



MWool[®]

by MANTECO

LIFE CYCLE ASSESSMENT

Textile industries are in the spotlight due to the heavy environmental impacts along their products' life cycle and, at the same time, a priority sector in the new circular economy action plan of the European Commission. A key strategy to reduce impacts and increase circularity is recycling of pre- and post-consumer textile waste for the production of new garments. Unfortunately, around 87% of globally discarded textiles are landfilled, even though more than 90% are reusable and recyclable.

In this framework, Manteco SpA has successfully developed an innovative value chain based on recycling of both pre-consumer waste wool, coming from spinning and garment-making processes, and post-consumer, discarded clothes. The output of such a recycling route is a secondary wool fibre named M Wool[®], which is used in Manteco's high-standard products.

This report is the first step of a broader research project and focuses on the Life Cycle Assessment (LCA) of the M Wool[®] fibres. The LCA of virgin wool fibres, mostly based on the latest scientific literature outcomes, is used as a reference to compare the environmental impacts of virgin and recycled wool fibres. The complexity of the recycling route, and in turn the environmental impacts associated to collecting, processing and transporting waste wool throughout continents, are captured in a fairly comprehensive LCA model based on industry data and transparent assumptions to fill data gaps. No relevant elements of the lifecycle are left out of the assessment.

Despite the long transportation routes and several manual or mechanical processes, including use of chemicals, wastewater treatment etc., the LCA results clearly show that **M Wool[®] has significantly lower environmental impacts in comparison to virgin wool fibres. For all the lifecycle indicators used in the assessment, the environmental impacts of M Wool[®] is less than 10% of the virgin counterpart, and less than 1% of the carbon footprint, particulate matter, acidification, terrestrial and freshwater eutrophication, freshwater ecotoxicity, land use, water use.**

With emphasis on climate change, 1 kg of M Wool[®] corresponds to 0,62 kg CO₂ eq., most of which coming from transportation. For comparison, virgin wool fibres have a carbon footprint of 75,8 kg CO₂ eq./kg, where the main contributor are the farming activities for the production of the greasy wool. In fact, according to the recent scientific literature, the carbon footprint of greasy wool is in the range of 20-60 kg CO₂ eq./kg, and 1,4 kg of greasy wool are needed to produce 1 kg of wool fibre. Further calculations have been carried out using the lowest and highest values of the above range, showing that the impact of the virgin wool fibre could range from 33,2 to 89,1 kg CO₂ eq.

An analysis has been carried out to evaluate how the impacts of M Wool[®] would change when considering input data in the upper or lower range: 100% pre- or 100% post-consumer waste, and inclusion/exclusion of fraying and spinning, which are sometimes unnecessary. M Wool[®] from spinning waste (which doesn't require further treatments) shows the best performance, while M Wool[®] from shredded post-consumer waste shows the worst performance. Although preliminary, as climate change is concerned, even in the worst case operational conditions, the carbon footprint of M Wool[®] results significantly lower than the carbon footprint of virgin wool fibres in their best scenario.



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1 Introduction

Life cycle assessment on MWool® fibres

1 Introduction

Textiles are considered a significant contributor to environmental impacts, from the production of raw materials to the garment manufacturing, use and disposal phases¹. A recent study² emphasises that around 87% of globally discarded textiles are landfilled, even though more than 90% are reusable and recyclable. Wool fibres can be obtained both from virgin and recycled wool. Virgin wool fibres are produced through a value chain which starts from the agricultural phase of sheep breeding for obtaining the 'greasy' wool on farm, which is then cleaned and dyed. Wool fibres can also be obtained from recycling of pre-consumer wool waste from the spinning and tailoring processes and post-consumer wool of discarded garments. **Recycling can significantly contribute to decrease textile waste and the related environmental consequences. At the same time, recycling of wool can also alleviate, at least partially, the environmental pressure of the agricultural phase of sheep breeding and, in most cases, the dyeing of wool fibres.** Manteco SpA is an Italian company that has successfully developed an innovative value chain based on recycling on both pre-consumer waste wool, coming from spinning and tailoring processes, and post-consumer discarded clothes. The output of such a recycling route is a secondary wool fibre, named M Wool[®], which is mainly used in Manteco's high-standard fabrics. This report is the first step of a broader research project funded by Manteco and focuses on the Life Cycle Assessment (LCA) of the M Wool[®] fibres. The LCA of virgin wool fibres, mostly based on the latest scientific literature outcome is used as a reference to compare the environmental impacts of virgin and recycled wool fibres. The starting point is a previous streamlined LCA of Manteco, which has been fine-tuned with additional information and industry data on the M Wool[®] collection network and processing chain. Paragraphs 2 and 3 detail the data collection (life cycle inventory) respectively for the M Wool[®] and virgin wool fibres, paragraph 4 shows the environmental impacts and the comparison between the two fibres, paragraph 5 summarises the conclusions.



This study has been issued as a scientific article on MDPI Resources



Our LCA of M Wool[®] Wool Fibers was selected as the cover of Issue 5, Volume 11, 2022.



This low impacts of M Wool[®] yarns were certified through the EDP[®] scheme.



1 Wiedemann, S.G.; Biggs, L.; Nebel, B.; Bauch, K.; Laitala, K.; Klepp, I.G.; Swan, P.G.; Watson, K. Environmental impacts associated with the production, use, and end-of-life of a woollen garment. *Int. J. Life Cycle Assess.* 2020, 25, 1486–1499, doi:10.1007/s11367-020-01766-0.

2 Moazzem, S.; Wang, L.; Daver, F.; Crossin, E. Environmental impact of discarded apparel landfilling and recycling. *Resour. Conserv. Recycl.* 2021, 166, 105338, doi:https://doi.org/10.1016/j.resconrec.2020.105338.



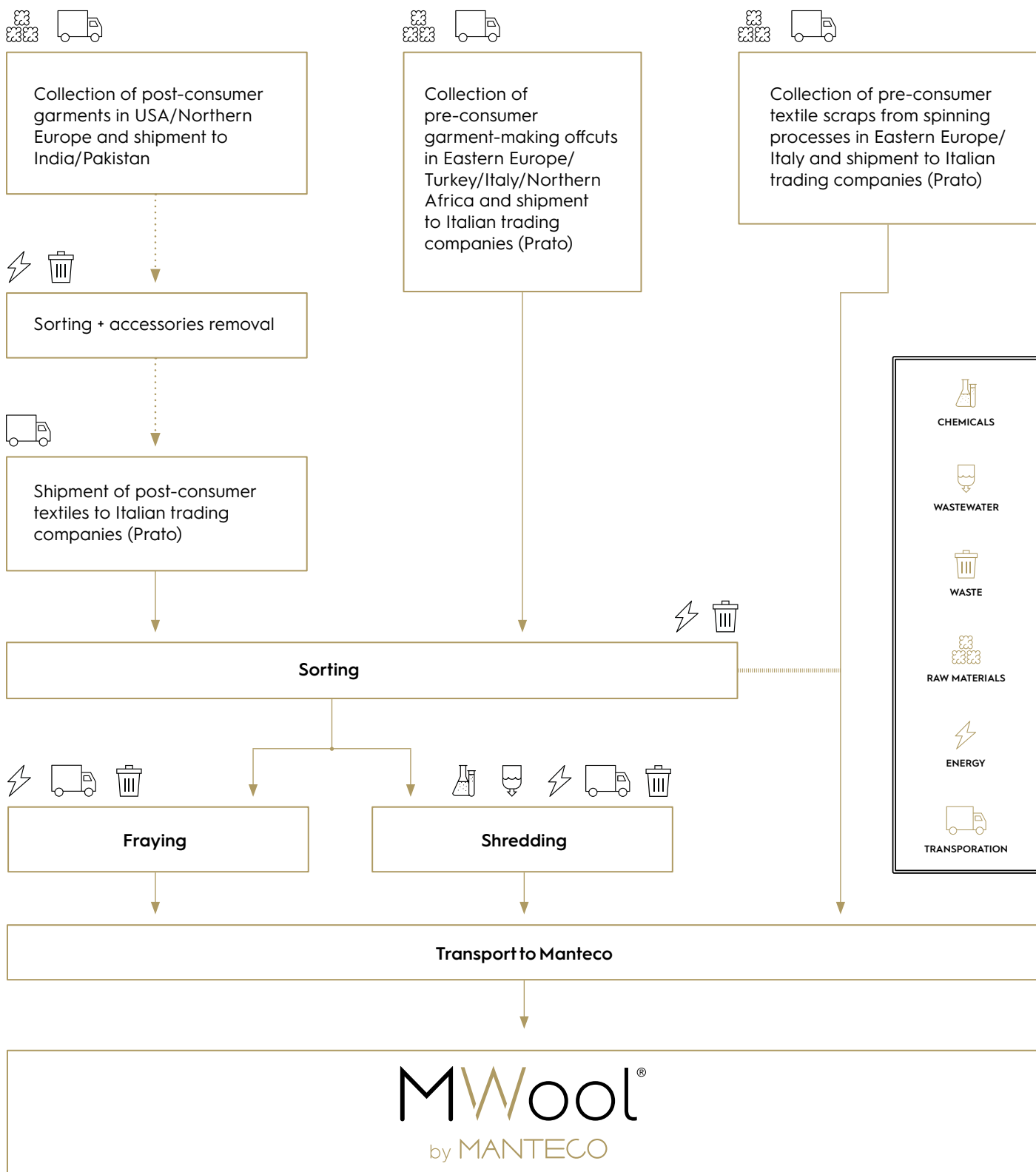
2 Life cycle inventory for the production of M Wool[®] fibres

Life cycle assessment on M Wool[®] fibres

2 Life cycle inventory for the production of M Wool® fibres

This paragraph describes and quantifies the inventory for the M Wool® fibres, as well as the assumptions considered in the study. The flow chart in Figure 1 shows the system boundaries, i.e. the processes / steps included in the assessment. Each process of the value chain is hereafter detailed.

Figure 1. System boundaries of the LCA study on M Wool®



2.1 Collection of post-consumer garments in usa/northern europe and shipment to india/pakistan

Post-consumer garments are collected in USA and Northern Europe, where end-of-life clothes are deposited in dedicated containers, and/or in plastic bags. Subsequently, they are transported to a collection centre, where clothes are gathered, packed into big bales and sent to India or Pakistan. For this phase the following assumptions have been made:

- Discarded clothes are packed by the final user into PE plastic bags containing 5 kg of clothes;
- 50% of discarded clothes is collected in USA and 50% in North Europe;
- The location of reference for the clothes collection in USA is Dalton (textile area¹);
- The location of reference for the clothes collection in North Europe is Amsterdam (highly sensitive to recycling²);
- A 100 km distance with a small lorry is assumed to pick clothes from the containers and transport them to the collection centre;
- Big bales of HDPE are assumed to contain 400 kg of used clothes³ ;
- Of the total amount of collected clothes, 85% is sent to India and 15% to Pakistan;
- The location of reference for clothes sorting in India is Ahmedabad (textile area⁴)
- The location of reference for clothes sorting in Pakistan is Faisalabad (large textile industry⁵)

1 <https://www.industryselect.com/blog/10-largest-textile-mills-in-the-us>

2 <https://www.iamsterdam.com/en/living/settling-in/waste-and-recycling/recycling-in-amsterdam>

3 <https://www.usedclothingstock.com/>

4 https://en.wikipedia.org/wiki/Ahmedabad_textile_industry

5 Iqbal, H.; Mushtaq, A.Q.; Khan, R. Cotton Processing and Spinning Industry in Pakistan: A Case Study of Lyallpur City. 2018.

Starting from these assumptions, the table here below summarises the inventory data.

Table 1. Inventory for the phase of collection of post-consumer garments in USA/Northern Europe and shipment to India/Pakistan

| FLOW | QUANTITY | UNIT OF MEASURE | ECOINVENT DATASET | NOTES |
|---|-----------------|------------------------|--|---|
| <i>OUTPUT</i> | | | | |
| Post-consumer garments, at sorting centre (India/Pakistan) | 1 | t | | |
| <i>INPUT</i> | | | | |
| Plastic bag | 1,6 | kg | <i>Packaging film, low density polyethylene {GLO} market for Cut-off, S</i> | <i>LDPE, 8 g/bag</i> |
| Transport with small lorry | 100 | tkm | <i>Transport, freight, light commercial vehicle {Europe without Switzerland} market for transport, freight, light commercial vehicle Cut-off, S</i> | <i>From containers to collection centre</i> |
| Big bales | 1,1 | kg | <i>Polyethylene, high density, granulate {GLO} market for Cut-off, S + Extrusion, plastic film {GLO} market for Cut-off, S</i> | <i>HDPE, 432 g/bag (width: 0,1 mm, surface: 4,6 m², density: 940 kg/m²)</i> |
| Transport with 16-32 t lorry | 53 | tkm | <i>Transport, freight, lorry 16-32 metric ton, euro5 {RoW} market for transport, freight, lorry 16-32 metric ton, EURO5 Cut-off, S</i> | <i>Average transport from USA/north Europe to India/Pakistan</i> |
| Transport with transoceanic ship | 14456 | tkm | <i>Transport, freight, sea, container ship {GLO} transport, freight, sea, container ship Cut-off, S</i> | <i>Average transport from USA/north Europe to India/Pakistan</i> |
| Waste: plastic | 2,7 | kg | <i>Waste plastic, mixture {RoW} treatment of waste plastic, mixture, municipal incineration Cut-off, S</i> | |

2.2 Sorting and accessories removal of post-consumer garments

In India/Pakistan textiles are manually sorted, according to the type of material, and accessories/components (such as zips, buttons, labels, liners, linings) are removed. Subsequently, textiles are packed into big plastic bales (which are assumed to contain 400 kg of textile). The process of clothes sorting and accessories removal is manual, and just electricity for working environments is considered, assuming the consumption of 11 kWh/t of sorted textiles. This consumption has been estimated considering a throughput per person of 100 tonnes/year¹, assuming 25 people working in a 60x30 m² environment, for a consumption of electricity for lightening of 15 kWh/m²y².

Table 2. Inventory for the phase of sorting and accessories removal of post-consumer garments

| FLOW | QUANTITY | UNIT OF MEASURE | ECOINVENT DATASET | NOTES |
|---|--------------|-----------------|--|--|
| <i>OUTPUT</i> | | | | |
| Post-consumer textile, accessories removed | 1 | t | | |
| <i>INPUT</i> | | | | |
| Post-consumer garments, at the sorting centre | 1 | t | | |
| Electricity in Pakistan | 11*0,15=1,65 | kWh | <i>Electricity, low voltage {PK} market for electricity, low voltage Cut-off, S</i> | 15% of post-consumer garments are sorted in Pakistan |
| Electricity in India | 11*0,85=9,35 | kWh | <i>Electricity, low voltage {IN-Western grid} market for electricity, low voltage Cut-off, S</i> | 85% of post-consumer garments are sorted in India |
| Big bales | 1,1 | kg | <i>Polyethylene, high density, granulate {GLO} market for Cut-off, S + Extrusion, plastic film {GLO} market for Cut-off, S</i> | HDPE, 432 g/bag (width: 0,1 mm, surface: 4,6 m ² , density: 940 kg/m ²) |

¹ Humpston, G.; Willis, P.; Tyler, D.; Han, S. Technologies for sorting end of life textiles 2014.

² Carletti, C.; Cellai, G.; Pierangioli, L.; Scurpi, F.; Secchi, S. The influence of daylighting in buildings with parameters nZEB: application to the case study for an office in Tuscany Mediterranean area. Energy Procedia 2017, 140, 339–350.

2.3 Shipment of post-consumer textiles to Italy

Post-consumer textile after accessories removal in India/Pakistan are sent to Italian trading companies (located in Prato). The total amount of post-consumer textile, with reference to year 2019, is of 962626 kg, assumed 50% coming from India and 50% coming from Pakistan.

Table 3. Inventory for the shipment of post-consumer textiles to Italy

| FLOW | QUANTITY | UNIT OF MEASURE | ECOINVENT DATASET | NOTES |
|---|--------------|-----------------|--|--|
| <i>OUTPUT</i> | | | | |
| Post-consumer textile, at Italian trading company (Prato) | 1 | t | | |
| <i>INPUT</i> | | | | |
| Post-consumer textile, accessories removed | 1 | t | | |
| Transport with >32 t lorry | 201 | tkm | Transport, freight, lorry >32 metric ton, euro5 {RoW} market for transport, freight, lorry >32 metric ton, EURO5 Cut-off, S | Average transport from India/Pakistan to Manteco SpA |
| Transport with transoceanic ship | 11*0,85=9,35 | kWh | Transport, freight, sea, container ship {GLO} transport, freight, sea, container ship Cut-off, S | Average transport from India/Pakistan to Manteco SpA |

2.4 Shipment of pre-consumer textiles to Italy

Pre-consumer textile waste are produced before textiles reach final consumers. It includes waste from the spinning process and the tailoring phase (fabric leftover after cutting out a pattern or textiles presenting some flaws, for example). Pre-consumer textile from tailoring is sent to Italian trading companies (located in Prato), where it is sorted and treated (as detailed in paragraphs 5 and 6), while pre-consumer textile from spinning can be also sent directly to Manteco SpA, since it doesn't require further treatments. The table here below gives details on quantities and source of pre-consumer textiles used by Manteco SpA, referred to the year 2019, considered representative of an average year of production.

Table 4. quantities and source of pre-consumer textiles used by Manteco SpA in 2019

| | QUANTITY USED IN 2019 (kg) | RELATIVE QUANTITY AGAINST THE TOTAL PRE-CONSUMER WASTE 2019 [%] | ORIGIN |
|-----------------------------|----------------------------|---|---|
| Pre-consumer from spinning | 366111 | 68% | Eastern Europe, Italy |
| Pre-consumer from tailoring | 168674 | 32% | Eastern Europe, Turkey, Italy, North Africa |

For this phase the following assumptions have been made:

- 50% of pre-consumer textile from spinning is collected in Eastern Europe and 50% in Italy;
- 25% of pre-consumer textile from tailoring is collected in Eastern Europe, 25% in Turkey, 25% in Italy and 25% in North Africa;
- The location of reference for the pre-consumer textile waste in Eastern Europe is Bucharest (Romania);
- The location of reference for the pre-consumer textile waste in Turkey is Istanbul since in this city the textile sector is particularly active²;
- The location of reference for the pre-consumer textile waste in North Africa is Alexandria (Egypt) since in this city there is an agglomeration of spinning, weaving and garment firms³;
- A distance of 200 km is assumed for pre-consumer textile coming from Italy;
- Big bales of HDPE are assumed to contain 400 kg of used pre-consumer textile⁴.

¹ Șerbănel, C. ROMANIAN TEXTILE INDUSTRY AND ITS COMPETITIVE ADVANTAGE. 2014.

² <https://era.iturkey.com/news/textile-industry-in-turkey-in-2020/>

³ Kashiwagi, K.; Iwasaki, E. Effect of agglomeration on technical efficiency of small and medium-sized garment firms in Egypt. African Dev. Rev. 2020, 32, 14–26, doi:<https://doi.org/10.1111/1467-8268.12411>.

⁴ <https://www.usedclothingstock.com/>

Table 5. Inventory for the shipment of pre-consumer textiles in Italy

| FLOW | QUANTITY | UNIT OF MEASURE | ECOINVENT DATASET | NOTES |
|--|----------|-----------------|---|---|
| <i>OUTPUT</i> | | | | |
| Pre-consumer textile, at Italian trading company (Prato) | 1 | t | | |
| <i>INPUT</i> | | | | |
| Big bales | 1,1 | kg | <i>Polyethylene, high density, granulate {GLO} market for Cut-off, S + Extrusion, plastic film {GLO} market for Cut-off, S</i> | <i>HDPE, 432 g/bag (width: 0,1 mm, surface: 4,6 m2, density: 940 kg/m2)</i> |
| Transport with >32 t lorry | 848 | tkm | <i>Transport, freight, lorry >32 metric ton, euro5 {RoW} market for transport, freight, lorry >32 metric ton, EURO5 Cut-off, S</i> | <i>Average transport from Eastern Europe/ Turkey/Italy/ North Africa to Manteco SpA</i> |
| Transport with transoceanic ship | 1144 | tkm | <i>Transport, freight, sea, container ship {GLO} transport, freight, sea, container ship Cut-off, S</i> | <i>Average transport from Eastern Europe/ Turkey/Italy/ North Africa to Manteco SpA</i> |

2.5 Sorting

Pre-consumer textiles from tailoring and the post-consumer textiles arrive at Italian trading companies (located in Prato) in big plastic bales. Here the packaging is removed and the textile is sorted according to the type of treatment (shredding or fraying) it will be subjected to and according to the colour. This step is manual and requires time and expertise, but allow to avoid the treatment of dyeing (and the related environmental impacts). The total amount of sorted textile for year 2019 is of 1131,3 t, of which 85% of post-consumer and 15% of pre-consumer from tailoring. For this phase, the data collected by the previous study of Manteco SpA are used. The inventory is summarised in the table here below.

Table 6. Inventory for the phase of pre- and post-consumer sorting

| FLOW | QUANTITY | UNIT OF MEASURE | ECOINVENT DATASET | NOTES |
|---|-----------------------------|-----------------|--|---|
| <i>OUTPUT</i> | | | | |
| Textile sorted, at Italian trading company (Prato) | 1 | t | | |
| <i>INPUT</i> | | | | |
| Post-consumer textile, at Italian trading company (Prato) | $1,03 \cdot 0,85 = 0,876$ t | t | | |
| Pre-consumer textile, at Italian trading company (Prato) | $1,03 \cdot 0,15 = 0,155$ | t | | |
| Electricity | 42,11 | kWh | <i>Electricity, medium voltage {IT} market for I Cut-off, S</i> | |
| Natural gas | 42 | MJ | <i>Heat, district or industrial, natural gas {Europe without Switzerland} heat production, natural gas, at industrial furnace low-NOx >100kW I Cut-off, S</i> | $0,025 \text{ m}^3/\text{MJ}$ $1,05 \text{ m}^3 = 42 \text{ MJ}$ |
| Diesel | 168 | MJ | <i>Diesel, burned in building machine {GLO} market for I Cut-off, S</i> | $0,0243 \text{ kg}/\text{MJ} = 0,0291 \text{ l}/\text{MJ}$ $4,88 \text{ l} = 4,08 \text{ kg} = 168 \text{ MJ}$ |

| FLOW | QUANTITY | UNIT OF MEASURE | ECOINVENT DATASET | NOTES |
|---|-----------------|------------------------|--|--------------|
| Water | 0,27 | m ³ | Tap water {RER} market group for I Cut-off, S | |
| Transport with lorry | 300 | tkm | Transport, freight, lorry >32 metric ton, euro5 {RER} market for transport, freight, lorry >32 metric ton, EURO5 I Cut-off, S | >32t, Euro5 |
| Transport with transoceanic ship | 10000 | tkm | Transport, freight, sea, container ship {GLO} transport, freight, sea, container ship I Cut-off, S | |
| Waste: plastic | 1,1 | kg | Waste plastic, mixture {CH} treatment of, municipal incineration I Cut-off, S | |
| Waste: textile | 0,032 | t | Municipal solid waste {CH} treatment of, sanitary landfill I Cut-off, S | |

2.6 Treatments to obtain recycled wool fibres

After the sorting process, the pre- and post-consumer textiles are ready to be transformed into secondary wool fibres. **According to the state of the textile, it can be submitted to the processes of shredding or to the process of fraying. In addition, in some cases, waste from spinning (pre-consumer textile) are already fibres and, as a consequence, do not require any type of treatment.** The table here below indicates the absolute and relative quantities of pre- and post-consumer textiles that have been shredded/frayed/not treated with reference to year 2019.

Table 7. Absolute and relative quantities of pre- and post-consumer textiles that have been shredded/frayed/not treated in 2019

| | QUANTITY (KG) | QUANTITY (%) |
|--------------------|----------------------|---------------------|
| Shredded | 390176 | 26,1% |
| Frayed | 1055035 | 70,5% |
| Not treated | 52200 | 3,5% |
| Total | 1497411 | 100% |

2.7 Shredding

The shredding is a mechanical process that turns textiles into fibres of recycled wool. This operation is made with a machine that “opens” the fabric with teeth and blades. To reduce the resistance of the fabric while maintaining the natural elasticity of the fibres, a wetting is carried out too. Finally, fibres are dried. The inventory data for the shredding process comes from the previous LCA study of Manteco SpA. These data refer to the production year 2018 and were collected from 1 supplier, which provides around 20% of the total shredded textile used by Manteco SpA. The table here below summarizes the inventory for the shredding process.

Table 8. Inventory for the shredding process

| FLOW | QUANTITY | UNIT OF MEASURE | ECOINVENT DATASET | NOTES |
|---|----------|-----------------|--|---|
| <i>OUTPUT</i> | | | | |
| Wool fibres, from shredding process | 1 | t | | |
| <i>INPUT</i> | | | | |
| Textile sorted, at Italian trading company | 1,03 | t | | |
| Electricity | 391 | kWh | <i>Electricity, medium voltage {IT} market for I Cut-off, S</i> | |
| Natural gas | 1729 | MJ | <i>Heat, district or industrial, natural gas {Europe without Switzerland} heat production, natural gas, at industrial furnace low-NOx >100kW I Cut-off, S</i> | <i>0,025 m3/MJ 43,22 m3 = 1729 MJ</i> |
| Diesel | 141 | MJ | <i>Diesel, burned in building machine {GLO} market for I Cut-off, S</i> | <i>0,0243 kg/MJ = 0,0291 l/MJ 4,09 l = 3,42 kg = 141 MJ</i> |
| Water | 1,33 | m3 | <i>Tap water {RER} market group for I Cut-off, S</i> | <i>0,0243 kg/MJ = 0,0291 l/MJ 4,88 l = 4,08 kg = 168 MJ</i> |
| No foam agent | 3,83 | kg | <i>Silicone product {RER} market for silicone product I Cut-off, S</i> | |

| | | | | |
|-----------------------------|-------|----------------|--|----------|
| Transport with lorry | 20 | tkm | <i>Transport, freight, lorry 7.5-16 metric ton, euro5 {RER} market for transport, freight, lorry 7.5-16 metric ton, EURO5 Cut-off, S</i> | 3.5-20 t |
| Waste: textile | 25,66 | kg | <i>Municipal solid waste {CH} treatment of, sanitary landfill Cut-off, S</i> | |
| Waste: iron | 3,17 | kg | <i>Iron scrap, sorted, pressed {RER} sorting and pressing of iron scrap Cut-off, S + Avoided product: Pig iron {RoW} pig iron production Cut-off</i> | |
| Wastewater | 1,33 | m ³ | <i>Wastewater, average {Europe without Switzerland} treatment of wastewater, average, capacity 1E9l/year Cut-off, S</i> | |

2.8 Fraying

Depending on operational conditions of production requirements, instead of being sent to shredding, the pre- and post-consumer textiles can be fed to fraying. This is a mechanical dry process that reduces the textile into fibres of recycled wool. Primary data on input/output flows have been provided by 1 trading company, as detailed in the table here below.

Table 9. Inventory for the fraying process

| FLOW | QUANTITY | UNIT OF MEASURE | ECOINVENT DATASET | NOTES |
|---|-----------------|------------------------|---|--------------|
| <i>OUTPUT</i> | | | | |
| Wool fibres, from fraying process | 1 | t | | |
| <i>INPUT</i> | | | | |
| Textile sorted, at Italian trading company | 1,02 | t | | |
| Electricity | 0,19 | kWh | <i>Electricity, medium voltage {IT} market for I Cut-off, S</i> | |
| Transport with lorry | 20 | tkm | <i>Transport, freight, lorry 7.5-16 metric ton, euro5 {RER} market for transport, freight, lorry 7.5-16 metric ton, EURO5 I Cut-off, S</i> | 3.5-20 t |
| Waste: textile | 22,83 | kg | <i>Municipal solid waste {CH} treatment of, sanitary landfill I Cut-off, S</i> | |
| Waste: iron | 7,09 | kg | <i>Iron scrap, sorted, pressed {RER} sorting and pressing of iron scrap I Cut-off, S + Avoided product: Pig iron {RoW} pig iron production I Cut-off, S</i> | |

2.9 Transport of recycled wool to manteco

The fibres of recycled wool are transported with lorries from the trading companies to Manteco SpA, within an average distance of 20 km. **The recycled wool fibres take the brand M Wool® and are ready to be spun. The table here below summarises the inventory data.**

Table 10. Inventory for the transportation of recycled wool fibres to Manteco SpA

| FLOW | QUANTITY | UNIT OF MEASURE | ECOINVENT DATASET | NOTES |
|---|-----------------|------------------------|---|-----------------|
| <i>OUTPUT</i> | | | | |
| M Wool® fibres | 1 | t | | |
| <i>INPUT</i> | | | | |
| Wool fibres, from shredding process | 0,261 | t | | |
| Wool fibres, from faying process | 0,705 | kWh | <i>Electricity, medium voltage {IT} market for I Cut-off, S</i> | |
| Pre-consumer textile, at Italian trading company (Prato) | 0,035 | tkm | <i>Transport, freight, lorry 7.5-16 metric ton, euro5 {RER} market for transport, freight, lorry 7.5-16 metric ton, EURO5 I Cut-off, S</i> | <i>3.5-20 t</i> |
| Transport with lorry | 20 | tkm | <i>Municipal solid waste {CH} treatment of, sanitary landfill I Cut-off, S</i> | <i>3.5-20</i> |
| Waste: iron | 7,09 | kg | <i>Iron scrap, sorted, pressed {RER} sorting and pressing of iron scrap I Cut-off, S + Avoided product: Pig iron {RoW} pig iron production I Cut-off, S</i> | |

2.10 Wastewater treatment

GIDA (Gestione Impianti Depurazione Acque spa), located in Prato, treats wastewaters originated both from civil and industrial usage. Inventory data for the wastewater treatment are taken from the EMAS certification of GIDA, updated on the 31st March 2021. Due to the Covid pandemic period and the effects on the market, data for years 2020-2021 are not representative of an average year. For this reason the chosen year of reference is 2019, when **the total volume of treated wastewater was of 45.839.958 m³.** **Table 11 details the inventory for the treatment of 1 m³ of water.**

Table 11. Inventory for the wastewater treatment

| FLOW | QUANTITY | UNIT OF MEASURE | ECOINVENT DATASET | NOTES |
|---------------------------|-----------------------------------|------------------------|--|---|
| <i>OUTPUT</i> | | | | |
| Wastewater treated | 1 | m ³ | | |
| <i>INPUT</i> | | | | |
| Wastewater | 0,261 | m ³ | | |
| Electricity | 0,699 | kWh | <i>Electricity, medium voltage {IT} market for I Cut-off, S</i> | |
| Natural gas | 0,396 kWh = 0,041 Sm ³ | tkm | <i>Heat, district or industrial, natural gas {Europe without Switzerland} heat production, natural gas, at industrial furnace low-NOx >100kW I Cut-off, S</i> | |
| Diesel | 0,098 | MJ | <i>Diesel, burned in building machine {GLO} market for I Cut-off, S</i> | <i>0,0243 kg/MJ 0,238 g = 0,098 MJ</i> |
| Gasoline | 0,0017 | MJ | <i>Petrol, unleaded, burned in machinery {GLO} market for petrol, unleaded, burned in machinery I Cut-off, S</i> | <i>0,0221 kg/MJ 0,039 g = 0,0017 MJ</i> |
| LPG | 0,00032 | MJ | <i>Heat, central or small-scale, natural gas {GLO} propane extraction, from liquefied petroleum gas I Cut-off, S</i> | <i>0,0310 kg/MJ 0,01 g = 0,00032 MJ</i> |

| | | | | |
|------------------------------|-------|----------------|---|---------------------------------|
| Aluminium trichloride | 25,60 | g | <i>Aluminium chloride {GLO} market for aluminium chloride Cut-off, S</i> | |
| Citric acid | 0,33 | m ³ | <i>Citric acid {RER} production Cut-off, S</i> | |
| Sulfuric acid 50% | 0,43 | kWh | <i>Sulfuric acid {RER} market for sulfuric acid Cut-off, S + Tap water {RER} market group for Cut-off, S</i> | |
| Sulfuric acid 96% | 0,07 | tkm | <i>Sulfuric acid {RER} market for sulfuric acid Cut-off, S + Tap water {RER} market group for Cut-off, S</i> | |
| Hydrogen peroxide | 0,25 | MJ | <i>Hydrogen peroxide, without water, in 50% solution state {RER} hydrogen peroxide production, product in 50% solution state Cut-off, S + Tap water {RER} market group for Cut-off, S</i> | |
| No foam agent | 1,13 | MJ | <i>Silicone product {RER} market for silicone product Cut-off, S</i> | |
| Ferric chloride | 24,60 | MJ | <i>Iron (III) chloride, without water, in 40% solution state {GLO} market for Cut-off, S</i> | |
| Bleaching agent | 5,71 | g | <i>Sodium dithionite, anhydrous {RER} market for sodium dithionite, anhydrous Cut-off, S</i> | |
| Sodium hydroxide | 1,57 | g | <i>Sodium hydroxide, without water, in 50% solution state {GLO} market for Cut-off, S + Tap water {RER} market group for Cut-off, S</i> | <i>Assumption: 50% solution</i> |

| | | | | |
|---------------------------------|------|----------------|--|--|
| Sodium hypochlorite | 2,37 | g | <i>Sodium hypochlorite, without water, in 15% solution state {RER} market for sodium hypochlorite, without water, in 15% solution state Cut-off, S + Tap water {RER} market group for Cut-off, S</i> | |
| Oxygen | 0,12 | m ³ | <i>Oxygen, liquid {RER} market for Cut-off, S</i> | |
| Anionic polyelectrolyte | 1,34 | kWh | <i>Polyacrylamide {GLO} market for Cut-off, S</i> | |
| Cationic polyelectrolyte | 5,03 | tkm | <i>Polyacrylamide {GLO} market for Cut-off, S</i> | |
| Urea | 0,05 | MJ | <i>Urea {RER} market for urea Cut-off, S</i> | |



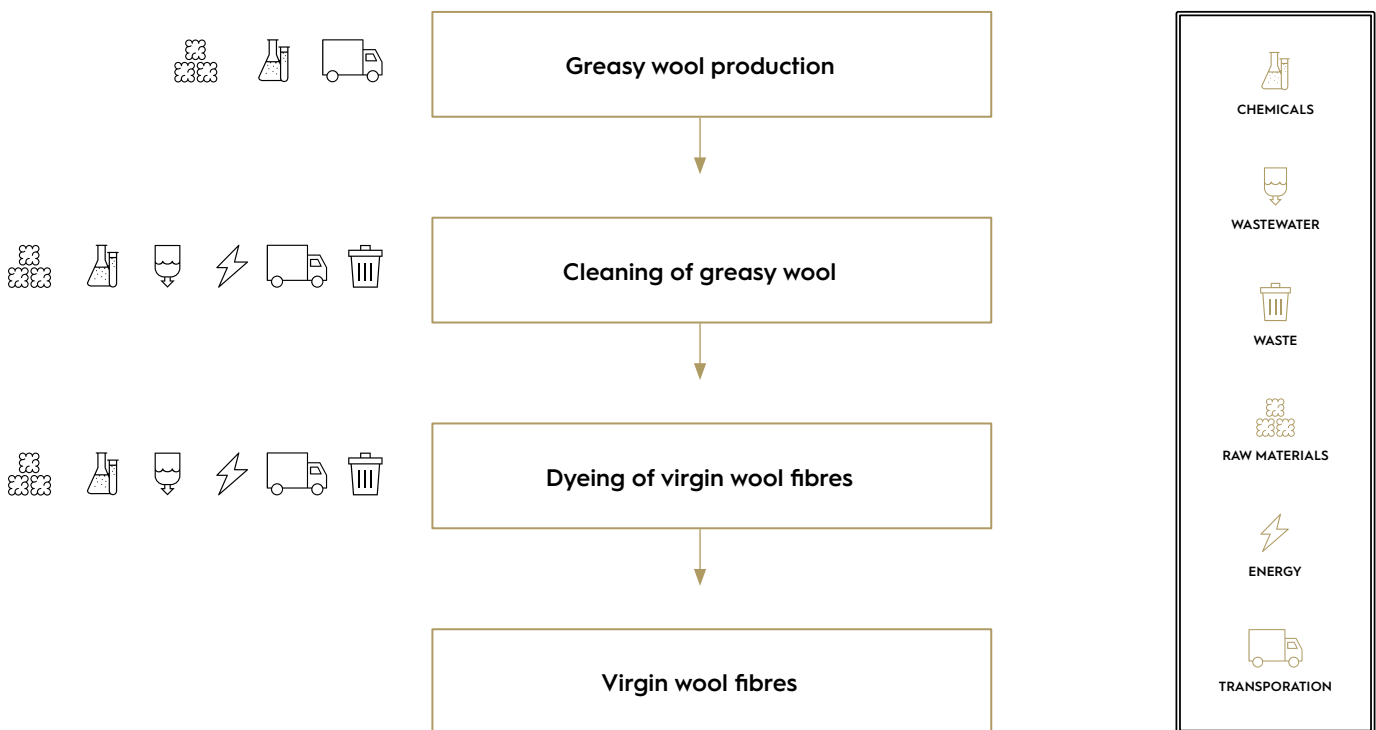
3 Life cycle inventory for the production of virgin wool fibres

Life cycle assessment on MWool® fibres

3 Life cycle inventory of virgin wool fibres

The LCI of virgin fibres has been carried out for comparison between virgin and recycled fibres. The inventory is based on the category rules for wool carded fabrics¹ developed for the national voluntary scheme named “Made Green in Italy”.² These category rules are aligned with the PEF (Product Environmental Footprint) method of the European Commission.

Figure 2. System boundaries of the LCA study on virgin wool fibres



1 Ministero della Transizione Ecologica Schema nazionale volontario «MADE GREEN IN ITALY». Regole di categoria di prodotto (RCP): tessuti in lana cardata o pelli fini cardati; 2015;

2 <https://www.mite.gov.it/pagina/made-green-italy>

Tables 12, 13 and 14 respectively summarise the inventory for the production of clean virgin wool, virgin wool short fibres and the dyeing process.

Table 12 - Inventory for the process to obtain clean wool

| FLOW | QUANTITY | UNIT OF MEASURE | ECOINVENT DATASET |
|-------------------------------------|-----------------|------------------------|---|
| <i>OUTPUT</i> | | | |
| Clean virgin wool | 1,00038 | t | |
| <i>INPUT</i> | | | |
| Electric energy | 141,90 | kJ | <i>Electricity, medium voltage {GLO} market group for Cut-off, U</i> |
| Steam | 8,69 | kg | <i>Steam, in chemical industry {RoW} production Cut-off, U</i> |
| Water | 9,18 | kg | <i>Tap water {GLO} market group for Cut-off, U</i> |
| Virgin wool in the grease | 1,398 | kg | <i>Sheep fleece in the grease {RoW} sheep production, for wool Cut-off, S</i> |
| Detergents | 6,39 | g | <i>Non-ionic surfactant {GLO} market for non-ionic surfactant Cut-off, U</i> |
| Sodium carbonate | 6,39 | g | <i>Soda ash, dense {GLO} market for Cut-off, U 50%</i> <i>Soda ash, light, crystalline, heptahydrate {GLO} market for Cut-off, U 50%</i> |
| Sulfuric acid | 0,71 | g | <i>Sulfuric acid {RoW} market for sulfuric acid Cut-off, U</i> |
| Lorry for waste collection | 19,87 | kgkm | <i>Municipal waste collection service by 21 metric ton lorry {RoW} processing Cut-off, U</i> |
| Wastewater treatment | 3,67 | kg | <i>Wastewater, average {RoW} treatment of, capacity 1E9 /year Cut-off, U</i> |
| Disposal of washing residues | 397,31 | g | <i>Municipal solid waste {RoW} treatment of, sanitary landfill Cut-off, U</i> |

Table 13 - Inventory for the process to obtain virgin wool fibers

| FLOW | QUANTITY | UNIT OF MEASURE | ECOINVENT DATASET |
|-----------------------------------|-----------------|------------------------|--|
| <i>OUTPUT</i> | | | |
| Virgin wool, short fibres | 1 | kg | |
| <i>INPUT</i> | | | |
| Clean virgin wool | 1,00038 | kg | |
| Electric energy | 16,96 | kJ | <i>Electricity, medium voltage {GLO} market group for Cut-off, U</i> |
| Steam | 4,22 | kg | <i>Steam, in chemical industry {RoW} production Cut-off, U</i> |
| Antistatic | 3,391 | kg | <i>Glycerine {RoW} market for glycerine Cut-off, U 21%</i> <i>Ethoxylated alcohol (AE>20, AE11, ae3, ae7) {GLO, RoW} market for ethoxylated alcohol (AE>20) Cut-off, U 12%</i> |
| Grease 1 | 1,696 | kg | <i>Glycerine {RoW} market for glycerine Cut-off, U 16,5%</i> <i>Ethoxylated alcohol (AE>20, AE11, ae3, ae7) {GLO, RoW} market for ethoxylated alcohol (AE>20) Cut-off, U 12%</i> <i>Benzene {GLO} market for Cut-off, U 8%</i> |
| Grease 2 | 1,696 | g | <i>Glycerine {RoW} market for glycerine Cut-off, U 32,5%</i> <i>Ethoxylated alcohol (AE>20, AE11, ae3, ae7) {GLO, RoW} market for ethoxylated alcohol (AE>20) Cut-off, U 22,5%</i> <i>Benzene {GLO} market for Cut-off, U 19,5%</i> |
| Grease 3 | 1,696 | g | <i>Benzene {GLO} market for Cut-off, U 42%</i> <i>Ethoxylated alcohol (AE>20, AE11, ae3, ae7) {GLO, RoW} market for ethoxylated alcohol (AE>20) Cut-off, U 11,5%</i> <i>Chemical, organic {GLO} market for Cut-off, U 10,5%</i> |
| Film PE | 11,98 | g | <i>Packaging film, low density polyethylene {GLO} market for Cut-off, U</i> |
| Iron | 3,99 | g | <i>Steel, low-alloyed {GLO} market for Cut-off, U</i> <i>Wire drawing, steel {RER, RoW} processing Cut-off, U</i> |
| Lorry for waste collection | 0,21 | kgkm | <i>Municipal waste collection service by 21 metric ton lorry {RoW} processing Cut-off, U</i> |

| | | | |
|-----------------------------|----------|------|--|
| Transport with ship | 21999,62 | kgkm | <i>Transport, freight, sea, container ship {GLO} transport, freight, sea, container ship Cut-off, U</i> |
| Transport with lorry | 698,85 | kgkm | <i>Transport, freight, lorry >32 metric ton, EURO4 {RoW} transport, freight, lorry >32 metric ton, EURO4 Cut-off, U</i> |
| Disposal of residues | 4,24 | g | <i>Municipal solid waste {RoW} treatment of, sanitary landfill Cut-off, U</i> |

Table 14 - Inventory for the fibre dyeing process

| FLOW | QUANTITY | UNIT OF MEASURE | ECOINVENT DATASET |
|--------------------------------------|-----------------|------------------------|--|
| <i>OUTPUT</i> | | | |
| Dyeing wool fibres | 1 | kg | |
| Emission: CO | 97,897 | mg | <i>Carbon monoxide</i> |
| Emission: NOx | 768,901 | mg | <i>Nitrogen oxides, IT</i> |
| Avoided product: sulfate pulp | 2,865 | g | <i>Sulfate pulp, unbleached {RER} sulfate pulp production, from softwood, unbleached Cut-off, U</i> |
| Avoided product: | 11,365 | g | <i>Pig iron {RoW} pig iron production Cut-off, U</i> |
| <i>INPUT</i> | | | |
| Electric energy | 1,271 | kJ | <i>Residual Mix_Electricity, medium voltage {IT} market for Cut-off, U</i> |
| Thermal energy | 329,293 | l | <i>Heat, district or industrial, natural gas {Europe without Switzerland} heat production, natural gas, at boiler modulating >100kW Cut-off, U 50% Heat, district or industrial, natural gas {Europe without Switzerland} heat production, natural gas, at boiler condensing modulating >100kW Cut-off, U 50%i</i> |
| Water | 35,414 | l | <i>Tap water {RER} market group for Cut-off, U</i> |
| Acetic acid | 9,157 | g | <i>Acetic acid, without water, in 98% solution state {GLO} market for Cut-off, U</i> |
| Formic acid | 6,680 | g | <i>Formic acid {RER, RoW} market for Cut-off, U</i> |

| | | | |
|--|---------|----|--|
| Sulfuric acid | 1,920 | g | <i>Sulfuric acid {RER, RoW} market for sulfuric acid Cut-off, U</i> |
| Ammonia 18% | 3,485 | g | <i>Sodium hypochlorite, without water, in 15% solution state {RER, RoW} market for sodium hypochlorite, without water, in 15% solution state Cut-off, U</i> |
| Ammonia 24.5% | 1,729 | mg | <i>Sodium hypochlorite, without water, in 15% solution state {RER, RoW} market for sodium hypochlorite, without water, in 15% solution state Cut-off, U</i> |
| Ammonium sulfate | 1,641 | g | <i>Ammonium sulfate, as N {GLO} market for Cut-off, U</i> |
| Detergent | 46,479 | mg | <i>Ethoxylated alcohol (AE>20, AE11, ae3, ae7) {GLO, RoW} market for ethoxylated alcohol (AE>20) Cut-off, U (5%) Chemical, organic {GLO} market for Cut-off, U (10%)</i> |
| Reducing and whitening agent | 265,586 | mg | <i>Sodium dithionite, anhydrous {RER, RoW} market for sodium dithionite, anhydrous Cut-off, U 45% Sodium nitrite {RER, RoW} market for sodium nitrite Cut-off, U 5% Chemical, inorganic {GLO} market for chemicals, inorganic Cut-off, U 2%</i> |
| Detergent | 804,563 | mg | <i>Ethoxylated alcohol (AE>20, AE11, ae3, ae7) {GLO, RoW} market for ethoxylated alcohol (AE>20) Cut-off, U 35% Fatty acid {GLO} market for Cut-off, U 35% 2-methyl-2-butanol {GLO} market for Cut-off, U 30%</i> |
| Sodium carbonate (SOLVAY) | 3,022 | g | <i>Sodium bicarbonate {GLO} market for sodium bicarbonate Cut-off, U</i> |
| Auxiliary for oil-repellent finishing | 79,868 | mg | <i>3-methyl-1-butanol {GLO} market for Cut-off, U 3% Ethoxylated alcohol (AE>20, AE11, ae3, ae7) {GLO, RoW} market for ethoxylated alcohol (AE>20) Cut-off, U 3% Chemical, organic {GLO} market for Cut-off, U 0,003%</i> |
| Auxiliary for dyeing | 1,279 | g | <i>Ammonium chloride {GLO} market for Cut-off, U 10% Ethylamine {GLO} market for Cut-off, U 10% Diethylene glycol {GLO} market for Cut-off, U 5%</i> |

| | | | |
|----------------------------------|---------|----|--|
| Leveling agent | 5,958 | g | <i>Ethoxylated alcohol (AE>20, AE11, ae3, ae7) {GLO, RoW} market for ethoxylated alcohol (AE>20) Cut-off, U 10% Alkyl sulphate (C12-14) {GLO} market for alkyl sulphate (C12-14) Cut-off, U 5% Diethylene glycol {GLO} market for Cut-off, U 3%</i> |
| Softener | 338,095 | mg | <i>Chemical, organic {GLO} market for Cut-off, U 10% Polydimethylsiloxane {GLO} market for polydimethylsiloxane Cut-off, U 5% Potassium hydroxide {GLO} market for Cut-off, U 0,2%</i> |
| Anti-reducing agent | 362,298 | mg | <i>Alkylbenzene sulfonate, linear, petrochemical {GLO} market for Cut-off, U</i> |
| Hydrogen peroxide | 838,940 | mg | <i>Hydrogen peroxide, without water, in 50% solution state {RER, RoW} market for hydrogen peroxide, without water, in 50% solution state Cut-off, U</i> |
| Sodium dichromate | 417,618 | mg | <i>Sodium dichromate {GLO} market for Cut-off, U</i> |
| Sodium hydrosulfite | 798,438 | mg | <i>Sodium dithionite, anhydrous {RER, RoW} market for sodium dithionite, anhydrous Cut-off, U</i> |
| Sodium hydrosulfite stab. | 99,527 | mg | <i>Sodium dithionite, anhydrous {RER, RoW} market for sodium dithionite, anhydrous Cut-off, U</i> |
| Auxiliary for dyeing | 87,080 | g | <i>Tert-butyl amine {GLO} market for Cut-off, U 60% Propyl amine {GLO} market for Cut-off, U 15% Ethylamine {GLO} market for Cut-off, U 7,5% Chemical, organic {GLO} market for Cut-off, U 7,5% Ethylene glycol dimethyl ether {GLO} market for Cut-off, U 5% Ethylene glycol {GLO} market for Cut-off, U 5%</i> |
| Whitener | 26,425 | mg | <i>Alkylbenzene sulfonate, linear, petrochemical {GLO} market for Cut-off, U</i> |

| | | | |
|----------------------|--------|---|--|
| blue dye 1 | 1,791 | g | <i>Anthraquinone {GLO} market for I Cut-off, U 80%</i> |
| blue dye 1B | 0,301 | g | <i>Anthraquinone {GLO} market for I Cut-off, U 40%</i> |
| blue dye 2 | 2,162 | g | <i>Sodium dichromate {GLO} market for I Cut-off, U (75% - 15)</i> |
| blue dye 3 | 0,001 | g | <i>Sodium hydrogen sulfate {GLO} market for sodium hydrogen sulfate I Cut-off, U 85%</i> |
| blue dye 4 | 0,011 | g | <i>EDTA, ethylenediaminetetraacetic acid {GLO} market for I Cut-off, U 5%</i> |
| blue dye 5 | 0,021 | g | <i>Chemical, organic {GLO} market for I Cut-off, U 80%</i> |
| blue dye 5B | 0,003 | g | <i>Chemical, organic {GLO} market for I Cut-off, U 50%</i> |
| Orange dye | 0,193 | g | <i>Sodium bicarbonate {GLO} market for sodium bicarbonate I Cut-off, U 10% Sodium dichromate {GLO} market for I Cut-off, U 70%</i> |
| Bordeaux dye | 0,037 | g | <i>Alpha-naphthol {GLO} market for I Cut-off, U 25%</i> |
| Brown dye 1 | 0,662 | g | <i>Anthraquinone {GLO} market for I Cut-off, U 70%</i> |
| Brown dye 2 | 0,375 | g | <i>Sodium dichromate {GLO} market for I Cut-off, U 90%</i> |
| Yellow dye 1 | 0,147 | g | <i>Alpha-naphthol {GLO} market for I Cut-off, U 85%</i> |
| yellow dye 1B | 0,290 | g | <i>Alpha-naphthol {GLO} market for I Cut-off, U 45%</i> |
| Yellow dye 2 | 0,009 | g | <i>Sodium bicarbonate {GLO} market for sodium bicarbonate I Cut-off, U 15%</i> |
| Yellow dye 3 | 0,131 | g | <i>Sodium dichromate {GLO} market for I Cut-off, U 75%</i> |
| Yellow dye 4 | 0,163 | g | <i>Sodium hydrogen sulfate {GLO} market for sodium hydrogen sulfate I Cut-off, U 90%</i> |
| Black dye 1 | 20,435 | g | <i>Sodium dichromate {GLO} market for I Cut-off, U (95% - 5)</i> |
| Black dye 2 | 0,915 | g | <i>Naphthalene sulfonic acid {GLO} market for I Cut-off, U 90%</i> |
| Red dye | 1,349 | g | <i>Naphthalene sulfonic acid {GLO} market for I Cut-off, U 75%</i> |
| Green dye 1 | 0,790 | g | <i>Methane sulfonic acid {GLO} market for I Cut-off, U 95%</i> |

| | | | |
|-----------------------------------|--------|------|---|
| Green dye 2 | 0,009 | g | <i>Chemical, organic {GLO} market for Cut-off, U 90%</i> |
| Violet dye 1 | 0,010 | g | <i>Naphthalene sulfonic acid {GLO} market for Cut-off, U 75%</i> |
| Violet dye 2 | 0,024 | g | <i>Alpha-naphthol {GLO} market for Cut-off, U 56%</i> <i>Sodium sulfate, anhydrite {RER, Row} market for Cut-off, U 38,5%</i> |
| Film PE | 1,818 | g | <i>Packaging film, low density polyethylene {GLO} market for Cut-off, U</i> |
| Iron | 3,636 | g | <i>Steel, low-alloyed {GLO} market for Cut-off, U</i> <i>Wire drawing, steel {RER, RoW} processing Cut-off, U</i> |
| Lorry | 25,136 | kgkm | <i>Transport, freight, lorry 3.5-7.5 metric ton, EURO3, 4, 5, 6 {RER} transport, freight, lorry 3.5-7.5 metric ton, EURO3 Cut-off, U</i> |
| Lorry for waste collection | 1,291 | kgkm | <i>Municipal waste collection service by 21 metric ton lorry {CH} processing Cut-off, U</i> |
| Wastewater treatment | 33,728 | l | <i>Wastewater, average {Europe without Switzerland} treatment of wastewater, average, capacity 1E9l/year Cut-off, U</i> |
| Disposal of residues | 25,828 | g | <i>Municipal solid waste {CH} treatment of, sanitary landfill Cut-off, U</i> |
| Waste paper sorting | 2,865 | g | <i>Waste paper, sorted {Europe without Switzerland} treatment of waste paper, unsorted, sorting Cut-off, U</i> |
| Waste iron sorting | 11,365 | g | <i>Iron scrap, sorted, pressed {RER} sorting and pressing of iron scrap Cut-off, U</i> |



4 Environmental impacts of MWool® and virgin wool fibres

Life cycle assessment on MWool® fibres

4 Environmental impacts of M Wool® and virgin wool fibres

The potential impacts of M Wool® fibres and virgin wool fibres have been assessed with the Life Cycle Impact Assessment method EF 3.0, in line with the PEF and the Made Green in Italy guidelines. The impact categories have been chosen according to the most relevant issues for the analysed products. Specifically, the following impact categories have been selected: **Climate change, Ozone depletion, Photochemical ozone formation, Particulate matter, Acidification, freshwater Eutrophication, terrestrial Eutrophication, freshwater Ecotoxicity, Land use, Water use, Resource use – fossils, Resource use – minerals and metals.** The potential environmental impacts of M Wool® are summarised in Table 15, beside the impacts of virgin wool.

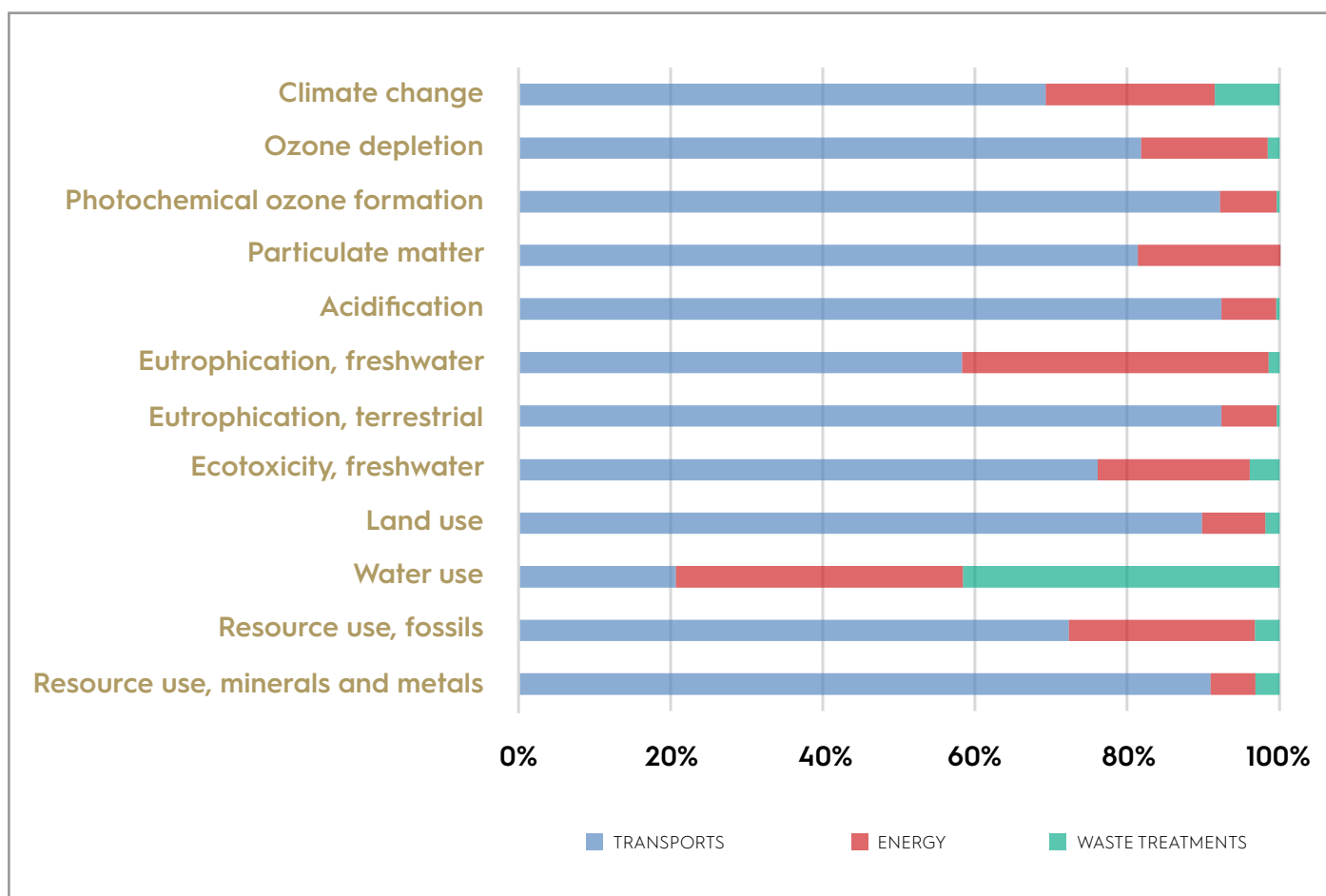
Table 15 - Potential impacts of 1kg of M Wool® and virgin wool.

| IMPACT CATEGORY | UNIT | M Wool® | VIRGIN WOOL |
|-----------------------------------|--------------|----------|-------------|
| Climate change | kg CO2 eq | 6,22E-01 | 7,58E+01 |
| Ozone depletion | kg CFC11 eq | 1,10E-07 | 1,17E-06 |
| Photochemical ozone formation | kg NMVOC eq | 6,40E-03 | 7,31E-02 |
| Particulate matter | disease inc. | 3,46E-08 | 1,19E-05 |
| Acidification | mol H+ eq | 8,29E-03 | 1,69E+00 |
| Eutrophication, freshwater | kg P eq | 6,00E-05 | 1,83E-02 |
| Eutrophication, terrestrial | mol N eq | 2,36E-02 | 7,43E+00 |
| Ecotoxicity, freshwater | CTUe | 6,24E+00 | 1,20E+03 |
| Land use | Pt | 2,94E+00 | 7,74E+03 |
| Water use | m3 depriv. | 9,25E-02 | 1,39E+01 |
| Resource use, fossils | MJ | 8,33E+00 | 1,25E+02 |
| Resource use, minerals and metals | kg Sb eq | 3,31E-06 | 1,38E-04 |

As climate change is concerned, the carbon footprint for 1 kg of recycled fibres is of 0,628 kg CO2 eq. It emerges that a high share of the impact on climate change is due to the collection of post-consumer garments with small lorry and the transport from USA and Eastern Europe to India and Pakistan with container ships. Figure 4 shows the contribution of transports, energy and other (materials and waste treatments) for all the analysed impact categories. For all categories, except water use, transports are responsible of the highest contribution (from 64% for freshwater eutrophication to 93% for photochemical ozone formation, acidification and terrestrial eutrophication). For the water use, a not negligible contribution (16%) is due to the water used in the shredding process.

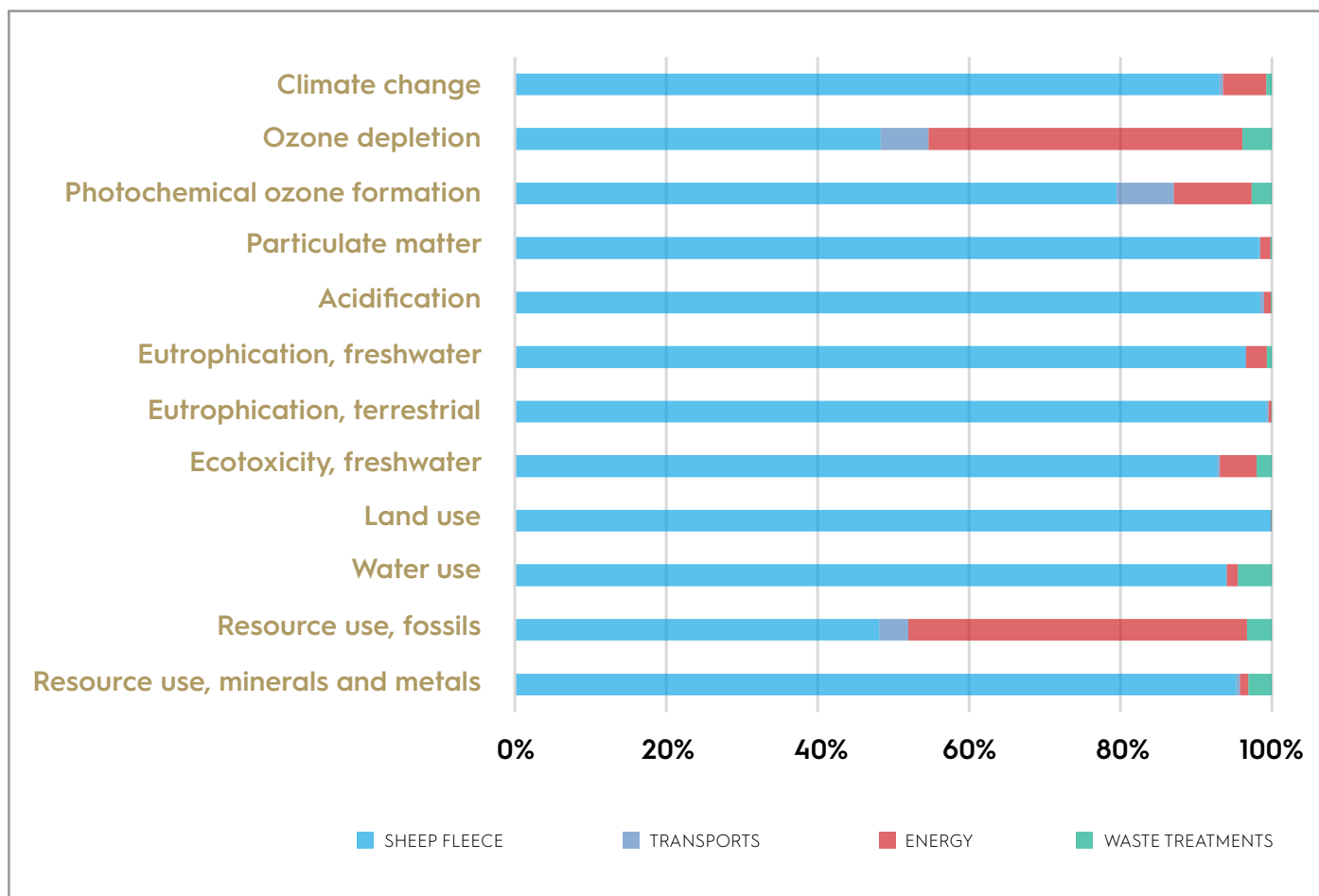
As climate change is concerned, the impact for 1 kg of virgin fibres is 75,8 kg CO₂ eq. it emerges that almost the entire impact (93%, 70,6 kg CO₂ eq.) is due to the sheep breeding. The graph in Figure 6 shows the contributions of sheep fleece, energy, transports and others (materials, waste treatment) for all the selected impact categories. As it can be noticed, the sheep fleece is the main contributor for all the impact categories (from 48% for ozone depletion and resource use – fossils to 99,9% for land use). This is mainly due to the enteric fermentation and feed production. According to a recent review paper¹, the range of GHG emission for greasy wool is 20–60 kg CO₂ eq./kg. **The dataset from Ecoinvent database used in this study considers 50 kg CO₂/kg, which is therefore in the upper part of that range. The mentioned review paper underlines as well that the variation of flows and impacts between farms is too high to define an average value of the entire industry.** As a consequence, it is suggested to preferably avoid generic data from life cycle databases and to use IPCC or GLEAM models when adequate data is available. However, since the goal of this study is to compare the M Wool® to virgin wool fibres (generally, not a specific and traceable production of virgin wool fibres), the use of the dataset from Ecoinvent database results reasonable. **To have a more complete view, the impact on climate change has been calculated also considering the lowest and highest values of the above-mentioned range (respectively 20 and 60 kg CO₂ eq./kg of greasy wool), as discussed in next paragraph.**

Figure 4 - Contribution of transports, energy and “other” (materials and waste treatments) to the total impact of the M Wool®, for the selected impact categories.



¹ Bhatt, A.; Abbassi, B. Review of environmental performance of sheep farming using life cycle assessment. J. Clean. Prod. 2021, 293, 126192, doi:https://doi.org/10.1016/j.jclepro.2021.126192

Figure 6 - Contribution of sheep fleece, transport, energy and “other” (materials and waste treatments) to the total impact of virgin wool fibres, for the selected impact categories.



The environmental impacts of M Wool® fibres have been compared with the virgin wool fibres. It results that for all the selected impact categories the M Wool® has significantly lower environmental burdens. Graph in Figure 7 shows this comparison, where the lower value is calculated as a percentage of the higher one, which is set as 100%. For all the categories, the impact of M Wool® results lower than 10% of the virgin wool impact. In addition, for the impact categories of climate change, particulate matter, acidification, terrestrial and freshwater eutrophication, freshwater ecotoxicity, land use, water use, the impact of M Wool® is lower than 1%.

A further analysis has been carried out to evaluate how the impact on climate change of virgin wool fibres varies if it is considered the lowest and highest value of the range indicated by the study of Bhatt and Abbassi¹ for the greasy wool (20-60 kg CO₂ eq./kg). It results that when the lowest value is considered, the impact for 1 kg of virgin wool fibres decreases to 33,2 kg CO₂ eq., while when the highest value is considered, the impact increases to 89,1 kg CO₂ eq. Graph in Figure 8 summarises the impact on climate change obtained for the M Wool® and for the virgin wool fibres calculated with the minimum and maximum values for greasy wool and with the dataset from Ecoinvent database. It is clear that, even when the greasy wool is calculated considering the lowest impact, the environmental advantage of M Wool® remains high.

¹ Bhatt, A.; Abbassi, B. Review of environmental performance of sheep farming using life cycle assessment. J. Clean. Prod. 2021, 293, 126192, doi:https://doi.org/10.1016/j.jclepro.2021.126192

Figure 7 - Relative comparison of impacts between 1 kg of M Wool® and 1 kg of virgin wool fibres.

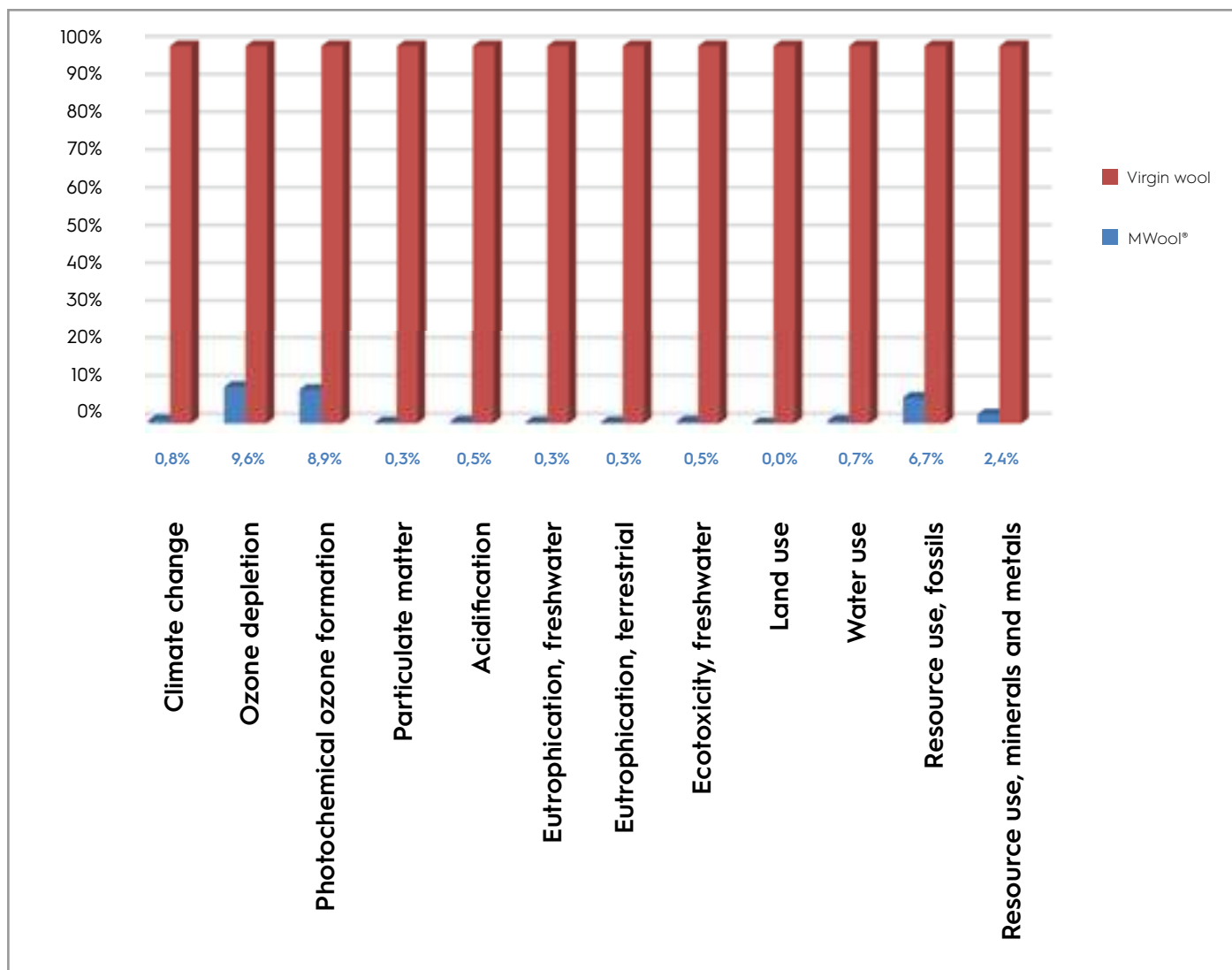
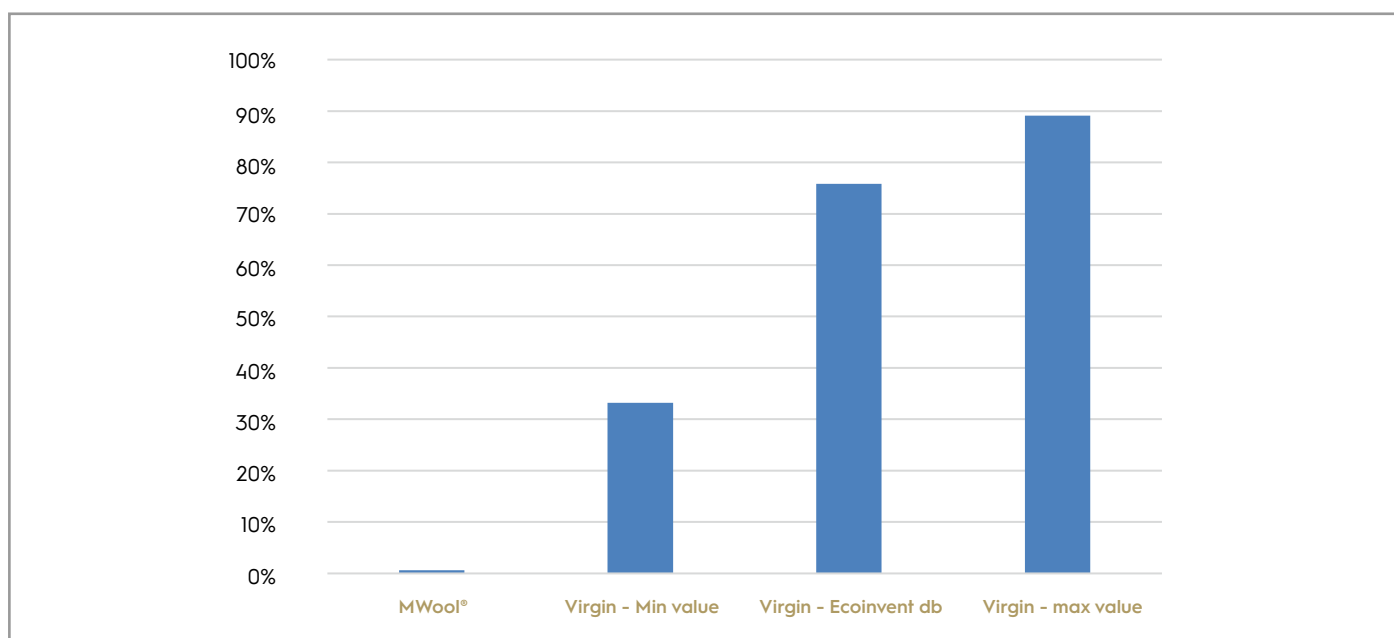


Figure 8 - Comparison of impacts on climate change for the production of 1 kg of M Wool® and 1 kg of virgin wool fibres, calculated attributing different impacts to the greasy wool (respectively 20 kg CO2 eq./kg for the “Min value”, 50 kg CO2 eq./kg for the “Ecoinvent db” and 60 kg CO2 eq./kg for the “Max value”).



In addition, a sensitivity analysis has been carried out on the M Wool® fibres to evaluate the range of results when input data are picked from the upper or lower range. Specifically, the assessment has been developed for the following scenarios:

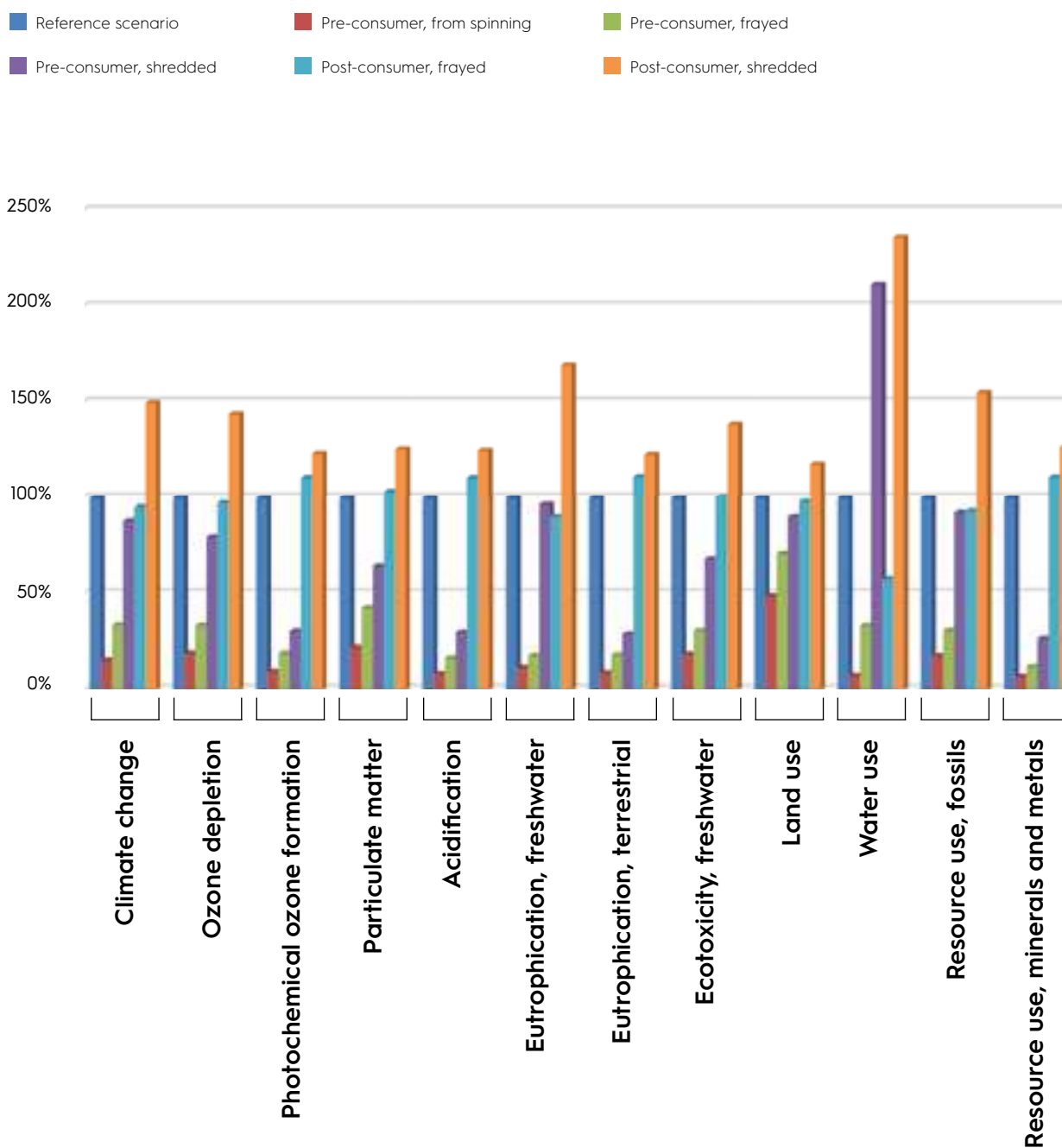
- M Wool® produced from 100% pre-consumer waste from spinning (which is not further treated)
- M Wool® produced from pre-consumer waste, 100% frayed
- M Wool® produced from pre-consumer waste, 100% shredded
- M Wool® produced from post-consumer waste, 100% frayed
- M Wool® produced from post-consumer waste, 100% shredded

Table 16 lists the impacts, in absolute value, of 1 kg of M Wool® obtained from the different scenarios, while Figure 9 shows the relative comparison, where the higher value is set as 100%. Impacts of the reference scenario are indicated as well, to facilitate the discussion.

Table 16 - Impacts of 1 kg of M Wool® for the analysed scenarios.

| IMPACT CATEGORY | UNIT | REFERENCE SCENARIO | ONLY FROM PRE-CONSUMER WASTE | | | ONLY FROM POST-CONSUMER WASTE | |
|-----------------------------------|--------------|--------------------|------------------------------|-------------|---------------|-------------------------------|---------------|
| | | | 100% FROM SPINNING WASTE | 100% FRAYED | 100% SHREDDED | 100% FRAYED | 100% SHREDDED |
| Climate change | kg CO2 eq | 6,22E-01 | 9,76E-02 | 2,12E-01 | 5,51E-01 | 5,92E-01 | 9,36E-01 |
| Ozone depletion | kg CFC11 eq | 1,10E-07 | 2,12E-08 | 3,72E-08 | 8,77E-08 | 1,07E-07 | 1,59E-07 |
| Photochemical ozone formation | kg NMVOC eq | 6,40E-03 | 6,27E-04 | 1,22E-03 | 1,97E-03 | 7,10E-03 | 7,91E-03 |
| Particulate matter | disease inc. | 3,46E-08 | 7,73E-09 | 1,48E-08 | 2,24E-08 | 3,58E-08 | 4,36E-08 |
| Acidification | mol H+ eq | 8,29E-03 | 7,13E-04 | 1,39E-03 | 2,50E-03 | 9,18E-03 | 1,04E-02 |
| Eutrophication, freshwater | kg P eq | 6,00E-05 | 7,36E-06 | 1,13E-05 | 6,04E-05 | 5,35E-05 | 1,03E-04 |
| Eutrophication, terrestrial | mol N eq | 2,36E-02 | 2,14E-03 | 4,35E-03 | 6,90E-03 | 2,63E-02 | 2,91E-02 |
| Ecotoxicity, freshwater | CTUe | 6,24E+00 | 1,18E+00 | 1,95E+00 | 4,31E+00 | 6,27E+00 | 8,67E+00 |
| Land use | Pt | 2,94E+00 | 1,45E+00 | 2,09E+00 | 2,67E+00 | 2,89E+00 | 3,47E+00 |
| Water use | m3 depriv. | 9,25E-02 | 7,01E-03 | 3,11E-02 | 1,97E-01 | 5,32E-02 | 2,19E-01 |
| Resource use, fossils | MJ | 8,33E+00 | 1,50E+00 | 2,61E+00 | 7,76E+00 | 7,76E+00 | 1,30E+01 |
| Resource use, minerals and metals | kg Sb eq | 3,31E-06 | 2,35E-07 | 4,03E-07 | 8,96E-07 | 3,68E-06 | 4,20E-06 |

Figure 9. Relative comparison of impacts for the selected scenarios.



As it can be noticed, for all impact categories (except freshwater eutrophication and water use), M Wool® from pre-consumer textile waste always shows lower impacts than M Wool® from post-consumer garments. This result is mainly due to the longer distance that post-consumer garments have to cover. As expected, M Wool® from spinning waste (which doesn't require further treatments) has the best environmental performance. For both pre- and post-consumer textile, the fraying treatment has lower impacts than the shredding, since this latter requires a significantly higher amount of energy. With emphasis on climate change, the impact of M Wool® from pre-consumer spinning waste results about 10 times lower than M Wool® from shredded post-consumer garments, while the difference between the impact of shredded pre-consumer waste (0,551 kg CO2 eq./kg) and frayed post-consumer waste (0,592 kg CO2 eq./kg) is limited. It is relevant to notice that even in the worst scenario (fibres from shredded post-consumer waste), the impact of M Wool® on climate change (0,936 kg CO2 eq./kg) results significantly lower than the impact of virgin wool fibres in the best scenario (33,2 kg CO2 eq./kg).

Finally, to have a wider frame of reference, the impact on climate change for the production of 1 kg of cotton, organic cotton, polyester, silk and viscose fibres have been calculated, starting from the general datasets available in the Ecoinvent database (Table 17). As it can be noticed, the impact of these fibres is much lower than the impact of virgin wool fibres. The impact of organic cotton results similar to the impact of MWool®.

Table 17. Impact on climate change for the production of 1 kg of different fibres.

| FIBRE | ECOINVENT DATASET | IMPACT ON CLIMATE CHANGE KG CO2 EQ |
|-----------------------|---|---|
| Cotton | <i>Fibre, cotton {GLO} market for fibre, cotton Cut-off, S</i> | 4,69 |
| Organic Cotton | <i>Fibre, cotton, organic {GLO} market for fibre, cotton, organic Cut-off, S</i> | 0,67 |
| Polyester | <i>Fibre, polyester {GLO} market for fibre, polyester Cut-off, S</i> | 4,31 |
| Silk | <i>Fibre, silk, short {GLO} market for fibre, silk, short Cut-off, S</i> | 0,01 |
| Viscose | <i>Fibre, viscose {GLO} market for fibre, viscose Cut-off, S</i> | 3,22 |
| MWool® | | 0,62 |



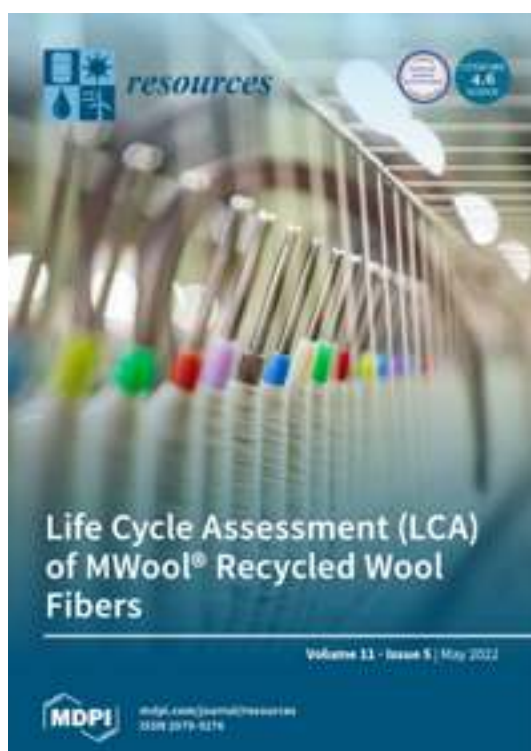
5 Conclusions

Life cycle assessment on MWool® fibres

5 Conclusions

Although preliminary, the current LCA results show that the carbon footprint of 1 kg of M Wool[®] is 0.63 kg CO₂ eq. The potential impact of virgin wool fibres ranges between 33,2 to 89,1 kg of CO₂ eq. As a consequence, the environmental advantage of M Wool[®] against the virgin wool fibres is significant, even when the lowest value of impact for the virgin wool is considered. Also for the other analysed impact categories, the M Wool[®] shows significantly better environmental performances.

This study required several assumptions to fill data gaps, mainly on the specific locations of collection and sorting centres in USA, Europe, India, Pakistan, Turkey, Eastern Europe. Other assumptions concern the mean of transport, the waste textile packaging and the energy used in India and Pakistan to remove accessories. Nevertheless, all the above assumptions can be considered fairly representative of the collection network and recycling chain, so also the result can be considered representative of the impacts of M Wool[®]. Similarly to most of LCAs, the study could be further fine-tuned with more detailed primary data.



This study has been issued as a scientific article on MDPI Resources



Our LCA of M Wool[®] Wool Fibers was selected as the cover of Issue 5, Volume 11, 2022.



This low impacts of M Wool[®] yarns were certified through the EDP[®] scheme.





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