

RECYCLED WOOL

A Primer for Newcomers & Rediscoverers



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Important Note for the Reader:

This document is a 'living document'. It is a representation of the current knowledge at the time of writing.

Therefore, we proactively invite input, feedback, and improvement suggestions from experts, in order to keep readers up to date with the latest findings and information.

The document will be re-disseminated following relevant updates.

Wool is slowly recovering some of its former popularity. While for some it is an old acquaintance, for many others in this current time and age, it is a new, or maybe more accurately, novel material for the portfolio. New generations of users might consider wool as one option to improve a brand's materials portfolio. Wool also opens up opportunities for product innovation, as well as for learning afresh about the challenges and benefits related to using this animal-originated fibre.

It is in this context that awareness about, and hence scrutiny of, a range of possible challenges increases. A few of the most important to mention are related to the environmental credentials of recycled content, its traceability and authenticity, and animal welfare.

Such focus aligns well with the wider work done in this area such as the development of the Responsible Wool Standard (RWS) [TE RWS], which focuses on the traceability of virgin wool.

As a result of all of these different efforts, step-wise progress is made: Traceability and impact data gaps are being closed; design guidelines are being made publicly available; old processes are being unearthed; and new technologies are being developed or discovered.

In the last years, the apparel industry has increasingly looked for recycled materials. The questions that have been worked on for materials such as cotton, polyester, nylon and even down, are now also being asked for wool: is recycled, rather than virgin wool, a viable and desirable ingredient, both from a product as well as sustainability point of view¹?

Unlike many other textile fibres, used wool clothing has long been compatible with both open loop and closed loop recycling processes, and commercially exploited as a raw material for at least 200 years. The shoddy/mungo process is believed to have originated in Batley (West Yorkshire, UK) [Jubb, 1860], consequence of the work of Benjamin Law around ca. 1813 [Wikipedia GTM]. It still represents one of the longest standing examples of post-consumer product recycling in the textile industry. Shortly after shoddy was introduced, mungo was developed as a way of incorporating recycled tailors' clippings into the woollen processing pipeline (cf. Figure 1).

In the early 20th century, Prato (near Florence, Italy) successfully managed to establish a woollen industry based on recovered wool, subsequently expanding its output while other areas in Europe contracted. In this way, it gradually took over Yorkshire's leadership role in the quality and variety of goods that could be made from recovered wool blends [Rose, 2013].

In Europe, we are lucky that with Prato we have even in the present time and age a global centre for recycling of wool at our proverbial doorstep. Indeed, there is no better place to obtain effective and meaningful insights into the wool recycling processes, the technology and its value chain.

For the remainder, this document broadly covers the following areas:

- Background: Terminology and legal setting
- Supply chain and production processes
- Sustainability benefits and challenges

The following aspects are currently and explicitly beyond the scope of this document:

- Comprehensive coverage of best available techniques/technologies at every stage of sourcing and/or processing of recycled wool
- A comprehensive coverage of all legislation that applies to the sourcing, processing, trading (import, export) of recycled wool (although we cover some of it)
- A comprehensive and in-depth coverage and comparison of currently available (proprietary, second party, third party) certification standards
- Labour conditions in factories and all related issues, challenges and topics.

The sole aims of this report are to help the understanding of recycled wool's backstory, and empower the designers and product managers to evaluate this material's credentials.

This report is designed to outline and summarise relevant information, which may be usable and useful for brands that want to consider integrating recycled wool into their materials portfolio. In short, it is intended to foster the dialogue and relationship building between brands and the recycled wool supply chain.

¹ These questions equally apply to cashmere as well as mohair, not only sheep wool. However, while production processes in principle are the same, or very similar, for all three fibers, the details in this report refer specifically to the use of recycled sheep wool only.

1.1 Key Questions to be Addressed in this Report

As the title of this document indicates, the content presented is a 'primer' to recycled wool. It is assumed that the reader has not much more than conceptual knowledge about the existence of recycled wool as textile material, yet is interested in understanding if and how it might add diversity to the material portfolio.

The questions this document therefore is focused on, are the following:

- What is recycled wool?
- How is it being processed?
- What are its benefits (and challenges) from a sustainability and traceability point of view?
- What do we know about the scientific credentials of recycled wool – such as LCA analyses - and where are there gaps that will need addressing in the years to come?

2. BACKGROUND

In the last few decades, the use of recycled wool, as well as wool noils (cf. Chapter 2.1 Terminology), was first and foremost an opportunity for European businesses to remain competitive in an economic sense, specifically in the lower price brackets chiefly of interest to multinationals more familiar with sourcing from overseas for cost reasons.

It is only since the early 2010s that increased focus on the textile sector's environmental and social impacts, together with the emergence of circular economy [Wikipedia CE] concepts, have triggered fresh attention on value added processes and products that capitalise on 'waste' as primary input material. It is hence in the realm of this more recent development that recycled wool and its credentials have been rediscovered and increasingly showcased in the public eye.

NUMBERS AT A GLANCE:

Wool remains a popular and valuable recyclable:

Of the total amount of clothing donated for recycling by consumers, 5% of all clothing donations by end-consumers are wool [Russell et al., 2016]



This exceeds substantially the estimated 1.5% that virgin wool has of the world market [WACR, 2013]

The Italian district of Prato alone processes an approximate 22 Mio kgs [Cardato, 2015] of post- and pre-consumer 'primary textile materials' as well as significant amounts of noils.



In addition, any material not suitable for yarn and fabric production, and therefore for apparel or interiors, is fed into the making of products such as mattresses, car upholstery fillings or non-woven products of various types [Borgliotti, duk].

Text Box 1: Relevant quantifications at a glance.

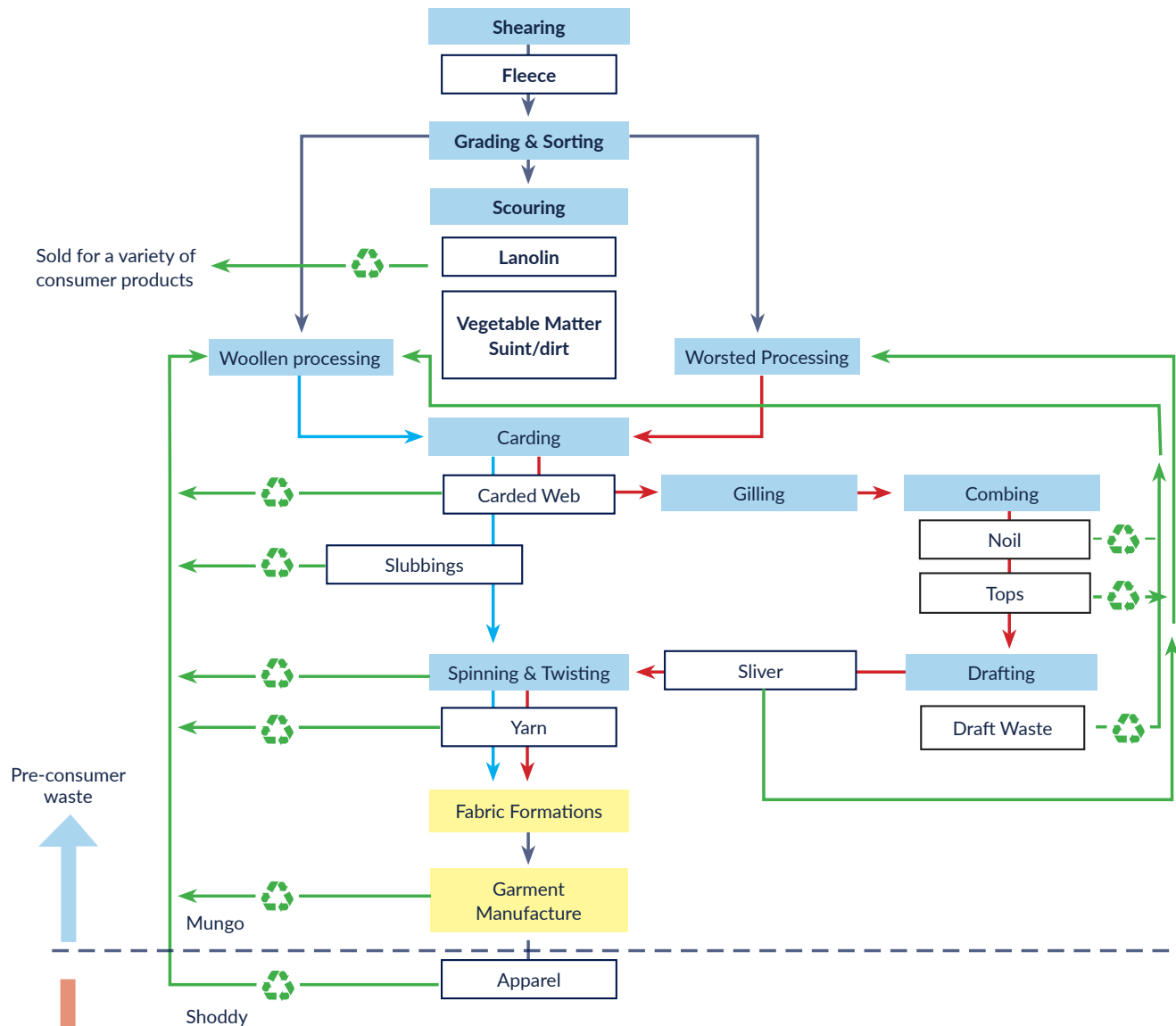


Figure 1: Simplified wool fibre processing steps showing recycling flows of post- industrial (pre-consumer) and post- consumer wastes (Source: [Russell et al., 2016])

2.1 Terminology

Recycled Wool

Wool fibre, yarn or fabric produced from raw material that stems from post-production or post-consumer primary woollen material.

Mungo

Fibrous woollen material generated from waste fabric, particularly tightly woven cloths and rags. [Wikipedia GTM]

Shoddy

Recycled or remanufactured wool. Historically generated from loosely woven materials. [...]. Shoddy is inferior to the original wool; "shoddy" has come to mean "of poor quality" in general (not related to clothing), and the original meaning is largely obsolete. [Wikipedia GTM]

Wool Noils

"Short fibres removed during the combing of textile fibres and often separately spun into yarn." [MW:Noil] (Eds. by the authors) In the present context, from wool fleeces. Often still containing vegetable matter at and from its origin.

Pre-consumer Material (cf Figure 1) (also: post-production material):

'Material diverted from the waste stream during the manufacturing process. Excluded is the reutilisation of materials such as rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it.' [TE RCS]

In the context of wool, post-industrial wool processing waste is routinely recycled back into the manufacturing process flow. This is unlike post-consumer waste, a large proportion of which may be discarded as waste.

Post-consumer Material (cf Figure 1):

"Material generated by households or by commercial, industrial, and institutional facilities in their role as end-users of the product that can no longer be used for its intended purpose. This includes returns of materials from the distribution chain." [TE RCS]

2.2 Legal Context: Textile Waste & the Law

European Union:

At the time of writing, there is no specific waste stream for textiles in the EU legislation that is legally enforced [EU ENV]. There is however, a reference to textiles in the Waste Framework Directive [EU Lex, 2008], which is currently undergoing revision. This directive calls for the development of 'End of Waste' specific criteria, also (but not only) for textiles. This development has not been undertaken yet [EC JRCCE]. As a consequence of the lack of EU wide applicable criteria for textiles, each individual member state's national rules apply.

Therefore, once the currently ongoing revision of the Waste Framework Directive is concluded, it is most probable that the above outlined mandatory separate collection of textiles (required to be in place by 2025) will be addressed at the EU level. Until then, textile-based waste is considered 'general' waste.

United Kingdom:

Duty of care provisions in section 34 of the environmental protection act [UK, 1990] stipulates that if any organisation such as a charity, local authority or business passes second-hand clothing waste to a textile recycling merchant, they must ensure that that merchant has the legal authority to take the waste. In effect this means, that the merchant is a member of the Textile Recycling Association, and holds compulsory employer's liability insurance. [Osborn, 2012]

France:

France is the only European member state that has implemented a legal framework related to 'End Producer Responsibility' (EPR) of textile producers [France CE], as well as regarding take back schemes of end-consumer products. [EcoTLC] lists all relevant legal provisions.

Italy:

Since the beginning of 2017, post-production and post-consumer textiles are considered 'special waste' ('rifiuti speciali'), and no longer 'urban waste' as before. Any such material must now comply with the new legislative framework on traceability and management. The consequence is that transport and handling of such 'waste' can only be done by companies with the required license, and that stringent documentation needs to be provided along the chain. [Altalex, 2017]

United States:

No specific regulation applies. Instead legal provisions are absorbed in the 'Resource Conservation and Recovery Act' [RCRA, 1976]. The act insists upon specific methods for the generation, storage, transport, treatment and disposal of hazardous waste produced during manufacturing of textiles and clothing. [Osborn, 2012]

China:

In summer 2017, the Chinese government decided to ban the imports of solid waste destined for recycling. The decision relates to 24 materials including plastic, paper and textiles, equivalent to 70% of all waste shipped to China. [GOSC, 2018; WTO, 2017]

2.2 Primary Material Availability, Pricing & Quality

Wool fibre recyclate extracted from knitwear remains a relatively valuable raw material because of compatibility with woollen yarn manufacturing. According to [Russell et al., 2016], a bale of mixed colour wool sweaters in Europe was traded at around GBP 350/tonne (35p/kg) in around 2016. This compared at the time to ca. GBP 87.5/tonne (8.75p/kg) for a bale of mixed synthetics.

This is however a significant decline in value when compared to the 1990 as well as the mid-2000s (Table 1).

Sales price per tonne		1990	2005
Recycling Grades	White wipers	£600	£200
	Other wipers	£150	£50
	Wool wipers	£500	£300
	Uni-colour acrylic knits	£220	£110
	Filling materials	£100	£30
Clothing Grades	Clothing for re-use Africa	£1000	£900
	Clothing for re-use Pakistan	£220	£200

Table 1: Rag Prices per Tonne, 1990 and 2005, quoted in GBP [Oakdene Hollins, 2006]

The commercial value of wool was (and remains) highly dependent on its homogeneity (relative to a benchmark of 100% wool of similar colours), and the degree to which fibre length can be preserved after mechanical recycling.

Additional sorting of items into uniform colours can assist with subsequent dyeing processes. Sorting to produce finer diameter wool batches can further help to yield premium prices. Hence, as a general rule of thumb, the more uniform the colours arising from the sorting process, and the longer the staple length emerging from the pulling process, the higher commercial value of the fibre, as well as the resulting products (yarn, fabric).

According to [Russell et al., 2016], the economic feasibility of wool recycling heavily favours large batch processing (minimum of 50 tonnes).

3. THE (CLOSED LOOP) RECYCLING WOOL PROCESS

In the present, post-industrial wool processing waste is routinely recycled back into the manufacturing process flow. However, the same does not hold true with regards to post-consumer material, where a large proportion is discarded as waste: Existing data suggest that the majority of post-consumer items are being sent to incineration or landfill. Only about 25% in Europe [FoEE, 2013; EEA EIONET, 2018], and around 15% in the US [Planet Aid, 2015] of clothing items are channelled into various recycling streams.

Globally, there remains a small number of 'recycled wool' hubs, examples of which are Prato (Italy) [Van Delden, 2018], and Panipat (India) [Norries, 2012].

Pre-consumer as well as post-consumer textiles are delivered (sometimes in a pre-sorted state) to these districts from all over the world to be recycled into fibres for wovens and knits (closed loop), as well as nonwovens (open loop). (cf. Figure 2)

In the remainder of this document we will focus on the closed loop wool recycling process only, which is illustrated in further detail in Figure 3.

Further details on additional open loop processes can be consulted (in Italian) in [Borgliotti, duk].

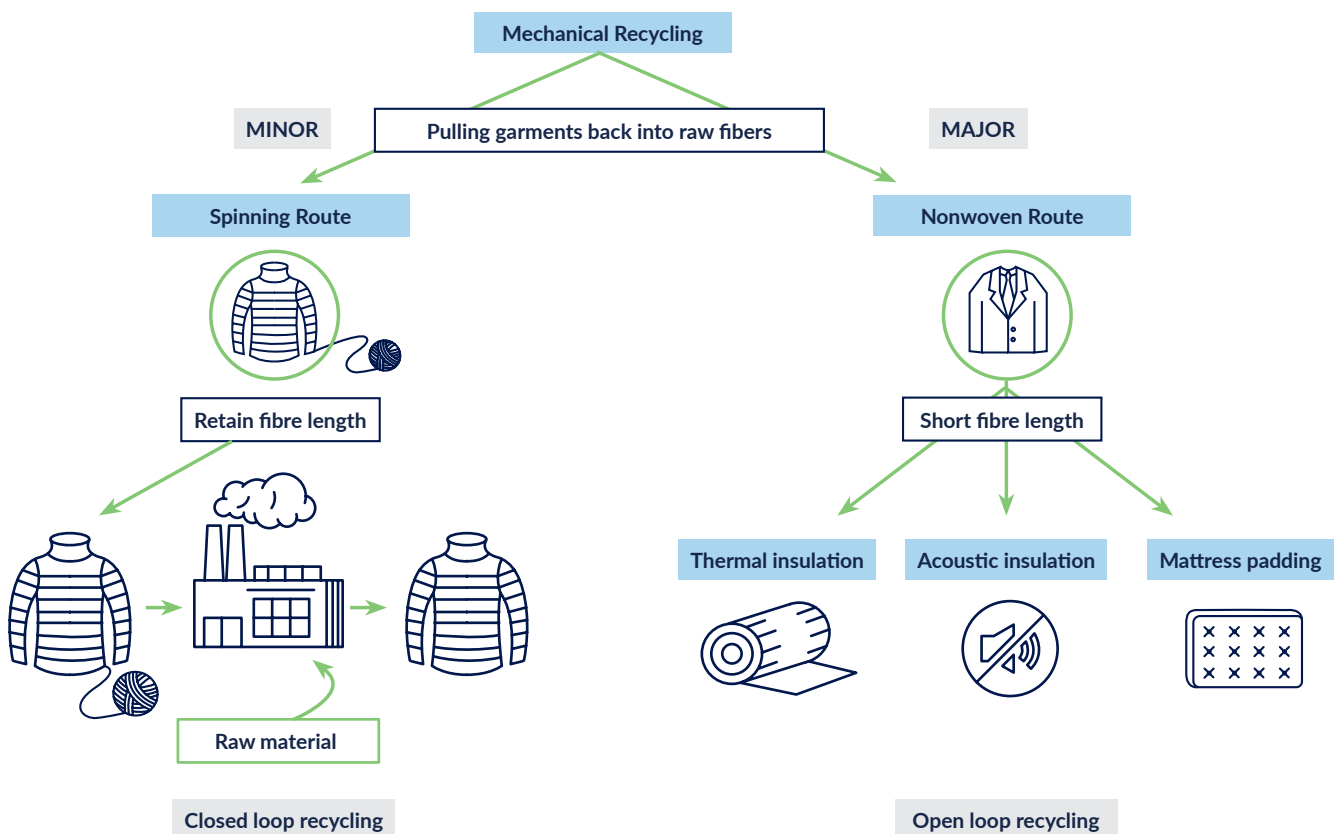


Figure 2: Mechanical recycling of wool textile garments based on open and closed loop recycling [Russell et al., 2016]

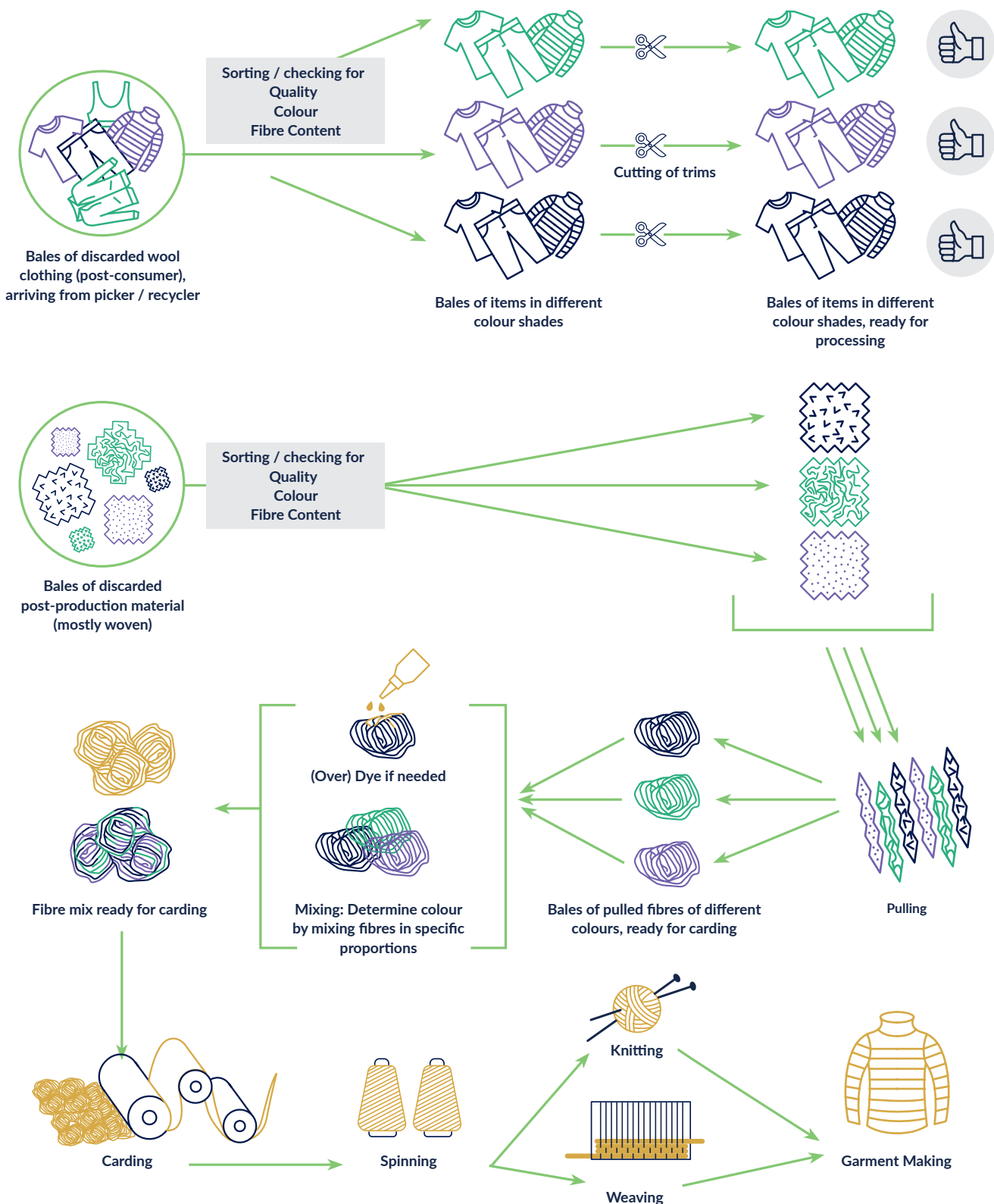


Figure 3: (Closed Loop) Recycled wool production process

Top row: post-consumer items are received pre-picked. They undergo at least two more picking stages in which they are colour sorted, and fibre-content checked, and then freed from any attached trims and labels.

Middle row: Post-production material is undergoing at least one picking stage, in which the material is colour sorted and fibre content checked.

Bottom (2) rows: Once the primary material is colour graded and sorted, it undergoes pulling, mixing to achieve specific colour shades (more rarely: overdyeing), and then follows through the traditional carding, spinning and weaving/knitting, (including finishing), and finally garmenting process as any fibre would.

3.1 Production in Practice: A Photo Story

The following sections explain and illustrate the typical processes of a recycled wool supply chain.

However, there is a word of caution to note at this moment:

One of Prato's key opportunities may also be potentially its Achilles heel.

While the processes, as explained in this document, are illustrated as if they were completed 'in-house' by a single company fully owning all relevant processes (physical and operational business integration), this is by far not the typical case, neither in Prato nor elsewhere.

The most typical operational case is that of a 'supply chain management hub'. One company – typically the firm owning the direct brand (client) relationship - purchases the required 'raw material'. It subsequently contracts out the processing of said material to a range of specialist companies in the district (cf. Figure 4), to complete the required steps based on a service agreement.

Only at the end, depending on the client's order either at the garment stage (cf. Figure 4) or the fabrics stage, the 'supply chain management hub' takes back physical ownership of the order, so as to ensure contract fulfilment and suitable delivery to the client.

This structure, while effective from a processing point of view, does offer traceability challenges: Specifically, in peak time, or in the case of tight margins, sub-contracting may potentially happen without the ordering brand, or possibly even the 'supply chain management hub', being aware of it.

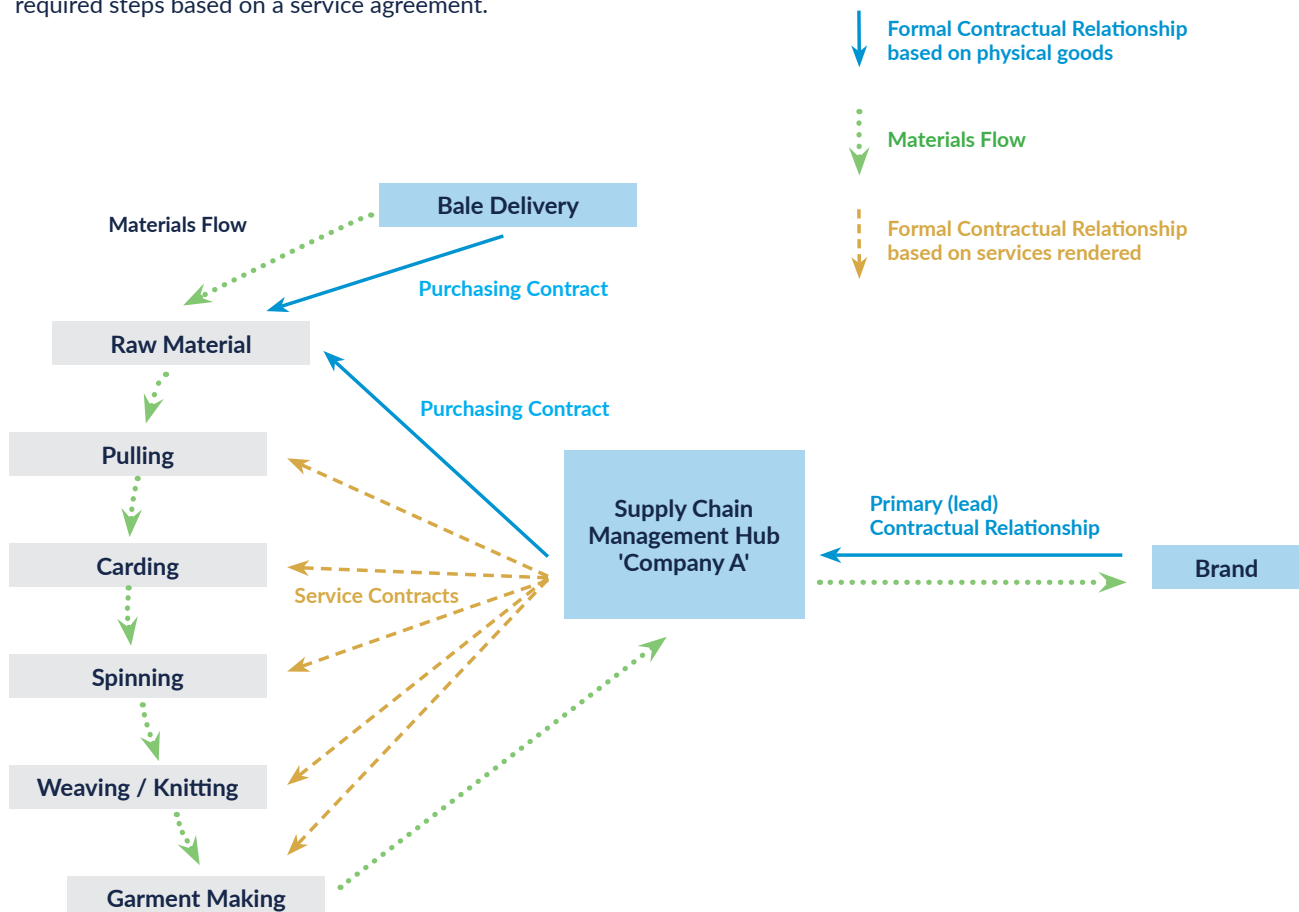


Figure 4: A typical Prato supply chain for recycled wool, from bale delivery through to finished garment.

3.1.1 Incoming Material

'Raw material' for the closed loop recycling comes in as bales from post-consumer (garment) traders, or from post-industrial processes (i.e. weaving trims, leftover yarns). They vary in grade of sorting (colour and material mix) and degree of pre-selection and sorting (preparation).



Unsorted knitted garment



Sorted knitted garment



Sorted knitted garment



Unsorted woven garments



Post production: weaving trims



Post production: leftover yarns

3.1.2 Quality Control & Sorting

Sorting is to this date pure manual work. Automated systems [e.g. Circle Economy, 2018] are in development but have not yet been widely adopted.

Incoming material is sorted by colour and by material quality.

All trims and foreign materials like zippers, buttons and labels are cut out. Depending on the type of material and the orders which have to be processed, the material will be cut into pieces immediately, or stored to be processed later.

For critical colours specifically, samples of all material are taken for chemical lab testing to avoid contamination through legacy chemicals (cf. Chapter 4.3).



Knitted garment sorting for material content



Knitted garment sorting for colour



Colour sorting of wovens



Sorting of cut pieces



Cut pieces sorted by colour



Trims and buttons cut offs

3.1.3 Pulling of Knitted Material

Knitted garments like pullovers, jumpers and jackets are typically pulled in a dry process. The yarns are pulled mechanically from the knitted structure, always making sure that the residual fibre length remains as long as possible. The material might pass the pulling machine several times to keep the quality as high as possible, by ensuring that all of the fabric has been converted back in to fibres.



Knitted material ready for pulling



After 1st process plus 'new' material



Finished pulled material

3.1.4 Wet-pulling Process for Woven Materials

Woven constructions will normally be pulled through a mechanical wet process to get a usable fibre length. Knitted material may also undergo this process, but with the above described dry pulling process, an alternative option does exist for that case.

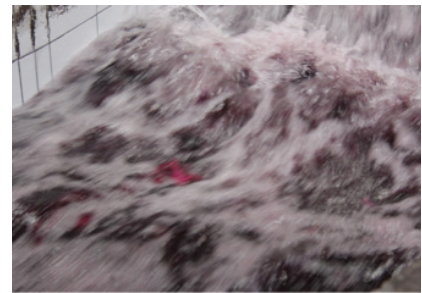
To eliminate foreign fibre content, the cut pieces then undergo carbonisation².



Woven materials ready for carbonisation



Start of wet pulling process



'Fibre sauce' during wet-pulling

3.1.5 Lab Recipe

Determining the colour composition recipe in laboratory conditions is the process by which fibres of different colours are blended to result in a 'new' colour. The purpose of this effort is, ideally, to avoid dyeing the (recycled) fibres altogether. The base material for the new material mix are the existing fibre lots, already pulled and colour sorted. Leadtimes are influenced by a supplier's ability to colour sort and blend fibre batches. With the right set up, leadtimes can be shortened considerably by avoiding (re-)dyeing (cf Chapter 4.4).

Most suppliers have a standard colour card, from which customers can choose. If a more specific colour is required, individual recipes need to be created. Usually the aim is to prevent any over-dyeing of already existing material.

In the lab, fibre blending is first done using a lab-scale carding machine, which simulates the outcome of the bulk process, producing a carded web containing fibres of different colours to produce a particular shade. The carding will be done several times to get a homogeneous mix, which allows a colour check according to the customers' master samples and standard laboratory testing approaches.

It becomes apparent that it could be considered an 'art' to find the right balance between many parameters: customers' colour expectation, the quantity and quality of available raw material, and the aim to use as much recycled wool as possible.

Recycled Wool & Quality: Virgin is never far

It is important to note that it may be difficult to achieve specific colour shades, or yarn/fabric quality criteria, based on 100% recycled wool.

As a consequence, most yarns and/or fabrics made from recycled wool will invariably contain some percentage of either virgin wool, or alternatively other virgin fibres such as cotton, polyester, nylon etc.

This fact is not only relevant in terms of product quality, but will invariably also influence how materials certification and supply chain traceability will need to be handled.

Text Box 2: Virgin Fibres – a necessary ingredient in yarns and fabrics made from recycled wool.

² "Sometimes scoured wool contains vegetable impurities that cannot be completely removed through mechanical operations and sulphuric acid is used for destroying these particles in a process called carbonising." This is considered a best available technique in the textile industry. [Wiki ZE] Carbonisation can also be used to treat waste wool garments containing cotton or other cellulosic material. During the process, the cotton is chemically degraded, leaving the wool behind.



Overview of fibres in stock



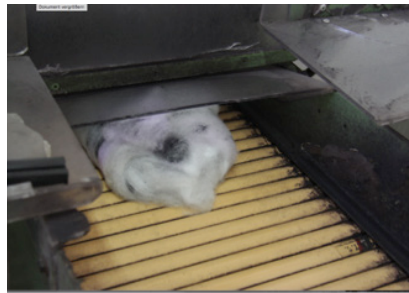
Fibres for blending



Weighing out fibres for blending in the lab



Start of first carding process



Start of second carding process, the blend is turned by 90°



Carded web after the last carding process



A mix of water and soap is added to allow felting



Sample after felting



Colour control after washing and drying the felted sample. Result: sample is far too light in colour.



How the result should look like



How a recipe could look like



Standard colours available

3.1.6 Blending

After defining in the laboratory the recipe for a new lot of fibres based on recycled material, the full-scale bulk blending process can start. The defined quantities by weight of each of the different recycled and virgin wool materials are blended by individual lot in a big blending box, which contains 200 kg of fibre or more.



Overview of inventory for bulk blending



Blending recipe



Container for blending (blending bin)



Blended material in the blending bin



Blended fibres



Blended fibres

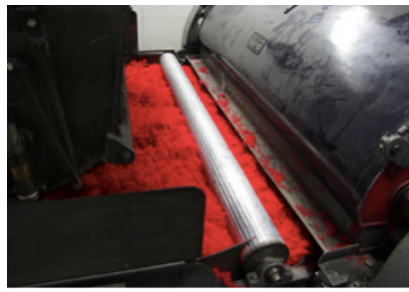
3.1.7 Carding

The blended fibres are further mixed, disentangled and transformed into a carded web. Woollen carding is done by passing fibres between a series of rotating toothed rollers before producing a web of fibres that is condensed to form a rope-like structure. Said structure is transported via belts before being laid down at approximately 90° on the feed sheet of a second carding machine, which further intensively mixes and disentangles the fibres before producing the final web.

At the end, the final web is separated into ca. 1cm wide strands, which are rubbed into slubbings to increase their strength, and then wound onto packages ready for the next stage.



Blended material in a round drum



Blended fibres at the beginning of carding process



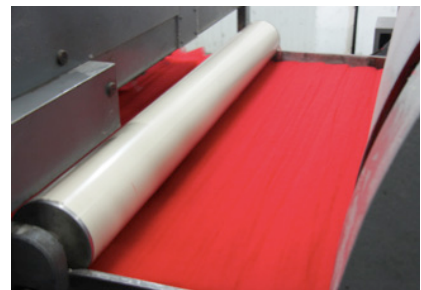
Fibres spread out in the form of a web



The web is condensed together into ca. 20% of its original width...



... and then laid down at 90° on the feed sheet of the second carding section



In-feed to the second carding section



... and again spreading the web.

Carding and spreading the web is typically repeated 2 to 3 (or more times) before proceeding.



After splitting the final carded web into multiple thin strands, they are rubbed between oscillating belts to increase their strength. These rubbed strands are called slubbings.



The slubbings are the final output of the woollen carding machine. They are wound on to packages.

3.1.8 Spinning and twisting to finished yarn

The last process steps for the spinning of yarns containing recycled wool fibre, is in principle the same as it is for virgin fibre: Spinning, twisting, rewinding on bigger bobbins and delivery for weaving or knitting.



Yarn spinning (the slubbings are tensioned to make them thinner and twisted).



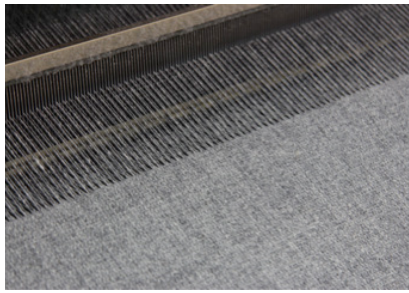
Yarn Spinning



Colour match to master sample



Twisted yarn



Weaving

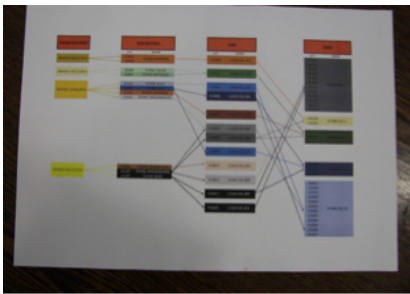


Knitted sample

3.1.9 Finished Product

The traceability of closed loop recycled woollen materials today is only possible back to the source of collected post-consumer garments. There is no information available about the condition of wool harvesting or animal welfare of the original woollen raw material, and neither with regards to the 'first-life' dyeing and finishing processes. However, these are characteristics which all post-consumer recycled materials today still have in common, for natural fibres as well as man-made synthetics.

Suppliers in the Prato region are able to supply yarns, woven and knit fabrics and finished products, from closed loop recycled sources with a traceability back to the collecting point. This is documented and certified according to, for example, the Global Recycled Standard [TE GRS] (further detail: cf Chapter 4.2 below).



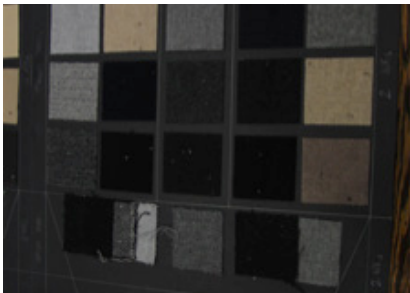
Traceability from 'waste' bale to finished fabric



Barcode on fabric role for full traceability



Available colours from a supplier



Example of delivery time of recycled material (5-11 weeks, depending on raw material available in stock)



Example of delivery time of virgin material (8 weeks if raw material is not available in stock)



Certified to Global Recycled Standard [TE GRS]



Sample loom



Sample loom



Closing the loop: the weaving trims become raw material for the next recycling process

BENEFITS & CHALLENGES OF RECYCLED WOOL

The process of wool recycling presents its own benefits and challenges. The benefits seem on first sight evident – the re-use of an existing resource at a lower environmental and production cost than seems to be the case when using virgin material.

However, while intuition is often a good point of departure for further intelligence, scientific evidence that would prove – or dispel – intuitive assumptions are as of yet not always as succinct, and in the present case rather hard to come by.

In this chapter therefore, we intend to summarise the current state-of-play for the following key areas:

- Recycled Wool & Life Cycle Assessments: Status Quo
- Integrity and Traceability
- Chemical Management
- Leadtimes

4.1 Recycled Wool & Life Cycle Assessment: Status Quo

For the environmental credentials of materials and processes, the currently cleanest approach to receive answers with regards to the extent and type of impacts, is via Life Cycle Assessment (LCA) data. However, unfortunately, there is not a huge amount of data available at the moment when it comes to recycled wool.

Some LCA data is owned by manufacturers and is applicable to their specific process only. Other data, such as the one elaborated by the University of Leeds and the IWTO for the Prato district as a whole, and presented at the occasion of their Harrogate congress [TV Prato, 2017], has a broader approach but the results have not yet been widely circulated. More generic LCA-based research into recycled wool is currently being undertaken and is planned to be published in scientific journals in the course of 2018 and 2019 [Russell et al., 2017]. Lastly, for some specific LCA dimensions, such as, for example, eutrophication, eco-toxicity or human toxicity, there does not currently exist yet an agreed scientific consensus on (a small number of) method(s). Therefore, such dimensions remain difficult, if not impossible, to assess beyond qualitative measures.

This all said, given the data available at this point of time, it looks as if the use of recycled wool may offer substantial environmental gains (cf. sample in Table 2) over the use of virgin wool across all relevant and currently measurable LCA categories. It remains to be seen how this then would compare to other fibres in a typical cradle-to-gate LCA assessment as well as in increasingly pursued cradle-to-grave LCA assessments³, specifically also in comparison to other widely available recycled fibre types such as polyester or cotton.

When looking at a typical/generic closed-loop wool recycling process (shown in Figure 2 and Figure 3), it becomes apparent that virgin and recycled processes are similar/identical from the yarn spinning stage onwards. It can therefore be assumed that when looking at LCA impact analyses, the substantive impact gains for recycled wool would become manifest prior to spinning, while the later stages would result in same or very similar data points for both recycled as well as virgin wool.

³ There is no current agreement on a LCA approach for the usage phase [Cheah, 2013]. Therefore, we do not mention this topic further in this document.

The following table presents a set of indicative LCA data, currently known and available to the authors of this report:

	Recycled Wool [Ø all processes]	Virgin Wool [Ø all processes]	Improvement by Factor
Global Warming Potential (GWP 100)	0.76	18,57	24
Ozone Depletion	6,56E-08	3,68E-07	5.6
Abiotic Depletion - Mineral Fossils	5,90E-03	2,42E-02	4.1
Natural Land Transformation	1,11E-04	8,48E-04	7.64
Human Toxicity - Cancer	4,22E-11	2,49E-06	Huge (> 50'000)
Human Toxicity - Non-cancer	4,45E-11	9,28E-07	Huge (> 20'000)
Freshwater Eco-toxicity	6,16E+00	2,99E+01	4.8
Particulate / Smog Caused by Emissions of Inorganics Substance	6,10E-04	2,81E-02	46
Ionising Radiation, Human Health	5,80E-02	4,18E-01	7.2
Photochemical Ozone Formation	2,46E-03	2,92E-02	11.9
Eutrophication - Terrestrial	1,07E-03	1,75E-01	163.5
Freshwater Eutrophication	1,20E-04	6,74E-03	56.2
Marine Eutrophication	1,11E-04	1,11E-04	1 (identical)
Water Depletion	2,62E-02	2,38E-01	9.1
Acidification	2,50E-01	2,00E+01	80
Cumulative Energy Demand	1,18E+01	4,89E+01	4.1

Table 2: LCA-based advantage of recycled over virgin wool, according to [PrimaQ, 2015]

However, the following points need to be taken into consideration when assessing currently indicative LCA results such as the ones illustrated in Table 2 above:

- Currently applied LCA methodologies do not typically consider the usage phase of a garment and do not take in to account the potentially substantial differences that may exist between different types of garments in terms of their modes of use, washing frequency or service life. This is a frequent point of contention between different players in the apparel and related raw material field.

At the time of writing of this report, it may be said that there is agreement across the board that the usage phase and its length have a (probably significant) impact on the results of LCA studies.

However, there is so far little scientific agreement on what type of garments or ingredient fibre, would benefit or lose most if the usage phase would indeed be covered by LCAs. [Van der Helden et al., 2014; IWTO, 2016]

- Currently applied LCA methodologies assume a one-directional cradle-to-grave direction in the product's life cycle. Circular economy aspects are challenging to be considered adequately in the current methodologies – an issue of particular relevance when it comes to recycle being the raw material for a newly produced finished product [Pré, 2018].
- Continuing from the above, current calculations and procedural analysis typically assume that the input material to the process of generating recycled textile fibres, is 'free' in terms of environmental impact. The question still remains if indeed such fibre should, or not, be allocated a fraction of the original (virgin) fibre's impact, and if so following what methodology. [Russell et al., 2017]

It cannot be ignored that recycled wool is a material that already in the past has been used, in undeclared quantities, in the production of wool yarns – in order to reduce the price point of the yarn, while keeping ‘just’ within the quality specification demanded by customers. Therefore, this means that the environmental performance in particular of lower grade knits and wovens may have ‘inadvertently’ (and to an extent accidentally) been somewhat better in the past already, than current LCA results may suggest.

In conclusion, it can be said that the LCA data for recycled wool that is currently publicly or semi-publicly available [TV Prato, 2017; PrimaQ, 2015] indicates that the benefits in terms of environmental impact of using recycled rather than virgin wool may be significant.

However, there remains some methodological and research work to be done in order to obtain reliable, replicable and valid data to really compare recycled and virgin on an apple-to-apple basis.

4.2 Integrity & Traceability

The right level of transparency is **the** key ingredient for claims about and insights into the integrity of any product, including for products made from (virgin or recycled) wool. In other words, provably honest claims of ingredient quality and origin are crucial to gain the customers’ (both B2B and B2C) trust.

In recycled raw materials, this question needs also to be understood in a broader context:

- For one, there exist different types of recycled input materials (cf. Section 2.1 Terminology); pre- and post-industrial, post-consumer content
- Additionally, the amount and type of virgin fibre typically needed for quality reasons (Text Box 2), further defines the traceability/chain-of-custody approach to be followed.

But how far can traceability be pushed for the case of either recycled wool (from pre- or post-consumer materials) or wool noils as primary input material?

For that purpose, it is of utmost relevance to be fully aware of, and educated about, the parameters that define traceability options, in the present, but also the potential they offer going forward.

Primary Material Type	Possible Traceability Origin	Rationale
Pre-consumer (post-production)	<ul style="list-style-type: none"> • Always: Factory where the pre-consumer material originates from • Potential: Farm (via Chain of Custody) 	<ul style="list-style-type: none"> • The direct commercial, and therefore known, relationship is with the tier 1 supplier. • Potential to track back from there using new technologies [Wallace, 2009], or with more effort using state-of-the-art Chain of Custody mechanisms.
Post-consumer	<ul style="list-style-type: none"> • Always: Clothing Picking Company • Potential: Collection point where end-consumers deposit the garments (via Chain of Custody) 	<ul style="list-style-type: none"> • The direct commercial, and therefore known, relationship is where the fibre manufacturer procures the input material. • Potential to track back from there using new technologies [Wallace, 2009].
Noils	<ul style="list-style-type: none"> • Always: Trader • Potential: Farm (via Chain of Custody) the virgin wool originated from 	<ul style="list-style-type: none"> • Noils are typically traded by agents/traders, with whom the commercial relationship lies. • Chain of Custody offers the opportunity to trace back from there to the origins of the fleeces (hence farm) the noils stem from.

Table 3: How far can different types of wool waste be traced back in the present (now, realistically), and in the future (potential)?

Increasingly, certifications and standards are used as tools to support traceability claims and supply chain efforts. While there exists a wide range of standards to certify generic recycled material, Table 4 summarises the (in Prato) most often encountered product labels in the context of recycled wool.

	Global Recycled Standard [TE GRS]	Recycled Claim Standard [TE RCS]	Cardato Recycled [Cardato, 2015b]
ISO Ecolabel Type [ISO, 2018]	Type I	Type I	Type III
ISO Ecolabel Type Description [GEN, 2018]	Voluntary, multiple-criteria based, third party programme that awards a license that authorises the use of environmental labels on products, indicating overall environmental preferability of a product within a particular product category, based on life cycle considerations		Voluntary programmes that provide quantified environmental data of a product, under pre-set categories of parameters set by a qualified third party and based on life cycle assessment, and verified by that or another qualified third party.
Traceability / Chain-of-Custody	Content Claim Standard [TE CCS] Chain of custody system from the source to the final product, certified by an accredited third-party Certification Body		<ul style="list-style-type: none"> • Not on ongoing basis • Self-declared disclosure of supply chain partners, specific to the time of the environmental impact audit
Environmental Management Requirements	<ul style="list-style-type: none"> • Environmental Management System • Chemical Management System • Wastewater Management Requirement to Measure: <ul style="list-style-type: none"> • Energy Use • Water Use • Wastewater/effluent • Emission to Air [TE GRS], pp. 26	N/A	General Systems Management Certification (e.g. ISO9001) for at least 5 years. Measurement of environmental impact along entire production cycle taking of: <ul style="list-style-type: none"> • Water • Energy • CO2 consumption
Chemical Management Requirements	<ul style="list-style-type: none"> • Substance exclusion list • ZDHC MRSL v.1.1 [ZDHC 2015; 2017] [TE GRS], pp. 32	N/A	
Social & Labour Requirements	<ul style="list-style-type: none"> • Code of Conduct/Policy • Specific requirements for: Forced, bonded, indentured and prison labour • Child Labour • Freedom of Association, Collective Bargaining • Discrimination, Harassment, Abuse • Health & Safety • Wages, Benefits, Terms of Employment, Working Hours 	N/A	

Table 4: Comparison: Global Recycled Standard (GRS), Recycled Claim Standard (RCS), Cardato Recycled

	Global Recycled Standard [TE GRS]	Recycled Claim Standard [TE RCS]	Cardato Recycled [Cardato, 2015b]
Product Claims, Logo Use	<ul style="list-style-type: none"> GRS with % indication: 50% - 95% Recycled Content GRS (no % indication): 95% to 100% Recycled Content. <p>[GRS/RCS, 2017], pp. 29</p>	<ul style="list-style-type: none"> RCS Blended: 5% - 95% Recycled Content RCS 100: 95% - 100% Recycled Content <p>[GRS/RCS, 2017], page 16</p>	<p>Cardato Recycled:</p> <ul style="list-style-type: none"> 65% - 100% Recycled Content Exclusively Produced in Prato District
Labels/ Trademarks			

Table 4: Comparison: Global Recycled Standard (GRS), Recycled Claim Standard (RCS), Cardato Recycled

An increasing number of Prato-based manufacturers follow with the Global Recycle Standard (GRS) [TE GRS] certification a recognised and available ‘best practice’ approach. They have thoroughly analysed and understood the related traceability prerequisites, processes and investments, and can prove it.

Yet, while the willingness of manufacturers to certify is increasing, the pull-demand from brands for certified recycled wool seems to be less evident.

In fact, unfortunately, many brands seem to be satisfied with superficial or self-declared ‘recycled’ credentials, which reduces somewhat the meaning of thorough credentials such as the GRS. However, since ‘recycled light’ material is not based on a suitable stringent verification (i.e. certification) process, said brands expect the material’s price point to be lower than the one of properly certified material, and hence more beneficial to their own cost structure.

Traceability (as well as Chain of Custody) currently becomes impractical, for commercial or scaling reasons, if the material being traced is nothing more than a commodity, and no added value (monetary or other) is generated as a consequence of the traceability option.

In summary, it can be said that certification and traceability systems become of relevance once either a business case exists that justifies separating specific batches of materials from the general commodity market (e.g. for allergy avoidance purpose), or if is of importance that such batches guarantee credentials that the general commodity market cannot guarantee (as it the case with wool in terms of animal welfare and/or environmental impacts).

When it comes to recycled wool, traceability/certification is a necessary due diligence mechanism for identifying and labelling the finished product as ‘made from recycled materials’, and therefore comply with consumer law requirements on the one hand, as well as transparency demands from consumer organisations.

Animal Welfare Concerns and Recycled Wool

As outlined in Table 4 above, and also in Text Box 2, there is typically (one could say always) a percentage of virgin wool mixed in with recycled wool (of both, post-consumer as well as post-production origin).

The reason for doing so: product quality management.

It is only by adding a certain percentage of virgin fibre that product qualities such as yarn strength or abrasion resistance can be suitably controlled and guaranteed.

Noils – waste from the combing stage - are an interesting and challenging hybrid:

- On the one hand it is clearly a wool production waste product (post-production waste)
- At the same time, it is also ‘virgin’ wool, i.e. with direct connections to the original (virgin) sheep fleece.

The use of virgin wool of some origin, mixed in with predominantly recycled wool for quality reasons, brings a rather unexpected challenge to the forefront, and indeed one that we did not intend to focus on with this report: Animal welfare.

It is widely known that many major end-consumer facing brands have huge animal welfare concerns when it comes to the use of virgin wool (e.g. [H&M Animal Welfare]).

Without going into further detail, and for the purpose of this report, we propose that the most straight forward way is that any virgin material best be certified against the Responsible Wool Standard [TE RWS] or an equivalent approach.

Text Box 3: Animal Welfare Concerns and Recycled Wool

4.3 Chemical Management

Chemical Management has become a key concern for the textile industry at large. In sync with legislative efforts, globally operating brands and civil society are working towards the challenging goal of rolling out chemical management best practices within their sphere of influence.

Therefore, it is a matter of course that relevant questions are also being asked to the manufacturers of fabrics and yarns made from recycled content [ChemSec, 2018], be it from cotton, polyester, or as in our case, recycled wool. This development is also reflected in the requirements set out in the Global Recycled Standard (Table 4 above, as well as [TE GRS]).

Some issues relate to more general chemical management aspects, examples of which would be: The presence or absence of proper waste water management systems at facilities. The remainder of this chapter will address the key issues related specifically to recycled wool.

In this context, the lead questions we would like to address are the following:

1. What is the (chemical management) status of primary (input) materials going into the process? Are there differences between post-production and post-consumer primary materials?
2. What are the most important (known) chemical management risks that originate in the primary material?
3. What are the state-of-the-art chemical management processes (dye houses, washing and finishing facilities) for recycled wool?
4. What are the most important benefits that the use of recycled primary material has in the context of chemical management?

Status of primary input material

As explained above (cf. Figure 4), there exist, fundamentally, two main sources of primary input material, each of which entails a different risk profile as well as related remediation options:

- **Remediation approach:**
A due diligence process is required– either embedded in the buying process of the material or thereafter – with the intention of obtaining relevant information directly from the supplying factory. Governing law and chemical management guidelines can be applied to such a supplier, and therefore the input material.
This means that the subsequent recycling process normally would comply, and be in line, with modern prerequisites and practices.
- **Post-consumer material**, most frequently garments. Typically originating from western consumer markets, although picking services may take place globally, and hence shipments may arrive from as diverse geographies as the United Kingdom, Scandinavia, India or Pakistan. This material may be very old or very recent. It is, typically, nearly impossible to say when (or where and how), any one garment contained in a bale of primary material, was produced. As a consequence, no statement can be made about chemical ingredients contained in a bale of primary material.
 - **Remediation approach:**
A ‘worst case scenario’ approach is required. There is absolutely no prior information as to what type of processes this material has undergone in its first life, and neither during any of the subsequent processing phases (picking, shipping). Such material is normally compiled of an arbitrary mix of goods that have been produced in the past, and the original production time range can cover several decades from the most recent to the oldest product contained in a single shipping. As a consequence, it must be assumed that at the very least some of the material would contain chemical components that in the current time and age are no longer acceptable, and would be banned by governing legislation.
It is therefore here that the highest risk exists that legacy chemicals could impact production processes and eventually cause the resulting end products to be non-compliant with modern standards.
- **Post-production material**, most frequently from weaving mills, but not only, and typically located in Italy and (in the present) to a lesser extent elsewhere in Europe. This material is mostly ‘young’, as it is a leftover-product from current or soon to be released fabric collections/production runs. As a consequence, credentials of chemical ingredients could in principle be researched and inquired at the original production facility.

What chemicals may be present in primary raw material for recycled wool?

Over the last decades, science and regulation have increased pressure to fade out chemicals of concern.

Post-consumer material requires particular scrutiny as its origins are entirely unknown. In the case of post-production material, the risk depends vastly on the location of the producing facility: whereas in Europe REACH regulation has ruled out many hazardous substances, overseas facilities would require a case-by-case approach to understand their individual approach to modern chemical management practices.

The probability that hazardous chemicals or chemicals of concern may be found in the primary material of recycled wool is first and foremost a consequence of the respective chemistries being used in the material's first life (post-farm, i.e. in production).

Table 5 hereafter outlines the chemical classes that most likely could be encountered in the wool production process post-farm, and indicates the potential implications for the wool's second+ life⁴.

Group	Use	Probability of Virgin Wool's exposure (post farm) [probability]	Probability of Presence in Primary Raw material of recycled wool
Alkylphenols APEOs (~90% are NPEOs) [REACH 46; 46a]	Detergents	Widespread in the past. Banned in REACH In the present being replaced through alternatives.(+)	<ul style="list-style-type: none"> European Post-production: Low due to REACH Overseas post-production: Facility dependent Post-Consumer: Low to Medium, depending on age of input material
Phthalates [REACH 51; 52]	Plastics	Low	Low
Br/Cl flame retardants	FR plastics	Low	Low
Azo compounds [REACH 43]	Dyes	Low	Low
Organotins	Anti-bacterial finishes	Low	Low
Perfluorines	Stain repellents	<ul style="list-style-type: none"> Medium in the past. Non-critical for wool. In present being replaced through non-fluorinated alternatives.(+) 	Low
Chlorobenzenes	Dye & pesticide manufacture	<ul style="list-style-type: none"> Low to medium. Usage in present decreasing (+) 	Low
Chlorinated solvents	Dry-cleaning and spot cleaning fluids	<ul style="list-style-type: none"> Widespread 	<ul style="list-style-type: none"> Post-production: Widespread Post-Consumer: Low to medium (due to washing during use phase)
Chlorophenols	Pesticides	Low	Low

Table 5: Typical Chemistries used in the wool's first and 2nd+ life are summarised in the above table. Column 1 to 3 [Duffield, 2012] unless otherwise indicated; amendments (+) thanks to [Kettlewell, 2017]; Column 4 and legislative cross-reference by the authors.

Table continues on the next page

⁴ We would however like to underline that this table does not exclude other regulated substances of concern potentially being present.

Group	Use	Probability of Virgin Wool's exposure (post farm) [probability]	Probability of Presence in Primary Raw material of recycled wool
Chlorinated paraffins	Plasticisers	Low	Low
Heavy metals (Cd etc.) Banned in REACH	Mordants for dyes (metal complex)	<ul style="list-style-type: none"> Widespread in the past, Mostly replaced by reactive dyes in the present (+). 	<ul style="list-style-type: none"> European Post-production: low due to currently valid REACH regulation Overseas post-production: Facility dependent. Post-Consumer: Medium to high
(+) Adsorbable organic halides AOX	(+) 'Super-wash'	<ul style="list-style-type: none"> (+) Medium Applied to wool intended for machine washing. 	<ul style="list-style-type: none"> Post-production: Low – treatment typically applied to woollens at finishing stage only Post-consumer: Low to Medium – typically washes out in usage phase.

Table 5: Typical Chemistries used in the wool's first and 2nd+ life are summarised in the above table. Column 1 to 3 [Duffield, 2012] unless otherwise indicated; amendments (+) thanks to [Kettlewell, 2017]; Column 4 and legislative cross-reference by the authors.

Chemical Management Approach in Dyeing, Washing and Finishing of Recycled Wool

For recycled wool, there are two key approaches to how the final colour shade can be achieved. Each of these has a direct impact on the chemical management process and options available:

- Overdyeing:** Normally done at fibre stage. Primary material of the same colour family is overdyeed so as to achieve a same, uniform colour shade. Typically, the overdyeed shade is of a darker hue than the average of the departing shade. Example: various blue shades are overdyeed with a darker blue shade, or a variety of colours is overdyeed in deep black.
 - The responsibility for (legal) compliance and the remediation of potentially present legacy chemicals is handed over to the dye house. It is the dye house that is expected to manage them in the course of the dyeing, and potentially in-house finishing, processes.
- Colour matching-and-mixing:** Departing from fibre lots of different colours and shades that are in stock, a recipe is created in order to achieve a visually uniform colour shade across the batch. By mixing different colours in pre-determined proportions, the aimed-for shade is achieved (cf Figure 3, 'mixing').

While in the final result there remain, at a microscopic level, individual fibres of the departure colours, the batch as a whole matches the target colour.

Example: Dark blue fibre plus a percentage of white fibre mixed, results in a paler blue shade.

 - The responsibility for (legal) compliance and remediation of potentially present legacy chemicals is associated with the direct handling of the fibre. Remediation options include washing, mixing (with materials that are guaranteed to be compliant), and lastly the finishing processes.

Table 6 hereafter outlines the most prominent risks and benefits of these two approaches to colour management in recycled wool.

	W Overdyeing		W/O Overdyeing (Mixing)	
	Chem Mgt Benefits	Chem Mgt Risks	Chem Mgt Benefits	Chem Mgt Risks
Post-Production Primary Material	Chemical point of departure ingredients can be researched quite accurately as recent production batches.	Present day finishing and dyeing chemicals Interaction with existing chemicals contained in material	Chemical point of departure ingredients can be researched quite accurately as recent production batches No additional new dye chemicals	Present day finishing chemicals
Post-Consumer Primary Material	Dyes applied are known, as are their compliance risks and related thresholds.	Legacy ingredients from dyes and finishes. Present day finishing and dyeing chemicals Interaction with existing chemicals contained in material	No additional new dye chemicals	Legacy ingredients from dyes and finishes Present day finishing chemicals

Table 6: Comparison and overview: Chemical Management risk and benefits for Overdye process vs Mixing process

At the finishing stage, processing of recycled wool differs little from that of virgin wool:

Finishes that may potentially be applied – depending on customer requirements – and that might introduce chemical management challenges may include e.g. water and stain repellency characteristics (cf Table 1).

RSL Compliance of products made from recycled wool

Modern state-of-the-art processors of recycled wool, all across the production chain are (or should) be aware of REACH and similar legal requirements applicable to end-consumer products.

As a consequence, and precisely as a result of the legacy chemicals challenge that these manufacturers face, it would be considered normal to have a stringent testing regime in place.

Therefore, experts consider it good practice that at the point of handover to the customer – whether it is at fibre, yarn or fabric stage – the corresponding third-party laboratory test results are provided to avoid unwelcome surprises.

In addition, [Kettlewell, 2017] suggests requiring Ökotex100 or equivalent compliance to be in place. In this way, the testing ensures an approach that goes beyond mere regulatory compliance on the one hand, while at the same time testing for the presence of substances considered 'of concern' in best practice terms is also completed.

4.4 Leadtimes

Leadtimes, as found in locally and vertically integrated districts such as Prato in Italy, are in the global context very competitive, which is the result of two principal factors: The flexibility of the recycled wool industry overall (and the Prato one in particular); and the advantages offered by using this type of raw material which is in this present moment fairly readily available.

Leadtimes for purely recycled fibre may be around seven to eight weeks – the time needed for the fibre to be processed from primary raw material (e.g. jumpers) into fabric (cf. Table 7).

However, in cases where noils (combing waste) are used as primary material, it is possible for greige fabric to be produced ahead of time, stocked, and later piece dyed. This procedure allows for a (partial) decoupling of production leadtimes and customer demand/order cycles. In such cases, the leadtimes from customer order to delivery may be reduced significantly and can be as low as two to three weeks - merely the time needed for dyeing and finishing - in function of the backlog at the dye house (cf. Table 8).

Approximate: Used Wool Leadtime	
3 weeks for	Production of raw material fibre (sorting, pulling, blending – assuming colours are not 'special')
1 week for	Spinning (yarn counts, colour blends)
2 weeks for	Weaving
2 weeks for	Finishing
TOTAL: 7 to 8 weeks	<i>Important: dyeing not included, assumes fibres can be mixed from recycled wool colour palette</i>

Table 7: Typical leadtimes for fabrics made from recycled wool (pre- and post-consumer). Data courtesy of [NovaFides, 2017].

Approximate: Leadtime with Noils as raw materials	
1 weeks for	Obtaining Input Material
1 week for	Spinning (yarn counts, colour blends)
2 weeks for	Weaving
4 weeks for	Dyeing and Finishing
TOTAL: app. 8 weeks	<i>Important: As greige material typically is stocked by suppliers, the leadtimes can in fact be reduced to about three weeks.</i>

Table 8: Typical leadtimes for piece dye fabrics when produced from noils from scratch. Data courtesy of [NovaFides, 2017]

With the ever-growing relevance of sustainability for brands' materials choices, recycled wool offers a double advantage to material portfolios by combining environmental benefits with the option for European near-shore quality production at affordable cost. Hence, recycled wool now comes to bear in its own right.

Large international buyers such as Inditex [Fashionista, 2016], M&S [Telegraph, 2011; Edie, 2017], or H&M [H&M Materials] are not the only ones to have recognised this opportunity, and are actively investigating where and how to best make use of such an opportunity in scale – including possibly expanding it by closing the loop in their own product portfolio in the future [Guardian 2017].

Intuitively, recycled wool could offer many advantages: Reducing environmental impact as well as making good use of existing 'waste' material, so as to work towards 'closing the loop'. What could be seen throughout this report is, that there is a significant amount of skill and expertise required in order to truly leverage the material's potential and optimise its product value once it enters its second (recycled) life.

For brands open to experimentation and strong in innovation, it is a perfect time to look into how this material can be used suitably, effectively, and with the desired outcomes, both environmentally as well as from a product perspective.

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EDITORIAL INFORMATION

About this report

This document is the result of a research trip to the Italian city of Prato – one of the few centres in the world with strong expertise in the open and closed loop recycling of wool.

In the past two years or so, the interest in wool has grown again across the textile industry. At the same time, sustainability related discussions have taken place at a much stronger and more sophisticated level than ever before, covering topics such as animal welfare, environmental and social impact issues. Work done in this area on behalf of end-consumer brands, such as the development of the Responsible Wool Standard (RWS), which focuses on the traceability of virgin wool, have further fostered and strengthened the discussion.

Unlike many other textile fibres, used wool clothing has long been compatible with both open loop and closed loop recycling processes, and commercially exploited as a raw material for at least two hundred years.

The questions that have been worked on for materials such as cotton, polyester, nylon and even down are now being asked also for wool: is recycled, rather than virgin wool, a viable and desirable ingredient, both from a product as well as sustainability point of view?

Broadly, this document covers the following areas:

- Background: Terminology and legal setting
- Supply chain and production processes
- Sustainability benefits and challenges

It is important to state however, that this present document does not cover a scientific and nuanced discussion of environmental and/or social benefits or challenges comparing virgin vs recycled wool. The principle reasons for this decision is the lack of available and peer reviewed data, as well as methodological questions related to LCA framing.

About the European Outdoor Group (EOG)

The European Outdoor Group is the membership association of internationally operating outdoor brands, retailers and technology brands, in Europe.

The association exists to represent the common interests of the European outdoor industry, and was founded in 2003 by 19 of the world's largest outdoor companies, who recognised the need for a cohesive, cross-border approach to representation of the outdoor sector. Our membership consists – as at writing – of approximately 100 corporate members (brands, retailers, and technology brands) in addition to 10 national associations.

The origins of the outdoor industry lie in the enthusiasm and value sets of individual entrepreneurs who have challenged themselves in the outdoors and in the development of their business.

The EOG strongly believes that increased participation in outdoor sports will benefit both individuals and society as a whole. We share a vision to encourage people of all ages and in all locations to be active outdoors. As an industry we are also committed to maintaining 'our roots': the natural environment and society we draw our inspiration from.

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