MWool®

by MANTECO

LIFE CYCLE ASSESSMENT

Abstract

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 MWool®, 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 MWool® 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 **MWool® has significantly lower environmental impacts in comparison to virgin wool fibres. For all the lifecycle indicators used in the assessment, the environmental impacts of MWool® 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.**

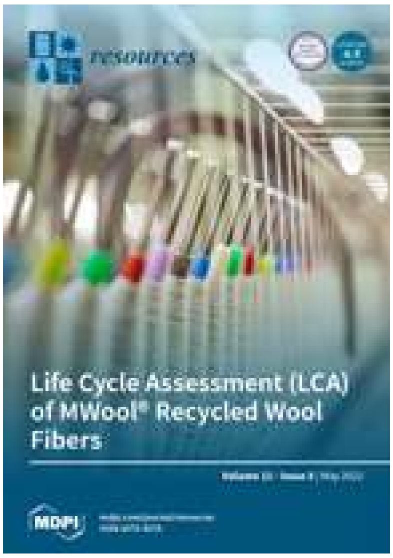
With emphasis on climate change, 1 kg of MWool® corresponds to 0,62 kg CO2 eq., most of which coming from transportation. For comparison, virgin wool fibres have a carbon footprint of 75,8 kg CO2 eq./kg, where the main contributor are the farming activities for the production of the greasy wool. In fact, 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 MWool® 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. MWool® from spinning waste (which doesn't require further treatments) shows the best performance, while MWool® 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 MWool® results significantly lower than the carbon footprint of virgin wool fibres in their best scenario.

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 phases[1]. A recent study[2] 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 than 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 MWool®, 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 MWool® fibres. The LCA of virgin wool fibres, mostly bases 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 MWool® collection network and processing chain. Paragraphs 2 and 3 detail the data collection (life cycle inventory) respectively for the MWool® and virgin wool fibres, paragraph 4 shows the environmental impacts and the comparison between the two fibres, paragraph 5 summarises the conclusions.**



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https://www.mdpi.com/2079-9276/11/5/41

Life Cycle Assessment (LCA) of MWool® Recycled Wool Fibers was selected as the cover of Issue 5, Volume 11, 2022.

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.

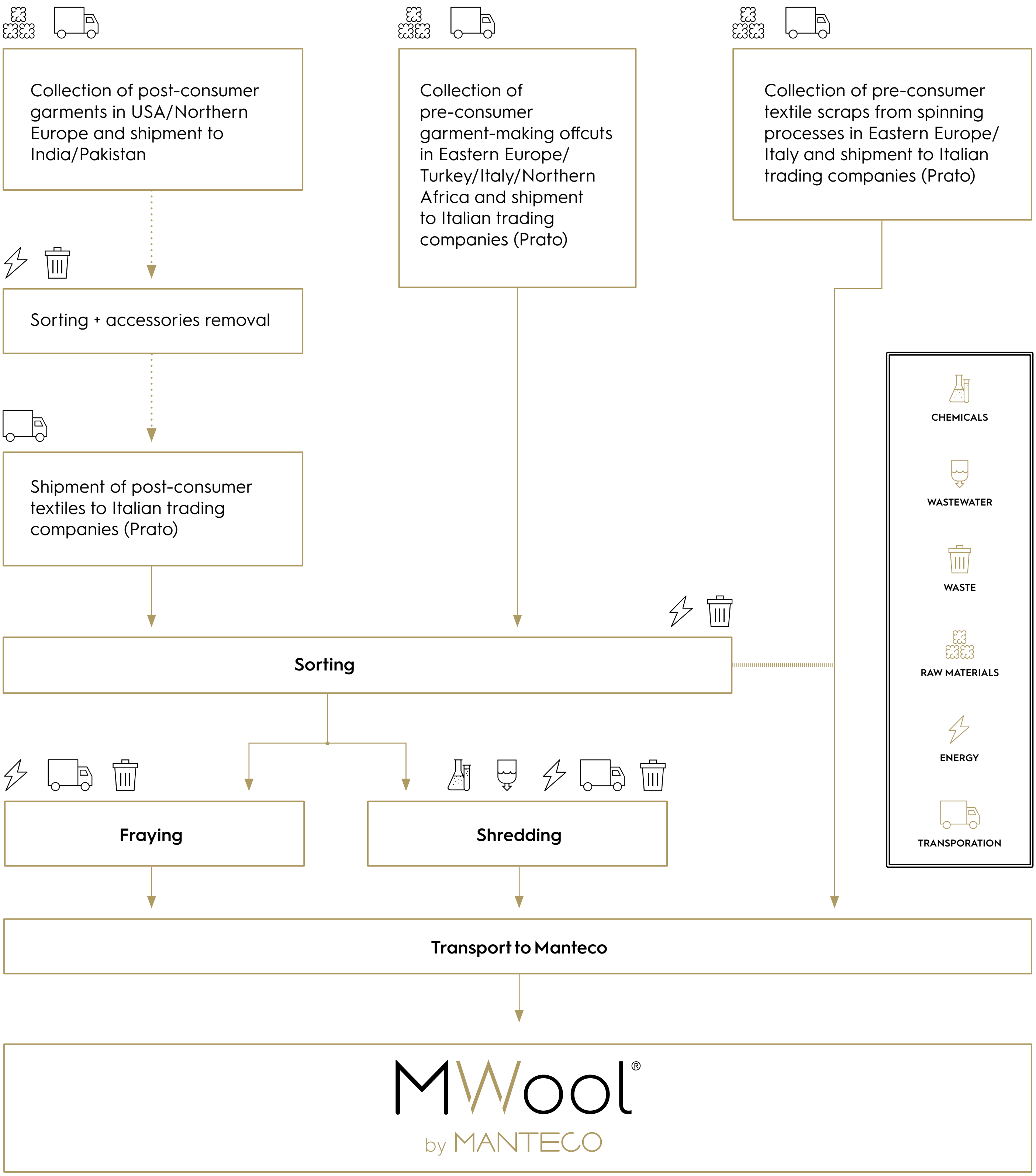
2 Moazzem, S.; Wang, L.; Daver, F.; Crossin, E. Environmental impact of discarded apparel landfilling and recycling. Resour. Conserv. Recycl. 2021, 166, 105338, doi:https://doi.org/10.1016/j.resconrec.2020.105338.

2 Life cycle inventory for the production of MWool® fibres

2 Life cycle inventory for the production of MWool® fibres

This paragraph describes and quantifies the inventory for the MWool® 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 MWool®



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 area[1]);**

- **The location of reference for the clothes collection in North Europe is Amsterdam (highly sensitive to recycling[2]);**

- **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 clothes[3] ;**

- **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 area[4])**

- **The location of reference for clothes sorting in Pakistan is Faisalabad (large textile industry[5])**

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

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/year [1], assuming 25 people working in a 60x30 m2 environment, for a consumption of electricity for lightening of 15 kWh/m2y [2].

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

FLOW	QUANTITY	UNIT OF MEASURE	ECOINVENT DATASET	NOTES
OUTPUT				
Post-consumer textile, accessories removed	1	t		
INPUT				
Post-consumer garments, at the sorting centre	1	t		
Electricity in Pakistan	11*0,15=1,65	kWh	*Electricity, low voltage {PK}I market for electricity, low voltage I Cut-off, S*	*15% of post-consumer garments are sorted in Pakistan*
Electricity in India	11*0,85=9,35	kWh	*Electricity, low voltage {IN-Western grid}I market for electricity, low voltage I Cut-off, S*	*85% of post-consumer garments are sorted in India*
Big bales	1,1	kg	*Polyethylene, high density, granulate {GLO}I market for I Cut-off, S + Extrusion, plastic film {GLO}I market for I Cut-off, S*	*HDPE, 432 g/ bag (width: 0,1 mm, surface: 4,6 m2, density: 940 kg/m2)*

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

2 Carletti, C.; Cellai, G.; Pierangioli, L.; Sciurpi, 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
OUTPUT				
Post-consumer textile, at Italian trading company (Prato)	1	t		
INPUT				
Post-consumer textile, accessories removed	1	t		
Transport with >32 t lorry	201	tkm	*Transport, freight, lorry >32 metric ton, euro5 {RoW}I market for transport, freight, lorry >32 metric ton, EURO5 I 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}I transport, freight, sea, container ship I 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 Easter Europe is Bucharest (Romania)[1];**
- **The location of reference for the pre-consumer textile waste in Turkey is Istanbul since in this city the textile sector is particularly active[2];**
- **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 firms[3];**
- **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 textile[4].**

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

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

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
OUTPUT				
Textile sorted, at Italian trading company (Prato)	1	t		
INPUT				
Post-consumer textile, at Italian trading company (Prato)	1,03*0,85 = 0,876 t	t		
Pre-consumer textile, at Italian trading company (Prato)	1,03 * 0,15 = 0,155	t		
Electricity	42,11	kWh	*Electricity, medium voltage {IT}| market for | Cut-off, S*	
Natural gas	42	MJ	*Heat, district or industrial, natural gas {Europe without Switzerland}| heat production, natural gas, at industrial furnace low-NOx >100kW | Cut-off, S*	*0,025 m3/MJ* *1,05 m3 = 42 MJ*
Diesel	168	MJ	*Diesel, burned in building machine {GLO}| market for | Cut-off, S*	*0,0243 kg/MJ = 0,0291 l/MJ* *4,88 l = 4,08 kg = 168 MJ*

FLOW	QUANTITY	UNIT OF MEASURE	ECOINVENT DATASET	NOTES
Water	0,27	*m3*	*Tap water {RER}| market group for | 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 | Cut-off, S*	*>32t, Euro5*
Transport with transoceanic ship	10000	tkm	*Transport, freight, sea, container ship {GLO}| transport, freight, sea, container ship | Cut-off, S*	
Waste: plastic	1,1	kg	*Waste plastic, mixture {CH}| treatment of, municipal incineration | Cut-off, S*	
Waste: textile	0,032	t	*Municipal solid waste {CH}| treatment of, sanitary landfill | 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
OUTPUT				
Wool fibres, from shredding process	1	t		
INPUT				
Textile sorted, at Italian trading company	1,03	t		
Electricity	391	kWh	*Electricity, medium voltage {IT}| market for | Cut-off, S*	
Natural gas	1729	MJ	*Heat, district or industrial, natural gas {Europe without Switzerland}| heat production, natural gas, at industrial furnace low-NOx >100kW | Cut-off, S*	*0,025 m3/MJ 43,22 m3 = 1729 MJ*
Diesel	141	MJ	*Diesel, burned in building machine {GLO}| market for | Cut-off, S*	*0,0243 kg/MJ = 0,0291 l/MJ 4,09 l = 3,42 kg = 141 MJ*
Water	1,33	m3	*Tap water {RER}| market group for | Cut-off, S*	*0,0243 kg/MJ = 0,0291 l/MJ 4,88 l = 4,08 kg = 168 MJ*
No foam agent	3,83	kg	*Silicone product {RER}| market for silicone product | Cut-off, S*	

Transport with lorry	20	tkm	*Transport, freight, lorry 7.5-16 metric ton, euro5 {RER}I market for transport, freight, lorry 7.5-16 metric ton, EURO5 I Cut-off, S*	*3.5-20 t*
Waste: textile	25,66	kg	*Municipal solid waste {CH}I treatment of, sanitary landfill I Cut-off, S*	
Waste: iron	3,17	kg	*Iron scrap, sorted, pressed {RER}I sorting and pressing of iron scrap I Cut-off, S* + *Avoided product: Pig iron {RoW}I pig iron production I Cut-off*	
Wastewater	1,33	m3	*Wastewater, average {Europe without Switzerland}I treatment of wastewater, average, capacity 1E9l/year I Cut-off, S*	

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

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 MWool® and are ready to be spun. The table here below summarises the inventory data.**

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

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

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
OUTPUT				
Wastewater treated	1	m3		
INPUT				
Wastewater	0,261	m3		
Electricity	0,699	kWh	*Electricity, medium voltage {IT}| market for | Cut-off, S*	
Natural gas	0,396 kWh = 0,041 Sm3	tkm	*Heat, district or industrial, natural gas {Europe without Switzerland}| heat production, natural gas, at industrial furnace low-NOx >100kW | Cut-off, S*	
Diesel	0,098	MJ	*Diesel, burned in building machine {GLO}| market for | Cut-off, S*	*0,0243 kg/MJ 0,238 g = 0,098 MJ*
Gasoline	0,0017	MJ	*Petrol, unleaded, burned in machinery {GLO}| market for petrol, unleaded, burned in machinery | Cut-off, S*	*0,0221 kg/MJ 0,039 g = 0,0017 MJ*
LPG	0,00032	MJ	*Heat, central or small-scale, natural gas {GLO}| propane extraction, from liquefied petroleum gas | Cut-off, S*	*0,0310 kg/MJ 0,01 g = 0,00032 MJ*

Aluminium trichloride	25,60	g	*Aluminium chloride {GLO}I market for aluminium chloride I Cut-off, S*	
Citric acid	0,33	m3	*Citric acid {RER}I production I Cut-off, S*	
Sulfuric acid 50%	0,43	kWh	*Sulfuric acid {RER}I market for sulfuric acid I Cut-off, S* *+* *Tap water {RER}I market group for I Cut-off, S*	
Sulfuric acid 96%	0,07	tkm	*Sulfuric acid {RER}I market for sulfuric acid I Cut-off, S* *+* *Tap water {RER}I market group for I Cut-off, S*	
Hydrogen peroxide	0,25	MJ	*Hydrogen peroxide, without water, in 50% solution state {RER}I hydrogen peroxide production, product in 50% solution state I Cut-off, S* *+* *Tap water {RER}I market group for I Cut-off, S*	
No foam agent	1,13	MJ	*Silicone product {RER}I market for silicone product I Cut-off, S*	
Ferric chloride	24,60	MJ	*Iron (III) chloride, without water, in 40% solution state {GLO}I market for I Cut-off, S*	
Bleaching agent	5,71	g	*Sodium dithionite, anhydrous {RER}I market for sodium dithionite, anhydrous I Cut-off, S*	
Sodium hydroxide	1,57	g	*Sodium hydroxide, without water, in 50% solution state {GLO}I market for I Cut-off, S* *+* *Tap water {RER}I market group for I Cut-off, S*	*Assumption: 50% solution*

Sodium hypochlorite	2,37	g	*Sodium hypochlorite, without water, in 15% solution state {RER}I market for sodium hypochlorite, without water, in 15% solution state I Cut-off, S* + *Tap water {RER}I market group for I Cut-off, S*	
Oxygen	0,12	m3	*Oxygen, liquid {RER}I market for I Cut-off, S*	
Anionic polyelectrolyte	1,34	kWh	*Polyacrylamide {GLO}I market for I Cut-off, S*	
Cationic polyelectrolyte	5,03	tkm	*Polyacrylamide {GLO}I market for I Cut-off, S*	
Urea	0,05	MJ	*Urea {RER}I market for urea I Cut-off, S*	

3 Life cycle inventory for the production of virgin wool 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 fabrics[1] 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 peli 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
OUTPUT			
Clean virgin wool	1,00038	t	
INPUT			
Electric energy	141,90	kJ	*Electricity, medium voltage {GLO}| market group for | Cut-off, U*
Steam	8,69	kg	*Steam, in chemical industry {RoW}| production | Cut-off, U*
Water	9,18	kg	*Tap water {GLO}| market group for | Cut-off, U*
Virgin wool in the grease	1,398	kg	*Sheep fleece in the grease {RoW}| sheep production, for wool | Cut-off, S*
Detergents	6,39	g	*Non-ionic surfactant {GLO}| market for non-ionic surfactant | Cut-off, U*
Sodium carbonate	6,39	g	*Soda ash, dense {GLO}| market for | Cut-off, U 50%* *Soda ash, light, crystalline, heptahydrate {GLO}| market for | Cut-off, U 50%*
Sulfuric acid	0,71	g	*Sulfuric acid {RoW}| market for sulfuric acid | Cut-off, U*
Lorry for waste collection	19,87	kgkm	*Municipal waste collection service by 21 metric ton lorry {RoW}| processing | Cut-off, U*
Wastewater treatment	3,67	kg	*Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cut-off, U*
Disposal of washing residues	397,31	g	*Municipal solid waste {RoW}| treatment of, sanitary landfill | Cut-off, U*

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

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

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

Table 14 - Inventory fof the fibre dyeing process

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

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

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

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

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

4 Environmental impacts of MWool® and virgin wool fibres

Life cycle assessment on MWool® fibres

4 Environmental impacts of MWool® and virgin wool fibres

The potential impacts of MWool® 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 MWool® are summarised in Table 15, beside the impacts of virgin wool.

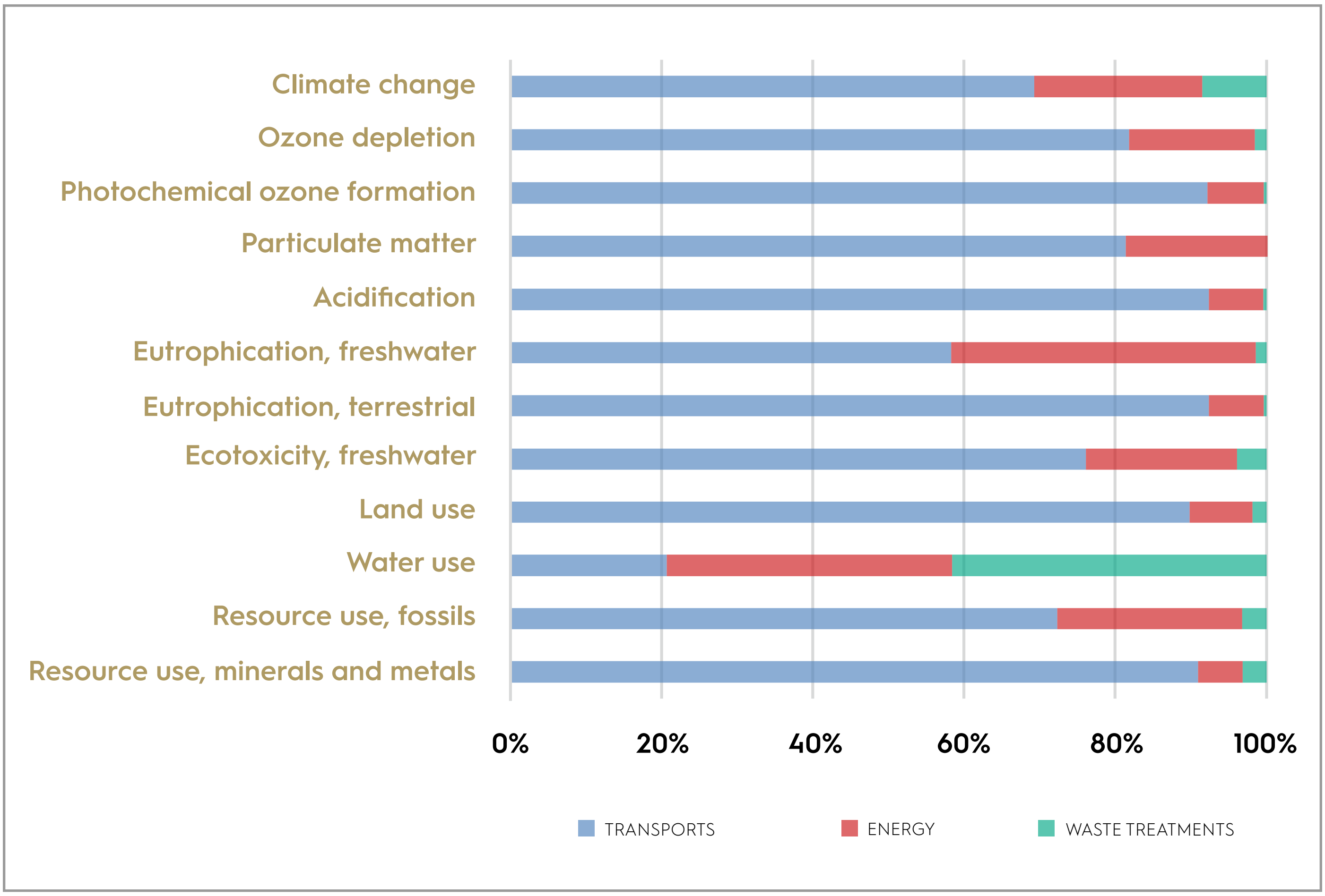
Table 15 - Potential impacts of 1kg of MWool® and virgin wool.

IMPACT CATEGORY	UNIT	MWool®	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.**

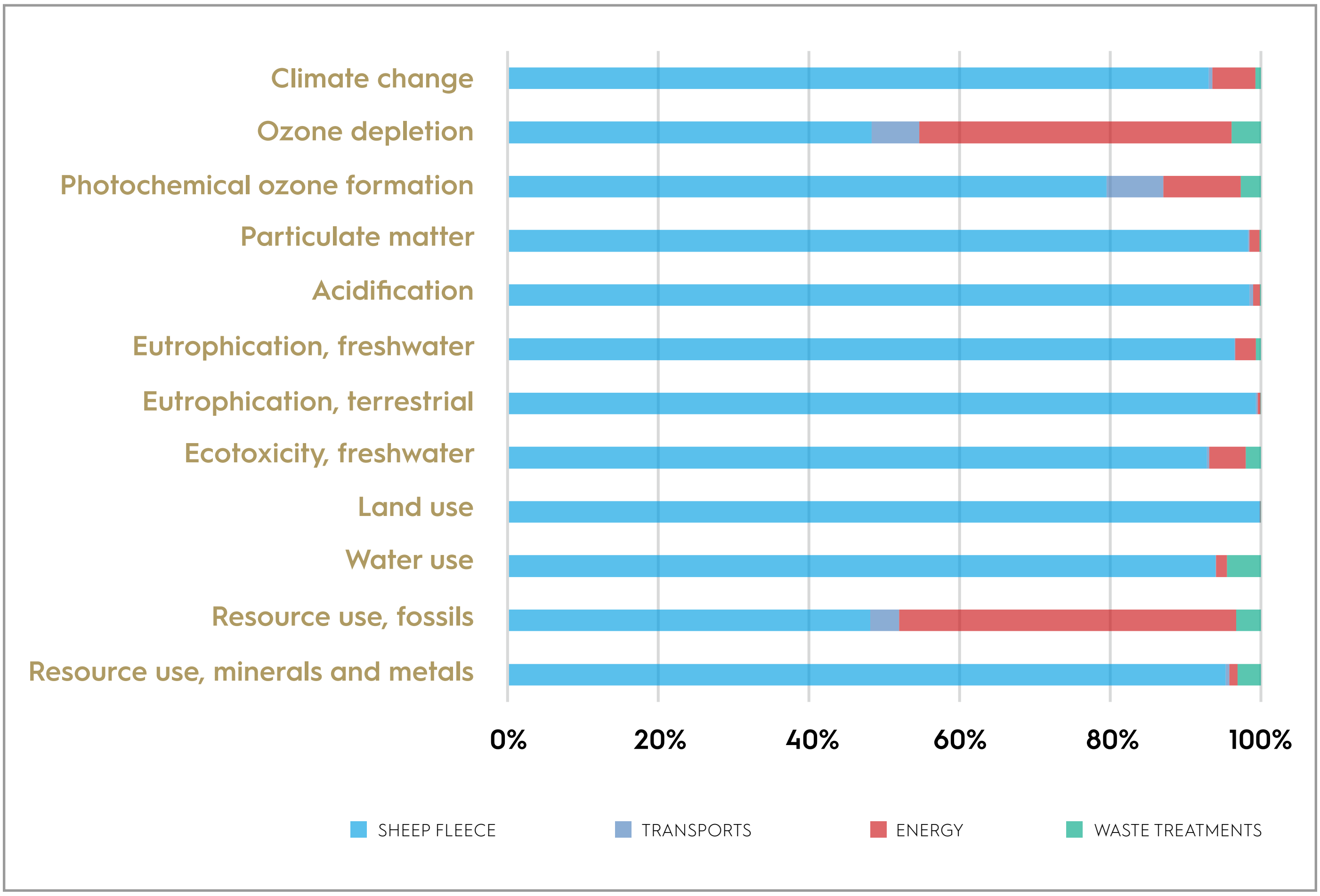
As climate change is concerned, the impact for 1 kg of virgin fibres is 75,8 kg CO2 eq. it emerges that almost the entire impact (93%, 70,6 kg CO2 eq.) is due to the sheep breeding. The graph in Figure 6 shows the contributions of sheep fleece, energy, transports and others (materials, waste treatment) 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 paper[1], 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 IPPC or GLEAM models when adequate data is available. However, since the goal of this study is to compare the MWool® 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. T**o 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 MWool®, 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 MWool® fibres have been compared with the virgin wool fibres. It results that for all the selected impact categories the MWool® 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 MWool® 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 MWool® 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 Batth and Abbassi[1] 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 MWool® 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 MWool® 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 MWool® and 1 kg of virgin wool fibres.

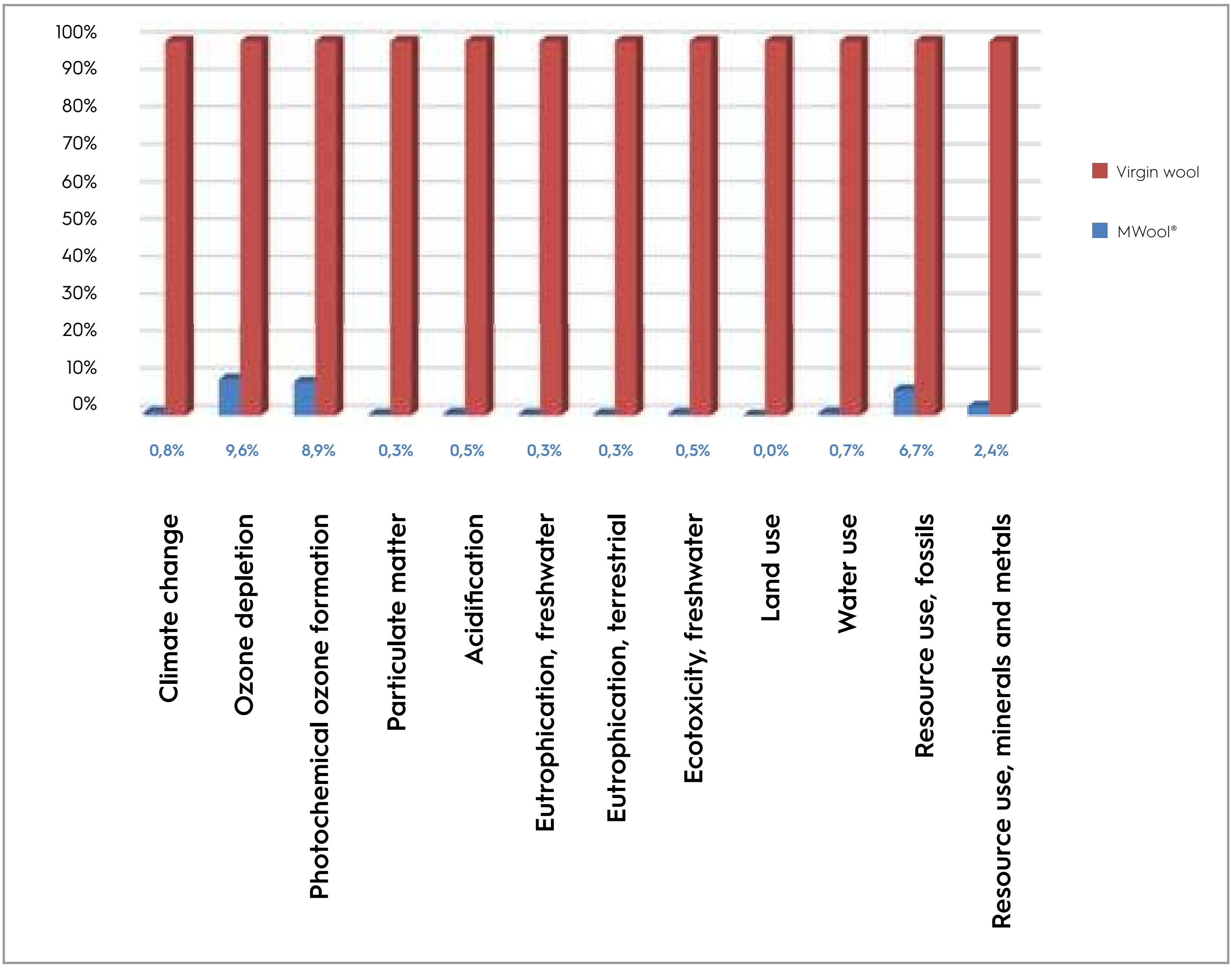
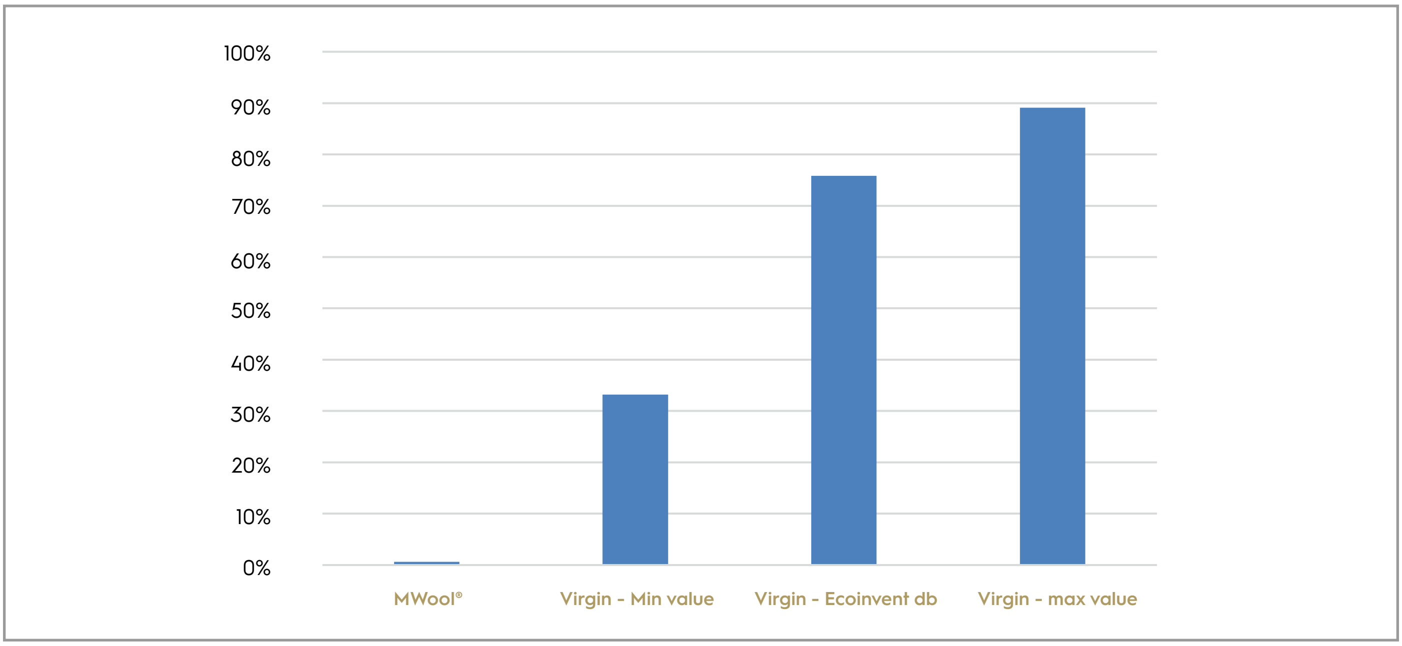


Figure 8 - Comparison of impacts on climate change for the production of 1 kg of MWool® and 1 kg of virgin wool fibres, calculated attributing different impacts to the greasy wool (respectively 20 kg CO2 eq./kg for the "Min value", 50 kg CO2 eq./kg for the "Ecoinvent db" and 60 kg CO2 eq./kg for the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



In addition, a sensitivity analysis has been carried out on the MWool® 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:

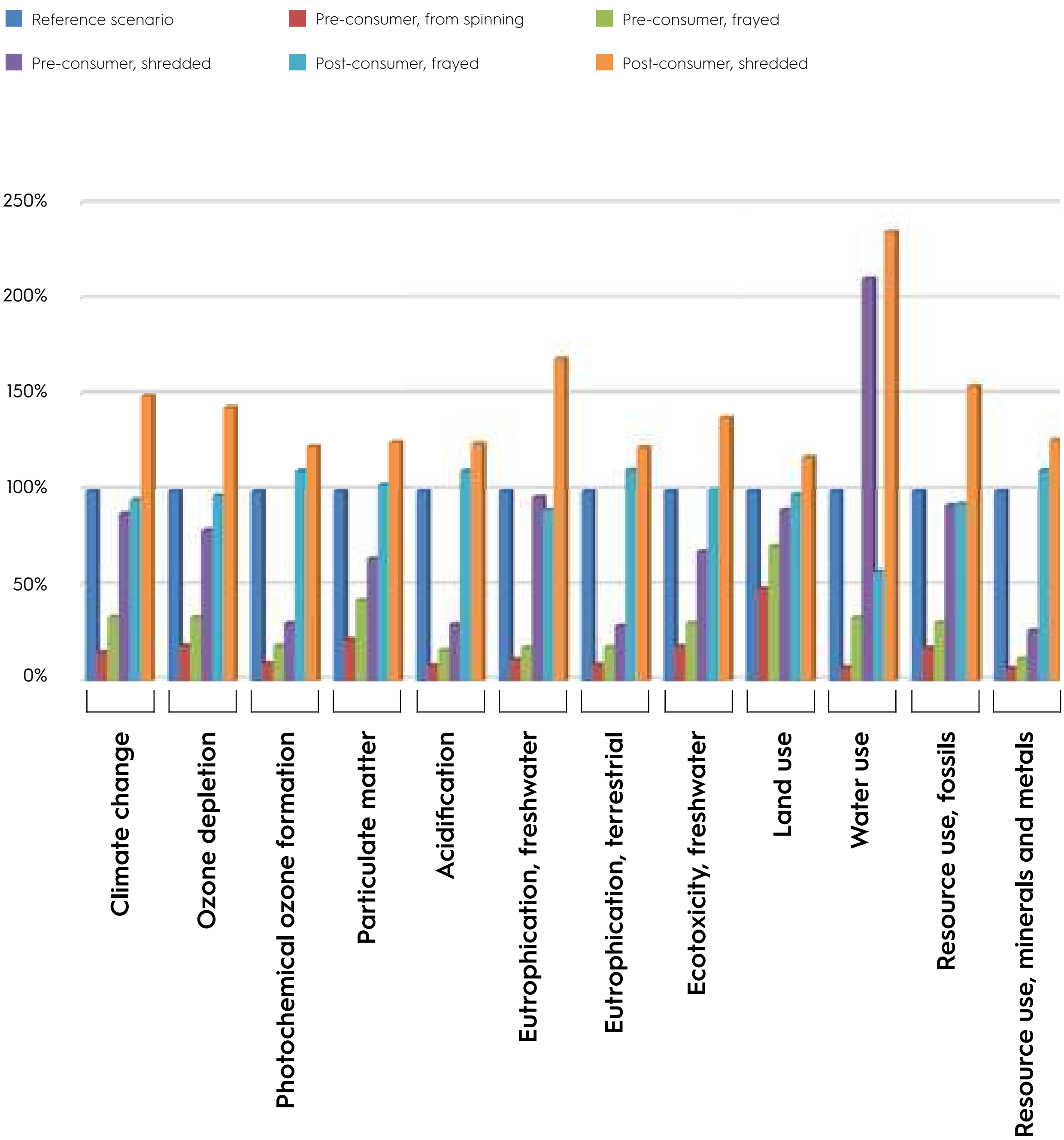
- **MWool® produced from 100% pre-consumer waste from spinning (which is not further treated)**
- **MWool® produced from pre-consumer waste, 100% frayed**
- **MWool® produced from pre-consumer waste, 100% shredded**
- **MWool® produced from post-consumer waste, 100% frayed**
- **MWool® produced from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

Table 16 lists the impacts, in absolute value, of 1 kg of MWool® 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 MWool® for the analysed scenarios.

			ONLY FROM PRE-CONSUMER WASTE			ONLY FROM POST-CONSUMER WASTE	
IMPACT CATEGORY	**UNIT**	**REFERENCE SCENARIO**	**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), MWool® from pre-consumer textile waste always shows lower impacts than MWool® from post-consumer garments. This result is mainly due to the longer distance that post-consumer garments have to cover. As expected, MWool® 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 MWool® from pre-consumer spinning waste results about 10 times lower than MWool® 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 MWool® 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	*Fibre, cotton {GLO}I market for fibre, cotton I Cut-off, S*	*4,69*
Organic Cotton	*Fibre, cotton, organic {GLO}I market for fibre, cotton, organic I Cut-off, S*	*0,67*
Polyester	*Fibre, polyester {GLO}I market for fibre, polyester I Cut-off, S*	*4,31*
Silk	*Fibre, silk, short {GLO}I market for fibre, silk, short I Cut-off, S*	*0,01*
Viscose	*Fibre, viscose {GLO}I market for fibre, viscose I Cut-off, S*	*3,22*
MWool®		*0,62*

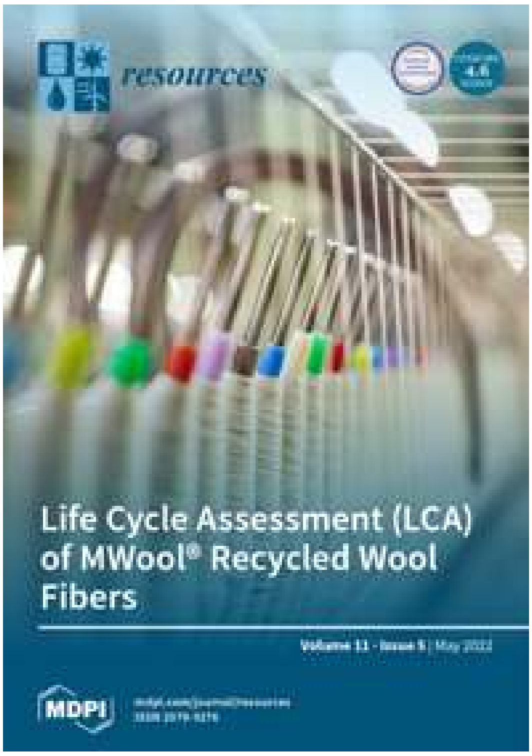
5 Conclusions

Life cycle assessment on MWool® fibres

5 Conclusions

Although preliminary, the current LCA results show that the carbon footprint of 1 kg of MWool® 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 MWool® 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 MWool® 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 MWool®. 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 on April the 20th, 2022

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