Van Duijn, H., Papú Carrone, N. 2019. Potential barriers for the long-term implementation of the Fibersort. Report for the Interreg NWE Fibersort project. Available at: https://www.nweurope.eu/media/6811/fibersort-barriers-report-final.pdf

# 3 VOLUMES AND MARKETS POST 2025

## 3.1 Future volumes of collected textiles

The obligation to collect textiles waste separately by 2025 will radically change the market: The supply of textiles will further increase and the quality of collected textiles might be lowered and not primarily focused on textiles with a quality that allow reuse. Altogether, separated collected textiles overall are expected to increase across EU-27 from 2025 onwards, and McKinsey & Company estimates a potential collection of 8,5 – 9 million tonnes by 2030[42]. However, the volumes of textiles collected depend on the system implemented in given member states and the initiatives to promote separate collection of textiles. A rough estimate – based on historical evidence and country targets – is an average increase in volumes to between 150 to 200 g/capita/year, from which roughly half can be reused (up to 100 g/capita/year).The increase in supply of non-reusable textiles imply that more recycling opportunities will be needed.

## 3.2 End-markets trends

The quantities of second-hand used textiles collected in Europe are increasing, while the proportion of high-quality reusable garments is decreasing[43]. Traditional reuse markets are facing increasing competition, partly driven by both new textiles, and used textiles from China. The market for industrial wipes has less demand for wipes made from post-consumer textiles as a result of substituting wipes[44] which is one of the recycled fractions that generate revenue. As a result, European textile collectors and sorting companies report decreasing revenues from reuse[45]. Some textile sorting companies have begun to reject unsorted collected post-consumer textiles (original) with low proportions of reusable clothing in high quality (crème), and in some cases have even cancelled contracts with long-term customers. This results in increasing challenges for textile collectors in relation to selling both pre-sorted textiles and 'original' for sorting.

The declining proportions of 'crème' in the collected 'originals' and the increasing competition in the traditional second-hand markets have major consequences for the profitability of manual textile sorting companies, because the current manual sorting mainly focuses on sorting for reuse. While non-reusable used clothing typically accounts for at least 20 % of the quantities collected, they contribute less than 3 % of the income[46].

It is estimated that less than 1 % of collected used clothing is recycled back into clothing using current chemical and/or mechanical fibre-to-fibre recycling technologies[47], but throughout Europe and other global regions new innovative fibre-to-fibre technologies are emerging at different scales. Currently, not many are operating at full scale, but as Figure 4 below shows, many facilities are expected to expand their capacity substantially towards 2030.

[42] McKinsey & Company. (2022). Scaling textile recycling in Europe–turning waste into value.
[43] Euwid Recycling & Entsorgung (2019)
[44] Personal communication with sorters and recyclers. November 2022.
[45] Ljungkvist et al (2018)
[46] Watson et al (2016)
[47] Ellen MacArthur Foundation (2017) A new Textiles Economy: Redesigning Fashion's Future, Circular Fibres Initiative.

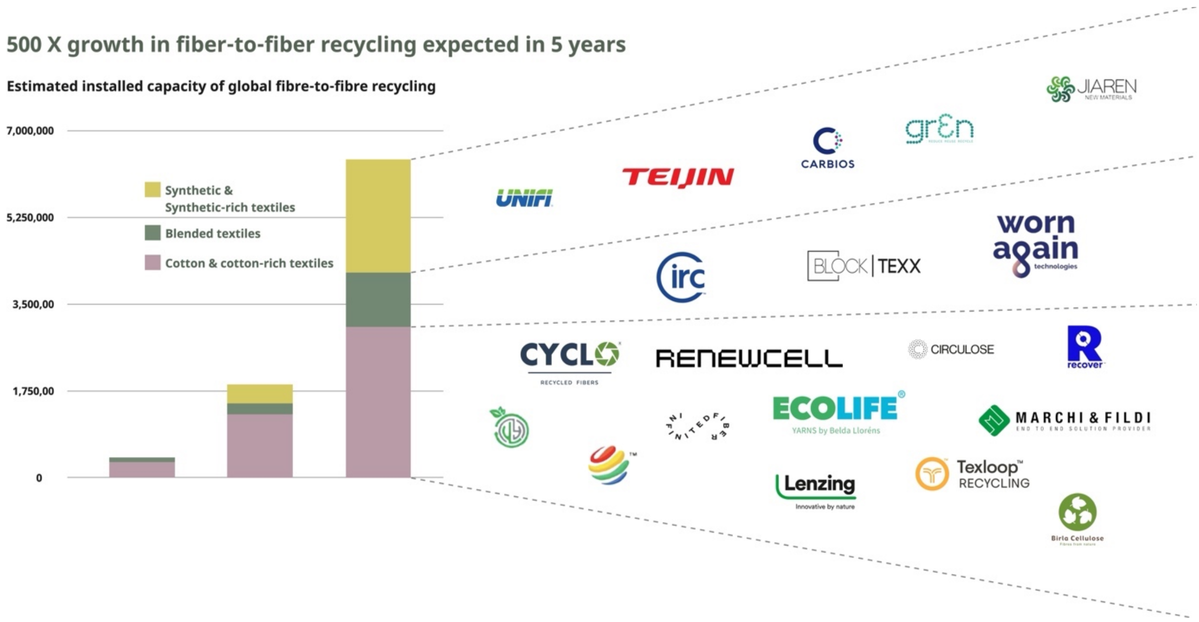


Figure 4: Estimation from presentation by Reverse Resources

## 3.3 Projected composition of collected textiles

The potential destinations of sorted textiles are firstly determined by their quality, style, and potential fit with the demand on domestic and international second-hand markets. When textiles are not suitable for resale on the second-hand markets, their future use is determined by their fibre composition and characteristics such as mono- vs. multi-layered and presence of disruptors. As automated sorting technologies to determine the actual composition of textiles using NIR are still upcoming, only limited data is available on the current composition of used textiles. Previous research by the French EPR organisation Refashion[48] and the Fibersort project consortium[49] shows the prevalence of cotton and polyester (and blends of both fibre types) in today's non-rewearable used textiles[50].

[48] Étude de caractérisation des TLC usagés entrant en centres de tri ainsi que de déchets ultimes résultant du tri, EcoTLC / Refashion (2014). Available at: https://refashion.fr/pro/sites/default/files/rapport-etude/RESULTAT_Rapport_Caracterisation_flux_entrants_et_dechets_TLC_web_0.pdf

[49] Manual sort of post-consumer textiles in North-West Europe (2019). Report for the Interreg NWE Fibersort project. Available at: https://www.nweurope.eu/media/3453/fibersort_manual-sort-pct_jan2018.pdf

[50] More data will be available mid 2022 once the outcomes of the Sorting for Circularity project by Fashion for Good are published

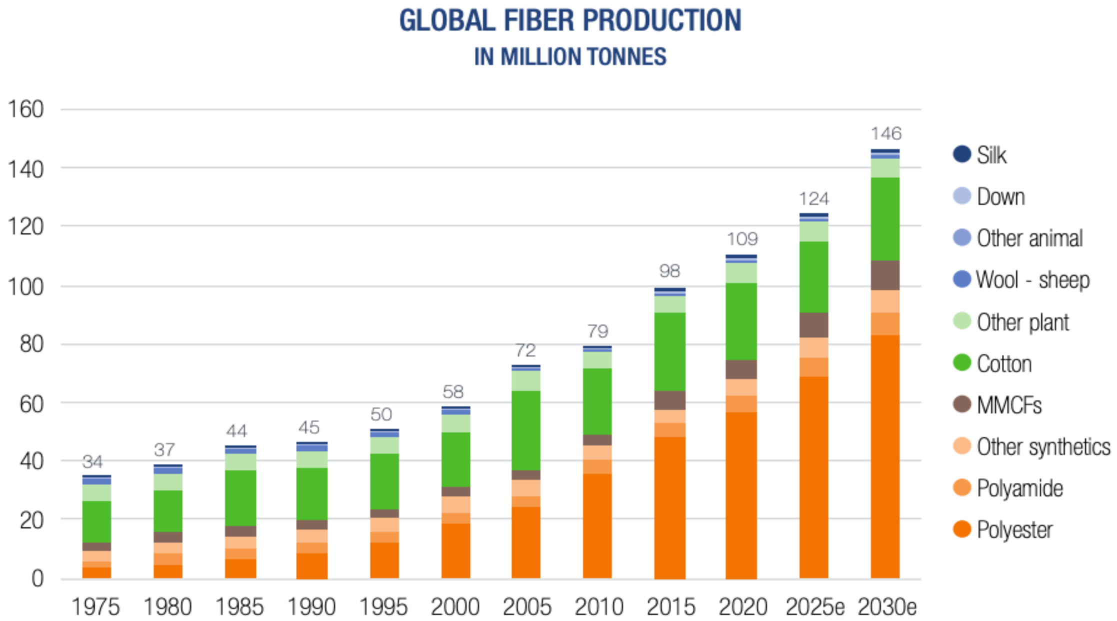


Figure 5: Preferred Fibres and Materials Market Report 2021, Textile Exchange

The dominance of cotton and polyester in textiles production is also reflected in the reports published by industry organisation Textile Exchange[51]. Their data shows polyester is the most used textiles fibre, in 2020 it represented 52 % of the global fibre production. The second most prevalent textile fibre is cotton, representing 24 % of the world's fibre production. As illustrated in Figure 5 above, the global fibre production is expected to grow from 109 million tonnes in 2020 to 146 million tonnes in 2030. This growth of fibre production is projected to be driven by a further rise in the coming decades of the volume of polyester textile fibre produced globally.

Fibre blends containing elastane are increasing on the market and are projected to increase further. The elastane is typically mixed in with cotton to provide better stretch and recovery properties in fabrics such as denim and rib knit collars[52].

# 4 LCA OF IMPORTED NEW GARMENTS VS IMPORTED SECOND-HAND GARMENTS

The following section presents the results of the comparative life cycle assessment of new garments versus second-hand garments. This chapter briefly describes the goal and scope in section 6.1, including the different scenarios, functional unit, system boundaries and the used life cycle impact assessment method with its impact categories. In section 6.2 the data inventory process is described and, where possible, the used data is provided. Section 6.3 shows the results of the LCA, which are interpreted and discussed in section 6.4. In this last section also, limitations are discussed, and conclusions are formulated.

## 4.1 Goal and scope

This LCA is intended to identify the scale of environmental benefits derived from reuse of clothing at various levels of quality by comparing the environmental impact of a reused (second-hand) garment to

[51] Preferred Fibers and Materials Market Report, Textile Exchange (2021). Available at: https://textileexchange.org/wp-content/uploads/2021/08/Textile-Exchange_Preferred-Fiber-and-Materials-Market-Report_2021.pdf
[52] Manshoven et al. (2021) Plastic in textiles: potentials for circularity and reduced environmental and climate impacts

that of a new garment. The reference product that is chosen to represent this garment is a basic t-shirt without embellishments. However, different quality levels are distinguished based on their composition. To ensure fair comparison, one should differentiate between these, therefore three scenarios were defined (one per quality level) which are found in Table 4.

Thus, it is very important to note that within this LCA, comparison of results between alternatives from different scenarios (for instance, a 100 % cotton reused shirt and a 100% polyester reused shirt) is not allowed since it would lead to incorrect conclusions.

Table 4: Overview of the three considered quality levels and associated scenarios

| Scenario | Quality level | Reused garment | New garment |
|---|---|---|---|
| 1 | Crème | 100% cotton second-hand shirt sorted in Europe and sold in Europe | 100% cotton new shirt produced in Asia and sold in Europe |
| 2 | B-grade | 30/70 polycotton second-hand shirt sorted in Europe and sold in sub-Saharan Africa | 30/70 polycotton new shirt produced in Asia and sold in sub-Saharan Africa |
| 3 | C-grade | 100% polyester second-hand shirt sorted in Europe and sold in Pakistan | 100% polyester new shirt produced in Asia and sold in Pakistan |

**The scenarios were defined based on the following elements:**

- **Quality level**: Crème, B-grade, and C-grade to represent various qualities.
- **Fibre type**: Cotton, 30/70 polycotton, and 100 % polyester. These fibre types have been selected to ensure that the price of the t-shirt is affordable on global markets in e.g., Asia and Pakistan. The fibre types are further chosen to enable various recycling possibilities (for the second LCA, see chapter 7).
- **Country of production and consumption**: The countries are selected from the basis of the EU's export of second-hand clothing (often sub-Saharan Africa and Pakistan). Asia is selected for production of B-grade and C-grade due to the huge clothing industry in Asian countries including China, Bangladesh, and Vietnam.
- **Functional unit** for new and second-hand garments of **52 wears/washes** (not looking into use nor end of life). Lifetimes of textiles can be measured in years, number of wears, number of users or cleaning cycles. Here it is measured as 52 cleaning cycles, which is a similar functional unit to that selected under the Commission's PEF pilot for t-shirts[53]. However, we have adjusted this to exclude laundering and the end-of-life phase, since these are assumed to be the same for both the new and the second-hand shirt. Likewise, functional lifetime has been excluded, even though it might be expected that the used shirt would have a shorter remaining lifetime than the new shirt. However, we should be comparing products that are roughly price equivalent in each comparison scenario. A new shirt that might be affordable to someone in sub-Saharan Africa, may be of a lower starting quality than the second-hand shirt was at the beginning of its life. It could be argued that in each scenario comparison, assuming equivalent price, the life expectancy of the purchased shirt is the same. Moreover, the crème quality shirts do not necessarily have a longer lifespan than the C grade shirt, as a purchaser in Pakistan may tolerate more wear and tear before discarding than a purchaser in Europe.
- **Replacement rate**: normally when carrying out an LCA of used textiles one assumes a replacement rate by a second-hand purchase of a new purchase. However, in this chapter we compare the impacts of a used shirt with a new one. As such we do not need to consider replacement rates. Replacement rates are an important factor in the calculations in Chapter 7 though.

[53] Single Market for Green Products - The Product Environmental Footprint Pilots - Environment - European Commission (europa.eu))

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The **functional unit** (FU) is the basis of comparison between alternatives and aims to quantify the performance of a product. We focused here on an adult's t-shirt. The Product Environmental Footprint category rules (PEFCR) for t-shirts distinguishes between babies', children's, women's, and men's shirts, which have different weights due to the obvious size difference. The PEFCR states that the weight of a men's and a woman's shirt equals 160 and 150 grams respectively. Therefore, we assumed the average weight of an adult's t-shirt is 155 grams. The FU is defined for all scenarios as *"access to a t-shirt for 52 wears"*, where the composition of the t-shirt depends on the scenario and was described in Table 4.

The cradle-to-gate **life cycle stages** and processes included in (and excluded from) the system boundary for both the reused and the new t-shirt are listed in Table 5 below. Note that from the point of sale on, the treatment of the shirt is considered identical for both the new and the used shirt. Therefore, the laundering cycles and end-of-life treatments are streamlined (excluded from the LCA). The reused shirts enter the product system burden-free, meaning that impacts of the production of the shirts are allocated to the first use.

Table 5: Life cycle stages in scope

| Life cycle element | Description | Data source |
|---|---|---|
| Reused | | |
| Transport to sorting facility | Transport from European collection points to hub(s)<br>Transport from hub(s) to sorting facilities | Key collectors |
| Manual sorting in Europe | Sorting, pressing and baling | Key sorters |
| Transport to point of sale | Transport inside Europe (crème grade) - long haul<br>Transport from Europe to sub-Saharan Africa (B grade) - medium haul<br>Transport from Europe to Pakistan (C grade) - short haul | Estimations - see Annex 3 |
| Laundering | Excluded – considered equivalent for the new and used shirt | |
| End of life | Excluded – considered equivalent for the new and used shirt | |
| New | | |
| Production of new shirt (cradle-to-gate) | Fibre production<br>Yarn production<br>Fabric production<br>Finishing<br>Confection | Literature |
| Transport to point of sale | Transport from Asia to Europe (crème grade)<br>Transport from Asia to sub-Sahara Africa (B grade)<br>Transport from Asia to Pakistan (C grade) | Estimations – see Annex 3 |
| Laundering | Excluded – considered equivalent for the new and used shirt | |
| End of life | Excluded – considered equivalent for the new and used shirt | |

The **system boundary diagrams** visualising the processes in scope are shown in Figure 6.

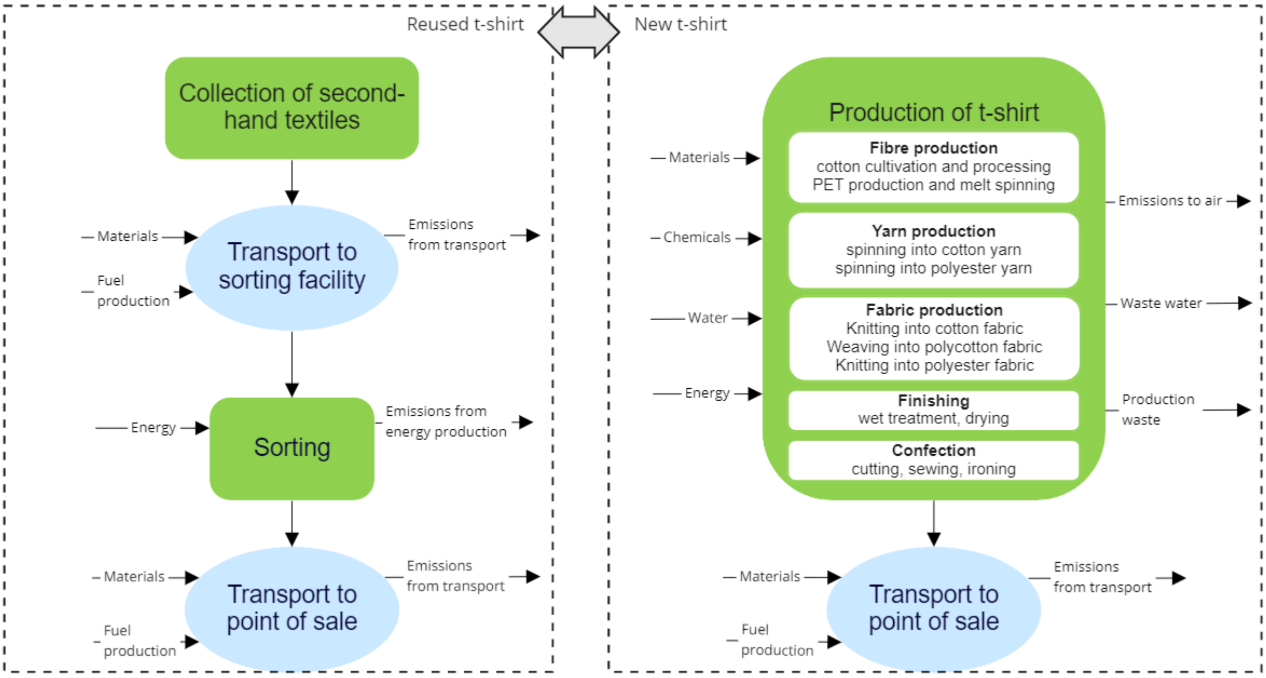


Figure 6: System boundary diagrams for the reused t-shirt (left) and the new t-shirt (right). The functional unit is defined as "access to a t-shirt for 52 wears"

Results will focus on climate change and water use selected from the 16 main **impact categories**[54] of the Product Environmental Footprint (PEF), see Table 6, as well as a single score (providing a weighted average overall environmental impact from the EF impact categories, valued in points – See Annex 1).

Table 6: EF impact categories to be used to calculate the environmental profiles

| Impact category | Indicator | Unit | Recommended default LCIA method |
|---|---|---|---|
| Climate change | Radiative forcing as Global Warming Potential (GWP100) | kg $CO_2$ eq | Baseline model of 100 years of the IPCC (based on IPCC 2013) |
| Water use | User deprivation potential (deprivation-weighted water consumption) | $m^3$ deprived | Available WAter REmaining (AWARE) Boulay et al., 2016[55] |

For the life cycle impact assessment, the EF reference package 3.0 is used[56].

## 4.2 Life cycle inventory analysis

In the inventory phase all data needed to analyse the environmental impacts associated with the t-shirts (reused and new) are gathered. In summary this means that all input flows (materials, energy, water etc.) and all output flows (emissions, waste etc.) are described and quantified. This is done for all life cycle phases within the system boundaries for both t-shirts. The life cycle data on the reused t-shirt is largely based on primary data, while the data on the new t-shirt is retrieved from literature.

### 4.2.1 Life cycle inventory for a reused t-shirt

The data inventory process is focused on the following life cycle phases:

[54] EC (2019). Product Environmental Footprint Category Rules (PEFCR). https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_tshirt.pdf
[55] more information available online: https://wulca-waterlca.org/aware/what-is-aware/
[56] We used the adapted version of EF 3.0 method in SimaPro software. This method is compatible with records from the ecoinvent LCI database.

1. Transport from collection points to sorting facility;
2. Manual sorting process, which includes the energy needed for operation of the sorting facility;
3. Transport to the point of sale.

For the first two phases, specific data was gathered from members of the European Recycling Industries' Confederation (EuRIC). 15 European sorting facilities from 7 companies provided data on their inputs (amount of collected textiles, transportation (distances and transport modes), energy use, etc.) and outputs (The amount of sorted textiles and their quality, sales markets). This company-specific data was converted into one aggregated dataset which is used for the analysis. Aggregation is based on a weighted average, according to the annual sorted output.

To ensure data confidentiality, the LCIs will not disclose information about the countries where the sorters are located. For instance, although different national grid mixes are used, the amounts of electricity are summed and listed here as one value.

For the third phase, transport to point of sale, estimations were used since EuRIC Textiles members do not have this information available. The point of sale differs per scenario, dictated by the quality level. T-shirts for reuse made of cotton are assumed to be sold in the EU, while second-hand t-shirts of polycotton and polyester are assumed to be sold in, respectively, Sub-Saharan Africa and Pakistan as documented in chapter 4.2. This assumption is aligned with the data from EuRIC Textiles members. The assumed transport modes and distances are shown in Table 7 below.

Table 7: Scenarios for transport of second-hand t-shirts to point of sale

| Transport scenario | Distance (km) | Comment |
|---|---|---|
| Crème grade scenario: transport within Europe for sale (short haul) | | |
| Transport over road- lorry 16-32 tonne (EURO4) | 1150 | Transportation across Europe |
| B grade scenario: transport to Sub-Saharan Africa for sale (medium haul) | | |
| Transport over road – lorry 16-32 tonne (EURO4) | 1150 | Assumption of average distance within Europe before shipping |
| Transport over sea – freight ship | 6282.83 | |
| Transport over road– lorry 16-32 tonne (EURO3) | 441.97 | |
| C grade scenario: transport to Pakistan for sale (long haul) | | |
| Transport over road – lorry 16-32 tonne (EURO4) | 1150 | Assumption of average distance within Europe before shipping |
| Transport over sea – freight ship | 10465.56 | |
| Transport over road– lorry 16-32 tonne (EURO3) | 524.04 | |

The data inventories per scenario are presented in the tables below.

Table 8: Data inventory for 1 reused t-shirt - crème grade

| 1. Collection | | | | | |
|---|---|---|---|---|---|
| Input flows | | | | | |
| Flow | Amount | Unit | Data source | Record | Comment |
| Transport over road – van <3.5 tonne | $5.3*10^{-3}$ | tkm | sorters | Transport, freight, light commercial vehicle {Europe without Switzerland}\| processing \| Cut-off, U | Transport to sorting facility |

| | | | | | |
|---|---|---|---|---|---|
| Transport over road – lorry 16-32 tonne (EURO5) | 5.2*10-2 | tkm | sorters | Transport, freight, lorry 16-32 metric ton, EURO5 {RER}\| transport, freight, lorry 16-32 metric ton, EURO5 \| Cut-off, U | |
| Transport over road – lorry 16-32 tonne (EURO6) | 2.7*10-2 | tkm | sorters | Transport, freight, lorry 16-32 metric ton, EURO6 {RER}\| transport, freight, lorry 16-32 metric ton, EURO6 \| Cut-off, U | |
| Transport over road – lorry > 32 tonne (EURO4) | 3.1*10-4 | tkm | sorters | Transport, freight, lorry >32 metric ton, EURO4 {RER}\| transport, freight, lorry >32 metric ton, EURO4 \| Cut-off, U | |
| Transport over road – lorry > 32 tonne (EURO6) | 1.1*10-3 | tkm | sorters | Transport, freight, lorry >32 metric ton, EURO6 {RER}\| transport, freight, lorry >32 metric ton, EURO6 \| Cut-off, U | |
| Transport over sea – freight ship | 5.1*10-3 | tkm | sorters | Transport, freight, sea, bulk carrier for dry goods {GLO}\| transport, freight, sea, bulk carrier for dry goods \| Cut-off, U | |
| 2. Sorting | | | | | |
| Electricity - from grid [country] | $2.61*10^{-2}$ | kWh | sorters | Electricity, medium voltage {country}\| market for \| Cut-off, U | Country specific grid mixes were used but are not reported here to maintain confidentiality |
| Natural gas | $2.34*10^{-2}$ | kWh | sorters | Heat, central or small-scale, natural gas {Europe without Switzerland}\| market for heat, central or small-scale, natural gas \| Cut-off, U | |
| Electricity | $-2.81*10^{-3}$ | MJ | sorters | Electricity, medium voltage {RER}\| market group for \| Cut-off, U | Electricity recovery from incineration of waste from sorting – allocated to crème grade |
| Heat | $-5.89*10^{-3}$ | MJ | sorters | Heat, district or industrial, natural gas {RER}\| market group for \| Cut-off, U | Heat recovery from incineration of waste from sorting – allocated to crème grade |
| Incineration | $2.81*10^{-4}$ | kg | sorters | Waste paperboard {CH}\| treatment of, municipal incineration \| Cut-off, U | Proxy for incineration of sorting waste with energy recovery – allocated to crème grade |
| Landfill | $9.35*10^{-3}$ | kg | sorters | Inert waste, for final disposal {CH}\| treatment of inert waste, inert material landfill \| Cut-off, U | Landfill of sorting waste – allocated to crème grade |
| 3. Transport of second-hand t-shirt (crème grade) to point of sale (short haul) | | | | | |
| Flow | Amount | Unit | Data source | Record | Comment |
| Transport over road – lorry 16-32 tonne (EURO4) | 0.18 | tkm | Estimations | Transport, freight, lorry 16-32 metric ton, EURO4 {RER}\| transport, freight, lorry 16-32 metric ton, EURO4 \| Cut-off, U | Transport from European sorter to Europe (average distance)<br>Assumption: loss in distribution phase of 1% |

Table 9: Data inventory for 1 reused t-shirt - B- grade

| Flow | Amount | Unit | Data source | Record | Comment |
|---|---|---|---|---|---|
| **1. Collection** | | | | | |
| Input flows | | | | | |
| Flow | Amount | Unit | Data source | Record | Comment |
| Transport over road – van <3.5 tonne | $5.3*10^{-3}$ | tkm | sorters | Transport, freight, light commercial vehicle {Europe without Switzerland}\| processing \| Cut-off, U | Transport to sorting facility |
| Transport over road – lorry 16-32 tonne (EURO5) | 5.2*10-2 | tkm | sorters | Transport, freight, lorry 16-32 metric ton, EURO5 {RER}\| transport, freight, lorry 16-32 metric ton, EURO5 \| Cut-off, U | |
| Transport over road – lorry 16-32 tonne (EURO6) | 2.7*10-2 | tkm | sorters | Transport, freight, lorry 16-32 metric ton, EURO6 {RER}\| transport, freight, lorry 16-32 metric ton, EURO6 \| Cut-off, U | |
| Transport over road – lorry > 32 tonne (EURO4) | 3.1*10-4 | tkm | sorters | Transport, freight, lorry >32 metric ton, EURO4 {RER}\| transport, freight, lorry >32 metric ton, EURO4 \| Cut-off, U | |
| Transport over road – lorry > 32 tonne (EURO6) | 1.1*10-3 | tkm | sorters | Transport, freight, lorry >32 metric ton, EURO6 {RER}\| transport, freight, lorry >32 metric ton, EURO6 \| Cut-off, U | |
| Transport over sea – freight ship | 5.1*10-3 | tkm | sorters | Transport, freight, sea, bulk carrier for dry goods {GLO}\| transport, freight, sea, bulk carrier for dry goods \| Cut-off, U | |
| **2. Sorting** | | | | | |
| Electricity - from grid [country] | $1.74*10^{-2}$ | kWh | sorters | Electricity, medium voltage {country}\| market for \| Cut-off, U | Country specific grid mixes have been used but are not reported in this table to maintain confidentiality |
| Natural gas | $1.56*10^{-2}$ | kWh | sorters | Heat, central or small-scale, natural gas {Europe without Switzerland}\| market for heat, central or small-scale, natural gas \| Cut-off, U | |
| Electricity | $-6.65*10^{-3}$ | MJ | sorters | Electricity, medium voltage {RER}\| market group for \| Cut-off, U | Electricity recovery from incineration of waste from sorting – allocated to B grade |
| Heat | $-1.40*10^{-2}$ | MJ | sorters | Heat, district or industrial, natural gas {RER}\| market group for \| Cut-off, U | Heat recovery from incineration of waste from sorting – allocated to B grade |
| Incineration | $6.65*10^{-4}$ | kg | sorters | Waste paperboard {CH}\| treatment of, municipal incineration \| Cut-off, U | Proxy for incineration of sorting waste with energy recovery – allocated to B grade |
| Landfill | $2.22*10^{-2}$ | kg | sorters | Inert waste, for final disposal {CH}\| treatment of inert waste, inert material landfill \| Cut-off, U | Landfill of sorting waste – allocated to B grade |
| **3. Transport of second-hand t-shirt (B- grade) to point of sale (medium haul)** | | | | | |
| Flow | Amount | Unit | Data source | Record | Comment |

| | | | | | |
|---|---|---|---|---|---|
| Transport over road – lorry 16-32 tonne (EURO4) | 0.18 | tkm | Estimations | Transport, freight, sea, container ship {GLO}\| market for transport, freight, sea, container ship \| Cut-off, U | Assumption: Loss in distribution phase of 1% |
| Transport over sea | 0.98 | tkm | Estimations | Transport, freight, lorry 16-32 metric ton, EURO4 {RER}\| transport, freight, lorry 16-32 metric ton, EURO4 \| Cut-off, U | Assumption: Loss in distribution phase of 1% |
| Transport over road – lorry 16-32 tonne (EURO3) | 0.07 | tkm | Estimations | Transport, freight, lorry 16-32 metric ton, EURO3 {RoW}\| transport, freight, lorry 16-32 metric ton, EURO3 \| Cut-off, U | Assumption: Loss in distribution phase of 1% |

Table 10: Data inventory for 1 reused t-shirt - C- grade

| 1. Collection | | | | | |
|---|---|---|---|---|---|
| Input flows | | | | | |
| Flow | Amount | Unit | Data source | Record | Comment |
| Transport over road – van <3.5 tonne | $5.3*10^{-3}$ | tkm | sorters | Transport, freight, light commercial vehicle {Europe without Switzerland}\| processing \| Cut-off, U | Transport to sorting facility |
| Transport over road – lorry 16-32 tonne (EURO5) | 5.2*10-2 | tkm | sorters | Transport, freight, lorry 16-32 metric ton, EURO5 {RER}\| transport, freight, lorry 16-32 metric ton, EURO5 \| Cut-off, U | |
| Transport over road – lorry 16-32 tonne (EURO6) | 2.7*10-2 | tkm | sorters | Transport, freight, lorry 16-32 metric ton, EURO6 {RER}\| transport, freight, lorry 16-32 metric ton, EURO6 \| Cut-off, U | |
| Transport over road – lorry > 32 tonne (EURO4) | 3.1*10-4 | tkm | sorters | Transport, freight, lorry >32 metric ton, EURO4 {RER}\| transport, freight, lorry >32 metric ton, EURO4 \| Cut-off, U | |
| Transport over road – lorry > 32 tonne (EURO6) | 1.1*10-3 | tkm | sorters | Transport, freight, lorry >32 metric ton, EURO6 {RER}\| transport, freight, lorry >32 metric ton, EURO6 \| Cut-off, U | |
| Transport over sea – freight ship | 5.1*10-3 | tkm | sorters | Transport, freight, sea, bulk carrier for dry goods {GLO}\| transport, freight, sea, bulk carrier for dry goods \| Cut-off, U | |
| 2. Sorting | | | | | |
| Electricity - from grid [country] | $2.55 *10^{-2}$ | kWh | sorters | Electricity, medium voltage {country}\| market for \| Cut-off, U | Country specific grid mixes have been used but are not reported in this table to maintain confidentiality |
| Natural gas | $2.29*10^{-2}$ | kWh | sorters | Heat, central or small-scale, natural gas {Europe without Switzerland}\| market for heat, central or small-scale, natural gas \| Cut-off, U | |
| Electricity | $-5.58*10^{-3}$ | MJ | sorters | Electricity, medium voltage {RER}\| market group for \| Cut-off, U | Electricity recovery from incineration of waste from sorting – allocated to C grade |
| Heat | $-1.17*10^{-2}$ | MJ | sorters | Heat, district or industrial, natural gas {RER}\| market group for \| Cut-off, U | Heat recovery from incineration of waste from sorting – allocated to C grade |

| | | | | | |
|---|---|---|---|---|---|
| Incineration | 5.58*10$^{-4}$ | kg | sorters | Waste paperboard {CH}\| treatment of, municipal incineration \| Cut-off, U | Proxy for incineration of sorting waste with energy recovery – allocated to C grade |
| Landfill | 1.86*10$^{-2}$ | kg | sorters | Inert waste, for final disposal {CH}\| treatment of inert waste, inert material landfill \| Cut-off, U | Landfill of sorting waste – allocated to C grade |
| 3. Transport of second-hand t-shirt (C- grade) to point of sale (long haul) | | | | | |
| Flow | Amount | Unit | Data source | Record | Comment |
| Transport over road – lorry 16-32 tonne (EURO4) | 0.18 | tkm | Estimations | Transport, freight, lorry 16-32 metric ton, EURO4 {RER}\| transport, freight, lorry 16-32 metric ton, EURO4 \| Cut-off, U | Assumption: Loss in distribution phase of 1% |
| Transport over sea | 1.64 | tkm | Estimations | Transport, freight, sea, container ship {GLO}\| market for transport, freight, sea, container ship \| Cut-off, U | Assumption: Loss in distribution phase of 1% |
| Transport over road – lorry 16-32 tonne (EURO3) | 0.08 | tkm | Estimations | Transport, freight, lorry 16-32 metric ton, EURO3 {RoW}\| transport, freight, lorry 16-32 metric ton, EURO3 \| Cut-off, U | Assumption: Loss in distribution phase of 1% |

### 4.2.2 Life cycle inventory for a new t-shirt

For the LCA's of the new t-shirts, no specific data was collected. All data was retrieved from literature, more specifically from Sandin *et al.* (2019)[57], for the largest part.

The comprehensive publication by Sandin *et al.* includes very well-documented life cycle assessments of 6 different garments, among which a 100% cotton t-shirt. This garment was used as the basis for our LCA's of new t-shirts. However, to model a 100% polyester and a 30%/70% polycotton shirt, adjustments needed to be made. For instance, the data on polyester melt spinning and polyester yarn spinning needs to be included. Therefore, the data as reported for a dress in this publication was adopted.

The considered production stages for a cotton t-shirt are cotton fibre sourcing, yarn production (spinning), fabric production (knitting), wet treatment (dyeing and finishing) and confectioning (cutting, sewing) (see Figure 6). For a polyester t-shirt these processes are analogous, apart from polyester fibre production. The specific wet treatments and associated chemicals (e.g., for dyeing) also differ between polyester and cotton textiles. Production of a polycotton shirt starts from the first two steps of both fibres (i.e., until cotton yarn and polyester yarn spinning). These yarns are then woven together to obtain a polycotton blend, using the polyester and cotton yarns in a 30/70 ratio. Wet treatment and confectioning are then analogous to the other two t-shirts. The data inventories for the cotton, polycotton and polyester t-shirts can be found in Annex 1.

The adjustments that were made to the original cotton t-shirt dataset as reported by Sandin *et al.*, (for example with data obtained from the polyester dress dataset from the same publication) are listed below:

- Sandin *et al.* assume a weight of 110 g for a cotton t-shirt. To follow the PEFCR for t-shirts as well as possible, we assumed a weight of 155 g (average of 150 g and 160 g, for a woman's and a men's t-shirt, respectively).

[57] Sandin, G. et al. (2019). *Environmental assessment of Swedish clothing consumption.*

- The cotton fibre dataset as available in the ecoinvent database was not used by Sandin *et al.* due to concerns about the accuracy of the dataset. Sandin *et al*. had access to another database, containing a dataset on cotton fibres which they found more appropriate. For this project, we have selected the ecoinvent database as an LCIA database and we have consistently used this database in the study, also for cotton fibres.
- Production of the t-shirt is (for this assessment) assumed to take place in Asia. For that reason, the electricity grid mixes as reported by Sandin *et al.* was slightly adapted by excluding Turkey from the country mix. The adapted electricity mix for our assessment therefore contains the country grid mixes of following countries:
  - China: 63.2%
  - Bangladesh: 20.2%
  - India: 6.9%
  - Cambodia: 3.4%
  - Pakistan: 3.4%
  - Vietnam: 2.9%
- No data was available for wet treatment of polycotton (this fabric was not part of their assessment). Therefore, this process was simplified by assuming that, respectively, 30% and 70% of the inputs for wet treatments of polyester and cotton are needed.
- Material losses during the various production processes were largely adopted from Sandin *et al.* with three exceptions. Firstly, knitting of polyester was not part of their study, therefore the loss percentage is considered equal to knitting of cotton. Losses during weaving of polycotton were considered equal to those during weaving of denim (adopted from the jeans case in the study). Lastly, the losses during wet treatment of polycotton are unknown. The material losses are listed in the table below.

Table 11: Material losses during production of a new t-shirt

| Production process | Cotton | Polyester | Polycotton |
|---|---|---|---|
| Cotton fibre production | 35.6% | | 35.6% |
| Polyester fibre production (melt spinning) | | 24.4% | 24.4% |
| Yarn production (spinning) | 20.6% | 23.8% | 20.6% (cotton yarn)<br>23.8 % (polyester yarn) |
| Fabric production (knitting) | 18.8% | 18.8% | |
| Fabric production (weaving) | | | 17.2% |
| Wet treatment | 18.8% | 23.8% | 18.8% (cotton part)<br>23.8 % (polyester part) |
| Confectioning (cutting, sewing, ironing) | 1% | 1% | 1% |
| Distribution and retail | 1% | 1% | 1% |

- For the transport to point of sale life cycle stage, average transport data from Asia to Europe have been used, covering both road and oversea transport. For transport to Sub-Saharan Africa (B grade scenario), transport was assumed between Shanghai and the major port of the 5 largest importers of clothing in Sub-Saharan Africa (Comtrade, 2021). These are Kenya (37%), Tanzania (37%), Burkina Faso (13%), Senegal (13%) and Benin (1%). From there on, transport via truck towards the capital of the country was assumed. For transport to Pakistan (C grade scenario), transport via Shanghai and the largest port of Pakistan was assumed, followed by road transport towards the capital. The road distances were calculated via Google Maps, sea distances with seadistances.org. Road transport was assumed with EURO 3 trucks with a capacity of > 32 tonne for both the B and C grade scenarios. The assumptions are summarised in Table 12.

Table 12: Scenarios for transport of new garments to point of sale

| Transport scenario | Origin | Destination | Distance (km) |
|---|---|---|---|
| Crème grade scenario: transport to EU for sale | | | |
| Transport over sea – freight ship | NR (average distance) | NR (average distance) | 10,466 |
| Transport over road – lorry 16-32 tonne (EURO4) | NR (average distance) | NR (average distance) | 524 |
| B grade scenario: transport to Sub-Saharan Africa for sale | | | |
| Transport over sea – freight ship | China (Shanghai port) | Benin (Cotonou Port) | 22,604 |
| | China (Shanghai port) | Kenya (Mombasa port) | 12,929 |
| | China (Shanghai port) | Senegal (Dakar port) | 22,237 |
| | China (Shanghai port) | Tanzania (Dar es Salaam port) | 12,971 |
| | China (Shanghai port) | Burkina Faso (via Lomé port, Togo) | 22,657 |
| Transport over road– lorry >32 tonne (EURO3) | Benin (Cotonou Port) | Benin (Porto-Novo) | 40 |
| | Kenya (Mombasa port) | Kenya (Nairobi) | 600 |
| | Senegal (Dakar port) | Senegal (Dakar) | 10 |
| | Tanzania (Dar es Salaam port) | Tanzania (Dodoma) | 450 |
| | Burkina Faso (via Lomé port, Togo) | Burkina Faso (Ouagadougou) | 950 |
| C grade scenario: transport to Pakistan for sale | | | |
| Transport over sea – freight ship | China (Shanghai port) | Pakistan (Gwadar Port) | 11,427 |
| Transport over road– lorry >32 tonne (EURO3) | Pakistan (Gwadar port) | Pakistan (Islamabad) | 2,000 |

*NR: not relevant*

## 4.3 Life cycle impact assessment

This paragraph discusses the results of the life cycle assessment for the reused and the new t-shirt in each quality scenario. The environmental themes (impact categories) are presented here, describing the impact of **a t-shirt for 52 wears**. The environmental profiles show the contributions of every life cycle stage to the environmental burden of both alternatives. The absolute values of these contributions are found in the tables corresponding with the profiles. The boundary diagram visualising all relevant life cycle stages was shown in Figure 6 in Section 6.1.

## 4.3.1 Scenario 1: reused cotton t-shirt vs. new cotton t-shirt (crème grade)

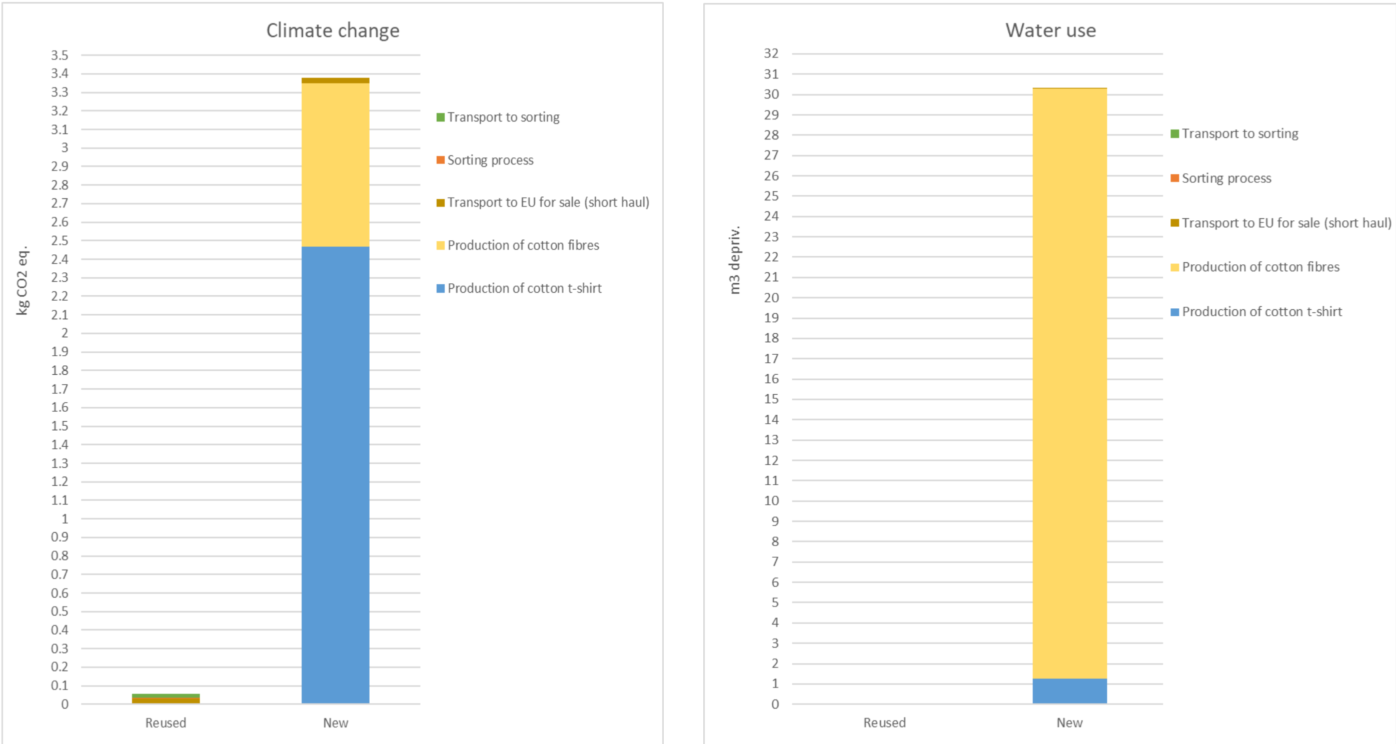


Figure 7: Comparative profile for ‘access to a crème grade t-shirt for 52 wears’ - climate change (left) and water use (right)

Table 13: Impact values climate change and water use for ‘access to a crème grade t-shirt for 52 wears’

| Impact category | Unit | Alternative | Total | Transport to sorting | Sorting process | Transport to sale (short haul) | Production of cotton fibres | Production of cotton t-shirt |
|---|---|---|---|---|---|---|---|---|
| Climate change | kg $CO_2$ eq | Reused | 0.0570 | 0.0230 | 0.0027 | 0.0313 | | |
| | | New | 3.3783 | | | 0.0294 | 0.8805 | 2.4685 |
| Water use | m3 depriv. | Reused | 0.0033 | 0.0013 | 0.0004 | 0.0016 | | |
| | | New | 30.767 | | | 0.0016 | 29.016 | 1.2755 |

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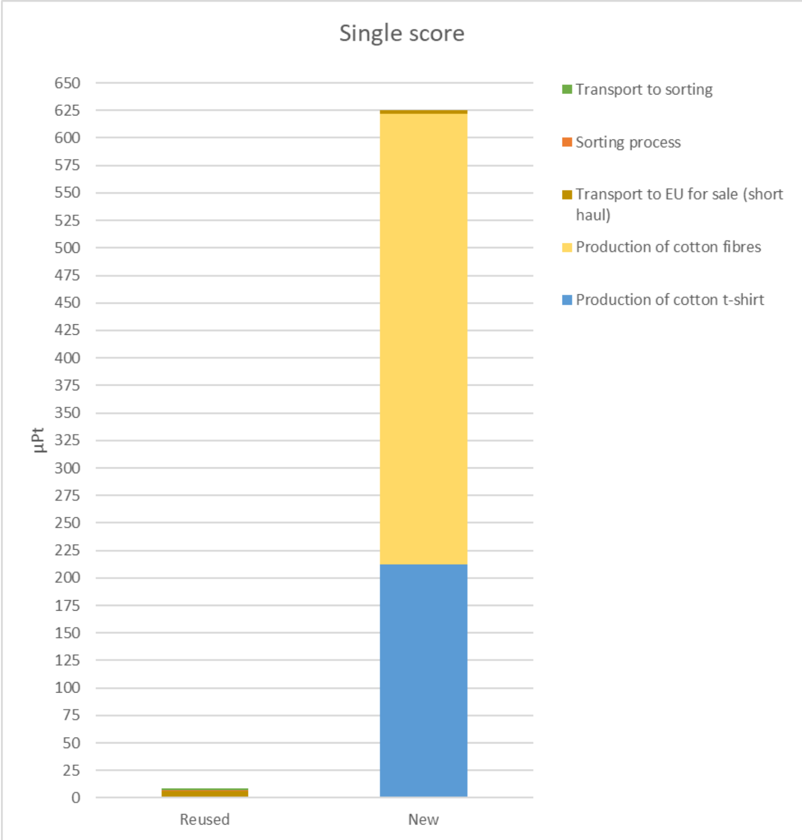


Figure 8: Comparative profile for 'access to a crème grade t-shirt for 52 wears'- single score

Table 14: Single score values for 'access to a crème grade t-shirt for 52 wears'

| Impact category | Unit | Alternative | Total | Transport to sorting | Sorting process | Transport to sale (short haul) | Production of cotton fibres | Production of cotton t-shirt |
|---|---|---|---|---|---|---|---|---|
| Single score | µPt | Reused | 9.0 | 2.2 | 0.4 | 6.5 | | |
| | | New | 628.4 | | | 3.4 | 409.2 | 212.3 |

## 4.3.2 Scenario 2: reused polycotton t-shirt vs. new polycotton t-shirt (B grade)

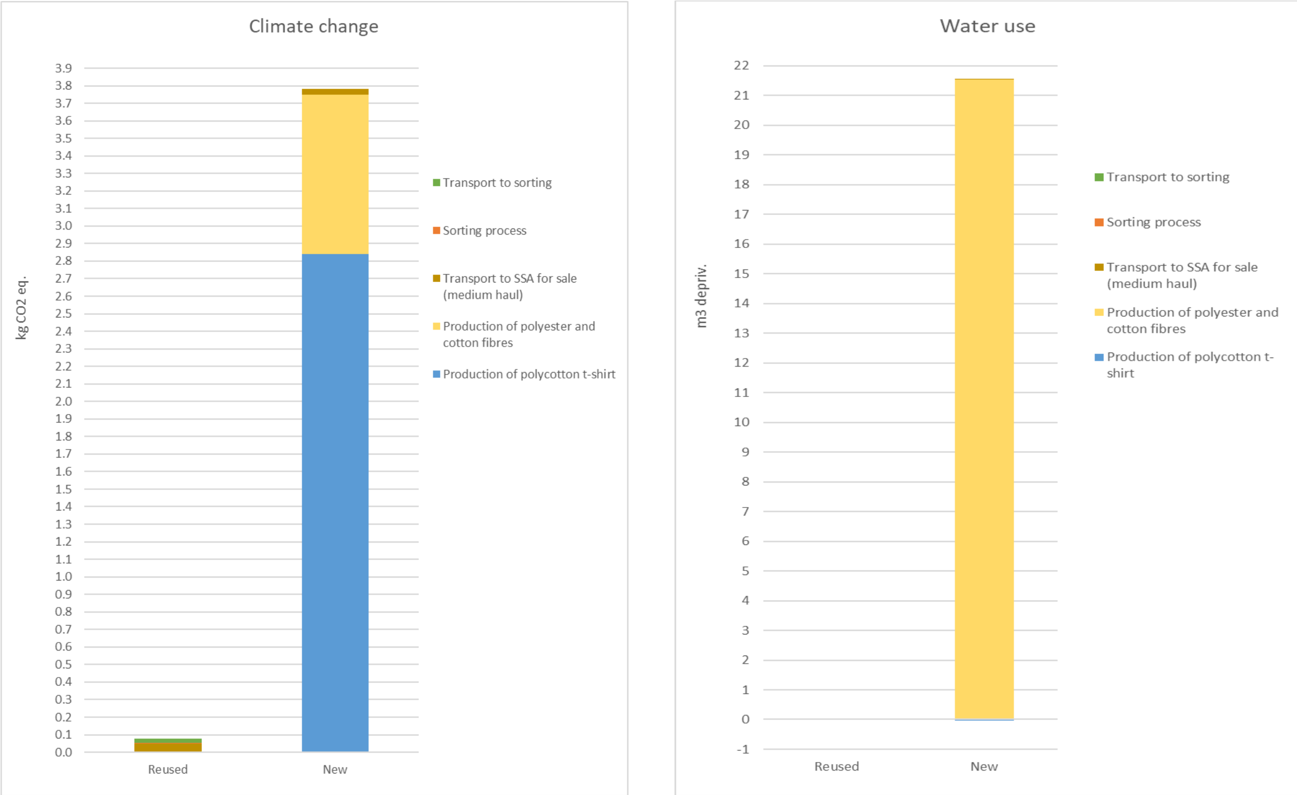


Figure 9: Comparative profile for 'access to a B grade t-shirt for 52 wears' - climate change (left) and water use (right)

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Table 15: Impact values climate change and water use for 'access to a B grade t-shirt for 52 wears'

| Impact category | Unit | Alternative | Total | Transport to sorting | Sorting process | Transport to sale (medium haul) | Production of polyester and cotton fibres | Production of polycotton t-shirt |
|---|---|---|---|---|---|---|---|---|
| Climate change | kg $CO_2$ eq | Reused | 0.0775 | 0.0230 | 0.0035 | 0.0510 | | |
| | | New | 3.7806 | | | 0.0307 | 0.9083 | 2.8416 |
| Water use | m3 depriv. | Reused | 0.0040 | 0.0013 | 0.0005 | 0.0022 | | |
| | | New | 21.496 | | | 0.0010 | 21.5260 | -0.0309 |

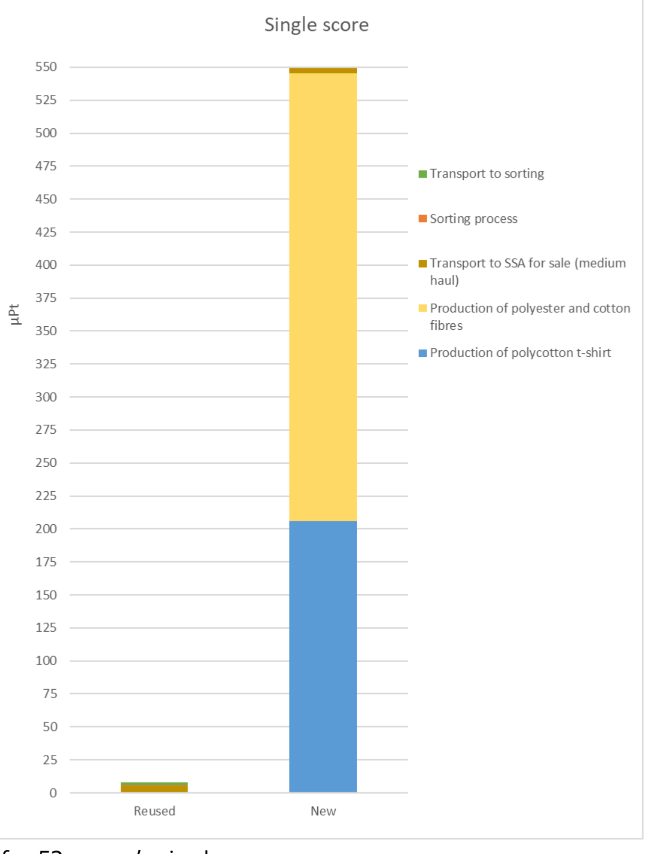


Figure 10: Comparative profile for 'access to a B grade t-shirt for 52 wears'- single score

Table 16: Single score values for 'access to a B grade t-shirt for 52 wears'

| Impact category | Unit | Alternative | Total | Transport to sorting | Sorting process | Transport to sale (medium haul) | Production of polyester and cotton fibres | Production of polycotton t-shirt |
|---|---|---|---|---|---|---|---|---|
| Single score | µPt | Reused | 7.9 | 2.2 | 0.4 | 5.3 | | |
| | | New | 549.6 | | | 4.3 | 339.6 | 205.7 |

### 4.3.3 Scenario 3: reused polyester t-shirt vs. new polyester t-shirt (C grade)

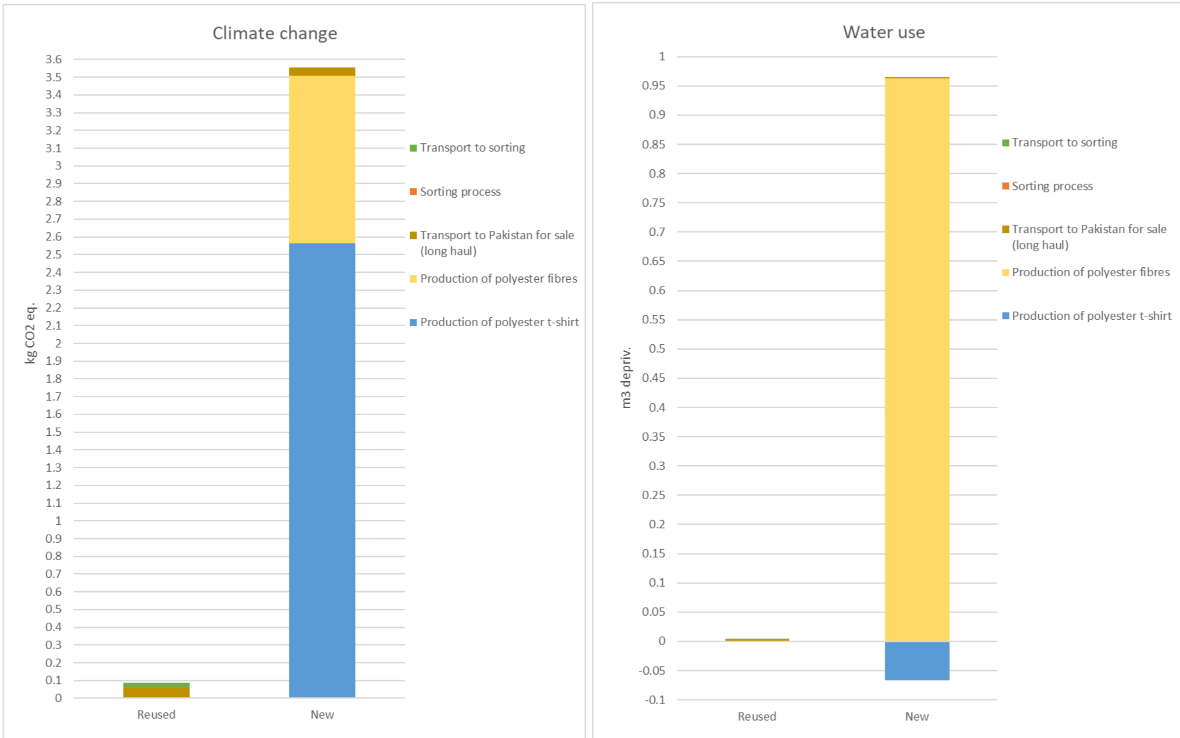


Figure 11: Comparative profile for 'access to a C grade t-shirt for 52 wears' - climate change (left) and water use (right)

Table 17: Impact values climate change and water use for 'access to a C grade t-shirt for 52 wears'

| Impact category | Unit | Alternative | Total | Transport to sorting | Sorting process | Transport to sale (long haul) | Production of polyester fibres | Production of polyester t-shirt |
|---|---|---|---|---|---|---|---|---|
| Climate change | kg $CO_2$ eq | Reused | 0.0857 | 0.0230 | 0.0033 | 0.0594 | | |
| | | New | 3.5546 | | | 0.0465 | 0.9430 | 2.5650 |
| Water use | m3 depriv. | Reused | 0.0042 | 0.0013 | 0.0005 | 0.0024 | | |
| | | New | 0.8989 | | | 0.0021 | 0.9629 | -0.0661 |

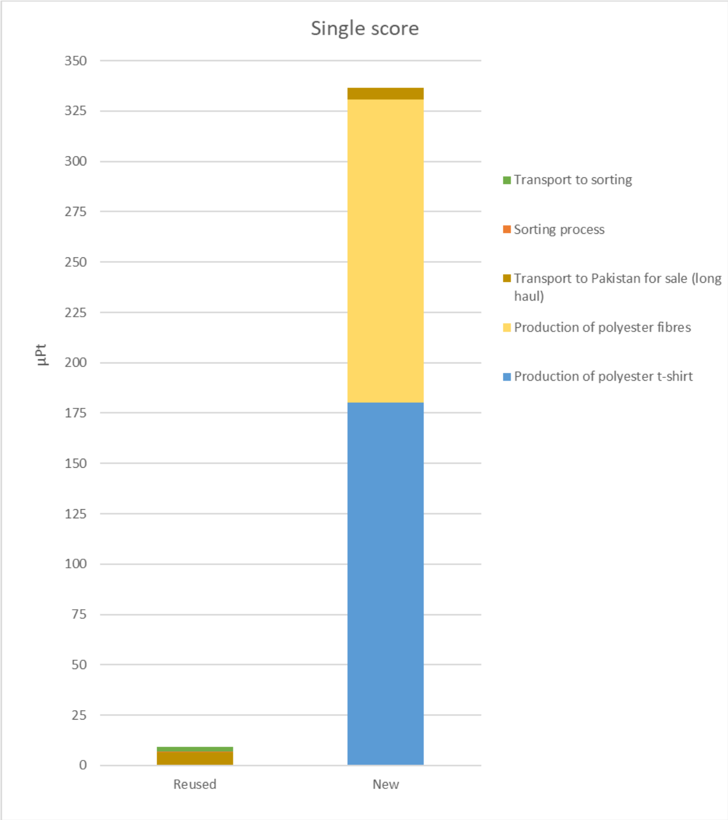


Figure 12: Comparative profile for 'access to a C grade t-shirt for 52 wears'- single score

Table 18: Single score values for 'access to a C grade t-shirt for 52 wears'

| Impact category | Unit | Alternative | Total | Transport to sorting | Sorting process | Transport to sale (long haul) | Production of polyester fibres | Production of polyester t-shirt |
|---|---|---|---|---|---|---|---|---|
| Single score | µPt | Reused | 9.0 | 2.2 | 0.4 | 6.5 | | |
| | | New | 336.7 | | | 5.7 | 150.6 | 180.3 |

## 4.4 Interpretation

This study confirms that the environmental impact of reusing a t-shirt is less than making a new one. However, the objective of this study is not just to confirm this hypothesis but also to identify the scale of the environmental benefits of reuse compared to the production of new t-shirts at three different levels of quality: crème, B grade and C grade.

Table 19 shows the single score, $CO_2$-e and water use for the three different qualities compared to a new t-shirt.

Table 19: Environmental impact values for crème, B-grade and C-grade compared

| | CRÈME | | B-GRADE | | C-GRADE | |
|---|---|---|---|---|---|---|
| | New | Reused | New | Reused | New | Reused |
| Single score | 628,4 | 9.0 | 549.6 | 7.9 | 336.7 | 9.0 |
| $CO_2$-e | 3,3783 | 0,0570 | 3.7806 | 0.0775 | 3.5546 | 0.0857 |
| Water use | 30,767 | 0,0033 | 21.496 | 0.0040 | 0.8989 | 0.0042 |

For the **crème t-shirt,** the calculations show that the Single score (the overall environmental impact covering all 16 EF impact categories) of a new t-shirt is approximately 70 times larger than for a reused t-shirt. It is the production of cotton fibre that contributes to the large environmental impact as it is almost twice as big as the impact of the actual production of the t-shirt. For the reused t-shirt, it is primarily the transport to the point of sale that contributes to the overall environmental impact. In comparison, the transport to the point of sale is the process that contributes the least for the new t-shirt.

Regarding the **carbon footprint,** the new shirt emits 3,38 kg $CO_2$-e, or almost 60 times more than a reused t-shirt in crème quality which only emits 0,06 kg $CO_2$-e. For a reused t-shirt, it is the transport that contributes most to the climate change while the sorting process only accounts for 5% of the impact. Water use is calculated as *deprived water use*, meaning taking water availability in a certain location into account. The **water use** of a reused t-shirt is only 0.01% of that of a new t-shirt, as a reused t-shirt uses 0,0003 m3 water while a new t-shirt has a water use of 30,77 m3. The low water use for the reused t-shirt is due to the sorting process not consuming any water directly and that the impact of transport on water use is minimal. The impact on water use of a new cotton shirt is mostly defined by fibre production, such as cotton cultivation.

It is worth noting that the transport assumption for reuse of a Crème t-shirt within Europe is a worst-case scenario with transportation over 1.150 km. Often, crème textiles will be reused within the country of collection or nearby, which signifies a shorter transportation distance. For most cases, the reuse therefore has an even lower climate change score, as well as an overall environmental impact, in comparison with a new t-shirt.

For the **B grade t-shirt,** the LCA shows that, like the crème t-shirt, the Single score of a new t-shirt is approximately 70 times larger than for a reused polycotton t-shirt. Production of fibres is the dominant contributor, caused by cotton cultivation for the largest part. The contribution to the impact of a reused shirt is mainly due to transport to point of sale which is 72% of the total impact, followed by transport to sorting which accounts for 24% while the sorting process only constitutes 4% of the overall impact. Although transport is the major contribution to the impact of the reused shirt, even longer transportation distances than what were calculated on in this study, are not likely to outweigh the significantly lower impact from reuse compared to the production of a new shirt.

When looking at **climate change**, the carbon footprint of a new polycotton t-shirt is approximately 47 times larger than that of a reused one. 75 % of the new shirt's impact on climate change is due to production of the t-shirt, while only 24 % is from the production of the polyester and cotton fibres. The impact of a reused polycotton t-shirt is mainly defined by transport to sale accounting for 66 % of the total. Like for the crème t-shirt, the sorting process contributes for only 5% to the carbon footprint of a reused polycotton shirt. The impact on **water use** is minimal for a reused polycotton t-shirt compared to the water consumption of a new t-shirt as it is more than a factor 5000 lower with only 0,0004 m3 deprived whereas a new polycotton t-shirt uses 21,5 m3. It is the production of the cotton fibres that dominates the impact but there is also a small environmental benefit from the production of the new t-shirt from treatment of wastewater from dyeing[58].

For the **C grade t-shirt**, the overall environmental impact is relatively lower than for the crème and B grade as the overall impact across categories is 37 times larger for a new polyester t-shirt than for a reused one. The larger environmental impact from the new t-shirt is due to the relatively large overall impact of production of the t-shirt and secondary the production of polyester fibres. Transport is a small contributor to the impact of the new t-shirt, even when it is long haul.

The **carbon footprint** of a new polyester t-shirt is approximately 40 times larger than that of a reused t-shirt. Like the polycotton t-shirt, the production of the t-shirt is the largest contributor to the impact on climate change, while production of the polyester fibre accounts for 27 % of the carbon footprint. Due to the large transport distance, transport to point of sale accounts for the main part of the impact of the reused piece with 70 %. As the polyester t-shirts does not include cotton, the **water use** is much less than for the other t-shirts. Still, the water use of a new polyester t-shirt is 214 times that of a reused one, mainly due to water us in the production of polyester fibres.

When looking at the production of a new B and C grade t-shirt, there is a negative impact value for 'production of t-shirt' on water use which represents a benefit to the environment. However, this benefit does not show for a cotton t-shirt since the benefit is coming from wastewater treatment. This treatment is also done for a cotton t-shirt, but the burdens caused by other processes during cotton t-shirt production outweighs this benefit. Since there is no direct water use during transport or sorting, the impact on water use of a reused t-shirt is solely the result of indirect use in the background processes, mostly for production of energy and fuels. Also, the contribution of transport to any impact category is relatively small for the new t-shirts, even for the long-haul transportation. Instead, is it the production of fibres and the t-shirt itself that drive the impact.

## 4.5 Limitations of the study

The LCA methodology is widely acknowledged as a framework to systemically analyse the environmental impact of a product[59], and is standardised by the International Organization for Standardization (ISO) in the ISO-14040 series[60]. Despite the recognition of the methodology and the standardisation, every LCA is subject to limitations and uncertainties, partly due to the associated assumptions. This chapter presents and discusses such limitations for the above comparative LCA on reuse versus a new product.

[58] This benefit could be because the corresponding ecoinvent dataset accounts for application of the produced sludge as a fertiliser, which replaces production of an artificial fertiliser.
[59] Ding, G. K. (2014). Life cycle assessment (LCA) of sustainable building materials: an overview. *Eco-efficient construction and building materials*, 38-62.
[60] Nieuwlaar, E. (2004). Life Cycle Assessment and Energy Systems, Encyclopedia of Energy.

**Burden-free reuse**
It is worth noting that the three different qualities of reused t-shirts enter the product system burden-free, meaning that the impacts of producing the t-shirts are allocated to the first use of the t-shirts. Another allocation of the impacts of the primary product over the two life cycles will alter the results. It is also worth noting that the exclusion of the end-of-life phase could have an impact on the results. If the calculations were done in a similar study including this phase the results might look different.

**Functional Unit of 52 wears**
The reused product might in reality be used for less wears than the new garment. This would change the outcome, most likely increasing slightly the environmental impact of reuse, reducing the gap to a new garment. But very unlikely enough for a new garment to be better than reuse.

**Equal end-of-life**
The study assumes an equal end-of-life for the two products. However, it might be that the end-of-life scenario is not actually equal, and that the reused garment is more likely to end up in landfill or being burned as it is already worn, whereas the new garment might be reused another cycle rather than going to landfill. If that was the case, this would add environmental impact to the reused garment, however, doubly enough to alter the result of reuse having less environmental impact.

## 4.6 Conclusion

This lifecycle assessment set out to identify the scale of environmental benefits derived from reuse, by comparing reuse of a garment with a new garment. The reference product was a basic t-shirt without embellishments, and the analysis differentiates between three quality levels, based on their composition.

| Scenario | Quality level | Reused garment | New garment |
|---|---|---|---|
| 1 | Crème | 100% cotton second-hand shirt sorted in Europe and sold in Europe | 100% cotton new shirt produced in Asia and sold in Europe |
| 2 | B-grade | 30/70 polycotton second-hand shirt sorted in Europe and sold in sub-Saharan Africa | 30/70 polycotton new shirt produced in Asia and sold in sub-Saharan Africa |
| 3 | C-grade | 100% polyester second-hand shirt sorted in Europe and sold in Pakistan | 100% polyester new shirt produced in Asia and sold in Pakistan |

The lifecycle impact assessment confirms that the environmental impact of reuse is significantly lower than the production of a new garment, for all three qualities.

For both the crème and the B-grade t-shirt, the new garment is responsible for almost 70 times more overall environmental impact than a reused t-shirt, and in terms of $CO_2$-equivalents, the reuse of both types of garments saves more than 3 kg $CO_2$.

Overall, it is the production of fibres (both cotton and polyester), as well as the production processes which causes the impact of the new garments. Transportation contributes insignificantly to the impact of a new t-shirt, even when it is long haul.

The impact of reused garments primarily comes from the transportation to the point of sales, as there are few other processes involved with preparing a collected garment for reuse. Even when the garment is transported far to reach a market for reuse, the environmental impact is trivial compared to the environmental impact from the production of a new garment. This means that having a global second-hand market whereas many collected textiles as possible can be reused, makes strong environmental sense.

# 5 LCA COMPARISON OF EXPORTED REUSED TEXTILES VS RECYCLING IN EUROPE

The following section presents the results of the comparative life cycle assessment of reusing of garments versus recycling of garments, represented partly as a future fibre recycling scenario. This chapter briefly describes the goal and scope in section 7.1, including the different scenarios, functional unit, system boundaries and the used life cycle impact assessment method with its impact categories. In section 7.2 the data inventory process is described and, where possible, the used data is provided. Section 7.3 shows the result of the LCA, which are analysed and discussed in section 7.4. In this last section also, limitations are discussed, and conclusions are formulated.

## 5.1 Goal and scope

This LCA is intended to compare the environmental impact of reusing a garment to that of recycling a garment. The reference product is again a basic t-shirt. For this LCA as well, the quality levels crème, B grade and C grade are distinguished to ensure fair comparison. The scenarios for comparison are found in Table 20. Different recycling technologies, corresponding with the chosen fibre types, are assessed. For cotton recycling, two recycling technologies are assessed.

Note that, as for the previous LCA, comparison of results between alternatives from different scenarios (for instance, reuse of a 100% cotton reused shirt and reuse of a 100% polyester shirt) is not allowed since it would lead to incorrect conclusions.

Table 20: Overview of the three considered quality levels and associated scenarios

| Scenario | Quality level | Reuse of garment | Recycling of garment |
|---|---|---|---|
| 1 | Crème | Reuse of a 100% cotton second-hand shirt sorted in Europe and sold in Europe | Mechanical recycling of 100% cotton shirt into fibres ready for spinning<br>Chemical recycling of 100% cotton shirt into cellulose |
| 2 | B-grade | Reuse of a 30/70 polycotton second-hand shirt sorted in Europe and sold in sub-Sahara Africa | Chemical recycling of 30/70 polycotton shirt into cellulose and PET |
| 3 | C-grade | Reuse of a 100% polyester second-hand shirt sorted in Europe and sold in Pakistan | Chemical recycling of 100% polyester into monomers and repolymerisation into PET |

**These scenarios were defined based on the following elements:**

- **Quality level**: Crème, B-grade, and C-grade to represent various qualities.
- **Fibre type**: Cotton, 30/70 polycotton, and 100% polyester. These fibre types have been selected to ensure that the price of the t-shirt is affordable on global markets in e.g. Asia and Pakistan. The fibre types are further chosen to enable various recycling possibilities.
- **Substitution**, which represents the production impacts of an equivalent new shirt, as modelled in Chapter 6, will be 'awarded' to the reused shirt as a benefit. This share will depend on the assumed replacement rate.

- **Replacement rate**

The replacement rate is defined as the degree to which the purchase of second-hand clothing and household textiles replaces the purchase of similar new items[61]. Many studies assume a 1:1 replacement. In other words, that the purchase of a used clothing item fully replaces the purchase of a new one. This is however found to be unrealistic, as several studies find that actual replacement rates vary[62]. The country's purchasing power is believed to be a key reason, meaning that low purchasing power is related to a high replacement rate[63]. Other factors are however also likely to be relevant, such as culture (the view on second-hand clothes), accessibility of second-hand clothes as well as new items, and the perceived and factual quality of second-hand. Consequently, the replacement rate of a given country is not fixed, but changes according to development or change of the above-mentioned factors, although more research is needed on this topic. A 1:1 replacement is therefore problematic as it reduced the reliability of any LCA results[64].

Because RR vary between countries and over time, this study is not based on only one RR. Rather, this study compares the environmental impact of three different replacement rates in combination with three different transport distances. This gives the possibility to assess a country's current specific replacement rate and get an idea of whether reuse outside of Europe is environmentally more beneficial than recycling in Europe, depending on where (transport distance) the reuse happens.

There is little research on the replacement rate in different countries and regions, and the chosen rates have therefore been chosen based on the indications given from existing research in combination with general assumptions. This report is therefore to be considered as an early take on the topic and replacement rates are something that should be taken a deeper look into.

This study calculates the environmental impact of the three replacement rates of 10%, 40% and 80%.

| | Replacement Rate | Assumption |
|---|---|---|
| Low assumption | 10 % | A low RR was set because:<br>• It is assumed that a country that imports second-hand for reuse will have a market for the items, and that at least to a certain extent, what is sold replaces the purchase of new items. Therefore, a replacement rate below 10 % has not been included in the study<br>• Some countries, like Pakistan and India, import used textiles for sorting, recycling, and re-export, meaning that very little of what is imported end up for sale in the local market[65]. As there has not been found any specific studies on replacement rates for this region, and the typical trajectory is not reuse, the replacement rate is set to be low.<br><br>10 % is therefore chosen to cover those countries with low replacement rates. |
| Central assumption | 40 | A central RR of 40 % was set because:<br>• The replacement rates for second-hand textiles in the three countries studied by Nørup et al. were the following; Angola 63 ± 6%, Malawi 35 ± 1 % and Mozambique 37 ± 5 %[66]. |

[61] Nørup, N., Pihl, K., Damgaard, A., & Scheutz, C. (2019). Replacement rates for second-hand clothing and household textiles – A survey study from Malawi, Mozambique and Angola. Journal of Cleaner Production, 235, 1026-1036. https://doi.org/10.1016/j.jclepro.2019.06.177
[62] Sandin, G. et al. (2018). *Environmental impact of textile reuse and recycling – a review*
[63] Nørup, N., Pihl, K., Damgaard, A., & Scheutz, C. (2019). Replacement rates for second-hand clothing and household textiles–A survey study from Malawi, Mozambique and Angola. *Journal of Cleaner Production*, *235*, 1026-1036.
[64] Sandin, G. et al. (2018). *Environmental impact of textile reuse and recycling – a review*
[65] European Environment Agency. (In press). EU Export of used textiles.
[66] Nørup, N., Pihl, K., Damgaard, A., & Scheutz, C. (2019). Replacement rates for second-hand clothing and household textiles – A survey study from Malawi, Mozambique and Angola. Journal of Cleaner Production, 235, 1026-1036. https://doi.org/10.1016/j.jclepro.2019.06.177

| | | |
|---|---|---|
| | | • In Great Britain, a study from 2013 found that the highest value for England was 41.1 % (London) compared to 20.9% for the Southwest of England. Scotland had the highest regional displacement value of 47.5 % for the Highlands and Islands and the lowest of 9.5 % for Forth[67].<br>40 % is therefore a central assumption for such countries in the middle of the spectrum. |
| High assumption | 80 % | A high RR of 80 % was set because:<br>• An often-cited replacement rate for African countries is 85 % – a value provided by Farrant et al. (2010) and based on a 'best guess' for Sub-Saharan countries[68]. However, as seen above, some Sub-Saharan countries have lower rates.<br>• Even countries with considerably high replacement rates, such as Tunisia and Ghana, only reach around 92-95 %[69]. Reaching 100 % therefore does not seem likely, and would be an extreme assumption.<br>• Second-hand clothing is mostly used and thereby worn down, meaning that the lifetime is likely not as long as for new clothes. The replacement rate is therefore rarely 100%.<br>• Some clothes are more likely to be bough new, such as underwear.<br>80 % is therefore chosen as the high assumption. |

**End-of-life:** For reuse in Sub-Saharan Africa and in Pakistan it is assumed that the **end-of-life** will be in an open landfill or burning without energy recovery. This will follow the models used for the Nordic Council of Ministers[70]. For reuse in Europe, we will use the end-of-life scenario's established in the PEF, which are for a T-shirt: 11% recycling, 49% landfill, 40% incineration[71]. The **functional unit** (FU) is defined for all scenarios as *"Treatment of 1 post-consumer t-shirt"*, where the composition of the t-shirt depends on the scenario and was described in Table 19. We assumed an average weight of 155 grams (as was done in Chapter 6).

The **life cycle stages** and processes included in (and excluded from) the system boundary for both the reused t-shirt and the recycled t-shirt are listed in Table 21. Note that the starting point of the assessment for both alternatives is the exit gate of the sorting facility. This LCA will look at the end of life for a reused garment, but not the use phase.

Table 21: Life cycle stages in scope

| Life cycle element | Description | Data source |
|---|---|---|
| Reuse | | |
| Transport to point of sale | Transport inside Europe (crème grade)<br>Transport from Europe to sub-Saharan Africa (B grade)<br>Transport from Europe to Pakistan (C grade) | Estimations – see Annex 3 |
| End of life | EOL in EU: 11% recycling, 49% landfill, 40% incineration with E recovery (crème grade)<br>EOL in Sub-Saharan Africa: 50% landfill, 50% incineration without E recovery (B grade)<br>EOL in Pakistan: 50% landfill, 50% incineration without E recovery (C grade) | Literature |

[67] WRAP. (2013). Study into consumer second-hand shopping behaviour to identify the re-use displacement affect. Retrieved from https://www.zerowastescotland.org.uk/sites/default/files/Study%20into%20consumer%20second-hand%20shopping%20behaviour%20to%20identify%20the%20re-use%20displacement%20affect.pdf
[68] Nørup, N., Pihl, K., Damgaard, A., & Scheutz, C. (2019). Replacement rates for second-hand clothing and household textiles – A survey study from Malawi, Mozambique and Angola. Journal of Cleaner Production, 235, 1026-1036. https://doi.org/10.1016/j.jclepro.2019.06.177
[69] European Environment Agency. (In press). EU Export of used textiles.
[70] Watson et al (2016) Exports of used textiles from Nordic countries: Fate, Benefits and Impacts
[71] See: Annex_C_V2.1_May2020.xlsx (live.com)

| | | |
|---|---|---|
| Avoided primary production of t-shirt* | Avoided production of cotton t-shirt (crème grade), 3 substitution rates: 10%, 40% and 80%<br>Avoided production of polycotton t-shirt (B grade), 3 substitution rates: 10%, 40% and 80%<br>Avoided production of polyester t-shirt (C grade), 3 substitution rates: of 10%, 40% and 80% | Literature |
| Recycling | | |
| Transport to recycling facility | Transport by lorry to recycling facility in Europe | Estimations |
| Recycling of t-shirt | Mechanical recycling of 100% cotton shirt into spinnable fibres (crème grade)<br>Chemical recycling of 100% cotton shirt into cellulose (crème grade)<br>Chemical recycling of 30/70 polycotton shirt into cellulose and PET (B grade)<br>Chemical recycling of 100% polyester* into monomers and repolymerisation into PET (C grade) | Recyclers |
| Avoided primary production of materials* | Avoided production of spinnable fibres, subst. rate of 15% (crème grade)<br>Avoided production of cellulose, subst. rate of 100% (crème grade)<br>Avoided production of cellulose and PET, subst. rate of 100% for both (B grade)<br>Avoided production of PET, substitution rate of 100% (C grade) | Literature, recyclers |

*Avoided primary production of t-shirts and materials has been taken into account. The avoided production implies an avoided end-of-life treatment. This has not been taken into account in this study due to the uncertainty related to the geography and the type of end-of-life treatment.

The **system boundary diagrams** visualising the processes in scope are shown in Figure 16[72].

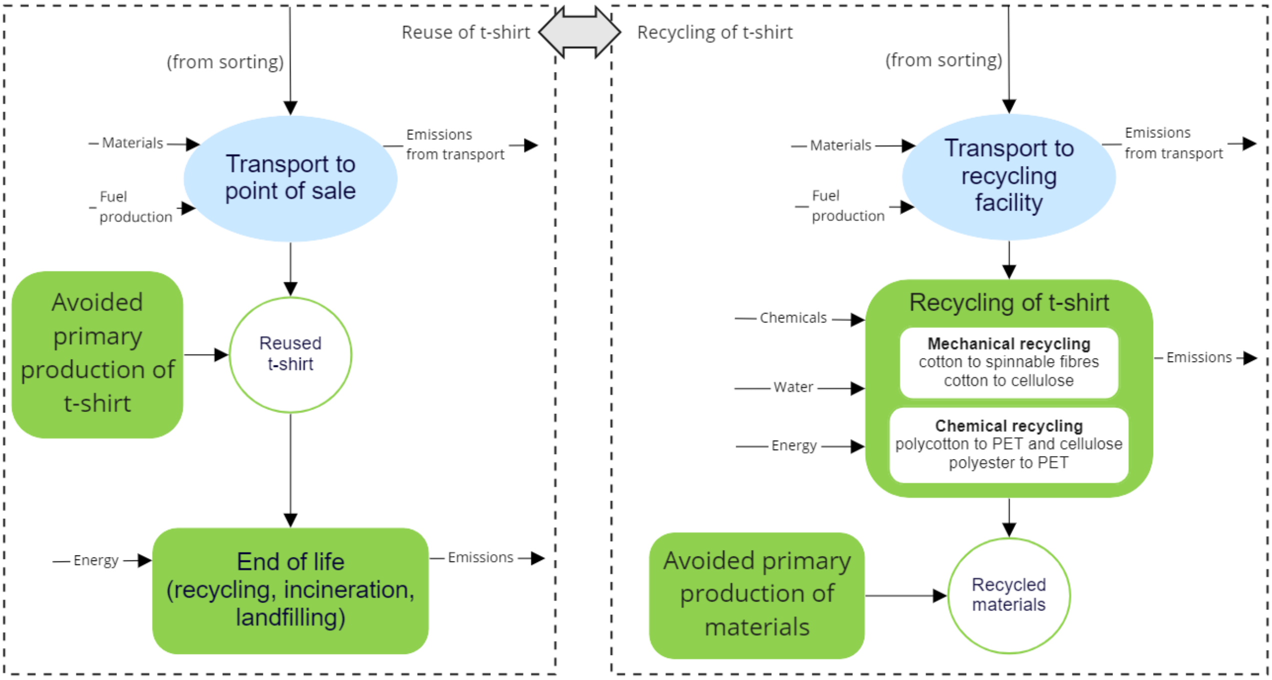


Figure 13: System boundary diagrams for reuse of a t-shirt (left) and recycling of a t-shirt (right). The functional unit is defined as "treatment of 1 post-consumer t-shirt".

Results will focus on climate change and water use selected from the 16 main **impact categories**[73] of the Product Environmental Footprint (PEF), see Table 6 (Chapter 6), as well as a single score (providing a weighted average overall environmental impact from the EF impact categories, valued in points).

[72] For more information about 'recycled materials', see table 20 and paragraph 7.2.2.
[73] EC (2019). Product Environmental Footprint Category Rules (PEFCR). https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_tshirt.pdf

## 5.2 Life cycle inventory analysis

In the inventory phase all data needed to analyse the environmental impacts associated with the treatments of t-shirts (reuse and recycling) are gathered. In summary this means that all input flows (materials, energy, water, etc.) and all output flows (emissions, waste, etc.) are described and quantified. This is done for all life cycle phases within the system boundaries for both treatments. The life cycle data on these treatments is partly based on primary data.

### 5.2.1 Life cycle inventory for reuse of a t-shirt

The data inventory process for reuse of a t-shirt is focused on the following life cycle phases:

1. Transport to point of sale;
2. Avoided primary production of a t-shirt;
3. End of life.

For transport to the point of sale, the same assumptions (which were confirmed by the primary data from EuRIC Textilesmembers) were made as in the previous LCA; sorted crème grade garments are sold in the EU (short haul), B grade garments in Sub-Saharan Africa (medium haul) and C grade garments in Pakistan (long haul). The assumed transport modes and distances were summarised in Table 7, Chapter 6.

Avoided primary production of a t-shirt is modelled the same way as the new t-shirts (of three quality levels) in the previous LCA. For the data inventory of this avoided production, we refer to Annex 2. A reused t-shirt, however, only partly replaces a new one, therefore a replacement rate must be applied. Due to the multitude of replacement rates found in studies conducted in different countries around the world, three different replacement rates are adopted in this study, being 10%, 40% and 80%. This implies that 9 possibilities for reuse are evaluated; 3 quality levels (and associated transport distances) paired with 3 possible replacement rates. The three different replacement rates are shown in each inventory table.

For the end-of-life phase in Europe (crème grade scenario), the end-of-life scenarios established in the PEF are used, which are 11% recycling, 49% landfill and 40% incineration for a t-shirt. The recycled content approach was used to model this end-of-life scenario. This implies that the impact of recycling is allocated to the next life cycle and therefore only the impact of transport to the recycling facility was considered for recycling of cotton waste. A transport distance of 1.150 km to the recycling facility was assumed (which is the distance between the centre of France and the south of Poland) since most of the sorting takes place in Eastern Europe, while recycling facilities are mainly located in Western Europe. In Sub-Saharan Africa (B grade scenario) and in Pakistan (C grade scenario) 50% open landfill and 50% burning without energy recovery is assumed.

The data inventories per scenario are presented in the tables below.

Table 22: Data inventory for reuse of a t-shirt - crème grade

| 1. Transport to point of sale (crème grade) (short haul) | | | | | |
|---|---|---|---|---|---|
| Flow | Amount | Unit | Data source | Record | Comment |
| Transport over road – lorry 16-32 tonne (EURO4) | 0.18 | tkm | Estimation | Transport, freight, lorry 16-32 metric ton, EURO4 {RER}\| transport, freight, lorry 16-32 metric ton, EURO4 \| Cut-off, U | Transport from European sorter to Europe Assumption: Loss in distribution phase of 1% |
| 2. Avoided primary production of t-shirt (crème grade) | | | | | |

| Flow | Amount | Unit | Data source | Record | Comment |
|---|---|---|---|---|---|
| New cotton t-shirt | -0.0155 | kg | N.R. | N.R. | if replacement rate is 10% |
| | -0.062 | kg | N.R. | N.R. | if replacement rate is 40% |
| | -0.124 | kg | N.R. | N.R. | if replacement rate is 80% |
| **3. End of life (crème grade)** | | | | | |
| Flow | Amount | Unit | Data source | Record | Comment |
| Transport over road – lorry 16-32 tonne (EURO4) | 0.003 | tkm | Estimation | Transport, freight, lorry 16-32 metric ton, EURO4 {RER}\| transport, freight, lorry 16-32 metric ton, EURO4 \| Cut-off, U | Transport to recycling |
| Electricity | -0.1 | MJ | PEF | Electricity, medium voltage {RER}\| market group for \| Cut-off, U | Electricity recovery from incineration of cotton |
| Heat | -0.2 | MJ | PEF | Heat, district or industrial, natural gas {RER}\| market group for \| Cut-off, U | Heat recovery from incineration of cotton |
| Incineration | 0.06 | kg | PEF | Waste paperboard {CH}\| treatment of municipal incineration \| Cut-off, U | Proxy for incineration of cotton waste with energy recovery |
| Landfill | 0.08 | kg | PEF | Inert waste, for final disposal {CH}\| treatment of inert waste, inert material landfill \| Cut-off, U | Landfill of cotton waste |

Table 23: Data inventory for reuse of a t-shirt - B-grade

| **1. Transport to point of sale (B grade) (medium haul)** | | | | | |
|---|---|---|---|---|---|
| Flow | Amount | Unit | Data source | Record | Comment |
| Transport over road – lorry 16-32 tonne (EURO4) | 0.18 | tkm | Estimations | Transport, freight, sea, container ship {GLO}\| market for transport, freight, sea, container ship \| Cut-off, U | Assumption: Loss in distribution phase of 1% |
| Transport over sea | 0.98 | tkm | Estimations | Transport, freight, lorry 16-32 metric ton, EURO4 {RER}\| transport, freight, lorry 16-32 metric ton, EURO4 \| Cut-off, U | Assumption: Loss in distribution phase of 1% |
| Transport over road – lorry 16-32 tonne (EURO3) | 0.07 | tkm | Estimations | Transport, freight, lorry 16-32 metric ton, EURO3 {RoW}\| transport, freight, lorry 16-32 metric ton, EURO3 \| Cut-off, U | Assumption: Loss in distribution phase of 1% |
| **2. Avoided primary production of t-shirt (B grade)** | | | | | |
| Flow | Amount | Unit | Data source | Record | Comment |
| New polycotton t-shirt | -0.0155 | kg | N.R. | N.R. | if replacement rate is 10% |
| | -0.062 | kg | N.R. | N.R. | if replacement rate is 40% |
| | -0.124 | kg | N.R. | N.R. | if replacement rate is 80% |
| **3. End of life (B grade)** | | | | | |
| Output flow | Amount | Unit | Data source | Record | Comment |
| Landfill of cotton | 0.054 | kg | Literature | Waste paperboard {GLO}\| treatment of waste paperboard, open dump, dry infiltration class (100mm) \| Cut-off, U | Proxy for landfill of cotton waste |
| Landfill of polyester | 0.023 | kg | Literature | Waste polyethylene terephthalate {GLO}\| treatment of waste polyethylene terephthalate, open dump, dry infiltration class (100mm) \| Cut-off, U | Proxy for landfill of polyester textile waste |
| Incineration of polycotton | 0.078 | kg | Literature | Waste textile, soiled {RoW}\| treatment of, municipal incineration \| Cut-off, U | |

Table 24: Data inventory for reuse of a t-shirt - C-grade

| 1. Transport to point of sale (C grade) (long haul) | | | | | |
|---|---|---|---|---|---|
| Flow | Amount | Unit | Data source | Record | Comment |
| Transport over road – lorry 16-32 tonne (EURO4) | 0.18 | tkm | Estimations | Transport, freight, lorry 16-32 metric ton, EURO4 {RER}\| transport, freight, lorry 16-32 metric ton, EURO4 \| Cut-off, U | Assumption: Loss in distribution phase of 1% |
| Transport over sea | 1.64 | tkm | Estimations | Transport, freight, sea, container ship {GLO}\| market for transport, freight, sea, container ship \| Cut-off, U | Assumption: Loss in distribution phase of 1% |
| Transport over road – lorry 16-32 tonne (EURO3) | 0.08 | tkm | Estimations | Transport, freight, lorry 16-32 metric ton, EURO3 {RoW}\| transport, freight, lorry 16-32 metric ton, EURO3 \| Cut-off, U | Assumption: Loss in distribution phase of 1% |
| **2. Avoided primary production of t-shirt (C grade)** | | | | | |
| Flow | Amount | Unit | Data source | Record | Comment |
| New polyester t-shirt | -0.0155 | kg | N.R. | N.R. | if replacement rate is 10% |
| | -0.062 | kg | N.R. | N.R. | if replacement rate is 40% |
| | -0.124 | kg | N.R. | N.R. | if replacement rate is 80% |
| **3. End of life (C grade)** | | | | | |
| Output flow | Amount | Unit | Data source | Record | Comment |
| Landfill of polyester | 0.078 | kg | | Waste polyethylene terephthalate {GLO}\| treatment of waste polyethylene terephthalate, open dump, dry infiltration class (100mm) \| Cut-off, U | Proxy for landfill of polyester textile waste |
| Incineration of polyester | 0.078 | kg | | Waste textile, soiled {RoW}\| treatment of, municipal incineration \| Cut-off, U | |

### 5.2.2 Life cycle inventory for recycling of a t-shirt

The data inventory process for recycling of a t-shirt is focused on the following life cycle phases:

1. Transport to recycling facility;
2. Recycling of t-shirt;
3. Avoided primary production of materials.

Transport to the recycling facilities is assumed to be done by lorry, over distances of a few hundred kilometres (else it would not be economically viable). An identical transport distance of 1150 kilometres was assumed.

The recycling technologies evidently differ per fibre type and thus per quality scenario. Cotton may be mechanically recycled as well as chemically. Mechanical recycling of cotton results in spinnable fibres which can then be respun into cotton yarn, although a large percentage of the input cotton pulverises into fluff and dust, which cannot be respun anymore. Chemical recycling of cotton yields another output; cellulose, which can be used again as input for viscose production. When polycotton is chemically recycled, it yields cellulose as well as PET. In the third scenario, polyester is chemically recycled into its constituent monomer DHET, which is repolymerised again into PET pellets. Data on these technologies, which will not be disclosed for confidentiality reasons, are provided by three European recyclers. It concerns data on:

- Chemical recycling of cotton into cellulose[74];
- Chemical recycling of polycotton into PET and cellulose;
- Chemical recycling of polyester into monomers and subsequently into PET pellets[75].

The data for mechanical recycling of cotton was retrieved from Duhoux *et al.* (2021)[76], for which the inventory data is shown in Table 25.

The avoided primary production of materials depends on the recycled material (output of recycling process). Usually, primary production of these materials is not avoided for 100% due to the lower quality of a recycled material compared to virgin materials. This is considered by means of a substitution rate. In the case of cotton, production of (spinnable) fibres (substitution rate of 12.5%[77]) as well as materials for use in non-woven fabrics (substitution rate of 100%) are avoided when mechanical recycling is applied. Like Duhoux *et al.* (2021) it is assumed that PET, PP, cotton fluff and cellulose fluff are replaced in equal fractions in the non-woven industry. Cotton fluff and cellulose fluff are output products of cotton fibre production of which the impact is allocated entirely to the fibre, hence the use of cotton fluff and cellulose fluff in a non-woven does not generate avoided impacts. When cotton is chemically recycled, virgin cellulose pulp made from soft wood or hard wood is avoided. However, the impact of the avoided product depends on which pulping process is replaced; for instance, sulfite pulp has a larger environmental impact than sulfate pulp. Both options were assessed here since we cannot know which of both is effectively avoided. In case of chemical recycling of polycotton, production of cellulose and PET are avoided, with an assumed substitution rate of 100% for both PET and cellulose (the produced PET is virgin grade according to the recycler and it is assumed that recycled cellulose can replace virgin pulp completely). For chemical recycling of polyester, PET is depolymerized and then repolymerized again into PET pellets which are also considered virgin grade (100% substitution).

Table 25: Data inventory for recycling of a t-shirt - crème grade

| 1) Transport to recycling facility | | | | | |
|---|---|---|---|---|---|
| Flow | Amount | Unit | Data source | Record | Comment |
| Transport over road – lorry 16-32 tonne (EURO4) | 0.03 | tkm | Estimation | Transport, freight, lorry 16-32 metric ton, euro4 {RER}\| market for transport, freight, lorry 16-32 metric ton, EURO4 \| Cut-off, U | |
| 2) Mechanical recycling of a cotton t-shirt (crème grade) | | | | | |
| Flow | Amount | Unit | Data source | Record | Comment |
| Electricity | 0.08 | kWh | Duhoux et al. | Electricity, low voltage {RER}\| market group for \| Cut-off, U | |
| Tap water | 0.003 | kg | Duhoux et al. | Tap water {RER}\| market group for \| Cut-off, U | |
| Waste treatment of textile | $4.65*10^{-3}$ | kg | Duhoux et al. | Waste textile, soiled {CH}\| treatment of municipal incineration \| Cut-off, U | Incineration of cotton waste |
| Electricity | -0.006 | MJ | Duhoux et al. | Electricity, medium voltage {RER}\| market group for \| Cut-off, U | Electricity recovery from cotton incineration |
| Heat | -0.013 | MJ | Duhoux et al. | Heat, district or industrial, natural gas {RER}\| market group for \| Cut-off, U | Heat recovery from cotton incineration |
| 3) Avoided primary production of materials (crème grade) | | | | | |
| Flow | Amount | Unit | Data source | Record | Comment |

[74] The provided data are calculated LCA results, no inventory data has been made available.
[75] The provided data are calculated carbon footprint results, no inventory data has been made available.
[76] Duhoux et al. (2021), *Study on the technical, regulatory, economic and environmental effectiveness of textile fibres recycling.*
[77] Duhoux et al (2021) report that in the worst case, the output of the mechanical recycling process of cotton replaces 5% of spinnable fibres, while the best case scenario is 20% replacement of spinnable fibres. This study uses the average value, being 12.5%.

| | | | | | |
|---|---|---|---|---|---|
| Cotton fibre (spinnable fibres) | -0.018 | kg | Duhoux et al. | Fibre, cotton {GLO}\| market for fibre, cotton \| Cut-off, U | Assumption: 12.5% spinnable fibres |
| Avoided PET | -0.031 | kg | Duhoux et al. | Polyethylene terephthalate, granulate, bottle grade {RER}\| production \| Cut-off, U | Avoided products for use in non-woven fabrics: PET granulate, and PP granulate |
| Avoided PP | -0.031 | kg | Duhoux et al. | Polypropylene, granulate {RER}\| production \| Cut-off, U | |
| Avoided cotton fluff | -0.031 | kg | Duhoux et al. | N.R. | By-products of cotton fibre production, impact allocated to fibre production and hence no avoided impact for avoided fluff production |
| Avoided cellulose fluff | -0.031 | kg | Duhoux et al. | N.R. | |

## 5.3 Life cycle impact assessment

This paragraph discusses the results of the life cycle assessment for reuse and recycling of a t-shirt in each quality scenario. The environmental themes are presented here, describing the impact of “treatment of one post-consumer t-shirt”. The environmental profiles show the contributions of every lifecycle stage to the environmental burden of both alternatives. The absolute values of these contributions are found in the tables corresponding with the profiles. The boundary diagram visualising all relevant life cycle stages was shown in Figure 17.

### 5.3.1 Scenario 1: reuse vs. recycling of a cotton t-shirt (crème grade)

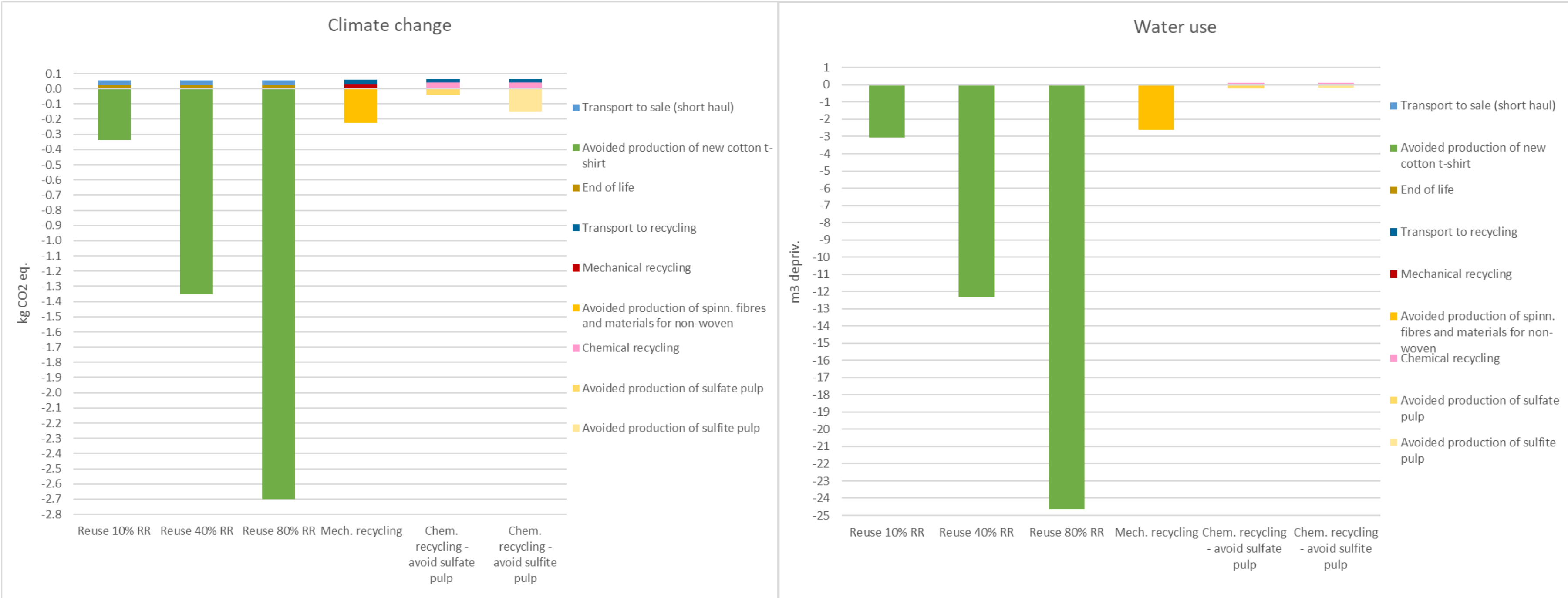


Figure 14: Comparative profile for 'treatment of 1 crème grade post-consumer t-shirt' - climate change (left) and water use (right)

Table 26: Impact values climate change and water use for 'treatment of 1 crème grade post-consumer t-shirt'

| Impact category | Unit | Alternative | Total | Transport to sale (short haul) | Avoided production of cotton t-shirt | End of life | Transport to recycling | Recycling process | Avoided production of materials |
|---|---|---|---|---|---|---|---|---|---|
| Climate change | kg $CO_2$ eq | Reuse - 10% RR | -0.2835 | 0.0313 | -0.3378 | 0.0231 | | | |
| | | Reuse - 40% RR | -1.2970 | 0.0313 | -1.3513 | 0.0231 | | | |
| | | Reuse - 80% RR | -2.6483 | 0.0313 | -2.7027 | 0.0231 | | | |
| | | Mech. recycling | -0.1671 | | | | 0.0294 | 0.0298 | -0.2263 |
| | | Chem. recycling - avoided sulfate pulp | 0.0235 | | | | 0.0242 | 0.0401 | -0.0409 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Chem. recycling - avoided sulfite pulp | -0.0893 | | | | 0.0242 | 0.0401 | -0.1536 |
| Water use | m3 depriv. | Reuse - 10% RR | -3.0716 | 0.0016 | -3.0767 | 0.0035 | | | |
| | | Reuse - 40% RR | -12.3017 | 0.0016 | -12.3068 | 0.0035 | | | |
| | | Reuse - 80% RR | -24.6085 | 0.0016 | -24.6136 | 0.0035 | | | |
| | | Mech. recycling | -2.6214 | | | | 0.0013 | 0.0075 | -2.6303 |
| | | Chem. recycling - avoided sulfate pulp | -0.1003 | | | | 0 | 0.1280 | -0.2284 |
| | | Chem. recycling - avoided sulfite pulp | -0.0463 | | | | 0 | 0.1280 | -0.1744 |

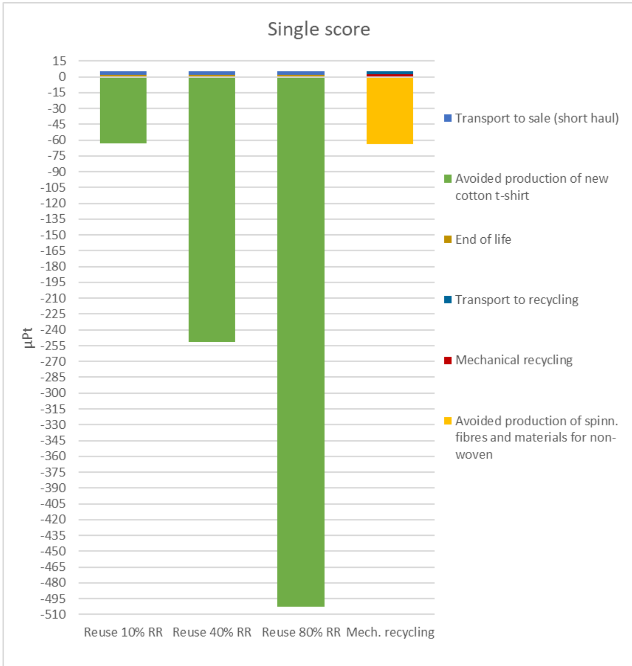


Figure 15: Comparative profile for ‘treatment of 1 crème grade post-consumer t-shirt’- single score

Table 27: Single score values for 'treatment of 1 crème grade post-consumer t-shirt'

| Impact category | Unit | Alternative | Total | Transport to sale (short haul) | Avoided production of cotton t-shirt | End of life | Transport to recycling | Recycling process | Avoided production of materials |
|---|---|---|---|---|---|---|---|---|---|
| Single score | µPt | Reuse - 10% RR | -57.8 | 3.2 | -62.8 | 1.8 | | | |
| | | Reuse - 40% RR | -246.3 | 3.2 | -251.4 | 1.8 | | | |
| | | Reuse - 80% RR | -497.7 | 3.2 | -502.7 | 1.8 | | | |
| | | Mech. recycling | -58.5 | | | | 2.7 | 2.8 | -64.0 |

*There is no single score for chemical recycling as the recycling partner providing calculated LCA results of chemical recycling of cotton did not report a single score value.

### 5.3.2 Scenario 2: reuse vs. recycling of a polycotton t-shirt (B grade)

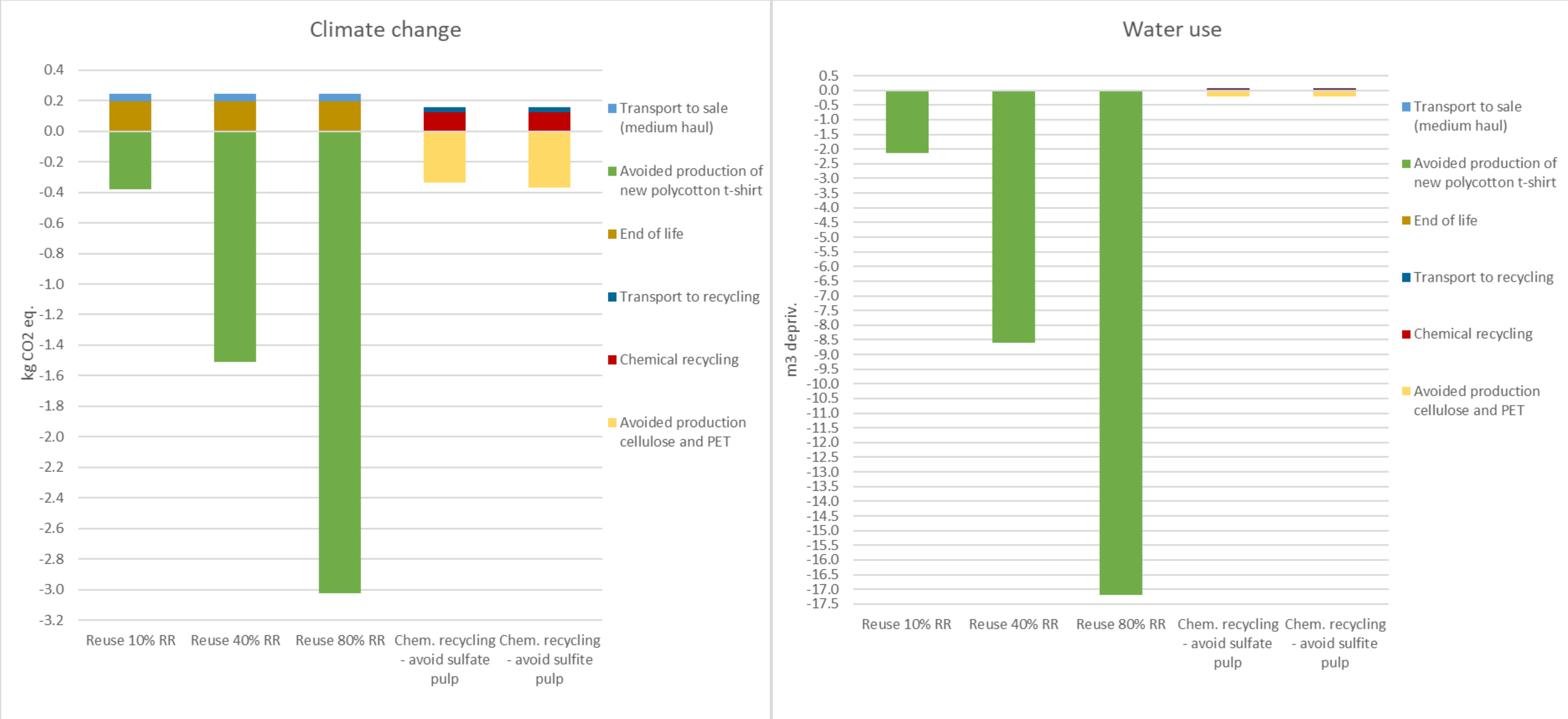


Figure 16: Comparative profile for 'treatment of 1 B grade post-consumer t-shirt' - climate change (left) and water use (right)

Table 28: Impact values climate change and water use for 'treatment of 1 B grade post-consumer t-shirt'

| Impact category | Unit | Alternative | Total | Transport to sale (medium haul) | Avoided production of polycotton t-shirt | End of life | Transport to recycling | Chemical recycling | Avoided production of cellulose and PET |
|---|---|---|---|---|---|---|---|---|---|
| Climate change | kg $CO_2$ eq | Reuse - 10% RR | -0.1314 | 0.0510 | -0.3781 | 0.1957 | | | |
| | | Reuse - 40% RR | -1.2655 | 0.0510 | -1.5122 | 0.1957 | | | |
| | | Reuse - 80% RR | -2.7778 | 0.0510 | -3.0244 | 0.1957 | | | |
| | | Chem. recycling - avoided sulfate pulp | -0.1818 | | | | 0.0294 | 0.1265 | -0.3377 |
| | | Chem. recycling - avoided sulfite pulp | -0.2134 | | | | 0.0294 | 0.1265 | -0.3693 |
| Water use | m3 depriv. | Reuse - 10% RR | -2.1437 | 0.0022 | -2.1496 | 0.0037 | | | |
| | | Reuse - 40% RR | -8.5926 | 0.0022 | -8.5984 | 0.0037 | | | |
| | | Reuse - 80% RR | -17.1910 | 0.0022 | -17.1968 | 0.0037 | | | |
| | | Chem. recycling - avoided sulfate pulp | -0.1809 | | | | 0.0013 | 0.0367 | -0.2190 |
| | | Chem. recycling - avoided sulfite pulp | -0.1661 | | | | 0.0013 | 0.0367 | -0.2042 |

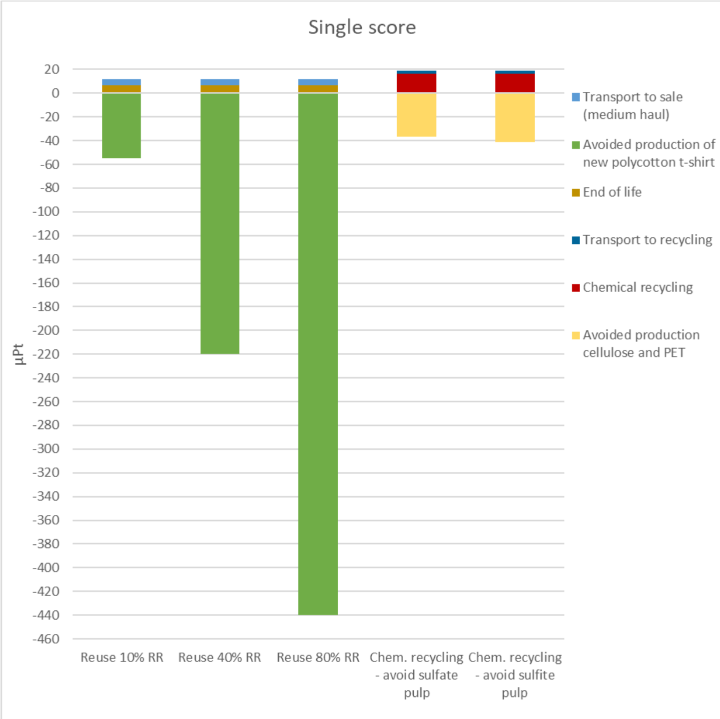


Figure 17: Comparative profile for 'treatment of 1 B grade post-consumer t-shirt'- single score

Table 29: Single score values for 'treatment of 1 B grade post-consumer t-shirt'

| Impact category | Unit | Alternative | Total | Transport to sale (medium haul) | Avoided production of polycotton t-shirt | End of life | Transport to recycling | Chemical recycling | Avoided production of cellulose and PET |
|---|---|---|---|---|---|---|---|---|---|
| Single score | µPt | Reuse - 10% RR | -43.0 | 5.3 | -55.0 | 6.6 | | | |
| | | Reuse - 40% RR | -207.9 | 5.3 | -219.8 | 6.6 | | | |
| | | Reuse - 80% RR | -427.7 | 5.3 | -439.6 | 6.6 | | | |
| | | Chem. recycling - avoided sulfate pulp | -17.5 | | | | 2.7 | 16.5 | -36.7 |
| | | Chem. recycling - avoided sulfite pulp | -21.9 | | | | 2.7 | 16.5 | -41.0 |

### 5.3.3 Scenario 3: reuse vs. recycling of a polyester t-shirt (C grade)[78]

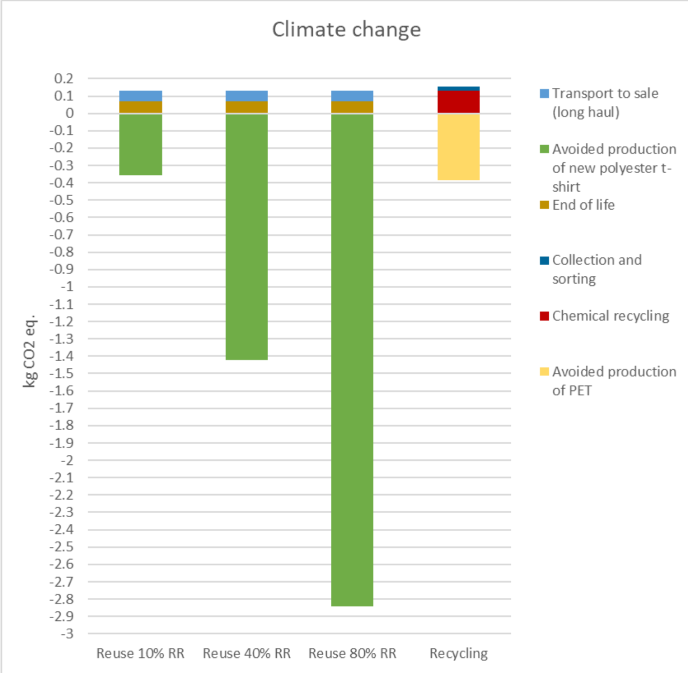


Figure 18: Comparative profile for 'treatment of 1 C grade post-consumer t-shirt' - climate change

Table 30: Impact values climate change for 'treatment of 1 C grade post-consumer t-shirt'

| Impact category | Unit | Alternative | Total | Transport to sale (long haul) | Avoided production of polyester t-shirt | End of life | Collection and sorting | Chemical recycling | Avoided production of PET |
|---|---|---|---|---|---|---|---|---|---|
| Climate change | kg $CO_2$ eq | Reuse - 10% RR | -0.2264 | 0.0594 | -0.3555 | 0.0697 | | | |
| | | Reuse - 40% RR | -1.2928 | 0.0594 | -1.4218 | 0.0697 | | | |
| | | Reuse - 80% RR | -2.7146 | 0.0594 | -2.8437 | 0.0697 | | | |
| | | Chem. recycling | -0.2292 | | | | 0.0251 | 0.1299 | -0.3842 |

[78] The recycler currently does not process polyester textile but uses PET bottles as the input for their recycling technology. Therefore, it is technically not correct to refer to it as 'recycling of a C grade t-shirt'. We use the recycler's LCA results (carbon footprint only) as a proxy for polyester textile recycling. Therefore, we do not have any Water use or Single score on this scenario.

## 5.4 Interpretation

Overall, the waste hierarchy's assumption that reuse is environmental beneficial compared to recycling is confirmed in this study. However, the study also shows that under some circumstances with a low replacement rate in the receiving country combined with an effective recycling method in Europe, recycling can be an equal effective solution from an environmental impact perspective.

> **Box 4: Replacement Rates (RR)**
>
> Is defined as the degree to which the purchase of second-hand clothing and household textiles replaces the purchase of similar new items[79]. The replacement rate in any given country depends on many factors and is constantly changing in response to the changes in the deciding factors.

| | CRÈME | | | | B-GRADE | | | | C-GRADE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Reuse | | Recycling | | Reuse | | Recycling | | Reuse | | Recycling | |
| $CO_2$-e | RR 10 % | -0.2835 | Mech. recycling | -0.1671 | RR 10 % | -0.1314 | Chem. recycling - avoided sulfate pulp | -0.1818 | RR 10 % | -0.2264 | | |
| | RR 40 % | -1.2970 | Chem. recycling - avoided sulfate pulp | 0.0235 | RR 40 % | -1.2655 | Chem. recycling - avoided sulfite pulp | -0.2134 | RR 40 % | -1.2928 | Chem. recycling | -0.2292 |
| | RR 80 % | -2.6483 | Chem. recycling - avoided sulfite pulp | -0.0893 | RR 80 % | -2.7778 | | | RR 80 % | -2.7146 | | |
| Water use | RR 10 % | -3.0716 | Mech. recycling | -2.6214 | RR 10 % | -2.1437 | Chem. recycling - avoided sulfate pulp | -0.1809 | | | | |
| | RR 40 % | -12.3017 | Chem. recycling - avoided sulfate pulp | -0.1003 | RR 40 % | -8.5926 | Chem. recycling - avoided sulfite pulp | -0.1661 | | | | |
| | RR 80 % | -24.6085 | Chem. recycling - avoided sulfite pulp | -0.0463 | RR 80 % | -17.1910 | | | | | | |

Table 31: Environmental impact values for crème, B-grade and C-grade compared.

**Note**: The percentages for different replacement rates should not be compared with the type of recycling on the same line, rather, the reuse and recycling can be compared overall.

For a **crème grade t-shirt**, reuse has the best **single score** in all scenarios except for a replacement rate of 10% or lower when combined with mechanical recycling, as this has a slightly better score than reuse. There is no Single score for the chemical recycling as the recycling partner providing calculated LCA results of chemical recycling of cotton were not able to report a single score value. However, when looking at the climate change impact, the mechanical recycling has a better impact than the chemical recycling so it is expected that this would also have been the result had a single score been provided.

Although all recycling options have either a very low or negative **carbon footprint**, the impact on climate change of chemical recycling of a cotton t-shirt is the highest, because the avoided impact of recycled materials is the lowest. For both recycling technologies the recycling process itself has the largest negative impact on the climate. For chemical recycling, the environmental profile shows that, to draw solid conclusions, it becomes important to identify which pulping process is effectively avoided by using cellulose instead of either sulfate or sulfite pulp as the difference when avoiding sulfite pulp is much less than that of avoiding sulfate.

For all alternatives to reuse, the impact of **water use** is almost solely a result of the avoided impact of the production of the t-shirt or spinnable fibres production. Impacts such as transport and sorting do

[79] Nørup, N., Pihl, K., Damgaard, A., & Scheutz, C. (2019). Replacement rates for second-hand clothing and household textiles – A survey study from Malawi, Mozambique and Angola. Journal of Cleaner Production, 235, 1026-1036. https://doi.org/10.1016/j.jclepro.2019.06.177

not consume water directly, and mechanical recycling only requires a small amount of water. For all assessed replacement rates, reuse of a cotton t-shirt is less water-intensive than recycling.

As for the **B grade t-shirt**, chemical recycling has a **single score** that is almost twice as big as the single score for reuse, even in the scenario with a low replacement rate at 10%. In the case that the used t-shirt almost not at all replaces the purchase of a new, the environmental impact of reuse is larger for than recycling. This is because, the environmental impact of chemical recycling is smaller than the impact from the end-of-life scenario for a polycotton t-shirt, and therefore the total **carbon footprint** of recycling a polycotton t-shirt is slightly smaller than for reusing it at a replacement rate of 10% or lower. Of all the alternatives, chemical recycling of a polycotton t-shirt saves the least **water**. The impact on water use of recycling when sulfate pulp is avoided is almost equal to that in case sulfite pulp is the avoided material.

For the **C grade t-shirt**, when focusing only on burdens, and not what is avoided, recycling is less favourable than reuse from a **climate change** point of view although the difference is very small with 0,155 kg $CO_2$-e for recycling of a polyester t-shirt compared to 0,129 kg $CO_2$-e when reusing the t-shirt. The LCA calculations also show that for a replacement rate of 10% or lower, recycling of a t-shirt has a lower carbon footprint than reusing it. At higher replacement rates reuse is the more carbon-negative option. At the highest calculated replacement rate at 80%, reuse would become considerably more beneficial with regards to climate change, as the carbon footprint of recycling is over 10 times larger than that of reuse. One of the reasons behind this is that the $CO_2$-e of chemical recycling of polyester is larger than that of textile waste treatment (end of life i.e., incineration and landfill). In the case of reuse, the impact of transportation of the t-shirt is almost as large as that of waste treatment of the t-shirt. It is however important to use the results of this polyester recycling with some reservations since the starting point currently is PET bottles and not yet textiles.

The LCA results clearly demonstrate that avoiding the production of both t-shirts and feedstock provide the largest savings on both climate change and water use. It also illustrates that avoiding production (e.g., a new t-shirt) – has a more significant impact than recycling processes, transport, and waste treatment.

The replacement rate in the specific country where the textiles are sent for reuse plays a significant role and only in scenarios with very low replacement rate, is it beneficial to recycle the textiles in Europe instead of exporting them for reuse. If the replacement rate is not very low in the receiving country it is almost irrelevant how low the environmental impacts from the recycling process, transportation etc. is, as recycling will still have a higher negative environmental impact than reuse. More specifically, the higher negative environmental impact for both chemical and mechanical recycling comes from its contribution to climate change and water use. Furthermore, it is worth remembering when comparing a reused t-shirt with recycling that the system boundary for recycling in this study ends with the recycled material and not a new t-shirt made from the recycled materials, thus spinning, weaving etc. is not included in the LCA. If it was, the environmental benefits from reuse would probably be even larger compared to recycling than in this study.

## 5.5 Limitations of the study

**Functional Unit of 52 wears:**
The reused product might in reality be used for less wears than the new garment. This would require that more items are bought – potentially new garments. If that is the case, the positive environmental impact of reuse would be a little lower, narrowing the difference between reuse and recycling. But most probably not enough to make recycling the better environmental option.

**Impact categories**
As the recycling partner providing calculated LCA results of chemical recycling of cotton did not report a single score. This means that the study is not able to present single scores for chemical recycling, and thereby the other impact categories than contribution to climate change and water use, are not included. For instance, *Acidification* and *Land use* are not included, although these can be assumed to be impacted by landfill and incineration, especially outside of Europe. If these had been included, the environmental burden from sending used clothing to reuse, especially to countries with low replacement rates and where the items are likely to quickly end up in landfill, might have been higher, making recycling in Europe a comparably better option.

**System boundaries:**
The starting point of the assessment for both alternatives is the exit gate of the sorting facility. There might be differences in environmental impact between sorting for recycling compared to sorting for reuse, but these are assumingly minor.

The system boundary for recycling in this study ends with the recycled material and not a new t-shirt made from the recycled materials, thus spinning, weaving etc. is not included in the LCA. If it was, the environmental benefits from reuse would probably be even larger compared to recycling than in this study.

**Recycling method**
This study only includes mechanical recycling as part of the recycling scenario for crème, and not for B-grade and C-grade. For this quality, the study finds that mechanical recycling has a lower environmental impact than chemical recycling, and consequently if mechanical recycling had been included also for the two other qualities, the difference in environmental impact between recycling and reuse might have been smaller. This could have led to recycling being preferable from an environmental perspective for even higher replacement rates than 10 %.

**Substitution rate of mechanically recycled material**
The avoided primary production of materials depends on the recycled material (output of recycling process). Usually, primary production of these materials is not avoided for 100% due to the lower quality of a recycled material compared to virgin materials. This is considered by means of a substitution rate. In the case of cotton, the production of spinnable fibres is assumed to have a substitution rate of 12.5%[80]. However, this might be a conservative estimate. Other sources state that mechanically recycled fibres are typically mixed with 20 – 50 % of virgin fibres to ensure sufficient quality[81]. This would signify a substitution rate of 80 – 50 %, rather than 12,5 %. If the substitution rate of this study had been higher, the environmental burden of recycling would likely have been lower, as the burden would have been countered by the larger replacement of virgin fibres. This could have made recycling a more beneficial scenario compared to reuse, even for higher replacement rates than 10 %.

**Replacement Rates**
The environmental impact of the reuse of a t-shirt versus recycling is as this LCA shows, highly dependent on the assumed replacement rate of the garment for reuse. Instead of analysing the scenario of one replacement rate, this study compares three different rates, for the study to be useful for a range of scenarios. This decision was partly also based on the fact that there are few studies on replacement rates across the world, in addition to that these are in constant change and consequently any study would quickly expire. The three replacement rates chosen for this study are nonetheless based on what

[80] Duhoux et al (2021) report that in the worst case, the output of the mechanical recycling process of cotton replaces 5% of spinnable fibres, while the best case scenario is 20% replacement of spinnable fibres. This study uses the average value, being 12.5%.
[81] Lifestyle and Design Cluster. (2022). *Research and identification of textile plants globally - focusing on fiber-to-fiber recycling for the fashion & textile industry*

has been found of information. As these studies are few, this study would have benefitted from having access to more detailed studies from different countries, and such information might have led to the choice of other rates.

**The social aspect of reuse**
An LCA is strictly focused on environmental impacts. However, the topic of used clothes and the market of second-hand clothes around the world is also highly connected to social aspects. For instance, people in many developing countries that are receivers of used clothing from the EU are dependent on this to be dressed in dignity and would otherwise not be able to afford clothing to the same extent. This means that the question of what is 'better' might have one answer looking only at the findings of the LCA, and another if also taking social aspects into account. However, the LCA finds that only in situation where the replacement rate is low, is recycling an environmentally better option. If the replacement rate is low, the second-hand clothes are not actually the only option to obtain clothing, and hence prioritizing recycling over reuse when this makes sense from an environmental perspective, also aligns with social aspects.

**Time frame for study**
The study is based on data up until 2020, and hence does not include market data after this point. Prices and trends might be changing, affecting the basis for the conclusions drawn. However, the conclusions are based on long term trends, and as yearly fluctuations are common in the market of used textiles, such recent changes are not believed to significantly impact the relevance of the recommendations. That said, the most recent indications from the market states that both prices and demand for used textiles is increasing. This points to that these types of studies have an expiration date and should be regularly updated to precisely reflect the shifting market dynamics.

**Future research**
In sum, the above limitations indicate that the following further research could contribute to a more nuanced picture.

- Include mechanical recycling for all quality categories
- Include new products made from recycled yarn, don't stop at yarn production
- Include more impact categories
- Include social impact category
- Understand more of where the used textiles end up, and whether it will replace new products.

## 5.6 Conclusion

This lifecycle assessment set out to compare the reusing of garments globally versus recycling of garments in Europe. The reference product was a basic t-shirt without embellishments, and the analysis differentiates between three quality levels, based on their composition. In addition, the comparison takes into account three different *Replacement Rates*, in order to differentiate to which extent, the garments exported for reuse actually replaces the purchase of new garments.

| Scenario | Quality level | Reuse of garment | Recycling of garment |
|---|---|---|---|
| 1 | Crème | Reuse of a 100% cotton second-hand shirt sorted in Europe and sold in Europe | Mechanical recycling of 100% cotton shirt into fibres ready for spinning<br>Chemical recycling of 100% cotton shirt into cellulose |

| | | | |
|---|---|---|---|
| 2 | B-grade | Reuse of a 30/70 polycotton second-hand shirt sorted in Europe and sold in sub-Sahara Africa | Chemical recycling of 30/70 polycotton shirt into cellulose and PET |
| 3 | C-grade | Reuse of a 100% polyester second-hand shirt sorted in Europe and sold in Pakistan | Chemical recycling of 100% polyester into monomers and repolymerisation into PET |

Both reuse and recycling are processes which come with certain environmental impacts, such as transport or electricity use. However, both strategies are indented to replace the production of either a new garment or new fibre. Therefore, the assessment shows the result mainly in terms of what has been *avoided.*

Overall, the study confirms that reuse avoids more than recycling, and is therefore environmentally beneficial for all three qualities. However, if the reuse does not to a large degree replace the production of new garments, recycling can be slightly more environmentally beneficial.

For **crème**, if the replacement rate is equal to or lower than 10 %, mechanical recycling is to be preferred. For **B Grade**, reuse is better than recycling as chemical recycling is twice as harmful to the environment than reuse, even if the reuse replaces very little of the production of new items. However, if the replacement rate is lower than 10 %,  the environmental impact of reuse is larger than recycling. For **C Grade**, even though the item will end up in landfill at the end-of-life, reuse is generally better than recycling. At the highest calculated replacement rate at 80%, recycling has over 10 times larger (negative) impact on climate change than reuse. However, at a replacement rate of 10 %, recycling has a smaller environmental impact than reuse. **Transport** has a small impact on all quality levels

For **B- and C-grade**, reuse has only been compared to chemical recycling. However, the assessment for Crème, where both mechanical and chemical recycling is investigated, shows that mechanical recycling has a smaller negative impact on the environment than chemical recycling. This suggests that if the reuse of C-grade, had been compared to mechanical recycling, recycling could have been preferable to reuse at higher replacement rates than 10 %. For instance, if a large part of what is exported for reuse to sub-Saharan Africa or Asia in reality ends up at landfill or open incineration, it could be environmentally beneficial to rather mechanically recycle the used textiles in Europe.

Overall, the benefit of both reuse and recycling comes from the consequential avoidance of production of new garments or new fibres. Reuse globally is to be preferred over recycling despite long haul transport, as long as it replaces the production of new products. When the reuse does not significantly replace new garments, recycling the garments in Europe has a smaller environmental impact.

# 6 RECOMMENDATIONS

**Ensure durability**

The study identifies the importance of reuse, and increased durability of garments is the most important strategy to increase both the first use phase, and to ensure the reusability of the collected textiles. EuRIC Textilestherefore strongly supports the introduction and enforcement of the Ecodesign for Sustainable Products Regulation.

**Continued global trade of used textiles**

This study proves that reuse has a lower environmental footprint compared to the production of a new textile item or recycling, as long as it replaces new garments. To maximize the benefits of the already available textiles, the export of second-hand textiles outside the EU for reuse should not be restricted, as long as they replace new garments. At low replacement rates, recycling in Europe is to be preferred.

**Better sorting**

This study finds that global reuse is better than recycling, but that this depends on whether the exported garments efficiently replace the production of new garments. Therefore, it is essential to avoid the export of textiles which will not be used and rather end up as waste in the receiving country. To achieve this, EuRIC Textiles recommends a better sorting process and a better understanding of the receiving markets.

**Better sorting could be achieved with the following steps:**

1. The high-quality sorting process shall be aimed at preparing the collected post-consumer textile waste for reuse or, if reuse is not possible, for subsequent recycling. It is a complex process and typically consists of several steps. While the sorting process may differ from operator to operator, following requirement shall be the mandatory basis to ensure high-quality sorting:
    a. During the sorting process, higher-quality fractions (reusable textiles sorted at individual item level) shall be completely separated from lower-quality recycling fractions as well as any foreign materials such as plastics, metals etc.
    b. The suitability for reuse or recycling shall be checked manually by a trained professional who has undergone task-specific training at the beginning of the employment and whenever changes to the sorting process occur. The trained professional shall manually check the suitability for reuse or recycling for each individual piece that is fed into the sorting process in accordance with the waste hierarchy of the Waste Framework Directive. The professional sorters shall receive more and continuously updated education about market needs and likely use of the exported textiles.
    c. Since sorted textiles are packaged according to a certain need, materials from loose bulk shall not be considered as outcome of a high-quality sorting. Is shall be ensured that the sorted and packaged textiles are properly labelled (due to missing uniform specifications, plant specific codes may be used) and only moved gently.

**More categories within the waste hierarchy**

The study finds that mechanical recycling produces less environmental impacts than chemical recycling. Although mechanical recycling as of today is mainly used for the production of industry wipes and filling, the process has the potential to produce yarn of sufficient quality. Mechanical recycling should therefore be prioritised over chemical recycling, which should be mainly considered as a supplemental role to mechanical recycling.

Textiles should be dealt with in a cascading approach: Used textiles should first be recycled into yarn used for the production of new garments, repeatedly until the fibres are too short to produce useful yarn. Then, the garment should be mechanically recycled into industry wipes and / or filling. Only when such products are wasted, should the textile be chemically recycled to again produce high-quality yarn. This way the least environmentally harmful process is prioritised as long as possible. This prioritisation should be reflected in the waste hierarchy. Firstly, the definition of recycling could be made more robust by explicating the substitution element of recycling, since recycled materials substitute primary raw materials or substances. Second, the waste hierarchy should reflect a more granular definition where chemical recycling will have an intermediary position between mechanical recycling (above) and (energy) recovery (below) to better highlight the complementary nature of chemical recycling as well as its larger environmental footprint.

**Improved recycling infrastructure across the world**

The study finds that recycling is less environmentally harmful than landfilling and incineration. To be able to process the increased volumes of non-reusable collected textiles according to the Waste Hierarchy, recycling infrastructure and technology therefore needs to be strengthened both in Europe and globally.

In Europe, there is an urgent need for funding for capacity building and innovation of technologies for fibre-to-fibre recycling, both based on mechanical and chemical processes, in order to fulfil the above suggested differentiation of the waste hierarchy.

Even if used textiles are exported based on updated and correct information about the needs and capacities of the receiving country, and thus textiles exported for reuse are indeed reused, eventually all clothing becomes too worn out to be used/reused any more. Potentially more and more rapidly if the quality is indeed decreasing. Given that textile waste in many developing countries end up in landfill or are incinerated in open air with the connected negative environmental impacts, it is therefore crucial that recycling capacity is strengthened worldwide.

# ANNEX 1 – SINGLE SCORE

The Single score used in the LCA impact categories is the sum of the weighted impacts of all 16 impact categories calculated by the EF Method. They are weighted (after normalization) using the weighting factors in table 30 below, adopted by the European Commission. This weighting g reflect the perceived relative importance of the impact categories considered. The single score is calculated directly by the used software package SimaPro. In this way all impact categories are lumped in 1 dimensionless number (expressed in points), covering all 16 environmental aspects.

Table 30: Weighting of Single score

| Impact category | Normalisation | | Weighting factors |
|---|---|---|---|
| | Unit | Factor (unit/person) | Unit: - (dimensionless) |
| Climate change | kg $CO_2$ eq | 0.0001235 | 0.2106 |
| Ozone depletion | kg CFC-11 eq | 18.64 | 0.0631 |
| Ionising radiation | kBq $U^{235}$ eq | 0.0002370 | 0.0501 |
| Photochemical ozone formation | kg NMVOC eq | 0.02463 | 0.0478 |
| Particulate matter | Disease incidence | 1680 | 0.0896 |
| Human toxicity, non-cancer | CTUh | 4354 | 0.0184 |
| Human toxicity, cancer | CTUh | 59173 | 0.0213 |
| Acidification | Mol H+ eq | 0.01800 | 0.062 |
| Eutrophication, freshwater | kg P eq | 0.6223 | 0.028 |
| Eutrophication, marine | kg N eq | 0.05116 | 0.0296 |
| Eutrophication, terrestrial | mol N eq | 0.005658 | 0.0371 |
| Ecotoxicity, freshwater | CTUe | 0.00002343 | 0.0192 |
| Land use | Dimensionless | 0.000001220 | 0.0794 |
| Water use | $m^3$ world eq | 0.00008719 | 0.0851 |
| Resource use, minerals and metals | Kg Sb eq | 0.00001538 | 0.0832 |
| Resource use, fossils | MJ | 15.71 | 0.0755 |

# ANNEX 2 - DATA INVENTORY NEW T-SHIRT

Table 31: Data inventory for 1 new t-shirt - crème grade

| 1. Production of new t-shirt (crème grade) | | | | | |
|---|---|---|---|---|---|
| Input flows | | | | | |
| Flow | Amount | Unit | Data source | Record | Comment |
| Water | 0.011 | $m^3$ | Sandin et al. | Water, river | For bleaching |
| Cotton fibre | 0.211 | kg | Sandin et al. | Fibre, cotton {GLO}\| market for fibre, cotton \| Cut-off, U | Includes all processes from seed-cotton processing through ginning |
| Acrylic acid | $2.98*10^{-3}$ | kg | Sandin et al. | Acrylic acid {RoW}\| market for acrylic acid \| Cut-off, U | Lubricant for spinning, knitting and bleaching |
| Polyacrylamide | $5.95*10^{-3}$ | kg | Sandin et al. | Polyacrylamide {GLO}\| market for \| Cut-off, U | |
| Water, ultrapure | 0.021 | kg | Sandin et al. | Water, ultrapure {RoW}\| market for water, ultrapure \| Cut-off, U | |
| Acrylic acid | $9.21*10^{-3}$ | kg | Sandin et al. | Acrylic acid {RoW}\| market for acrylic acid \| Cut-off, U | Detergent/wetting agent for bleaching |
| Fluorescent whitening agent | 0.011 | kg | Sandin et al. | Fluorescent whitening agent, distyrylbiphenyl type {GLO}\| market for \| Cut-off, U | For bleaching |
| Formic acid | $1.84*10^{-3}$ | kg | Sandin et al. | Formic acid {RoW}\| market for \| Cut-off, U | For bleaching |
| Hydrogen peroxide | 0.013 | kg | Sandin et al. | Hydrogen peroxide, without water, in 50% solution state {RoW}\| market for hydrogen peroxide, without water, in 50% solution state \| Cut-off, U | For bleaching |
| Acrylic acid | $3.69*10^{-5}$ | kg | Sandin et al. | Acrylic acid {RoW}\| market for acrylic acid \| Cut-off, U | Peroxide stabilizer, for bleaching |
| Magnesium oxide | $1.84*10^{-6}$ | kg | Sandin et al. | Magnesium oxide {GLO}\| market for \| Cut-off, U | |
| Phosphoric acid | $3.69*10^{-5}$ | kg | Sandin et al. | Phosphoric acid, industrial grade, without water, in 85% solution state {GLO}\| market for \| Cut-off, U | |
| Water, ultrapure | $2.93*10^{-4}$ | kg | Sandin et al. | Water, ultrapure {RoW}\| market for water, ultrapure \| Cut-off, U | |
| Sodium hydroxide | $4.60*10^{-3}$ | kg | Sandin et al. | Sodium hydroxide, without water, in 50% solution state {GLO}\| market for \| Cut-off, U | For bleaching |
| Diethanolamine | $1.66*10^{-4}$ | kg | Sandin et al. | Diethanolamine {GLO}\| market for \| Cut-off, U | Softener, for bleaching |
| Stearic acid | $1.11*10^{-3}$ | kg | Sandin et al. | Stearic acid {GLO}\| market for stearic acid \| Cut-off, U | |
| Water, ultrapure | $4.25*10^{-3}$ | kg | Sandin et al. | Water, ultrapure {RoW}\| market for water, ultrapure \| Cut-off, U | |
| Sulfuric acid | $3.69*10^{-3}$ | kg | Sandin et al. | Sulfuric acid {RoW}\| market for sulfuric acid \| Cut-off, U | For bleaching |
| Tap water | 0.028 | kg | Sandin et al. | Tap water {GLO}\| market group for \| Cut-off, U | For confectioning |
| Yarn, cotton | $5.47*10^{-4}$ | kg | Sandin et al. | Yarn, cotton {GLO}\| market for yarn, cotton \| Cut-off, U | Proxy for sewing thread, for confectioning |
| Kraft paper | $7.83*10^{-3}$ | kg | Sandin et al. | Kraft paper {RoW}\| market for kraft paper \| Cut-off, U | Proxy for confectioning template, for confectioning |
| Corrugated board box | $9.39*10^{-3}$ | kg | Sandin et al. | Corrugated board box {RoW}\| market for corrugated board box \| Cut-off, U | For confectioning |

| | | | | | |
|---|---|---|---|---|---|
| Packaging film, LDPE | $3.13*10^{-3}$ | kg | Sandin et al. | Packaging film, low density polyethylene {GLO}\| market for \| Cut-off, U | For confectioning |
| Electricity, medium voltage (Bangladesh) | 0.298 | kWh | Sandin et al. | Electricity, medium voltage {BD}\| market for electricity, medium voltage \| Cut-off, U | Electricity for spinning, knitting, wet treatment, drying and confectioning.<br>Electricity mix based on the seven biggest contributors to Swedish clothing imports in 2013-2017 (Eurostat), excluding Turkey[82]:<br>-Bangladesh: 20%<br>-China: 63%<br>-Cambodia: 3%<br>-Pakistan: 3%<br>-Vietnam: 3%<br>-India: 7% |
| Electricity, medium voltage (China) | 0.936 | kWh | Sandin et al. | Electricity, medium voltage {CN}\| market group for \| Cut-off, U | |
| Electricity, medium voltage (Cambodia) | 0.045 | kWh | Sandin et al. | Electricity, medium voltage {KH}\| market for electricity, medium voltage \| Cut-off, U | |
| Electricity, medium voltage (Pakistan) | 0.045 | kWh | Sandin et al. | Electricity, medium voltage {PK}\| market for electricity, medium voltage \| Cut-off, U | |
| Electricity, medium voltage (Vietnam) | 0.045 | kWh | Sandin et al. | Electricity, medium voltage {VN}\| market for electricity, medium voltage \| Cut-off, U | |
| Electricity, medium voltage (India) | 0.104 | kWh | Sandin et al. | Electricity, medium voltage {IN}\| market group for electricity, medium voltage \| Cut-off, U | |
| Heat, central or small-scale, other than natural gas | 6.99 | MJ | Sandin et al. | Heat, central or small-scale, other than natural gas {RoW}\| heat production, light fuel oil, at boiler 100kW, non-modulating \| Cut-off, U | For wet treatment and drying |
| Heat, central or small-scale, natural gas | 0.011 | MJ | Sandin et al. | Heat, central or small-scale, natural gas {GLO}\| market group for \| Cut-off, U | For confectioning |
| Output flows | | | | | |
| Flow | Amount | Unit | Data source | Record | Comment |
| Treatment of cotton production waste | 0.053 | kg | Sandin et al. | Waste paperboard {RoW}\| treatment of, municipal incineration \| Cut-off, U | Proxy for incineration of cotton waste from spinning, knitting and confectioning (no E recovery) |
| Wastewater treatment from textile production | $8.29*10^{-3}$ | $m^3$ | Sandin et al. | Wastewater from textile production {GLO}\| market for wastewater from textile production \| Cut-off, U | Water from bleaching |
| 2. Transport of new t-shirt (crème grade) to point of sale | | | | | |
| Flow | Amount | Unit | Data source | Record | Comment |
| Transport over sea | 1.64 | tkm | Estimation | Transport, freight, sea, container ship {GLO}\| transport, freight, sea, container ship \| Cut-off, U | Average distance to Europe by ship<br>Assumption: loss in distribution phase of 1% |
| Transport over road – lorry 16-32 tonne | 0.08 | tkm | Estimation | Transport, freight, lorry 16-32 metric ton, EURO6 {RoW}\| transport, freight, lorry 16-32 metric ton, EURO6 \| Cut-off, U | Average distance to Europe by truck<br>Assumption: loss in distribution phase of 1% |

Table 32: Data inventory for 1 new t-shirt - B- grade

| 1. Production of new t-shirt (B grade) |
|---|
| Input flows |

[82] It was assumed that production was done in Asia.

| Flow | Amount | Unit | Data source | Record | Comment |
|---|---|---|---|---|---|
| Water | 0.026 | $m^3$ | Sandin et al. | Water, river | For dyeing of polyester and bleaching of cotton |
| PET pellets | 0.058 | kg | Sandin et al. | Polyethylene terephthalate, granulate, amorphous {GLO}\| market for \| Cut-off, U | |
| Acrylic acid | $9.21*10^{-6}$ | kg | Sandin et al. | Acrylic acid {RoW}\| market for acrylic acid \| Cut-off, U | Lubricant for cotton yarn spinning |
| Polyacrylamide | $1.84*10^{-5}$ | kg | Sandin et al. | Polyacrylamide {GLO}\| market for \| Cut-off, U | |
| Water, ultrapure | $6.45*10^{-5}$ | kg | Sandin et al. | Water, ultrapure {RoW}\| market for water, ultrapure \| Cut-off, U | |
| Acrylic acid | $5.78*10^{-4}$ | kg | Sandin et al. | Acrylic acid {RoW}\| market for acrylic acid \| Cut-off, U | Proxy for detergent/wetting agent for dyeing |
| Lubricating oil | 0.0248 | kg | Sandin et al. | Lubricating oil {RoW}\| market for lubricating oil \| Cut-off, U | Lubricating oil for melt spinning of polyester fibres |
| Antimony | $1.16*10^{-5}$ | kg | Sandin et al. | Antimony {GLO}\| market for \| Cut-off, U | For melt spinning |
| Toluene diisocyanate | $1.16*10^{-5}$ | kg | Sandin et al. | Toluene diisocyanate {RoW}\| market for toluene diisocyanate \| Cut-off, U | For melt spinning |
| Cotton fibre | 0.147 | kg | Sandin et al. | Fibre, cotton {GLO}\| market for fibre, cotton \| Cut-off, U | |
| Acrylic acid | $1.95*10^{-3}$ | kg | Sandin et al. | Acrylic acid {RoW}\| market for acrylic acid \| Cut-off, U | Lubricant for spinning and bleaching of cotton and weaving of polycotton |
| Polyacrylamide | $3.84*10^{-3}$ | kg | Sandin et al. | Polyacrylamide {GLO}\| market for \| Cut-off, U | |
| Water, ultrapure | 0.014 | kg | Sandin et al. | Water, ultrapure {RoW}\| market for water, ultrapure \| Cut-off, U | |
| Aniline | $9.59*10^{-3}$ | kg | Sandin et al. | Aniline {RoW}\| market for aniline \| Cut-off, U | For dyeing |
| Ethylene glycol monoethyl ether | $2.88*10^{-3}$ | kg | Sandin et al. | Ethylene glycol monoethyl ether {RoW}\| market for ethylene glycol monoethyl ether \| Cut-off, U | For dyeing |
| Formic acid | $2.88*10^{-3}$ | kg | Sandin et al. | Formic acid {RoW}\| market for \| Cut-off, U | For dyeing |
| Hydrogen peroxide | $2.88*10^{-3}$ | kg | Sandin et al. | Hydrogen peroxide, without water, in 50% solution state {RoW}\| market for hydrogen peroxide, without water, in 50% solution state \| Cut-off, U | For dyeing |
| Phosphoric acid | $3.84*10^{-3}$ | kg | Sandin et al. | Phosphoric acid, industrial grade, without water, in 85% solution state {GLO}\| market for \| Cut-off, U | Proxy for sequestering agent for dyeing |
| Soda ash | $4.32*10^{-3}$ | kg | Sandin et al. | Soda ash, dense {GLO}\| market for \| Cut-off, U | For dyeing |
| Sodium hydroxide | $9.59*10^{-4}$ | kg | Sandin et al. | Sodium hydroxide, without water, in 50% solution state {GLO}\| market for \| Cut-off, U | For dyeing |
| Acrylic acid | $1.44*10^{-3}$ | kg | Sandin et al. | Acrylic acid {RoW}\| market for acrylic acid \| Cut-off, U | Detergent, for dyeing |
| Dimethyl sulfate | $7.19*10^{-4}$ | kg | Sandin et al. | Dimethyl sulfate {RoW}\| market for dimethyl sulfate \| Cut-off, U | |
| Ethoxylated alcohol (AE3) | $3.60*10^{-3}$ | kg | Sandin et al. | Ethoxylated alcohol (ae3) {RoW}\| market for ethoxylated alcohol (AE3) \| Cut-off, U | |
| Ethoxylated alcohol (AE7) | $1.44*10^{-3}$ | kg | Sandin et al. | Ethoxylated alcohol (ae7) {RoW}\| market for ethoxylated alcohol (AE7) \| Cut-off, U | |

| | | | | | |
|---|---|---|---|---|---|
| Water, ultrapure | $7.19*10^{-3}$ | kg | Sandin et al. | Water, ultrapure {RoW}\| market for water, ultrapure \| Cut-off, U | |
| Diethanolamine | $1.15*10^{-3}$ | kg | Sandin et al. | Diethanolamine {GLO}\| market for \| Cut-off, U | Softener, for dyeing |
| Stearic acid | $7.67*10^{-3}$ | kg | Sandin et al. | Stearic acid {GLO}\| market for stearic acid \| Cut-off, U | |
| Water, ultrapure | 0.030 | kg | Sandin et al. | Water, ultrapure {RoW}\| market for water, ultrapure \| Cut-off, U | |
| Fatty alcohol | $9.59*10^{-4}$ | kg | Sandin et al. | Fatty alcohol {GLO}\| market for \| Cut-off, U | Wetting/penetrating agent (synthetic), for dyeing |
| Maleic anhydride | $2.88*10^{-4}$ | kg | Sandin et al. | Maleic anhydride {GLO}\| market for maleic anhydride \| Cut-off, U | |
| Water, ultrapure | $6.71*10^{-4}$ | kg | Sandin et al. | Water, ultrapure {RoW}\| market for water, ultrapure \| Cut-off, U | |
| Calcium carbonate | $1.92*10^{-5}$ | kg | Sandin et al. | Calcium carbonate, precipitated {RoW}\| market for calcium carbonate, precipitated \| Cut-off, U | Reducing agent VAT, for dyeing |
| Sodium dithionite | $8.63*10^{-4}$ | kg | Sandin et al. | Sodium dithionite, anhydrous {RoW}\| market for sodium dithionite, anhydrous \| Cut-off, U | |
| Sodium sulfite | $7.67*10^{-5}$ | kg | Sandin et al. | Sodium sulfite {RoW}\| market for sodium sulfite \| Cut-off, U | |
| Water, deionised | 0.028 | kg | Sandin et al. | Water, deionised {RoW}\| market for water, deionised \| Cut-off, U | For ironing |
| Polyester fibre | $5.47*10^{-4}$ | kg | Sandin et al. | Fibre, polyester {GLO}\| market for fibre, polyester \| Cut-off, U | Proxy for sewing thread |
| Confectioning template | $7.83*10^{-3}$ | kg | Sandin et al. | Kraft paper {RoW}\| market for kraft paper \| Cut-off, U | |
| Corrugated board box | 9.39*10-3 | kg | Sandin et al. | Corrugated board box {RoW}\| market for corrugated board box \| Cut-off, U | Packaging |
| Packaging film, LDPE | 3.13*10-3 | kg | Sandin et al. | Packaging film, low density polyethylene {GLO}\| market for \| Cut-off, U | Packaging |
| Electricity, medium voltage (BD) | 0.396 | kWh | Sandin et al. | Electricity, medium voltage {BD}\| market for electricity, medium voltage \| Cut-off, U | Electricity for melt spinning of polyester, spinning of polyester and cotton yarn, weaving, dyeing, drying and confectioning.<br>Electricity mix based on the seven biggest contributors to Swedish clothing imports in 2013-2017 (Eurostat), excluding Turkey[83]:<br>-Bangladesh: 20%<br>-China: 63%<br>-Cambodia: 3%<br>-Pakistan: 3%<br>-Vietnam: 3%<br>-India: 7% |
| Electricity, medium voltage (CN) | 1.245 | kWh | Sandin et al. | Electricity, medium voltage {CN}\| market group for \| Cut-off, U | |
| Electricity, medium voltage (KH) | 0.059 | kWh | Sandin et al. | Electricity, medium voltage {KH}\| market for electricity, medium voltage \| Cut-off, U | |
| Electricity, medium voltage (PK) | 0.059 | kWh | Sandin et al. | Electricity, medium voltage {PK}\| market for electricity, medium voltage \| Cut-off, U | |
| Electricity, medium voltage (VN) | 0.059 | kWh | Sandin et al. | Electricity, medium voltage {VN}\| market for electricity, medium voltage \| Cut-off, U | |
| Electricity, medium voltage (IN) | 0.138 | kWh | Sandin et al. | Electricity, medium voltage {IN}\| market group for electricity, medium voltage \| Cut-off, U | |
| Heat, central or small-scale, other than natural gas | 7.41 | MJ | Sandin et al. | Heat, central or small-scale, other than natural gas {RoW}\| heat production, light fuel oil, at boiler 100kW, non-modulating \| Cut-off, U | For melt spinning, dyeing and drying |

83 It was assumed that production was done in Asia.

| | | | | | |
|---|---|---|---|---|---|
| Heat, central or small-scale, natural gas | 0.011 | MJ | Sandin et al. | Heat, central or small-scale, natural gas {GLO}\| market group for \| Cut-off, U | For confectioning |
| Output flows | | | | | |
| Flow | | Unit | Data source | Record | Comment |
| Dimethyl terephthalate | 5.78*10$^{-7}$ | kg | Sandin et al. | Terephthalate, dimethyl | Emission to air from melt spinning |
| Treatment of polyethylene production waste | 9.27*10$^{-3}$ | kg | Sandin et al. | Waste polyethylene {RoW}\| treatment of waste polyethylene, municipal incineration \| Cut-off, U | Incineration of polyester waste from yarn spinning, weaving and confectioning (no energy recovery) |
| Treatment of cotton production waste | 0.037 | kg | Sandin et al. | Waste paperboard {RoW}\| treatment of, municipal incineration \| Cut-off, U | Proxy for incineration of cotton waste from yarn spinning, weaving and confectioning (no energy recovery) |
| Wastewater treatment from textile production | 8.63*10$^{-3}$ | $m^3$ | Sandin et al. | Wastewater from textile production {GLO}\| market for wastewater from textile production \| Cut-off, U | Water from dyeing |
| Sludge treatment from dyeing | 0.096 | kg | Sandin et al. | Sludge from pulp and paper production {CH}\| treatment of, sanitary landfill \| Cut-off, U | Sludge from dyeing |
| 2. Transport of new t-shirt (B grade) to point of sale | | | | | |
| Flow | Amount | Unit | Data source | Record | Comment |
| Transport over sea | 2.45 | tkm | Estimation | Transport, freight, sea, container ship {GLO}\| transport, freight, sea, container ship \| Cut-off, U | Assumptions: transport between Shanghai and the major port of the 5 largest importers of clothing in Sub-Sahara Africa, loss in distribution phase of 1% |
| Transport over road – lorry >32 tonne | 0.08 | tkm | Estimation | Transport, freight, lorry >32 metric ton, euro3 {RoW}\| market for transport, freight, lorry >32 metric ton, EURO3 \| Cut-off, U | Assumptions: transport via truck towards the capital of the country of import, loss in distribution phase of 1% |

Table 33: Data inventory for 1 new t-shirt - C grade

| 1. Production of new t-shirt (C grade) | | | | | |
|---|---|---|---|---|---|
| Input flows | | | | | |
| Flow | Amount | Unit | Data source | Record | Comment |
| Water | 0.015 | $m^3$ | Sandin et al. | Water, river | For dyeing |
| PET pellets | 0.192 | kg | Sandin et al. | Polyethylene terephthalate, granulate, amorphous {GLO}\| market for \| Cut-off, U | |
| Acrylic acid | 1.54*10$^{-3}$ | kg | Sandin et al. | Acrylic acid {RoW}\| market for acrylic acid \| Cut-off, U | Lubricant for yarn spinning and knitting |
| Polyacrylamide | 3.08*10$^{-3}$ | kg | Sandin et al. | Polyacrylamide {GLO}\| market for \| Cut-off, U | |
| Water, ultrapure | 0.011 | kg | Sandin et al. | Water, ultrapure {RoW}\| market for water, ultrapure \| Cut-off, U | |
| Acrylic acid | 3.84*10$^{-3}$ | kg | Sandin et al. | Acrylic acid {RoW}\| market for acrylic acid \| Cut-off, U | Proxy for detergent/wetting agent for dyeing |
| Lubricating oil | 1.92*10$^{-3}$ | kg | Sandin et al. | Lubricating oil {RoW}\| market for lubricating oil \| Cut-off, U | Lubricating oil for melt spinning of polyester fibres |

| | | | | | |
|---|---|---|---|---|---|
| Antimony | $3.86*10^{-5}$ | kg | Sandin et al. | Antimony {GLO}\| market for \| Cut-off, U | For melt spinning |
| Toluene diisocyanate | $3.86*10^{-5}$ | kg | Sandin et al. | Toluene diisocyanate {RoW}\| market for toluene diisocyanate \| Cut-off, U | For melt spinning |
| Aniline | $9.59*10^{-3}$ | kg | Sandin et al. | Aniline {RoW}\| market for aniline \| Cut-off, U | For dyeing |
| Ethylene glycol monoethyl ether | $2.88*10^{-3}$ | kg | Sandin et al. | Ethylene glycol monoethyl ether {RoW}\| market for ethylene glycol monoethyl ether \| Cut-off, U | For dyeing |
| Formic acid | $2.88*10^{-3}$ | kg | Sandin et al. | Formic acid {RoW}\| market for \| Cut-off, U | For dyeing |
| Hydrogen peroxide | $2.88*10^{-3}$ | kg | Sandin et al. | Hydrogen peroxide, without water, in 50% solution state {RoW}\| market for hydrogen peroxide, without water, in 50% solution state \| Cut-off, U | For dyeing |
| Phosphoric acid | $3.84*10^{-3}$ | kg | Sandin et al. | Phosphoric acid, industrial grade, without water, in 85% solution state {GLO}\| market for \| Cut-off, U | Proxy for sequestering agent for dyeing |
| Soda ash | $4.32*10^{-3}$ | kg | Sandin et al. | Soda ash, dense {GLO}\| market for \| Cut-off, U | For dyeing |
| Sodium hydroxide | $9.59*10^{-4}$ | kg | Sandin et al. | Sodium hydroxide, without water, in 50% solution state {GLO}\| market for \| Cut-off, U | For dyeing |
| Acrylic acid | $1.44*10^{-3}$ | kg | Sandin et al. | Acrylic acid {RoW}\| market for acrylic acid \| Cut-off, U | Detergent, for dyeing |
| Dimethyl sulfate | $7.19*10^{-4}$ | kg | Sandin et al. | Dimethyl sulfate {RoW}\| market for dimethyl sulfate \| Cut-off, U | |
| Ethoxylated alcohol (AE3) | $3.60*10^{-3}$ | kg | Sandin et al. | Ethoxylated alcohol (ae3) {RoW}\| market for ethoxylated alcohol (AE3) \| Cut-off, U | |
| Ethoxylated alcohol (AE7) | $1.44*10^{-3}$ | kg | Sandin et al. | Ethoxylated alcohol (ae7) {RoW}\| market for ethoxylated alcohol (AE7) \| Cut-off, U | |
| Water, ultrapure | $7.19*10^{-3}$ | kg | Sandin et al. | Water, ultrapure {RoW}\| market for water, ultrapure \| Cut-off, U | |
| Diethanolamine | $1.15*10^{-3}$ | kg | Sandin et al. | Diethanolamine {GLO}\| market for \| Cut-off, U | Softener, for dyeing |
| Stearic acid | $7.67*10^{-3}$ | kg | Sandin et al. | Stearic acid {GLO}\| market for stearic acid \| Cut-off, U | |
| Water, ultrapure | 0.030 | kg | Sandin et al. | Water, ultrapure {RoW}\| market for water, ultrapure \| Cut-off, U | |
| Fatty alcohol | $9.59*10^{-4}$ | kg | Sandin et al. | Fatty alcohol {GLO}\| market for \| Cut-off, U | Wetting/penetrating agent (synthetic), for dyeing |
| Maleic anhydride | $2.88*10^{-4}$ | kg | Sandin et al. | Maleic anhydride {GLO}\| market for maleic anhydride \| Cut-off, U | |
| Water, ultrapure | $6.71*10^{-4}$ | kg | Sandin et al. | Water, ultrapure {RoW}\| market for water, ultrapure \| Cut-off, U | |
| Calcium carbonate | $1.92*10^{-5}$ | kg | Sandin et al. | Calcium carbonate, precipitated {RoW}\| market for calcium carbonate, precipitated \| Cut-off, U | Reducing agent VAT, for dyeing |
| Sodium dithionite | $8.63*10^{-4}$ | kg | Sandin et al. | Sodium dithionite, anhydrous {RoW}\| market for sodium dithionite, anhydrous \| Cut-off, U | |
| Sodium sulfite | $7.67*10^{-5}$ | kg | Sandin et al. | Sodium sulfite {RoW}\| market for sodium sulfite \| Cut-off, U | |
| Water, deionised | 0.0558 | kg | Sandin et al. | Water, deionised {RoW}\| market for water, deionised \| Cut-off, U | For ironing |
| Polyester fibre | $5.47*10^{-4}$ | kg | Sandin et al. | Fibre, polyester {GLO}\| market for fibre, polyester \| Cut-off, U | Proxy for sewing thread |

| | | | | | |
|---|---|---|---|---|---|
| Confectioning template | $7.83*10^{-3}$ | kg | Sandin et al. | Kraft paper {RoW}\| market for kraft paper \| Cut-off, U | |
| Corrugated board box | $3.13*10^{-3}$ | kg | Sandin et al. | Corrugated board box {RoW}\| market for corrugated board box \| Cut-off, U | Packaging |
| Packaging film, LDPE | 0.094 | kg | Sandin et al. | Packaging film, low density polyethylene {GLO}\| market for \| Cut-off, U | Packaging |
| Electricity, medium voltage (BD) | 0.358 | kWh | Sandin et al. | Electricity, medium voltage {BD}\| market for electricity, medium voltage \| Cut-off, U | Electricity for melt spinning of polyester, spinning of polyester and cotton yarn, weaving, dyeing, drying and confectioning.<br>Electricity mix based on the seven biggest contributors to Swedish clothing imports in 2013-2017 (Eurostat), excluding Turkey[84]:<br>-Bangladesh: 20%<br>-China: 63%<br>-Cambodia: 3%<br>-Pakistan: 3%<br>-Vietnam: 3%<br>-India: 7% |
| Electricity, medium voltage (CN) | 1.130 | kWh | Sandin et al. | Electricity, medium voltage {CN}\| market group for \| Cut-off, U | |
| Electricity, medium voltage (KH) | 0.054 | kWh | Sandin et al. | Electricity, medium voltage {KH}\| market for electricity, medium voltage \| Cut-off, U | |
| Electricity, medium voltage (PK) | 0.054 | kWh | Sandin et al. | Electricity, medium voltage {PK}\| market for electricity, medium voltage \| Cut-off, U | |
| Electricity, medium voltage (VN) | 0.054 | kWh | Sandin et al. | Electricity, medium voltage {VN}\| market for electricity, medium voltage \| Cut-off, U | |
| Electricity, medium voltage (IN) | 0.126 | kWh | Sandin et al. | Electricity, medium voltage {IN}\| market group for electricity, medium voltage \| Cut-off, U | |
| Heat, central or small-scale, other than natural gas | 7.72 | MJ | Sandin et al. | Heat, central or small-scale, other than natural gas {RoW}\| heat production, light fuel oil, at boiler 100kW, non-modulating \| Cut-off, U | For melt spinning, dyeing and drying |
| Heat, central or small-scale, natural gas | 0.011 | MJ | Sandin et al. | Heat, central or small-scale, natural gas {GLO}\| market group for \| Cut-off, U | For confectioning |
| Output flows | | | | | |
| Flow | | Unit | Data source | Record | Comment |
| Dimethyl terephthalate | $1.92*10^{-6}$ | kg | Sandin et al. | Terephthalate, dimethyl | Emission to air from melt spinning |
| Treatment of polyethylene production waste | 0.043 | kg | Sandin et al. | Waste polyethylene {RoW}\| treatment of waste polyethylene, municipal incineration \| Cut-off, U | Incineration of polyester waste from yarn spinning, weaving and confectioning (no energy recovery) |
| Wastewater treatment from textile production | $8.63*10^{-3}$ | $m^3$ | Sandin et al. | Wastewater from textile production {GLO}\| market for wastewater from textile production \| Cut-off, U | Water from dyeing |
| Sludge treatment from dyeing | 0.096 | kg | Sandin et al. | Sludge from pulp and paper production {CH}\| treatment of, sanitary landfill \| Cut-off, U | Sludge from dyeing |
| 2. Transport of new t-shirt (C grade) to point of sale | | | | | |
| Flow | Amount | Unit | Data source | Record | Comment |
| Transport over sea | 1.78 | tkm | Estimation | Transport, freight, sea, container ship {GLO}\| transport, freight, sea, container ship \| Cut-off, U | Assumptions: transport between Shanghai and Gwadar port (Pakistan), loss in distribution phase of 1% |

84 It was assumed that production was done in Asia.

| | | | | | |
|---|---|---|---|---|---|
| Transport over road – lorry >32 tonne | 0.31 | tkm | Estimation | Transport, freight, lorry >32 metric ton, euro3 {RoW}\| market for transport, freight, lorry >32 metric ton, EURO3 \| Cut-off, U | Assumptions: Gwadar port to capital Islamabad, loss in distribution phase of 1% |

# ANNEX 3 – TRANSPORT ASSUMPTIONS

We have selected three ranges and levels for transport from the EU: Short, medium and long.

**Short distance:**

- For the short distance, which corresponds to transport within the EU, see Assumptions for recycling in Europe in the bottom of this annex

**Medium and long distance:**

- We have based the chosen destinations on the Top 10 importing countries of EU textiles, according to the UN Comtrade database. Amongst these, there are no South American countries, and this continent is therefore not represented
- The mode of transport is identified based on input from sorters, as well as publicly available information on typical transformation (https://www.searates.com/services/distances-time/)
- The starting point has been taken based on the main exporting countries in the EU: Germany, the Netherlands, Belgium, Italy and Poland. Of these, Germany mainly exports to other EU Countries, which then exports outside of the EU. Germany is therefore not included in the overview
- To find the transport distances, we have searched for the distance between each European country, to each of the receiving countries. This then gives both on-land and sea transportation. Although the starting and end point in each country is the middle of the country, and not a specific city or port (due to the data from searates.com), this approach then includes a proxy for the likely land transport included
- The average is calculated for each **receiving country**, meaning the average truck and boat transport from the different EU hubs. As the EU countries are closer geographically to each other, the combined average distance from all the EU countries to the receiving countries (with the exception of Italy to Tunisia, which has a different (shorter) route than the other EU hubs), are rather equal
- When making the average of truck and boat into one scale of medium and long transport, the basis has been the boat distance, as this is the one that changes the most and is the mean of transport for the large majority of the transport
- This gave 9 boat averages, which were then divided into 2 levels. The average of the specific distances of each level was then calculated, giving both a range and an average. The range can be used in the report to give readers the opportunity to use the rapport for their specific situation, whereas the average is calculated to allow for the LCA calculations.

**Documentation of method:**

- Collection of numbers for each country from four EU hubs, from (https://www.searates.com/services/distances-time/)

| | | | Africa | | | | | Asia | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Tunisia | Ghana | Cameroon | Togo | Nigeria | Pakistan | UAE | India | Turkey |
| Europe | The Netherlands | Truck | 55.63 km | 55.63 km | 55.63 km | 55.63 km | 55.63 km | 55.63 km | 55.63 km | 55.63 km | 55.63 km |
| | | Boat | 4489.11 km | 7379.32 km | 9137.69 km | 7551.28 km | 8323.78 km | 11401.19 km | 11580.56 km | 12106 km | 6371.54 km |
| | | Truck | 56.12 km | 407.97 km | 451.6 km | 357.45 km | 698.34 km | 627.47 km | 155.84 km | 484.37 km | 389.19 km |
| | Belgium | Truck | 71.32 km | 71.32 km | 71.32 km | 71.32 km | 71.32 km | 71.32 km | 71.32 km | 71.32 km | 71.32 km |
| | | Boat | 4353.47 km | 7243.68 km | 9003.64 km | 7415.64 km | 8186.6 km | 12792.64 km | 11444.92 km | 11970.36 km | 6235.91 km |
| | | Truck | 56.12 km | 407.97 km | 451.6 km | 357.45 km | 698.34 km | 627.47 km | 155.84 km | 484.37 km | 389.19 km |
| | Italy | Truck | 36.57 km | 36.57 km | 36.57 km | 36.57 km | 36.57 km | 36.57 km | 36.57 km | 36.57 km | 36.57 km |
| | | Boat | 908.74 km | 6906.1 km | 8666.06 km | 7078.06 km | 7850.56 km | 8974.73 km | 7627 km | 8152.45 km | 2387.38 km |
| | | Truck | 56.12 km | 407.97 km | 451.6 km | 357.45 km | 698.34 km | 627.47 km | 155.84 km | 484.37 km | 389.19 km |
| | Poland | Truck | 174.13 km | 174.13 km | 174.13 km | 174.13 km | 174.13 km | 174.13 km | 174.13 km | 174.13 km | 174.13 km |
| | | Boat | 6092.57 km | 8982.78 km | 10740.47 | 9154.74 km | 9927.24 km | 14531.74 km | 13184.02 km | 13709.46 km | 7975.01 km |
| | | Truck | 56.12 km | 407.97 km | 451.6 km | 357.45 km | 698.34 km | 627.47 km | 155.84 km | 484.37 km | 389.19 km |

- Calculation of combined transport to each receiving country, for both truck and boat, then calculation of the average of truck and boat transportation for each receiving country.

| | | | Africa | | | | | Asia | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Tunisia | Ghana | Cameroon | Togo | Nigeria | Pakistan | UAE | India | Turkey |
| Europe | The Netherlands | Truck | 55,63 | 55,63 | 55,63 | 55,63 | 55,63 | 55,63 | 55,63 | 55,63 | 55,63 |
| | | Boat | 4489,11 | 7379,32 | 9137,69 | 7551,28 | 8323,78 | 11401,19 | 11580,56 | 12106,00 | 6371,54 |
| | | Truck | 56,12 | 407,97 | 451,60 | 357,45 | 698,34 | 627,47 | 155,84 | 484,37 | 389,19 |
| | Belgium | Truck | 71,32 | 71,32 | 71,32 | 71,32 | 71,32 | 71,32 | 71,32 | 71,32 | 71,32 |
| | | Boat | 4353,47 | 7243,68 | 9003,64 | 7415,64 | 8186,60 | 12792,64 | 11444,92 | 11970,36 | 6235,91 |
| | | Truck | 56,12 | 407,97 | 451,60 | 357,45 | 698,34 | 627,47 | 155,84 | 484,37 | 389,19 |
| | Italy | Truck | 36,57 | 36,57 | 36,57 | 36,57 | 36,57 | 36,57 | 36,57 | 36,57 | 36,57 |
| | | Boat | 908,74 | 6906,10 | 8666,06 | 7078,06 | 7850,56 | 8974,73 | 7627,00 | 8152,45 | 2387,38 |
| | | Truck | 56,12 | 407,97 | 451,60 | 357,45 | 698,34 | 627,47 | 155,84 | 484,37 | 389,19 |
| | Poland | Truck | 174,13 | 174,13 | 174,13 | 174,13 | 174,13 | 174,13 | 174,13 | 174,13 | 174,13 |
| | | Boat | 6092,57 | 8982,78 | 10740,47 | 9154,74 | 9927,24 | 14531,74 | 13184,02 | 13709,46 | 7975,01 |
| | | Truck | 56,12 | 407,97 | 451,60 | 357,45 | 698,34 | 627,47 | 155,84 | 484,37 | 389,19 |
| | Combined from EU | Truck | 562,13 | 1969,53 | 2144,05 | 1767,45 | 3131,01 | 2847,53 | 961,01 | 2275,13 | 1894,41 |
| | | Boat | 15843,89 | 30511,88 | 37547,86 | 31199,72 | 34288,18 | 47700,30 | 43836,50 | 45938,27 | 22969,84 |
| | Average from EU | Truck | 140,53 | 492,38 | 536,01 | 441,86 | 782,75 | 711,88 | 240,25 | 568,78 | 473,60 |
| | | Boat | 3960,97 | 7627,97 | 9386,97 | 7799,93 | 8572,05 | 11925,08 | 10959,13 | 11484,57 | 5742,46 |

- Sorting of the average transport distances, according to boat, and identification of two levels (for the majority, the truck transport follows the boat distance, meaning that longer boat travel correlates with longer truck travel). The third, shortest transport, is for transport within Europe, which does not include boat, and is based on assumptions of intra-EU transport.

| Truck | Boat |
|---|---|
| 140,5325 | 3960,97 |
| 711,8825 | 5742,46 |
| 473,6025 | 7627,97 |
| 441,8625 | 7799,93 |
| 782,7525 | 8572,05 |
| 492,3825 | 9386,97 |
| 240,2525 | 10959,13 |
| 568,7825 | 11484,57 |
| 536,0125 | 11925,08 |

| Truck | Boat |
|---|---|
| 140,5325 | 3960,97 |
| 711,8825 | 5742,46 |
| 473,6025 | 7627,97 |
| 441,8625 | 7799,93 |
| 782,7525 | 8572,05 |
| 492,3825 | 9386,97 |
| 240,2525 | 10959,13 |
| 568,7825 | 11484,57 |
| 536,0125 | 11925,08 |

- Definition of the average transport, in km, including both truck and boat for the three identified levels:

| | Short | Medium | Long |
|---|---|---|---|
| | Europe: Crème | Sub-Saharan: B Grade | Asia: C grade |
| Truck | 1150 | 441.97 | 524.04 |
| Boat | x | 6282.83 | 10465.56 |

**Assumptions for recycling in Europe:**

For recycling within Europe, it is assumed that the clothes go from the west, where they are collected, to sorters in the east, and then back to the west for recycling. This is based on interviews with sorters that state that most sorting happens in the east, and a report on recycling in Europe which shows that most recycling happens in the west.

The transport was therefore calculated on the centre of the West (centre of France) to the centre of the East (South of Poland), and back to the West: **1152.79 km.**