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Comparative Environmental Performance of Major Textile Fibers and Fabrics

*Textiles
Today
A Cleaner
Tomorrow*

Evidence Review 2026

Dr. Chris DeArmitt

FIMMM, FRSC, CChem

Cotton • organic cotton
Linen/flax • viscose/rayon
Lyocell • polyester/PET
Nylon/polyamide • wool
Alpaca • cashmere



CLIMATE &
RESOURCES



WATER
IMPACTS



DURABILITY
& SERVICE



FIBER SHEDDING
& ENVIRONMENTAL
FATE



CIRCULARITY
& END OF LIFE

A PLASTICS RESEARCH COUNCIL PUBLICATION

FACTS FOR A BRIGHTER FUTURE

Comparative Environmental Performance of Major Textile Fibers and Fabrics

Evidence review focused on finished textiles, functional service, durability, life-cycle resource use, fiber shedding, environmental fate and end of life

Cotton • organic cotton • linen/flax • viscose/rayon • lyocell • polyester/PET • nylon/polyamide • wool • alpaca • cashmere

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Plastics Research Council

EVIDENCE SYNTHESIS • VERSION 1.0
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Prepared from the assembled textile-fiber literature and supporting study set.

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Executive summary

Environmental performance is a property of the finished textile system, not a “natural” or “synthetic” label. Compare equivalent acceptable service—such as a day of wear or a hotel-bed rental—using the actual product mass, construction, realized life, care, production location and end-of-life pathway. The evidence below shows how the denominator can change a result; it does not rank entire fiber classes (Laitala et al. 2018; Watson & Wiedemann 2019; Beton et al. 2014).

Four comparisons that explain the report

Study / application	Result within the study	Boundary that must travel with the result
T-shirts JRC, 2014	PET: about 25% lower climate-change impact and 21% lower fossil depletion than cotton per day of modeled wear.	Test-informed lifetimes: 50 / 80 / 95 washes for cotton / blend / PET. Care assumptions also differ. (§2.1)
Hotel sheets Kalliala & Nousiainen, 1999	The 50/50 cotton/PET blend used about 17% less laundering energy and 42% less production energy for equal 100-cycle service.	100 versus 50 modeled rentals. Production and laundering are separate terms; 42% is not a total-life-cycle saving. (§2.2)
Construction quality De Saxcé et al., 2012	Premium combed/easy-care cotton reached 100.2 modeled washes, versus 78 for the basic blend and 60 for basic cotton.	A product-engineering result, not an intrinsic lifetime for every cotton or polyester fabric. (§2.3)
Equal realized life Xu et al., 2026	PET: 9.62 kg CO ₂ e; cotton: 6.10 kg CO ₂ e when both garments were assigned 20 washes.	Different products and inventory from the JRC case. No product-specific lifetime difference was established. (§2.4)

Read across, not down: these are separate product-service systems, not interchangeable absolute LCAs or a league table. The case overview is retained in Figures 11A–11B; full source values and calculations are in Appendix B.

The central finding

Durability and care can change the environmental comparison when their benefits are actually realized. PET and cotton/PET perform well in the evaluated systems, while high-quality cotton can outperform poorer constructions. No fiber is assigned a universal rank.

Executive summary | interpretation and use

Question	What the evidence supports
Material-specific burdens	Cotton and organic-cotton results depend strongly on yield, location and water context. Linen conversion and care can dominate crop-stage advantages. Viscose and lyocell differ in process chemistry and energy needs. Animal-fiber climate burdens are strongly methane-related; service-life assumptions remain decisive. (§§3–4)
Microfibers and effects	Separate measured release, environmental composition, fate, exposure, laboratory effects and LCIA outputs. The reviewed field evidence does not establish greater PET harm at the exposures considered; this does not establish equal risk or absence of harm. Conditional model results and adverse laboratory findings remain part of the assessment. (§6)
Metals and treatments	Metals occur in natural, regenerated and synthetic textiles. The cotton manufacturing study traced metal increases at coloration and separately measured sweat extraction. Total content, release and absorbed dose are not interchangeable. The historical finished-fabric criteria were met in that study. (§6.4; Figure 9A)
Carbon and end of life	Fossil feedstock, fuel burned, total energy and greenhouse-gas emissions are different quantities. Carbon-containing fibers can release CO ₂ when burned. Biogenic uptake and release must be accounted for consistently; temporary fossil-carbon storage is not atmospheric removal. (§§1.7, 5.4; Figure 6A)
Cost, recycling and claims	Cost per service depends on purchase price, use and care—not raw-fiber price alone. PET, cotton and wool all have recycling routes with different constraints. Technical recyclability is not an observed recycling rate, and recycled content is not an automatic environmental credit. (§§5.5–5.6)

Apply one standard to all materials. Keep climate, fossil resources, land and water separate; identify whether a quantity was measured, test-informed, assumed or model-derived; and test whether plausible changes in lifetime, care, geography or allocation alter the conclusion. The summary matrix follows in Figure ES1 and is repeated in the conclusions. Source-linked comparisons and the ten-fiber evidence map remain in Figures 11A–11B in Section 7.

Current evidence synthesis by criterion

Source-bounded findings — not a universal fiber ranking or weighted “eco-score”

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Material	Climate Named case / stage	Fossil resources & energy Indicator / stage stated	Land Study-specific finding	Water Study-specific indicator	Durability & service Evidence type stated	Evidence limits No overall confidence grade
Polyester (PET)	Lower in JRC ≈25% below cotton per day of wear [1]	Lower in JRC ≈21% below cotton; fossil depletion / day [1]	Lower in JRC Agricultural-land occupation / day [1]	Lower in JRC Water-depletion indicator / day [1]	95 modeled washes Cotton: 50. Test-informed; care also differs [1]	One named service case Xu climate reverses at 20 assumed washes [4]
Cotton	Higher in JRC Reference = 100; PET ≈75 per day [1]	Higher in JRC Reference = 100; PET ≈79 per day [1]	Higher in JRC Same land-occupation comparison as PET [1]	Higher in JRC Same water-depletion comparison as PET [1]	Construction matters Premium cotton outlasted basic blend sheets [6]	Not a fiber constant Yield, care and product design change results [17]
Organic cotton	Yield-dependent No universal per-kg climate advantage [8]	Input / yield trade-off Lower inputs need not lower impact / kg [8]	Yield-dependent Lower yield can raise land needed / kg [17]	Location-dependent Organic does not mean low water scarcity [17]	Not a durability label Construction, not farming label, determines service [17]	Cultivation evidence Matched service advantage not established [8,17]
Linen / flax	Stage-dependent Crop gains; yarn conversion can dominate [9,16]	261 MJ/kg yarn Non-renewable energy; not fossil-only [9]	Yield-dependent Favorable crop examples; no service rank [17]	Often low irrigation Retting and processing still matter [17]	Service rank unresolved Garment ageing exists; matching is limited [16]	Production ≠ service Yarn data cannot rank finished garments [9,16]
Viscose / rayon	Process-dependent Production region and conversion matter [10]	Conversion-sensitive Heat, electricity and chemical recovery [10]	Forestry-dependent Pulp source and allocation matter [17]	Process-dependent Water use and chemical recovery vary [17]	Realized-life gap Comparative service ranking unresolved [17]	Production evidence No generic garment-life claim follows [10,17]
Lyocell	Energy-sensitive Cleaner grids improve production GHG [10]	Recovery energy Heat / electricity for solvent recovery [10]	Forestry-dependent Pulp source and allocation matter [17]	System-dependent Water result remains process-specific [17]	Realized-life gap Yarn tenacity is not measured garment life [10]	Metric-sensitive Mass adjustment changes GHG comparisons [10]
Nylon / polyamide	Above PET in model Polymer production: 8.64 vs 2.70 kg CO ₂ e/kg [11]	Higher CED than PET 129.7 vs 78.4 MJ/kg; not fossil-only [11]	Low crop-land use Component finding; not a service rank [17]	No crop irrigation Process water remains; not a full water rank [17]	Failure mode matters Strong abrasion resistance; PET more wash-stable [17]	Upstream comparison Service-life LCA vs PET remains a gap [17]
Wool	Methane hotspot High upstream burden; not a per-service rank [12]	Processing hotspot 0.88 MJ fossil energy / wear in Merino model [12]	Grazing-land demand High upstream demand; no service rank [17]	Context-dependent Geography and scarcity method matter [12,17]	Realized use matters Long use and less washing lower modeled impacts [12]	Claim-specific support Methane: high; service / fate: moderate [17]
Alpaca	Farm methane hotspot 84.96–92.69% of farm GWP; not whole-life [13]	Comparative gap Insufficient cross-system resource evidence [17]	Grazing dependence High reliance; no service rank [17]	Comparative gap Water comparison not established [17]	Lifetime borrowed 109 wears assumed from Merino; not measured [13]	Upstream vs service Upstream: moderate; service / fate: low [17]
Cashmere	155–183 kg CO₂e/kg Clean dehaired fiber; upstream, not per wear [14]	109–144 MJ/kg PEF fossil resource; upstream, not per wear [14]	High grazing burden Land-use indicator; not a service rank [14,17]	Comparative gap Finished-service water evidence insufficient [17]	Longevity unresolved No demonstrated offset; not proof of short life [15]	Some mass efficiency Credit matched function; no universal lifetime [15]

Lower impact Named comparison only
 Higher impact Named comparison only
 Context-dependent Not an intermediate rank
 Evidence gap Not a finding of poor performance
 Not graded Descriptive evidence / limits

Counterexample retained: Xu [4] reports cotton 6.10 vs PET 9.62 kg CO₂e at 20 assumed washes; a different product system.

PET/cotton colored cells use the same JRC per-day model [1]. Nylon/PET colored cells are upstream [11]. Other stages are not interchangeable. JRC lifetimes are test-informed, with different care assumptions; production is already included. Service and evidence-limit columns are not impact-graded. Source numbers [1–17] link through Appendix B5. Appendix B6 records every cell's classification and boundary. Fiber release, fate and effects remain separate.

Figure ES1. Source-bounded ten-fiber summary. Sources: Appendix B5 • Cell classifications: Appendix B6

1. Scope, evidence hierarchy and analytical rules

1.1 Question addressed

The question is not “Which fiber has the lowest cradle-to-gate number per kilogram?” It is: “How much environmental burden is required to deliver a comparable amount of acceptable textile service?” This distinction is required because textiles made from different fibers differ in mass, yarn fineness, construction, abrasion resistance, dimensional stability, drying requirements, washing frequency and realized lifespan. Laitala, Klepp & Henry (2018) showed why fiber-production rankings omit product lifespan, quality, functionality and use. Watson & Wiedemann (2019) likewise identified functional unit and incomplete system boundaries as major sources of error in textile rating systems.

The present review covers cotton, organic cotton, linen/flax, regenerated cellulose fibers (viscose/rayon and lyocell), polyester (PET), nylon/polyamide, wool, alpaca and cashmere, plus cotton/PET blends where direct evidence exists. Carpets and technical textiles are used only when they illuminate a methodological issue; they are not treated as direct proxies for apparel.

1.2 Independence, funding and competing interests

This Plastics Research Council evidence review was independently initiated and prepared by Dr. Chris DeArmitt without external funding, sponsorship or commissioning. No outside party directed the research question, source selection, evidence grading, interpretation, wording, conclusions, graphics or publication decisions. The work was undertaken without payment for preparation of this report and was not submitted to an external sponsor for review or approval. Evidence was evaluated according to study design, analytical validity, system boundary, functional unit, service-life relevance, consistency and causal strength, irrespective of whether a finding was favorable or unfavorable to natural, regenerated or synthetic fibers or to any particular material or industry. Dr. DeArmitt is founder of the Plastics Research Council and president of Phantom Plastics; these affiliations are disclosed because this review compares natural, regenerated and synthetic textile materials. No external sponsor funded, commissioned, selected evidence for, reviewed or approved this report.

Acknowledgement. The author thanks Neil Shackelton APkgPrf FIMMM, independent life cycle analysis expert and founder of Medoola, for reviewing this report and for valuable contributions. His review was advisory; editorial control, source selection, interpretation and final conclusions remained with the author.

1.3 Evidence assembly, inclusion and reproducibility

This document is a structured evidence synthesis, not a preregistered PRISMA systematic review. The source library was assembled iteratively from primary papers and reports supplied for the project, citation chaining from relevant studies and reviews, targeted bibliographic searches for specific comparison questions, and verification of recent literature through 29 September 2026. Because the library was built over multiple review rounds rather than from one frozen database search and query string, retrieval is not fully reproducible in the manner of a formal systematic review and the report does not claim exhaustive coverage of every textile study. The inclusion logic and evidentiary weight are therefore stated explicitly so that individual conclusions can be audited against the cited sources.

Evidence was prioritized when it directly addressed the product-service question: matched finished textiles with measured or test-informed durability/service life and LCA; cradle-to-grave garment LCAs with explicit lifetime/care; matched mechanical or shedding studies; transparent fiber/yarn/fabric LCAs; field-fate studies; comparative toxicology; systematic reviews; and standards or technical reports containing unique, auditable primary data. Advocacy or marketing summaries were not used to override primary evidence. Duplicate publications or reports based on the same dataset were not treated as independent replication. Industry-

funded work was scrutinized for methods, assumptions, transparency and reproducibility but was not rejected solely because of funding source.

Confidence reflects seven attributes: directness of the functional unit, quality of analytical methods, degree of material/construction matching, measured versus assumed service life, completeness of the life-cycle boundary, replication/consistency, and sensitivity to allocation or model assumptions. Numerical results are kept within their original functional unit, geography, energy mix and boundary unless an explicit within-study normalization is reported. Incompatible LCAs are therefore compared qualitatively rather than pooled.

1.4 Evidence hierarchy used in this report

Level	Evidence type	Interpretive weight
A	Matched finished products or fabrics with measured or test-informed durability/service life and LCA	Highest when service life is directly observed; high when lifetime is transparently modeled from standardized durability testing. Direct product comparison, but modeled lifetime adds uncertainty.
B	Cradle-to-grave garment LCA with observed or well-supported use/lifetime data	High, but sensitive to consumer-behavior assumptions.
C	Matched durability/physical-property studies without full LCA	High for material performance; cannot alone establish total environmental impact.
D	Fiber/yarn/fabric cradle-to-gate LCA	Important upstream input, but not a final product ranking.
E	Field persistence, biodegradation or shedding studies	Used as a separate environmental-fate evidence layer unless an accepted LCIA characterization factor exists.
F	Industry or advocacy summaries	Context only unless traceable to primary data; not used to override peer-reviewed or transparent technical evidence.

1.5 No single weighted “eco-score”

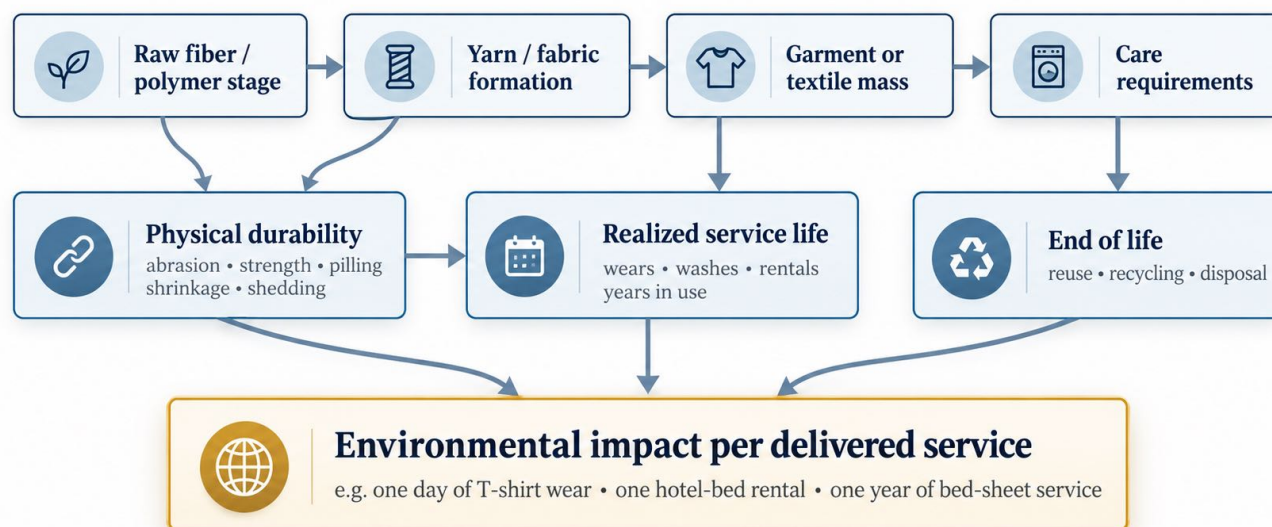
Climate change, fossil-resource use, water scarcity, land occupation, eutrophication, ecotoxicity and other impacts are different physical outcomes. Combining them into one number requires value-based weighting. This report therefore compares categories separately and identifies where conclusions are robust across categories. A single ordinal “greenest fiber” ranking is avoided unless the underlying functional unit and weighting rule are explicitly defined. Some LCIA frameworks use the word “damage” for a modeled endpoint indicator. In this report, that terminology is not treated as evidence of observed environmental damage: model outputs are described as characterization factors, potential-impact indicators or modeled ecosystem-quality results unless independent field evidence demonstrates ecological injury.

A 2023 systematic review by Fonseca et al. illustrates why numerical normalization alone does not solve this problem. Its compiled cradle-to-grave values show very large material ranges, but the underlying studies used different garment lifetimes, care frequencies, inventories and boundaries. The review is useful evidence of heterogeneity; its kg-normalized headline values are not treated here as a service-equivalent fiber ranking. The 2025 Apparel & Footwear PEF CR likewise prohibits use of its single score for business-to-consumer comparative communication, consistent with this report’s decision not to collapse distinct impact categories into one value-based eco-score (Fonseca et al. 2023; Apparel & Footwear PEF Technical Secretariat 2025).

1.6 Functional service and durability

How this review compares textile materials

Environmental performance is evaluated per delivered textile service—not per kilogram of fiber alone



Core principle: service life, textile construction, care and replacement rate can change the environmental ranking.

Figure 1. Conceptual diagram showing why this review compares textiles by delivered service rather than by kg of fiber alone.

The preferred functional unit is application-specific: one day of acceptable T-shirt wear; one hotel-bed rental; a fixed number of bed-nights; a defined area of upholstery for a defined period; or another measure of equivalent performance. Mechanical durability should be supported by the relevant failure modes—abrasion, tensile/burst strength, pilling/appearance, dimensional stability and material loss—rather than a single test where possible. Realized lifetime should be distinguished from physical capability: a mechanically durable garment may still be discarded early for fashion, fit, staining or aesthetics.

The 2025 Apparel & Footwear Product Environmental Footprint Category Rules independently adopt a per-use functional unit and define reference flow as a fraction of product lifetime (for example, 1/45 of a T-shirt under the default lifetime). They also incorporate intrinsic-durability and reparability multipliers. This is methodological support for service normalization, not direct evidence that a specific garment lasts exactly the default number of uses: the PEFCR explicitly combines test results with Technical Secretariat judgement, and the intrinsic-durability multiplier ranges from 0.67 to 1.45. Measured product-specific lifetime remains preferable where available.

1.7 Fossil energy and carbon accounting

Four quantities must not be conflated: (1) fossil feedstock embodied in a polymer, (2) fossil fuel burned to provide process heat/electricity/transport, (3) total or non-renewable cumulative energy demand, which may include nuclear energy depending on the method, and (4) greenhouse-gas emissions, which may be dominated by methane or nitrous oxide even when fossil-energy use is modest. The current review therefore uses study-reported fossil-resource or fossil-energy metrics when available. It does not convert all electricity to “fossil fuel” with one global percentage when the LCA already incorporates a regional energy mix.

Lower fossil-resource depletion does not, by itself, prove lower fossil fuel combustion or show that a published GHG result is wrong. The resource indicator may include feedstock retained in the material, whereas GHG accounting tracks emissions and removals, including methane and nitrous oxide. Carbon stored in PET is not

carbon already burned; fossil feedstock must not be counted as combusted at production and again at incineration. The same carbon-flow logic applies to every fiber (World Resources Institute & WBCSD 2011, Chapter 11; Section 5.4).

Important correction to common reasoning

Fossil feedstock origin does not determine service-normalized fossil-resource demand. Biobased materials may use fossil energy for fertilizer, machinery, irrigation, spinning, heat, transport and laundering. Compare the study's stated resource indicator for equivalent service; do not rename it "fuel burned" unless fuel and feedstock inventories have been separated.

Figure 6A in Section 5.4 summarizes the parallel carbon-flow accounting for fossil-derived and biogenic fibers.

1.8 Environmental-fate terminology

- Degradation: any physical or chemical deterioration, including chain scission, oxidation, surface erosion or fragmentation.
- Fragmentation: production of smaller particles; not equivalent to destruction or mineralization.
- Biodegradation: biologically mediated breakdown; the endpoint and test method must be specified.
- Mineralization: conversion of organic carbon to inorganic carbon, commonly measured as CO₂ under aerobic conditions. Ultimate biodegradation can also produce new biomass; biomass formation is not itself mineralization. Anaerobic degradation and methane formation should be described separately (OECD 1992, Annex I).
- Persistence: continued presence under a specified real environmental condition. Persistence at one site does not establish universal persistence in all environments.

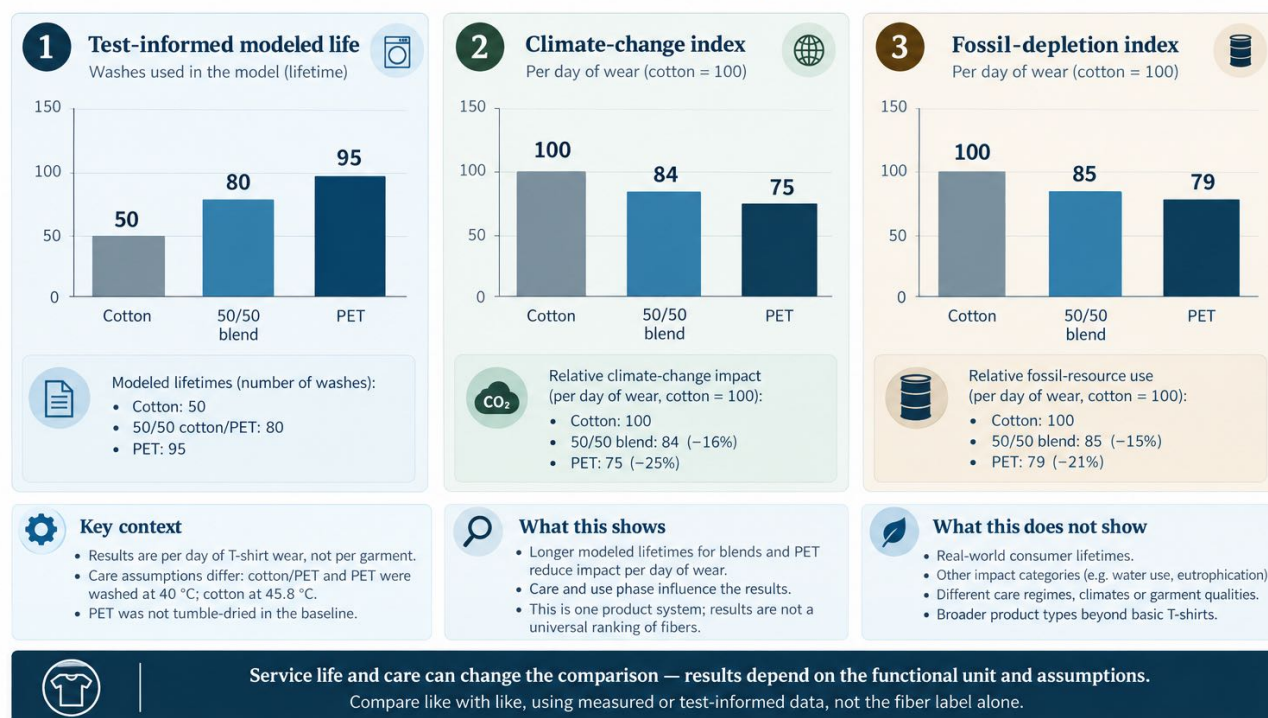
2. Direct finished-textile comparisons: the strongest evidence

2.1 European Commission JRC IMPRO T-shirt comparison

JRC T-shirts: service and care change the comparison

Functional unit: one day of T-shirt wear • Test-informed lifetimes and modeled life-cycle impacts (Beton et al. 2014)

SAME FUNCTION
DIFFERENT CARE
DIFFERENT OUTCOMES



Source: Beton et al. (2014), JRC IMPRO Textiles, Table 57 and Figure 55. Indices rounded; see §2.1.

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Figure 2. JRC IMPRO T-shirt comparison: test-informed modeled lifetime and rounded service-normalized impact indices. The modeled care assumptions also differ; the full result must not be attributed to durability alone.

The JRC IMPRO Textiles study is one of the strongest direct comparisons because it used the functional unit “wearing one T-shirt for one day” and did not assume identical lifetimes across cotton, cotton/PET and PET. Because reliable public service-life data were unavailable, ENSAIT conducted standardized Martindale abrasion, Crock Meter rubbing-fastness and machine-wash color-fastness testing. Those results were converted into modeled lifetimes of 50, 80 and 95 washes. The values are therefore best described as test-informed modeled lifetimes—not direct observations that each garment survived exactly that number of wash cycles (Beton et al. 2014).

Fiber composition	Modeled lifetime	Lifetime ratio vs cotton	Selected result vs cotton
100% cotton	50 washes	1.00	Reference
50% cotton / 50% PET	80 washes	1.60	~16% lower climate impact; ~15% lower fossil depletion

Fiber composition	Modeled lifetime	Lifetime ratio vs cotton	Selected result vs cotton
100% PET	95 washes	1.90	~25% lower climate impact; ~21% lower fossil depletion

The study reports that the cotton/PET and PET T-shirts had lower environmental impacts than cotton for all reported indicators. It identifies longer lifetime as the main explanation; PET-containing T-shirts also had a lower assumed washing temperature (40 °C vs 45.8 °C for cotton), and the PET T-shirt was not tumble-dried in the baseline. Therefore, the entire difference should not be attributed to polymer durability alone. Nonetheless, this case directly demonstrates that a ranking can reverse when the functional unit moves from material mass to modeled delivered service (Beton et al. 2014, Table 57 and Figure 55).

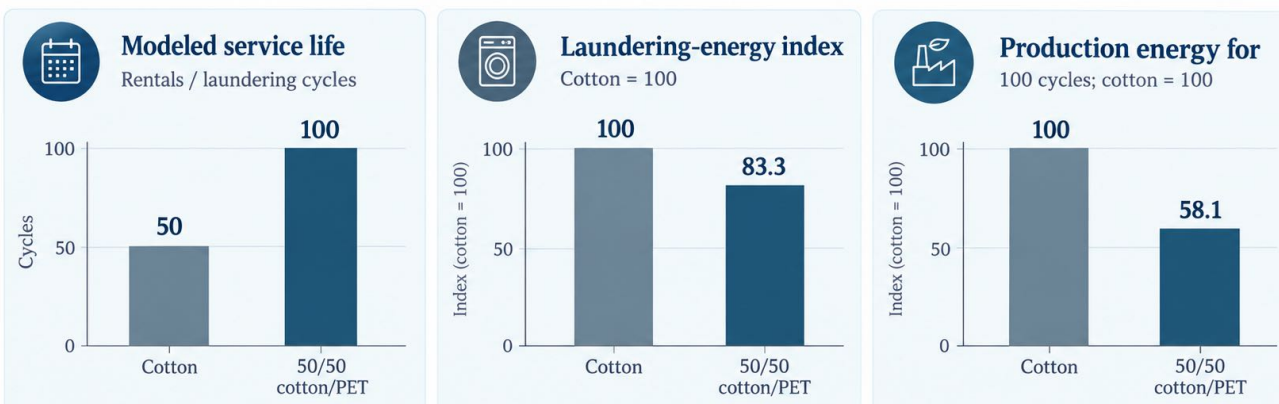
Why the JRC result matters for fossil-resource claims

The PET T-shirt had lower modeled fossil depletion than cotton under the specified lifetime and care assumptions. Fossil origin and life-cycle fossil-resource demand are different quantities. This indicator does not separately measure how much fossil fuel was burned.

2.2 Hotel sheets: Kalliala & Nousiainen (1999)

Hotel sheets: production and care are separate terms

Kalliala & Nousiainen (1999) • Cotton versus 50/50 cotton/PET • Equal 100-cycle modeled service



Blend laundering energy: about 17% less ($100 \div 1.20 = 83.3$). Production energy for equal service: about 42% less ($100 \div 1.72 = 58.1$). Neither is a total life-cycle index.



Counterexample: average laundering mass loss was 1.6% for cotton and 2.6% for the blend. Greater abrasion life is not the same as lower shedding.

Source: Kalliala & Nousiainen (1999), pp. 11–12; report §2.2 and Appendix B.

Figure 3. Kalliala & Nousiainen (1999): modeled rentals, laundering energy and production energy for equivalent 100-cycle service. Cotton is indexed to 100 in the energy panels; the blend indices are 83.3 and 58.1. Production and care are separate terms, not a single total-life-cycle index.

Kalliala & Nousiainen studied commercial hotel bed linen and textile services. At the raw-fiber stage, their inventory found cotton fiber production used about 40% less energy than polyester fiber production even when the feedstock value of crude oil and natural gas used as polyester raw material was included. That fiber-stage advantage changed when fabric durability and laundering were considered.

- 100% cotton retained more moisture after laundering. The authors estimated 29% more drying energy and about 20% higher total laundering energy than 50/50 cotton/PET. With cotton indexed to 100, the blend is $100/1.20 = 83.3$, or about 16.7% lower—not 20% lower.
- Within comparable specific-mass ranges, 50/50 cotton/PET sheets had at least twice the abrasion resistance of 100% cotton sheets; tensile tests also indicated approximately twice the potential physical life.
- The modeled rate-of-use was 100 rentals/washes for 50/50 cotton/PET versus 50 for cotton.
- Under the modeled 100-cycle service comparison, two cotton sheets were required versus one cotton/PET sheet. Producing the cotton sheets required on average 72% more energy and more than 300% more water. The blend production-energy index is therefore $100/1.72 = 58.1$, about 42% lower. GWP and acidification potentials for producing the blend sheet were 38% lower than for the two cotton sheets. These are production results for equivalent modeled service, not production-plus-laundering totals.
- Cotton spinning losses were reported at almost 20% versus 2–3% for polyester spinning in the studied supply chains.
- The same study reported average material losses after 100 laundering cycles of 1.6% for cotton and 2.6% for the blend. This counterexample is important: superior abrasion resistance or a longer modeled service life is not synonymous with lower mass loss or lower microfiber release (Kalliala & Nousiainen 1999, Results).

The authors concluded that the compared 50/50 cotton/PET hotel sheets had fewer environmental consequences because of longer assigned service and lower drying-energy demand (Kalliala & Nousiainen 1999). This older regional inventory is not a current global estimate. The rentals were derived from durability tests and available industry statistics; the participating laundries did not keep product replacement-ratio statistics. The conclusion applies to the studied sheet constructions, not automatically to all hotel textiles.

2.3 Bed-sheet lifetime: De Saxcé, Pesnel & Perwuelz (2012)

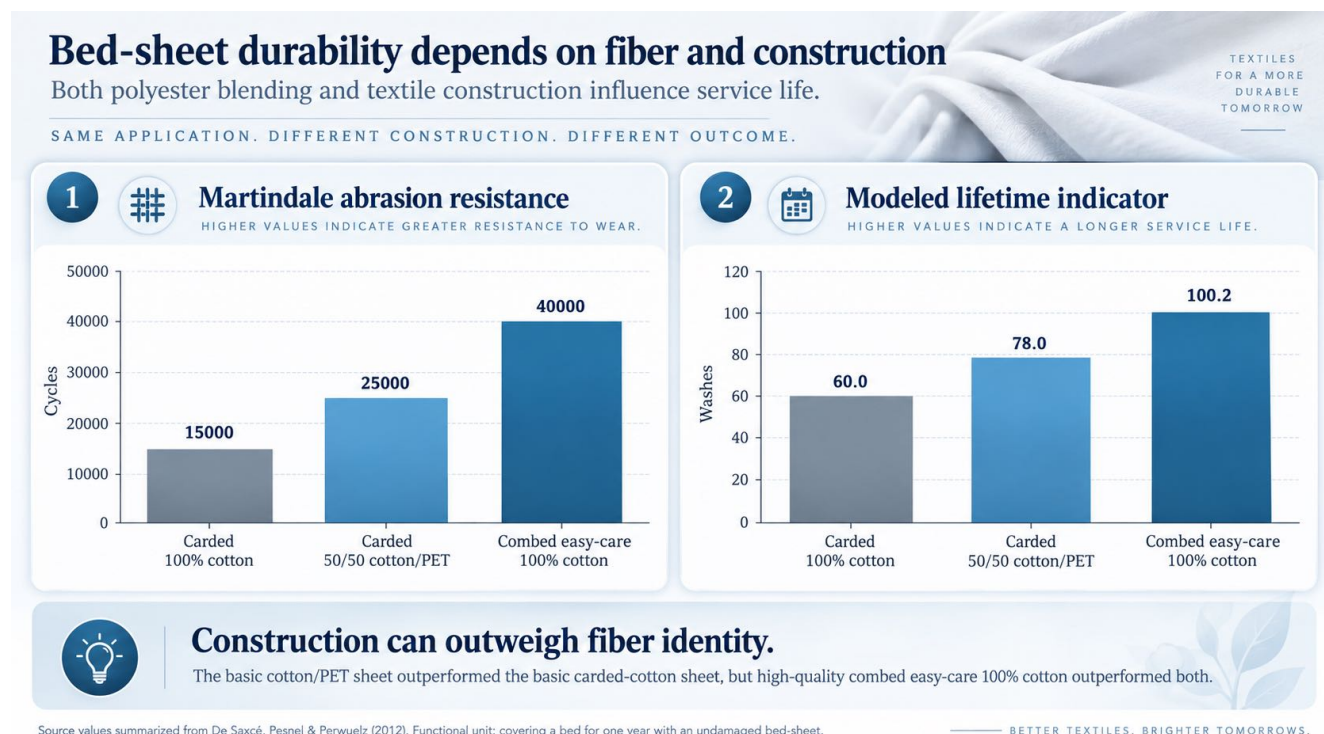


Figure 4. Summary of De Saxcé et al. (2012). The key lesson is that both fiber composition and textile construction influence lifetime.

De Saxcé et al. compared eight plain-weave sheets of approximately 115 g/m² and explicitly defined the functional unit as “covering a bed for one year with an undamaged bed-sheet.” They combined abrasion and color-fastness testing into a lifetime indicator.

Sample	Construction / fiber	Martindale cycles	Modeled lifetime
1	100% cotton, carded	15,000	60 washes
2	50/50 cotton/PET, carded	25,000	78 washes
8	100% cotton, combed + easy-care	40,000	100.2 washes

The matched basic cotton/PET sheet therefore delivered ~30% more modeled life than the carded-cotton reference, consistent with a polyester durability contribution. Equally important, the best 100% cotton construction substantially exceeded both. The paper showed that lifetime had a clear influence on energy, water and impact indicators, and that manufacturing changes which increase initial impacts can still reduce impacts per year if they increase useful life sufficiently (De Saxcé et al. 2012).

Unbiased interpretation

The evidence supports two statements at the same time: polyester can materially improve durability; and high-quality cotton can outperform lower-quality polyester blends. Fiber composition is one determinant among yarn quality, weave/knit, mass per area, finishing and care.

2.4 Equal-lifetime fast-fashion comparison: Xu et al. (2026)

Xu et al. modeled one polyester and one cotton fast-fashion T-shirt under the same 20-wash functional scenario. Under that equal-realized-lifetime scenario, PET produced 9.62 kg CO₂e versus 6.10 kg CO₂e for cotton, while cotton dominated land and water use. Air freight was the most sensitive climate parameter, and extending life could cut GHG emissions by about half in both systems (Xu et al. 2026).

This is a legitimate equal-realized-lifetime scenario and is not inherently inconsistent with the JRC case. Different garments, inventories, care assumptions and retirement patterns can produce different results. Xu et al. do not establish a product-specific PET-versus-cotton lifetime difference, and the JRC 95/50 ratio should not be imported into these garments without supporting evidence. Together, the studies show why both lifetime assumptions and the full product-system inventory must remain visible.

2.5 Methodological example: wool vs nylon carpet

Sim & Prabhu (2018) reported 6.35 kg CO₂e and 20.42 MJ for 0.09 m² of wool carpet, versus 4.80 kg CO₂e and 25.42 MJ for nylon. Their assumed service lives were 25 years for wool and 11 years for nylon. Normalizing the headline figures by those stated service lives changes the interpretation: approximately 0.254 versus 0.436 kg CO₂e per 0.09 m²-year, and 0.82 versus 2.31 MJ per 0.09 m²-year. This is not evidence that wool clothing is better than nylon clothing—the product is carpet and lifetime assumptions are product-specific—but it is a useful demonstration that the denominator can dominate the conclusion.

2.6 Koch et al. (2025): favorable modeled PET results followed by a qualitative exclusion

Koch et al. (2025) modeled the environmental pressure of Dutch clothing consumption using a hybrid input-output/process approach. The study was explicitly limited to two environmental indicators—greenhouse-gas emissions and land use—and defined the functional unit as the purchase and use of one garment over its total lifetime. For alternative materials, the model incorporated material-specific changes in garment weight,

lifetime, washing frequency, washing temperature and drying behavior. This makes the study directly relevant to the service-based framework used in the present review (Koch et al. 2025; Supplementary Information SI 6). The supplementary results show a consistent advantage for the polyester option relative to the study default in both modeled impact categories. Annual GHG emissions were lower by 8.7% for the pullover, 15.1% for the shirt and 14.2% for trousers. Annual land use was lower by 83.6%, 84.3% and 77.1%, respectively. The study’s underlying fiber inventory likewise assigned polyester 4.3 kg CO₂e/kg and 0.2 m² land/kg, compared with 4.6 kg CO₂e/kg and 5.8 m²/kg for conventional cotton, 46.7 kg CO₂e/kg and 97.2 m²/kg for wool, and 1.4 kg CO₂e/kg and 0.4 m²/kg for linen. These values should not be treated as universal material constants; they are inputs to this specific model. Nevertheless, they establish what the authors’ own calculation actually found.

Table 3A. Koch et al. (2025) SI 6 results for the default and polyester material options. Polyester was not the lowest-GHG option in every material comparison—some bast-fiber and lyocell scenarios were lower—but it was lower than the default for every garment and had the lowest land-use values among the material options modeled.

Garment	Default GHG kg CO2e/yr	Polyester GHG kg CO2e/yr	Default land m²/yr	Polyester land m²/yr
Pullover	3.307	3.019 (-8.7%)	0.752	0.123 (-83.6%)
Shirt	2.219	1.884 (-15.1%)	0.499	0.078 (-84.3%)
Trousers	5.563	4.776 (-14.2%)	1.798	0.412 (-77.1%)

Polyester versus the study’s default garments

Koch et al. (2025), Supplementary Information SI 6 • Annualized model outputs, not all-material rankings

Garment	GHG: default → PET	Land: default → PET	PET change ¹
 Pullover	3.307 → 3.019 kg CO ₂ e/year	0.752 → 0.123 m ² /year	GHG -8.7% Land -83.6%
 Shirt	2.219 → 1.884 kg CO ₂ e/year	0.499 → 0.078 m ² /year	GHG -15.1% Land -84.3%
 Trousers	5.563 → 4.776 kg CO ₂ e/year	1.798 → 0.412 m ² /year	GHG -14.2% Land -77.1%



PET was lower than the default on both modeled indicators. It was not the lowest-GHG material in every comparison; some bast-fiber and lyocell scenarios were lower.

Model includes garment mass, lifetime and care. ¹ Percentage labels retain the reported rounding in Table 3A.
Source: Koch et al. (2025), SI 6; report §2.6, Table 3A and Appendix B.

Figure 4A. Koch et al. (2025), SI 6: polyester versus the study’s default garments, not versus every alternative material. Both annualized indicators were lower than the default; some bast-fiber and lyocell scenarios had lower GHG than PET.

Despite those quantitative results, the authors explicitly excluded polyester from their “environmentally-friendly material” selection because polyester fabrics release microplastics. The three references cited for this decision—Hernandez et al. (2017), Dalla Fontana et al. (2020) and Šaravanja et al. (2022)—demonstrate that polyester textiles can release fibers during washing. They do not establish that polyester produces a larger total fiber burden or greater environmental effect than all alternative textiles, and microfiber pollution was not one of the two indicators in the Koch et al. model. The exclusion was therefore an external qualitative criterion

rather than an output of the modeled GHG/land-use comparison. 2026 LCIA developments now provide a route to calculate model-based aquatic microfiber characterization terms; a future reanalysis should apply such methods comparatively, label the output as modeled potential impact rather than observed damage, and avoid a categorical yes/no exclusion (Saadi & Boulay 2026; Verones et al. 2026).

The treatment of organic cotton provides a useful methodological contrast. Koch et al. retained organic cotton within the “environmentally-friendly” group even though their own model predicted higher land use, citing biodiversity benefits of organic farming that were outside the modeled indicators. Polyester, by contrast, was removed despite favorable modeled GHG and land-use results because of a potential microfiber disadvantage that was also outside the model. Both decisions can be discussed as broader sustainability judgments, but they should not be presented as if they arose from a common quantitative comparison. A consistent comparative assessment would quantify—or at minimum apply symmetrically—the external criteria used to override the modeled result.

Methodological lesson

If microfiber emissions are included in a comparative assessment, distinguish measurement from modeling. GLAM and Saadi & Boulay provide LCIA characterization factors that can generate a modeled potential-impact term, but that term is not direct evidence of ecosystem damage. Release or persistence alone likewise does not establish harm. A defensible comparison keeps release inventory, environmental concentration, fate, laboratory hazard, demonstrated field effect and the other life-cycle impact categories separate for all candidate fibers.

2.7 Modern industrial laundering: Jasińska (2023)

Jasińska (2023) provides a modern physical-durability test relevant to the older hotel-sheet evidence. Five bed-linen fabrics—two 100% cotton, two 50/50 cotton/PET and a cotton reference—were followed through up to 100 commercial wash/dry cycles. The products had similar mass per area (approximately 140–150 g/m² for the four commercial fabrics) but differed in weave, yarn system and fiber length, so the study is not a perfectly matched chemistry experiment.

After 100 industrial washes, the largest strength loss in the cotton fabrics was about 30%, whereas the 50/50 cotton/PET fabrics lost up to about 20% and were described as more durable. Both cotton and blend fabrics nevertheless retained strong mechanical performance after 100 chlorine-free cycles, and the author judged 200 or more washes plausible from the viscosity/strength trends. Chlorine treatment caused much faster cellulose damage. This independently supports two existing conclusions: adding PET can improve laundering durability, and well-constructed cotton can itself be highly durable. Because construction was not held constant, the exact 30% versus 20% difference should not be attributed to fiber chemistry alone.

2.8 A conditional wool-versus-synthetic reversal: Bech et al. (2019)

Bech et al. modeled a highly specific military base-layer service: providing T-shirts to one soldier for six months. The reference used five 157-g shirts made from 50% polyester/50% nylon and 36 machine washes per tour; the proposed service system used three same-mass 100% Merino shirts and 20 washes, with collection, reuse over multiple six-month tours and a 30% raw-wool substitution credit for closed-loop recycling. On a single-shirt basis, the Merino shirt’s climate-change impact was about 3.5 times that of the synthetic reference because wool production was much more GHG intensive.

The service-system model then reversed the result. The authors’ recommended scenario reported 17.7 kg CO₂e per functional unit for the reference system versus 7.0 kg CO₂e for the proposed Merino PSS. Their sensitivity analysis showed that reducing Merino service from four six-month tours to two was enough to reverse that advantage. The PSS had not yet been implemented, and quantitative reuse/refurbishment process data were omitted. The study is therefore strong evidence that service life and care can overturn a per-garment result, but only moderate evidence for the exact size of a wool advantage in real operation.

3. Fossil resources and energy: feedstock is not fuel use

3.1 Accounting framework

For this review, fossil-resource data are interpreted in the following order: (1) a study-reported fossil-energy or fossil-resource indicator; (2) a separated cumulative energy demand by source; (3) if neither exists, a future reconstruction from reported electricity, thermal fuel and transport using the region/year energy mix. Total “energy” values are not silently relabeled as fossil fuel because electricity may include nuclear, hydro, wind, solar or biomass.

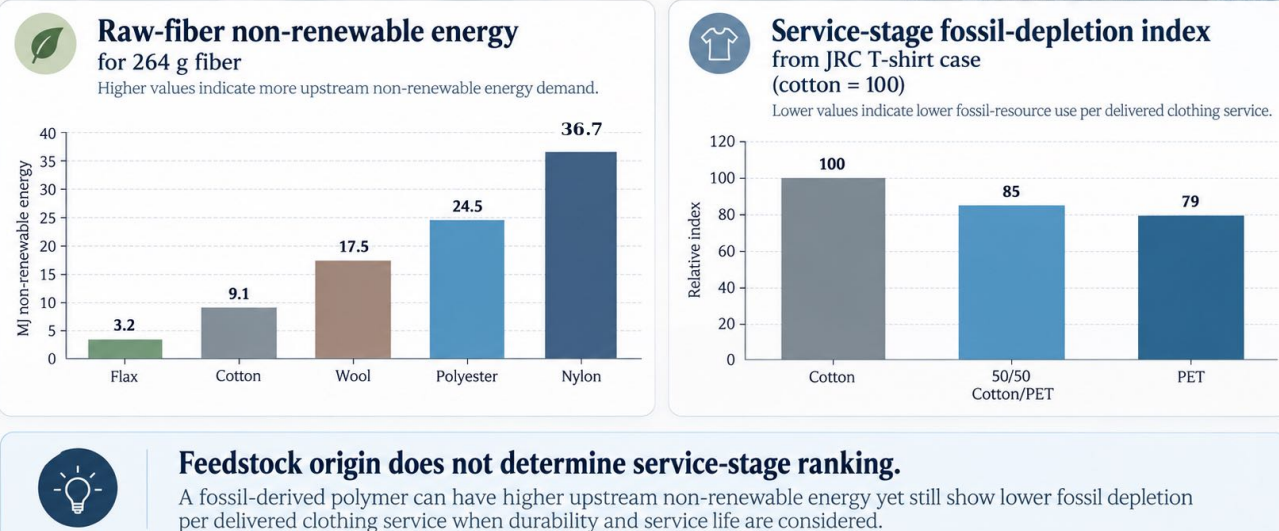
Quantity	What it means	Why it matters
Fossil feedstock	Oil/gas carbon incorporated into polymer or chemical intermediates	Resource use; not necessarily combusted during production.
Fossil fuel burned	Coal/oil/gas combusted for electricity, heat, transport, fertilizer, machinery, etc.	Directly drives fossil CO ₂ and fossil-resource consumption.
ADP fossil / fossil resource use	LCA metric for depletion/use of fossil energy carriers; method-specific	Best available common indicator when reported; may include feedstock as well as fuel.
Non-renewable CED	Primary non-renewable energy; may include nuclear as well as fossil depending method	Must not be called “fossil energy” without decomposition.
GHG / GWP	CO ₂ e from CO ₂ , CH ₄ , N ₂ O and other gases	Can be high even when fossil energy is moderate, as wool/cashmere demonstrate.

3.2 Selected upstream energy/resource results

Feedstock origin is not the same as life-cycle fossil-resource use

Raw-material origin and full delivered-service performance answer different questions.

SAME MATERIALS. DIFFERENT FUNCTIONAL QUESTIONS. DIFFERENT RESULTS.



The panels answer different functional questions. A fossil-derived polymer can have higher upstream energy yet lower fossil depletion per delivered clothing service.

SCIENCE FOR CIRCULAR TEXTILES

Figure 5. Left panel: Schmutz et al. (2021), non-renewable cumulative energy demand (nr-CED) for 264 g of fiber under their raw-material comparison; right panel: Beton et al. (2014), JRC service-normalized T-shirt fossil-depletion index. The panels answer different functional questions and are not a direct material ranking.

The following figures are deliberately not presented as a direct ranking because boundaries and indicators differ. They are included to show the magnitude and, crucially, the separation between fossil-resource use and GHG.

Material / study	Boundary & metric	Result	Interpretation
Virgin PET staple (Textile Exchange 2026)	Cradle-to-fiber; CML ADP fossil	80.7 MJ/kg; 4.55 kg CO ₂ e/kg	Substantial fossil-resource demand at fiber production.
Cotton (Textile Exchange 2026)	Cradle-to-gin-gate; CML ADP fossil	1.5–40.3 MJ/kg across selected systems; 0.44–4.17 kg CO ₂ e/kg examples	Very large geographic/agronomic variation; irrigation/fertilizer energy can be important.
Cashmere (Textile Exchange 2026)	Primary production + scouring/dehairing; PEF fossil resource	109 MJ/kg farmed; 144 MJ/kg nomadic; 155–183 kg CO ₂ e/kg	GHG vastly exceeds what fossil-energy use alone would imply because methane dominates.
Wool sweater (Wiedemann et al. 2020)	Full cradle-to-grave, per wear	0.88 MJ fossil energy and 0.17 kg CO ₂ e per wear	Processing dominates fossil energy; sheep methane dominates GHG.
Flax bleached yarn (van der Werf & Turunen 2008)	Crop through bleached yarn; non-renewable energy	261 MJ/kg yarn; 13.6 kg CO ₂ e/kg yarn	Metric is non-renewable, not fossil-only; spinning/yarn stage dominates.
Nylon mix (van der Velden et al. 2014)	Polymer/fiber-stage CED in one harmonized model	~129.7 MJ/kg CED; ~8.64 kg CO ₂ e/kg	Higher production energy/GHG than PET in the same model; CED not identical to fossil-only energy.

The apparent contradiction between PET’s 80.7 MJ/kg fossil-resource burden at the fiber gate and its ~21% lower fossil-depletion result than cotton in the JRC T-shirt service comparison is precisely the point: the final answer is affected by how many garments are required and how they are cared for. Material origin is not an adequate proxy for service-normalized fossil-resource use.

3.3 Energy-mix sensitivity

Textile Exchange’s 2026 PET analysis explicitly treats electricity mix as a major sensitivity parameter, modeling baseline regional mixes as well as coal and renewable scenarios for recycling systems. Likewise, cotton irrigation impacts depend not merely on water volume but on the electricity and diesel required for pumping. Future quantitative normalization should therefore preserve the study-specific grid and thermal-fuel mix rather than impose a single global fossil percentage (Textile Exchange 2026a; Textile Exchange 2026b).

4. Material-specific evidence

4.1 Cotton

Cotton cannot be represented by one environmental profile. The 2026 Textile Exchange primary-data study spans multiple countries and management systems. Selected cradle-to-gate climate results ranged from 0.44 kg CO₂e/kg lint for Brazil organic and 0.48 for Peru organic to 4.17 for the India country-average system; US country-average and US organic were 1.55 and 1.77 kg CO₂e/kg, respectively. The corresponding ADP-fossil values also varied substantially—from about 1.5 MJ/kg for Peru organic to 40.3 MJ/kg for India country average. These figures are upstream fiber values, not garment results (Textile Exchange 2026a).

Major drivers include nitrogen balance and N₂O emissions, fertilizer production, irrigation energy, machinery and land-use change in some regions. Water scarcity depends strongly on geography and irrigation source. Cotton's mechanical performance is equally heterogeneous: the De Saxcé sheet data demonstrate that combed yarn and finishing can transform service life. Therefore “cotton” must be specified by origin, yield, irrigation, yarn quality, construction and finish before a finished-product conclusion is credible.

A 2025 primary-data cradle-to-grave LCA of a 104-g Pima-cotton T-shirt produced in Peru further demonstrates the importance of geography and yield (Montoya Flores & Salhofer 2025). The base year was highly atypical: cotton yield was about 700 kg/ha versus a long-term average of 6,445 kg/ha. Under the low-yield case, total GWP was 4.25 kg CO₂e per T-shirt and water-scarcity footprint 241.52 m³ world-eq; substituting a typical-yield scenario reduced these to 2.93 kg CO₂e and 35.24 m³ world-eq. In the base case, garment use contributed 36% of GWP and 47% of eutrophication potential, while irrigation accounted for 97% of water-scarcity footprint. These are not universal cotton values; they are direct evidence that a single crop-year yield and watershed context can change the cotton result by multiples.

4.2 Organic cotton

Organic cultivation can reduce synthetic pesticide and fertilizer inputs, but lower yield can increase impacts per kg product because more land and farm activity are required per unit of lint. Vitale et al. (2025) systematically reviewed 20 peer-reviewed cotton LCAs and concluded that organic cotton generally performs better per hectare but can perform worse per unit mass. In one included comparison, organic cotton per tonne of lint was approximately 98% higher for climate change, 124% higher for mineral/fossil depletion and 172% higher for water consumption, while several metrics improved when expressed per hectare.

The 2026 primary-data set demonstrates that the result is not universal: some organic systems are very low-impact, while US organic had higher modeled climate impact than the US country average. “Organic” is therefore a farming-practice label, not a guaranteed environmental-performance specification. The appropriate unit for a textile comparison is ultimately impact per delivered textile service, not per hectare.

4.3 Polyester (PET)

The 2026 Textile Exchange dataset reports an average cradle-to-gate virgin staple-fiber climate impact of 4.55 kg CO₂e/kg and ADP-fossil of 80.7 MJ/kg. Those upstream numbers are higher than many cotton systems. The finished-product evidence, however, repeatedly shows advantages in abrasion/laundrying durability, dimensional stability, drying demand and replacement rate (Beton et al. 2014; Kalliala & Nousiainen 1999; De Saxcé et al. 2012; Pušić et al. 2023; Woo et al. 2026).

PET's environmental performance is therefore strongly dependent on whether its durability is realized. A PET garment discarded after 20 wears for fashion reasons cannot recover its higher initial manufacturing burden

through longer service. Conversely, where garments are used to functional failure—as in hotel bedding—the durability advantage becomes a major LCA parameter.

Koch et al. (2025) independently reinforces the importance of service-based modeling. Their polyester garment scenarios were lighter and longer-lived than the defaults and produced lower annual GHG emissions and land use for pullovers, shirts and trousers. Polyester had the lowest land use of all material options in SI 6. It was not always the lowest-GHG material—several bast-fiber or lyocell scenarios were lower—so the appropriate conclusion is not that PET universally “wins,” but that its modeled performance was favorable and substantially better than the authors’ subsequent qualitative classification might suggest.

For microfiber assessment, distinguish comparative field observations from conditional model evidence. The field evidence identified in this review does not establish greater ecological harm from polyester than from the alternatives at the measured exposures considered; this does not establish equal risk or absence of harm. GLAM (2026) and Saadi & Boulay (2026) can assign larger PET potential-impact terms because inventories and modeled environmental fate differ. Those results deserve assessment of their assumptions and uncertainty, not dismissal merely because they are modeled. Sections 6.1–6.5 keep release, environmental composition, laboratory effects, fate and modeled potential impacts separate.

Horn et al. (2023) add a product-level PET case showing that use behavior can outweigh some recycling choices. Their sports T-shirt baseline assumed 200 uses, 150 washes and tumble drying in 34% of cases; a technical maximum of 400 uses was estimated from brand information rather than measured by standardized durability testing. In the authors’ EF-weighted comparison, reducing washing to 100 cycles and avoiding tumble drying produced the largest single-strategy reduction (~37%), whereas recycled-bottle input or end-of-life garment recycling changed the weighted result by only ~8–9%, and reuse to 400 uses by ~18%. The weighted percentages are study-specific and are not adopted as a cross-material eco-score here; the robust lesson is that care frequency and realized life can dominate the choice among circularity pathways.

Braun et al. (2021) reached a related systems conclusion for a 390-g polyester workwear jacket. A circular wear2wear configuration reduced multiple impact categories relative to an otherwise similar linear system, with GHG savings rising to roughly one third over repeated loops. However, a recycled-PET-bottle input was not better than virgin PET in every impact category, and the four-year garment lifetime and loop behavior were partly expert-judgement assumptions. The relevant conclusion is not “recycled PET is always better,” but that recycling benefit depends on allocation, material quality, number of loops, energy, transport and whether service life is preserved.

4.4 Linen / flax

Flax often appears highly favorable when only crop or raw-fiber production is compared. The downstream evidence complicates that picture. Van der Werf & Turunen (2008) report 1,360 kg CO₂e and 26,100 MJ non-renewable energy per 100 kg of bleached flax yarn in their dew-retted flax scenario, equivalent to 13.6 kg CO₂e/kg and 261 MJ/kg. Yarn production contributed roughly 69–78% of climate impact and about 85–88% of non-renewable energy in the relevant scenarios. Thus the apparent advantage at the farm gate can be overwhelmed by spinning and yarn preparation.

Gómez-Campos et al. (2021) similarly show substantial spinning/weaving burdens for a finished technical flax textile, but that product is a reinforcement textile rather than apparel. Finished-apparel evidence is stronger than crop- and yarn-stage data alone suggest, but it remains less complete than for cotton/PET systems.

Benkirane (2019) and the subsequent Benkirane et al. (2022) work provide direct T-shirt durability evidence. The research program evaluated 29 commercial T-shirts spanning cotton, flax/linen and polyester using standardized physical tests, repeated wash/care ageing and consumer assessment of whether aged garments remained acceptable for normal use. Six T-shirts were then selected for LCA: two cotton, two polyester and two 100% flax/linen products. The two linen T-shirts weighed 348 and 349 g and both reached a 15-wash

normative lifetime in that product set; the selected cotton products reached 30 and 15 washes and the polyester products 15 and 50 washes. These values are product-specific, not intrinsic fiber lifetimes. The broader 29-shirt analysis found that yarn strength alone did not determine longevity: elongation, fabric density and construction were important contributors. This is directly consistent with the report's central conclusion that textile engineering can outweigh fiber identity (Benkirane 2019; Benkirane et al. 2022).

The linen evidence nevertheless has important boundaries. Benkirane's linen inventory combined primary French scutching and wet-spinning data collected over 2016-2019 with older secondary cultivation data and partly proxied downstream processes where linen-specific inventories were unavailable. An earlier critically reviewed comparative LCA of a linen shirt and cotton shirt used the functional unit of wearing a shirt for one day and showed that use-phase assumptions, especially ironing time, could materially change the result; reducing assumed linen ironing time from 9 to 7 minutes reduced several indicators by 3-16% in its sensitivity analysis (Labouze, Le Guern & Petiot 2007). Separate laundering studies likewise show that linen wrinkling and shrinkage can be altered substantially by care technology rather than treated as fixed fiber properties. Göcek et al. (2013) reported that conventional easy-care finishes can improve wrinkling but may reduce fabric strength, while Arslan et al. (2016) improved smoothness rating from 1.40 to as high as 3.63 and reduced shrinkage from 5.50% to as low as 3.45% using optimized steam-assisted laundering conditions.

The remaining linen gap is therefore narrower than previously stated. The literature now supports real garment-level durability and life-cycle analysis, but a modern, peer-reviewed, tightly matched linen-versus-cotton/PET finished-garment study that combines controlled construction, measured physical durability, experimentally established or observed service life, actual garment mass and contemporary cradle-to-grave manufacturing inventories has not been identified. Linen should therefore remain "Uncertain" for comparative finished-service performance, not because garment evidence is absent, but because the available products and inventories do not yet isolate a robust material-specific ranking.

Linen / flax: judge the finished product

Garment evidence exists • Construction, conversion and care still prevent a universal service-based ranking

NATURAL
FIBERS
BRIGHTER
TOMORROWS

PEOPLE • PRODUCTS • A HEALTHIER PLANET



1 Crop-stage evidence

Cultivation can be favorable, but a crop or raw-fiber result does not include yarn production, garment manufacture or care.

van der Werf & Turunen (2008)



2 Yarn and fabric conversion

One bleached-flax-yarn scenario: 13.6 kg CO₂e and 261 MJ non-renewable energy per kg yarn. Conversion can dominate.

van der Werf & Turunen (2008)



3 Garment-level ageing

29 commercial T-shirts were tested. Two selected linen shirts (348–349 g) each had a 15-wash normative lifetime in that product set.

Benkirane (2019); Benkirane et al. (2022)



4 Construction and care

Yarn strength alone did not determine longevity. Fabric construction matters; easy-care finishing and washing alter appearance and performance.

Benkirane; Göcek et al. (2013)



5 Garment LCA and care

A critically reviewed linen/cotton shirt LCA found care assumptions—including ironing—material to the comparison.

Labouze, Le Guern & Petiot (2007)



6 The remaining evidence gap

A modern, tightly matched linen/cotton/PET service comparison combining measured life and current inventories was not identified.

Evidence synthesis: report §4.4



Strengths and trade-offs must be assessed per delivered textile service—not per fiber label.



Care references: Göcek et al. (2013), Textile Research Journal 83(18), 1961–1973; Arslan et al. (2016), Textile Research Journal 86(10), 1097–1108.
Product-specific wash lives are not intrinsic fiber lifetimes. Full evidence, care results, study boundaries and DOI links remain in §4.4 and the bibliography.

FLAX
FOR A MORE
CIRCULAR FUTURE

Figure 5A. Linen/flax evidence synthesis. Garment-level ageing and LCA evidence exists, but product matching, construction, care and inventory limits prevent a universal service ranking. The six-panel overview is based on Section 4.4; the full study results remain in the text and Appendices A–B.

4.5 Regenerated cellulose: viscose/rayon and lyocell

Forfora et al. (2026) provide a useful controlled cradle-to-gate comparison of T-shirts made from viscose, lyocell, cotton and polyester under a common manufacturing framework that includes spinning, knitting, wet processing, garment assembly and regionalized energy. Their primary functional unit is 1 kg of T-shirts. To explore material efficiency, they also normalized garment mass using yarn tenacity: a 250-g cotton reference corresponded to modeled equivalent masses of 250 g viscose, 153 g lyocell and 115 g polyester for the same force limit. This is a transparent mechanical-function proxy, but it is not a measured garment-lifetime or wear-equivalence experiment.

Under the Chinese production scenario, cotton had the lowest reported cradle-to-gate GWP per kilogram of T-shirt (14.1 kg CO₂e/kg) while lyocell was highest (21.6 kg CO₂e/kg); cotton also had the highest water demand. Viscose showed large toxicity-related burdens from carbon disulfide and other chemical-intensive processing, whereas lyocell's closed-loop NMMO route generally reduced toxicity-related impacts but required more energy for solvent recovery and purification. When the authors adjusted mass by yarn tenacity, the GWP ordering changed to viscose highest, followed by cotton, lyocell and polyester—another example of why a mass-only comparison can mislead. The regional electricity/steam mix also materially changed the result; cleaner production locations reduced the GWP of energy-intensive man-made cellulose (Forfora et al. 2026).

Forfora et al. also calculated a simplified “plastic accumulation potential” based mainly on assumed biodegradation/persistence. The authors explicitly note that this is not part of ReCiPe and that standardized plastic-pollution characterization was lacking in that analysis. This report therefore does not use that indicator to rank the fibers. The newer GLAM and Saadi & Boulay methods provide a more formal way to model aquatic physical-effect potential, but their characterization outputs are not measurements of environmental damage. The current conclusion for regenerated cellulose is consequently moderate-confidence: viscose and lyocell should not be grouped as one low-impact category, conversion chemistry and energy geography matter greatly, and direct evidence on realized garment service life remains limited.

4.6 Nylon / polyamide

Nylon generally has higher production energy and GHG than PET in harmonized studies. Van der Velden et al. (2014) modeled ~8.64 kg CO₂e/kg and 129.7 MJ/kg CED for their nylon 6/66 input versus ~2.70 kg CO₂e/kg and 78.4 MJ/kg CED for PET granulate. The same paper also demonstrated that yarn fineness can dominate textile processing: at very fine 70 dtex, spinning and weaving energy became so large that material rankings changed compared with 300 dtex yarn.

Nylon's mechanical strength and abrasion resistance can be exceptional, so its strongest environmental case is in applications where abrasion is the dominant failure mode and the longer service is actually realized. The 2026 laundering study by Woo et al. adds an important qualification: PET retained dimensional stability and strength better during repeated washing, while nylon 6 showed up to 24% tensile-strength loss after 50 cycles at 40 °C and up to 66% under the harsh 60 °C condition. Thus “nylon is more durable” is too broad; nylon is especially abrasion-resistant, whereas PET appears more laundering-stable in this direct test.

4.7 Wool

Enteric fermentation is a reported climate hotspot

Different denominators are shown explicitly • These percentages are not a cross-material footprint ranking



Merino wool



48.1%

OF WHOLE-GARMENT GHG



300-g sweater; cradle to grave;
109-wear model.

Alpaca: small farm



92.69%

OF FARM-STAGE GWP



Farm phase within the
303-g sweater system.

Alpaca: medium farm



84.96%

OF FARM-STAGE GWP



Farm phase within the
303-g sweater system.



**Longer realized service can reduce impact per wear.
It does not make the underlying enteric emissions physically disappear.**

Sources: Wiedemann et al. (2020), Merino value chain; Kern et al. (2026), alpaca farm-phase contribution.

Figure 6. Enteric-fermentation contributions with their denominators shown separately: 48.1% of whole-garment cradle-to-grave GHG for the Merino sweater, and 92.69% / 84.96% of farm-stage GWP for the small- / medium-farm alpaca systems. These percentages are not a cross-material footprint ranking.

Wool has a well-documented climate hotspot in sheep production. Wiedemann et al. (2020) modeled a 300-g Merino sweater over a 109-wear lifetime and reported 0.17 ± 0.02 kg CO₂e, 0.88 ± 0.18 MJ fossil energy and 0.96 ± 0.42 L H₂O-e water stress per wear. Methane represented 53.7% of total GHG by gas, and enteric methane alone accounted for 48.1% of the complete cradle-to-grave value-chain GHG.

Service life is nevertheless a powerful mitigation factor. Increasing sweater lifetime to 400 wears reduced modeled GHG by 67.5%, fossil energy by 61.3% and water stress by 49.4%. Conversely, disposal after only one season greatly increased impacts. Wool therefore deserves a real service-life credit when supported by use data; that credit should not be used to erase the equally real methane burden.

Allocation methodology also changes the apparent upstream footprint. Wiedemann et al. (2019) found approximately 31.5 kg CO₂e/kg clean wool under the attributional case for the modeled fine-wool system, compared with ~18.2 and ~13.6 kg/kg in two consequential cases. This >2× methodological spread demonstrates why wool numbers from different rating tools cannot be compared without checking allocation.

2026 biogenic-carbon debate in wool

Blignaut et al. (2026) proposed a biogenic carbon-flow treatment that can sharply reduce estimated wool carbon intensity depending on assumptions such as manure-carbon retention. A formal comment by Mazzetto et al. (2026) argues that several internal biogenic flows were interpreted as atmospheric removals in a way inconsistent with standard LCA/GHG accounting unless durable stock increases are demonstrated. This report therefore retains conventional net-GHG accounting as the baseline and treats the proposed gross biogenic credit as a methodological sensitivity, not an established correction.

The Bech et al. (2019) military base-layer case adds an important service-level qualification. Per garment, Merino was substantially more climate intensive than the 50/50 polyester/nylon reference, but a modeled

system with fewer garments, fewer washes and four six-month service periods could reverse the result. This does not erase methane; it quantifies how much additional service must be delivered to amortize the upstream burden.

Hester, van der Velden & Vogtländer (2026) examined virgin, mechanically recycled and unravelled/reknitted 300-g Merino jumpers. Their cradle-to-grave results were 21.93 kg CO₂e for virgin wool, 1.56 kg for recycled wool and 0.89 kg for unravelled wool, or 0.278, 0.020 and 0.011 kg CO₂e per wear under an assumed 79 wears and 15.2 washes. The very large recycling advantage is allocation-sensitive: under the study's cut-off rule, the prior virgin-wool burden assigned to recycled input was zero, and the authors explicitly note that alternative allocation methods give different results. This is useful evidence for circular-wool pathways, not evidence that wool's original methane burden disappears physically.

4.8 Alpaca

Kern et al. (2026) provide the strongest current full-life alpaca analysis. The functional unit is a 303-g dyed sweater. Total cradle-to-grave climate impact was 40.58 kg CO₂e for the small-farm system and 35.44 kg for the medium-farm system. The cradle-to-retailer stage contributed 36.02 and 30.88 kg CO₂e, respectively. Enteric fermentation accounted for 92.69% and 84.96% of farm-phase GWP.

The apparent per-wear result is less secure because the study assumes 109 wears and 21 washes, explicitly borrowed from the Merino sweater study rather than measured for alpaca. Therefore the high upstream methane-dominated burden is a strong finding; the exact per-wear footprint is conditional on an unvalidated service-life assumption for alpaca.

An independent alpaca study strengthens the climate hotspot conclusion. Bartl et al. (2023) calculated a cradle-to-grave carbon footprint for a Peruvian alpaca sweater and found that fiber production contributed about 70% of total climate impact; within the fiber-procurement stage, enteric fermentation accounted for 87% of the impact. Because this study used a different author group and system, it provides useful independent corroboration that alpaca climate burden is strongly methane-driven, although it is a carbon-footprint study rather than a full multi-impact comparison.

4.9 Cashmere

The 2026 Textile Exchange cashmere study is the strongest upstream dataset presently available: primary data from 170 herders/farmers in Mongolia and China plus primary processing facilities. Per kg clean dehaired cashmere, the study reports 183 kg CO₂e for nomadic and 155 kg CO₂e for farmed systems, excluding land-use and land-use-change effects; fossil-resource use is 144 and 109 MJ/kg, respectively. Primary production contributes more than 75% of the total for five of the six highlighted indicators, grazing contributes >99% of land-use impact, and methane contributes 80% and 74% of climate impact in the two systems (Textile Exchange 2026c).

Independence note. The Textile Exchange cashmere study was prepared by Integrity Ag with contributions including Stephen Wiedemann, who also led the Merino garment LCA work cited in this report. The cashmere and Merino results therefore should not be counted as independent author-group replication, although Textile Exchange reports that the cashmere study underwent multiple rounds of independent critical review. This makes independent animal-fiber studies, such as Bartl et al. (2023) for alpaca, particularly useful corroboration of the methane hotspot.

Cashmere does have a measurable material-efficiency advantage in one controlled knit experiment. McGregor & Postle (2008) found no significant fiber-composition effect on thermal insulation at matched fabric tightness, while pure cashmere fabrics were lighter. For R36/2 yarn, pure cashmere mass was 150.5 vs 168.6 g/m² at tightness factor 14.0, 178.3 vs 192.2 at 15.5, and 203.7 vs 213.6 at 17.0 compared with standard superfine wool—roughly 5–11% less mass. This should be credited when function is equivalent.

However, the same experimental program does not establish a longevity advantage. Cashmere and low-crimp wool yarns had lower tenacity/elongation than standard wool, and the authors infer greater loop distortion for cashmere knitwear because of lower bending hysteresis (McGregor & Postle 2008). McGregor's 2006 pilling-method study adds an important caution: pure cashmere and low-crimp blends could achieve better pilling/appearance grades while simultaneously losing more fabric mass, indicating that pills or loose fibers may detach and make the surface look cleaner. The 2009 wear study likewise shows strong interactions among pilling, shrinkage, fabric structure and fiber curvature. Pilling grade alone is therefore not a durability metric, and the current evidence supports softness/handle and modest mass efficiency as cashmere benefits, not exceptional longevity.

A downstream-only cashmere study provides useful boundary context. Chen et al. (2021) quantified processing from raw cashmere through finished fabric and found substantial differences between knitted and woven routes, with energy and wet processing important contributors. Because goat husbandry/farm methane was outside that system boundary, those fabric-stage carbon-footprint values must not be compared directly with the 155–183 kg CO₂e/kg clean-dehaired-fiber results from the 2026 farm-inclusive cashmere LCA.

5. Durability, material efficiency and the use phase

5.1 Why durability can outweigh fiber-stage differences

A product that lasts twice as long does not automatically halve every impact because laundering, transport and end-of-life may scale differently. But production impacts are amortized over more service events. The effect is largest where manufacturing or raw-material production is a major hotspot. The JRC T-shirt comparison, Kalliala hotel sheets, De Saxcé bed sheets and the wool-sweater sensitivity analysis all demonstrate that service life can move total impacts by tens of percent or more.

Evidence	Service / durability basis	Implication
JRC IMPRO T-shirts	50 cotton / 80 blend / 95 PET washes; test-informed modeled lifetimes	Longer modeled lifetime is a main contributor to the lower service-normalized results; care assumptions also differ.
Kalliala hotel sheets	50 cotton vs 100 cotton/PET modeled rentals	One blend sheet replaces two cotton sheets in the modeled 100-cycle service comparison.
De Saxcé sheets	60 basic cotton / 78 blend / 100.2 premium cotton	Construction/finishing can be as important as fiber identity.
Wool sweater	109 baseline wears; 400-wear sensitivity	400 wears reduced GHG 67.5% and fossil energy 61.3% vs baseline.
Xu fast-fashion T-shirts	Both fixed at 20 washes	Legitimate equal-realized-life scenario; product-specific lifetime differences were not established.
Schmutz et al. cotton T-shirt	44-wash baseline vs 11-wash life; four shirts needed for same 44-wash service	Short life raised climate +261%, nr-CED +231%, water +293% and ecological scarcity +275%.
Sandin et al. Swedish clothing model	T-shirt 30 vs 90 uses; national scenario doubles garment use	90 uses lowered T-shirt climate impact/use 65%; doubled use cut national climate 49%, energy 42%, water scarcity 48%.
Jasińska industrial bed linen	Up to 100 commercial wash/dry cycles	Strength loss up to ~30% in cotton vs up to ~20% in 50/50 cotton/PET; construction/yarn also differed.
Wiedemann et al. wool care sensitivity	109-wear baseline; reuse and 400-wear scenarios	Multiple-user reuse reduced impacts ~25–28%; 400 wears reduced impacts ~60–68% depending category.

Independent LCAs strongly replicate the central service-life result. Schmutz, Hirschier & Som (2021) held total cotton-T-shirt service constant at 44 wash cycles and shortened one shirt's life to 11 cycles; four shirts were then required, increasing climate impact by 261%, non-renewable cumulative energy demand by 231%, water footprint by 293% and ecological-scarcity score by 275%. Sandin et al. (2019) found that increasing a T-shirt from 30 to 90 uses reduced climate impact per use by 65%; doubling garment use in their national model reduced climate impact 49%, energy use 42% and water-scarcity impact 48%. These are within-study sensitivity results, not interchangeable absolute LCAs, but both show that lifetime can dominate fiber-stage differences.

For wool specifically, Wiedemann et al. (2021) modeled best-practice care around the same 300-g Merino sweater system. Washing less often reduced impacts by roughly 4–20% depending category; multiple-user reuse by ~25–28%; and increasing life from 109 to 400 wears by ~60–68%. The combined best-practice

scenario reduced modeled impacts by about 75% across the assessed indicators. These are scenario results rather than observations that all wool garments achieve such lifetimes, but they quantify the leverage available if long service is actually realized.

5.2 Material loss and fiber shedding as durability evidence

Pušić et al. (2023) tested similarly constructed plain-weave 100% cotton and 50/50 cotton/PET fabrics through 3, 10 and 50 washes. After 50 cycles, total wear in the warp direction was 41.2% for cotton versus 30.9% for the blend, and cotton produced significantly more dry-state particles across the measured size classes. Zhang et al. (2025), using chemical separation to identify polyester in cotton/PET blends, likewise found shedding from blends could be substantially greater than pure polyester and that weave and blend ratio strongly affected the result. These studies support the broader point that fiber release is not uniquely a synthetic-textile issue and that material loss is linked to textile durability.

Mass loss is only one failure-related measure and is not interchangeable with abrasion life. Kalliala & Nousiainen (1999) found higher laundering mass loss for the blend (2.6%) than cotton (1.6%) despite its greater abrasion resistance and longer assigned service. Comparisons should therefore report the actual metric—strength retention, abrasion cycles, appearance, mass loss or particle release—rather than collapsing them into a single durability claim.

5.3 Physical durability versus realized lifetime

Wardrobe surveys show that the time consumers keep a garment depends on price, attachment, fashion, fit, garment category and number of users as well as physical deterioration (Laitala & Klepp 2020). Wool garments, for example, often remain in wardrobes for long periods, while physically durable synthetic garments can still be discarded early. For environmental comparisons, the scientifically clean approach is to report both: (a) physical service capability under standardized testing and (b) realized service life in actual use.

Realized lifetime must therefore not be inferred mechanically from a laboratory durability score. The 2025 PEFCR attempts to connect durability and repairability tests to a duration-of-service multiplier, but its conversion factors include expert judgement. Conversely, wardrobe data measure actual retention/use but confound physical failure with fashion, fit, price and attachment. The strongest future evidence would pair standardized failure-mode testing with longitudinal wear/use data for the same product classes.

5.4 End of life, reuse and recycling: allocation matters

End of life should not be treated as a single material property. Reuse, repair, mechanical or chemical recycling, incineration and landfill shift burdens in different ways, and LCA conclusions depend strongly on whether previous production burdens are carried into the recycled product, cut off at the system boundary, or credited through substitution. These choices must be reported rather than hidden inside a generic “circular” label.

The existing product studies illustrate the range. Horn et al. (2023) found use frequency and tumble-drying assumptions more influential than several PET recycling choices in their sports-T-shirt model. Braun et al. (2021) found that a designed closed-loop polyester jacket system could reduce multiple impacts over repeated loops, but recycled-bottle input was not superior in every category. Hester et al. (2026) reported very large reductions for recycled and unravelled wool under a cut-off allocation, while explicitly noting that alternative allocation rules change the result. These are system-level effects, not intrinsic properties of “recycled” fiber.

Combustion can release CO₂ from the carbon in all of the fibers covered here, not only PET. Carbon stocks in materials, gross end-of-life emissions and net life-cycle GHG results must be reported separately. For biogenic fibers, account consistently for atmospheric carbon uptake and its later release, together with land-use effects and other greenhouse gases. Fossil carbon retained in PET is not an atmospheric removal. Apply the same

functional service, end-of-life scenario and allocation rules to every material (World Resources Institute & WBCSD 2011, Chapter 11).

If PET is incinerated without carbon capture, its polymer carbon contributes fossil CO₂ at end of life. Cotton, linen, regenerated cellulose, wool, alpaca and cashmere can also release CO₂ when burned; their biogenic-carbon accounting must include uptake and release consistently rather than treating the gross combustion flow as absent. Recycling or reuse can delay release and displace new production, but any storage or substitution credit requires an explicit method and must not be counted twice.

Biodegradability is not an automatic overall environmental credit. Faster breakdown can reduce a fiber stock while returning its carbon to the environment sooner. Its climate significance depends on the products formed, timing, receiving environment and carbon-accounting boundary; a lower persistence or accumulation indicator is not necessarily a lower climate impact. Compare the complete life cycle rather than assigning a generic positive or negative score to degradation (Sections 1.7–1.8 and 6).

Carbon in a fiber is not carbon already emitted

Track material carbon, process emissions and removals separately • Compare the same delivered service.

DIFFERENT FLOWS.
CLEARER INSIGHTS.
A LOWER-CARBON
TEXTILE FUTURE.

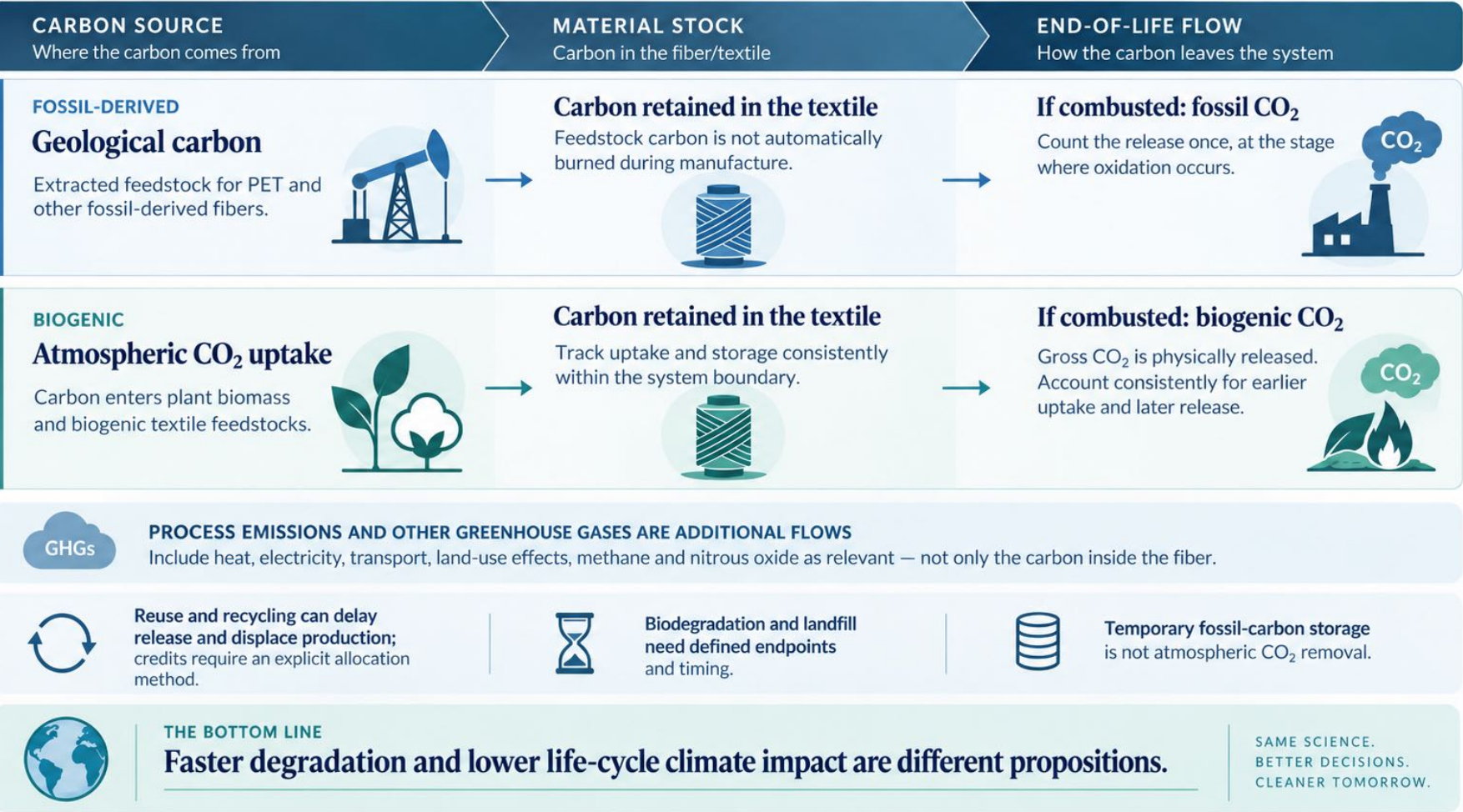


Figure 6A. Carbon accounting across textile life cycles. Gross carbon release, atmospheric uptake, material stocks and net life-cycle GHG are separate quantities. Use the same delivered service, end-of-life boundary and allocation rules. Based on Sections 1.7 and 5.4 and WRI & WBCSD (2011), Chapter 11. Arrow widths are not quantitative.

5.5 Recyclability: PET has strong polymer-level routes, but cotton & wool are recyclable too

Polyester does have an important technical recycling advantage, but the phrase “easy to recycle” requires qualification. For clean, predominantly mono-material PET, established or demonstrated routes include mechanical recycling, thermo-mechanical remelting, solvent-based separation and chemical depolymerization processes such as glycolysis, hydrolysis and methanolysis. Enking et al. (2025) identified multiple PET textile-to-textile pathways and emphasized that high-purity feedstock simplifies recycling. The same review also found that less than 1% of fibers are currently made from discarded textiles, showing that technical recyclability should not be confused with actual textile-to-textile recycling rate.

PET’s polymer chemistry gives it a distinctive closed-loop option: as a thermoplastic it can be remelted, and its ester bonds can be cleaved chemically to recover intermediates suitable for repolymerization. This can avoid the fiber-length loss that constrains purely mechanical recycling of staple natural fibers. The advantage is strongest for clean mono-material streams. Post-consumer polyester blends, elastane, dyes, coatings, dirt and other additives can reduce yields, obstruct melt filtration or require separation before high-quality fiber can be produced (Enking et al. 2025).

Cotton is not unrecyclable. A 2025 review describes mechanical cotton recycling as widely implemented because of its relative simplicity and cost-effectiveness, but shredding/card opening reduces fiber length and strength with each cycle; high-quality yarn often requires blending recovered cotton with virgin fiber. Cotton can also be chemically dissolved or depolymerized and converted to regenerated-cellulose fiber, which avoids the mechanical fiber-length limitation, but dyes/finishes, energy use, process chemistry, cost and scale remain important constraints (Grover et al. 2025).

Wool is also demonstrably recyclable. Mechanical wool recycling has an established industrial history, and Glasper et al. (2024) found that mechanical recycling had little effect on the tensile strength of tested wool and cashmere fibers; retained fiber length, rather than loss of intrinsic fiber strength, was the main constraint on repeated closed-loop recycling. The Hester et al. (2026) LCA likewise demonstrates a viable recycled/unravelling wool pathway, although its environmental result is strongly allocation-dependent.

The defensible conclusion is therefore narrower than “PET is recyclable and cotton/wool are not.” Clean mono-material PET has a strong polymer-level recycling advantage because both remelting and depolymerization routes are available, potentially restoring feedstock quality without relying on retained staple-fiber length. Cotton and wool are also recyclable, but mechanical recycling tends to shorten fibers and can limit repeated high-quality spinning. For every fiber, collection, sorting, trims, blends, dyes/finishes, contamination, process yield, energy use and economics determine whether technical recyclability becomes practical closed-loop recycling.

5.6 Economic performance: raw price is not cost per wear

The economic analogue of the report’s environmental functional unit is cost per delivered textile service. The conventional consumer metric “cost per wear” (CPW) is purchase price divided by the number of wears; a fuller ownership-cost calculation can additionally include laundering, drying, repair, alteration and end-of-life costs. Eckmann & Reisch (2025) show that CPW is a useful economic framing, but their experiments are consumer-behavior scenarios rather than measured cross-fiber lifetime comparisons. Accordingly, this report does not invent a universal dollar-per-wear ranking for generic fibers.

Raw-fiber prices nevertheless provide useful market context when their limitations are explicit. The following values are selected recent market benchmarks, not standardized procurement quotes: grades, geography, date, currency, delivery basis and processing state differ. They should not be used as a direct garment-cost or environmental ranking.

Material / benchmark	Date / market basis	Indicative price	Interpretive boundary
Polyester staple fiber	Q2 2026 regional commercial benchmarks	US\$0.99–1.58/kg	IMARC regional PSF values (China to USA range); commercial market context, not a peer-reviewed scientific dataset.
Cotton	Cotlook A Index, 25 Sep 2026	~US\$2.07/kg	Converted from 93.75 US¢/lb; international cotton benchmark, not finished yarn/fabric or garment cost.
Long flax	EU Masters of FLAX FIBRE™, Mar 2026	€5.89/kg	Average long-fiber price across reported EU qualities/regions; currency and grade not normalized to other rows.
Wool	AWEX Eastern Market Indicator, 17 Sep 2026	~US\$13.25/kg clean	Broad clean-wool auction benchmark; not a specific fine-Merino apparel grade or finished yarn price.

The selected benchmarks support only a broad raw-input observation: bulk PET and cotton were relatively low-cost inputs in the cited 2026 market snapshots compared with long flax and especially clean wool. They do not establish garment retail price. Spinning, fabric construction, dyeing/finishing, cut-and-sew operations, logistics, quality level and retail margins can dominate the price paid by the user. A contemporaneous, grade-matched market series covering every fiber in this review was not identified, so a complete raw-fiber price ranking is deliberately not shown.

Wardrobe evidence also warns against equating low purchase price with low cost per wear. In a five-country survey, Laitala & Klepp (2020) found that, after controlling for the other variables in their model, garments costing more than US\$100 were estimated to receive 31 more wears than garments costing less than US\$10. This is an observational association, not proof that spending more causes durability, but it reinforces the need to include actual service in an economic comparison.

The strongest fiber-relevant economic calculation is therefore a break-even price ratio using the service-life evidence already evaluated in this report. If care and repair costs are temporarily excluded, two products have the same acquisition cost per service event when their purchase-price ratio equals their service-life ratio. The table below uses only within-study service denominators; it does not insert assumed retail prices.

Evidence comparison	Service-life basis	Break-even purchase-price ratio	Meaning at equal acquisition cost per service
JRC 50/50 cotton/PET vs cotton T-shirt	80 vs 50 modeled washes	1.60×	The blend could cost 60% more upfront than cotton and tie on acquisition cost per modeled service event.
JRC PET vs cotton T-shirt	95 vs 50 modeled washes	1.90×	PET could cost 90% more upfront than cotton and tie on acquisition cost per modeled service event.
Kalliala 50/50 cotton/PET vs cotton hotel sheet	100 vs 50 rentals/washes	2.00×	The blend could cost twice as much upfront and tie on acquisition cost per rental; lower laundering energy further favors operating cost in that system.

Evidence comparison	Service-life basis	Break-even purchase-price ratio	Meaning at equal acquisition cost per service
De Saxcé 50/50 blend vs basic carded cotton sheet	78 vs 60 modeled washes	1.30×	The blend could cost 30% more upfront and tie on acquisition cost per modeled wash.
De Saxcé premium cotton vs basic carded cotton sheet	100.2 vs 60 modeled washes	1.67×	Premium cotton could cost about 67% more upfront and tie on acquisition cost per modeled wash, illustrating that construction quality can outweigh fiber identity.

These ratios are not observed consumer prices and should not be described as measured cost per wear. They are transparent break-even calculations from the report's test-informed or modeled service lives. A true comparative cost-per-wear study would need matched garments, actual transaction prices, longitudinal wears/washes, care and repair costs, and a consistent endpoint for retirement. For hotel textiles, labor, water, detergent, drying energy and replacement logistics should be included because the use phase is economically material.

6. Fiber shedding, degradation, biodegradation and persistence

6.1 Fiber release is not a uniquely synthetic phenomenon

Measured textile release is not unique to synthetic fibers. Cotton-containing fabrics can release more material than pure PET under some tested wear/wash conditions, while heterogeneous product comparisons can give similar mean mass loss for cotton/wool and polyester. Textile construction, fiber size, treatment, product age and the measurement method affect the comparison. Release quantity should therefore be measured directly and reported for all candidate fibers rather than inferred from polymer origin (Pušić et al. 2023; Zhang et al. 2025; Vassilenko et al. 2021).

Koch et al. (2025), discussed in Section 2.6, illustrates why evidence that polyester sheds is not by itself a comparative pollution assessment. A defensible comparison requires release inventories for the alternatives and a transparent treatment of fate, exposure and effects. LCIA may quantify conditional differences, but a categorical exclusion based solely on the label “microplastic” is not a substitute for that analysis.

The strongest global surface-ocean fiber dataset in the present evidence base is Suaria et al. (2020). The authors compiled 916 seawater samples from 617 locations in six ocean basins and chemically characterized approximately 2,000 recovered fibers by micro-FTIR. Of those characterized surface-water fibers, 79.5% were cellulosic and 12.3% animal-origin, while 8.2% were synthetic polymers. Cotton was the most frequent spectral match at 50%; polyester represented 6.2%, acrylic 0.7%, nylon 0.7%, polypropylene 0.4% and aramid 0.3%. Natural versus regenerated cellulose can be difficult to distinguish by FTIR, so 91.8% is best described as cellulosic or animal-origin fibers rather than “natural fibers,” and the 50% cotton figure should be understood as the study’s spectral assignment rather than proof that every matching cellulosic fiber was virgin/natural cotton. These percentages are composition by characterized fiber count in sampled surface waters—not fiber mass, not the whole water column or sediments, and not a claim about all fibers throughout the ocean (Suaria et al. 2020).

Woodall et al. (2014) provides an independent deep-sea counterpart. FT-IR analysis of 12 sediment samples found rayon in every sample; the authors explicitly described rayon as a man-made non-plastic polymer, yet it comprised 56.9% of recovered fibers—more than twice polyester. This reinforces the need for chemical identification rather than assuming fiber = plastic. The dataset was small, heterogeneous and insufficiently replicated for statistical site comparisons, and individual fiber sources could not be assigned. Suaria et al. independently reached the same classification caution for surface waters.

Direct textile experiments support that mechanism. De Falco et al. (2020) found that a 50/50 polyester/cotton knit released the greatest mass to wash water among four tested garments; thermogravimetric analysis indicated about 80% of released fibers in water and 97% of fibers released to air from the blend were cotton. In the more recent chemical-separation study by Zhang et al. (2025), commercial-laundry slurry solids were estimated at approximately 85% cotton and 15% polyester after validating selective cellulose removal. These observations do not mean cotton always sheds more than every PET construction; they show that polymer origin alone is an unreliable predictor and that natural-fiber release cannot be ignored.

Vassilenko et al. (2021) provide an additional peer-reviewed consumer-textile comparison. Across 37 textile samples washed over five domestic laundry cycles, the four cotton/wool samples released 165 ± 44 mg/kg per wash, essentially the same mean mass as the 18 polyester samples at 161 ± 173 mg/kg per wash; nylon was much lower at 27 ± 14 mg/kg per wash. The products were heterogeneous rather than matched by construction, and the natural-fiber group was small, so this does not establish a chemistry-only ranking. It does

independently reinforce the report's narrower conclusion that substantial microfiber release is not unique to polyester and that textile construction can outweigh polymer identity.

Comparative ecological conclusion.

The field evidence identified in this review does not establish that polyester textile fibers cause greater ecological harm than cotton, wool or regenerated-cellulose fibers at the measured exposures considered. This does not establish equal risk or absence of harm. Comparative LCIA may estimate different potential impacts because release, exposure and fate differ; those modeled results should be reported with their assumptions and uncertainty, separately from observed field effects.

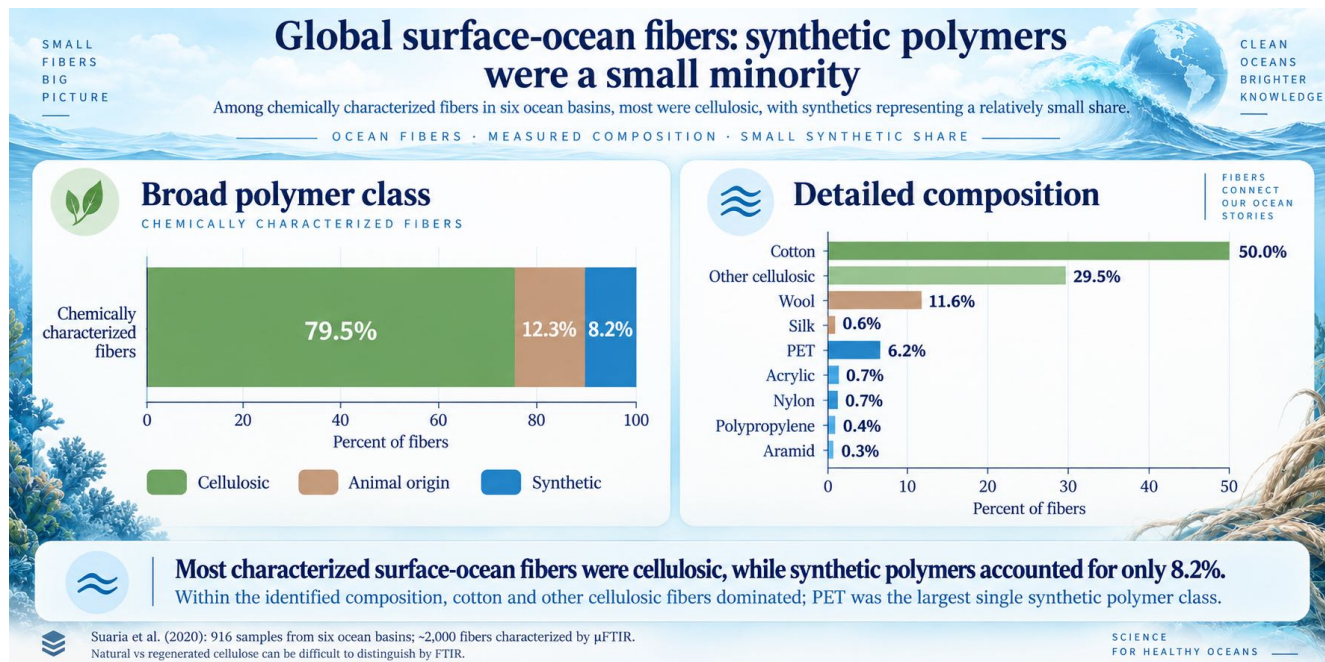


Figure 7. Suaria et al. (2020): among chemically characterized fibers recovered from the sampled global surface waters, 91.8% were cellulosic or animal-origin and 8.2% were synthetic polymers; PET accounted for 6.2% and cotton was the most frequent individual match at 50%. The percentages are fiber counts in the sampled surface-water dataset, not ocean-wide fiber mass.

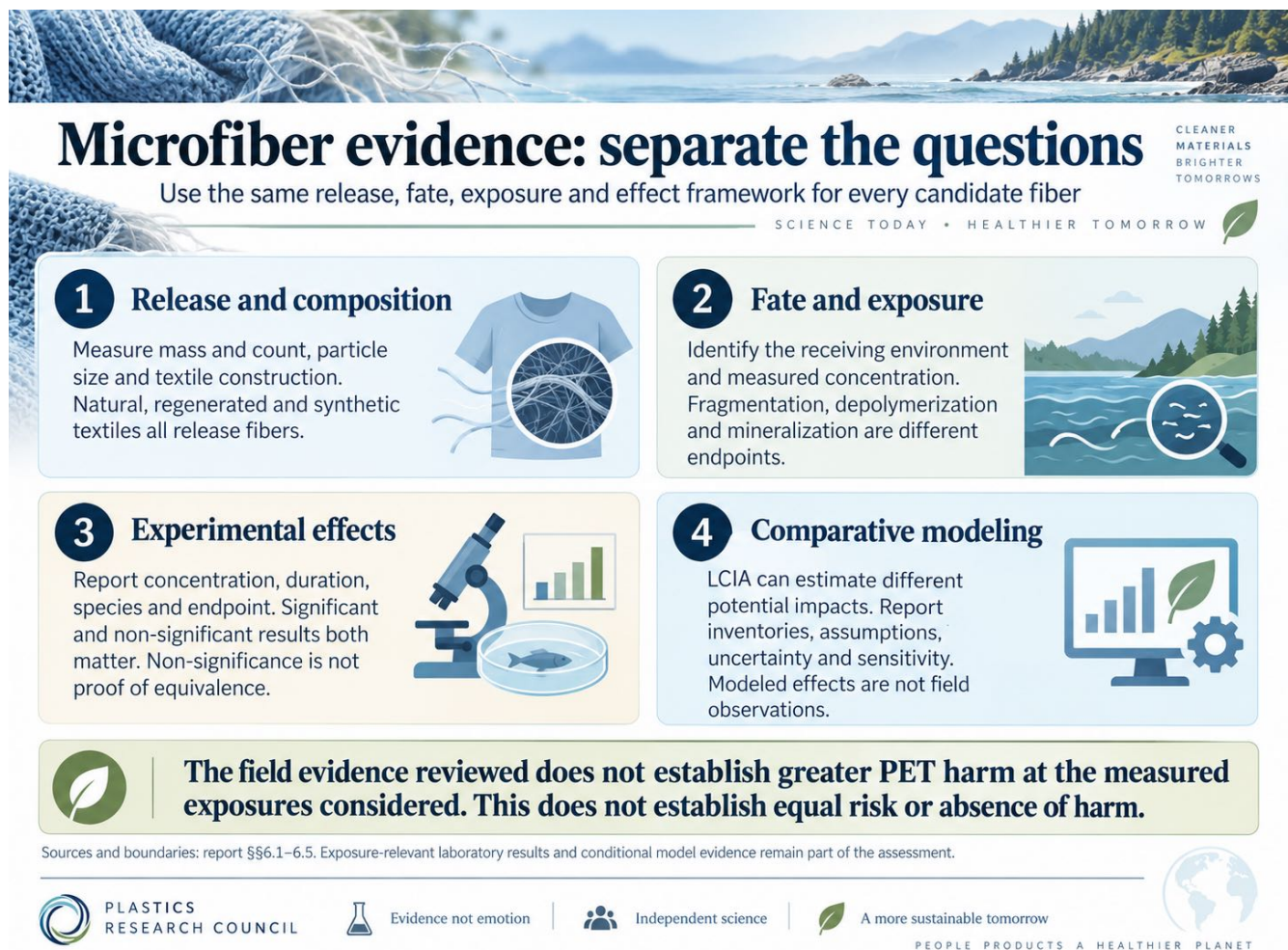


Figure 7A. Microfiber interpretation framework: release, fate and exposure, experimental effects, and modeled potential impacts answer different questions. The absence of an identified comparative field effect does not establish equal risk or absence of harm.

6.2 Natural fibers can persist for very long periods

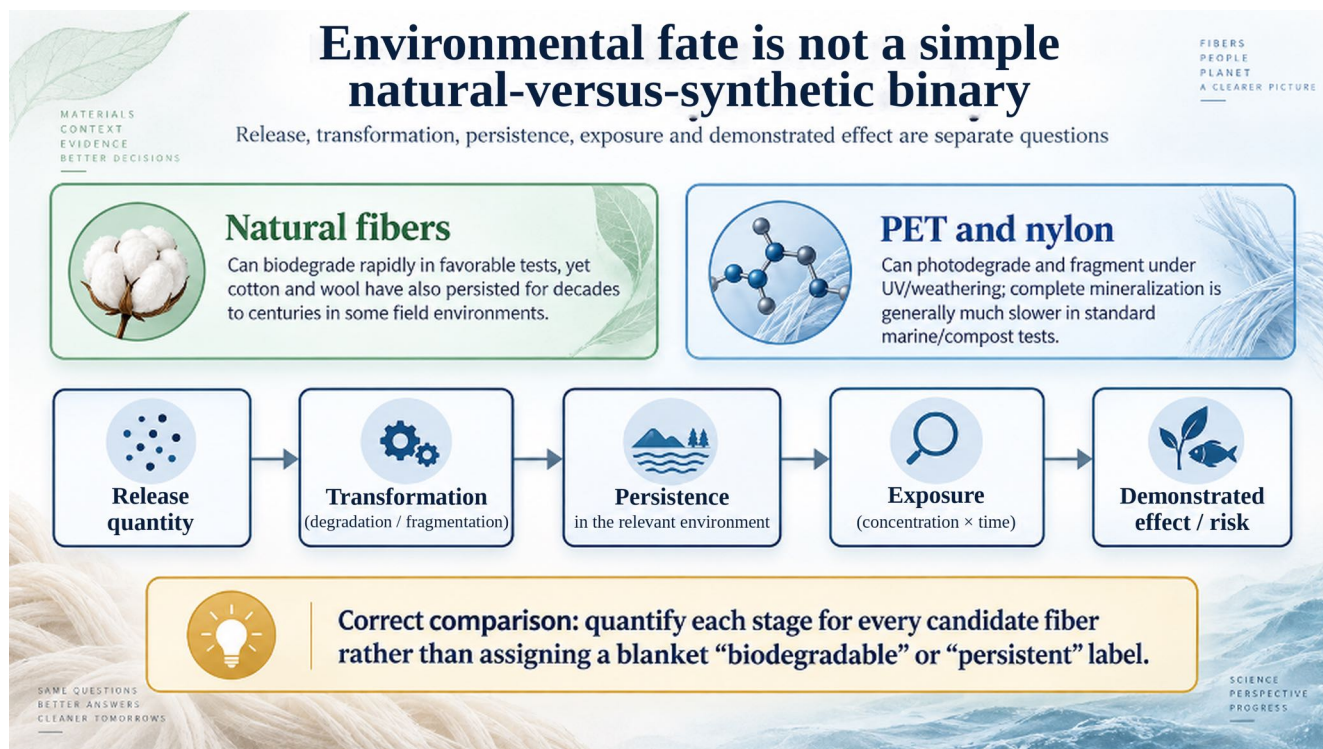


Figure 8. Environmental fate cannot be reduced to a natural-versus-synthetic dichotomy: release, degradation, biodegradation, mineralization, persistence and demonstrated effects are separate questions.

Stanton et al. (2026) recovered 67 textile fibers from dated sediment layers in a Rudyard Lake core spanning approximately 150 years, to about 1876 ± 25 . Cotton accounted for 70% of recovered fibers; before approximately 1979 all but two recovered fibers were cotton or wool, and the deepest layer contained wool. After 1979, the rise in fibers was driven particularly by cotton. The study demonstrates recovery of natural fibers from old dated layers and shows that rapid disappearance cannot be assumed under those sediment conditions; it does not independently date each individual fiber or establish a universal environmental lifetime.

This field evidence should not be over-generalized. It is one lake core, and buried or anoxic sediment can preserve materials that degrade more rapidly in warm, oxygenated biological systems. It shows why rapid disappearance of cotton or wool cannot be assumed for every receiving environment; the layer dates do not independently date each recovered fiber.

6.3 Polyester and nylon do degrade; mineralization rate is a separate question

PET is not environmentally inert. Allen et al. (1994) showed that PET environmental degradation is strongly condition-dependent and identified hydrolysis as a dominant chain-scission pathway under wet conditions. In direct fiber experiments, Sait et al. (2021) found substantial surface alteration and fragmentation of PET and polyamide microfibers during ten months of UV exposure in water. Sørensen et al. (2021) likewise found rapid UV ageing of PET fibers: under their accelerated simulated-sunlight experiment, PET developed extensive surface damage and fragmented within 56 days, with median fiber length falling from about $3,115 \mu\text{m}$ to $257 \mu\text{m}$. These results establish chemical and physical degradation, not complete mineralization.

Stanica-Ezeanu & Matei (2021) derived hydrolysis kinetics from $190\text{--}215^\circ\text{C}$ reactor experiments and extrapolated them to ocean temperatures. Their Table 5 gives approximately 4.5 years for 50% PET conversion and 72 years for 99.999% conversion at 35°C . At 30°C , however, Table 5 reports 116 years for 99.999% conversion while the conclusion reports 162 years. This is an unresolved internal source discrepancy; neither

30 °C value is adopted here as a headline lifetime. All of these ocean-temperature estimates are kinetic extrapolations, not long-term field observations, and concern depolymerization rather than complete biological mineralization. They support a mechanistic discussion of hydrolysis, not a validated universal marine disappearance time.

Fiber geometry is also relevant. Textile microfibers have far greater surface area per unit mass than bottle walls or large flakes, increasing the polymer-water and polymer-light interface available for surface-mediated hydrolysis and photooxidation. Exact scaling from a bottle or flake to a fiber lifetime has not been established, so the Stanica-Ezeanu & Matei numbers should not simply be divided by a geometric factor. Direct fiber data nevertheless point in the same direction: Chen, Zhao & Wu (2026) exposed 5-mm PET microfibers to accelerated UV irradiation in freshwater and seawater for 12 days and observed marked surface roughening, oxidation, ester-bond cleavage, altered crystallinity and molecular-weight loss; ageing was stronger in seawater than in ultrapure water. The authors explicitly caution that accelerated lamp exposure is not equivalent to natural sunlight.

Biological transformation is now better documented as well. Alam et al. (2025) combined structure-informed screening, functional assays, metagenomics and metatranscriptomics across 415 ocean samples. They identified 23 functional PETase variants in nearly 80% of samples, including deep-ocean waters, and detected active transcription of PETase genes by marine microorganisms. Functional assays confirmed PET-degrading activity for motif-complete enzymes. The study does not quantify a whole-ocean PET disappearance rate and cannot prove that PET pollution caused the evolutionary origin of these genes, but it establishes that enzymatic PET-degradation capacity is widespread and active in marine microbiomes.

Standard short-duration biodegradation tests remain useful but answer a different question. Collie et al. (2024, 2025) found rapid mineralization of wool and regenerated cellulose under favorable marine or composting test conditions, whereas PET, nylon and polypropylene showed little or no mineralization over the test periods. The 2025 review by Skilbeck, Blackburn & Kay likewise emphasizes strong dependence on chemistry, processing, finishes and environment. The defensible interpretation is therefore not “PET does not degrade,” but that degradation, depolymerization, fragmentation, enzymatic attack and ultimate mineralization proceed by different pathways and on different timescales.

Environmental-fate conclusion

Natural fibers can mineralize rapidly in favorable biological tests yet remain recoverable in some dated sediment settings. PET is not inert: hydrolysis, photooxidative chain scission, fragmentation and enzymatic attack are documented. Accelerated ageing, high-temperature kinetic extrapolation and detection of functional PETases do not establish a field mineralization or disappearance rate. Compare the same endpoints and receiving environments for every fiber; neither “biodegradable” nor “persistent” is an automatic whole-life environmental score.

PET transformation is not a field lifetime

Chemical change, fragmentation, enzyme activity and complete mineralization are different findings

PET

POLYESTER



Hydrolysis: kinetic extrapolation

190–215 °C reactor data were extrapolated to ocean temperatures. The 35 °C model gives ~4.5 years for 50% conversion and ~72 years for 99.999%; neither is a field lifetime.

KINETIC EXTRAPOLATION
190–215 °C
Reactor experiments
↓
35 °C model
Not a field lifetime



Source discrepancy at 30 °C

Stanica-Ezeanu & Matei's Table 5 gives 116 years for 99.999% conversion, but the conclusion gives 162. The unresolved value is not adopted as a headline lifetime.

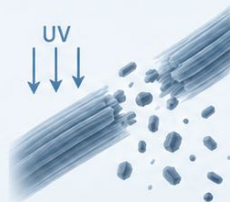


116 years
(Table 5)
?
162 years
(Conclusion)



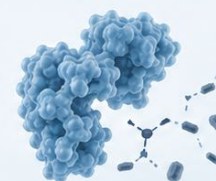
Microfibers: accelerated UV tests

Direct fiber experiments show oxidation, chain scission and fragmentation. Lamp exposure cannot be read as equivalent days of natural sunlight or complete environmental removal.



Ocean microbes: enzymatic capacity

Functional PETases and active gene transcription are documented. This establishes biological capacity, not a quantified ocean-wide removal flux or a microfiber-versus-bottle lifetime ratio.



PET is not inert. Realistic disappearance and mineralization rates remain condition- and endpoint-dependent.

Sources: Stanica-Ezeanu & Matei (2021), Table 5/conclusion; Sait and Sørensen (2021); Alam (2025); Chen (2026).

Plastics Research Council
SCIENCE FOR A CIRCULAR TOMORROW

Figure 8A. Evidence for PET transformation, with explicit endpoint and extrapolation limits. The hydrolysis source contains conflicting 30 °C values (Table 5 versus conclusion). Accelerated microfiber experiments and ocean PETase evidence do not validate a marine disappearance rate or a microfiber-versus-bottle lifetime ratio.

6.4 Ecotoxicity and risk: exposure and comparative evidence

The field evidence identified in this review does not establish that polyester textile fibers cause greater ecological harm than cotton, wool or regenerated-cellulose fibers at the measured exposures considered. This does not establish equal risk or absence of harm. Comparative LCIA may estimate different potential impacts because release, exposure and fate differ; those modeled results should be reported with their assumptions and uncertainty, separately from observed field effects. Laboratory studies identify effects under defined test conditions and can inform risk estimates; matched comparators, measured exposure and ecologically relevant endpoints determine how far those findings transfer. A particle-free control alone does not establish that a response is specific to plastic (Ogonowski, Gerdes & Gorokhova 2018; DeArmitt 2026a).

Parker, Lewis & Galloway (2025) provide useful comparative laboratory-hazard evidence. Their meta-analysis extracted 472 endpoints from 38 aquatic microfiber studies and reported statistically negative pooled endpoints for both petroleum-based and non-petroleum microfiber classes, including cotton, viscose/lyocell and polyester/PET among common textile fibers. The evidence base was strongly imbalanced—89 non-petroleum versus 383 petroleum-based endpoints—and exposure designs, concentrations, endpoints and fiber properties were heterogeneous. The meta-analysis therefore does not demonstrate ecosystem damage from ordinary environmental PET exposure and cannot support an intrinsic-toxicity ranking in which polyester is treated as uniquely harmful. Instead, it shows that laboratory biological responses are not unique to synthetic fibers and must be interpreted against dose and real-world exposure.

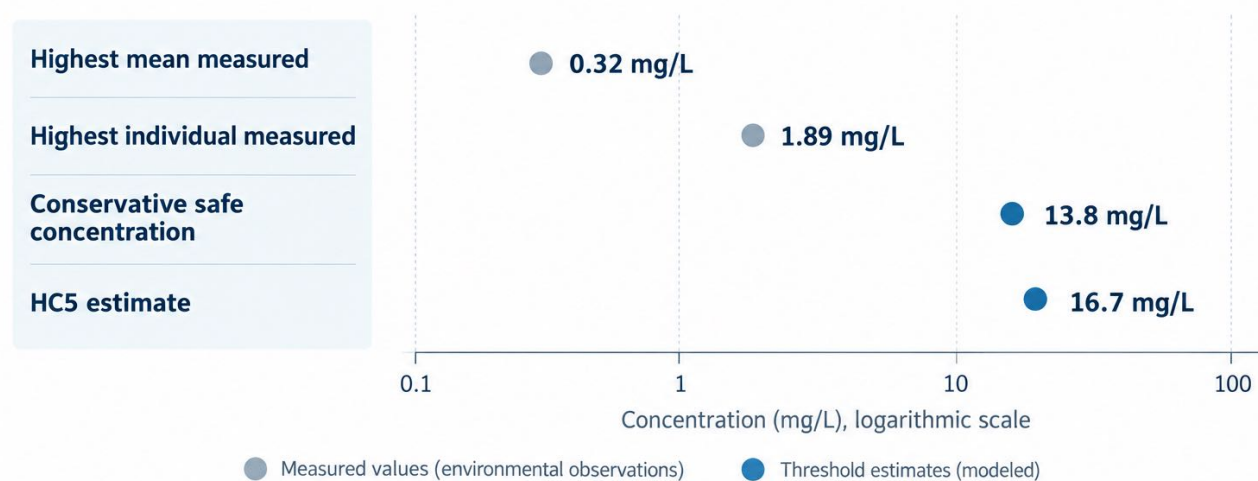
The broader Plastics Research Council Microplastics Science 2026 synthesis is a risk-interpretation cross-check rather than a replacement for primary textile studies. It evaluates exposure, particle identity, dose, methods and toxicity across 1,661 canonical evidence records. For the present comparison, field composition, measured release and experimental effects remain separate evidence layers: the predominance of non-synthetic fibers by count in Suaria et al. (2020) does not itself establish a risk ranking. The exposure-specific comparative conclusion is stated in Section 6.4; hotspots, formulations and unusual exposures require their own assessment (DeArmitt 2026a).

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SCIENCE FOR A CLEANER OCEAN

Ocean microplastic risk: a 2020 assessment

Then-monitored ~100–5000 μm particles • Not fiber-specific • Not a 2026 assessment



The 13.8 mg/L threshold is ~7.3× the reported maximum and ~43× the highest mean. The study does not resolve <10 μm particles or nanoplastics.

Source: Beiras & Schönemann (2020), Results and Table 3. Thresholds are modeled; exposure values are compiled measurements.

PLASTICS
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Figure 9. Beiras & Schönemann's 2020 assessment of then-monitored ~100–5000 μm microplastics. The 13.8 mg/L conservative threshold was approximately 7.3 times the reported maximum (1.89 mg/L) and 43 times the highest mean (0.32 mg/L). Thresholds are modeled and concentrations compiled from measurements; this is not a fiber-specific assessment or a conclusion about <10 μm particles or nanoplastics.

Controlled fiber studies show why endpoint and statistical status matter. Mateos-Cárdenas et al. (2021) found ingestion of both cellulose and PET fibers by freshwater amphipods without an apparent acute survival effect over 96 hours. Walkinshaw et al. (2023) exposed juvenile mussels for 94 days. Overall mean growth rate was 35.6% lower at ~80 PET fibers/L than the control ($p = 0.004$); the decreases at ~80 cotton fibers/L (18.7%, $p =$

0.09) and ~8 PET fibers/L (3.1%, $p = 0.40$) were not statistically significant. The direct ~80 PET-versus-cotton comparison was also not significant ($p = 0.12$). The authors described ~8 fibers/L as a current-exposure scenario and ~80 fibers/L as a feasible future or highly polluted-water scenario. These are laboratory results, not field observations; non-significance does not prove equivalence. Cotton also differed from control at one individual growth timepoint, which should not be confused with the non-significant overall growth-rate contrast.

Erdle et al. (2026), testing cotton and PET at 50 and 500 fibers/L over a full life cycle in *Chironomus dilutus*, found no effects on emergence percentage, fecundity or hatchability. At the higher concentration, time to emergence increased across microfiber treatments, with some inconsistent growth/survival effects. Taken together, these experiments show concentration-, species- and endpoint-dependent responses in both synthetic and cellulosic fibers; they do not alone establish a universal field-risk ordering.

Metals, colorants, mordants and finishes across textile fibers

Cross-fiber evidence. Metals associated with textile fibers are a formulation, processing and exposure question, not an intrinsic property unique to polyester. The PET repeat unit contains no metals, but finished textiles can acquire metals through raw-material impurities, process contamination, dyes and pigments, mordants, catalysts, stabilizers, sizing agents and functional finishes, including antimicrobial and flame-retardant treatments. Rezić & Steffan (2007), Sungur & Gülmez (2015), Rovira et al. (2015) and Rujido-Santos et al. (2022) provide evidence across natural, regenerated and synthetic products. Their combined coverage includes cotton, flax, wool, silk, viscose, acrylic, nylon, polypropylene and polyester; individual studies did not test every fiber or every treatment.

Dyes, pigments and mordants. Rezić & Steffan (2007) describe metal-complex colorants used on wool and nylon, including chromium- and cobalt-containing systems, and metal salts used in mordanting or dye fixation. Their 16-product survey included two dyed wool fabrics. The commercial dye recipes were not analytically established: detecting a metal does not identify its exact source. Metallic mordants, metal-containing colorants and metal-free fixing agents must not be treated as interchangeable categories.

Cotton processing. Rybicki et al. (2004) traced cotton bed-cloth manufacture and analyzed the reactive and pigment dyestuffs. Total copper rose from 1.02 mg/kg in raw cotton to 279.7 mg/kg in finished cloth; cobalt and chromium increased at dyeing, and nickel at printing (Table 5). Selected dye formulations contained 45,210 mg/kg Cu, 6,088 mg/kg Co or 8,818 mg/kg Cr (Table 6; dye-product, not fabric, mass). Finished-cloth sweat extracts met the paper's historical ÖKO TEX Standard 100 criteria, but extraction varied from about 3% for Co to 70% for Ni (Table 7). These are product-specific measurements, not wearer uptake. Appendix B provides the verified data and limits.

Fixation can reduce release. Matyjas-Zgondek et al. (2012) dyed flax with copper-containing C.I. Direct Blue 86, then compared unfixed fabric with fabric treated using a cationic fixing agent. Copper extraction fell after fixation (Figure 9A). The experiment demonstrates why a treatment can increase total metal content yet a subsequent fixing step can reduce the releasable fraction. It does not establish that all fixatives contain metals or that all dye systems behave similarly.

Functional finishes and pigments. Rujido-Santos et al. (2022) combined product composition information with ICP-MS measurements. Examples included ZnO-finished viscose/cotton and polyester/cotton shirts, TiO₂-finished cotton/modal products, and silver-treated cotton-containing and synthetic garments. A "natural" fiber label therefore does not establish a metal-free finished product. These selected samples do not measure market prevalence; elemental totals do not establish particle form or metal speciation.

Antimony: a specific polyester qualification. Antimony compounds used in PET polycondensation can leave catalyst residues in polyester. Biver, Turner & Filella (2021) measured roughly 125–470 mg Sb/kg textile and about 0.05–2% mobilization under their default artificial-sweat procedures. Extraction depended on time,

temperature, pH and filtration. This distinguishes retained catalyst content from mobilized material; neither quantity is itself an absorbed human dose.

Exposure and risk remain product-specific. The dedicated 69-record antimony synthesis (DeArmitt 2026b) reports no demonstrated meaningful systemic uptake from ordinary garment wear; the human biomonitoring result it discusses involved trousers that were not conventional polyester and is not direct proof for ordinary PET clothing. Rovira et al. (2017) reported mean Sb hazard quotient 0.4 and a value above 1 for one polyester T-shirt under their dermal-exposure assumptions. That is a model-based screening result, not observed illness. Conversely, Zuo et al. (2024) estimated metal intakes from the polyester microfibers they studied roughly three to six orders of magnitude below the selected tolerable-intake thresholds for their human and fish scenarios. Neither study establishes a universal risk ranking across textile materials.

MATERIALS
CONTEXT
EVIDENCE
BETTER DECISIONS

Metals in textiles: look beyond the fiber label

Colorants, mordants, functional finishes and catalysts can introduce metals across natural, regenerated and synthetic fibers. Documented examples, not prevalence or risk grades.

PEOPLE
PLANET
CLEANER TEXTILES
BRIGHTER TOMORROW

Dyed cotton, wool and flax

Metals measured in commercial textiles



- Copper (Cu) in dyed cotton and flax.
- Chromium (Cr) and cobalt (Co) in wool.
- Commercial dye recipes were not identified.

Rezič & Steffan (2007), Tables 1, 8

Functional textile finishes

Metals intentionally added for specific properties



- Zinc oxide (ZnO) on viscose/cotton and PET/cotton.
- Titanium dioxide (TiO₂) on cotton/modal blends.
- Silver (Ag) in antimicrobial treatments.

Rujido-Santos et al. (2022), Tables 1, 5

Polyester catalyst residues

Antimony from PET manufacture



- Antimony (Sb) residues can remain from PET production.
- Measured extraction into artificial sweat is generally low, but depends on conditions.
- Metals are not unique to polyester and occur across many fiber types.

Biver et al. (2021), extraction study

1 Cotton manufacture: a measured process sequence

Total copper content, mg/kg textile (Rybicki et al. 2004, Table 5)



Key findings from the full study

- Copper, cobalt and chromium increased substantially at the dyeing stage.
- Nickel increased at pigment printing.
- Dye formulations contained high levels of metals (e.g. 45,210 mg/kg Cu in a pigment dye; 6,088 mg/kg Co and 8,818 mg/kg Cr in a reactive black).
- Finished fabric met the historical ÖKOTEX Standard 100 criteria for extractable metals.

2 Content is not absorbed dose

Finished cotton cloth: total vs. amount extracted (Rybicki et al. 2004, Table 7)

Metal	Total content (mg/kg)	Extracted amount (mg/kg)	Extracted fraction
Copper (Cu)	279.7	11.83	4.2%
Cobalt (Co)	18.24	0.5518	3.0%
Chromium (Cr)	5.34	0.502	9.4%
Nickel (Ni)	1.29	0.9072	70.3%



Nickel shows much higher extractability (70.3%). Low extractability cannot be assumed for every metal.

3 Fixation can reduce release



In a controlled study on flax, a fixing treatment reduced copper extraction into artificial sweat from 4.910 to 1.554 mg/kg textile.

Matyjas-Zgondek et al. (2012), Table 5



Fixatives are not a uniform source of additional metal exposure. Processing choices can reduce release.

Important context



Total content, release, absorbed dose and health effects are different measurements.



Results are product-specific and historical. They do not indicate current market prevalence.



Evaluate the actual finished product, its processing and test data — not the fiber label alone.



METAL CONTENT, RELEASE, ABSORBED DOSE AND HEALTH EFFECT ARE DIFFERENT MEASUREMENTS.

Evaluate the finished product — not “natural” or “synthetic” alone.

Figure 9A. Metals in textiles: source-linked examples and a measured manufacturing sequence. Rybicki et al. (2004), Tables 5–7, supplies the cotton values and calculated extraction fractions. The complete cross-fiber evidence map is retained as Table B4, alongside the cotton source data and study limitations.

Table 6A. Selected comparative evidence relevant to microfiber hazard and ecological risk. The studies use different species, endpoints and concentrations and should not be pooled into a single toxicity score; laboratory responses are not equivalent to demonstrated field ecosystem damage.

Study / system	Exposure / comparison	Main result	What it supports
Parker, Lewis & Galloway (2025)	38 aquatic microfiber studies; 472 endpoints; petroleum vs non-petroleum	Statistically negative experimental endpoints reported for both broad classes; cotton, viscose/lyocell and polyester/PET among fibers with significant pooled effects; non-petroleum evidence much smaller	Comparative laboratory-hazard evidence; does not demonstrate field ecosystem damage or a simple intrinsic-toxicity ordering
Beiras & Schönemann (2020)	Global ocean; monitored ~100–5000 µm MPs	Modeled conservative threshold 13.8 mg/L vs measured maximum 1.89 and highest mean 0.32 mg/L: ratios ~7.3 and ~43. Modeled $P(\text{exceedance}) = 0.00004$.	2020 broad large-microplastic assessment, not fiber-specific; not a conclusion about <10 µm particles or nanoplastics.
Mateos-Cárdenas et al. (2021)	Cellulose vs PET; <i>Gammarus duebeni</i> ; 96 h	Both ingested; no apparent acute survival effect	Natural and synthetic fibers can both be ingested without acute mortality under these test conditions
Walkinshaw et al. (2023)	PET ~8 and ~80 fibers/L; cotton ~80 fibers/L; juvenile mussels, 94 d. Authors' current and future / polluted-water scenarios.	Overall growth-rate decrease vs control: ~80 PET 35.6% ($p = 0.004$); ~80 cotton 18.7% ($p = 0.09$); ~8 PET 3.1% ($p = 0.40$). Direct high-PET vs cotton: $p = 0.12$.	Significant overall growth-rate reduction in the high-PET condition; non-significant contrasts do not prove equivalence. Laboratory evidence, not a field-damage observation.
Erdle et al. (2026)	Cotton and PET; 50 and 500 fibers/L; full life cycle	No emergence/fecundity/hatchability effect; delayed emergence at 500 fibers/L across treatments	High experimental loading can alter timing for both cotton and PET; no emergence/fecundity/hatchability effect and no plastic-specific field-damage inference

6.5 LCIA microfiber characterization: conditional potential-impact estimates

A methodological change occurred in 2026. The Global Guidance for Life Cycle Impact Assessment (GLAM) ecosystem-quality method includes aquatic microplastic pollution among its LCIA categories and provides global characterization factors for 11 polymers, three particle shapes—including microfibers—and five particle sizes (1, 10, 100, 1000 and 5000 µm), with water-column and sediment terms combined. These factors convert inventory and modeled fate/effect information into a potential ecosystem-quality indicator. They are not field observations that a modeled quantity of microfibers has damaged an ecosystem. The factors remain global rather than regional and can vary by orders of magnitude; GLAM reports uncertainty of up to roughly three orders for some polymers. The method is therefore useful for scenario comparison, but its output must remain explicitly model-labeled (Verones et al. 2026).

Saadi & Boulay (2026) extended this modeling framework to six cellulosic microfiber types: cotton, linen, viscose, lyocell, rayon and modal. Their abstract emphasizes two findings that should be retained alongside the present report's interpretation: cellulosic microfibers can produce harmful biological effects at concentrations the authors describe as environmentally relevant, and in their comparative T-shirt LCA polyester microfiber

emissions made a significant contribution relative to other modeled life-cycle impacts whereas cotton microfiber emissions did not. At the same time, their species-sensitivity distribution found the HC20 for cellulosic microfibers was not significantly different from that for microplastics, suggesting similar physical-effect mechanisms in the experimental evidence they modeled. The lower cellulosic characterization factors—one to two orders of magnitude below synthetic microfiber factors—arose mainly from faster modeled degradation and therefore shorter modeled marine residence. Accordingly, the study supports taking microfiber emissions seriously in LCA while also showing that the synthetic-versus-cellulosic difference is driven substantially by modeled fate/persistence rather than a demonstrated intrinsic-toxicity difference.

The same model-evaluation standards apply to microfiber LCIA and to the service-life models used elsewhere in this report. Each should be judged by inventory quality, boundary completeness, empirical support, uncertainty, sensitivity and validation—not accepted or rejected simply because it is modeled. Henry, Laitala & Klepp (2019) proposed an interim indicator combining release and persistence; later fate-weighted LCIA makes such assumptions explicit. Conditional potential-impact estimates are scientifically relevant evidence, while remaining distinct from measured field ecosystem effects.

Saadi & Boulay's cradle-to-grave case assumed an equal 45-wear lifetime for cotton and polyester T-shirts. The microfiber physical-effect term represented about 0.7% of the total modeled ecosystem-quality indicator for cotton in the Québec-use scenario and 2.5% in the low-income-country scenario, compared with 7.3% and 27.0% for PET. The total modeled indicator was nevertheless higher for cotton because land, water, climate and other production burdens outweighed the microfiber difference. Both the larger PET microfiber component and the higher cotton total are conditional model results and should be retained. Terrestrial pathways were omitted, and leakage and fate assumptions materially affect transfer to other systems; neither output is a measurement of field damage.

The calculated magnitude is strongly model- and product-system-dependent. Pellengahr, Ghannadzadeh & van der Meer (2025) modeled a recycled-PET/elastane cycling jersey and estimated the marine-microplastic physical-effect term at only $1.48 \times 10^{-4}\%$ of the total modeled ecosystem-quality indicator in that case. The authors noted important omissions from the available characterization factors, including resuspension and degradation in marine sediments, and did not include potential toxicological effects. The contrast with Saadi & Boulay is not evidence for one universal microfiber percentage; it shows that release inventory, end-of-life leakage, fate assumptions, compartment coverage and product system can change an LCIA characterization result by orders of magnitude. Neither case is a direct measurement of ecosystem damage.

Table 6B. Model-based LCIA characterization of microfiber physical-effect potential. Values are scenario outputs, not measurements of ecosystem damage.

Saadi & Boulay (2026) modeled metric	Cotton T-shirt	Polyester T-shirt	Interpretation
Modeled microfiber share of total ecosystem-quality indicator: Québec use	0.7%	7.3%	Equal 45-wear lifetime; authors describe polyester microfiber emissions as a significant contributor relative to other modeled life-cycle impacts in this scenario. The term is a modeled marine physical-effect characterization, not observed ecosystem damage.
Modeled microfiber share of total ecosystem-quality indicator: low-income-country scenario	2.5%	27.0%	Higher assumed leakage/mismanagement increases the modeled microfiber term

Saadi & Boulay (2026) modeled metric	Cotton T-shirt	Polyester T-shirt	Interpretation
Total modeled ecosystem-quality indicator	Higher overall	Lower overall	Cotton land/water/climate and other modeled burdens outweighed the PET microfiber term in this scenario; not a field observation
Characterization-factor basis	Cellulosic CFs 1–2 orders lower	Synthetic CFs higher	Difference driven mainly by modeled environmental fate/degradation. The modeled organism-sensitivity distributions were not significantly different; the result supports fate-weighted LCIA rather than an intrinsic-toxicity ranking.

The newer PET-fate evidence also makes persistence a key sensitivity parameter in microfiber LCIA. Characterization factors that assume extremely slow or fixed PET persistence can materially influence synthetic-versus-cellulosic comparisons. Such models should therefore be sensitivity-tested against hydrolysis, photoaging and biological-degradation evidence rather than treating PET as effectively inert. This does not justify assigning a single rapid field-disappearance rate: Stanica-Ezeanu & Matei provide a model extrapolation, Chen et al. use accelerated UV, and Alam et al. establish enzymatic capacity rather than a global removal flux. The uncertainty should be represented explicitly.

Report position. Use measured release, environmental abundance, fate, exposure, experimental effects and appropriate models together, with the same evidentiary standards for each fiber. A larger modeled PET term can support a conditional potential-impact difference; it must not be relabeled as measured toxicity or observed ecosystem damage. Conversely, the absence of an identified comparative field effect must not be used to discard that model result or to infer equal risk. Section 6.4 states the bounded field-evidence conclusion.

6.6 Recycled polyester: current evidence does not establish a universal shedding penalty

Claims that recycled polyester inherently releases more fibers than virgin polyester are not settled. Özkan & Gündoğdu (2021) produced controlled knitted fabrics from virgin and recycled polyester yarns and reported greater microfiber release from the recycled fabrics. By contrast, Gao et al. (2024) tested four commercial virgin/recycled PET pairs described as identical except for polyester origin. Across washing and Martindale abrasion, there was no statistically significant overall difference in released microplastic-fiber counts between virgin and recycled PET ($p>0.05$), and no overarching difference in fibril counts. Fabric structure—filament versus staple yarns—and surface treatment strongly affected release. Their overall conclusion was that the mechanically recycled PET textiles tested showed no significant deficiency in fiber/fibril release potential relative to virgin PET.

The 2024 critical systematic review by Tedesco, Fisher & Stuetz reached the broader conclusion that studies of virgin versus recycled polymer origin gave opposing results. It also found that 81% of the textile-feature studies reviewed failed to provide clear causal evidence for the claimed effects, and warned that small-scale laboratory laundering can overestimate emissions relative to full-size machines. This gives more evidential weight to well-controlled matched comparisons than to simple cross-product averages.

A larger 2026 study by Gündoğdu et al.—the peer-reviewed publication arising from the 51-garment dataset used in the earlier Changing Markets report—found a higher descriptive mean fiber count for rPET (12,430 fibers/g) than virgin PET (8,028 fibers/g), approximately +55%. However, the published paper states that this material-category difference was not statistically significant because within-group variability was high. The same study reported cotton at 9,776 fibers/g but 1.85 mg/g by mass, versus 0.36 mg/g for rPET and 0.24 mg/g for virgin PET. Thus the apparent ranking changes according to whether one counts fragments or weighs the

material lost. The commercial garments were not matched pairs, and the authors acknowledged that comparable garment types could not always be sourced.

The most defensible current conclusion is therefore performance-based: recycled PET may shed more in some constructions and recycling histories, but there is no demonstrated universal rPET multiplier that can be applied across textiles. Even if a given rPET fabric releases more PET fibers than its virgin analogue, the environmental relevance still requires comparison with the total fiber release, fiber-size distribution, service life and risk of realistic alternatives such as cotton and wool. Figure 10 summarizes why a single recycled-PET shedding multiplier is not justified by the current evidence.

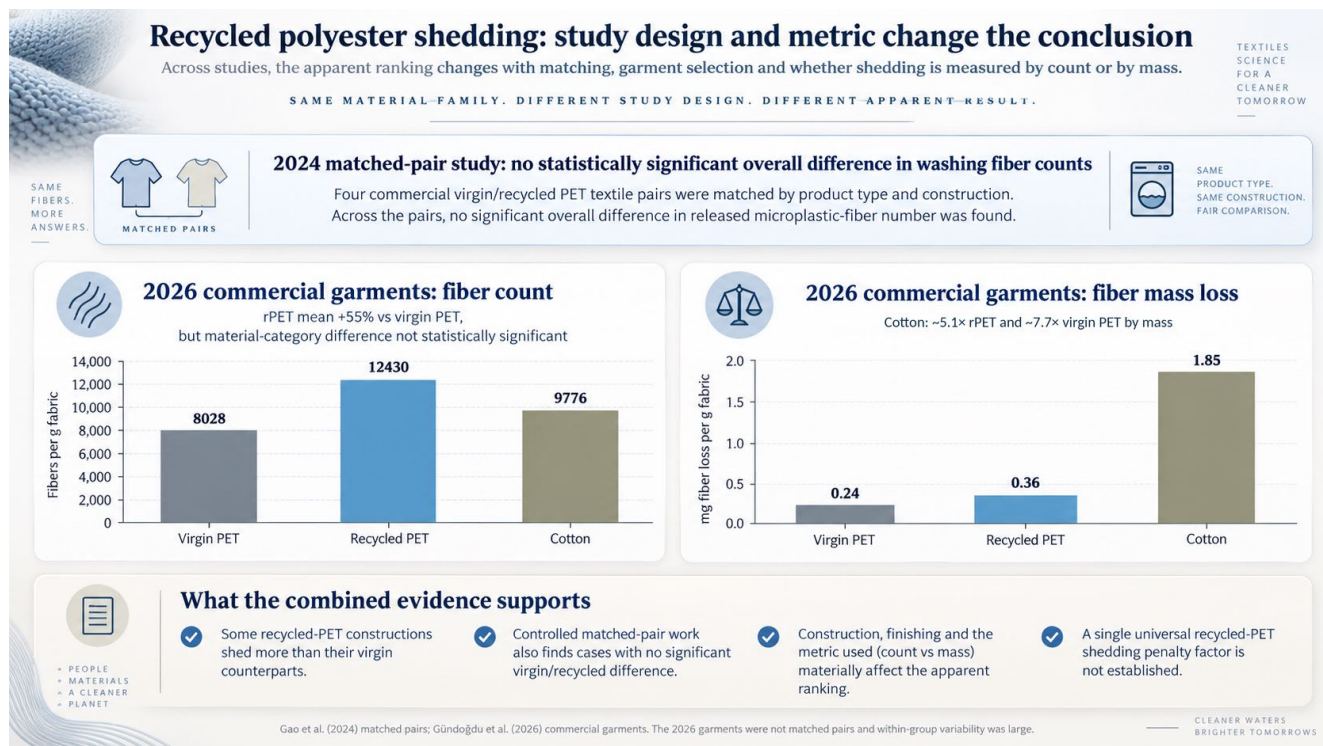


Figure 10. Recycled-PET shedding evidence is not one-directional. Gao et al. (2024) found no significant virgin-versus-recycled difference in matched textile pairs; Gündoğdu et al. (2026) found a higher descriptive rPET fiber count in commercial garments but no statistically significant material-category difference, while cotton lost substantially more fiber by mass.

Table 6C. Evidence on virgin versus recycled polyester shedding. Current studies do not support a single universal penalty factor for recycled PET.

Evidence	Design	Result	Weight in this review
Özkan & Gündoğdu (2021)	Controlled knitted virgin vs recycled PET yarns	rPET released more fibers; released fibers were shorter	Supports a possible rPET effect in that textile system
Gao et al. (2024)	Four matched commercial virgin/rPET pairs; washing + abrasion	No significant overall virgin/rPET difference in fiber counts or fibril counts; construction/surface treatment mattered	Strong controlled counterevidence to a universal rPET penalty
Tedesco et al. (2024)	Critical systematic review of 57 experimental shedding studies	Virgin/recycled results were inconsistent/opposing; most textile-feature claims lacked clear causal evidence	Supports uncertainty and the need for controlled designs
Gündoğdu et al. (2026)	51 commercial garments; ISO lab + domestic-scale methods	rPET mean count +55% descriptively, but not statistically significant across material categories; cotton mass loss much higher	Useful real-product screening; weaker for causal attribution because garments were not matched

7. Cross-material synthesis and current assessment

The detailed synthesis is split into separate physical categories and is not a weighted score. Climate, fossil-resource demand, land, water, service performance and fiber-emission evidence have different units and meanings. Figure 11A shows source-linked product-system comparisons; Figure 11B separately maps production-stage findings and service limitations. Tables 7A and 7B retain the detailed cross-material synthesis. “Confidence / boundary” describes support for a stated comparison, not the intrinsic quality of a material.

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TEXTILE EVIDENCE REVIEW · VERSION 1.0

Current evidence synthesis by criterion

Read within each row — source, metric and comparison basis remain attached to every color

A · PRODUCT-SYSTEM COMPARISONS

Study / metric	Comparison basis	Lower / lowest	Intermediate	Higher	Source and limit
JRC T-shirts · climate	Per day of wear; index: cotton = 100	PET · 75 ≈25% below cotton	50/50 blend · 84 ≈16% below cotton	Cotton · 100 Reference	[1] Modeled washes Cotton / blend / PET: 50 / 80 / 95; care differs.
JRC T-shirts · fossil depletion	Per day of wear; index: cotton = 100	PET · 79 ≈21% below cotton	50/50 blend · 85 ≈15% below cotton	Cotton · 100 Reference	[1] Resource indicator Not a separate measure of fuel burned.
Hotel sheets · laundering energy	Care-energy term; index: cotton = 100	50/50 blend · 83.3 ≈17% lower	—	Cotton · 100 Reference	[2] Laundering only Not a total-life-cycle saving.
Hotel sheets · production energy	Production for equal 100-cycle modeled service	50/50 blend · 58.1 ≈42% lower; cotton = 100	—	Cotton · 100 Two sheets versus one blend	[2] Production only Cotton 50 / blend 100 modeled rentals.
Koch garments · climate	Annualized model; three garment types	PET option 8.7–15.1% below defaults	—	Study defaults Study-defined baselines	[3] Default comparators Not every alternative material.
Koch garments · land use	Annualized model; three garment types	PET option 77.1–84.3% below defaults	—	Study defaults Study-defined baselines	[3] Land, not water Mass, life and care included.
Xu T-shirts · climate	kg CO ₂ e per garment; both assigned 20 washes	Cotton · 6.10 Lower in this scenario	—	PET · 9.62 Higher in this scenario	[4] Different system Do not transfer JRC lifetime ratios.
Xu T-shirts · land use	Same 20-wash scenario; reported direction	PET Lower than the cotton case	—	Cotton Higher than the PET case	[4] Land only No numerical value inferred.
Xu T-shirts · water use	Same 20-wash scenario; reported direction	PET Lower than the cotton case	—	Cotton Higher than the PET case	[4] Water only No numerical value inferred.
Merino service model · climate	kg CO ₂ e per soldier over six months	Merino system · 7.0 Conditional service model	—	PET/nylon · 17.7 50/50 synthetic reference	[5] Proposed system Reuse, care and recycling assumptions.

LOWER / LOWEST

Within the named comparison

INTERMEDIATE

Between alternatives in that row

HIGHER

Within the named comparison

UNRESOLVED

An explicit comparative evidence gap

Construction still matters: premium cotton 100.2 > basic blend 78 > basic cotton 60 modeled washes in the bed-sheet comparison [6].
The color follows the finding — not the fiber name.

— = no intermediate option shown, not missing evidence. Production and laundering remain separate; no weighted overall score.

[1] Beton 2014, \$2.1 · [2] Kalliala & Nousiainen 1999, \$2.2 · [3] Koch 2025, \$2.6 · [4] Xu 2026, \$2.4 · [5] Bech 2019, \$2.8 · [6] De Saxcé 2012, \$2.3

50/50 blend = cotton/PET. Source-linked SVG cells and the companion register give the full study and classification details.

Figure 11A. Product-system comparisons; colors apply within each named row. [Source key \(Appendix B5\): \[1\] \[2\] \[3\] \[4\] \[5\] \[6\]](#)

Current evidence synthesis by criterion

Production-stage findings and service limitations — do not combine these rows into a league table

B · TEN-FIBER EVIDENCE MAP — CONTEXT IS NOT A RANK

Material	Climate: production	Resources / energy: production	Land context	Water context	Service evidence and limits
Polyester (PET)	4.55 kg CO ₂ e/kg [7] Virgin staple; fiber gate.	80.7 MJ/kg [7] CML ADP fossil; fiber gate.	Very low [17] Agricultural land demand.	No irrigation [17] Process water still matters.	Strong in tested systems [1,17] See A for whole-life advantages; realized life and care matter.
Cotton	0.44–4.17 kg CO ₂ e/kg [7] Selected gin-gate systems.	1.5–40.3 MJ/kg [7] Selected CML ADP fossil results.	Yield-dependent [17] Low yields add land per kg.	Location matters [17] Irrigation and watershed matter.	Construction-dependent [6] Premium cotton had the longer modeled sheet life.
Organic cotton	No fixed advantage [8] Yield changes the per-kg result.	Inputs and yield [8] Lower inputs can be offset by lower yield.	Yield matters [17] Lower yields can add land/kg.	Location-specific [17] “Organic” does not specify water scarcity.	Not a service-life label [17] Cultivation method alone does not determine textile durability.
Linen / flax	13.6 kg CO ₂ e/kg yarn [9] Crop through bleached yarn.	261 MJ/kg yarn [9] Non-renewable energy; not fossil-only.	Yield-dependent [17] Some crop systems favorable.	Often low irrigation [17] Retting and processing still matter.	Service rank unresolved [16] Garment evidence exists; tightly matched comparisons are limited.
Viscose / rayon	Process / region [10] Garment-gate results vary.	Conversion inputs [10] Heat, electricity and chemical recovery.	Forestry / pulp [17] Sourcing and allocation matter.	Process-specific [17] Water and recovery system matter.	Realized-life gap [17] Comparative service evidence remains limited.
Lyocell	Energy-sensitive [10] Solvent recovery and grid matter.	Recovery energy [10] Heat and electricity can dominate.	Forestry / pulp [17] Sourcing and allocation matter.	System-specific [17] Water result still varies by process.	Mass is not lifetime [10] Tenacity may reduce modeled mass; realized life remains uncertain.
Nylon / polyamide	Above PET in the model [11] Polymer/fiber production.	129.7 MJ/kg CED [11] Cumulative energy is not fossil depletion.	Very low [17] Agricultural land demand.	No irrigation [17] Process water still matters.	Failure mode matters [17] Abrasion resistance is strong; PET was more wash-stable in the cited test.
Wool	Methane hotspot [12] High upstream GHG contribution.	Processing hotspot [17] No common fiber-gate rank supplied.	High grazing [17] Land demand in the source.	Context-dependent [17] Geography and scarcity method.	Realized service matters [12] Long use and less washing can reduce per-wear impacts.
Alpaca	Farm methane hotspot [13] 84.96–92.69% of farm-stage GWP.	Comparative gap [17] Less well characterized across systems.	High reliance [17] On grazing land.	Comparative gap [17] Insufficient water evidence.	Lifetime is borrowed [13] 109 wears assumed from Merino; not measured for alpaca.
Cashmere	155–183 kg CO ₂ e/kg [14] Clean dehaired fiber; upstream.	109–144 MJ/kg [14] PEF fossil; upstream, not per service.	High impact [17] Grazing-land impact in the source.	Comparative gap [17] Finished-service data limited.	Longevity benefit unproven [15] Not evidence of universally inferior service life.

Neutral cells report source findings, not environmental grades. Grey marks explicit comparative gaps.

Stages and indicators differ: fiber gate ≠ gin gate ≠ yarn gate; CML ADP fossil ≠ PEF fossil resource ≠ cumulative energy.

[7] Textile Exchange 2026, cotton/PET · [8] Vitale 2025 · [9] van der Werf & Turunen 2008 · [10] Forfora 2026 · [11] van der Velden 2014

[12] Wiedemann 2020 · [13] Kern 2026 · [14] Textile Exchange 2026, cashmere · [15] McGregor & Postle 2008/09 · [16] Benkirane 2019/22 · [17] Report Tables 7A–7B

Figure 11B. Ten-fiber evidence map; production context is not a comparative rank. [Source key \(Appendix B5\): \[7\] \[8\] \[9\] \[10\] \[11\] \[12\] \[13\] \[14\] \[15\] \[16\] \[17\]](#)

Table 7A. Cross-material synthesis of climate, fossil-resource, land and water evidence. Categories remain separate and are not combined into a score.

Material	Climate evidence	Fossil resource / energy	Land evidence	Water evidence
PET polyester	Moderate fiber-gate GHG; lower than cotton in JRC service-normalized T-shirt case	High virgin fiber-gate fossil resource; service-normalized JRC fossil depletion lower than cotton	Very low agricultural land requirement	No irrigation burden; process water/energy still system-dependent
Cotton	Highly variable by geography/yield; can be low at farm gate	Often below virgin PET per kg fiber; irrigation, fertilizer and machinery can add fossil demand	Can be high per kg when yields are low	Strongly watershed/irrigation dependent; can dominate in irrigated systems
Organic cotton	No universal climate advantage per kg; yield is decisive	Often lower synthetic-input burden, but lower yield can offset	Land per kg can increase with lower yield	System- and location-specific; “organic” does not specify water scarcity
Linen / flax	Crop stage can be favorable; yarn conversion can dominate	Yarn/spinning can be energy intensive	Crop land requirement is yield-dependent; cited flax systems can be favorable, but finished-service evidence is insufficient	Often low irrigation demand; retting/processing context matters
Viscose / rayon	Conversion can be high; strongly process- and region-dependent	Industrial heat/electricity and chemical recovery important	Depends on forestry/pulp sourcing and allocation	Process water and chemical-recovery system important
Lyocell	Energy-intensive solvent recovery can raise GHG; cleaner grids materially improve result	Heat/electricity can dominate conversion	Depends on forestry/pulp sourcing and allocation	Closed-loop process reduces some chemical burdens; water result remains system-specific
Nylon / polyamide	Generally above PET at polymer/fiber production in harmonized studies	High cumulative energy demand	Very low agricultural land requirement	No irrigation burden; process impacts remain
Wool	High upstream GHG dominated by enteric methane	Processing is major fossil-energy hotspot; full-garment fossil energy can be moderate per long service	High grazing-land demand	Water result depends strongly on scarcity method and geography
Alpaca	Very high farm-stage GHG dominated by enteric fermentation	Less well characterized across systems	High grazing dependence	Insufficient comparative evidence
Cashmere	Extremely high upstream GHG; methane dominated	109–144 MJ fossil resource/kg clean dehaired fiber in current LCA	Very high grazing-land impact	Insufficient comparative water evidence in finished-service terms

Table 7B. Cross-material synthesis of service performance and fiber-emission evidence. Fiber release, fate and effect are not treated as a binary plastic/non-plastic attribute.

Material	Service / durability evidence	Fiber release, fate and effect evidence	Confidence / boundary
PET polyester	Strong evidence in tested T-shirt and repeatedly laundered bedding systems; benefit depends on realized life and care	Some tested PET constructions lose less mass than cotton-containing comparators. No greater comparative field effect was established at the measured exposures considered; this is not proof of equal risk. LCIA can estimate higher PET microfiber potential from inventory and fate differences; report the assumptions, sensitivity and uncertainty (Sections 6.3–6.5).	High for direct cotton/PET systems; transfer to other apparel requires care
Cotton	Highly construction-dependent; premium cotton can equal or exceed lower-quality blends	Can shed high fiber mass; dominant individual spectral match in Suaria surface-water dataset. Laboratory effects can occur at selected concentrations, as for synthetic fibers; no field evidence establishes an intrinsic toxicity advantage. Lower modeled cellulosic CF mainly reflects faster modeled fate, not lower organism sensitivity.	High evidence density but large product/agronomic variability
Organic cotton	Same construction-dependent textile durability as cotton	No separate fiber-fate advantage established solely from organic cultivation	High confidence that cultivation label alone does not determine textile service
Linen / flax	Direct T-shirt ageing evidence exists across commercial flax/linen products; longevity is strongly construction-dependent. No tightly matched linen-vs-cotton/PET service-life LCA yet isolates a material-specific advantage.	Cellulosic LCIA factors modeled below synthetics mainly from faster fate; direct shedding, field exposure and effect evidence remain limited	Moderate for garment durability evidence; low-moderate for comparative service ranking
Viscose / rayon	Direct realized-lifetime evidence remains weak	Woodall et al. found rayon in every sampled deep-sea sediment core and 56.9% of recovered fibers overall in a small multiregional dataset; occurrence does not establish source or ecological damage. Parker meta-analysis reports experimental negative endpoints for viscose; no generic field-damage conclusion; Saadi & Boulay model lower cellulosic CFs mainly because of faster fate.	Moderate for production; low-moderate for service/fate
Lyocell	Higher yarn tenacity can reduce modeled material mass; realized-lifetime evidence remains weak	Parker meta-analysis reports experimental negative endpoints for lyocell; no generic field-damage conclusion; lower modeled cellulosic CFs than synthetics mainly reflect fate assumptions	Moderate for production; low-moderate for service/fate

Material	Service / durability evidence	Fiber release, fate and effect evidence	Confidence / boundary
Nylon / polyamide	Exceptional abrasion resistance; PET more stable under repeated laundering in current direct test	Longer modeled persistence can increase LCIA characterization factors; direct matched shedding and field-risk evidence are limited	Moderate
Wool	Often long realized ownership and fewer washes; lifetime strongly changes per-wear impact	Can release substantial fiber mass; can biodegrade rapidly in favorable tests yet persist in dated sediments. No comparative field evidence establishes lower or higher intrinsic ecological toxicity than PET at ordinary exposure; comparative field-risk evidence remains limited.	High for methane; moderate for comparative service/fate
Alpaca	Key LCA borrows 109-wear life from Merino rather than measuring alpaca	Comparative microfiber fate/effect evidence sparse	Moderate upstream; low service/fate
Cashmere	Some mass efficiency; a compensating longevity advantage has not been demonstrated. Comparative service evidence is insufficient for a universal lifetime ranking.	Comparative microfiber fate/effect evidence sparse	High upstream; moderate-low service/fate

The overview is an aid to reading the case studies, not a substitute for the detailed evidence. In particular, the absence of a demonstrated compensating longevity advantage for cashmere is not proof of universally inferior service life. The linen, alpaca and regenerated-cellulose service comparisons also retain the limitations stated in Table 7B.

7.1 What can be stated with high confidence

- A kg-of-fiber ranking is insufficient for comparing clothing or household textiles. Direct studies show that useful lifetime and care can reverse the result.
- Fossil feedstock origin does not determine service-normalized fossil-resource demand. In the JRC T-shirt case, PET had lower modeled fossil depletion than cotton under the specified lifetime and care assumptions. That indicator does not separately quantify how much fossil fuel was burned.
- Polyester-containing bedding repeatedly shows a durability and drying-energy advantage over basic cotton, although high-quality cotton can match or exceed blend durability.
- Organic cotton cannot be assigned a generic lower-impact rating; yield and location are essential.
- Wool, alpaca and cashmere climate impacts are strongly driven by enteric methane. Cashmere has by far the highest upstream GHG intensity in the current evidence set.
- Natural-fiber environmental persistence can be long; “natural = biodegradable in the environment” is not a defensible generalization.
- PET and nylon can undergo physical and chemical degradation. For PET, hydrolysis, photooxidative chain scission, fragmentation and enzymatic attack are documented. Accelerated and extrapolated results do not establish a field mineralization lifetime. Standard short-duration tests generally found faster mineralization of wool/cellulosics than PET/nylon under the tested conditions; field outcomes remain environment-specific (Section 6.3).
- A qualitative “environmentally-friendly” label should not be treated as an LCA output when it overrides the modeled indicators using an external criterion. Koch et al. (2025) quantitatively favored polyester over its defaults for GHG and land use, then excluded polyester because of microfiber release without a comparative fiber-pollution calculation (in several comparative studies polyester released far less fiber material than cotton or wool).
- Global surface-ocean fiber measurements do not support the assumption that most chemically characterized fibers in sampled surface waters are polyester. In Suaria et al. (2020), 91.8% of characterized fibers were cellulosic or animal-origin and 8.2% synthetic; “cotton” was the most frequent spectral match (50%) and PET 6.2%. Because FTIR cannot always resolve natural from regenerated cellulose, the broad class result is more robust than assigning every cellulosic match to a specific textile source. The percentages describe fiber counts in sampled surface waters, not total ocean fiber mass.
- Current evidence does not establish that mechanically recycled PET universally sheds more than virgin PET. Controlled matched-pair evidence found no significant overall difference, and the largest 2026 commercial-garment study found a higher rPET mean count but no statistically significant material-category difference.
- Independent lifetime-sensitivity studies now replicate the conclusion that realized service life can alter whole-life impacts by tens to hundreds of percent; this is not an artifact of the JRC T-shirt case alone.
- Modern industrial-laundry evidence supports lower strength loss in 50/50 cotton/PET than in tested cotton bed linens, while simultaneously showing that well-constructed cotton can remain serviceable through very high wash counts.
- Recycled-content and circularity labels are not automatic environmental credits. Benefits depend on allocation, retained material quality, number of loops, care, transport and realized lifetime (Horn et al. 2023; Braun et al. 2021; Hester et al. 2026).

- The field evidence identified in this review does not establish a greater polyester-specific ecological effect at the measured exposures considered. This is a statement about the limits of the reviewed comparative evidence, not proof of safety or equal risk. Laboratory responses occur in both synthetic and non-synthetic fibers; LCIA can provide conditional potential-impact differences and must be assessed symmetrically (Sections 6.4–6.5).
- Regenerated cellulose cannot be treated as one homogeneous low-impact category. Viscose and lyocell have materially different chemistry and energy profiles, and tenacity-based material efficiency can change comparative GWP. Direct realized service-life evidence remains limited (Forfora et al. 2026).
- The 2025 microfiber meta-analysis reports statistically negative experimental endpoints for both petroleum and non-petroleum fiber classes, including cotton/viscose/lyocell and polyester/PET. The evidence is too imbalanced and heterogeneous to support a simple intrinsic-toxicity ranking, and the pooled laboratory results do not demonstrate field ecosystem damage at ordinary environmental exposure.
- Economic value follows the same service-normalization principle as environmental impact. Raw-fiber price alone does not determine cost per wear. The existing lifetime evidence supports transparent break-even purchase-price ratios—for example, 1.90× for the JRC PET-versus-cotton T-shirt comparison and 2.00× for the hotel-sheet blend-versus-cotton comparison—while a generic fiber-by-fiber dollar-per-wear ranking is not supported by matched market data.
- Clean mono-material PET has a distinct technical recycling advantage because it can be remelted and chemically depolymerized, but cotton and wool are also recyclable. Mechanical cotton recycling is widely used yet shortens/weakens fibers and commonly requires virgin blending for high-quality yarn; wool has established closed-loop mechanical recycling, with retained fiber length limiting repeated loops. Actual textile-to-textile recycling remains constrained by collection, sorting, blends, finishes and economics.

7.2 What should not yet be stated

- That one fiber is universally the “greenest” across all impact categories and applications.
- That linen is definitively the lowest-impact finished garment. Garment-level ageing and LCA evidence exists, but a robust, tightly matched service-equivalent ranking has not been established.
- That nylon is universally more durable than PET; durability mode matters (abrasion versus laundering/hydrothermal stability).
- That wool’s long lifetime fully compensates its methane footprint in ordinary apparel; this must be shown product by product.
- That alpaca provides 109 wears in real use; that denominator is borrowed from wool.
- That cashmere longevity offsets its upstream burden; current mechanical and wear evidence does not establish such an advantage.
- That persistence alone equals environmental harm. Persistence must be linked to release, exposure and demonstrated effects.
- That either polyester or natural/regenerated fibers are universally harmless, that non-significant results prove equivalence, or that laboratory effects alone establish observed ecosystem damage. The reviewed field evidence does not establish greater PET harm at the measured exposures considered, but laboratory and model evidence remains relevant to conditional risk estimates (Parker et al. 2025; Walkinshaw et al. 2023; DeArmitt 2026a).
- That a descriptive difference in fiber counts between unmatched commercial rPET and virgin-PET garments proves that recycling itself caused the difference. Controlled studies and systematic reviews show inconsistent results.
- That recycled fiber—synthetic or natural—is automatically lower-impact irrespective of allocation method, processing burden, quality loss and service life.

- That a higher LCIA microfiber term proves observed field damage, or that a modeled difference should be ignored because field damage has not been demonstrated. GLAM and Saadi & Boulay can estimate conditional aquatic potential impacts; evaluate release inventories, exposure, fate, experimental effects and uncertainty consistently for all fibers.
- That lower LCIA characterization factors for cellulosic microfibers prove lower intrinsic particle hazard. Saadi & Boulay found similar organism-sensitivity distributions under the experimental evidence they modeled; the lower cellulosic factors arose mainly from faster modeled environmental degradation/fate.
- That viscose or lyocell is universally lower-impact because it is cellulose-based. Their production chemistry, solvent recovery, energy mix, pulp sourcing, garment mass and service life can change the result.
- That Suaria et al.'s surface-water percentages represent the mass or composition of all fibers throughout the global ocean. They describe chemically characterized fibers recovered from the sampled surface waters.
- That PET textile waste is universally “easy to recycle,” or that cotton and wool are unrecyclable. Clean mono-material PET has favorable remelt/depolymerization options, but post-consumer blends, elastane, dyes, finishes and contamination can make high-quality textile-to-textile recycling difficult; cotton and wool both have established recycling routes.
- That current raw-fiber spot/benchmark prices are equivalent to garment cost or cost per wear. Prices differ by grade, geography, processing state and date, and the user ultimately buys a finished product whose value depends on construction, service life and care.

8. Evidence gaps and recommended next work

Priority	Gap	Recommended evidence
1	Matched linen/flax finished-apparel service LCA	Existing T-shirt ageing/LCA work provides real garment-level evidence. The remaining priority is a modern linen-vs-cotton/PET comparison with tightly matched construction, measured abrasion/pilling/dimensional stability, observed or experimentally established service life, actual garment mass, contemporary manufacturing inventories and cradle-to-grave LCA.
2	Nylon apparel-level service LCA	Modern PET-vs-nylon garment or matched-fabric study combining laundering + abrasion performance with full LCA and actual service life.
3	Cashmere and alpaca realized lifetime	Wardrobe/service-life studies specific to cashmere and alpaca; do not proxy from wool.
4	Fossil fuel burned vs fossil feedstock	For key LCAs, extract inventory-level electricity, heat and direct fuels and report burned fossil energy separately from fossil feedstock/resource depletion.
5	Matched microfiber loss	Standardized mass and particle-count shedding across cotton, wool, linen, PET and nylon using matched fabric structures; track both total material loss and polymer-specific release.
6	Environmental fate under field-realistic conditions	Long-duration comparative field studies that distinguish fragmentation, depolymerization, enzymatic attack and ultimate mineralization; directly validate PET hydrolysis/photoaging kinetics at environmental temperatures; quantify the effect of fiber geometry/surface area; and include processed/dyed/finished textiles.
7	Effect evidence	Link realistic environmental fiber concentrations to demonstrated ecological effects; avoid treating release or persistence alone as a harm metric.
8	Updated geographic manufacturing	Recalculate spinning, weaving, dyeing and garment manufacture with current country-specific power/heat mixes, since conversion energy can dominate some fibers.
9	Durability-to-realized-life validation	Pair standardized abrasion/pilling/strength/dimensional-stability tests with longitudinal wearer data for the same products so laboratory durability can be converted to actual service with known uncertainty.
10	Circularity allocation sensitivity	For PET and wool recycling, report results under cut-off, substitution and other accepted allocation approaches, and test whether recycled input changes garment life or quality.
11	Regenerated-cellulose service life	Matched viscose/lyocell/cotton/PET garments with measured mass, mechanical durability, realized wears/washes and cradle-to-grave LCA; distinguish viscose, modal, rayon and lyocell rather than pooling MMCfS.

Priority	Gap	Recommended evidence
12	Microfiber LCIA validation and field-risk linkage	Validate GLAM/MarILCA characterization factors against measured environmental concentrations, field-relevant chronic effects and population/community endpoints. Fate sensitivity should include newer PET hydrolysis, photoaging and PETase evidence rather than a single fixed persistence assumption; add terrestrial compartments, better release inventories and uncertainty analysis for both cellulosic and synthetic fibers.
13	Cost per delivered textile service	Matched-product studies combining transaction price, measured longitudinal wears/washes, laundering/drying, repair and retirement endpoint. Report acquisition cost per wear separately from total ownership cost per wear.
14	Fiber-to-fiber recycling performance across repeated loops	Compare PET, cotton, wool and major blends under matched collection/sorting assumptions; measure yield, retained polymer/fiber quality, virgin-material substitution, number of viable loops, process energy/chemicals, economics and cradle-to-grave impacts.

The next quantitative step should be a study-by-study extraction database with separate fields for functional unit, product mass/GSM, yarn fineness, fabric construction, allocation, geographic electricity/heat mix, fossil feedstock, direct fossil fuel, GHG, water scarcity, land use, number of wears/washes, tested failure mode, shedding, and end-of-life. Only studies with compatible system boundaries should be numerically pooled.

9. Conclusions

The current evidence changes the answer substantially compared with a raw-fiber ranking. Environmental performance is a property of a product system, not simply a fiber name. The same fiber can perform very differently depending on farming or petrochemical pathway, yarn fineness, fabric construction, finishing, garment mass, useful life and care behavior.

For cotton versus polyester, the strongest direct finished-textile evidence is favorable to PET or PET/cotton in the specific T-shirt and repeatedly laundered bedding systems where the polyester-containing product is modeled or observed to last longer and/or require less drying energy. Those studies do not prove that PET is lower impact in every apparel category. They do demonstrate that a fossil-derived fiber can have higher fossil-resource demand per kilogram yet lower service-normalized fossil depletion when fewer replacements and lower care are required.

Cotton remains highly competitive in favorable agricultural systems and high-quality constructions. The De Saxcé study demonstrates that excellent cotton textile engineering can exceed the durability of poorer alternatives. Organic cotton cannot be given an automatic advantage because yield and location determine per-mass impacts.

Regenerated cellulose adds a distinct middle case. The best current matched cradle-to-gate comparison shows that viscose and lyocell differ substantially: viscose is strongly influenced by chemical-intensive conversion, whereas lyocell reduces several toxicity-related burdens but can carry high energy-related GHG under carbon-intensive grids. Higher tenacity can reduce the material mass required in a modeled functional comparison, but realized garment lifetime remains poorly measured. These fibers should therefore be evaluated by process, geography, construction and service rather than grouped together as inherently “natural” or low impact.

Linen/flax cannot yet be assigned the low-impact “winner” status often implied by crop-level data. Spinning and yarn production can dominate its energy and climate burden. Garment-level ageing and LCA evidence now exists, including flax T-shirts tested through repeated washing and consumer acceptability assessment, but the available products and inventories are not sufficiently matched to establish a robust linen-versus-cotton/PET service ranking. Nylon has a strong abrasion-performance case but generally higher upstream energy/GHG than PET and weaker laundering stability in the newest direct study.

The animal fibers require a different interpretation. Wool can deliver long service and low washing frequency, both of which matter. Yet enteric methane is sufficiently large that it remains a dominant climate burden even in a full garment LCA. Alpaca shows a similar methane-dominated pattern, with less secure lifetime data. Cashmere is the most extreme: 155–183 kg CO₂e/kg clean dehaired fiber in the newest primary-data LCA, with no evidence of a compensating longevity advantage. Its lighter fabric mass and superior hand are real functional properties, but the mass saving is modest relative to the upstream climate burden.

Economic performance follows the same logic. There is no scientifically defensible universal cost-per-wear ranking by fiber because retail price, garment quality and realized service life are product-specific. The direct durability evidence nevertheless permits useful break-even calculations: under the JRC test-informed lifetimes, PET could cost 1.90 times the cotton reference upfront and tie on acquisition cost per modeled service event; the hotel-sheet blend could cost twice as much as cotton and tie on acquisition cost per rental before lower laundering-energy demand is included. These ratios demonstrate why cheap fiber or cheap purchase price is not the same as low cost per service.

Recycling likewise resists a simple synthetic-versus-natural label. Clean mono-material PET has a strong technical advantage because it can be remelted and chemically depolymerized to reusable polymer intermediates. Cotton and wool are also recyclable, but mechanical recycling shortens staple fibers and can constrain repeated high-quality spinning; cotton chemical recycling can regenerate cellulose through a different process, and wool has long-established mechanical closed-loop routes. The most accurate conclusion is therefore that PET offers particularly versatile polymer-level recycling options, not that cotton or wool cannot be recycled. Circularity for each material is governed by collection, sorting, dyes/finishes, process yield, retained quality and economics.

Environmental fate is not a natural-versus-synthetic binary. Cotton and wool were recovered from dated sediment layers spanning roughly 150 years, while PET and nylon can photodegrade and fragment; PET also undergoes hydrolysis and enzymatic attack. Accelerated tests and hydrolysis extrapolations do not establish realistic disappearance or mineralization times, and the hydrolysis source's 30 °C values conflict internally. Short-duration mineralization tests generally favored wool/cellulosics under their test conditions. The source discrepancy and endpoint distinctions are preserved in Section 6.3 rather than converted into a universal lifetime claim.

Overall evidence assessment

The strongest contribution of this evidence base is the product-service comparison. PET and PET/cotton perform well in the evaluated T-shirt and repeatedly laundered bedding cases when the assumed or observed service and care advantages are realized; high-quality cotton can also perform strongly. No fiber is assigned a universal rank.

For microfiber assessment, the comparative field evidence has not established greater PET harm at the measured exposures considered, but that does not establish equal risk or absence of harm. Model-based potential impacts and laboratory results must be evaluated alongside field measurements with consistent standards for all materials.

The conclusions are bounded by the literature assembled through 29 September 2026, the stated functional units and the quality of each study's measurements and assumptions.

Suaria et al. (2020) found 91.8% cellulosic or animal-origin fibers and 8.2% synthetic fibers among chemically characterized counts in sampled surface waters; PET accounted for 6.2%. This is composition by count in one environmental compartment, not total ocean fiber mass or a harm ranking. Comparative release experiments and the heterogeneous Vassilenko product set likewise show why the alternatives must be included rather than treating shedding as a uniquely synthetic phenomenon (Section 6.1).

Comparative laboratory evidence is mixed and endpoint-specific. Parker et al.'s meta-analysis reported negative experimental endpoints for both petroleum and non-petroleum fibers, with imbalanced and heterogeneous evidence. Walkinshaw et al. found a significant overall growth-rate reduction in the high-PET treatment, but no significant direct high-PET-versus-cotton difference; the other growth-rate contrasts were also non-significant. These results neither establish a universal intrinsic-hazard ordering nor prove equivalence. Beiras & Schönemann's 2020 broad large-microplastic risk assessment supplies exposure context, not a fiber-specific conclusion (Section 6.4).

Textile chemistry requires the same cross-material discipline. Metals have been measured in natural, regenerated and synthetic textiles, and documented colorants, mordants, finishes and catalyst residues provide multiple source pathways. Neither "natural" nor "synthetic" predicts the finished article's metal exposure. Compare measured migration, speciation and relevant doses, not elemental presence alone (Section 6.4; Figure 9A).

LCIA adds conditional evidence, not field observations. In Saadi & Boulay's equal-45-wear case, PET had the larger modeled microfiber physical-effect component while cotton had the higher total modeled ecosystem-quality indicator. Both outcomes matter. Differences in release, leakage, fate, compartment coverage and characterization can change the comparison substantially, as the contrasting Pellengahr case illustrates. Apply the same scrutiny to these models and to favorable service-life models; do not convert potential-impact estimates into observed damage or discard them merely because they are modeled (Section 6.5).

Recycled polyester remains an open rather than settled question. One controlled study found increased shedding, a later matched-pair commercial study found no significant difference, a critical systematic review found opposing results across experiments, and the 2026 51-garment study reported a 55% higher rPET mean count that was not statistically significant across material categories. The correct report position is therefore that rPET should be evaluated by measured textile performance, not assigned a generic shedding multiplier.

Koch et al. (2025) illustrates the distinction between quantitative model outputs and external sustainability criteria. Its polyester options were lower than the study's default garments on GHG and land use, yet PET was excluded from a preferred-material set because it sheds microfibers. That exclusion was not a calculated comparative fiber-pollution result. The appropriate response is a symmetric, transparent assessment of the extra criterion—not a claim that modeled GHG and land use alone settle every environmental question (Section 2.6). The summary matrix is reproduced immediately below (Figure ES1, conclusions copy); detailed comparisons remain in Figures 11A–11B.

Current evidence synthesis by criterion

Source-bounded findings — not a universal fiber ranking or weighted “eco-score”

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Material	Climate Named case / stage	Fossil resources & energy Indicator / stage stated	Land Study-specific finding	Water Study-specific indicator	Durability & service Evidence type stated	Evidence limits No overall confidence grade
Polyester (PET)	Lower in JRC ≈25% below cotton per day of wear [1]	Lower in JRC ≈21% below cotton; fossil depletion / day [1]	Lower in JRC Agricultural-land occupation / day [1]	Lower in JRC Water-depletion indicator / day [1]	95 modeled washes Cotton: 50. Test-informed; care also differs [1]	One named service case Xu climate reverses at 20 assumed washes [4]
Cotton	Higher in JRC Reference = 100; PET ≈75 per day [1]	Higher in JRC Reference = 100; PET ≈79 per day [1]	Higher in JRC Same land-occupation comparison as PET [1]	Higher in JRC Same water-depletion comparison as PET [1]	Construction matters Premium cotton outlasted basic blend sheets [6]	Not a fiber constant Yield, care and product design change results [17]
Organic cotton	Yield-dependent No universal per-kg climate advantage [8]	Input / yield trade-off Lower inputs need not lower impact / kg [8]	Yield-dependent Lower yield can raise land needed / kg [17]	Location-dependent Organic does not mean low water scarcity [17]	Not a durability label Construction, not farming label, determines service [17]	Cultivation evidence Matched service advantage not established [8,17]
Linen / flax	Stage-dependent Crop gains; yarn conversion can dominate [9,16]	261 MJ/kg yarn Non-renewable energy; not fossil-only [9]	Yield-dependent Favorable crop examples; no service rank [17]	Often low irrigation Retting and processing still matter [17]	Service rank unresolved Garment ageing exists; matching is limited [16]	Production ≠ service Yarn data cannot rank finished garments [9,16]
Viscose / rayon	Process-dependent Production region and conversion matter [10]	Conversion-sensitive Heat, electricity and chemical recovery [10]	Forestry-dependent Pulp source and allocation matter [17]	Process-dependent Water use and chemical recovery vary [17]	Realized-life gap Comparative service ranking unresolved [17]	Production evidence No generic garment-life claim follows [10,17]
Lyocell	Energy-sensitive Cleaner grids improve production GHG [10]	Recovery energy Heat / electricity for solvent recovery [10]	Forestry-dependent Pulp source and allocation matter [17]	System-dependent Water result remains process-specific [17]	Realized-life gap Yarn tenacity is not measured garment life [10]	Metric-sensitive Mass adjustment changes GHG comparisons [10]
Nylon / polyamide	Above PET in model Polymer production: 8.64 vs 2.70 kg CO ₂ e/kg [11]	Higher CED than PET 129.7 vs 78.4 MJ/kg; not fossil-only [11]	Low crop-land use Component finding; not a service rank [17]	No crop irrigation Process water remains; not a full water rank [17]	Failure mode matters Strong abrasion resistance; PET more wash-stable [17]	Upstream comparison Service-life LCA vs PET remains a gap [17]
Wool	Methane hotspot High upstream burden; not a per-service rank [12]	Processing hotspot 0.88 MJ fossil energy / wear in Merino model [12]	Grazing-land demand High upstream demand; no service rank [17]	Context-dependent Geography and scarcity method matter [12,17]	Realized use matters Long use and less washing lower modeled impacts [12]	Claim-specific support Methane: high; service / fate: moderate [17]
Alpaca	Farm methane hotspot 84.96–92.69% of farm GWP; not whole-life [13]	Comparative gap Insufficient cross-system resource evidence [17]	Grazing dependence High reliance; no service rank [17]	Comparative gap Water comparison not established [17]	Lifetime borrowed 109 wears assumed from Merino; not measured [13]	Upstream vs service Upstream: moderate; service / fate: low [17]
Cashmere	155–183 kg CO₂e/kg Clean dehaired fiber; upstream, not per wear [14]	109–144 MJ/kg PEF fossil resource; upstream, not per wear [14]	High grazing burden Land-use indicator; not a service rank [14,17]	Comparative gap Finished-service water evidence insufficient [17]	Longevity unresolved No demonstrated offset; not proof of short life [15]	Some mass efficiency Credit matched function; no universal lifetime [15]

Lower impact Named comparison only
 Higher impact Named comparison only
 Context-dependent Not an intermediate rank
 Evidence gap Not a finding of poor performance
 Not graded Descriptive evidence / limits

Counterexample retained: Xu [4] reports cotton 6.10 vs PET 9.62 kg CO₂e at 20 assumed washes; a different product system.

PET/cotton colored cells use the same JRC per-day model [1]. Nylon/PET colored cells are upstream [11]. Other stages are not interchangeable. JRC lifetimes are test-informed, with different care assumptions; production is already included. Service and evidence-limit columns are not impact-graded. Source numbers [1–17] link through Appendix B5. Appendix B6 records every cell's classification and boundary. Fiber release, fate and effects remain separate.

Figure ES1 (conclusions copy). Source-bounded ten-fiber summary. Sources: Appendix B5 • Cell classifications: Appendix B6

9.1 How to compare two actual textile products

Start with two specified products and one required service—not two generic fiber names. Use the same questions for both candidates and distinguish measured values from test-informed estimates and assumptions.

Comparison step	Record or check for both candidates	Basis
1 Define the service	Specify acceptable function, fit, coverage, comfort and the retirement endpoint. Choose the same delivered-service unit for both products (for example, a day of wear or bed-night).	\$1.6
2 Describe the products	Record fiber blend, garment/fabric mass, area or GSM, yarn and construction, dyes/finishes, production location and any relevant performance requirement.	\$§2–4
3 Establish useful life	Use relevant failure modes: abrasion, strength, pilling, dimensions and appearance. Separate physical capability from actual wears/washes; do not transfer another product's lifetime ratio.	\$5.3
4 Include care and replacement	Specify wash frequency, temperature, drying, ironing, repair and replacements over equal service. Include the associated cost when comparing ownership cost.	\$§5.1–5.6
5 Align life-cycle boundaries	Use compatible inventories, geography, allocation and end-of-life assumptions. Report climate, fossil resources, land and water separately; do not relabel total energy as fossil fuel burned.	\$§1.7, 3, 5.4
6 Ask what was measured	For fibers: mass/count, size, release, fate, exposure and effects. For chemicals: identity/speciation, total content, migration and relevant dose. A model result is not a field observation.	\$6
7 Test the conclusion	Check lifetime, care, energy mix, allocation and fate sensitivities. State the category-specific result and conditions under which it changes; retain adverse and null findings for both products.	\$7

Evidence labels to carry into the final comparison: measured • test-informed • assumed • model-derived. Where a field is missing, report the gap instead of supplying a fiber-wide default without justification.

Practical output

A defensible comparison states which product delivers the required service, the result for each impact category, the evidence behind its lifetime and exposure assumptions, and the sensitivities that could reverse the result.

Appendix A. Key-study evidence matrix

Study	Material(s)	Functional unit / boundary	Key evidence used here	Main limitation
Beton et al. 2014, JRC IMPRO	Cotton, 50/50 cotton/PET, PET T-shirts	One day of T-shirt wear; full modeled life cycle	Test-informed modeled lifetime 50/80/95 washes; PET/blend lower all indicators vs cotton; PET ~-25% climate, ~-21% fossil depletion	Lifetimes modeled from standardized tests; care assumptions differ; older background data
Kalliala & Nousiainen 1999	Cotton vs 50/50 cotton/PET hotel linen	Hotel-sheet production + laundering; rate-of-use	Blend $\geq 2\times$ abrasion life; modeled 100 vs 50 rentals. Cotton ~20% higher laundering energy; blend production index 58.1 for equal service. Mass loss: cotton 1.6%, blend 2.6%.	Older regional inventories. Rentals test-/statistics-informed, not observed replacement ratios; mass loss and abrasion life differ.
De Saxcé et al. 2012	Eight cotton/blend bed sheets	Cover a bed one year with undamaged sheet	15k/25k/40k Martindale; 60/78/100.2 washes shows both PET effect and quality effect	Modeled lifetime from test indicator
Xu et al. 2026	Cotton vs PET fast-fashion T-shirts	One T-shirt, fixed 20-wash scenario	PET 9.62 vs cotton 6.10 kg CO ₂ e/kg; land/water favor PET; lifespan and air freight highly sensitive	Equal realized lifetime assumed; the study does not establish product-specific lifetime differences.
Textile Exchange 2026 polyester	Virgin/recycled PET	Cradle-to-fiber	Virgin staple avg 4.55 kg CO ₂ e/kg; 80.7 MJ ADP fossil/kg	Industry technical report; not garment service
Textile Exchange 2026 cotton	Cotton across 9 countries/systems	Cradle-to-gin-gate	Large variation: 0.44–4.17 kg CO ₂ e/kg selected systems; 1.5–40.3 MJ/kg ADP fossil examples	Not finished textile; farm data vary in quality
Vitale et al. 2025	Cotton/organic cotton	Systematic review of 20 peer-reviewed LCAs	Organic often lower/ha but can be higher/kg; use phase can dominate energy	Heterogeneous methods/studies
van der Werf & Turunen 2008	Flax/hemp yarn	Crop through bleached yarn	Flax 13.6 kg CO ₂ e/kg; 261 MJ/kg non-renewable; yarn stage dominates	Older energy mix; yarn not garment
van der Velden et al. 2014	Cotton, PET, nylon, acrylic, elastane	Cradle-to-gate/cradle-to-grave modeling	Yarn fineness changes ranking; nylon input > PET in GHG/CED	Modeled data; specific textile constructions

Study	Material(s)	Functional unit / boundary	Key evidence used here	Main limitation
Woo et al. 2026	Virgin/recycled PET and nylon	Repeated laundering 30–50 cycles	PET more stable; nylon strength loss up to 24% at 40°C and 66% at 60°C	Durability test, not LCA
Wiedemann et al. 2020	Merino wool sweater	300-g sweater, 109 wears, cradle-to-grave	0.17 kg CO ₂ e and 0.88 MJ fossil/wear; enteric CH ₄ 48.1% total GHG; 400 wears sharply reduces impacts	Use-life survey uncertainty; wool-sector context
Wiedemann et al. 2019	Fine wool	Production methodological comparison	~31.5 vs 18.2 vs 13.6 kg CO ₂ e/kg depending attributional/consequential method	Demonstrates methodological sensitivity rather than one “correct” value
Kern et al. 2026	Alpaca sweater	303-g sweater cradle-to-grave	35.44–40.58 kg CO ₂ e/sweater; enteric 84.96–92.69% farm GWP	109-wear life borrowed from wool
Textile Exchange 2026 cashmere	Cashmere	Primary production + dehairing, per kg clean fiber	155–183 kg CO ₂ e/kg; 109–144 MJ fossil resource/kg; CH ₄ 74–80%	Upstream only; industry technical report
McGregor & Postle 2008/2009	Cashmere / superfine wool	Controlled knitted fabrics	Cashmere softer/lighter; similar insulation; no clear durability advantage; wear properties depend on blend/crimp/structure	Not full garment LCA
Pušić et al. 2023	Cotton vs cotton/PET	Matched fabric, repeated washing	Cotton 41.2% vs blend 30.9% wear in warp after 50 washes; greater cotton particle release	No full environmental impact characterization
Zhang et al. 2025	Cotton/PET blends vs PET	Fiber-specific shedding	Blend/weave affect release; blends shed more than pure PET	Focus is polyester microplastic fraction, not total life-cycle impact
Stanton et al. 2026	Cotton, wool, PET, nylon, acrylic	150-year lake sediment core	Cotton 70% of recovered fibers; cotton/wool found in dated layers extending to ~1876 ± 25; natural-fiber disappearance cannot be assumed under those sediment conditions	Single site; buried sediment preserves materials differently; layer age does not independently date each individual fiber
Sait et al. 2021; Sørensen et al. 2021	PET, PA, wool and others	UV exposure in water	PET/PA photodegrade and fragment; wool also degrades	Fragmentation ≠ mineralization

Study	Material(s)	Functional unit / boundary	Key evidence used here	Main limitation
Allen et al. 1994	PET bottle/sheet materials	Wet soil, humidity and UV environmental-ageing experiments	Environmental degradation rate strongly condition-dependent; chain scission measured; hydrolysis identified as a dominant wet-environment pathway.	Older bulk PET materials; not a direct field-lifetime or microfiber-mineralization study.
Stanica-Ezeanu & Matei 2021	Waste PET / marine water	Controlled hydrolysis + kinetic model extrapolated to marine temperatures	Table 5 extrapolates 50% conversion at 35 °C to ~4.5 y and 99.999% to ~72 y. At 30 °C: 116 y in Table 5 versus 162 y in the conclusion; unresolved discrepancy.	Ocean-temperature values extrapolated from 190–215 °C data. Depolymerization is not mineralization or a measured field lifetime; no microfiber/bottle scaling established.
Alam et al. 2025	Ocean PETase-containing bacteria	Functional enzyme assays + metagenomics/metatranscriptomics across 415 ocean samples	23 functional PETase variants detected in nearly 80% of samples; active PETase transcription documented; functional assays confirmed PET-degrading activity.	Shows widespread enzymatic capacity, not a quantified ocean-wide PET removal rate; evolutionary causation remains inferential.
Chen, Zhao & Wu 2026	PET microfibers	5-mm PET fibers; 12 d accelerated UV in freshwater/seawater	Marked surface roughening, oxidation, ester-bond cleavage, crystallinity change and molecular-weight loss; ageing stronger in natural waters, especially seawater.	Accelerated 500 W UV exposure differs from natural sunlight; does not establish a field disappearance/mineralization lifetime.
Collie et al. 2024/2025	Wool, PET, nylon, PP, cellulose	Marine / compost biodegradation tests	Wool/cellulosics biodegrade readily; PET/nylon little or none in test periods	Standardized favorable test systems; industry funding for wool work
Koch et al. 2025	Cotton/PET defaults and alternative garment materials	Pullover, shirt and trousers over total lifetime; hybrid process/input-output model	SI 6: PET lower than default GHG by ~8.7–15.1% and land use by ~77.1–84.3%, attributed to lower mass and longer lifetime; PET then excluded from “environmentally-friendly” set for microfiber release	Only GHG and land use modeled; manufacturing/retail partly price-allocated; lifetimes partly based on older data/assumptions; microfiber criterion not quantitatively compared across fibers

Study	Material(s)	Functional unit / boundary	Key evidence used here	Main limitation
Suaria et al. (2020)	Cotton, wool, PET, acrylic, nylon and other ocean fibers	916 seawater samples from 617 locations in six ocean basins; ~2,000 fibers chemically characterized by μ FTIR	79.5% cellulosic + 12.3% animal-origin fibers; 8.2% synthetic. Cotton was 50% of all fibers; PET 6.2%.	Natural versus regenerated cellulose can be difficult to distinguish by FTIR; surface-water composition is not itself an effect or risk metric.
Gao et al. (2024)	Virgin versus mechanically recycled PET textiles	Four matched commercial virgin/rPET pairs; washing and Martindale abrasion	No statistically significant overall difference in released fiber or fibril counts; fabric structure and surface treatment were influential.	Only four matched pairs and specific constructions; release potential does not by itself quantify environmental exposure or effect.
Gündoğdu et al. (2026)	Cotton, virgin/recycled PET and virgin/recycled polyamide garments	51 commercial garments; standardized ISO laundering methods	rPET mean fiber count was ~55% above virgin PET descriptively but not statistically significant across material categories; cotton had much greater mass loss.	Commercial garments were not matched pairs; within-group variability was large and count versus mass metrics gave different rankings.
Beiras & Schönemann (2020)	Microplastic particles in the global ocean (not fiber-specific)	Global ecological-risk assessment for the routinely monitored ~100–5000 μ m size range	2020 assessment: 13.8 mg/L modeled conservative threshold versus 1.89 mg/L measured maximum (~7.3-fold) and 0.32 highest mean (~43-fold). Authors classified large-MP global risk as negligible.	Not fiber-specific; conclusion does not extend to <10 μ m particles or nanoplastics; used here as broader exposure-to-threshold context
Tedesco, Fisher & Stuetz (2024)	Virgin and recycled synthetic textile shedding literature	Critical systematic review of 57 experimental textile-shedding studies	Virgin-versus-recycled findings were inconsistent/opposing; 81% of reviewed textile-feature studies lacked clear causal evidence for the claimed factor.	Heterogeneous methods and laundering setups; review supports uncertainty rather than a single release factor.
Jasińska 2023	Cotton vs 50/50 cotton/PET bed linens	Repeated industrial wash/dry cycles to 100; tensile strength + cellulose DP	Cotton strength loss up to ~30%; blend loss up to ~20%; both can remain durable through 100+ chlorine-free cycles	Fiber, weave, yarn type and fiber length were not perfectly matched; physical test, not LCA
Schmutz et al. 2021	Cotton T-shirt; sensitivity scenarios	154-g T-shirt; fixed 44-wash total service	Reducing shirt life 44→11 washes required four shirts; +261% climate, +231% nr-CED, +293% water, +275% ecological scarcity	Cotton-only scenario; Swiss use phase; model sensitivity rather than observed failure

Study	Material(s)	Functional unit / boundary	Key evidence used here	Main limitation
Sandin et al. 2019	Six garments; Swedish consumption model	Garment life cycles and national clothing consumption	T-shirt 30→90 uses: -65% climate/use; doubling garment use nationally: -49% climate, -42% energy, -48% water scarcity	Scenario model; not a controlled fiber-comparison experiment
Montoya Flores & Salhofer 2025	Pima-cotton T-shirt produced in Peru	104-g T-shirt cradle-to-grave; Peru production, US use/EOL	Low-yield year: 4.25 kg CO ₂ e and 241.52 m ³ world-eq water scarcity; typical yield scenario: 2.93 kg and 35.24 m ³ ; irrigation 97% of base WSF	Single supply chain; base cotton year was unusually low-yield
Bech et al. 2019	Merino vs 50/50 polyester/nylon military base layers	Provide T-shirts to one soldier for six months; PSS model	One Merino shirt ~3.5× synthetic shirt CCIP; modeled PSS 17.7 vs 7.0 kg CO ₂ e/FU under long-reuse/low-care/recycling assumptions	PSS not implemented; reuse/refurbishment process data partly omitted; exact advantage assumption-sensitive
Wiedemann et al. 2021	Merino wool sweater	Per wear; best/worst care and lifetime scenarios	Reuse -25–28%; 109→400 wears -60–68%; combined best practice ~75% reduction across assessed indicators	Scenario sensitivities around one wool-sweater model; does not prove all wool garments attain 400 wears
Braun et al. 2021	Circular vs linear polyester workwear jacket	390-g jacket; multiple loops	Circular design lowered multiple impacts; repeated loops reached ~one-third GHG reduction; bottle-rPET not superior in every category	Four-year life and some loop assumptions based on expert judgement; allocation/system design critical
Hester et al. 2026	Virgin, recycled and unravelled Merino jumpers	300-g jumper; 79 wears, 15.2 washes; cradle-to-grave	21.93 vs 1.56 vs 0.89 kg CO ₂ e/jumper; huge recycling benefit under study allocation	Cut-off assigns zero previous virgin burden to recycled input; allocation method materially drives result
Apparel & Footwear PEFCR v3.1 (2025)	Apparel and footwear methodology	Functional unit = one use; duration-of-service rules	Uses per-use reference flow; T-shirt default 45 uses; intrinsic durability multiplier 0.67–1.45 plus repairability	Methodological rule, not measured lifetime; multipliers include Technical Secretariat judgement
Fonseca et al. 2023	Systematic review of textile LCAs	73 qualitative / 39 quantitative studies	Large ranges attributed to methodology, inventories, use frequency and care; use phase often dominates when included	kg-normalized results still combine heterogeneous boundaries and service assumptions; not a service-equivalent ranking

Study	Material(s)	Functional unit / boundary	Key evidence used here	Main limitation
McGregor 2006	Cashmere/superfine-wool knit fabrics	ICI Pill Box vs Random Tumble pilling/appearance tests	Better apparent pilling grades for cashmere/low-crimp blends could coincide with greater fabric mass loss	Laboratory pilling methods differ; not garment lifetime or LCA
Gómez-Campos et al. 2021	Flax technical textile	Cradle-to-gate; 2400 m ² technical textile/y from 1 ha	Detailed flax cultivation-to-textile inventory; spinning/weaving and electricity are major contributors; geography changes result	Technical reinforcement textile, not apparel; functional unit tied to 1 ha; not a service-life comparison
Forfora et al. 2026	Cotton, PET, viscose, lyocell T-shirts	Cradle-to-gate; 1 kg T-shirts plus tenacity-adjusted mass scenario	Consistent manufacturing boundaries; cotton lowest GWP/kg in Chinese case; viscose chemistry and lyocell energy important; tenacity adjustment changes GWP ordering	No use/end-of-life; tenacity is a mechanical proxy, not measured garment service; simplified plastic-accumulation metric is non-standard
Parker, Lewis & Galloway 2025	Petroleum and non-petroleum microfibers	Meta-analysis of 38 aquatic studies; 472 endpoints	Statistically negative pooled experimental endpoints in both broad classes; cotton, viscose/lyocell and polyester/PET among common textile fibers with significant effects	Non-petroleum evidence underrepresented (89 vs 383 endpoints); heterogeneous concentrations/endpoints and exposure realism prevent field-damage or intrinsic-toxicity ranking
Saadi & Boulay 2026	Cotton, linen, viscose, lyocell, rayon, modal vs synthetic microfibers	Marine LCIA CF development + 45-wear cotton/PET T-shirt case	CMF organism-sensitivity distribution not significantly different from MPs; CMF CFs 1–2 orders lower mainly from faster modeled fate; PET modeled microfiber term 7.3–27% vs cotton 0.7–2.5%, while total modeled indicator was higher for cotton. These are modeled characterization results, conditional potential-impact evidence, not proof of greater intrinsic toxicity or observed ecosystem damage.	Equal 45-wear assumption; leakage/mismanagement and fate model sensitive; terrestrial pathways omitted; characterization uncertainty substantial. The model does not establish a polyester-specific excess ecological effect at real-world exposure.
Pellengahr et al. 2025	Recycled-PET/elastane cycling jersey	Cradle-to-grave; one year of cycling-jersey function	Modeled marine-microplastic physical-effect term = $1.48 \times 10^{-4}\%$ of the total modeled ecosystem-quality indicator in this case; production/use dominated	Single product/system; assumed end-of-life leakage and 1000-year fragmentation; characterization-factor omissions; not a measurement of environmental damage

Study	Material(s)	Functional unit / boundary	Key evidence used here	Main limitation
Verones et al. 2026 (GLAM)	Aquatic microplastics within ecosystem-quality LCIA	Consensus LCIA endpoint method	Aquatic microplastic pollution included as an LCIA ecosystem-quality characterization category; global CFs for 11 polymers, 3 shapes and 5 sizes; water + sediment terms	Global rather than regional CFs; uncertainty up to orders of magnitude; potential-impact modeling, not textile inventory or field proof of ecosystem damage
Laitala & Klepp 2020	Multiple garment and fiber categories	Five-country wardrobe survey; modeled garment lifespan and wears	After adjustment for other variables, garments >US\$100 were estimated to receive 31 more wears than garments <US\$10; price and care behavior were associated with lifespan.	Observational association; garment type, user behavior and quality are intertwined; does not establish fiber-specific cost per wear.
Eckmann & Reisch 2025	Clothing economics / quality	Six preregistered consumer experiments on cost-per-wear communication	Defines consumer CPW as purchase price divided by potential wears; communicating lower CPW shifted preference toward more expensive higher-quality options in the tested scenarios.	Behavioral experiments use scenario durability/cost inputs; not measured longitudinal cost per wear and not a fiber comparison.
Enking et al. 2025	PET-containing textiles	Systematic review of polyester-textile recycling technologies	Mechanical, thermo-mechanical, solvent-based and multiple chemical routes identified; clean PET can support textile-to-textile recycling; <1% of fibers globally made from discarded textiles.	Technology readiness varies; blends, dyes, coatings and impurities are major constraints; technical possibility is not actual recycling rate.
Grover et al. 2025	Cotton and cotton blends	Review of mechanical, chemical and biological recycling	Mechanical recycling widely implemented but reduces fiber length/strength and can require virgin blending; chemical recycling can regenerate cellulose.	Review combines heterogeneous technologies; energy, chemicals, economics and scale vary strongly by process and feedstock.
Glasper et al. 2024	Wool and cashmere	Closed-loop mechanical recycling study focused on fiber-length retention	Mechanical recycling had little effect on tensile strength of tested fibers; retained fiber length was the main limit on repeated closed-loop recycling.	Selected materials and process settings; does not represent every wool textile or complete life-cycle performance.

Study	Material(s)	Functional unit / boundary	Key evidence used here	Main limitation
Bartl et al. 2023	Alpaca sweater	Cradle-to-grave carbon footprint; one wear of Peruvian alpaca sweater	Fiber production ~70% of total climate impact; enteric fermentation 87% of fiber-procurement-stage impact; independent author group corroborates methane hotspot	Carbon-footprint study rather than full multi-impact LCA; use/service assumptions remain product-specific
Vassilenko et al. 2021	Cotton, wool, polyester, nylon consumer textiles	37 textile samples; five domestic laundry cycles; mass and fiber-count release	Cotton/wool samples 165 ± 44 mg/kg/wash vs polyester 161 ± 173 ; nylon 27 ± 14 ; construction strongly influenced shedding	Heterogeneous products, natural-fiber n=4 vs polyester n=18; not a matched chemistry-only comparison
Henry, Laitala & Klepp 2019	Apparel/home-textile microfibers	Critical review and sustainability-assessment framework	Proposed interim midpoint indicator combining microfiber mass/number released with environmental persistence	Conceptual indicator, not a validated field-damage metric; authors called for standardized methods and realistic ecotoxicology
Benkirane 2019/2022	Cotton, flax/linen and polyester T-shirts	29 commercial T-shirts: standardized performance tests + repeated wash/care ageing + consumer acceptability; six selected for LCA	Direct garment-level lifespan evidence. Selected flax T-shirts were 348-349 g and both reached 15 washes in that product set; longevity depended strongly on construction, yarn and fabric properties rather than fiber identity alone.	Commercial products were not tightly matched; flax LCI combined newer primary scutching/wet-spinning data with older secondary/proxy data. Product-specific lifetimes cannot be generalized to generic linen.
Walkinshaw et al. 2023	PET and cotton; juvenile mussels	94 days; PET ~8 / ~80 fibers/L; cotton ~80 fibers/L	Growth rate vs control: ~80 PET -35.6%, $p = 0.004$; cotton -18.7%, $p = 0.09$; ~8 PET -3.1%, $p = 0.40$. Direct high-PET/cotton: $p = 0.12$.	Laboratory current / future or polluted-water scenarios, not field damage; non-significance does not establish equivalence.
Rezić & Steffan 2007	Cotton, flax, wool, silk, PET and viscose/PET	16 commercial textiles; ICP-OES after sweat extraction and acid digestion	Metals measured across fiber groups; wool, cotton and flax examples in Figure 9A.	Tables 1, 7–8 checked. Dye formulations unknown; no chemistry-only causal comparison.
Rovira et al. 2015	Skin-contact clothing, including cotton, PA and PET	Trace-element measurements and dermal-risk modeling	Color-associated Cu/Cr and PET-associated Sb; product-specific evidence.	Not a matched fiber trial or a market-prevalence survey.

Study	Material(s)	Functional unit / boundary	Key evidence used here	Main limitation
Sungur & Gülmez 2015	Cotton, acrylic, PET, nylon, viscose and PP	Colored fibers from Turkish plants; MP-AES	Total and artificial-sweat results reported separately.	Method-specific survey; not wearer uptake. Detailed detection-limit consistency not independently revalidated.
Rujido-Santos et al. 2022	Cotton/viscose, cotton/modal, cotton/PET and other functional garments	14 commercial products; ICP-MS and stated product composition	ZnO, TiO ₂ and silver finish examples; measured metal contents vary by product.	Selected sample set; total elements do not determine particle form, source or absorbed dose.
Rybicki et al. 2004	Cotton bed-cloth and reactive/pigment dyestuffs	23 raw cottons (1997/98 crops); one production sequence; ICP after digestion and acid-sweat extraction. IAEA Cotton V-9 reference material.	Cu 1.02 → 279.7 mg/kg raw-to-finished; Co/Cr rose at dyeing and Ni at printing. Sweat-extractable fractions: Co 3.0%, Cr 9.4%, Cu 4.2%, Ni 70.3%; historical criteria met.	Full text, Tables 5–7 checked. Historical product/process data, not current prevalence or wearer uptake. See Appendix B for units, calculation and source inconsistency.
Matyjas-Zgondek et al. 2012	Flax fabric dyed with C.I. Direct Blue 86	Controlled bleaching, dye loading and cationic fixation	Fixation reduced copper extracted into artificial acid sweat (Table 5).	One dye/fixer system; does not establish that every fixative contains metals.
Biver, Turner & Filella 2021	Polyester skin-contact textiles	Artificial-sweat extraction; controlled method variations	Small, condition-dependent fraction of Sb mobilized from total residues.	Migration, not human biomonitoring; protocol affects the result.
Rovira et al. 2017	Skin-contact clothes including polyester	Elemental analysis, sweat migration and dermal-exposure modeling	Mean Sb HQ 0.4; one polyester T-shirt modeled above HQ 1.	Publisher abstract checked. Scenario-based screening result, not observed clinical harm.
Zuo et al. 2024	Polyester microplastic fibers	Simulated environmental/biofluid release and exposure scenarios	Low estimated intakes relative to selected tolerable-intake thresholds in the scenarios reviewed.	Existing report summary retained; not an all-textile or garment-wear risk assessment.

Appendix B. Figure data and calculation notes

This register makes the numerical basis of the figures available as editable text. Values retain the source study's units and comparison boundaries; derived percentages and ratios are identified explicitly. It is a traceability aid, not a new pooled dataset or an independent recalculation of every source inventory. Full citations and DOI links follow. Qualitative frameworks (Figures 1, 7A and 8) and the selected metal examples (Figure 9A) are explained in their captions and associated sections.

Figure / item	Numerical source values	Source locator	Calculation and boundary
Figures 2 / 5 (right); overview	Cotton / 50:50 blend / PET: modeled washes 50 / 80 / 95; climate indices 100 / 84 / 75; fossil depletion 100 / 85 / 79.	Beton et al. (2014), Table 57 and Figure 55; review Section 2.1.	Test-informed modeled lifetimes; full-life impacts per day of wear. Indices rounded to cotton = 100. Care assumptions differ.
Figure 3; overview	Modeled rentals: 50 cotton / 100 blend. Cotton laundering energy 20% above blend; production energy for equal 100 cycles 72% above blend. Mass losses 1.6% / 2.6%.	Kalliala & Nousiainen (1999), Results: laundering, textile durability and impact analyses, pp. 11–12; Section 2.2.	Blend laundering index = $100/1.20 = 83.3$; production index = $100/1.72 = 58.1$. Total index cannot be calculated from these ratios without stage weights.
Figure 4; overview	Carded cotton / carded 50:50 blend / combed easy-care cotton: 15,000 / 25,000 / 40,000 abrasion cycles; 60 / 78 / 100.2 modeled washes.	De Saxcé et al. (2012), sample 1 / 2 / 8 results and lifetime indicator; Section 2.3.	Functional unit: covering a bed for one year with an undamaged sheet. Measured abrasion and modeled life are separate. Sample-specific, not generic fiber lifetimes.
Figure 4A	Default → PET annual GHG: 3.307 → 3.019; 2.219 → 1.884; 5.563 → 4.776 kg CO ₂ e/y (pullover/shirt/trousers). Land: 0.752 → 0.123; 0.499 → 0.078; 1.798 → 0.412 m ² /y.	Koch et al. (2025), Supplementary Information SI 6; Table 3A.	Percentage change = $100 \times (\text{PET/default} - 1)$. Displayed percentages follow source rounding. Annualized model including mass, service and care; default comparator, not all alternatives.
Figure 5 (left)	Flax / cotton / wool / PET / nylon: 3.2 / 9.1 / 17.5 / 24.5 / 36.7 MJ non-renewable CED for 264 g of raw fiber.	Schmutz et al. (2021), raw-material comparison; Section 3.2.	Upstream mass basis; non-renewable CED is not necessarily fossil-only. Do not combine this panel numerically with the JRC service-based panel.
Figure 5A	Benkirane program: 29 commercial T-shirts; two selected linen shirts 348–349 g and 15 washes in that product set.	Benkirane (2019), garment selection and lifetime/LCA case analysis; Benkirane et al. (2022); Section 4.4.	Not tightly matched products or a generic linen lifetime. Contemporary scutching/spinning data were combined with older/proxy inventories.
Figure 6	Merino enteric methane 48.1% of whole-garment cradle-to-grave GHG. Alpaca enteric fermentation 92.69% / 84.96% of small- / medium-farm GWP.	Wiedemann et al. (2020), garment value-chain contribution; Kern et al. (2026), farm-phase contribution; Sections 4.7–4.8.	Different denominators are intentionally kept in separate cards. Percentages cannot rank total footprints. Merino 300 g / 109 wears; alpaca 303 g, borrowed lifetime assumption.

Figure / item	Numerical source values	Source locator	Calculation and boundary
Figure 7	Characterized surface-water fiber counts: cellulosic 79.5%, animal-origin 12.3%, synthetic 8.2%; PET 6.2%; cotton spectral match 50%. Detailed labels reproduce rounded source percentages.	Suaria et al. (2020), polymer-composition results; 916 samples / 617 locations / six basins; Section 6.1.	91.8% = 79.5 + 12.3. Count, not mass; sampled surface waters, not the entire ocean. FTIR does not always distinguish natural from regenerated cellulose.
Figure 8A	35 °C model: ~4.5 y to 50% conversion; ~72 y to 99.999%. At 30 °C, Table 5 gives 116 y while the conclusion gives 162 y.	Stanica-Ezeanu & Matei (2021), Table 5 and conclusion; Section 6.3.	190–215 °C kinetic extrapolation. The 30 °C discrepancy remains unresolved; neither value is adopted as a field lifetime. No conversion from fragmentation or PETase capacity to a removal flux.
Figure 9	Highest mean 0.32 mg/L; highest individual 1.89 mg/L; conservative threshold 13.8 mg/L; HC5 16.7 mg/L.	Beiras & Schönmann (2020), Results and Table 3; Section 6.4.	13.8/1.89 = 7.30; 13.8/0.32 = 43.13. Numerical log axis: position proportional to log ₁₀ concentration. Thresholds modeled; compiled exposure measurements; ~100–5000 µm, not fiber-specific.
Figure 9A	Wool Cr 4.93–5.07 / Co 5.07–5.23 mg/kg. Cotton Cu 193.9; flax Cu 98.91 / 89.5 mg/kg. Flax sweat Cu unfixed→fixed: 4.910→1.554; 8.220→1.142; 13.13→2.290 mg/kg. Sb mobilized ~0.05–2%.	Rezić & Steffan (2007), Tables 1 and 8; Matyjas-Zgondek et al. (2012), Table 5; Rujido-Santos et al. (2022), Tables 1/5 and §4.3; Biver et al. (2021), extraction results; other sources in Table B4. Rybicki et al. (2004), Tables 5–7, p. 72: full extraction and calculations in Tables B1–B3.	Original reported values, not pooled. Acid-digest content, normalized sweat-extractable content and fraction mobilized are separate quantities. No clinical dose or prevalence ranking calculated. Rybicki Table 7 reports Pb as nf in the total digest but ~0.269 mg/kg in the extract. This unresolved reporting/detection-basis mismatch is not corrected; no Pb extraction fraction is calculated.
Figure 10	Commercial counts (fibers/g): virgin PET 8,028; rPET 12,430; cotton 9,776. Mass (mg/g): 0.24 / 0.36 / 1.85. Gao: four matched virgin/rPET textile pairs.	Gündoğdu et al. (2026), material-category results; Gao et al. (2024), washing/abrasion comparisons; Section 6.6.	Count increase = (12,430/8,028 – 1) × 100 ≈ 55%; not statistically significant. Cotton mass ratios ≈7.7 versus virgin PET and ≈5.1 versus rPET. Commercial products unmatched.
Overview / Figures 11A–11B	Xu: 9.62 PET vs 6.10 cotton kg CO ₂ e, equal 20 washes. Bech: 17.7 vs 7.0 kg CO ₂ e per soldier / six-month service under the stated alternative-system model.	Xu et al. (2026), equal-life case; Bech et al. (2019), recommended service scenario and sensitivity; Sections 2.4 / 2.8.	Different questions and products; not comparable absolute LCAs. Xu establishes no lifetime difference; Bech depends on reuse, care and allocation, and the system was not implemented.
Table 6A statistical cross-check	Overall growth-rate changes: ~80 PET –35.6%, p = 0.004; ~80 cotton –18.7%, p = 0.09; ~8 PET –3.1%, p = 0.40. High-PET vs cotton p = 0.12.	Walkinshaw et al. (2023), Results: Effects of microfibers on mussel growth, Figure 1B; Section 6.4.	94-day laboratory experiment; significance applies to the specified overall growth-rate contrast. Non-significant material comparison is not an equivalence test.
Figure 6A	Conceptual carbon-flow diagram; no numerical mass balance or universal fiber footprint is implied.	Sections 1.7 and 5.4; WRI & WBCSD (2011), GHG Protocol Product Standard, Chapter 11.	Fossil feedstock, material stocks, biogenic uptake, gross release and net GHG remain separate. Arrows are not to scale; accounting boundaries and allocation must be explicit.

Cotton processing: verified full-text data

Rybicki et al. (2004), pp. 67–73 • Figure 9A supporting data • All source tables below are on p. 72.

The study examined 23 raw cottons from 1997/98 crops and tracked one bed-cloth production sequence. ICP measurements used microwave digestion and IAEA Cotton V-9 quality control; reported precision was 0.2–2% RSD, up to 30% near determination limits. Finished-cloth extraction used artificial acid sweat under PN-EN-ISO 105-E04:1999 (pp. 67–68). This is historical product/process evidence, not a survey of current textiles.

B1. Manufacturing stages — total elemental content (mg/kg textile)

Metal	Raw bale	After bleaching	After dyeing	After printing	Finished cloth
Copper (Cu)	1.02	nf	280.2	263.8	279.7
Cobalt (Co)	nf	nf	17.78	17.12	18.24
Chromium (Cr)	0.45	0.36	5.20	4.93	5.34
Nickel (Ni)	0.28	0.04	0.34	1.31	1.29

Source: Table 5 (selected stages). nf = not found, not zero. Total Cu raw-to-finished ratio = $279.7/1.02 \approx 274.2$ (calculated). No fold change is assigned to an nf baseline. The major Co/Cu/Cr increases followed reactive dyeing; Ni increased at pigment printing. Spinning, sizing, weaving, cropping and conventional finishing were not the main increases in this sequence.

B2. Tested colorant formulations — total elemental content (mg/kg dye product)

Commercial formulation	Product form / class	Measured element(s)
Pigmentex Navy RN	Liquid pigment dyestuff	Cu 45,210
Pigmentex Green B	Liquid pigment dyestuff	Cu 22,770
Błękit Helaktynowy D5RF	Powder reactive dyestuff	Cu 26,890
Czerń Helaktynowa DN	Powder reactive dyestuff	Co 6,088; Cr 8,818

Source: Table 6, selected examples from eight formulations. These concentrations refer to the dye preparation, not cloth. The authors attributed textile increases to dyestuffs/auxiliaries and assayed the formulations, but did not distinguish all metal-complex chemistry from impurities. Liquid/powder concentrations are not a like-for-like colorant ranking.

B3. Finished cloth — total content versus acid-sweat extract

Metal	Total (mg/kg)	Extractable (mg/kg textile)	Extracted fraction ¹	Study's historical criterion ²
Copper (Cu)	279.7	11.83	4.2%	≤50 mg/kg
Cobalt (Co)	18.24	0.5518	3.0%	≤4.0 mg/kg
Chromium (Cr)	5.34	~0.502	~9.4%	≤2.0 mg/kg
Nickel (Ni)	1.29	0.9072	70.3%	≤4.0 mg/kg

Source: Table 7. ¹ Calculated as $100 \times \text{extractable}/\text{total}$; not absorption by a wearer. ² ÖKO TEX Standard 100 values reproduced as applied in the 2004 paper, not current certification criteria. Compare the extractable values—not digested totals—with these limits. The tested finished fabric met the historical criteria; chromium(VI), pesticides and PCP were not detected. The authors flagged Ni's ~70% extractability as a potential allergy concern, not a measured clinical outcome.

B4. Metals in textiles — source-linked evidence

Supporting evidence for Figure 9A. These are documented products and treatments, not prevalence grades for entire fiber categories.

Evidence / product	What the source actually reports	Source locator and limit
Dyed wool, cotton and flax	Two wool samples: Cr 4.93–5.07 and Co 5.07–5.23 mg/kg. Green cotton: Cu 193.9 mg/kg; black and green flax: Cu 98.91 and 89.5 mg/kg.	Rezić & Steffan (2007), Tables 1 and 8. Total acid-digest content; dye recipes were not identified.
Cotton: dyeing and pigment printing	Cu: 1.02 → 279.7 mg/kg from raw to finished cloth. Dyeing raised Co/Cr; printing raised Ni. Finished-cloth extractable fractions: Co 3.0%, Cr 9.4%, Cu 4.2%, Ni 70.3%.	Rybicki et al. (2004), Tables 5–7, p. 72. Full text checked; percentages calculated. Historical extract criteria met; not absorbed dose.
Color-associated commercial clothing	High Cr in dark polyamide, high Sb in polyester and high Cu in some green cotton fabrics. Color and manufacturing route mattered.	Rovira et al. (2015), Results. Selected products; not a fiber-wide prevalence or toxicity ranking.
Flax: copper dye plus fixing treatment	Sweat-extractable Cu, unfixed → fixed: 4.910 → 1.554; 8.220 → 1.142; 13.13 → 2.290 mg/kg textile at increasing dye levels.	Matyjas-Zgondek et al. (2012), Table 5. C.I. Direct Blue 86 and one cationic fixer; extract, not absorbed dose.
Cotton, regenerated and synthetic finishes	ZnO: viscose/cotton and PET/cotton shirts. TiO ₂ : cotton/modal products. Silver: cotton-containing and synthetic garments.	Rujido-Santos et al. (2022), Tables 1 and 5, §4.3. Labelled formulations plus elemental measurements.
Six fiber classes: total versus extractable	Cotton, acrylic, PET, nylon, viscose and PP were tested by total digestion and artificial-sweat extraction; the two measurements gave different concentrations.	Sungur & Gülmez (2015), Tables 3–4. Regional, colored samples; method-specific reported results, not a matched risk comparison.
Polyester: antimony catalyst residue	Total Sb about 125–470 mg/kg. Roughly 0.05–2% mobilized under default artificial-sweat procedures; conditions changed release.	Biver et al. (2021), Abstract and extraction experiments. Not a measured human uptake study.

Total metal content ≠ extractable metal ≠ absorbed dose ≠ demonstrated harm

Quantities are study-reported examples. mg/kg = µg/g; extraction values are normalized to textile mass. No natural-versus-synthetic risk score is implied.

Table B4. Source-linked evidence map of metals in natural, regenerated and synthetic textiles. Direct product measurements, known formulations and controlled fixing experiments are distinguished. The map does not assign unsupported prevalence grades to untested fiber/treatment combinations.

Interpretive boundary. Report total content, extractable concentration, absorbed dose and the relevant effect endpoint separately. Chemical speciation matters, including the distinction between total chromium and chromium(VI). Some tested products have exceeded the criteria used by the respective authors; those findings should not be suppressed or converted into a claim about every fiber. Equally, detection alone is not evidence of harm. The cited studies support metals occurring across textile classes, but do not establish every “common/occasional” cell in a nine-fiber prevalence matrix, particularly for alpaca, cashmere or lyocell. A source-specific evidence map is therefore used here.

B5. Source key for the reconciled summary figures

This source key applies to Figure ES1 in the executive summary and conclusions and to Figures 11A–11B in Section 7. The source numbers are shared. Appendix B6 records the classification and comparison boundary for each Figure ES1 cell. Full bibliographic entries remain in References; these summaries do not introduce a pooled fiber ranking.

Key	Source and link	Locator / evidence boundary
[1]	Beton et al. (2014), JRC Source link	Report §2.1; Appendix B, Figures 2/5. Primary locator: Tables 56–57 and Figure 55 (printed pp. 126–127). Test-informed modeled lifetimes and complete modeled life-cycle impacts per day of T-shirt wear; care assumptions differ.
[2]	Kalliala & Nousiainen (1999) Source link	Report §2.2; Appendix B, Figure 3. Primary locator: Results, pp. 11–12. Older regional hotel-sheet inventory; test/statistics-informed 50 versus 100 rentals. Production and laundering energy are separate terms.
[3]	Koch et al. (2025) Source link	Report §2.6, Table 3A; Appendix B, Figure 4A. Primary locator: Supplementary Information SI 6. Annualized model for pullovers, shirts and trousers; PET compared with each study default, not every alternative material.
[4]	Xu et al. (2026) Source link	Report §2.4; Appendix A and Appendix B, Figures 11A–11B. Different garments and inventory from JRC; both assigned 20 washes. Land and water directions are reproduced from the report; no numerical values are invented.
[5]	Bech et al. (2019) Source link	Report §2.8; Appendix B, Figures 11A–11B. Primary locator: recommended service scenario and sensitivity. One soldier / six months; conditional reuse, care and recycling. The proposed Merino system had not been implemented.
[6]	De Saxcé et al. (2012) Source link	Report §2.3; Appendix B, Figure 4. Primary locator: samples 1, 2 and 8 and lifetime indicator. Measured abrasion and modeled wash lives for specified constructions; premium cotton is not a generic fiber lifetime.
[7]	Textile Exchange (2026), cotton / PET Source link Second source link	Report §§3.2, 4.1 and 4.3; Table 7A. Cotton: selected gin-gate systems; PET: virgin-staple fiber gate. Reported CML ADP fossil and GHG values. Stages and product states differ; the context panel does not grade these values against one another.
[8]	Vitale et al. (2025) Source link	Report §4.2; Appendix A. Comparative interpretation also summarized in Tables 7A–7B. Review of 20 LCAs; lower input use per hectare does not establish lower impact per kg or per delivered textile service.

B5. Source key for the reconciled summary figures (continued)

Key	Source and link	Locator / evidence boundary
[9]	van der Werf & Turunen (2008) Source link	Report §§3.2 and 4.4; Appendix A. Crop through bleached flax yarn. 13.6 kg CO ₂ e and 261 MJ non-renewable energy per kg bleached yarn in the cited scenario; not a raw-fiber or garment-service result.
[10]	Forfora et al. (2026) Source link	Report §4.5; Appendix A; Tables 7A–7B. Garment-production cradle-to-gate framework, with a tenacity-adjusted mass scenario. Tenacity is not measured garment lifetime.
[11]	van der Velden et al. (2014) Source link	Report §§3.2 and 4.6; Appendix A. Nylon input above PET in the same model: 8.64 versus 2.70 kg CO ₂ e/kg; 129.7 versus 78.4 MJ/kg CED. CED is not fossil depletion or fuel burned.
[12]	Wiedemann et al. (2020) Source link	Report §4.7; Appendix A. Merino 300-g sweater, 109-wear model. Enteric methane is an important contribution; per-wear results depend on life and care. No generic service ranking follows from the upstream hotspot.
[13]	Kern et al. (2026) Source link	Report §4.8; Appendix A; Figure 6. Primary locator: farm-phase contribution. 303-g sweater; enteric fermentation 84.96–92.69% of farm-stage GWP. The 109-wear life was borrowed from Merino, not measured for alpaca.
[14]	Textile Exchange (2026), cashmere Source link	Report §§3.2 and 4.9; Appendix A; Table 7A. 155–183 kg CO ₂ e/kg and 109–144 MJ PEF fossil resource/kg clean dehaired fiber, upstream. These are not a service-equivalent ranking against PET.
[15]	McGregor & Postle (2008/2009) Source link Second source link	Report §4.9; Table 7B; Appendix A. Some cashmere mass efficiency; a compensating longevity advantage is not established. That is not proof of universally inferior lifetime.
[16]	Benkirane (2019); Benkirane et al. (2022) Source link Second source link	Report §4.4; Table 7B; Appendix A. Commercial garments, not tightly matched material-only comparisons. Two selected linen products reached 15 washes; that is not intrinsic linen lifetime.
[17]	PRC report, Tables 7A–7B Table 7A Table 7B	Report §7; Table 7A for land/water and production context; Table 7B for service and evidence limits; §§4.1–4.9 for supporting studies. Source is the report's structured synthesis, not a new prevalence dataset, universal ranking or independent validation of all underlying inventories.

B6. Figure ES1 – classification and source register

The register covers all 60 evidence cells in the identical executive-summary and conclusions matrices. The numbered links below use Appendix B5. This is a controlled summary of the reviewed evidence, not a new literature search or meta-analysis.

G (green) = lower impact in a named within-study comparison; P (pink) = higher impact in that comparison. Y (yellow) = documented context or stage dependence, not an intermediate rank. X (grey) = an unresolved comparative evidence gap. N (neutral) = descriptive evidence, with no impact grade.

The PET/cotton impact cells use the same JRC per-day T-shirt model. Its production burden is already included; test-informed lifetimes and care differ. The nylon/PET cells use one upstream polymer-production model. Other production and service stages are not directly interchangeable.

Material	Climate	Fossil resources / energy	Land	Water	Durability / service	Evidence limits
Polyester (PET)	G · Lower in JRC JRC Figure 55, climate-change midpoint; complete modeled life cycle per day. Cotton is the comparator, not all fibers. Source [1]	G · Lower in JRC JRC Figure 55, fossil-depletion midpoint; the calculation already includes production. Do not subtract or penalize feedstock again. Source [1]	G · Lower in JRC JRC Figure 55 reports lower agricultural land occupation than cotton per day of modeled wear. Not a generic land requirement. Source [1]	G · Lower in JRC JRC Figure 55 reports lower water depletion than cotton per day. This is not inferred solely from absence of crop irrigation. Source [1]	N · 95 modeled washes JRC Tables 56–57: 95 PET, 50 cotton and 80 blend modeled washes; not observed consumer lifetimes. No impact grade is assigned here. Source [1]	N · One named service case The favorable JRC cells are case-specific. Section 2.4 retains Xu: PET 9.62 and cotton 6.10 kg CO ₂ e under equal 20-wash assumptions. Source [4]
Cotton	P · Higher in JRC Same climate indicator, inventory and service boundary as the PET cell. This is the JRC cotton reference, not all cotton production. Source [1]	P · Higher in JRC Same fossil-depletion indicator and per-day boundary as PET. Lower cotton fiber-gate inputs elsewhere do not change this within-study result. Source [1]	P · Higher in JRC Same JRC agricultural-land-occupation comparison and functional unit as the PET row; no global cotton land grade. Source [1]	P · Higher in JRC Same JRC water-depletion indicator and per-day boundary as PET. Water scarcity and irrigation geography remain product-specific. Source [1]	N · Construction matters De Saxcé samples 1/2/8: 60 basic cotton, 78 basic blend, 100.2 premium cotton modeled washes. This does not transfer the JRC lifetime ratio. Source [6]	N · Not a fiber constant Tables 7A–7B and Sections 2–4 retain product/agronomic variability. Xu is a distinct scenario, not a pooled counterweight to JRC. Source [17]
Organic cotton	Y · Yield-dependent Vitale review, Section 4.2: per-hectare and per-mass conclusions differ; lower inputs do not establish lower climate impact per delivered service. Source [8]	Y · Input / yield trade-off Section 4.2: lower synthetic inputs can be offset by lower yield. Yellow denotes this dependence, not a measured intermediate fossil-resource rank. Source [8]	Y · Yield-dependent Table 7A: land per kg can increase with lower yield. The matrix does not claim organic cotton always uses less land. Source [17]	Y · Location-dependent Table 7A: water result is system- and location-specific; cultivation label does not specify a water-scarcity result. Source [17]	N · Not a durability label Table 7B: organic cultivation alone does not establish different textile service life. Descriptive limitation, not a durability ranking. Source [17]	N · Cultivation evidence No generic service-level environmental advantage is inferred from the reviewed cultivation studies. Source [8] , [17]
Linen / flax	Y · Stage-dependent Sections 3.2/4.4: crop-stage and yarn/garment results differ. This is not an ordinal per-service climate rank. Source [9] , [16]	N · 261 MJ/kg yarn van der Werf & Turunen dew-retted bleached-yarn scenario, 261 MJ/kg. The metric and product stage differ from JRC fossil depletion per day. Source [9]	Y · Yield-dependent Table 7A: yield-dependent crop systems can be favorable; finished-service evidence does not establish a universal comparison with cotton. Source [17]	Y · Often low irrigation Table 7A: often low crop irrigation, with retting/processing qualifications. No green full-life water grade is inferred from this component. Source [17]	X · Service rank unresolved Section 4.4/Benkirane: commercial garment ageing exists but tightly matched material-specific service ranking is unresolved. Grey is not poor durability. Source [16]	N · Production ≠ service Crop/yarn evidence, garment ageing and a finished-service comparison answer different functional questions. Source [9] , [16]

Table B6a. Cell-by-cell classification basis for Figure ES1. Grey does not mean poor performance; an upstream hotspot does not establish a per-service rank.

B6. Figure ES1 – classification and source register (continued)

Same fixed rule: G/P compare named alternatives under one source boundary; Y means context dependence; X marks a comparative gap; N is descriptive. Service and evidence-limit columns are not impact-graded. Source links resolve to Appendix B5.

Material	Climate	Fossil resources / energy	Land	Water	Durability / service	Evidence limits
Viscose / rayon	Y • Process-dependent Forfora, Section 4.5: cradle-to-gate garment results depend on conversion and region. No universal climate rank per use. Source [10]	Y • Conversion-sensitive Section 4.5 and Table 7A: processing inputs are important. No common per-service fossil-resource ordering is established. Source [10]	Y • Forestry-dependent Table 7A: forestry/pulp sourcing and allocation govern the land context. Yellow denotes dependence, not mid-rank. Source [17]	Y • Process-dependent Table 7A: process water and chemical recovery are material to the result; not a water-depletion rank against JRC cotton/PET. Source [17]	X • Realized-life gap Table 7B: direct realized-lifetime evidence remains weak. The matrix does not infer short life or safety from this gap. Source [17]	N • Production evidence Production evidence is stronger than comparative realized-service evidence; the two are not converted into one confidence grade. Source [10] , [17]
Lyocell	Y • Energy-sensitive Section 4.5: solvent recovery and energy geography affect production GHG. Mass-adjusted and per-kg scenarios need separate interpretation. Source [10]	Y • Recovery energy Section 4.5/Table 7A: energy for recovery can dominate conversion. Not a quantified per-service fossil-only comparison. Source [10]	Y • Forestry-dependent Table 7A: same forestry/pulp sourcing and allocation caveat as viscose; the same classification rule is used. Source [17]	Y • System-dependent Table 7A: closed-loop chemistry reduces some chemical burdens, not necessarily the full water footprint. No automatic green grade. Source [17]	X • Realized-life gap Forfora uses a tenacity-based mass proxy; Table 7B states that realized-lifetime evidence remains weak. Source [10]	N • Metric-sensitive Do not turn lower modeled mass or a selected low-GHG scenario into a universal durability/environmental grade. Source [10]
Nylon / polyamide	P • Above PET in model van der Velden, Section 4.6: nylon 6/66 input versus PET granulate in the same harmonized model. Upstream only; not per wear. Source [11]	P • Higher CED than PET Same upstream model as the climate cell. Cumulative energy demand is not interchangeable with fossil depletion or fuel burned. Source [11]	N • Low crop-land use Table 7A: very low agricultural land demand. Unlike the PET cell, no named per-day apparel land comparison is supplied. Source [17]	N • No crop irrigation Table 7A: no irrigation burden, but process impacts remain. Same rule as flax: a component alone is not a full-life green water grade. Source [17]	N • Failure mode matters Section 4.6/Table 7B: abrasion resistance and repeated-laundering stability differ; no universal nylon/PET lifetime ranking. Source [17]	N • Upstream comparison The pink cells are for the specific polymer-production model; they do not establish a whole-garment per-service rank. Source [17]

Table B6b. Cell-by-cell classification basis for Figure ES1. Grey does not mean poor performance; an upstream hotspot does not establish a per-service rank.

B6. Figure ES1 — classification and source register (continued)

Same fixed rule: G/P compare named alternatives under one source boundary; Y means context dependence; X marks a comparative gap; N is descriptive. Service and evidence-limit columns are not impact-graded. Source links resolve to Appendix B5.

Material	Climate	Fossil resources / energy	Land	Water	Durability / service	Evidence limits
Wool	N · Methane hotspot Section 4.7: enteric methane is a strong source contribution. A hotspot does not compare equal service with PET or other apparel. Source [12]	N · Processing hotspot Wiedemann 300-g Merino sweater/109-wear model. No compatible comparator is supplied in this cell, so it is not impact-graded. Source [12]	N · Grazing-land demand Table 7A: high grazing-land demand. This descriptive source finding is not an ordinal per-service rank. Source [17]	Y · Context-dependent Table 7A/Section 4.7: water-stress results depend on method and geography. No universal water grade. Source [12] , [17]	N · Realized use matters Wiedemann service/care sensitivities are retained; an impact reduction under longer use is not a universal material lifetime. Source [12]	N · Claim-specific support Table 7B assigns confidence by claim. The matrix does not average methane, service and fate into one row-confidence score. Source [17]
Alpaca	N · Farm methane hotspot Kern: enteric-fermentation shares of farm-stage GWP in two systems, not a cross-fiber impact ranking or whole-garment percentage. Source [13]	X · Comparative gap Table 7A: resources are less well characterized across systems. This does not establish mixed/intermediate performance. Source [17]	N · Grazing dependence Table 7A: high grazing dependence is descriptive. No matched service comparator is supplied. Source [17]	X · Comparative gap Table 7A: insufficient comparative water evidence; not an unfavorable water result. Source [17]	X · Lifetime borrowed Kern borrowed Merino service assumptions. Grey identifies lack of validated alpaca service life, not poor durability. Source [13]	N · Upstream vs service Table 7B separates confidence in upstream findings from weaker service/fate evidence. Source [17]
Cashmere	N · 155–183 kg CO₂e/kg Textile Exchange cashmere LCA: farmed/nomadic upstream results excluding land-use-change effects. Not a service-equivalent rank. Source [14]	N · 109–144 MJ/kg PEF fossil-resource result per kg clean dehaired cashmere. Not directly compared with PET per day or a different energy indicator. Source [14]	N · High grazing burden Cashmere upstream grazing-land impact is high in the cited evidence; no universal garment-service ordering is inferred. Source [14] , [17]	X · Comparative gap Table 7A: no sufficient finished-service water comparison. Grey, not an adverse result. Source [17]	X · Longevity unresolved McGregor studies/Table 7B: no established compensating longevity advantage. This is not evidence of universally inferior durability. Source [15]	N · Some mass efficiency Controlled fabric work supports modest mass efficiency at matched function, not a generic longevity advantage. Source [15]

Table B6c. Cell-by-cell classification basis for Figure ES1. Grey does not mean poor performance; an upstream hotspot does not establish a per-service rank.

Counterexamples remain in the report: Xu's equal-20-wash climate case favors cotton; De Saxcé's premium cotton sheet outlasts the basic blend; the Bech Merino result depends on reuse, care and recycling. These do not change the JRC result or support pooling incompatible product systems.

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This report is a structured evidence synthesis prepared from the assembled textile-fiber literature and supporting study set. It is not a preregistered systematic review or meta-analysis, product certification, environmental product declaration, regulatory determination or universal fiber ranking. The evidence library was assembled iteratively from supplied sources, citation chaining, targeted searches and current-literature verification through 29 September 2026; absence of a study from this edition should therefore not be interpreted as proof that no such study exists.

Study summaries are concise evidence notes; the original source remains authoritative. Findings distinguish raw-fiber impacts, finished-product impacts, tested durability, assumed or observed service life, fiber release, degradation, persistence, exposure and demonstrated ecological effect. Numerical results remain bounded by each study's functional unit, system boundary, geography, energy mix, allocation method and care assumptions.

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Evidence synthesis | Version 1.0 | 29 September 2026

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