Textile Exchange

In collaboration with

sphera

Life Cycle Assessment for Cotton

Country averages, organic, regenerative, recycled

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March 2026

Title: Life Cycle Assessment for Cotton (Country averages, organic, regenerative, recycled)

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On behalf of Sphera Solutions, Inc., and its subsidiaries

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Textile Exchange is a global non-profit driving beneficial impacts on climate and nature across the fashion, textile, and apparel industry. We guide a growing community of brands, manufacturers, and farmers towards more purposeful production from the very start of the supply chain.

At the heart of our organizational strategy, Climate+, is the goal to help the industry reduce greenhouse gas emissions from fiber and raw material production by 45% by 2030, aligned with the 1.5°C pathway of the Paris Agreement. But our approach goes further, maintaining a holistic and interconnected perspective that aims to improve freshwater, soil health, and biodiversity.

Given Textile Exchange's role and reach in the industry, we believe that we are well-positioned to facilitate the development of Life Cycle Assessment (LCA) studies in a robust and impartial manner, helping to address key data gaps related to the environmental impacts of raw materials and fibers. By engaging stakeholders across and beyond our membership base, we can ensure that different supply chain actors are involved and considered within the LCA development process. Additionally, our LCA+ approach complements LCA results with qualitative insights on biodiversity, soil health, water use, animal welfare, and livelihoods, providing a more complete understanding of material impacts.

In 2022, Textile Exchange launched a series of LCA studies to support the industry in filling key LCA data gaps. Priority studies were identified based on the following criteria: total volume of a fiber or material used by the industry; current availability of impact data; and quality of available impact data.

As a result, seven priority LCA studies were identified: Cotton, Polyester, Leather (hide production), Responsible Wool Standard (RWS) Wool, Responsible Mohair Standard (RMS) Mohair, Nylon, and Cashmere. Each of these studies focuses on the pre-spin stage, or equivalent, impacts of the fiber or material.

For more information on Textile Exchange's position on LCA, please refer to our *Ensuring Integrity in the Use of Life Cycle Assessment Data* paper.

To ensure the LCA studies facilitated by Textile Exchange are robust and credible, we engage with multiple stakeholder groups throughout the study development process:

- **Data collection partners:**
  For example, organizations, schemes, and programs that support the collection and delivery of primary and secondary data.
- **Project sponsors forming a Project Advisory Group:**
  Brands and suppliers that financially support the improvement of LCA data and provide an industry perspective on the LCA needs for a given fiber or material.
- **Material and technical experts forming a Technical Advisory Group:**
  Subject matter experts reviewing initial project outputs ahead of the formal critical review process—helping ensure a robust, transparent, and inclusive review process.
- **Critical reviewers:**
  Independent third-party reviewers assessing the study's alignment with the principles and requirements of the relevant ISO standards.
- **Peer reviewers:**
  For the animal fiber and material LCA studies, peer-reviewed journal articles will be developed to validate and communicate findings.

LCA results are intended to support:	**LCA data should <u>not</u> be used for:**
✓ Environmental impact reduction strategies ✓ Scope 3 reporting and target-setting ✓ Default or "proxy" data for internal or supply chain-specific LCA studies ✓ Benchmarking and validation within supply chains ✓ Inclusion in LCA databases (for example, Higg MSI, Quantis WALDB) ✓ Holistic understanding of impacts, including social factors	× Public or marketing claims (including on-product labels) × Country-based sourcing or production decisions based solely on LCA averages × Comparisons between fibers or materials. Textile Exchange LCA studies are not comparative studies. They should not be used to investigate the differences in impacts between or within fiber or material types.

When reviewing the Life Cycle Assessment (LCA) results and reports, Textile Exchange advises that the scope of the studies, methodologies applied, and carbon accounting approaches utilized are carefully considered, in particular, biogenic carbon accounting and how this differs between natural and synthetic fibers and materials.

LCA studies assess only those environmental impacts that are anthropogenic in origin, meaning impacts that are caused by human activity.

For example, in the case of polyester, the LCA boundary begins at the extraction of crude oil, as this marks the point at which human intervention initiates environmental impacts. The geological formation of crude oil itself is not considered within the scope, as it is a natural process not attributable to human activity. The emissions associated with the fossil carbon contained in the oil and therefore the fiber are usually considered at the end-of-life (EoL) stage of the product.

For natural fibers, the starting point of the assessment differs. For animal-based fibers, it begins with animal rearing; for plant-based fibers, it begins with crop cultivation. All upstream activities related to feed and fertilizer production are also included.

In all cases, the associated impacts are allocated across the multiple outputs of the system, a process known as allocation in LCA methodology.

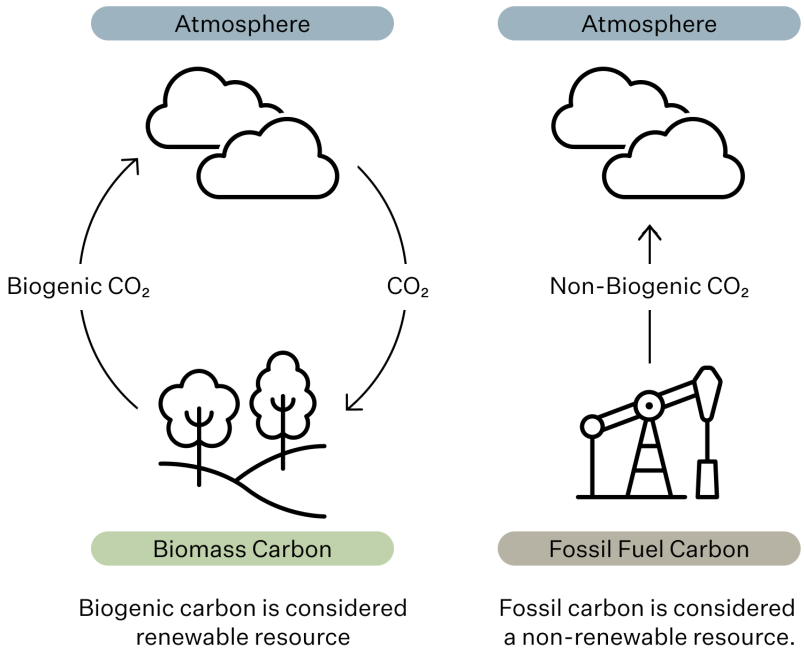
Natural fibers also contain biogenic carbon. Biogenic carbon is absorbed from the atmosphere by plants as they grow and can be released back into the atmosphere later when the plants burn or break down. This is different to fossil carbon that is from fossilized sources in the earth's crust that has formed over millions of years. New fossil material is not formed in natural conditions, so, for example, the incineration of fossil fuels or materials reduces fossil carbon stock and increases atmospheric carbon (never the opposite). Biogenic carbon is considered renewable and fossil carbon is non-renewable. There are several approaches for accounting for biogenic carbon. Its treatment is a critical consideration when comparing fiber types, as inconsistent inclusion or exclusion can lead to misleading or unfair comparisons between biobased and synthetic (fossil-based) materials.

Textile Exchange conducts LCA studies using a cradle-to-gate approach. This means that the studies assess impacts from raw material extraction through to fiber formation. The use phase and EoL stages are not included. However, if EoL were to be included, it would be essential to distinguish between the emissions profiles of biobased and fossil-based materials. For example, synthetic fibers may result in additional greenhouse gas impacts at EoL (for example, due to emissions of fossil carbon from incineration), whereas the emissions occurring from biobased materials are typically considered carbon-neutral at EoL since the emitted carbon was previously absorbed from the atmosphere. See the illustrative example below.

It is important to recognize that the challenge of accounting for biogenic carbon emissions and removals goes beyond carbon stored in the product, and different methods exist for accounting for biogenic carbon. For further guidance, please refer to Textile Exchange's *Biogenic Carbon* guidelines, which outlines recommended practices and considerations for incorporating biogenic carbon into LCA studies. For fossil-based carbon, there are established and standardized accounting methodologies such as the GHG Protocol and ISO guidelines. These methodologies require that emissions and resource use are directly attributable to human activity.

Accounting for Greenhouse Gas (GHG) emissions and the differences between natural and synthetic material production systems is an evolving area with ongoing research and methodology development. Textile Exchange continues to track developments in this area and relevance for its impact data and measurement work.

Illustrative example of natural (crop) vs. synthetic fiber production and the associated carbon cycle:



This study has been led by Textile Exchange in partnership with Sphera.

We sincerely thank all brands, producers and other stakeholders who contributed their time, expertise, and financial support to advance this work.

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List of Acronyms

ADP	Abiotic Depletion Potential
AP	Acidification Potential
a.i.	active ingredients
CML	Centre of Environmental Science at Leiden
dLUC	direct Land Use Change
ELCD	European Life Cycle Database
EoL	End-of-Life
EP	Eutrophication Potential
FAO	Food and Agriculture Organization of the United Nations
GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
GHG	Greenhouse Gas
GWP	Global Warming Potential
ILO	International Labor Organization
ILCD	International Life Cycle Data System
ISO	International Organization for Standardization
IPBES	International Platform on Biodiversity and Ecosystem Services
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LUC	Land Use Change
NMVOC	Non-Methane Volatile Organic Compound
OCA	Organic Cotton Accelerator
sLCA	social Life Cycle Assessment
sLUC	statistical Land Use Change
VOC	Volatile Organic Compound
US	United States of America

Glossary

Allocation

"Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO 14040:2006, section 3.17).

Background system

"Those processes, where due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process … and/or those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good…." (Joint Research Centre, 2010, pp. 97-98). As a general rule, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

Closed-loop and open-loop allocation of recycled material

"An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties."

"A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials." (ISO 14044:2006, section 4.3.4.3.3)

Critical review

"Process intended to ensure consistency between a Life Cycle Assessment and the principles and requirements of the International Standards on Life Cycle Assessment" (ISO 14044:2006, section 3.45).

Data levels

In general, there are different data levels in LCA studies. To ensure an understanding of how the terms are used in the report, the following definitions and explanations are provided:

- **Activity data:** Describes the input data into the assessment, for example, farm data such as yield, fertilizer use, irrigation etc. This term also applies to energy use at gin and transport. Activity data can be differentiated into primary data (collected directly at source), and secondary data (sourced from literature, statistics etc.).
- **LCA Model and emission factors:** The activity data is used in an LCA model to calculate emissions into the environment. The model usually calculates how the activities influence the exchange of matter with the environment. The model usually uses emission factors, i.e., data that specify how emissions are related to inputs. The result is a list of elementary flows for each process.
- **Life cycle inventories (LCI):** The compilation of elementary flows for a process is an inventory dataset (i.e., exchanges with the environment, for example, emission of carbon dioxide, methane, nitrous oxide, etc.). It should be noted that the term "inventory" is often also used to refer to the input data, i.e., activity data.
- **Result data (Life cycle impact assessment, LCIA):** The list of elementary flows can then be related to environmental impacts using characterization factors (for example, relating methane emissions to impacts on climate change).
- **Background data:** Datasets that are used in the background of the assessment, such as datasets on the provision of energy or on fertilizer production, are referred to as background data. These datasets are usually retrieved from LCA databases.

Foreground System

"Those processes of the system that are specific to it … and/or directly affected by decisions analyzed in the study." (Joint Research Centre, 2010, p. 97). This typically includes first-tier suppliers, the manufacturer itself, and any downstream life cycle stages where the manufacturer can exert significant influence. As a general rule, specific (primary) data should be used for the foreground system.

Functional unit

"Quantified performance of a product system for use as a reference unit" (ISO 14040:2006, section 3.20).

Life Cycle

A view of a product system as "consecutive and interlinked stages … from raw material acquisition or generation from natural resources to final disposal" (ISO 14040:2006, section 3.1). This includes all material and energy inputs as well as emissions to air, land, and water.

Life Cycle Assessment (LCA)

"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040:2006, section 3.2).

Life Cycle Impact Assessment (LCIA)

"Phase of Life Cycle Assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product" (ISO 14040:2006, section 3.4).

Life Cycle interpretation

"Phase of Life Cycle Assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations" (ISO 14040:2006, section 3.5).

Life Cycle Inventory (LCI)

"Phase of Life Cycle Assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle" (ISO 14040:2006, section 3.3).

Product system

"A collection of unit processes with elementary and product flows, performing one or more defined functions and modeling the life cycle of a product" (ISO 14040:2006, Section 3.3). A product system includes all processes needed to produce, use, and dispose of a product. It tracks all inputs (like energy, water, fertilizers) and outputs (like emissions, waste) for that product's life cycle and relates everything to the functional unit (the unit of performance being assessed, for example, "1 kg of cotton fiber at gin gate").

Executive Summary

Goal and scope

Textile Exchange, in collaboration with Sphera Solutions, has initiated a comprehensive Life Cycle Assessment (LCA) study to develop robust and transparent environmental datasets for cotton production systems in different regions. The study aims to address critical data gaps and methodological inconsistencies found in existing cotton LCA studies by generating new datasets for country average (reference system), organic, regenerative, and recycled cotton across key producing countries[1,2].

The primary objective is to provide the textile industry with credible and regionally relevant LCA data that support environmental hotspot analysis, scenario modeling, Scope 3 emissions reporting, and sustainability target setting, especially in cases where supplier-specific data is not available. Importantly, the data is not intended for public claims or comparisons between countries or farming systems.

The study follows a non-comparative, attributional LCA approach and focuses on cradle-to-gin-gate boundaries. The cradle-to-gin-gate system for cotton cultivation covers raw material production from field to ginning, with a functional unit of 1 kilogram (kg) of lint cotton at the gin gate (excluding packaging). The geographies included are Brazil, selected regions of China, India, Peru, Tanzania, Türkiye, and the United States of America (US). For recycled cotton, the scope includes three waste types: post-industrial yarn waste, post-industrial fabric waste, and post-consumer waste. System boundaries include waste collection, transport, and mechanical recycling processes. Averages are provided per waste type based on data from Bangladesh, China, India, Pakistan, and Türkiye. The functional unit is 1kg of recycled cotton fiber product for further processing at the factory gate[3].

In terms of allocation at the gin (cotton cultivation), this study follows the default allocation approach recommended by the Cascale Cotton LCA Methodology (Cascale, 2024b), namely, economic allocation based on the five-year average price data. For recycled cotton, which is a multi-output system, economic allocation is used to distribute impacts between the main product and by-products; however, the study takes a conservative approach by assuming 100% allocation to the main product.

In this study, environmental impacts are assessed across several key categories, including climate change, water consumption, eutrophication, and ecotoxicity, with all EF 3.1 impact categories listed in Annex G. Textile Exchange's LCA+ approach builds upon traditional Life Cycle Assessment (LCA) by integrating additional sustainability criteria such as biodiversity, soil health, and social impacts into material impact assessments. As part of the LCA+ approach, soil health and biodiversity are

1 The cotton cultivation reference system (country average), organic cotton, and regenerative cotton are collectively referred to as "cotton cultivation systems." Since recycled cotton represents an entirely different industrial production system, most sections distinguish between "cotton cultivation" and "recycled cotton."

2 While only the system names are listed here for conciseness, it is important to note that the process of defining cultivation systems presented several challenges; the definitions and the related methodological considerations are described and contextualized in detail in Section 3.1 of the report.

3 It should be noted that, although fiber quality is not considered within the study, recycled cotton spinnable fibers are typically lower quality than virgin cotton.

addressed through semi-quantitative metrics and are provided together with an assessment of social impacts in a separate section dedicated to the LCA+ approach.

This LCA study is conducted in accordance with ISO 14044:2006 *Environmental Management – Life Cycle Assessment – Requirements and Guidelines*. The study has undergone a critical review by an independent expert panel to help to ensure conformity with the ISO standard and the scientific robustness of the results. In addition, a Technical Advisory Group (TAG), comprising representatives from cotton initiatives, industry stakeholders, and LCA experts, was established to provide ongoing guidance and input throughout the study.

The methodology developed and applied in this study to assess cotton cultivation systems is closely aligned with existing industry standards, including the Cascale Cotton LCA Methodology, a consensus-based framework created by a coalition of cotton programs, LCA experts, and industry stakeholders. The resulting datasets are to be published in accessible formats and made available for integration into LCA software and industry databases such as the Higg Material Sustainability Index (Higg MSI), the World Apparel and Footwear Life Cycle Assessment Database (WALDB), Sphera's MLC database, Ecoinvent, and others.

Inventory data

According to ISO 14044, primary data, i.e., collected directly from the processes being assessed, are distinguished from secondary data, which are sourced from literature, databases, statistical compilations, or other indirect sources. In LCA, up-to-date and representative primary data are generally regarded as having the highest data quality, a distinction that is reflected in the data quality rating (DQR) frameworks commonly applied in LCA studies.

A foundational assumption of this study was that a significant amount of primary data collection is already ongoing within the cotton sector. The study aimed to leverage this existing data infrastructure as much as possible. To this end, a careful evaluation of all available data, both published and unpublished, was conducted. Additionally, contacts were established with relevant institutions and stakeholders to obtain access to primary datasets or to validate secondary data and related assumptions. However, it was not within the scope of this study to establish new data collection processes. In instances where primary data were unavailable or insufficient, secondary data were used to supplement the dataset. All data sources were assessed using a structured DQR approach, considering criteria such as technological, geographical, and temporal representativeness, completeness, and methodological consistency. Limitations associated with the DQR of secondary data are clearly communicated to ensure transparency in interpretation. The cultivation data used in this study was provided directly by participating organizations and is therefore self-reported. Internal plausibility checks were conducted by the project team, the Technical Advisory Group, and the independent critical review panel, but the data has not been externally audited or independently verified.

For cotton cultivation, data availability and connections with relevant in-country institutions vary depending on the geography. This is reflected in a detailed assessment of representativeness and data quality rating in this study. Typically, in extensive primary data collection efforts, stratification is employed to ensure that data from all relevant production strata are adequately captured. However, since no new primary data collection on farm level was initiated for this study, implementing a robust stratification strategy proved challenging. Despite these challenges, the assessment of representativeness revealed that the sampled production volumes were generally substantial enough to reflect the country-level trends. Main production regions were predominantly included within the

datasets, although the specific representativeness of each sub-region or stratum could not always be clearly assessed.

For recycled cotton, data availability and collaboration with relevant institutions is also variable between countries. Unlike cotton cultivation, there was no readily available published Life Cycle Inventory (LCI) data, so the study was reliant on primary data collection. The differentiation of waste types between post-industrial yarn, post-industrial fabric, and post-consumer waste was well defined, and data providers had no challenges in disaggregating the data collected accordingly. Production volumes sampled were of significant size; however, a lack of information on the breakdown of global annual production of recycled spinnable cotton fiber by country, as well as clear guidance on the classification of different mechanical recycling technology types or cotton waste textile inputs, made it challenging to quantify the representativeness of the data sampled (Textile Exchange, 2024).

Environmental impact assessment results

Cotton cultivation

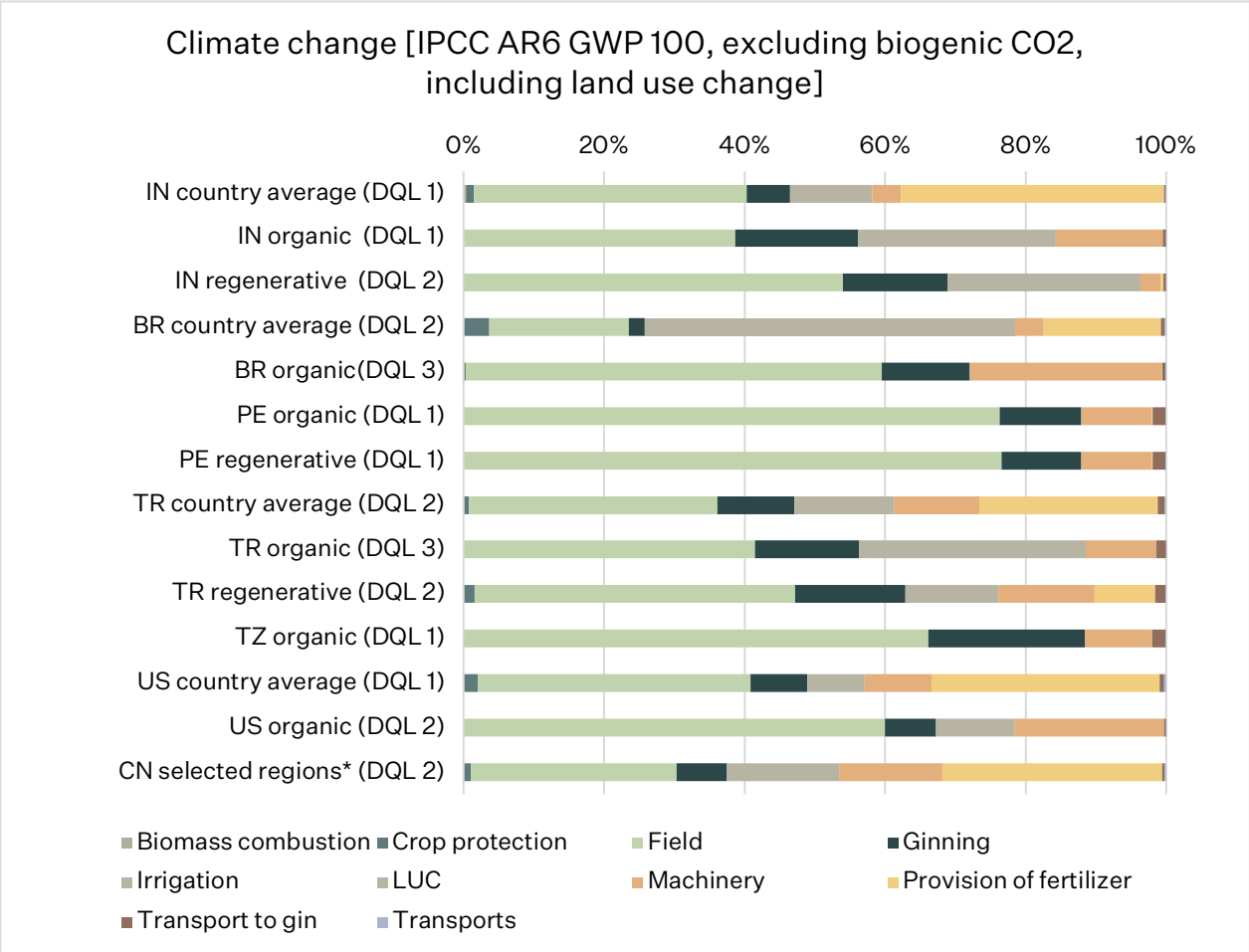

Figure 1-1: Climate change—contribution analysis
*For regions included, see Table 3-1
DQL = Data quality level, see section 6.3, 1=good, 2=medium, 3=limited

Environmental impacts associated with cotton cultivation are shaped by a small set of systemic drivers that cut across impact categories. Field emissions related to the nitrogen balance are central for climate change and eutrophication modelling; fertilizer provision impacts further condition results, with mineral fertilizer production contributing upstream burdens, while organic fertilizers are usually treated as residues or by-products whose upstream burdens are not allocated to cultivation (Figure 1-1 illustrates contribution analysis for impacts on climate change). Irrigation influences both blue-water consumption and energy-related emissions, and its relevance depends on water use efficiency, technique, and local hydrogeological conditions. Pesticide inventories and characterization factors strongly affect ecotoxicity modeling, where a limited number of active ingredients can have a disproportionate influence. Yield levels act as a scaling parameter across categories because inventory flows are expressed per unit of output. Post-harvest energy supply (for example, electricity for ginning) also contributes to the overall profile.

Scenario explorations indicate that results are sensitive to methodological choices, including the handling of organic fertilizer provision, selection of nitrous oxide and nitrate leaching factors, nutrient contents assumed for organic materials, the use of an N-balance approach for emission modeling and fertilizer inventories, aggregation versus substance-specific pesticide modeling, and the electricity mix used in ginning.

In addition to standard LCA impact categories, this study applied an LCA+ approach to provide indicative assessments of soil health and biodiversity. These are presented separately as high-level screening analyses together with an assessment of social impacts to highlight their exploratory nature and avoid confusion with core results.

For soil health, the study used soil organic carbon (SOC) as a proxy, applying the IPCC Tier 1 methodology. Results suggest that reduced tillage and especially increased organic inputs, such as cover crops or manure, can enhance SOC stocks and strengthen long-term soil resilience. However, these estimates rely on default factors, assume linear trends, and do not capture site-specific variation. They should, therefore, be interpreted as indicative scenarios, not as robust or reportable removals.

For biodiversity, impacts were assessed indirectly by interpreting existing environmental impact categories such as land use change, eutrophication, pesticide use, and water consumption as proxy indicators (see section 7.2). However, these indicators were not designed to measure biodiversity directly, and their correlation with actual biodiversity outcomes can be inconsistent or even inverse depending on local ecological conditions. While reductions in these pressures are generally expected to lower biodiversity risks, outcomes remain highly site specific, and no direct one-to-one relationship can be assumed. Some potential benefits of specific farming practices develop gradually over time and may fall outside the resolution of this LCA. This study, therefore, does not constitute a biodiversity assessment and should not be used as such by third parties. A meaningful evaluation of biodiversity impacts would require more detailed, spatially explicit, and locally grounded data, which go beyond the screening level possible with the LCA+ approach.

Recycled cotton

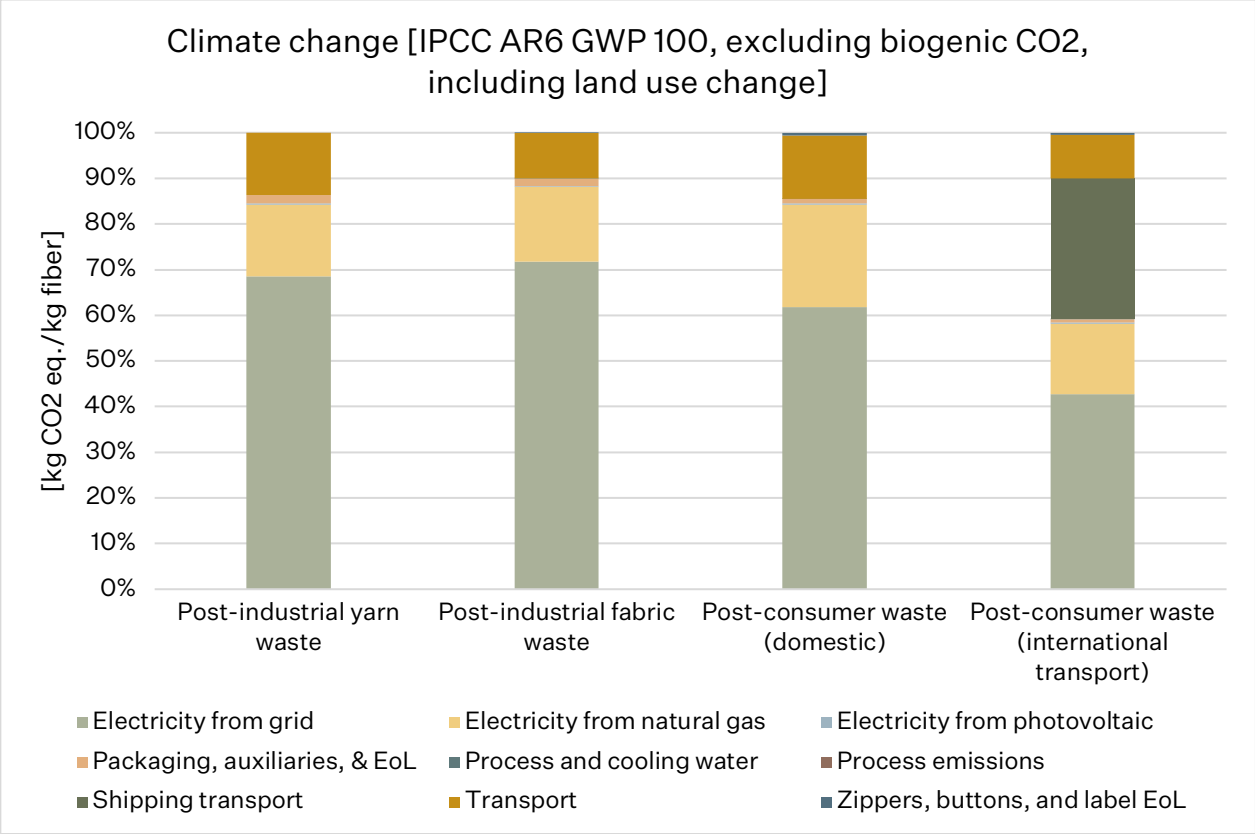

Figure 1-2: Climate change, global average recycled cotton

The environmental impact analysis identified electricity consumption and transportation as the key drivers of potential environmental impacts for all impact categories and inventories analyzed for the production of 1 kg of recycled spinnable fibers (Figure 1-2). For all cotton waste types, impacts are most significantly influenced by the intensity of the recycling process and electricity consumed in the production of recycled spinnable fibers. For post-consumer waste, there are additional processing steps required prior to fiber opening and higher process waste losses, contributing to high electricity consumption, which is evident in the impacts of this waste type. Furthermore, if post-consumer waste is internationally shipped prior to recycling, this can result in a significant contribution to the environmental impacts of this cotton waste type.

Despite these findings, due to the significant variation observed in key inventories between data providers, high uncertainty remains regarding the potential environmental impacts of individual suppliers of recycled cotton fibers, and it cannot be assumed that one waste type is inherently more impactful than another. Therefore, for companies procuring recycled spinnable fibers, the collection of supplier-specific externally validated inventory data, including electricity consumption and transportation (including international transportation from source), should be prioritized when analyzing supply-chain-specific impacts of fibers. Importantly, despite current limitations on data quality, the analysis clearly substantiates that the uptake of renewable electricity, as well as the shift from international transportation of post-consumer waste to domestic recycling, has the potential to significantly decarbonize the production of recycled spinnable cotton fibers.

Human rights impact assessment results

The human rights assessment, conducted as part of the Textile Exchange LCA+ approach, was designed as a qualitative screening and hotspot analysis. Since its setup differs significantly from the standard LCA structure, the assessment is presented separately in section 7.3. To analyze the status of human rights matters in the field, a survey containing 20 questions covering specific material topics was launched. For the selection of questions, the UNEP *Guidelines for Social Life Cycle Assessment of Products and Organizations* (United Nations Environment Programme, 2020) were consulted. The survey was sent to all participants of the study who were engaged to provide data for environmental assessments. In addition, four interviews with sector experts were conducted, discussing the content of the survey, the information collected from data providers, as well as additional topics such as recent improvements, challenges, and the future outlook of human rights issues in the cotton supply chain.

The human rights survey indicated, in almost all social impact subcategories, that there are human rights issues affecting workers in the cotton supply chain that still require improvement. Particularly for cotton cultivation, where there was high variability in answers, and for most of the subcategories, there was at least one data point indicating potential human rights issues.

There was consensus from experts that the type of cotton cultivation system is not a key driver behind human rights impacts, whereas legislative aspects, local infrastructure, and mechanization were mentioned to have strong influences. The main differences identified between other farming types and organic farming were within health and safety due to the differences in the use of chemicals, as well as other aspects such as income and education. Overall, improvements in human rights issues are being observed in areas such as awareness-building of labor rights, child labor, and structural changes in rural areas. However, several challenges persist, including forced labor, geopolitical risks, rising costs, and gender-based discrimination in task allocation and wages. Furthermore, the impact of climate change as a challenge was also strongly emphasized. Experts provided recommendations on the potential next steps, including suggestions for revising the survey.

As the scope of this assessment was a high-level screening of human rights issues, the survey conducted was subject to limitations. The main limitations included issues associated with the stakeholders surveyed (self-reporting) as well as the representativeness of data sampled. Therefore, the findings from this high-level human rights screening should not be used for any claims or external communication but can be used as a basis for more in-depth analyses.

Limitations

For cotton cultivation, the limitations stem primarily from data availability constraints, methodological assumptions, and the inherent complexity of agricultural systems. Key limitations include variability and uncertainty in primary data quality and challenges related to the representativeness of regional data. Specific uncertainties affecting inventory data include yield data for organic and regenerative systems, estimated irrigation water consumption, nutrient content estimations for organic fertilizers, and pesticide application rates in secondary datasets. This highlights a broader challenge in assessing agricultural systems, which are inherently shaped by complex natural environments. Hence, the results shown do not allow for drawing conclusions on the environmental performance of individual sites or farms. Beyond foreground data, background datasets such as those for fertilizer production also carry significant uncertainty, as regional sourcing patterns are often unknown and provision impacts are approximated by country of consumption.

Furthermore, the study applies an attributional LCA approach focused on environmental indicators; it does not account for market-mediated effects or include an economic analysis, which would require separate, dedicated studies.

For recycled cotton, the limitations stem primarily from the availability of benchmark LCI data, data availability constraints, and validation of primary data collection. Key limitations included variability and uncertainty in primary data quality and challenges related to quantifying the representativeness of supplier-specific data. Another key limitation is the exclusion of output fiber quality within the study. Specific uncertainties affecting inventory data include assumptions on packaging, auxiliaries, and transportation distances as well as electricity consumption data validation.

For both cotton cultivation and recycled cotton, the mentioned limitations must be explicitly considered in interpreting the study's outcomes. The robustness of the underlying data should be given equal or greater weight than the numerical value of the impact itself. Transparent documentation of data quality and uncertainty is essential to ensure responsible communication of results. For datasets identified with lower data quality, particular attention should be paid to the uncertainty ranges reflected in scenario and sensitivity analyses. In such cases, more detailed data collection and improved representativeness can lead to substantial changes in results. Although conservative estimates were applied in this study wherever necessary, the inherent uncertainty of lower-quality datasets implies that impacts will not necessarily decrease as data quality improves, but could also increase. Further refinements in data collection and modeling approaches are recommended to enhance the robustness and applicability of cotton LCA data in the future.

Conclusion and recommendations

This study represents a considerable advancement in the state of LCA data for cotton, including recycled cotton. While the study has clearly outlined limitations, particularly relating to data availability, representativeness, and methodological constraints, it has nonetheless delivered significant improvements compared to previous datasets. Notably, by systematically compiling transparent inventory data, adhering to industry-aligned methodologies such as the Cascale Cotton LCA Methodology, and providing comprehensive documentation, this study marks a clear step toward higher consistency, transparency, and robustness in cotton LCA results. Nevertheless, LCA results remain sensitive to assumptions and contextual factors; the results should be interpreted within their limitations, and simplistic rankings or claims based on these results should not be conducted. It should be reiterated that this study is non-comparative in nature; users are encouraged to interpret results within the context of Textile Exchange’s data integrity principles and guidance on appropriate application of LCA results.

This study presents actionable recommendations to enhance the quality of cotton Life Cycle Assessment (LCA) data and reduce environmental impacts across cotton cultivation and recycled cotton fiber production systems. To improve data quality, the study emphasizes methodological harmonization, particularly for recycled cotton, where inconsistencies in system definitions and inventory parameters persist. Priority actions include stratifying fiber waste types, classifying recycling technologies, and improving electricity metering at recycling facilities.

To reduce environmental impacts from cotton cultivation, the study emphasizes improving the efficiency of input use, particularly through better nitrogen management, the adoption of enhanced efficiency and low-carbon fertilizers, and the promotion of integrated pest management, while maintaining or increasing yields. Organic fertilizer strategies should be carefully managed to minimize provision-related impacts and emissions. Irrigation efficiency is another priority, combining improved technologies, training, and measures to improve water holding capacities in soils, to

reduce both water and energy demand. In addition, the adoption of renewable energy at ginning facilities offers a direct opportunity to lower the carbon footprint of post-harvest processing. For recycled cotton, the study emphasizes a switch to 100% renewable electricity generation for all waste types, as well as increasing the domestic treatment of post-consumer waste to avoid impacts associated with international transportation, which were both identified given the significance of their potential to effectively decarbonize the recycled, spinnable fiber supply chain.

A follow-up "Phase 2" study is proposed to address data gaps and leverage current stakeholder engagement. Strategic planning and alignment with specific-use cases will be essential to maximize the utility and impact of future assessments.

1. Introduction

1.1. Background

Cotton is the most widely used natural fiber in the fashion, textile, and apparel industry (Textile Exchange, 2024), and its production and consumption have significant environmental impacts. Life Cycle Assessment (LCA) is a tool that can help measure the environmental performance of different cotton products and systems. There is increasing concern over the robustness of existing LCA data that is commonly used, with the criticism that data is often outdated, incomplete, inconsistent, and/or poorly documented, which limits its usefulness and reliability.

In 2021, the report *Identifying Low Carbon Sources of Cotton and Polyester Fibers* was published under the Fashion Industry Charter for Climate Action[4] (FICCA, 2021). The report highlighted some of the limitations in the available LCA data around cotton, such as:

- Regional resolution: The data on cotton cultivation and processing are often aggregated at the global or national level, which does not capture the variations in climate, soil, irrigation, fertilization, and management practices across different regions and farms.
- Outdated data: The data on cotton production and emissions are often based on old studies or outdated statistics, which do not reflect the current technologies, practices, and policies that affect the environmental performance of cotton.
- Inconsistencies in LCA modeling approach and field emissions: The LCA studies on cotton use different methods, assumptions, and parameters to model the life cycle stages and impacts of cotton, especially the field emissions from soil organic carbon changes, nitrous oxide emissions, and biogenic carbon sequestration. This leads to inconsistencies and uncertainties in the results and comparisons across different studies and sources[5].
- Impact of organic fertilizer production: The LCA studies on cotton often do not account for the environmental impacts of producing the organic fertilizers (such as manure or compost) that are used in organic or low-input cotton systems.
- Background data and LCA software: The LCA studies on cotton rely on background data (such as energy, transport, chemicals, etc.,) and LCA software (such as SimaPro, LCA FE (formerly known as GaBi (Ganzheitliche Bilanzierung (German for “holistic balancing”),) etc.,) that may have different sources, quality, and updates. This may affect the accuracy and comparability of the LCA results and conclusions.
- Harmonized reporting requirements on biogenic carbon: The LCA studies on cotton do not follow a harmonized approach to report the biogenic carbon flows and stocks associated with cotton production. This may lead to confusion and inconsistency in how biogenic carbon is accounted for and allocated in the carbon footprint calculations.

4 The Fashion Industry Charter for Climate Action (FICCA) is a voluntary initiative that brings together fashion stakeholders, under the auspices of UN Climate Change, to “drive the fashion industry to net zero greenhouse gas emissions no later than 2050”. FICCA was launched in 2018 and has more than 130 companies and 41 supporting organizations as signatories. FICCA commits to setting science-based emissions-reduction targets, reporting on progress annually, and collaborating on low-carbon solutions across the value chain.

5 This is a point raised in the FICCA report; however, it should be noted that this study does not encourage comparisons in general, especially not across studies, see section 2.4.

- Land-use impacts: The LCA studies on cotton do not adequately address the land-use impacts of cotton cultivation, such as land use change, soil erosion, water scarcity, biodiversity loss, and social conflicts. These impacts may have significant implications for the carbon footprint and environmental impact assessment of cotton.

According to the FICCA report, these limitations pose challenges for identifying and promoting lower-impact sources of cotton fibers. There is a need for more reliable, consistent, and transparent data collection and reporting on the life cycle impacts of different cotton sources, as well as for more harmonized and robust LCA methods and tools to assess them.

At the same time, the pressure on the robustness of data is increasing, as sustainability reporting is now central to most companies, and investors, regulators, and consumers demand more transparency and accountability. This pressure is institutionalized by frameworks such as the European Sustainability Reporting Standard (ESRS), the Task Force on Climate-related Financial Disclosures (TCFD), or the Science Based Target initiative and network (SBTi and SBTN), which set high standards and expectations for sustainability reporting. Additionally, the European Commission has proposed the Green Claim Directive, aimed at preventing greenwashing and ensuring that consumers receive reliable, comparable, and verifiable environmental information on products and services. The directive will require companies to substantiate their voluntary environmental claims and labels using robust, science-based, and verifiable methods that are reviewed by an independent and accredited verifier.

Most LCA practitioners are aware of these challenges and are actively seeking ways to improve the quality, reliability, and transparency of the data sources and methods used in LCA studies. In this context, Textile Exchange is prioritizing and facilitating several LCA studies to fill critical impact-data gaps to better inform industry-wide modeling and decision-making. Improvement of LCA data on cotton is part of this effort.

The cotton LCA project began in 2023 with a separate scoping phase in accordance with ISO 14040, during which the study's goal and scope were defined, stakeholder engagement was initiated, and a framework for data collection and modeling was established. The LCA study started at the beginning of 2024 and concluded in the second half of 2025.

1.2. Textile Exchange's LCA+ approach

Textile Exchange launched its Climate+ strategy in 2019, establishing climate as a priority impact area to be addressed by the organization while also recognizing other interdependent impact areas such as biodiversity, soil health, and social aspects. The organization believes that taking a holistic view of impacts is critical to preventing the unintended consequences of having "carbon tunnel vision".

LCA+ describes Textile Exchange's approach to using impact data within the context of the Climate+ strategy. LCA is the most widely used methodology to assess the impacts of materials and products. However, there are important impact areas, such as biodiversity, soil health, and social aspects, that cannot be addressed through standard LCA methodology. Therefore, Textile Exchange has identified two concurrent priorities for its LCA+ work: improving the availability of LCA data to the industry and exploring how additional impact areas and alternative methodologies can be incorporated in an LCA approach.

As part of this study, three additional categories are addressed beyond the core LCA impact assessment: soil health, biodiversity, and social aspects (human rights). These assessments are intended as high-level screening approaches that complement the standardized impact categories. For this reason, they are presented in a separate section (section 7), to avoid confusion with the main impact assessment, to make their methodological limitations explicit, and to highlight their role as exploratory analyses rather than definitive quantifications.

It should be mentioned here that this life cycle assessment focuses on environmental impact indicators (and assesses social impacts at the screening level as part of the LCA+ approach), but economic analysis has not been included. Incorporating robust financial metrics would require a dedicated study, complete with detailed cost modeling, market-data collection, and stakeholder validation, which was beyond the scope of this study. However, the economic dimension is considered a central pillar of holistic sustainability assessments, and complementary economic assessments would be necessary before any conclusions about potential sustainability benefits of specific production systems or measurements discussed in this study can be drawn.

In addition, it needs to be highlighted that this study is conducted as attributional LCA. Attributional LCA is a method of life cycle assessment that describes the environmental impacts of a product or service based on the actual flows of materials and energy in its life cycle. ALCA does not consider how these flows may change in response to changes in demand or production of the product or service. The term attributional LCA is used to distinguish it from the term "consequential LCA" (CLCA), which is another method of life cycle assessment that aims to estimate the changes in environmental impacts caused by a decision or a change in the life cycle of a product or service (usually based on assumptions of new market situations caused by shifts in supply and demand). As such, this study does not evaluate how results might be affected by changes in supply and demand. It also does not assess whether demand could exceed supply (for example, in production systems currently reporting low production volumes), nor does it examine the potential consequences of such imbalances (for example, dilution or illegal circumvention of production standards).

2. Goal of the Study

2.1. General goals of the study

The primary goal of this Life Cycle Assessment (LCA) study is to provide the textile industry with high-quality, transparent, and regionally relevant environmental data on cotton production systems. This includes conventional, organic, regenerative, and recycled cotton across key cotton-producing countries (see section 3.1.1 for definitions). The study is designed to serve as a foundational resource for companies seeking to understand and reduce the environmental impacts associated with their cotton supply chains.

In particular, the study aims to:

- **Generate robust LCA datasets** for cotton cultivation and ginning, using consistent and transparent methods aligned with ISO 14040 standards. These datasets will reflect actual production conditions and practices in selected countries and systems.
- **Support credible Scope 3 reporting** and environmental impact accounting by providing supply chain actors with reliable default inventory data, especially where supply-chain-specific data is unavailable.
- **Support scenario modeling and strategy development** for impact reduction, allowing stakeholders to evaluate the potential benefits of alternative farming practices and management systems.
- **Provide data for benchmarking and validation** in internal assessments and broader sustainability frameworks, such as the Higg Material Sustainability Index (MSI), WALDB, and others.
- **Fill critical data gaps** identified in existing LCA literature and datasets, particularly regarding country- specific data, temporal relevance, and regenerative practices.
- **Inform future improvements and updates** by establishing a methodological framework that can be refined over time, supporting the ongoing development of life cycle inventory data in a dynamic and evolving industry.

This LCA study does not claim to drive farm-level change directly; rather, its purpose is to provide higher-quality data that enables more informed decision-making by identifying environmental impact hotspots, showcasing improvement potential, and highlighting data gaps. The results presented here are intended to demonstrate that measurable reductions in environmental impacts are achievable, and that these impacts can be quantified and reported.

Progress cannot be achieved through short-term sourcing decisions (see also section 2.3), such as simply switching from one production system or country of origin to another, but rather through long-term partnerships. Cotton programs can play a critical role in this process (see also the Theory of Change outlined in the Cascale Cotton LCA Methodology (Cascale, 2024b), and intended use in section 2.3, including the advice to prioritize the use of supply chain-specific data wherever possible).

In alignment with Textile Exchange's LCA+ approach, this study acknowledges that conventional LCA methods do not capture all relevant sustainability outcomes. Therefore, in addition to the classical LCA impact categories, soil health (via potential soil carbon sequestration), biodiversity, and social aspects are considered in this study. While soil health and biodiversity are addressed

through a screening-level assessment due to methodological and data limitations, comparatively greater effort was dedicated to evaluating human rights impacts through a structured qualitative assessment based on stakeholder surveys and expert interviews.

At the same time, this study acknowledges that some potential benefits of specific farming practices (for example, those associated with regenerative systems) are highly site-specific and develop only gradually over time. As such, they may fall outside the temporal or spatial resolution of conventional LCA modeling and are not fully reflected in the present assessment. To complement the LCA+ approach and close remaining data gaps, frameworks such as Textile Exchange's *Regenerative Agriculture Outcome Framework* (Textile Exchange, 2023) should be used to track progress across a holistic set of impact areas for specific systems and contexts over time and to look at measuring beneficial impacts (doing more good), not just negative impacts (doing less bad).

2.2. Alignment with industry standards

In developing the methodology for this study, care was taken to align with recognized international frameworks that guide Life Cycle Assessment (LCA) practice. These include ISO 14044 (ISO, 2006), the Product Environmental Footprint (PEF) method (European Commission, 2021), and the GHG Protocol Land Sector and Removals Guidance (GHG Protocol, 2022). However, these frameworks do not provide product- or sector-specific guidance for cotton cultivation systems. Therefore, the methodology developed and applied in this study to assess cotton cultivation systems[6] aligns closely with the *Industry Aligned Life Cycle Assessment Methodology and Requirements for Creating Cotton Fiber Datasets for the Higg Product Tools* (hereafter referred to as the "Cascale Cotton LCA Methodology") published by Cascale (formerly Sustainable Apparel Coalition) in 2024 (Cascale, 2024b).

This methodology represents a consensus-driven effort by a broad coalition of stakeholders including cotton programs, industry experts, NGOs, and LCA practitioners. It provides a standardized framework for the development of life cycle inventory datasets for cotton cultivation and ginning that can be used within the Higg Product Tools, particularly the MSI. The methodology defines clear guidance on data collection, inventory modeling, allocation, and impact assessment, with the objective of enabling consistent, scalable, and transparent cotton fiber datasets. Given the inclusive and collaborative nature of its development, and its intention to serve as a common reference across cotton initiatives, the Cascale Cotton LCA Methodology constitutes an industry-aligned baseline. Consequently, this study acknowledges the value of harmonization and aims to align with the Cascale Cotton LCA Methodology to the greatest extent possible. However, it should be noted that the method is used as a sectoral benchmark and its application in this project is not limited to the submission of datasets to the Higg MSI.

Specific areas of alignment with the Cascale Cotton LCA Methodology include:

- System boundaries (cradle-to-gin gate)
- Declared unit (1 kg of cotton lint)
- Use of economic allocation as a default
- Key inventory parameters such as pesticide and fertilizer use, irrigation water and energy, fuel use, and ginning electricity consumption

6 A similar methodological framework does not currently exist for recycled cotton.

- Adoption of the same core modeling frameworks (for example, IPCC Guidelines, PEF method)
- Use of defined and agreed-upon secondary data to fill data gaps
- Intended use cases for Scope 3 reporting, hotspot analysis, and tracking improvements over time

However, while methodological alignment is a priority, the scope and context of this study differ in some areas. Notably, the Cascale Cotton LCA Methodology is targeted at specific cotton programs, whereas this study focuses on country-level averages that may aggregate data from multiple providers. Similarly, the data collection approach differs, with this study incorporating inputs from various sources and applying production-weighted averaging to generate representative national datasets. Details on how and where alignment with the Cascale Cotton LCA Methodology has been implemented will be provided throughout the corresponding sections of this report, including system boundaries, allocation methods, impact categories, and data collection strategies.

In addition, this study intends to submit the resulting inventory datasets for integration into the Higg MSI under the Cascale Cotton LCA framework, WALDB and other databases (see next section).

2.3. Intended use and communication of study results

As described in section 1.1, there is a general awareness that data quality requirements have increased in recent years and that existing LCA data on cotton cannot meet all of these requirements. At the same time, there is also increasing public concern over how data of limited quality is used to make marketing claims. Therefore, much care is taken to define the intended use of the datasets in the final LCA study. Textile Exchange recently published a position paper titled *Ensuring Integrity in the Use of Life Cycle Assessment Data—Responsible impact measurement for the fashion, textile, and apparel industry* (Textile Exchange, 2025), which provides important context for interpreting and applying LCA data. Users of the data generated in this study are strongly encouraged to consult this publication to gain a comprehensive understanding of the possibilities and limitations associated with the use of LCA data from Textile Exchange's studies.

Intended use:

- Analyzing the environmental impact reduction potentials of alternative management practices in cotton cultivation
- Scope 3 reporting and target setting
- As a source of default inventory data for internal or supply-chain-specific assessments
- As a source of validation and benchmarking data for internal or supply-chain-specific assessments
- Submission to LCA databases, such as Higg MSI, WALDB and other databases
- Scenario analysis
- To promote holistic considerations of impact, including human rights impacts

Data shall not be used for (see also section 2.2 and section 2.4):

- Public claims, marketing claims (including for use on product labels), or any form of comparison:
    - based on the comparison of the LCI or LCIA results of this LCA study.
    - based on comparing the results of this LCA study to other studies

    - about differences between countries and production systems (including comparisons between virgin and recycled cotton)
- Production or sourcing decision-making based solely on country-average LCA results. Implementing reduction measures in high-impact regions is more environmentally beneficial than shifting sourcing, and social and economic impacts deriving from changing sourcing strategy require careful evaluation[7]

The datasets developed in this study are intended to support environmental impact assessments only in cases where more specific data are not available. Users are strongly advised to prioritize the use of supply chain-specific data wherever possible. The application of the results should adhere to the following hierarchy of data preference:

1. Supply chain-specific primary data[8]
2. Cotton program-level or initiative-level data averages
3. Country average datasets as developed in this study
4. Global average datasets without traceability to the source region

This hierarchy reflects the increasing uncertainty and declining representativeness associated with each step down the list. The country- and global-average datasets developed in this study should be considered as default values or gap fillers. They are not intended to replace traceable data sources when such data is available and robust. Consequently, the datasets presented here should *not* be used to override or substitute:

- Supplier-level LCA data[9]
- Program-specific data developed according to recognized methodologies (for example, Better Cotton Initiative, OCA, regenerative agriculture initiatives)
- Data collected through direct engagement with cotton growers or ginners

Wherever possible, activity data (see Glossary) and inventory models developed under this study should be adapted or recalibrated to reflect supply-chain-specific conditions. This enables more meaningful environmental assessments, aligns with ISO 14044 principles regarding data representativeness, and avoids misapplication of generic averages in contexts where more precise data exist.

To facilitate such supply-chain-specific assessments, and following the transparency principle, all activity data used in this study is published. Therefore, users do not need to rely on results data only and are invited to use the activity data in their own assessments.

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7 Shifting sourcing to low-carbon geographies is discouraged as well by SBTi FLAG guidance (p. 48), which emphasizes engagement and improvement in existing supply regions to avoid leakage and promote long-term sustainability outcomes (Anderson et al., 2022).

8 In the hierarchy of data use, "supply chain-specific primary data" should be understood as referring to situations where a long-term sourcing contract is in place. Using lowest-impact datasets without a sourcing commitment may undermine on-the-ground efforts to implement improved practices that deliver lower impacts over time, see also section above on "Data shall not be used for and sections 2.1, 2.2, and 2.4".

9 In an ideal case, supplier-specific data should be verified by an independent third party or certification body to ensure the credibility, traceability, and reliability of the underlying input information. This is also recommended as best practice by standards such as (GHG Protocol, 2022).

The activity data can also be used to generate LCI inventory datasets, i.e., the datasets can be used in LCA software to assess environmental impacts using different impact assessment methods or are combined with downstream processing models (for example, textile manufacturing). The LCI datasets will be published in Sphera's MLC database and as eILCD datasets to allow import into other commonly used LCA databases (for example, WALDB). In addition, this study intends to submit the resulting inventory datasets for integration into the Higg MSI under the Cascale Cotton LCA framework (see above section 2.2)[10].

Database owners might decide to use the activity data in their models and run their assessments rather than importing the final inventories. However, it remains clear that their results will differ from the results generated in this LCA study, as different database providers use different modeling assumptions and background data. Users who want to use activity data to reproduce the inventories created under this LCA study are encouraged to closely align modeling choices with the approaches developed under the study. Model developers can use the activity data compiled in this study in their models. In addition, Textile Exchange organizes an active exchange between different providers of LCA models to compare results and improve understanding of why results may differ. This effort is an ongoing side project through 2025, related to but not in the scope of this LCA study.

Use advice based on data quality rating (DQR)

The appropriate use of datasets in this study depends significantly on their data quality. A detailed data quality assessment has been conducted and is presented in section 6.4 of the report. The following table links recommended-use cases to the corresponding DQR levels to support transparent and appropriate application of the results.

Functional unit definition for recycled cotton

The Functional Unit (FU) of the study for both cotton cultivation and recycled cotton is the production of 1 kg of cotton lint/recycled spinnable fiber at gate. While any form of comparison of LCA results is specifically discouraged as part of this study, it should also be highlighted that the LCIA for recycled cotton fibers and virgin cotton fibers cannot be compared. This is due to the fact that while recycling of cotton textiles has the same function as cotton cultivation to produce a cotton fiber, it also addresses an additional waste management function. Therefore, as no system expansion has been utilized to address the additional functional unit of waste management for recycled cotton, it is not an appropriate comparison (see also section 3.3.2 on system boundaries and use of circular footprint formula as supposed in the PEF method). Furthermore, although fiber quality is not considered within the study, fiber quality should also be considered if making direct comparisons[11].

10 Note that cotton programs such as Better Cotton Initiative, REEL Cotton, and the U.S. Cotton Trust Protocol (CTP), already submit data to the Higg MSI.

11 Differences in fiber quality can have a subsequent effect on aspects such as process waste in yarn spinning and end use textile applications.

Table 2-1: Use advice based on data quality rating

Use case	Data quality level 1 (good)*	Data quality level 2 (medium)*	Data quality level 3 (limited)*
Analyzing the environmental impact reduction potentials of alternative management practices in cotton cultivation	✓	✓	(✓) Screening only
Scope 3 reporting and target setting	✓	(✓) Not if high risk or high priority materials are concerned	(✓) Only as preliminary proxy data
As a source of default inventory data for internal or supply chain-specific assessments	✓	✓	(✓) Screening only
As a source of validation and benchmarking data for internal or supply chain-specific assessments	✓	✓	(✓)
Submission to LCA databases, such as Higg MSI, WALDB and other databases	✓	✓	(✓) Limited DQR needs to be highlighted
Scenario analysis	✓	✓	(✓) Screening only
To promote holistic considerations of impact	✓	✓	✓
Public claims or marketing claims (including on product labels)	✗	✗	✗
Comparison of the LCI or LCIA results of this LCA study to other studies	✗	✗	✗
Claims about differences between countries and production systems	✗	✗	✗
Production or sourcing decision-making based solely on country average LCA results	✗	✗	✗

* See section 6.3

✗ = do not use
✓ = can be used
(✓) = limited use

2.4. Comparative assertions

As described in the previous section, the study should not be used to make claims regarding the superiority or equivalence of one product versus a competing product that performs the same function. Such claims are defined as "comparative assertions" in the ISO 14044. In a comparative study, it must be ensured that the systems being compared are equivalent in function, and use the same functional unit, system boundary, data quality requirements, and allocation procedures. The comparison also must use the same environmental indicators. Since several product systems[12] and regions are assessed in this LCA study, contribution analysis is conducted to explain the results and allow users to understand hot-spots and reduction potentials within one product system. Data quality is different for different product systems (see section 6.3), and it is difficult to quantify the uncertainty of the results for them (see section 5.4). Therefore, the results will not allow comparative assertions under the strict requirements of ISO 14044. **Furthermore, the data and results presented in this report, or any outputs derived from them, must not be used to make comparisons between production systems, regions, or products outside of this report. Any interpretation suggesting comparative superiority based on the presented results is not supported by the study design and would violate its intended use and ISO 14044 requirements** (see also section 2.3 on intended use). Nevertheless, data users should be enabled to choose the datasets that best represent their supply chain, understand what is driving the impacts, and where differences in the results come from.

2.5. Compliance with ISO 14044

This Life Cycle Assessment (LCA) study is conducted in accordance with ISO 14044:2006 *Environmental management—Life cycle assessment—Requirements and guidelines*. The study follows the methodological framework established in ISO 14040 and fulfills the specific requirements of ISO 14044 across all phases of the assessment, including:

- **Goal and scope definition:** The goal and scope are clearly defined, including a detailed description of the functional unit, system boundaries, allocation procedures, and intended applications of the study.
- **Life Cycle Inventory (LCI) Analysis:** Data collection methods, sources, assumptions, and data quality assessments are transparently documented, with an emphasis on the use of primary data wherever possible.
- **Life Cycle Impact Assessment (LCIA):** Characterization models are applied in accordance with ISO guidance, using recommended methodologies for indicator selection, classification, and characterization.
- **Interpretation:** Results are interpreted in line with the defined goal and scope, with consideration of data quality, uncertainties, sensitivity analysis, and study limitations.

A critical review process was carried out in accordance with section 6 of ISO 14044. A panel of independent experts evaluated the methodological approach, data sources, and the overall conformity of the study with ISO requirements to ensure transparency, consistency, and scientific robustness (see section 3.9).

12 See Glossary for definition of "product system".

3. Scope of the Study

The following sections describe the general scope of the project to achieve the stated goals. This includes, but is not limited to, the identification of specific product systems to be assessed, the product function(s), functional unit and reference flows, the system boundary, allocation procedures, and the study's cut-off criteria.

The study is carried out as attributional LCA (ALCA). Attributional LCA is a method of life cycle assessment that describes the environmental impacts of a product or service based on the actual flows of materials and energy in its life cycle. ALCA does not consider how these flows may change in response to changes in demand or production of the product or service. The term attributional LCA is used to distinguish it from the term "contribution LCA" (CLCA), which is another method of life cycle assessment that aims to estimate the changes in environmental impacts caused by a decision or a change in the life cycle of a product or service (usually based on assumptions on new market situations caused by shifts in supply and demand).

3.1. Product system(s)

Cotton is one of the most widely used materials in the fashion and textiles industry. According to Textile Exchange's *Materials Market Report* (Textile Exchange, 2024), it accounted for 20% of all global fiber production in 2023, and its production takes place in around 70 countries worldwide. While approximately 24.4 million tons of virgin cotton were produced in 2022–2023 (Textile Exchange, 2024) the production volume of recycled cotton is roughly estimated at around 319,000 tons (Textile Exchange, 2024), or approximately 1% of the total cotton production in 2023, although this is expected to grow significantly in the coming years.

The aim of this LCA study is to assess the following cotton production systems:

- Cotton cultivation reference system (country average)
- Organic cotton
- Regenerative cotton
- Recycled cotton

In this report, the cotton cultivation reference system (country average), organic cotton, and regenerative cotton are collectively referred to as "cotton cultivation systems." Since recycled cotton represents an entirely different industrial production system, most sections distinguish between "cotton cultivation" and "recycled cotton." Definitions and further details about each production system are provided in the following sections.

3.1.1. Cotton cultivation

Cotton cultivation systems included in this study are a reference system (country average), organic cotton, and regenerative cotton.

Cotton cultivation reference system (**country average):** This product system is intended to represent cotton that is not cultivated under a specific program[13] nor certified as organic or regenerative, as defined below. Although this type of system is typically referred to as "conventional," the use of that term was deemed problematic in the context of this study. In cases where secondary or national statistical data is used, it is often unavoidable that such data includes contributions from cotton programs. While the goal is to establish these product systems as reference systems and to exclude program data where possible, full separation was not always feasible. Therefore, the term "country average" was considered the most appropriate to reflect what the production system is intended to represent. Importantly, no claims are made about specific program data, even if a significant share of the country average may be derived from such programs.

Organic cotton: This is defined as "certified organic" i.e., certified under one of the organic standards in the IFOAM[14] Family of Standards.

Regenerative cotton: There is currently no universally agreed-upon definition of regenerative agriculture. As outlined in Textile Exchange's *Regenerative Agriculture Landscape Analysis* (Textile Exchange, 2022), regenerative systems are best understood as context-specific approaches aimed at improving soil health, agrobiodiversity, and ecosystem resilience. In addition to environmental outcomes, the Textile Exchange analysis highlights the importance of livelihoods and indigenous knowledge systems within regenerative approaches. Holistic regenerative systems are recognized as fostering interdependent co-benefits, including enhanced agrobiodiversity, improved water availability and quality, increased climate resilience, and strengthened rural livelihoods.

For the purposes of this study, commonly referenced practices in regenerative systems were identified based on Textile Exchange's *Regenerative Agriculture Landscape Analysis*, and used as reference for a system to qualify as regenerative (see Annex D for details):

- Integrated nutrient management
- Use of organic fertilizer
- Reduced tillage
- Integrated pest management
- No direct land use change (LUC)

The list of practices introduced here is non-exhaustive and intended only to support the operational definition of regenerative systems in this study. A more extensive overview is provided in table D-1 in Annex D. Production systems are considered regenerative if the program either self-identifies as regenerative or is certified under a regenerative program, and if they demonstrate implementation of at least some practices commonly associated with regenerative agriculture mentioned above. It should be noted that "use of organic fertilizer" refers to the application of organic fertilizers but does not require the exclusive use of organic inputs; mineral fertilizers[15] may also be used in combination

13 Cotton programs refer to organized initiatives that set standards or provide frameworks for sustainable cotton production, often including requirements on environmental practices, social criteria, and/or traceability. Examples include the Better Cotton Initiative, REEL Cotton, CmiA, and the U.S. Cotton Trust Protocol (CTP), see also (Textile Exchange, 2024).

14 IFOAM–Organics International, formerly known as the International Federation of Organic Agriculture Movements.

15 In this report, the term "mineral fertilizer" is used (sometimes also referred to as "synthetic fertilizer" for nitrogen products). This includes both industrially produced nitrogen fertilizers and mined/processed phosphorus and potassium fertilizers, to distinguish them from organic fertilizers.

with organic fertilizers within regenerative systems. However, in practice, regenerative systems observed in this study tended to fall into two broad categories:

- Integrated regenerative systems, which may apply synthetic or mineral-based fertilizers and pesticides
- Organic-aligned regenerative systems, which avoid synthetic inputs and typically include additional requirements for management practices that go beyond baseline organic certification (for example, "regenerative organic").

Future studies will benefit from distinguishing between these two approaches. However, in this study, the differentiation between "integrated regenerative systems" and "organic-aligned regenerative systems" was often only possible in hindsight, after reviewing data provided by contributors. Moreover, sample sizes were not consistently large enough to allow for a robust separation of the two categories. Therefore, both approaches are summarized under a single category, "regenerative", in this study.

Ginning is included in the scope of the study (see also section 3.3.1). The development of program-specific cotton datasets is not within the scope for this LCA study. The development of these datasets is currently undertaken by the HIGG MSI Cotton Expert Team led by Cascale (see section 2.2).

Based on an evaluation of relevance in global production (see Annex C) and the outreach of Textile Exchange to facilitate data collection, the following countries are included in the study.

Table 3-1: Geographical scope—cotton cultivation

Country	Abbreviation	Country average	Organic	Regenerative
Brazil	BR	yes	yes (1)	no (2)
China	CN	selected regions (7)	no	no
India	IN	yes	yes	yes
Peru	PE	no	yes (3)	yes
Tanzania	TZ	no	yes (3)	no
Türkiye	TR	yes	yes	yes
US	US	yes	yes	no (6)
Global average (weighted based on production volume) (4)	GLO	yes	yes	no (5)

(1) Low relevance in global production volume but included based on the active engagement of data provider.
(2) Included in the original scope of the study but excluded from the final analysis due to limited engagement from the data provider.
(3) Organic production systems in Peru and Tanzania were included due to their relevance to global organic cotton production; however, the country average (conventional) production systems in these countries were excluded because of their low relevance to global overall cotton production volumes.
(4) It is within the scope of the study to build a global average production dataset from the country average cultivation systems and for organic cotton cultivation systems. The available countries are weighted based on production volume into a global average (see Annex F). However, it needs to be

communicated that the average has to be used with care because relevant production regions are missing (especially for the global average reference system) and because data quality differs for different regions and countries (see section 6.3.1).

(5) No reliable production data is available for weighting into a global average. Additionally, many of the assessed systems were new and covered small sample sizes (see section 4.2.1), so that the data was also not considered robust enough to be aggregated into a global average.

(6) Included in the original scope of the study, but excluded from the final analysis due to limited data availability

(7) Included: Hebei, Henan, Shandong, Shaanxi, Anhui, Hubei, Hunan, Jiangsu, Jiangxi, Gansu.

The approach for data collection in the different regions can be found in section 4.1. Data availability and assessment of representativeness is provided in section 4.2.1. Data quality rating is provided in section 6.3.1.

3.1.2. Recycled cotton

Recycled cotton fibers are defined as a material that has been reprocessed from reclaimed material by means of a manufacturing process and made into a final product or into a component for incorporation into a product (Textile Exchange, 2021). The material recycling process refers to the point in the recycling life cycle when a reclaimed material is processed into a recycled material. This study considers the mechanical recycling of cotton textile waste, using a shredding recycling process for the production of recycled spinnable fiber. Chemical or biological recycling is not considered. The system boundaries of the cotton waste recycling process are from cradle-to-gate, and the functional unit is defined as the production of 1 kg of recycled spinnable fiber. The spinning process itself is excluded.

The study considers three types of cotton waste used in the production of recycled cotton, including:

- Post-industrial yarn waste
- Post-industrial fabric waste
- Post-consumer waste

The study also differentiates between post-consumer waste that has been recycled domestically in the country where the waste was generated, and waste that has been internationally shipped prior to recycling. The results of the study will, therefore, refer to the following four scenarios:

- Post-industrial yarn waste
- Post-industrial fabric waste
- Post-consumer waste (domestic)
- Post consumer waste (international transportation)

The definition of each type of cotton waste is outlined below:

Post-industrial yarn and fabric waste: Also defined as pre-consumer material, this is material diverted from the waste stream during the manufacturing process. Excluded is the reutilization of materials such as rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it (Textile Exchange, 2014).

It is important to note that as the accepted definition of post-industrial waste excludes the reutilization of materials back into the same textile production process, all post-industrial yarn and fabric waste included in the study is considered waste material that is transported and treated in a separate recycling process at a different recycling facility, otherwise it cannot be considered to be recycled.

Post-consumer waste: Material generated by households or by commercial, industrial, and institutional facilities in their role as end-users of the product that can no longer be used for its

intended purpose. This includes returns of materials from the distribution chain (Textile Exchange, 2021).

The outlined definitions of cotton waste types utilized for assessment within this study are taken from Textile Exchange's *Recycled Claim Standard 2.0* (Textile Exchange, 2014) and GRS-202 *Guide to Recycled Inputs Standard* (Textile Exchange, 2021). The global recycling standard (GRS) document also offers technical guidance on mechanically recycled cotton specifications, including output fiber quality (fiber length and yarn count), which could be used to further differentiate types of recycled spinnable fibers; however, quality of output fibers is not considered in the scope of this study. Additionally, differences in textile waste inputs, i.e., fabric construction or weave pattern, which impact the expected electricity consumption of the recycling process, could also be used to further differentiate types of recycled spinnable fibers in future studies.

Based on an expert judgement evaluation of relevance in global production and outreach of Textile Exchange to facilitate data collection, the following countries are included in the study: see table 3-2, below.

Table 3-2: Geographical scope—recycled cotton

Country	**Abbreviation**	**Post-industrial yarn**	**Post-industrial fabric**	**Post-consumer waste** (domestic and international transportation)
Pakistan	PK	yes	yes	yes
Bangladesh	BD	yes	yes	no
China	CN	yes	yes	yes
Türkiye	TR	yes	yes	yes
India	IN	no	no	yes
Global average (1)	GLO	yes	yes	yes

(1) It is within the scope of the study to build a global average production dataset. However, due to a lack of information on the breakdown of global annual production of recycled spinnable cotton fiber to country-specific production volumes, sampled production volumes were not utilized for weighting into a global average given the uncertainty of the representativeness of individual data points. Similarly to cotton cultivation, it needs to be communicated that the average has to be used with care because of the uncertainty of representativeness and because data quality differs for different data providers (see section 6.3.1).

The approach for data collection can be found in section 4.1. Data quality ratings are provided in section 6.3.2.

3.2. Product function(s) and functional unit

Cotton cultivation

In cotton production, seed cotton, sometimes also referred to as raw cotton, or unginned cotton, describes the material harvested directly from the cotton plant. It consists of cotton fibers still attached to the seeds, along with small amounts of leaf, stem, and field debris. Seed cotton must

undergo mechanical processing (ginning) to separate its components before further use. Through the ginning process, seed cotton is separated into:

- Lint cotton: The cleaned and separated fibers, which are spun into yarn and serve as the main input for textile manufacturing
- Cottonseed: The separated seeds, which may be further processed for oil extraction, animal feed, or replanting

In Life Cycle Assessment (LCA) studies, lint cotton is typically treated as the main product of ginning, while cottonseed is considered a co-product requiring appropriate allocation of environmental burdens (see section 3.3.1 for system boundaries and section 3.4 for allocation). In this study, the functional unit refers to:

- The cradle-to-gin gate system for cotton cultivation includes raw material production from field to ginning. The functional unit is 1 kg of lint cotton at the gin gate (excluding packaging)

The function of the product is lint cotton for further processing in the textile industry. Potential differences in fiber quality are not considered in the study.

Recycled cotton

In LCA studies, recycled spinnable cotton fibers are considered the main product of the recycling process, and fluff, filling material, and input cotton waste that do not meet quality requirements and are subsequently sold, require appropriate allocation of environmental burdens (see section 3.3.1 for system boundaries and 3.4 for allocation). In this study, the functional unit refers to:

- The functional unit refers to 1 kg of recycled spinnable cotton fiber (excluding packaging) for further processing at the factory gate. Further processing to yarn or fabric is not included.

Similar to cotton cultivation, recycled spinnable fibers are an intermediate product intended for further processing in the textile industry. Although potential differences in output fiber quality are not considered in the study, it should be reiterated that these differences should be considered when interpreting the results of the study for recycled cotton.

3.3. System boundary

3.3.1. Cotton cultivation (conventional, organic, regenerative)

The study is conducted as cradle-to-gate study from farm to gin, with the following system boundaries:

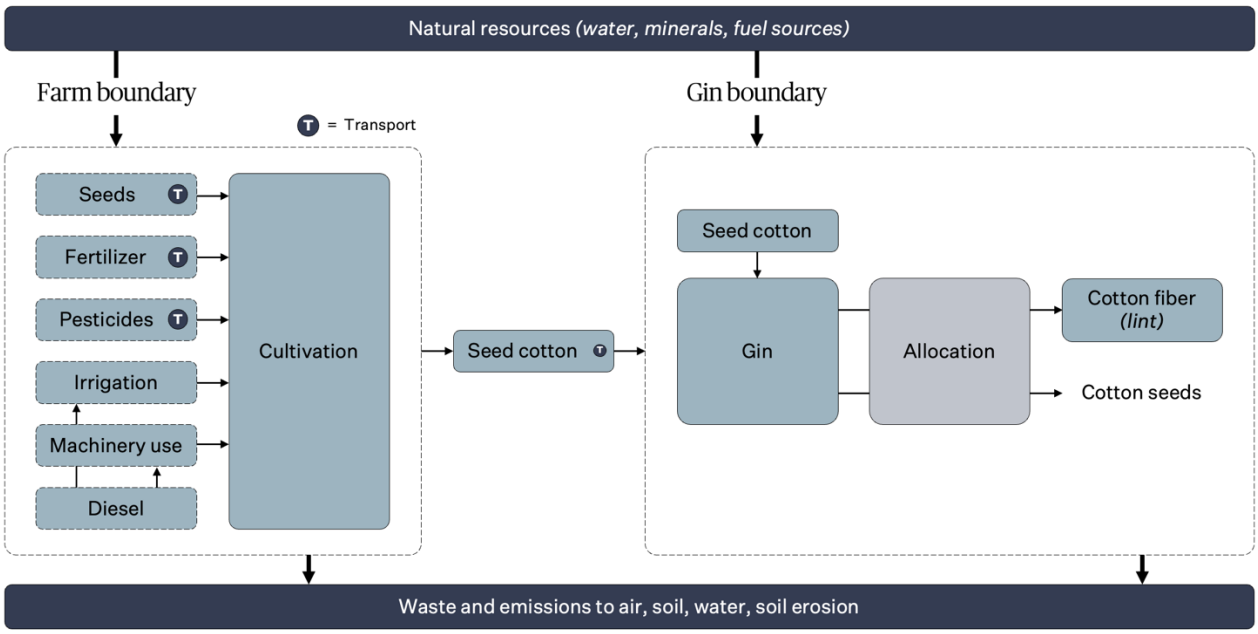

Figure 3-1: System boundaries—cotton cultivation

All material and energy flows required for the two phases of production (cultivation and ginning), as well as all associated waste and emissions, are included in the study. This includes fertilizer and pesticide production as well as field emissions (for example, N_2O), emissions related to fire clearing (i.e., the combustion of biomass remaining on the field from previous cultivation period) (for example, CH_4, SO_2), electricity for ginning, and all transport (fertilizer to the field, seed cotton to gin). An assessment of LUC is included in the scope of the study (statistical LUC used as proxy for direct LUC, see section 4.3.5); however, it was found to be relevant only for Brazil and not for the other regions assessed (see section 4.3.5).

Exclusions

- Draught animals. For the main cotton-producing regions assessed (Brazil, China, Türkiye, and the US), cotton farming is highly mechanized, and the contribution of draught animals is insignificant. In India and Tanzania, draught animals are still used by smallholder farmers, particularly for soil preparation and transport activities; however, their use represents a small share of total farm operations and is highly variable. In Peru, draught animals may still be employed in some small-scale organic or traditional farming systems, but their use was not reported in data collection. Where applicable, draught animals (for example, oxen) are typically used once per crop season, mainly for ploughing, and are shared across multiple crops and transport activities. Additionally, soil preparation is often performed by service providers, meaning an individual animal's use on cotton fields accounts for only a minor fraction of its overall useful life. This multipurpose role makes the allocation of environmental burdens from the livestock system to cotton cultivation both technically difficult and inconsistent with attributional modeling best practices. Therefore, the contribution of

draught animals to the environmental impacts of cotton cultivation is considered marginal and has been excluded from the system boundary. The exclusion is also aligned with the Cascale Cotton LCA methodology.

- End-of-life of ginning waste, i.e., considered to leave the product system burden-free and without any benefits to the main product. Gin waste consists of broken seeds, fibers, and plant remains (residues). In the worst case, it could be considered as waste that requires further treatment under specific consideration of pesticide remains. On the other hand, it is occasionally returned to the land as organic fertilizer, sold to horticulture farms to improve physical soil conditions, or used for composting. Therefore, attributing no burdens to the gin waste is a neutral approach, neglecting a small potential environmental impact along with a similarly small environmental benefit (fertilizer use). The exclusion is also aligned with the Cascale Cotton LCA methodology.
- Capital equipment and the maintenance of support equipment due to their expected minimal contribution and the large difficulty in measuring[16]. The exclusion is also aligned with the Cascale Cotton LCA methodology.
- Human labor is excluded from this study in alignment with common LCA practice and ISO 14044 guidelines. Labor inputs, such as manual field work, are generally considered to have a negligible contribution to the overall environmental impacts of agricultural production, particularly in comparison to material and energy flows. Furthermore, the environmental burdens associated with human metabolism (for example, food consumption, respiration) are outside the system boundaries defined for product-related LCA studies. Therefore, human labor is not included in the life cycle inventory or impact assessment (please refer to section 7 for human rights impacts).
- Provision impacts of organic fertilizer. In the baseline scenario of this study, the provision impacts of organic fertilizer are excluded. This is because organic fertilizers, such as manure and compost, are treated as residual products, i.e., waste outputs from other systems, rather than co-products of animal or waste management systems. As such, they are assumed to enter the cotton system without upstream environmental burdens, consistent with common LCA practice and the Cascale Cotton LCA methodology. Only emissions from their application in the field are included. However, a scenario analysis is conducted to assess the potential impact if provision burdens were to be included (see section 4.3.3 and section 5.2.1).
- Packaging materials at gin (for example, bale wrap, bale ties) were excluded due to negligible contribution, lack of consistent data, and to avoid overlap with downstream supply chain modeling.
- Indirect LUC, excluded due to lack of consensus on calculation approaches, methodological complexity and large uncertainties, see section 4.3.5.

16 (Frischknecht, Althaus, Bauer, & Doka, 2007) showed that infrastructure in agricultural supply chains can be relevant in certain impact categories (PED, toxicity). However, the assessment is based on European conditions, i.e., under the assumption that large machinery is used, such as a combine harvester. The environmental impact of providing such a machine can only be allocated to a relatively short period of use, resulting in comparatively high impacts per hour the machine is used. However, machine harvesting will only be applicable to a small fraction of the assessed farming systems. Also, contract harvesting might be more applicable than in the study for Frischknecht by now, limiting the impacts even further. The impact of the provision of other capital goods, such as buildings, is also expected to be low. For example, storage takes place at producer groups, so the scaling effect will result in very low impacts per kg final product. These considerations in relation to the relatively large effort in data collection required to assess the impact capital goods in the different production regions justify the exclusion of infrastructure.

Table 3-3: Summary of inclusions and exclusions (cotton cultivation)

Included	Excluded
✓ Fertilizer and pesticide production ✓ Irrigation and water consumption ✓ Energy consumption for irrigation ✓ Transport ✓ Seed and planting material inputs ✓ Field emissions ✓ Emissions from fertilizer and pesticide application ✓ Field clearing, biomass burning ✓ Plastic mulching (only applicable to cultivation systems in China) ✓ Direct LUC	× Draught animals × End-of-life of gin waste × Capital equipment × Human labor × Provision impacts of organic fertilizer (included in scenario) × Packaging at gin × Indirect LUC

Time coverage, technology coverage and geographical coverage

The aim is to cover data from at least three cultivation seasons to limit the influence of seasonal variability. The latest available data is used where applicable. If primary data is available but does not refer to the most recent cultivation season or does not span three years, this is not a reason for exclusion but is reflected in the time representativeness score of the DQR. Secondary data is also assessed for time representativeness. For both primary and secondary data, a 10-year threshold is applied, i.e., no data older than 10 years is used in the study[17]. Technological and geographical coverage is discussed in section 3.1.1 on definition of product systems.

3.3.2. Recycled cotton

The study is conducted as a cradle-to-gate study from the point of waste to the factory gate, where the recycled spinnable fiber product leaves for spinning into yarn. Post-industrial yarn, post-industrial fabric, and post-consumer cotton waste require different processing steps for the recycling process. Descriptions of their system boundaries are provided in figure 3-2–figure 3-4, below.

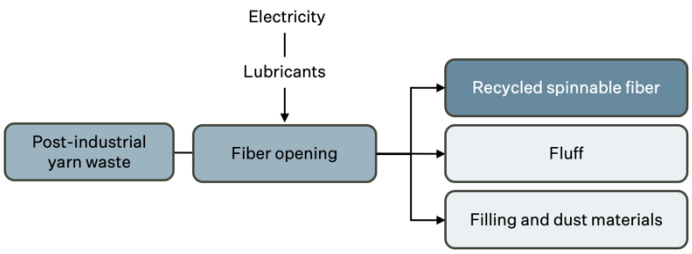

Figure 3-2: System boundaries—post-industrial yarn waste

17 Ten years might be considered a long period to include data, but it should be noted that many statistical data is only published with long delays. For example, statistical data on fertilizer use by country from the international fertilizer association was published in 2022 for the reference year 2018, and the next updated is only expected five years later.

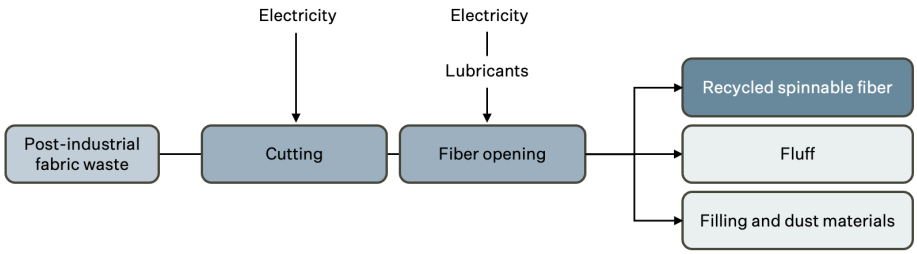

Figure 3-3: System boundaries—post-industrial fabric waste

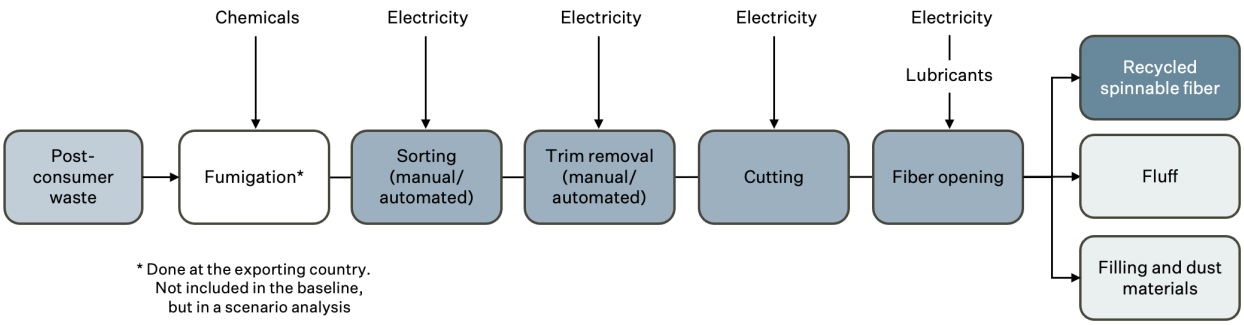

Figure 3-4: System boundaries—post-consumer waste

All energy and material flows required for each processing step of all cotton waste types, as well as associated process waste and emissions, are included in the study. Exclusions include auxiliary chemicals used in the pre-treatment of cotton waste to improve the quality of fibers (cut-off), as the output fiber quality is not considered in this study, as well as fumigation of international post-consumer waste; however, this is explored in a scenario analysis. Energy inputs, including electricity generation (grid, natural gas, and photovoltaic), fuels (diesel and heavy fuel oil), transportation, and material inputs, including water, packaging, and lubricants, are included in the baseline scenarios. Additionally, treatment of process waste and emissions, such as particulate matter and water vapor, was considered.

Exclusions

- Fumigation: Fumigation of internationally shipped post-consumer waste was cut off due to negligible impacts; however, it was investigated as part of a scenario analysis in section 5.2.11.
- Auxiliary chemicals: In the treatment of cotton waste, auxiliary chemicals such as washing aids or alkaline chemicals can be used in pretreatment processes. However, as the study does not consider the quality of recycled spinnable fiber output, auxiliary chemicals used to improve the quality of output fibers have been excluded.
- Washing and drying: Conventional washing and drying of post-consumer waste is extremely uncommon as part of the recycling process and is therefore cut off. However, given the potential significant Impacts of washing and drying it was investigated as part of a scenario analysis in section 5.2.10.
- End-of-life treatment of by-products, i.e., fluff and filling/dust material: Leaves the system burden free as these were identified by most data providers as valuable by-products that were sold. However, in some cases, if disposed of externally, modeling as leaving the system

burden-free would result in a small environmental impact not accounted for, although this is assumed to be of negligible contribution.

- Capital equipment and the maintenance of support equipment due to their expected minimal contribution and the large difficulty in measuring.
- Human labor: same reasoning for exclusion as described for cotton cultivation applies (see section above and refer to section 7.3 for human rights impacts).

Table 3-4: Summary of inclusions and exclusions (recycled cotton)

Included	Excluded
✓ Electricity and fuel inputs ✓ Packaging (cotton textile waste input and recycled spinnable fiber output) ✓ Lubricants ✓ End of life of process waste ✓ Transportation (from tier 1 supplier) ✓ International transportation ✓ Process emissions	× Fumigation (post-consumer) × Washing and drying (post-consumer) × Auxiliary chemicals × Packaging (auxiliaries) × End-of-life of by-products × Capital equipment × Human labor

In alignment with the non-comparative, attributional scope of the study, no upstream impacts or downstream credits are allocated to the waste inputs. Instead, the modeling follows a cut-off approach, in which the input waste enters the system burden-free, and no environmental credits are assigned for offsetting virgin material production or replacing alternative waste treatment options. It is important to clarify that this modeling decision does not constitute a general methodological recommendation but reflects the boundaries and purpose of the current study: to provide stand-alone inventory data for recycled cotton fibers. The intention is not to perform a full cradle-to-cradle or circularity assessment, but to isolate and document the impacts of the recycling process itself. The Circular Footprint Formula (CFF) outlined in the PEF provides an approach regarding how burdens and credits can be handled in the End-of-Life (EoL) phase of a product method (European Commission, 2021). However, for the reasons outlined above, it is not applied within this study. Users of this data are invited to incorporate the inventory datasets into full cradle-to-grave assessments, including downstream processing and EoL scenarios. In such cases, the use of allocation approaches aligned with the PEF method, such as the CFF, may be appropriate, subject to the scope of the respective LCA study. Users should be aware that such modeling choices can substantially influence the outcome and interpretation of comparative LCA studies and are outside the scope of the current assessment.

Time coverage, technology coverage, and geographical coverage

For time coverage, the aim is to take an average of annual production values from the most recent reference year possible. If primary data is available but does not refer to a full year or has an older reference year, this is not a reason for exclusion but is reflected in the time representativeness score of the DQR.

For technological coverage, classification of available cotton recycling technologies, including their respective market share and energy efficiency, is not readily available. However, where possible, available LCI data was utilized to assess reported electricity and transportation primary data against benchmarks for the technological representativeness score of the DQR.

For geographical coverage, the breakdown of global recycled cotton production into country-specific production volumes was not readily available. However, to ensure geographical representativeness, major production countries were identified through expert judgement and existing relationships

between Textile Exchange and cotton recycling companies. The number of data providers within the global average for each cotton waste type was reflected in the geographical representativeness score of the DQR.

3.4. Allocation

3.4.1. Cotton cultivation

When a system yields more than one valuable output, as is the case with cotton production (seed and lint following ginning), a decision must be made regarding the allocation of impacts. Allocation is defined as "partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO 14040:2006). This topic has been thoroughly addressed in the Cascale Cotton LCA methodology (Cascale, 2024b) and, therefore, will not be repeated in detail here.

This study follows the default allocation approach recommended by the Cascale Cotton LCA methodology (Cascale, 2024b), namely, economic allocation based on the five-year average price data. The resulting allocation split is presented in Table 3-5.

Table 3-5: Allocation at gin (Cascale, 2024b)

Process	Main product and co-products	Allocation factor	Source
Ginning	Cotton lint (main product)	82.7%	(ICAC, 2024)
	Cottonseed*	17.3%	
	Gin by-products**	0%	

* The LCIA results of cottonseed are not provided in the study.

** Gin by-products are excluded from the model (see section 3.3.1).

3.4.2. Recycled cotton

Similar to cotton cultivation, recycled cotton is also a multi-output system with valuable outputs including the recycled spinnable fiber (main product), and fluff and filling material (by-products). Furthermore, some post-consumer waste recyclers sort and sell purchased cotton waste if it does not meet their quality requirements. Unlike the recycled spinnable fiber, fluff, and filling material, this valuable by-product leaves the product system following manual sorting and is only subject to upstream impacts, such as transportation.

This study utilized a conservative assumption to allocate 100 percent of the impacts to the main product. Following this, a sensitivity analysis was also utilized to understand the potential influence of the chosen allocation approach, in this case, economic allocation, on the results of the study. The economic allocation utilized average price data reported by data providers for each of the recycled cotton waste types, and details, can be found in section 5.3.2 and Annex E2.

3.5. Cut-off criteria

No explicit cut-off criteria were established a priori for this study. As outlined in section 3.3, the system boundary was defined based on the goal and scope of the study, with the intention to capture

all environmentally relevant flows. All available data for energy and material inputs within the defined system boundary were included in the inventory model. In cases where specific LCI data was unavailable, proxy datasets were applied using conservative assumptions to avoid underestimation of potential impacts. In accordance with ISO 14044:2006, certain flows, for example, selected auxiliary chemicals used in cotton recycling, were excluded from the system boundary due to their assumed low environmental relevance. These exclusions are not expected to significantly affect the overall conclusions of the study. Exclusions are clearly documented in section 3.3. The use of proxy data and all background data selections are documented in Chapter 4.

3.6. Selection of LCIA methodology and impact categories

Various impact assessment methodologies are commonly applied in LCA studies, for example, Environmental Footprint v3.1 (EF 3.1), CML (Centre of Environmental Science at Leiden), or ReCiPe. The scope of this study includes the full set of EF 3.1 impact categories, as well as the additional categories recommended by Cascale for use in the Higg Material Sustainability Index (Higg MSI) (Cascale, 2024a). This means that, in total, 18 impact categories need to be assessed. However, not all of these are equally relevant to the systems studied. For instance, some impact categories may have limited applicability to agricultural processes, be largely influenced by background data, or show high correlation with other categories.

To support transparent communication and focused interpretation, three priority levels have been defined for the impact categories, as presented in Table 3-6 below.

Table 3-6: Classification of impact categories in this LCA study

Priority level	Purpose	Presentation format
Key impact categories	Core environmental indicators, central to interpretation and conclusions	Full LCIA results in main body of the report, contribution analysis included, detailed interpretation
Supplementary impact categories	Provide additional context and transparency, to complete HIGG MSI indicator dataset	Detailed LCIA results in annex including contribution analysis, brief interpretation summary
Complete EF 3.1 impact set	Ensure methodological compliance and transparency	Summary table in annex, no contribution analysis or interpretation

Table 3-7 lists the key impact categories that are included in the main body of the report. These categories are considered most relevant for interpreting the environmental performance of cotton cultivation and recycling systems. It should be noted that blue water consumption (included in key impact categories) and nitrogen balance (supplementary impact category) are, in a strict sense, inventory-level indicators. However, they are included under results because they are generated during the impact assessment phase, rather than being directly collected as input data, and these indicators provide valuable interpretive context for the impact assessment categories that directly depend on them, namely climate change, eutrophication, and acidification in the case of nitrogen balance, and water scarcity in the case of blue water consumption.

Table 3-7: Key impact categories (included in main body of the report)

Impact category	Description	Unit	Method
Climate change (global warming potential)	A measure of greenhouse gas emissions, such as CO_2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the Earth, increasing the natural greenhouse effect. This may, in turn, have adverse impacts on ecosystem health, human health, and material welfare.	kg CO_2 equivalent	IPCC AR6 (EF 3.1)
Eutrophication (terrestrial, freshwater, marine)	Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems, increased biomass production may lead to depressed oxygen levels because of the additional consumption of oxygen in biomass decomposition.	kg phosphate equivalent	CML 2016 (Higg MSI)
Blue water consumption	A measure of water withdrawn from a watershed that is not returned (for example, evaporation or incorporation into the product)[18]. This is not an indicator of environmental impact without the addition of information about regional water availability (i.e., water resources depletion/scarcity, see Table 3-8).	kg of water	inventory
Ecotoxicity	A measure of toxic emissions that are directly harmful to the health of the environment.	comparative toxic units (CTUe)	EF 3.1 (ecotoxicity)

The study includes an evaluation of ecotoxicity using the EF 3.1 methodology, which is based on the USEtox™ characterization model (with some modifications[19]). USEtox is currently the best-available approach to evaluate toxicity in LCA and, therefore, part of the EF 3.1 impact methods. However, it should be noted that the uncertainty for these assessments will be significantly higher than for the other impact categories noted above. In context of the Product Environmental Footprint (PEF), the Joint Research Center of the European Commission (JRC) provides robustness factors[20], used in weighting to aggregate midpoint impact categories into a single score, (Cerutti, Pant, & Sala, 2018). Ecotoxicity has a robustness factor of 17% compared to 87% for climate change or 67% for acidification. Given the limitations of the characterization model, results need to be interpreted with particular care for this impact category, as stated above.

18 Irrigation water applied is typically considered to be fully consumptive.

19 Modifications refer to some of the input data used in the calculation of the USEtox characterization factors. Most notable modification is that the characterization factors for heavy metals are much lower in EF datasets compared to the original USEtox factors. See (Saouter, et al., 2018) for details.

20 In the PEF method, robustness factors are weighting coefficients applied to impact categories when aggregating them into a single score. They reflect the relative confidence in the scientific basis, modeling robustness, and relevance of each impact category, with lower robustness factors down-weighting categories where uncertainty is higher.

Table 3-8 lists the Supplementary Impact Categories, which are included in Annex G to provide additional context and transparency, and to ensure completeness of the Higg MSI indicator dataset.

Table 3-8: Supplementary impact categories (detailed assessment in the Annex)

Impact category	Description	Unit	Method
N Balance[21]	Calculated as the difference between total nitrogen applied (via fertilizers) and the nitrogen taken up by the crop. The result may be a surplus or a deficit (see also section 4.3.2 and Annex G.1.1).	kg N per ha	Inventory
Acidification potential	A measure of emissions that cause acidifying effects to the environment. The acidification potential (AP) is a measure of a molecule's capacity to increase the hydrogen ion (H^+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline, and the deterioration of building materials.	moles H^+ equivalent	EF 3.1
Abiotic Resource Depletion Potential (fossil)	Abiotic Depletion Potential (ADP) is a measure for the use of non-renewable energy carriers, comparable to the Cumulative Energy Demand (CED) of fossil fuels.	MJ	CML 2016 (suggested by Cascale)
Green water consumption*	Green water refers to the precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation. Green water consumption refers to the actual evaporation from green-water resources.	m^3 of water	Inventory[22]
Water resources depletion/scarcity	An assessment of the potential to deprive other users of water, calculated as blue-water consumption multiplied by regional characterization factors (AWARE). It accounts for the net intake and release of freshwater across the product system, while considering differences in water availability between regions. It should be noted that AWARE is not a direct scarcity metric, but a measure of potential user deprivation.	m^3 world equivalent	EF 3.1 (water use), based on AWARE characterization factors
Land occupation*	The amount of land occupied for a certain time period to produce a product.	ha/year	inventory

*For recycled cotton, green water consumption and land occupation are reported solely for consistency across all cotton systems. It does not result from the recycling process itself but is entirely attributable to background processes, for example, biomass contributions in electricity grid mixes used in upstream supply chains.

21 N balance is only applicable to cotton cultivation and not to recycled cotton.

22 Green water consumption is usually not measured. These values are, therefore, always modeled with a lot of uncertainty. The University of Twente has published updated datasets on blue and green water use for important crops with global coverage (Mialyk et al., 2023). Their green water consumption values are multiplied with the respective crop yields in this study, not differentiating crop systems.

It should be noted that the above impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions were to (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the functional unit (relative approach). LCIA results are, therefore, relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

No grouping or further quantitative cross-category weighting is applied.

3.6.1. LCA+ approach—soil health

There is an ongoing debate on how best to assess the impacts of agriculture on soil health. The focus of this debate is on changes in soil carbon stocks, as there are high hopes that soil carbon sequestration in agricultural soils can provide a significant contribution to climate change mitigation. The discussion around soil carbon sequestration (and soil health) is not summarized in this study. Useful references in this regard are Textile Exchange's *Biogenic Carbon* guidelines (Textile Exchange, 2024a) and Textile Exchange's *Regenerative Agriculture Landscape Analysis* (Textile Exchange, 2022).

In the recently published *Draft for Testing and Review of the Land Sector and Removals Guidance* from the GHG (Greenhouse Gas) protocol (GHG Protocol, 2022), the assessment of soil carbon sequestration is discussed under "removals". The requirements to account for such GHG removals are quite strict:

- **Ongoing storage:** ongoing storage of claimed removals is monitored and documented, and losses of stored carbon from relevant carbon pools can be detected (Scope 1 and 3).
- **Traceability:** it must be ensured that removals are directly related to the activity under the control of the reporting organization.
- **Primary data:** only account and report for removals if the changes are accounted for using primary data specific to the land carbon pools where carbon is stored (measurements, model-based, or remote sensing).
- **Uncertainty:** increase in assessed carbon pools is statistically significant based on quantitative uncertainty estimates.
- **Reversal accountings:** companies shall account for and report net land carbon stock losses of previously reported removals.

The guideline does not provide a list of methods/tools to be used, only a question catalogue. However, it should become clear that the current study will not be able to provide assessments of changes in soil carbon stocks that would be robust enough to allow removals accounting under the GHG protocol.

Nevertheless, the potential increase in soil carbon stocks is one of the main possible benefits of regenerative practices such as reduced tillage, increased crop rotation, or increased use of organic fertilizer. Therefore, such impacts should be assessed at least on a screening level in the study to identify the removal potentials.

Therefore, this study provides an assessment of removal potentials based on the IPCC Tier 1 approach (see section 5.5.1). It should be reiterated that this analysis addresses sequestration potentials, and the assessment is currently not robust enough to include these removals in the final impact assessment results, or to claim these removals in reporting.

Soil health is more than just the carbon stocks (Textile Exchange, 2022). During the scoping phase of this study, it was decided to use soil carbon as a proxy indicator for soil health. A more detailed assessment of soil health parameters was considered but was not feasible within the scope, timeline, and methodological framework of this study[23].

3.6.2. LCA+ approach—biodiversity

During the scoping phase of the project, various approaches for assessing biodiversity were considered. However, it became evident that no widely accepted methodology is currently available. Methods such as the approach used in the last LCA on *Cotton made in Africa* (CmiA) (Fehrenbach, et al., 2019) or the Biodiversity Loss Potential metric implemented in LANCA, were discussed. These approaches were deemed to introduce considerable complexity to the study, with limited added value, particularly given their limited acceptance beyond specialized LCA expert communities. Consequently, it was decided not to conduct a separate quantitative assessment of biodiversity impacts. Instead, impacts were assessed indirectly by interpreting existing environmental impact categories, such as land use change, eutrophication, pesticide use, and water consumption as proxy indicators (see section 7.2). No attempt has been made to aggregate these indicators into a single biodiversity score. It should be noted that, while reductions in these pressures are generally expected to lower biodiversity risks, actual outcomes depend on local conditions, and no direct one-to-one- correlation can be assumed. Some potential benefits of specific farming practices are highly site-specific and develop gradually over time and may, therefore, fall outside the resolution of this LCA. Since the LCA+ approach primarily relies on screening methods, more granular and site-specific assessments may be necessary to fully capture long-term and localized environmental impacts and benefits.

3.6.3. LCA+ approach—social impacts

A social or human rights impact assessment is considered an important aspect of the LCA+ approach by all involved stakeholders. However, it was also highlighted that this is a very sensitive subject, and it will not be possible to rely on estimates or proxies for the purpose of quantitative assessments. Therefore, it was agreed to develop a qualitative screening approach that does not allow for any claims or external communication but should help to explore potential areas of concern and serve as a hot-spot analysis. Since the human rights impact assessment does not follow the same approach as the environmental impact assessment, details on the approach are provided separately in section 7 and Annex B.

The LCA+ approaches and results are presented in a separate section (section 7), to avoid confusion with the main impact assessment, to make the methodological limitations explicit, and to highlight their role as exploratory analyses rather than definitive quantifications.

23 It should be noted, though, that "land use" is one of the mandatory impact categories under EF 3.1. Within the framework of the calculation of the PEF, the LANCA method is proposed by the European Commission to assess land use impacts on soil. Land use type-specific characterization factors are used for the land use impact categories: erosion resistance, mechanical filtration, physicochemical filtration, groundwater regeneration, and soil carbon sequestration. LANCA results are provided in Annex F as part of the complete assessment of EF 3.1 methods, but are not assessed in detail.

3.7. Type and format of the report

In accordance with the requirements of ISO 14044 (ISO, 2006), this document aims to report the results and conclusions of the LCA completely, accurately, and without bias to the intended audience. The results, data, methods, assumptions, and limitations are presented in a transparent manner and in sufficient detail to convey the complexities, limitations, and trade-offs inherent in the LCA to the reader. This allows the results to be interpreted and used in a manner consistent with the goals of the study.

3.8. Software and database

The LCA models were created using Sphera's LCA FE software system for life cycle engineering, developed by Sphera Solutions Inc. Sphera's MLC LCI database (Version 2025.1) provides the life cycle inventory data for several of the raw and process materials relevant for the background system.

3.9. Technical advisory group and critical review

If results of an LCA are to be communicated to any third party (i.e., interested party other than the commissioner or the practitioner of the study) or conducted to be disclosed to the public, this affects the interests of competitors and other interested parties. In such cases, the standards ISO 14040:2009 and 14044:2006 require a critical review. The reviewers will have the task to assess whether:

- The methods used to carry out the LCA are consistent with the international standards ISO 14040 and ISO 14044.
- The methods used to carry out the LCA are scientifically and technically valid.
- The data used is appropriate and reasonable in relation to the goal of the study.
- The interpretations reflect the limitations identified and the goal of the study.
- The study report is transparent and consistent.

Table 3-9 provides the name and affiliation of the review panel for this study.

Table 3-9: Review panel

Name	Affiliation
Joel Mertens*	Cascale, Director of Higg Product Tools
Jesse S. Daystar	Triangle LCA
Allan Williams	Executive Director, Cotton Research and Development Corporation (CRDC)
Miguel Gómez-Escolar Viejo	Better Cotton Initiative, Head of Monitoring, Evaluation and Learning

*Review chair

The Critical Review Statement can be found in Annex A.

Technical Working Group

The critical review panel has a very formal function under the ISO requirements. Since the study has an ambitious scope, an additional expert group was installed to guide and supervise the project, named the technical working group. The goal of the technical working group was to provide additional expertise, especially regarding regional specific aspects, to review data and methodological approaches.

Table 3-10: Technical working group

Name	Company
João Paulo Saraiva Morais	EMBRAPA, researcher
Mitsuya Inagaki	Independent expert
Edwin Keh	Independent expert
Payal Luthra	WWF Global, Global Apparel and Textiles Lead
Ruud Schute	Organic Cotton Accelerator (OCA), Program Director
Murli Dhar	WWF-India, Director, Sustainable Agriculture Program
Rajeev Baruah	Beetle Regen/consultant

4. Life Cycle Inventory Analysis

4.1. Data collection procedure

The following table provides an overview of the production systems covered in the study, the data collection approach, and the number of data providers. Details on the respective data collection approaches are presented in the following sections.

Table 4-1: Data collection approaches (cotton cultivation)—number of data providers in brackets

Country	Country average	Organic	Regenerative
Brazil	Secondary	Primary (1)	No data available****
Selected regions of China***	Secondary	No data available	No data available****
India	Primary (3)	Primary (5)	Primary (4)
Peru	Not included in scope	Primary (1)	Primary (1)
Tanzania	Not included in scope	Primary (2)	Not included in scope
Türkiye	Secondary	Primary (2)	Primary (4)
US	Primary/secondary (1) *	Primary (1)	No data available****
Global**	Average based on country datasets	Average based on country datasets	Not applicable (insufficient data for global aggregation)

* Combination of US survey report (Bayramova, et al., 2024), and survey data from NASS, for details see Table 4-9
** See Annex F
*** For regions included, see Table 3-1
**** No data available indicates that the production system was within the study scope, but either no organization could be contacted to provide data, or the data obtained was insufficient for inclusion

Table 4-2: Data collection approaches (recycled cotton)—number of data providers in brackets

Country	Post-industrial yarn waste	Post-industrial fabric waste	Post-consumer waste
Pakistan	Primary (3)	Primary (4)	Primary (2)
Bangladesh	Primary (2)	Primary (2)	No data available
China	Primary (1)	Primary (1)	Primary (1)
Türkiye	Primary (3)	Primary (2)	Primary (1)
India	No data available	No data available	Primary (1)
Global	Primary (9)	Primary (9)	Primary (5)

4.1.1. Cotton cultivation

The most important data points used in this study to conduct the impact assessment of cotton cultivation systems include:

- Land use change (land use in the last 20 years)
- Fraction of farmers burning crop residues
- Seed input
- Yield
- Total N, P, K inputs and fertilizer type (including organic)
- Water and energy used for irrigation
- Pesticide use
- Machinery use and fuel consumption[24]
- Transport distance to the gin
- Energy use at the gin
- Seed and lint yield at gin
- Regenerative practices (list, see section 3.3.1)

The data points were compared against the data collection templates provided as part of the Cascale Cotton LCA methodology (Cascale, 2024b), and it was found that all data points requested as part of the Cascale method are covered in this study.

Primary data

According to ISO 14044, primary data (collected directly from the processes under study) are distinguished from secondary data, which are derived from literature, databases, statistical records, or other indirect sources. In LCA practice, up-to-date and representative primary data are generally considered to offer the highest data quality, a distinction that is formalized in widely used data-quality rating (DQR) frameworks (see also section 6.3 and Annex C). However, it should be noted that primary data is not necessarily more representative of a system if the sample size or coverage is limited. In some cases, well-documented and broadly representative secondary datasets may provide a more reliable basis for assessment.

24 Tillage practices were also included in the data collection (see Annex H), classified in alignment with definitions from IPCC (2006):

Full tillage: Substantial soil disturbance with full inversion and/or frequent within-year tillage operations, leaving less than 30% of the surface covered by residues at planting.

Reduced tillage: Shallow tillage operations without full inversion, typically leaving more than 30% surface coverage by residues at planting.

No-till: Direct seeding without primary tillage and only minimal disturbance in the seeding zone; herbicides are typically used for weed control.

While respondents were provided with these definitions, uncertainty may persist in the reported tillage classifications due to differing regional practices and respondent interpretation. The influence of tillage practices on environmental impact categories is generally indirect, primarily through effects on soil erosion (with consequences for eutrophication, see Annex H) and on fuel use (which is assessed separately). Therefore, uncertainties in tillage classification are not considered to substantially affect the robustness of the environmental impact assessment. A scenario assessing the influence of tillage on potential soil carbon sequestration is provided in section 7.1; however, this scenario compares full tillage with no tillage as an either/or option and does not incorporate the adoption rates reported by the data providers.

While primary data is usually preferred for its representativeness and reliability, obtaining such data for global cotton production presents considerable challenges. Comprehensive primary data collection would require surveying thousands of farmers across diverse countries, cultivation systems, and agroecological zones. To ensure representativeness, data would also need to be collected over multiple years to capture seasonal variability and long-term agronomic trends. These requirements involve significant time and resource commitments, and only a limited subset of such efforts could realistically be accommodated within the scope of this study.

At the same time, there was a good reason to assume that a substantial amount of primary data collection was already ongoing within the cotton sector, through sustainability initiatives, certification schemes, and research collaborations. The study, therefore, aimed to leverage this existing data infrastructure to the fullest extent possible. A systematic evaluation of available data—both published and unpublished—was carried out. In addition, relevant institutions and stakeholders were engaged to obtain access to existing primary datasets or to validate the use of secondary data and related assumptions.

Where primary data was unavailable or incomplete, secondary data was incorporated as supplementary information. All data sources were assessed using a structured DQR methodology, based on criteria including technological, geographical, and temporal representativeness, completeness, and methodological consistency. Limitations related to the use of secondary data are transparently documented in the corresponding DQR scores. The cultivation data used in this study was provided directly by participating organizations and is, therefore, self-reported. Internal plausibility checks were conducted by the project team, the Technical Advisory Group, and the independent critical review panel, but the data has not been externally audited or independently verified.

The following organizations provided primary data for cotton cultivation:

- **Brazil:** EMBRAPA
- **India:** Arvind, Welspun, CottonConnect, Suminter, India Organics, Chetna Organic, Organic Cotton Accelerator (OCA), Pratibha Syntex, Materra
- **Peru:** Bergman Rivera
- **Tanzania:** Aid by trade foundation
- **Türkiye:** Akasya Ltd, Egedeniz Textile, WWF Türkiye, SÖKTAŞ
- **US:** Cotton Incorporated, King-Mesa Gin

Data availability and outreach to relevant institutions vary across countries (see also section 4.2.1 on representativeness and Table 4-4). It was not possible to obtain high-quality primary data for all product systems, which led to certain restrictions and lower DQRs in some cases (see section 6.3.1).

Farming systems are complex and diverse. Cotton farming systems significantly differ based on factors such as agroclimatic zones, farm size, irrigation practices (irrigated vs. non-irrigated), the use of genetically modified organisms (GMO vs. non-GMO), and sociocultural contexts. In cases where primary data was collected, it remained challenging to ensure that the most relevant production systems are covered.

Typically, in extensive primary data collection efforts, stratification is employed to ensure that data from all relevant production strata is adequately captured. Stratification involves subdividing the broader population into subgroups based on characteristics such as region, irrigation practices, or production methods. However, since no new primary data collection on the farm level was initiated for this study, implementing a robust stratification strategy proved challenging.

To address this issue indirectly, an attempt was made to cover some of the climatic and socio-economic variabilities by differentiating the major cotton production regions[25]. However, this proved to be difficult due to the structure of the data provided and incomplete reference data.

Despite these challenges, the assessment of representativeness indicated that the sampled production volumes were substantial enough to ensure representativeness at the country level in most cases. Main production regions were predominantly included within the datasets, although the specific representativeness of each sub-region or stratum could not always be clearly assessed. Further details on the assessment of representativeness can be found in section 4.2.1.

Given that the primary goal of the study is to provide country-average reference data, specific comparisons between strata, such as irrigated versus non-irrigated, or GMO versus non-GMO systems, were beyond the scope of this assessment. Consequently, country averages were deemed appropriate for the purpose of this study, provided these averages accurately reflected true national conditions rather than being biased toward specific production systems. However, ensuring that these country averages truly represent national conditions remained challenging, particularly given the limitations identified regarding the ability to measure detailed stratification and representativeness comprehensively (see also section 6.2).

In cases where multiple data providers contributed data for a specific cultivation system, the results were aggregated into a country average, weighted by the represented production volume. When data providers supplied information for more than one cultivation season (ideally a multi-year average covering at least three years), results were first averaged per data provider before being aggregated to the country level based on their average production volume. Production volumes were calculated as yield multiplied by the represented area. The aggregation followed a proportional weighting approach, where each dataset was weighted by its share of the total reported production volume. No additional adjustments were applied to reflect geographic location or national production distributions, as this information was not consistently available and would have introduced further uncertainty.

Reported fertilizer products from farm-level data collection were mapped to fertilizer types available in Sphera's Agricultural LCA model. This mapping ensures consistent representation of nutrient inputs, emission factors, and production impacts across all systems. Where reported fertilizer formulations differed in nutrient content from dataset defaults, correction factors were applied to adjust application rates so that the effective nutrient inputs remained accurate. A detailed description of the fertilizer mapping logic and correction factor calculation is provided in Annex M.

The inventory data as reported in this study (see section 4.2.1) was reviewed by the technical advisory group, including local experts, and by the critical review panel (see section 3.9) to assess plausibility. The different levels of data availability are reflected in the data quality rating of data points and the complete dataset (see section 6.3.1 on data quality rating).

Compilation of secondary data for cotton cultivation

If no primary data was available, meaning neither already existing from external sources nor newly collected within the scope of this study, secondary data was used instead. Only country averages for Brazil, Türkiye, and the data for selected regions of China, are completely based on secondary data, see Table 4-1. Secondary data is also used to fill data gaps in primary data; these cases are referenced in the respective inventory tables (see section 4.2.2). When using secondary data, preference was given to statistical data from reliable and consistent data sources (for example,

25 An example of this approach can be found in the Cotton Incorporated LCA from 2016 (Cotton Incorporated, 2016).

national or international agricultural statistics) over single data points (for example, individual values from research papers). Table 4-3 below provides an overview of the approaches used to compile secondary data for various relevant model input parameters.

Table 4-3: Secondary data compilation approach for cotton cultivation (used Brazil and Türkiye country averages)

Aspect	Approach	Reference
Yield	Used ICAC lint yield and ICAC lint output at gin to calculate yields of raw seed cotton (two years average)	ICAC, cotton productivity, lint yield (kg/ha) (ICAC, 2024)
Fertilizer application rate	Used ICAC data on fertilizer input (NPK)	ICAC, fertilizer use (ICAC, 2024)
Fertilizer type	Data from International Fertilizer Association (IFA) on most used fertilizer (described in Sphera's agricultural model documentation, see references)	Approach described as in Sphera's Agricultural LCA Model, Part 2, Dataset Generation and Data Sources, section 3.2.4 (Sphera Solutions Inc., 2024b)
Pesticide use	Pesticide application data from ICAC per pest class (herbicide, fungicide, insecticide) used, combined with data from PEST-CHEMGRIDS to determine most used active ingredients per pest class	ICAC, pesticide use (per pest class herbicide, fungicide, insecticide) (ICAC, 2024) PEST-CHEMGRIDS to determine most used active ingredients per pest class (Maggi, Tang, la Cecilia, & McBratney, 2019)
Irrigation	Values from ICAC, used irrigation pump model to estimate energy use for irrigation, under consideration of country specific share of electricity and diesel, and country average ground water table (see references)	ICAC, Total irrigation water (mm/Ha) applied in cotton farms, (ICAC, 2024) Sphera irrigation pump model [process data set: irrigation pump generic]. Specification of energy source and ground water table depth based on (Qin, et al., 2024)
Fuel use	Used approach based on reference fuel consumption values and FAO (Food and Agriculture Organization of the United Nations) data for energy intensity described in Sphera's Agricultural model documentation	Approach described as in Sphera's Agricultural LCA Model, Part 2, Dataset Generation & Data Sources, section 3.6 (Sphera Solutions Inc., 2024b)
Soil erosion	Based on GIS data from JRC	European Soil Data Centre—Global Soil Erosion (Joint Research Centre, 2019)
Ginning	Energy use based on values suggested in Cascale Cotton LCA Methodology; lint output per kg raw cotton input based on ICAC	Energy use as suggested in (Cascale, 2024b); ginning output percentage lint (ICAC, 2024)

Secondary data has been compiled for cotton cultivation for all regions under study and used for benchmarking purposes, or in cases where primary data was missing (see section 4.2.2). The Türkiye country average and the Brazil country average are entirely based on secondary data compiled under the approach outlined above.

Selected regions of China

An exception to the approach outlined above is the secondary data compilation for selected regions of China. Data was compiled and reviewed by a local expert and is mainly based on official statistics from China (National Modern Cotton Industry Technology System Industrial Economy Research Office, 2021), which provided data on yield, fertilizer, irrigation, and fuel use with a reference year of 2021. Pesticide use and ginning energy use are based on the approach to compile secondary data outlined above. Data was compiled on a sub-regional level and then aggregated into a country average. In this study, the following regions were considered: Hebei, Henan, Shandong, Shaanxi, Anhui, Hubei, Hunan, Jiangsu, Jiangxi, Gansu.

4.1.2. Recycled cotton

The most important data points required in the impact assessment of recycled cotton production systems include:

- Cotton waste
- Transportation (from source)
- Electricity
- Process water
- Packaging, including End-of-Life (EoL) treatment
- Lubricants
- Zippers, buttons, and labels EoL treatment
- Particulate matter emissions
- Water vapor emissions

Please note that these are only the key activity data points. These data points were compared against available published LCI data; however, there is no specific guidance on which inventories to include for all types of cotton waste.

Primary data

Similar to cotton cultivation, this LCA study aimed to use the best available primary data. This means that it evaluated what data was available, either published or not published. At the same time, contacts with relevant institutions were established to provide primary data. It was not intended to create completely new data collection structures as part of this study.

The following organizations provided primary data for recycled cotton:

- **Pakistan:** Artistic Milliners, Soorty Enterprises, Sapphire Textile Mills, Shahjalal Poly Industries
- **Bangladesh:** Recover, Cyclo, Square Textiles, Shahjalal
- **China:** Ctctex
- **Türkiye:** Kipaş, Bossa, Haksa,
- **India:** Geetanjali Woollens

Additionally, Re-matters, a textile recycling consultancy, assisted in the data collection of the study.

Similar to cotton cultivation, the situation in terms of data availability and contact with relevant institutions varies across countries. It was not possible to obtain high-quality primary data for all product systems and, as a result, restrictions and lower DQRs had to be accepted in certain cases (see section 6.3.2).

Mechanical recycling technologies and the types of cotton waste textiles that are used in the production of recycled spinnable cotton fibers are diverse. The input of different cotton textile waste has significant variability based on aspects such as fiber thickness, weave structure, processing, and finishing; however, no clear classification of input waste types exists. In addition, recycling technologies vary based on factors such as the types of cotton waste they can process, their energy efficiency, and the quality of the output fibers. However, currently, no clear guidance is available on the classification of types of recycling technologies. These factors make it challenging to ensure that the most relevant production systems are covered. Furthermore, given the lack of information on the breakdown of the global annual production of recycled spinnable cotton fiber to country-specific production volumes, it was challenging to assess the representativeness of the primary data collected. Therefore, unlike cotton cultivation, no assessment of representativeness has been conducted as part of this study. The limitations associated with the uncertainty of the representativeness are detailed in section 6.2.2, and the recommendations to facilitate improvement in future studies to data quality and representativeness are highlighted in section 6.4.3.

The primary goal of the study was to provide country-average reference data; however, based on the limitations identified with the uncertainty of representativeness of data collected and other factors, such as the number of data providers per country for aggregation into country averages, the three types of cotton waste used in the production of recycled spinnable fibers were assessed at a global level.

The final inventory data compiled to use in the model (see section 4.4) was provided for review to the technical advisory group, and to the critical review panel (see section 3.9) for plausibility checks. The different levels of data availability are reflected in the data quality rating of data points and the complete dataset (see section 6.3.2 on data quality rating).

4.2. Cotton cultivation inventory data

4.2.1. Results of primary data collection and assessment of representativeness

Ensuring that the sample used in this study was representative of the broader population was a key objective of the data assessment process. Given that no new primary data collection was undertaken (see section 4.1.1), the assessment of sample size had to be conducted retrospectively to determine whether the data provided represented a sufficiently large and diverse sample. Typically, representativeness is evaluated by comparing the number of sampled farmers to the total population, for example, following the guidelines outlined in the Product Environmental Footprint (PEF) method (European Commission, 2021). However, in this study, the total number of farmers was either unavailable or unreliable for both the sampled data and the reference data. This approach necessitated alternative methods for evaluating representativeness, given the constraints on data availability.

Initially, a stratified sampling approach was considered, whereby data would be grouped based on major production regions to ensure that key variations in agricultural conditions were captured. However, in practice, the data provided was often already aggregated at the country level, preventing stratification by production regions. As a result, representativeness could only be assessed at the national level. To provide context and allow for a qualitative assessment of representativeness, the specific regions covered in the data provided are documented. However, the representativeness of data on the level of the main production regions could not be quantified. Variation in data in the form of minimum and maximum values is provided in Annex J.

To assess representativeness despite these limitations, two different approaches were used. First, a square root approach was used, based on the PEF method, to estimate an appropriate reference sample size. Instead of calculating the square root of the total number of farmers, which was unavailable or assessed to be unreliable, the square root of the total production volume was used as a proxy. The sampled production volume was then compared against this estimated value to determine whether a sufficiently broad fraction of total production had been captured.

In addition to the square root approach, Slovin's formula was applied as an alternative method to verify the estimated sample size. Slovin's formula is normally used when little is known about population variability[26]. In this study, production volume was used as a proxy for population size, enabling a comparative assessment of sampling adequacy. The application of this method provided an additional validation step, reinforcing confidence that the sample size was proportionally reflective of the overall population.

The use of production volume in place of farmer counts represents a stretch of the usual statistical assessment, such as suggested in the PEF guidance. However, since the number of farmers covered in the sampled data is unavailable or inconsistent, this approach allowed some statistical analysis by assessing a proportional representation of production scale within the sample. This approximation assumes that farms contributing to the same production volume are of broadly similar size; if this is not the case in a given country, an assessment of representativeness based on the number of farmers could lead to different results. The inability to stratify by production region introduces some limitations, as differences in agricultural practices and environmental conditions within countries may not be fully captured (see section 6.2).

The results of the assessment are presented in Table 4-4. The analysis indicates that, at least at the country level, the collected data adequately represents a significant share of the total production volume for all production systems and countries, with the exception of organic cotton in Türkiye. In this case, the sampled production volume was found to be insufficient to ensure full representativeness.

Additionally, the application of Slovin's formula led to the conclusion that the sampled production volume for organic cotton in Brazil did not meet the estimated required sample size for representativeness. This finding is somewhat counterintuitive, given that the sampled data covers an estimated 27 percent of Brazil's total organic cotton production. The discrepancy can be attributed to Slovin's formula generating disproportionately large sample size requirements when applied to populations with a small total reference size (in this case, total production volume rather than the number of farmers).

For regenerative cultivation systems, an assessment of representativeness could not be conducted due to the absence of reliable data on total production volumes that could serve as a reference. Without a defined benchmark for total regenerative cotton production, it was not possible to determine whether the sampled data accurately reflects the broader population of regenerative cotton production. However, it has to be noted that sampled production volumes were small in comparison to organic and country average production volumes, so that specific care to the use of advice in relation to data quality should be given (see section 2.3 and section 6.2).

As stated in the section 3.3.1, the aim of this study is to include data covering at least three cultivation seasons wherever possible to reduce the influence of seasonal variability. However, that was often

26 Slovin's formula is used to estimate an appropriate sample size when the population size is known, and the desired margin of error is specified, particularly in cases where little is known about population variability. It is expressed as $n = N / (1 + N \cdot e^2)$, where n is the sample size, N is the population size, and e is the margin of error.

not feasible. The impact of the assessment of representativeness on data quality is discussed further in 6.3 on data quality. Limitations and recommendations are discussed further in section 6.2 and section 6.4.

Table 4-4: Assessment of representativeness of primary data—cotton cultivation

Country	System	Data provided					Reference (6)		Assessment or representativeness based on PEF		Assessment or representativeness based on Slovin	
		Regions included	Data providers	Seed cotton production volume sampled (t)	Lint output	Lint production volume sampled (t)	Reference production volume (t)	Sampled proportion of total	SQRT of total reference production volume	Represented volume > SQRT?	Slovin error margin 0.05	Represented volume > result from Slovin
Brazil	Organic	Paraiba	1	93	42.4%	39	143	27%	12	yes	105	no
India	Country average	Maharashtra, Madhya Pradesh, Gujarat, Telengana	3[4)]	58,117	33.5%	19,760	4,343,621	0.4%	2,084	yes	400	yes
	Organic	Gujarat, Maharashtra, Madhya Pradesh, Odisha, Rajasthan, Telengana	5	29,252		10,039	270,635	4%	520	yes	399	yes
	Regenerative	Gujarat, Maharashtra, Madhya Pradesh, Odisha,	4	1,069		358	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Peru	Organic	Chincha	1	1,259	37.8%	477	1,318	36%	36	yes	307	yes
	Regenerative	Chincha	1	549		208	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Tanzania	Organic	Bariadi, Singida	2	13,836	39.1%	5,410	22,269	24%	149	yes	393	yes
Türkiye	Organic	Izmir	2	100 [5)]	42%	42	83,350	0.1%	289	no	398	no
	Regenerative	Izmir; Söke, Aydın	4	138[5)]		58	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
US	Country average	All [1)]	1[2)]	1,226,821	39.4%	483,367	2,235,541	22%	1,495	yes	400	yes
	Organic	Texas	1[3)]	2,009	38.0%	764	9,726	8%	99	yes	384	yes

1) South East: Alabama, Florida, Georgia, South Carolina, North Carolina, Virginia; Mid South: Missouri, Arkansas, Louisiana, Mississippi, Tennessee; South West: Texas, Oklahoma, Kansas; Far West: California, Arizona, New Mexico
2) US survey report (Bayramova, et al., 2024)
3) Five farmers surveyed separately
4) 99 percent of sampled production volume from Cotton Connect REEL control data
5) One data provider did not provide sample size data
6) Production volumes based on 2022/23 data from *Materials Market Report* (Textile Exchange, 2024), note that numbers for country averages as defined in this section refer to data excluding program data (see section 3.1.1)

4.2.2. Cotton cultivation inventory data

The following tables provide the inventory data for the different countries and cultivation systems under study.

India

Table 4-5: Inventory data cotton cultivation (India)

Inventory data	Unit	Country average	Organic	Regenerative [7)]
Main data source (see section 4.1.1)	-	Primary	Primary	Primary
Data quality level (see section 6.3.1)	-	1.8 (Level 1)	1.8 (Level 1)	2.4 (Level 2)
Yield (seed cotton)	[kg/ha]	1679	1586[2)]	1571
Mineral fertilizer				
NH3 (82% N)	[kg/ha]	0.0	0.0	0.0
AN (33.5% N)	[kg/ha]	0.0	0.0	0.0
CAN (27% N)	[kg/ha]	2.0	0.0	0.0
UAN (30% N)	[kg/ha]	0.0	0.0	0.0
Urea (46% N)	[kg/ha]	203.5	0.0	1.7
Rock phosphate (32% P_2O_5)	[kg/ha]	0.0	0.0	0.3
TSP (46% P_2O_5)	[kg/ha]	1.5	0.0	0.0
KCL (60% K2O)	[kg/ha]	61.3	0.0	0.5
NPK (15% N, 15% P_2O_5, 15% K_2O)	[kg/ha]	20.5	0.0	0.0
DAP (18% N)	[kg/ha]	229.6	0.0	0.6
Organic fertilizer				
FYM (as total N)	[kg/ha]	3.1	23.4	48.5
Other (as total N)	[kg/ha]	1.4	32.6	44.1
Total amount of nutrients applied				
N	[kg/ha]	143.0	56.0	93.5
P_2O_5	[kg/ha]	111.5	32.4	43.3

Inventory data	Unit	Country average	Organic	Regenerative [7)]
K_2O	[kg/ha]	43.0	n.a. [9)]	n.a. [9)]
Pesticide use				
Total amount (full list of ai applied provided in Annex L)	[kg ai/ha]	3.6	biopesticides (see section 4.3.6)	0.042 + biopesticides (see section 4.3.6)
Irrigation[5)]				
Irrigation applied	[m³/ha]	2155.9	2154.1[3)]	1989.6
Diesel use irrigation	[kg/ha]	56.1	0.0	0.0
Electricity use irrigation	[MJ/ha]	358.1	886.9	1008.4 [4)]
Machinery				
Diesel use tractor (excl irrigation)	[l/ha]	29.6[1)]	37.4	8.3 [6)]
Gin [8)]				
Distance to gin	[km]	20.0		
Energy use	[MJ/1000 kg raw cotton input]	326.4		
Lint output	[kg/1000 kg raw cotton input]	335		

1) Estimate from (CottonConnect, 2025).

2) Yield data presented is based on submissions from five data providers, covering six production regions in India (Gujarat, Maharashtra, Madhya Pradesh, Odisha, Rajasthan, and Telangana), and representing approximately 4 percent of the total organic cotton production volume (see section 4.2.1). However, review by the Technical Advisory Group emphasized that yields in organic cotton can vary significantly and, therefore, the reported yield figures should not be interpreted as evidence that organic systems can consistently achieve yields comparable to conventional systems. A recent review (Riar, et al., 2024) on the farm gate profitability of organic and conventional farming systems in the tropics provides more context in this regard.

3) For one significant data provider, irrigation water applications had to be estimated based on energy consumption. There is uncertainty around irrigation rates in India in general, because metering systems are rarely available. Please also see section 6.2 on limitations.

4) One significant data provider operates in Gujarat, Gandhinagar, where the groundwater table is deep, resulting in high energy consumption for pumping irrigation water. While there was some uncertainty around the initially reported energy values, consumption was remodeled using groundwater depth and the Sphera irrigation pump model, confirming the high energy demand. This influences the average energy consumption for regenerative systems in India, but the elevated values are driven by local hydrogeological conditions rather than by the cultivation system itself.

5) Note that the majority of cotton in India is rainfed (ICAC, 2024), i.e., the numbers represent country average situation and include irrigated and non-irrigated farms.

6) A larger fraction of farms reported using animal draft.

7) See section 3.1.1 on the definition of regenerative. This category includes integrated regenerative systems, which may apply synthetic or mineral-based fertilizers and pesticides, and organic-aligned regenerative systems, which avoid synthetic inputs and often aim to build on top of baseline organic certification (for example, regenerative organic)
8) Secondary data for ginning were used for all cultivation systems. While some data providers reported supply-chain-specific ginning data, these showed very large deviations between sources. Since ginning turnout and energy use at the gin are not dependent on cultivation systems, such deviations are more likely attributable to typical in-country variation or even unit conversion errors. To avoid distortions from these inconsistencies, the same default data were applied for all cases: energy use was taken from the Cascale Cotton LCA methodology, and lint output from ICAC (see section 4.1.1 for complete references and further information on secondary data).
9) n.a. = not applicable; K2O content of organic fertilizer was not inventoried as it is not considered in any of the environmental impact assessment pathways used in this study.

South America (Brazil and Peru)

Table 4-6: Inventory data cotton cultivation South America (Brazil and Peru)

Inventory data	Unit	Brazil country average	Brazil organic	Peru organic	Peru regenerative
Main data source (see section 4.1.1)	-	Secondary (see section 4.1.1 for approach and sources to compile secondary data)	Primary	Primary	Primary
Data quality level (see section 6.3.1)	-	3 (Level 2)	3.2 (Level 3)	1.9 (Level 1)	1.9 (Level 1)
Yield (seed cotton)	[kg/ha]	4304	1276	3220	3128
LUC	[kg CO_2 eq./ha]	2850[5)]	n.a.	n.a.	n.a.
Mineral fertilizer					
NH3 (82% N)	[kg/ha]	0.0	0.0	0.0	0.0
AN (33.5% N)	[kg/ha]	86.5	0.0	0.0	0.0
CAN (27% N)	[kg/ha]	16.6	0.0	0.0	0.0
UAN (30% N)	[kg/ha]	0.0	0.0	0.0	0.0
Urea (46% N)	[kg/ha]	163.7	0.0	0.0	0.0
Rock phosphate (32% P_2O_5)	[kg/ha]	10.7	0.0	0.0	0.0
TSP (46% P_2O_5)	[kg/ha]	107.5	0.0	0.0	0.0
KCL (60% K2O)	[kg/ha]	180.1	0.0	0.0	0.0
NPK (15% N, 15% P_2O_5, 15% K_2O)	[kg/ha]	16.4	0.0	0.0	0.0
DAP (18% N)	[kg/ha]	183.6	0.0	0.0	0.0
Organic fertilizer					
FYM (as total N)	[kg/ha]	0.0	21.9	20.0	20.0
Other (as total N)	[kg/ha]	0.0	0.0	60.3 [7)]	60.3 [7)]
Total amount of nutrients applied					
N	[kg/ha]	144.3	21.9	80.3	80.3
P_2O_5	[kg/ha]	139.8	11.0	40.0	40.0
K_2O	[kg/ha]	110.5	n.a. [9)]	n.a. [9)]	n.a. [9)]
Pesticide use					
Total amount (full list of ai applied provided in Annex L)	[kg ai/ha]	24.8	biopesticides (see section 4.3.6)	biopesticides (see section 4.3.6)	biopesticides (see section 4.3.6)

Inventory data	Unit	Brazil country average	Brazil organic	Peru organic	Peru regenerative
Irrigation					
Irrigation applied	[m³/ha]	70.0[8)]	0.0 [1)]	7000	7000
Diesel use irrigation	[kg/ha]	*1.4*	0.0	0.0	0.0
Electricity use irrigation	[MJ/ha]	*8.8*	0.0	0.0 [4)]	0.0 [4)]
Machinery					
Diesel use tractor (excluding irrigation)	[l/ha]	55.5	20.0 [2)]	18.0	18.0
Gin [6)]					
Distance to gin	[km]	50.0		30.0	
Energy use	[MJ/1000 kg raw cotton input]	265.6		237.2	
Lint output	[kg/1000 kg raw cotton input]	424.0		378.6	

1) Non-irrigated/rainfed.
2) Estimated by data provider.
3) All ginning data for Brazil organic was based on secondary data (see Brazil country average).
4) Only gravity irrigation.
5) Emissions from direct LUC was based on data from BRLUC (Embrapa, 2025), see also section 4.3.5.
6) Secondary data for ginning was used for all cultivation systems (no primary data available): energy use was taken from the Cascale Cotton LCA methodology, and lint output from ICAC (see section 4.1.1 for complete references and further information on secondary data). Data for Peru was based on "other countries"
7) Vermicompost and compost.
8) Inconsistent water data has been reported for Brazil in ICAC. For 2022, 7mm was reported, while 160mm was reported for 2023. Values were compared with modeled data from the University of Twente, where irrigation water applied of <2 mm was reported, and the ICAC 2022 (7mm=70 m³/ha) value was, therefore, retained.
9) n.a. = not applicable; K2O content of organic fertilizer was not inventoried as it is not considered in any of the environmental impact assessment pathways used in this study.

Türkiye

Table 4-7: Inventory data cotton cultivation (Türkiye)

Inventory data	Unit	Country average	Organic	Regenerative
Main data source (see section 4.1.1)	-	Secondary (see section 4.1.1 for approach and sources to compile secondary data)	Primary	Primary
Data quality level (see section 6.3.1)	-	3 (Level 2)	3.2 (Level 3)[1)]	2.5 (Level 2) [2)]

Inventory data	Unit	Country average	Organic	Regenerative
Yield (seed cotton)	[kg/ha]	4288	5400	4950
Mineral fertilizer				
NH3 (82% N)	[kg/ha]	0.0	0.0	0.0
AN (33.5% N)	[kg/ha]	52.9	0.0	80.8
CAN (27% N)	[kg/ha]	58.4	0.0	0.0
UAN (30% N)	[kg/ha]	0.0	0.0	0.0
Urea (46% N)	[kg/ha]	145.8	0.0	1.6
Rock phosphate (32% P_2O_5)	[kg/ha]	0.0	0.0	0.0
TSP (46% P_2O_5)	[kg/ha]	11.5	0.0	0.0
KCL (60% K_2O)	[kg/ha]	1.1	0.0	0.0
NPK (15% N, 15% P_2O_5, 15% K_2O)	[kg/ha]	142.2	0.0	36.4
DAP (18% N)	[kg/ha]	53.8	0.0	0.0
Organic fertilizer				
FYM (as total N)	[kg/ha]	0.0	100.0	101.0
Other (as total N)	[kg/ha]	0.0	60.0	20.5
Total amount of nutrients applied				
N	[kg/ha]	131.6	160.0	147.1
P_2O_5	[kg/ha]	51.4	80.0	26.8
K_2O	[kg/ha]	22.0	n.a. [7)]	n.a. [7)]
Pesticide use				
Total amount (full list of ai applied provided in Annex L)	[kg ai/ha]	2.5	Biopesticides (see section 4.3.6)	3.9
Irrigation				
Irrigation applied	[m³/ha]	3645	6615[3)]	3235
Diesel use irrigation	[kg/ha]	67.6	0.0	21.1
Electricity use irrigation	[MJ/ha]	799.1	5436.4	1360.4
Machinery				
Diesel use tractor (excluding irrigation)	[l/ha]	88.5	68.0 [4)]	79.8 [4)]
Gin [6)]				
Distance to gin	[km]	50.0		
Energy use	[MJ/1000 kg raw cotton input]	409.3		
Lint output	[kg/1000 kg raw cotton input]	420.0		

Inventory data	Unit	Country average	Organic	Regenerative
Seed output	[kg/1000 kg raw cotton input]	522.0		

1) Limited DQR (see section 4.2.1 and section 6.3.1)—only two data providers, small production volume represented, one data provider did not share sampled/represented area; therefore, simple average of two data providers was used.
2) Limited DQR (see section 4.2.1 and section 6.3.1)—four data providers, but small production volume represented, one data provider did not share sampled/represented area, was considered with 20% in weighting.
3) Please see above—limited DQR—might not be representative.
4) Used secondary data (see country average) where not specified.
5) Different forms of compost.
6) Secondary data for ginning was used for all cultivation systems. While some data providers reported supply-chain-specific ginning data, these showed very large deviations between sources. Since ginning turnout and energy use at the gin are not dependent on cultivation systems, such deviations are more likely attributable to typical in-country variation or even unit conversion errors. To avoid distortions from these inconsistencies, the same default data was applied for all cases: energy use was taken from the Cascale Cotton LCA methodology, and lint output from ICAC (see section 4.1.1 for complete references and further information on secondary data).
7) n.a. = not applicable; K2O content of organic fertilizer was not inventoried as it is not considered in any of the environmental impact assessment pathways used in this study.

Tanzania

Table 4-8: Inventory data cotton cultivation (Tanzania)

Inventory data	Unit	Tanzania organic
Main data source (see section 4.1.1)	-	Primary
Data quality level (see section 6.3.1)	-	1.7 (Level 1)
Yield (seed cotton)	[kg/ha]	716
Mineral fertilizer		
Not applicable		
Organic fertilizer		
FYM (as total N)	[kg/ha]	28.3 [1)]
Other (at total N)	[kg/ha]	0.0
Total amount of nutrients applied		
N	[kg/ha]	28.3
P_2O_5	[kg/ha]	14.1
K_2O	[kg/ha]	n.a. [5)]
Pesticide use		
Total amount (full list of ai applied provided in Annex L)	[kg ai/ha]	biopesticides (see section 4.3.6)

Inventory data	Unit	Tanzania organic
Irrigation		
Irrigation applied	[m³/ha]	0.0 [2)]
Diesel use irrigation	[kg/ha]	0.0
Electricity use irrigation	[MJ/ha]	0.0
Machinery		
Diesel use tractor (excluding irrigation)	[l/ha]	7.3 [3)]
Gin		
Distance to gin	[km]	61.8
Energy use	[MJ/1000 kg raw cotton input]	293.7 [4)]
Lint output	[kg/1000 kg raw cotton input]	391.6
Seed output	[kg/1000 kg raw cotton input]	572.9

1) Organic fertilizer input estimated based on N uptake of crop.
2) Rainfed.
3) Secondary data (see section 4.1.1 on secondary data).
4) Secondary data (Cascale Cotton LCA methodology, see section 4.1.1 on secondary data).
5) n.a. = not applicable; K2O content of organic fertilizer was not inventoried as it is not considered in any of the environmental impact assessment pathways used in this study.

United States

Table 4-9: Inventory data cotton cultivation (US)

Inventory data	Unit	US country average	Organic
Main data source (see section 4.1.1)	-	Primary/secondary	Primary
Data quality level (see section 6.3.1)	-	2.1 (Level 1)	2.3 (Level 2)
Yield (seed cotton)	[kg/ha]	2532[2)]	1079
Mineral fertilizer[2)]			
NH3 (82% N)	[kg/ha]	40.8	0.0
AN (33.5% N)	[kg/ha]	36.6	0.0
CAN (27% N)	[kg/ha]	0.0	0.0
UAN (30% N)	[kg/ha]	0.0	0.0
Urea (46% N)	[kg/ha]	72.6	0.0
Rock phosphate (32% P_2O_5)	[kg/ha]	0.0	0.0
TSP (46% P_2O_5)	[kg/ha]	6.4	0.0
KCL (60% K_2O)	[kg/ha]	126.9	0.0
NPK (15% N, 15% P_2O_5, 15% K_2O)	[kg/ha]	67.6	0.0
DAP (18% N)	[kg/ha]	96.0	0.0

Inventory data	Unit	US country average	Organic
Organic fertilizer			
FYM (as total N)	[kg/ha]	0.0	79.4 [9)]
Other (at total N)	[kg/ha]	0.0	0.0
Total amount of nutrients applied [3)]			
N	[kg/ha]	106.5	79.4
P_2O_5	[kg/ha]	57.2	39.7
K_2O	[kg/ha]	86.3	n.a. [11)]
Pesticide use			
Total amount (full list of ai applied provided in Annex L)	[kg ai/ha]	4.4 [4)]	biopesticides (see section 4.3.6)
Irrigation			
Irrigation applied	[m³/ha]	1359.7 [5)]	757.1 [6)]
Diesel use irrigation	[kg/ha]	16.3 [5)]	*16.1* [7)]
Electricity use irrigation	[MJ/ha]	667.0 [5)]	*925.0* [7)]
Machinery			
Diesel use tractor (excluding irrigation)	[l/ha]	47.9[10)]	49.8
Gin			
Distance to gin	[km]	35.0 [5)]	17.9
Energy use	[MJ/1000 kg raw cotton input]	249.1[10)]	245.0 [8)]
Lint output	[kg/1000 kg raw cotton input]	398.4[10)]	380 [8)]

1) Combination of US survey report (Bayramova, et al., 2024), survey data from national agricultural statistics service (NASS, (United States Department of Agriculture, 2025)) and additional information provided by Cotton Incorporated based on its upcoming LCA study (unpublished).
2) NASS data (United States Department of Agriculture, 2025).
3) US country average: amount of N, P, and K based on USDA NASS (United States Department of Agriculture, 2025), which reports values in line with Bayramova et al., 2024; specification of fertilizer type based on IFA most used fertilizer data (see section 4.1.1).
4) Based on NASS (United States Department of Agriculture, 2025), total amount applied divided by cotton cultivation area, approach aligned with Cotton Incorporated based on its upcoming LCA study
5) US survey report (Bayramova, et al., 2024), please note that the final value considers fraction of area irrigated (NASS values as well refer to application rates in irrigated farms and do not represent average application rates including rainfed farms).
6) The exact amount was not reported in the primary data. Irrigation water applied was, therefore, taken from the USDA National Agricultural Statistics Service (United States Department of Agriculture, 2025), under consideration of the fraction of farmers that irrigate. These values are not specific to organic cotton but follow the approach also used for the country average, applied here only for Texas.
7) Calculated based on Sphera irrigation pump, see Table 4-3 for references.

8) Secondary data (Cascale Cotton LCA methodology, see section 4.1.1).
9) Organic fertilizer data for some farms was incomplete. Used reported ratio of organic fertilizer application to yield as proxy, with average nutrient content.
10) Additional information provided by Cotton Incorporated based on its upcoming LCA study (unpublished).
11) n.a. = not applicable; K2O content of organic fertilizer was not inventoried as it is not considered in any of the environmental impact assessment pathways used in this study.

China (selected regions)

Table 4-10: Inventory data cotton cultivation (China (selected regions))

Inventory data	**Unit**	**Selected regions[1)]**
Main data source (see section 4.1.1)	-	Secondary (see section 4.1.1 for approach and sources to compile secondary data)
Data quality rating (see section 6.3.1)	-	3 (Level 2)
Yield (seed cotton)	[kg/ha]	2992
Mineral fertilizer		
NH3 (82% N)	[kg/ha]	0.0
AN (33.5% N)	[kg/ha]	0.0
CAN (27% N)	[kg/ha]	0.0
UAN (30% N)	[kg/ha]	0.0
Urea (46% N)	[kg/ha]	109.0
Rock Phosphate (32% P_2O_5)	[kg/ha]	0.0
TSP (46% P_2O_5)	[kg/ha]	12.7
KCL (60% K_2O)	[kg/ha]	32.7
NPK (15% N, 15% P_2O_5, 15% K_2O)	[kg/ha]	281.0
DAP (18% N)	[kg/ha]	38.3
Organic fertilizer		
FYM (as total N)	[kg/ha]	0.0
Other (at total N)	[kg/ha]	0.0
Total amount of nutrients applied [3)]		
N	[kg/ha]	99.2
P_2O_5	[kg/ha]	65.6
K_2O	[kg/ha]	61.8
Pesticide use		
Total amount (full list of ai applied provided in Annex L)	[kg ai/ha]	2.9
Irrigation		
Irrigation applied	[m^3/ha]	2598.1
Diesel use irrigation	[kg/ha]	0.0

Inventory data	Unit	Selected regions[1)]
Electricity use irrigation	[MJ/ha]	1895.1
Machinery		
Diesel use tractor (excluding irrigation)	[l/ha]	101.1
Gin		
Distance to gin	[km]	23.0
Energy use	[MJ/1000 kg raw cotton input]	250.6
Lint output	[kg/1000 kg raw cotton input]	400.0
Seed output	[kg/1000 kg raw cotton input]	540.0

1) For regions included, see section 3.1.1 Table 3-1.

4.3. Agricultural LCA model

4.3.1. Modeling approach—overview

Sphera's Agricultural LCA Model has been developed to assess the environmental impacts of crop cultivation from cradle to field gate using the most recent LCA-centered methodology for representing agricultural production systems. It is a robust and tested model, based on agreed standards for agricultural modeling in LCA that has been further developed from the first comprehensive and industry-leading model of 2003. The two current, main guiding standards for agricultural modeling are:

- 2019 IPCC Guidelines (IPCC, Climate Change and Land, 2019) for National GHG Inventories (Volume 4, Agriculture, Forestry and Other Land Use)
- PEF method, chapter 4.4.1 (European Commission, 2021)

In combination with datasets from the Sphera's MLC database, the model allows the inclusion of all impacts from upstream processes, on the field and from downstream processing (in this case, ginning). The contribution of each subprocess can be evaluated separately. The following table gives an overview of the different modules of the model, the modeling approach and reference to the detailed documentation (Sphera Agricultural LCA Model documentation 2024 Part 1 and 2) (Sphera Solutions Inc., 2024a) (Sphera Solutions Inc., 2024a, 2024b).

Table 4-11: Agricultural LCA Model: approach and documentation

Module	Approach	**Documentation** (Sphera Agricultural LCA Model documentation)
Fertilizer and pesticide production	Based on fertilizer and pesticide production datasets from LCA FE database (nearest available country proxy is used)	Part 1, Annex 4 (datasets) Part 2 Annex A (country proxies)
Provision of diesel and electricity	Based on energy provision datasets from LCA FE database	Part 1, Annex 4

Module	**Approach**	**Documentation** (Sphera Agricultural LCA Model documentation)
Emissions from combustion of biomass[27]	Modeled based on the amount of biomass burned, its carbon and nitrogen content, and based on emission factors from literature (for example, from IPCC, EPA or the soil enrichment protocol)	Part 1, 3.3
Gaseous emissions from fertilizer application	Based on emission factors provided in 2019 IPCC guidelines (aggregated for N2O, disaggregated for NH3).	Part 1, 3.1.1
Nitrate emissions	Based on emission factors provided in 2019 IPCC guidelines	Part 1, 3.1.1; see also section 4.3.2 (this report)
Emissions from crop residues	Based on approach provided in 2019 IPCC guidelines	Part 1, 3.1.2
Emissions from soil erosion	Based on data from Global Soil Erosion Modeling platform (GloSEM) and default nutrient content in soil, reduced erosion rates considered based on management practices (see Annex H of this report)	Part 1, 3.1.3 (approach) Part 3.3.3 (data)
Emission from tractor use and transport	Based on tractor and truck model in LCA FE	Part 1, 3.6
Pesticide emissions	Default emission factors from the PEF method have been applied (European Commission, 2017), i.e., 90% to soil, 9% to air, 1% to fresh water	Part 1, 3.2
Emissions from LUC	Sphera's Agricultural LCA Model does not directly model land use change emissions but requires data input from an assessment outside of the model	See section 4.3.5 (this report).
Irrigation	Water and energy use of irrigation was part of data collection if applicable, Sphera pump model used to estimate energy consumption from irrigation where necessary, country specific average water table depths were considered based on (Qin, et al., 2024)	Sphera irrigation pump model (Sphera Solutions Inc., 2025)
Ginning	Additional module added to the agricultural LCA model. Based on data collected on energy consumption, seed-to-lint ratios, typical transport distances and prices for allocation[28]	Not applicable

[27] Based on the data collected, this module was only used for the India country average, based on ICAC data on the fraction of farmers that burn cotton stalks in the field (ICAC, 2024)— use of cotton stalk residues.

28 See section 3.4.1. on allocation at the gin.

4.3.2. Emission modeling

The application of fertilizer causes direct and indirect field emissions, which are subdivided as follows:

- Nitrous oxide (N_2O) emissions to the air from microbial nutrient turnover (denitrification)
- Ammonia (NH_3) emissions to the air from mineral or organic fertilizer
- Nitrate (NO_x) emissions to water through leaching
- Carbon dioxide (CO_2) emissions from carbon contained in fertilizer (urea, lime)

The emission modeling is based on the IPCC guideline and their respective emission factors (IPCC, 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: AFOLU, 2019), including direct and indirect emissions. The table below provides the available default values from the IPCC. In this study, aggregated factors are used for EF N_2O, EF NH_3 organic and EF NO_3-N, while for EF NH_3 synthetic the disaggregated factors are used. Section 5.2.4 discusses the choice of emission factors and the scenarios applying disaggregated emission factors based on climate conditions.

Table 4-12: IPCC emission factors of fertilizer application

EF	Aggregated	Disaggregated		Unit
EF N_2O	0.010	Synthetic fertilizer inputs in wet climates	0.016	[kg N_2O-N/kg N applied]
		Other N inputs in wet climates	0.006	
		All N inputs in dry climates	0.005	
EF NH_3 synthetic	0.011	Urea	0.15	[kg NH_3-N/kg N applied]
		Ammonium-based	0.08	
		Nitrate-based	0.01	
		Ammonium-nitrate-based	0.05	
EF NH_3 organic	0.21	-	-	-
EF NO_3-N	0.24	Only applicable in wet climates		

For further details on emission modeling (including crop residues, phosphorus, soil erosion, and heavy metals), please refer to Sphera's Agricultural LCA Model documentation 2024 Part 1 (Sphera Solutions Inc., 2024a).

4.3.3. Organic fertilizer

The quantity of organic fertilizer applied is inventoried in all datasets. When organic fertilizer was used, it typically consisted of farmyard manure from animal production systems or compost (see section 4.2). There is ongoing debate regarding whether organic fertilizer should be classified as a waste product without associated environmental burdens from animal husbandry, or as a valuable co-product of milk and meat production, thereby carrying an environmental burden.

The LEAP guidelines published by the Food and Agriculture Organization (FAO, 2016) provide allocation guidance for manure exported off-farm, distinguishing between “co-product,” “waste,” and “residual” classifications. Most LCA studies and models currently treat organic fertilizers as “residual,” meaning they enter plant production systems without any upstream environmental

burdens from animal production but still account for emissions related to their field application. This is the approach used in the Cascale Cotton LCA methodology (Cascale, 2024b) and has thus been adopted as the default in this study.

The same logic and methodological approach also apply to compost. Composting, while primarily a waste treatment process, generates a fertilizer output. Consistent with the Cascale Cotton LCA methodology, compost provision is also treated as burden-free by default.

However, it's important to note that the assumption of burden-free provision could be challenged under certain conditions, potentially significantly affecting results. Therefore, the impact of including environmental burdens associated with the production of organic fertilizer is assessed through a scenario analysis (see section 5.2.1).

4.3.4. Biogenic carbon contained in the product

The results will not account for the (temporal) uptake of CO_2 in the fiber. As cotton is a short-lived consumer good, this carbon dioxide is released later at the end-of-life in the product, so that it is only temporarily stored. Therefore, the carbon uptake (and potential delay in emission) is not considered. This approach is consistent with the PEF method. However, the carbon content of the fiber will be inventoried and reported, for example, to allow consistent assessment in cradle-to-grave studies. For details, refer to the *Biogenic Carbon* guidelines from Textile Exchange (Textile Exchange, 2024a).

In a recent study (Pires, et al., 2024), it was highlighted that traditional static life cycle assessment methods often overlook the timing of GHG emissions, thereby underestimating the climate benefits associated with the temporary storage of biogenic carbon in products like cotton apparel. By employing dynamic LCA modeling, they observed reductions in cumulative radiative forcing of 22%, 5%, and 2% over 10-, 30-, and 100-year periods, respectively, compared to static models. While incorporating such dynamic assessments could enhance the accuracy of LCA studies, or at least be valuable for scenario analysis, current LCA standards do not permit accounting for delayed emissions (see *Biogenic Carbon* guidelines (Textile Exchange, 2024a)). Consequently, this study adheres to the conventional static LCA approach, excluding the potential benefits of temporary biogenic carbon storage. At the same time, it should be noted that more durable forms of carbon storage in cotton-based products (for example, insulation materials) are increasingly discussed as circularity strategies advance. Please also refer to Textile Exchange's *Biogenic Carbon* guidelines (Textile Exchange, 2024a) for a discussion of the conditions under which long-term storage at EoL of a product could be considered a permanent removal.

Consideration of biogenic carbon in partial (cradle-to-gate) LCA studies and interpretation in relation to fossil-based products

In LCA guidance documents, the most common approaches recommended for accounting biogenic carbon uptake and emissions from biobased materials are the 0/0 or -1/+1 approach (see *Biogenic Carbon* guidelines (Textile Exchange, 2024a)), and this study follows a 0/0 approach as outlined above. However, both approaches can influence study outcomes and potentially lead to misleading conclusions. For example, the -1/+1 approach may result in negative carbon footprint results in partial carbon footprint studies because biogenic carbon uptake is considered as negative emissions. Yet, emissions at EoL, which would balance out the uptake, are not included in cradle-to-gate studies. This oversight might incorrectly suggest that products lead to carbon removal and act as carbon sinks, despite the carbon being only temporarily stored (see above). On the other hand, the 0/0 approach may unfairly treat biobased products, since it does not account for the fact that the carbon they contain has been removed from the atmosphere. If EoL were included, there would be a

distinction in LCA results, as fossil-based products would have additional emissions (for example, from incineration) compared to biobased products where the emissions are treated as carbon neutral. To support consistent interpretation and transparency, the biogenic carbon content of the product is explicitly included in the life cycle inventory datasets (see above), and supplementary results accounting for biogenic carbon uptake are provided in Annex G. This dual reporting approach showing results both including and excluding biogenic carbon is consistent with the recommendations of Textile Exchange's *Biogenic Carbon* guidelines (Textile Exchange, 2024a), and the Together for Sustainability (TfS) Guidelines used in the chemical sector (TfS, 2023).

4.3.5. Land use change

Assessment of land use change (LUC) is included in the study. Ideally, this involves the collection of primary data on historical land use at the farm level to identify any direct land use change (dLUC) that may have occurred within the past 20 years. No data provider explicitly reported LUC associated with their cotton production systems. However, verification of actual LUC impacts was not possible, and some uncertainty remains in this regard (see section 6.2).

In cases where primary data is unavailable or not explicitly reported, statistical land use change (sLUC) assessments were used as a proxy to identify potential LUC impacts. This included the application of region-specific statistical datasets and recognized methodologies such as those from PAS 2050 (BSI, 2012) and IPCC Guidelines (IPCC, 2019). A screening of sLUC was conducted as part of this study based on data compiled for Sphera's Agricultural LCA Model (Sphera Solutions Inc., 2024b). The screening revealed the following results (Table 4-13):

Table 4-13: Screening assessment for sLUC

Country	sLUC >0
Brazil	Yes
China (selected regions)	No
India	Yes
Peru	No
Türkiye	No
Tanzania	Yes
US	No

Based on this assessment, countries identified with a potential risk of LUC associated with cotton cultivation (country average data) are Brazil, India, and Tanzania. In India, this risk was explicitly discussed with data providers; all confirmed that cotton cultivation areas have been under long-term agricultural use, and they were unaware of any recent expansions causing LUC. Consequently, the assumption of no LUC was made for India, in line with LCA of cotton in India from *Better Cotton Initiative in Indi*a (Better Cotton Initiative, 2021), Cotton Connect (CottonConnect, 2025), and OCA (OCA, 2025). While country-average cotton production in Tanzania could involve potential LUC risks, this study specifically assesses only organic cotton in Tanzania. Since the certification program followed for organic cotton explicitly prohibits LUC, the exclusion of LUC for organic cotton from Tanzania was justified. As a result, LUC impacts were included only for Brazil (country average), based on available statistical LUC data (Embrapa, 2025) (BRLUC 2.0—Brazilian Land Use Change).

Indirect land use change (iLUC) refers to land use change occurring outside of a company's value chain, indirectly induced by shifts in demand for agricultural commodities. Due to the methodological

complexity, large uncertainties, and lack of consensus on calculation approaches, iLUC emissions are not included in this study. In line with the GHG Protocol Land Sector and Removals Guidance, land occupation can be used as a land tracking metric, providing a measure of land use associated with cotton production. Please refer to Textile Exchange's *Biogenic Carbon* guidelines (Textile Exchange, 2024a) for a detailed discussion of iLUC.

4.3.6. Consideration of pesticide use in organic and regenerative cultivation systems (biopesticides)

Biopesticides are certain types of pesticides derived from such natural materials as animals, plants, bacteria, and certain minerals (US EPA, 2024). They are integral to Integrated Pest Management (IPM), and particularly relevant for organic and regenerative systems where use of conventional pesticides is prohibited (organic) or discouraged (regenerative, see section 3.1.1 on differentiation of integrated regenerative systems and organic-aligned regenerative systems). Biopesticides can be differentiated as follows (ibid):

- Biochemical (including botanical) pesticides: naturally occurring substances acting primarily via non-toxic or behavior-modifying mechanisms (for example, sex pheromones for mating disruption, attractants/repellents). In practice, organic cotton also uses botanical extracts with intrinsic toxicity, most notably neem preparations whose active ingredient is azadirachtin (antifeedant / insect-growth regulator).
- Microbial pesticides: products whose active ingredient is a microorganism (for example, *Bacillus thuringiensis*, *Beauveria bassiana*, *Metarhizium* spp., nucleopolyhedrovirus). Depending on the organism/strain, modes of action range from direct pathogenicity to specific pests to indirect antagonism or induced plant defense.

Plant-incorporated protectants, i.e., pesticidal substances expressed by genetically engineered plants (for example, Bt proteins), are not permitted in organic farming under all major organic standards. Certain inorganic/mineral pesticides are permitted under organic rules (for example, copper compounds as fungicides, subject to strict restrictions). These are not biopesticides but form part of the wider organic plant-protection toolbox. Their use is localized to humid, disease-prone environments, and episodic, and was also not reported by data providers in this study (see next section below).

Data and modeling in this study

Biopesticide use was included in primary data collection, but farmer responses were predominantly qualitative ("what was used"), making robust application rates difficult to derive. In addition, for most microbials and several botanicals, no LCI datasets exist, and LCIA characterization factors for toxicity are generally unavailable, except for specific actives with toxic modes of action (for example, azadirachtin). Consequently, it is difficult to include the impact of biopesticides in the study. However, to avoid a complete cut-off, the following approach was used to include biopesticides with proxy data:

- Microbial agents (antagonists/defense enhancers) were not considered, provision impacts assumed negligible given very low use rates and general ecotoxicity also considered to be irrelevant.
- Plant extracts: where neem use was reported explicitly, where plant extracts were referenced generically, or where pesticide use details were unspecified, a proxy seasonal rate of 0.032 kg a.i./ha azadirachtin was assumed. This represents a medium use assumption within label-consistent ranges for soluble neem (US EPA, 2020), see Annex L.

- Use of copper-based products was not reported by any data provider for organic or regenerative systems and, therefore, has not been considered.

4.4. Recycled cotton fibers inventory data

The following sections provide the inventory data for the production of 1 kg of recycled spinnable fiber from post-industrial yarn waste, post-industrial fabric waste, and post-consumer waste.

4.4.1. Recycled cotton inventory data

Table 4-14 provides the life cycle inventory data for the production of 1 kg of recycled spinnable fiber from post-industrial yarn waste, post-industrial fabric waste, post-consumer waste (domestic) and post-consumer waste (international transportation).

Table 4-14: Inventory data recycled cotton

Inputs	**Units**	**Post-industrial yarn waste**	**Post-industrial fabric waste**	**Post-consumer waste** (domestic)	**Post-consumer waste** (international transportation)
Energy					
Electricity from grid	kWh	0.47	0.5531	0.6825	0.6825
Electricity from natural gas	kWh	0.0971	0.1103	0.2462	0.2462
Electricity from solar	kWh	0.0666	0.0374	0.1464	0.1464
Water					
Process and cooling water	kg		0.010	0.0516	0.0516
Basic material					
Cotton waste	kg	1.07	1.15	1.79	1.79
Basic material transportation					
Truck	km	379	275	370	370
International truck	km				1,000
International shipping	km				10,000
Packaging and auxiliaries					
LDPE film	kg	0.0027	0.0027	0.0027	0.0027
Lubricants	kg	0.001	0.001	0.001	0.001
Outputs					
Valuable outputs					
Recycled spinnable fiber (main product)	kg	1	1	1	1
Fluff (sold by-product)	kg	0.0265	0.0612	0.0825	0.0825

Inputs	**Units**	**Post-industrial yarn waste**	**Post-industrial fabric waste**	**Post-consumer waste** (domestic)	**Post-consumer waste** (international transportation)
Filling/dust material (sold by-product)	kg	0.0399	0.0862	0.0643	0.0643
Sorted post-consumer waste (sold by-product)	kg			0.459	0.459
Wastes					
Zippers, buttons, and labels (waste)	kg		0.0011	0.177	0.177
Water vapor	kg	0.429	0.01	0.0516	0.0516
Emissions to the air (invisible loss to air)	kg	0.0008	0.006	0.0054	0.0054

4.5. Background data

4.5.1. Cotton cultivation

All background datasets used in the Agricultural LCA model are listed in Annex K. The electricity datasets also apply to energy use at the gin. Country-specific datasets for the production of mineral fertilizers are available for Brazil, China, India, and the United States. For Türkiye, a composite global average fertilizer provision mix was used, comprising datasets from Brazil (BR), China (CN), India (IN), the European region (RER), and Russia (RU).

It should be noted that the country of cotton cultivation was used as a proxy for the country of fertilizer production. While this assumption is common in agricultural LCA modeling, it introduces uncertainty, as the actual origin of fertilizers may differ significantly. Fertilizer consumption mixes based on trade data would provide a more accurate representation of upstream impacts, but were not available to be considered consistently in this study.

Country-specific electricity grid mix datasets (used to represent energy provision at irrigation and at gin) were available for Brazil, China, India, Türkiye, and the US. For Peru, the Brazilian grid mix was used as a proxy. For Tanzania, a grid mix specific for Africa (Regions of Africa, RAF) was used.

Pesticide provision impacts were based on a generic pesticide provision dataset.

4.5.2. Recycled cotton

Documentation for all LCA FE (f.k.a GaBi) datasets can be found online (Sphera Solutions Inc., 2025). All background datasets used in the recycled cotton LCA FE model can be found in Table 4-15 below.

National averages for fuel inputs and electricity grid mixes were obtained from the MLC 2025 databases. Table 4-15 shows the most relevant LCI datasets used in modeling the product systems. Electricity consumption was modeled using national grid mixes that account for imports from neighboring countries.

Data for upstream and downstream raw materials and unit processes were obtained from the MLC 2025 database. Table 4-15 shows the most relevant LCI datasets used in modeling the product systems.

Average transportation distances and modes of transport are included for the transport of the raw materials, operating materials, and auxiliary materials to production and assembly facilities. The MLC 2025 database was used to model transportation. Transportation was modeled using the MLC global transportation datasets. Fuels were modeled using geographically appropriate datasets.

Table 4-15: Key datasets used in recycled cotton inventory analysis

Inventory	Location	Dataset	Data provider	Reference year	Proxy
Energy					
Electricity (grid)	IN, BD, CN, PK, TR	Electricity grid mix	Sphera	2020	No
Electricity (NG)	BD, PK	Electricity from natural gas	Sphera	2020	No
Electricity (solar)	BD, PK, TR	Electricity from photovoltaic	Sphera	2020	No
Raw materials					
Process water	RER, IN	Tap water from groundwater (approximation)	Sphera	2023	Geo
LDPE film	RER	Polyethylene film (PE-LD) without additives	Sphera	2023	Geo
Lubricants	RER	Lubricants at refinery	Sphera	2020	Geo
LDPE film EoL	RER	Landfill of mixed polyolefins flexible packaging	Sphera	2023	Geo
Zippers, buttons, and labels EoL	RER	Plastic waste on landfill	Sphera	2023	Tech/ Geo
Transportation mode/fuels					
Truck transport	GLO	Truck, Euro V, 12–14t gross weight/9.3t payload capacity	Sphera	2023	No
Truck transport	GLO	Truck, Euro VI A-C, 28–32t gross weight/22t payload capacity	Sphera	2023	No
Ship transport	GLO	Container ship, 5,000–200,000 dwt payload capacity, deep sea	Sphera	2023	No
Diesel	IN, RER, CN, US, AU	Diesel mix at filling station	Sphera	2020	No
Heavy fuel oil	RER, CN, US, AU	Heavy fuel oil at refinery (1.0 wt.% S)	Sphera	2020	No

4.6. Life cycle inventory analysis results

ISO 14044 defines the LCI analysis result as the "outcome of a life cycle inventory analysis that catalogues the flows crossing the system boundary and provides the starting point for life cycle impact assessment". The complete inventory comprises hundreds of flows and is only of limited informational value without the associated impact assessment. A summary of the inventory with the main flows contributing to impact assessment categories under study is given in Annex I. Inventory datasets are also available in Textile Exchange's LCI library.

5. Results

This chapter contains the results for the impact categories and additional metrics defined in section 3.6. It shall be reiterated at this point that the reported impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions were to (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach).

LCIA results are, therefore, relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks. Please refer to section 2.3 on intended use and communication of the study results and section 2.4 for details on why no comparative assertions should be made based on the results.

5.1. Overall results

The following sections show the results for the country average cotton, organic, and regenerative cotton in the case of cotton cultivation, and recycled cotton fibers produced from post-industrial yarn waste, post-industrial fabric waste, and post-consumer waste (domestic) and post-consumer waste (international transportation) for the corresponding countries. Please refer to section 3.6 for an overview of the key impact categories selected for inclusion in the main report, along with the rationale for their selection. Additional, supplementary impact categories are presented in Annex E.

To emphasize the non-comparative nature of this assessment, only contribution analyses are presented graphically. Absolute results are provided in tabular format, accompanied by corresponding data quality ratings as detailed in section 6.3. It is reiterated that this is a non-comparative, attributional study (see section 2.4), and no conclusions regarding the environmental superiority of one product system over another should be drawn.

5.1.1. Cotton cultivation

Table 5-1 provides the definitions used for the contribution analyses in cotton cultivation results.

Table 5-1: Contribution analyses used in cotton cultivation results.

Contribution	Definition
Biomass combustion	Emissions related to the combustion of biomass after cultivation to clear the field
Crop protection	Emissions related to production and application of crop protection agents
Fertilizer production	Emissions related to fertilizer production
Field	Emissions from agricultural soil related to fertilizer application, crop residues, and soil erosion
Gin	Impacts associated with ginning cotton
Irrigation	Water consumption in irrigation, energy consumption from pumps, includes impacts of provision of energy and combustion emissions (in case of diesel pumps)

Contribution	Definition
LUC	Carbon emissions related to the conversion of forest (or other land use type) to agricultural land; refers to direct LUC, see section 4.3.5 for details
Machinery	Emissions from tractor use and provision of fuel
Transport to gin	Transport of raw cotton to the gin
Transport	Transport of agricultural inputs (fertilizer and pesticides) to the farm

Climate Change

Figure 5-1 and Table 5-2 present the climate change-related impacts and contribution analysis (excluding soil organic carbon) for various types of cotton cultivation across all the countries included in this analysis. The definition of contribution analyses used in the following graphs can be found in Table 5-1.

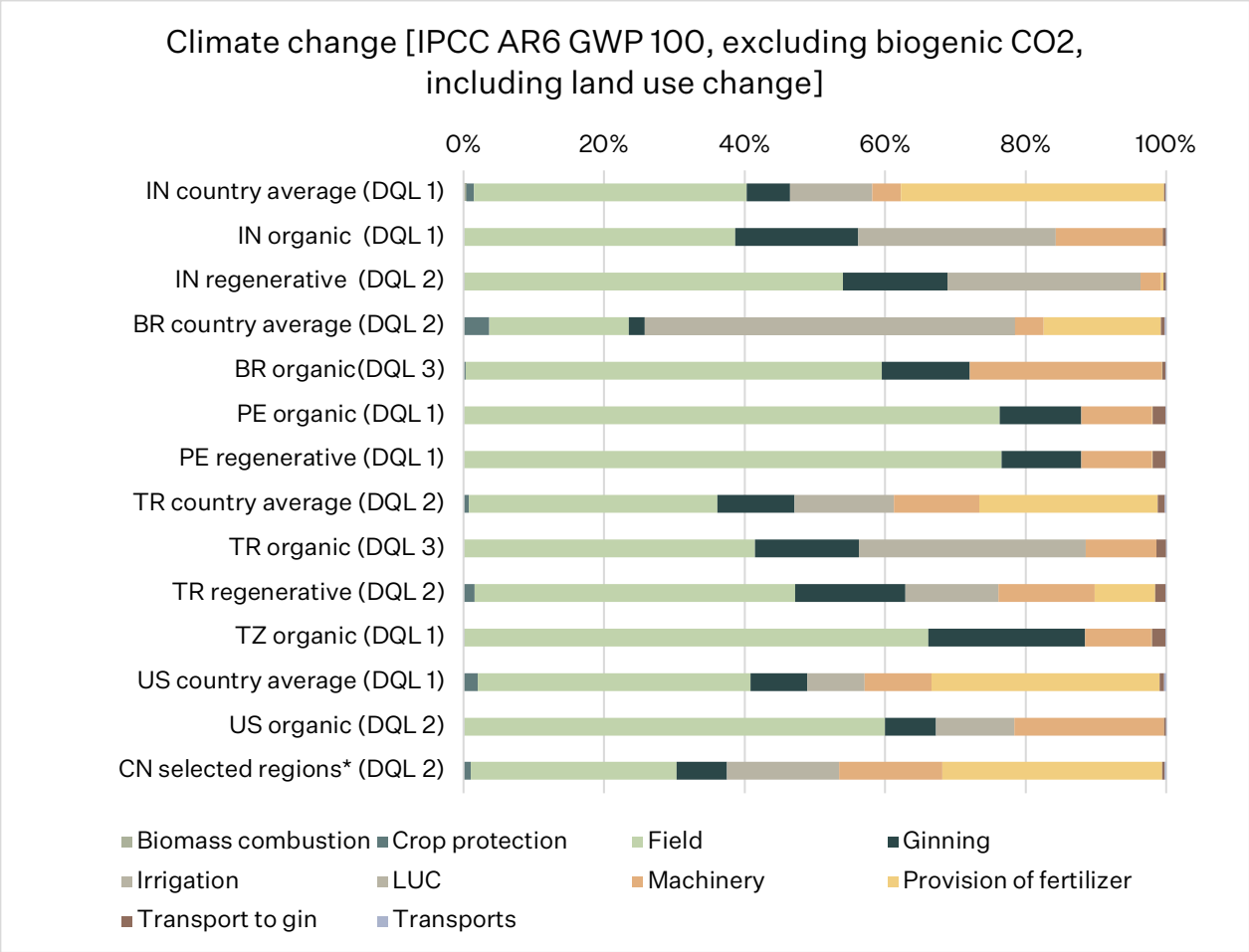

Figure 5-1: Climate change—contribution analysis

*For regions included, see Table 3-1
DQL = Data quality level, see section 6.3, 1=good, 2=medium, 3=limited

Table 5-2: Climate change results [kg CO_2 eq./kg fiber]

	DQL **	Biomass combustion	Crop protection	Field	Ginning	Irrigation	LUC	Machinery	Provision of fertilizer	Transport to gin	Transport	Total
IN country average	1	0.02	0.04	1.62	0.26	0.49	0.00	0.17	1.56	0.01	0.00	4.17
IN organic	1	0.00	0.00	0.57	0.26	0.41	0.00	0.22	0.00	0.01	0.00	1.46
IN regenerative	2	0.00	0.00	0.93	0.26	0.47	0.00	0.05	0.01	0.01	0.00	1.72
BR country average	2	0.00	0.09	0.49	0.06	0.00	1.29	0.10	0.41	0.01	0.00	2.46
BR organic	3	0.00	0.00	0.26	0.06	0.00	0.00	0.12	0.00	0.00	0.00	0.44
PE organic	1	0.00	0.00	0.37	0.06	0.00	0.00	0.05	0.00	0.01	0.00	0.48
PE regenerative	1	0.00	0.00	0.38	0.06	0.00	0.00	0.05	0.00	0.01	0.00	0.49
TR country average	2	0.00	0.01	0.45	0.14	0.18	0.00	0.16	0.33	0.01	0.00	1.29
TR organic	3	0.00	0.00	0.39	0.14	0.31	0.00	0.10	0.00	0.01	0.00	0.95
TR regenerative	2	0.00	0.01	0.41	0.14	0.12	0.00	0.12	0.08	0.01	0.00	0.89
TZ organic	1	0.00	0.00	0.59	0.20	0.00	0.00	0.08	0.00	0.02	0.00	0.89
US country average	1	0.00	0.03	0.60	0.12	0.13	0.00	0.15	0.50	0.01	0.00	1.55
US organic	2	0.00	0.00	1.06	0.13	0.20	0.00	0.38	0.00	0.00	0.00	1.77
CN selected regions*	3	0.00	0.02	0.50	0.12	0.27	0.00	0.25	0.54	0.01	0.00	1.72

*For regions included, see Table 3-1
**DQL = Data quality level, see section 6.3, 1=good, 2=medium, 3=limited

The primary hotspot in impacts across the cultivation systems in all countries (except Brazil country average, where LUC dominates the impacts) is field emissions, which are influenced by the nitrogen balance (see Annex G.1.1) resulting from fertilizer application in each system. In cases where mineral fertilizer is used, additional impacts arise from the production of mineral fertilizer (see section 4.5.1 on background data used). Organic fertilizers are considered to enter the system burden-free (see section 4.3.3).

Field emissions refer to the release of nitrous oxide (N_2O). Nitrous oxide is a potent greenhouse gas (GHG), approximately 273 times more powerful than carbon dioxide (CO_2) over a 100-year time period (IPCC AR6, 2021), and agricultural soils represent one of the largest sources of anthropogenic N_2O emissions globally. While current attention often centers on carbon sequestration and soil carbon dynamics, addressing N_2O emissions from nitrogen fertilizers is crucial to reducing the climate footprint of agricultural production systems. Additionally, the use of urea fertilizers results directly in CO_2 emissions. As an example, in the country average cotton scenario in India, the high

nitrogen surplus from fertilizer application leads to high N_2O emissions, as well as high environmental impacts related to fertilizer production.

The climate impact of irrigation is not only driven by total water consumption but also by the energy required for pumping, typically involving fossil fuels. Even in cases where water consumption is in the same range across cultivation systems, the irrigation-related impacts can differ due to differences in energy use (electricity and diesel consumption for pumping activities during irrigation), likely to be driven more by local conditions (for example, groundwater table depth, see notes to Table 4-5 than by specific management practices. Irrigation management practices, such as the choice of irrigation systems and water-saving techniques (for example, drip irrigation, precision irrigation scheduling, mulching), can nonetheless significantly affect water consumption and related climate impacts by increasing total water and energy use efficiency. The granularity of the collected data in this study, however, does not allow for conclusive statements regarding the actual use, distribution, or comparative efficiency of these different irrigation management practices.

For the country average cotton cultivation in Brazil, which was analyzed based on secondary data, LUC (direct Land Use Change, assessed on secondary data, see section 4.3.5) is notable as the main impact driver. Detailed data on machinery use in Brazil was limited, particularly for the organic cultivation system, fuel use had to be estimated. But available inventory data consistently indicated low overall fuel use. The irrigation impacts are very low for Brazil, since the cotton cultivation systems in Brazil are mainly rainfed, whilst cotton cultivation in Peru involves the use of gravity irrigation[29] and, therefore, there is no energy consumption involved.

For cotton cultivation in Tanzania, the primary impact hotspots are field emissions and ginning. This cultivation system is characterized by low intensity, with a relatively low yield, minimal fertilizer application, and no irrigation (see Table 4-8).

For cotton cultivation in Türkiye, field emissions are the main hotspot across all systems as well and are generally in a similar range. The organic system shows high irrigation-related impacts due to high reported irrigation application rates. However, the datasets for organic and regenerative systems are based on limited samples, which may not fully represent broader cultivation practices for these systems in Türkiye, also reflected in a lower DQL. Additionally, there is some uncertainty around nitrogen balance estimations in these systems (see Annex G.1.1 and the scenarios provided in section 5.2.3 and section 5.2.4), which might directly affect field emissions.

Uncertainty regarding nitrogen input also affects the US organic system, due to variability in the nitrogen content of organic fertilizers and the estimation of application rates (see section 4.2.2 and section 5.2.3). Based on the assumptions applied, the organic system shows a nitrogen surplus (see table G-1 in Annex C), which influences field emissions. In addition, yield plays a decisive role in scaling impacts: when machinery use or irrigation is distributed over a smaller harvest volume, the resulting impacts per kilogram of fiber produced are higher.

The impacts from selected regions of China[30] show a similar pattern as described above, with the primary hotspots being the impacts from provision of fertilizer, field emissions, irrigation, and machinery. The provision of fertilizer and field emissions hotspots correspond to the N balance (see Annex G.1.1).

29 In gravity irrigation, the water is conveyed from surface sources—primarily rivers or reservoirs—and is distributed to fields through a network of canals or pipelines using gravity.

30 For regions included in China country average, see Table 3-1

Eutrophication

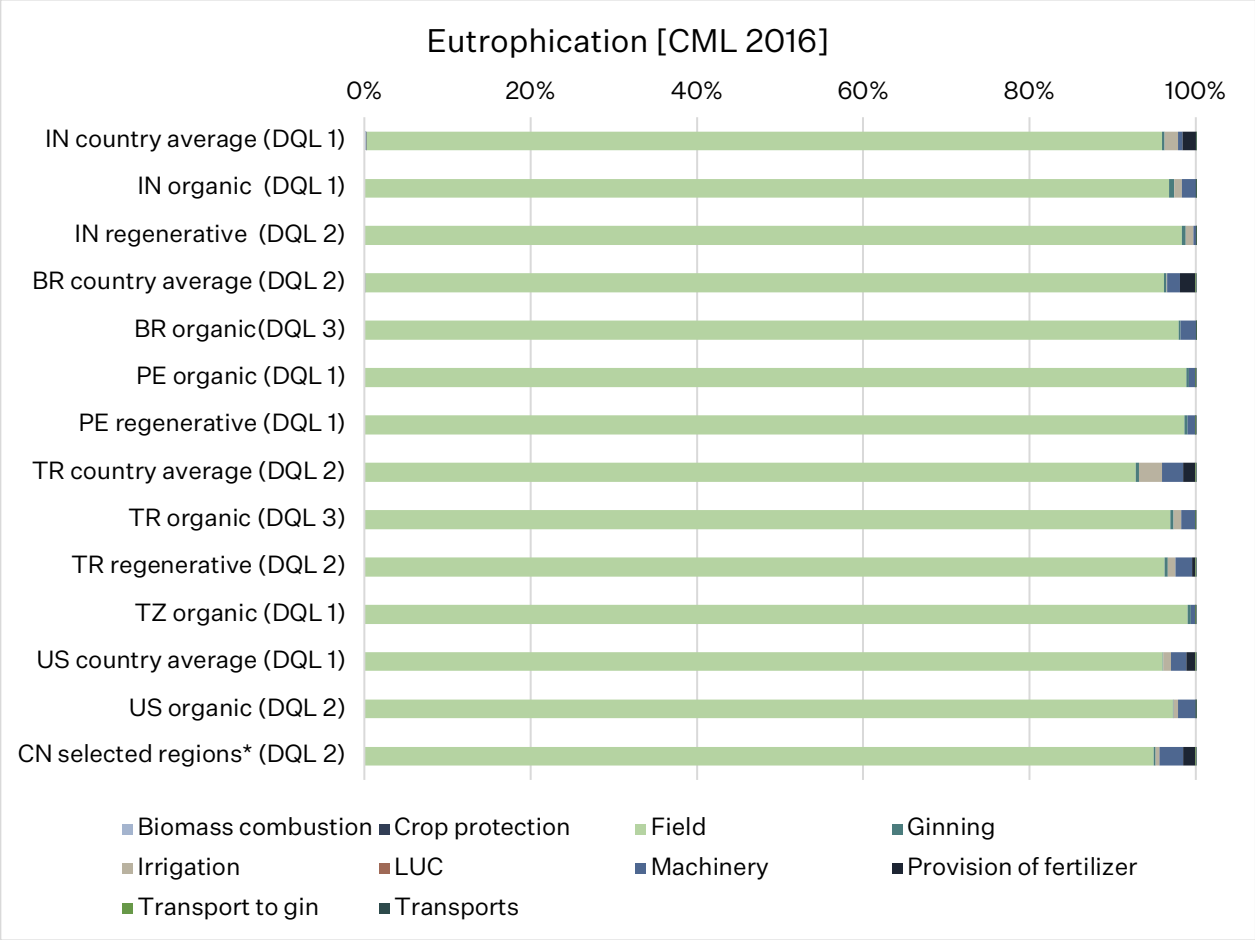

Figure 5-2: CML 2016 eutrophication—contribution analysis

*For regions included, see Table 3-1
**DQL = Data quality level, see section 6.3, 1=good, 2=medium, 3=limited

Table 5-3: Eutrophication [CML 2016] (kg phosphate eq./kg fiber)

	DQL **	Biomass combustion	Crop protection	Field	Ginning	Irrigation	LUC	Machinery	Provision of fertilizer	Transport to gin	Transport	Total
IN country average	1	0.000	0.000	0.052	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.054
IN organic	1	0.000	0.000	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.024
IN regenerative	2	0.000	0.000	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.030
BR country average	2	0.000	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012
BR organic	3	0.000	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013

	DQL**	Biomass combustion	Crop protection	Field	Ginning	Irrigation	LUC	Machinery	Provision of fertilizer	Transport to gin	Transport	Total
PE organic	1	0.000	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012
PE regenerative	1	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010
TR country average	2	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012
TR organic	3	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011
TR regenerative	2	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012
TZ organic	1	0.000	0.000	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.029
US country average	1	0.000	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015
US organic	2	0.000	0.000	0.033	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.034
CN selected regions*	3	0.000	0.000	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.017

*For regions included, see Table 3-1
**DQL = Data quality level, see section 6.3, 1=good, 2=medium, 3=limited

Figure 5-2 and Table 5-3 represent the eutrophication results. Field emissions are the dominant source of eutrophication impacts, contributing at least 90 percent of the total across all the cotton cultivation systems included in this analysis. Eutrophication impacts are primarily driven by the nitrogen balance (see Annex G.1.1), which reflects the relationship between fertilizer inputs and crop yield. A higher nitrogen surplus leads to greater emissions of nitrogen compounds to soil, air, and water, resulting in increased eutrophication impacts. While nitrogen emissions—particularly nitrate leaching and ammonia volatilization—are the primary drivers of eutrophication in most systems analyzed, phosphorus emissions are also included in the assessment. Phosphorus contributions to eutrophication potential are modeled via two main pathways: leaching of soluble phosphate compounds, and surface run-off and soil erosion, which can transport particulate-bound phosphorus into adjacent water bodies. The modeling of phosphorus-related emissions follows the approach documented in the Sphera Agricultural LCA Model, and further details are provided in the agricultural documentation (Sphera Solutions Inc., 2024a).

Yield also plays a key role in scaling the impacts: higher yields reduce the eutrophication impact per kilogram of fiber by distributing fixed field emissions over a greater amount of product. Similarly, lower land use per unit of product can reduce soil erosion-related eutrophication impacts, which are primarily area-dependent. While more intensive farming could theoretically increase soil disturbance and erosion risks locally, the baseline assumption is that agricultural activity always leads to some degree of soil erosion compared to undisturbed land. In this study, erosion mitigation measures were considered where applicable (see Annex H), but the erosion impacts are still scaled to the cultivated

area. Therefore, systems requiring more land per kilogram of fiber can show proportionally higher soil erosion-related impacts when normalized per functional unit.

It should be noted that nitrate leaching is influenced by many factors (for example, soil type, precipitation, and timing of application). A detailed assessment is highly complex and was beyond the scope of this study. In the baseline setting, a fixed emission factor of 24% of all nitrogen applied is used, in accordance with the IPCC guidelines (IPCC, Climate Change and Land, 2019) (see also section 4.3.2). However, this assumption does not necessarily hold under all conditions, particularly in arid regions (ibid). Moreover, nitrate leaching is also influenced by the total nitrogen surplus, which is not captured when using the fixed IPCC emission factor. For systems with a small surplus close to a closed nitrogen balance, the fixed factor may, therefore, overestimate emissions. The consideration of nitrogen balance in emission modeling is addressed in a dedicated scenario (see section 5.2.4).

For eutrophication results in India, the country average cotton cultivation system exhibits a high mineral fertilizer input, leading to a large nitrogen surplus (see Annex G.1.1). This surplus significantly increases the risk of nitrogen losses to the environment, primarily via nitrate leaching and ammonia volatilization, thus resulting in markedly elevated eutrophication impacts. The organic cultivation systems show a narrow nitrogen balance. Inputs of nitrogen are in the same range as crop uptake, leading to minimal surplus and consequently low nitrogen losses to air and water. Regenerative cotton systems in this study reported higher rates of organic fertilizers than traditional organic systems, and also maintained a moderate nitrogen surplus and thus a mid-range eutrophication impact. Across all systems, cotton yields are relatively similar, implying that the eutrophication differences per kilogram of fiber are not yield-driven but, instead, predominantly influenced by nitrogen management and associated field emissions.

All cultivation systems in Brazil and Peru show moderate eutrophication impacts. While Brazil's country average cotton system applies high amounts of mineral fertilizer, its eutrophication impact per kilogram of fiber is relatively low. This is primarily due to its comparatively high yields, which lead to a very low N surplus and scales the environmental impact per unit of output down. An assessment of the nitrogen balance (see N balance results, Annex C) reveals that the organic and regenerative systems in Brazil and Peru exhibit negative N balances. As a result, nitrogen losses, and thereby eutrophication impacts, are limited (potential variation in N application rates of organic fertilizer are assessed in section 5.2.3).

Even though the organic cotton cultivation system in Tanzania has low nutrient input (since the organic fertilizer input was estimated based on the crop N uptake), there will always be some baseline emissions associated with these systems which are scaled by the area use and yield values per kilogram of fiber production. Since cotton yields in Tanzania are relatively low, the land area required per kilogram of fiber is high. As discussed above, larger cultivated areas can lead to greater soil erosion-related impacts, which can contribute to eutrophication through the runoff of soil particles and associated nutrients. This mechanism is consistent with the findings from the CmiA Cotton LCA study, where erosion-driven eutrophication impacts were similarly observed under conditions of low yields and high area use (Aid by Trade Foundation, 2021).

The eutrophication impacts are low for all the cultivation systems in Türkiye as a result of the high yield associated with these systems (see Table 4-7), also corresponding to lower N-balance results.

A similar pattern as described above can be observed for the cultivation systems in the US. US country average cotton cultivation eutrophication results are shaped by a low N surplus (see table G-1 in Annex G) and comparatively high yields. The organic cultivation system is assessed to have a clearly positive N balance (see Annex G.1.1), which contributes to the eutrophication results. In addition, the yield scaling effect described above results in impacts per kg of fiber that are on the higher end of the observed range. As described above for cultivation systems using organic fertilizer,

it is important to note that the nitrogen input data for the organic system is subject to higher uncertainty due to the limited availability of detailed input records and variability in organic fertilizer characteristics. This uncertainty may lead to an overestimation of the nitrogen surplus and the associated eutrophication impact (N application rates for organic fertilizer are assessed in section 5.2.3).

The eutrophication impacts for selected regions of China are influenced by the high average yield associated with this system (see Table 4-10), corresponding to lower N-balance results on a per kg basis (see table G-1 in Annex G).

Blue water consumption

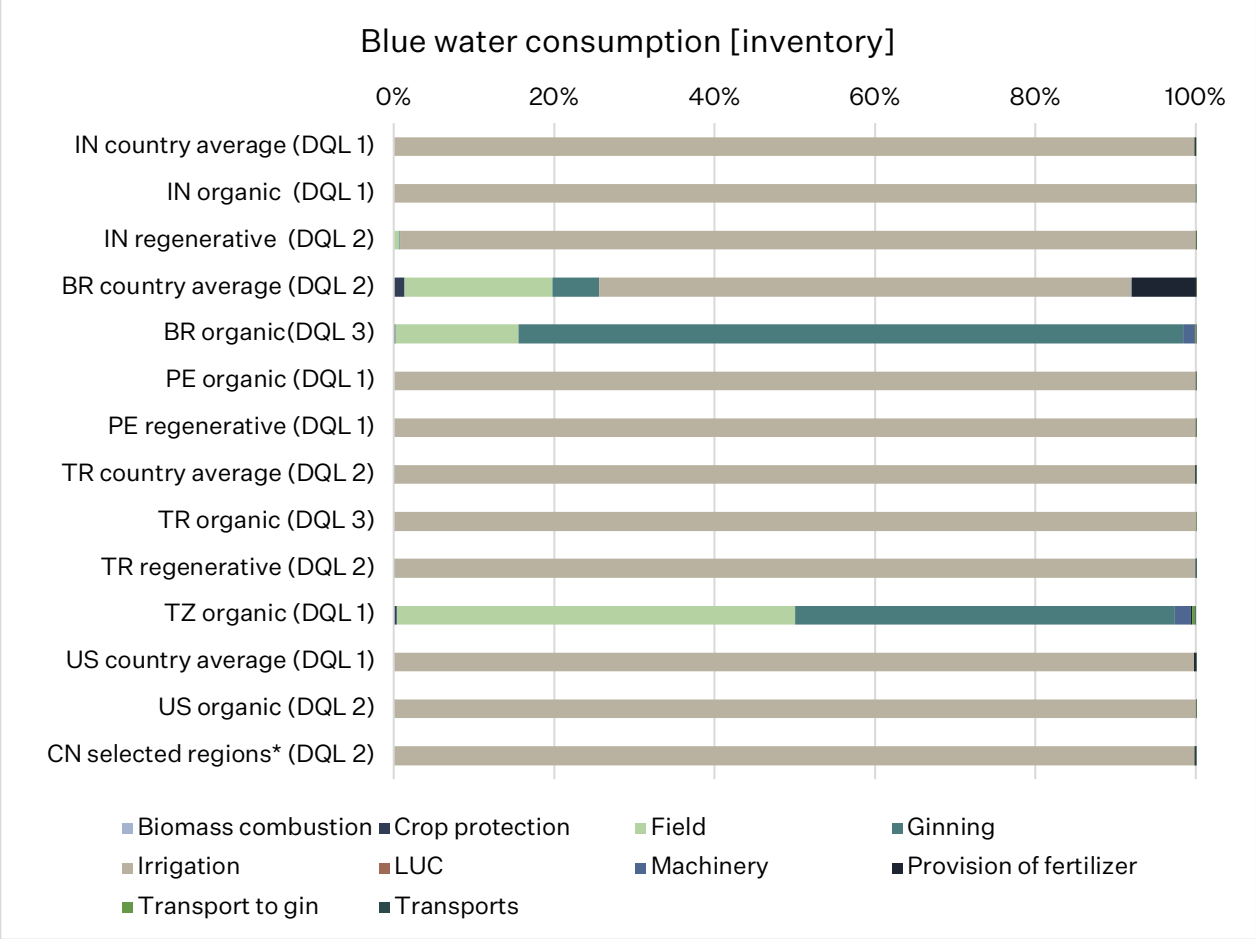

Figure 5-3: Blue water consumption—contribution analysis

*For regions included, see Table 3-1
DQL = Data quality level, see section 6.3, 1=good, 2=medium, 3=limited

Table 5-4: Blue water consumption [inventory] (kg/kg fiber)

	DQL**	Biomass combustion	Crop protection	Field	Ginning	Irrigation	LUC	Machinery	Provision of fertilizer	Transport to gin	Transport	Total
IN country average	1	0.0	0.3	0.0	1.0	3170.7	0.0	0.0	5.3	0.0	0.0	3177.4

	DQL**	Biomass combustion	Crop protection	Field	Ginning	Irrigation	LUC	Machinery	Provision of fertilizer	Transport to gin	Transport	Total
IN organic	1	0.0	0.0	0.0	1.0	3355.6	0.0	0.0	0.0	0.0	0.0	3356.6
IN regenerative	2	0.0	0.0	22.7	1.0	3128.4	0.0	0.0	0.0	0.0	0.0	3152.1
BR country average	2	0.0	0.6	8.8	2.8	31.7	0.0	0.0	3.8	0.0	0.0	47.9
BR organic	3	0.0	0.0	0.5	2.8	0.0	0.0	0.1	0.0	0.0	0.0	3.4
PE organic	1	0.0	0.0	0.4	2.8	4323.0	0.0	0.0	0.0	0.0	0.0	4326.2
PE regenerative	1	0.0	0.0	0.4	2.8	4450.1	0.0	0.0	0.0	0.0	0.0	4453.4
TR country average	2	0.0	0.1	1.6	1.5	1674.4	0.0	0.1	1.4	0.0	0.0	1679.0
TR organic	3	0.0	0.0	1.1	1.5	2415.5	0.0	0.0	0.0	0.0	0.0	2418.2
TR regenerative	2	0.0	0.1	0.4	1.5	1287.7	0.0	0.1	0.3	0.0	0.0	1290.0
TZ organic	1	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
US country average	1	0.0	0.2	0.1	0.5	1115.2	0.0	0.1	2.1	0.0	0.0	1118.2
US organic	2	0.0	0.0	0.3	0.5	1527.5	0.0	0.2	0.0	0.0	0.0	1528.6
CN selected regions*	3	0.0	0.1	0.3	0.9	1797.4	0.0	0.0	2.0	0.0	0.0	1800.7

*For regions included, see Table 3-1
**DQL = Data quality level, see section 6.3, 1=good, 2=medium, 3=limited

Figure 5-3 and Table 5-4 present the blue water (ground and surface water) consumption impacts of different cotton cultivation systems across all the countries included in this study. Variations are driven not only by differences in irrigation water applied, but also by differences in yield, as the results are expressed per kilogram of fiber. Consequently, systems with higher absolute irrigation water applied but also higher yields may show lower blue water consumption per kilogram of fiber compared to systems with lower irrigation inputs but substantially lower yields, due to the effect of scaling impacts relative to yield.

It is important to note that these results should not be interpreted as direct comparisons of management practices, as they reflect region-specific conditions with differing geographic and climatic contexts. The irrigation water requirement of a crop is primarily determined by local climatic conditions, although actual water consumption also depends on irrigation techniques and management practices. Furthermore, the choice of irrigation systems is often influenced by the financial and resource availability of programs and farmers; for example, highly efficient systems such as drip irrigation require significant investment and may not be accessible to all producers. Therefore, the low irrigation rates observed in some systems cannot be attributed solely to the cultivation scheme. Moreover, the results presented reflect country averages, and the systems being compared are not necessarily located in the same regions. For instance, US organic cotton is

predominantly grown in Texas, whereas the US country average reflects a broader range of production zones. Similarly, organic and regenerative cotton in India may be cultivated in more marginal areas with distinct agroclimatic characteristics compared to the national average. Consequently, meaningful comparisons of management practices require detailed spatial resolution and comparable agroecological contexts; this is not feasible within the scope of aggregated country-level data, and so such comparisons should not be made.

In nearly all cases, irrigation water applied accounts for 99–100% of the total blue water impact. Exceptions include cultivation systems in Brazil and Tanzania, which are predominantly rainfed. For these systems, the minimal blue water impacts arise and are primarily from background processes rather than direct field-level irrigation.

The reported inventory data on irrigation water applied in India (see Table 4-5) indicates comparable irrigation water applied and yield levels across all three systems. As a result, the calculated blue water consumption per kilogram of fiber is in a similar range and should be considered equivalent.

The low values for Brazil stem from negligible supplemental irrigation in the country-average system and none in the organic system, which is entirely rain-fed. In Peru, some 7,000 m^3 ha^{-1} of irrigation water is applied. According to follow-up discussions with the data provider, this water is not pumped from rivers or aquifers but originates from centuries-old rainwater-harvesting infrastructure, as well as large gravity-fed reservoirs that capture wet-season runoff from the Andes and release it downstream during the dry season. Conveyance occurs through open, gravity-driven canals, so the process entails virtually no energy use or related GHG emissions. Although one might question whether water stored in these mountain-runoff reservoirs should be classified as blue water, the Water Footprint Network explicitly defines harvested rainwater (since it is subject to human intervention, storage, and alteration of natural runoff flows) as blue water consumption. The Peruvian irrigation volumes are, therefore, reported here as blue water, in line with WFN guidance (Hoekstra, Chapagain, Aldaya, & Mekonnen, 2011). The small variation in water consumption values observed for Peru primarily reflects minor differences in reported yields (see inventory data) and should not be interpreted as significant.

The organic cotton cultivation system is rainfed in Tanzania (with only marginal contribution from background processes), resulting in negligible blue water consumption impacts.

Although yields are reported to be similar across the systems in Türkiye, the organic system reports high irrigation water applied (see Table 4-7), leading to high blue water consumption per kilogram of fiber. It should be noted here again that uncertainty in the inventory data for the organic and regenerative systems is relatively high (see section 4.2.1 and section 6.3.1), as these represent small areas with limited production volumes, which may affect the robustness of reported irrigation inputs.

Data for irrigation values for the cultivation systems in the US are based on a detailed survey (see Table 4-9). Irrigation water application rates reported for the organic system are based on values from Texas and are not specific to the organic cultivation system (see section 4.1.1). Therefore, reported water consumption values in the US are driven by regional climatic variation and not by cultivation practices.

The irrigation water applied to selected regions of China is also based on statistical data, which was reported separately for each region. The values presented, therefore, represent the average of the included regions.

Ecotoxicity, freshwater

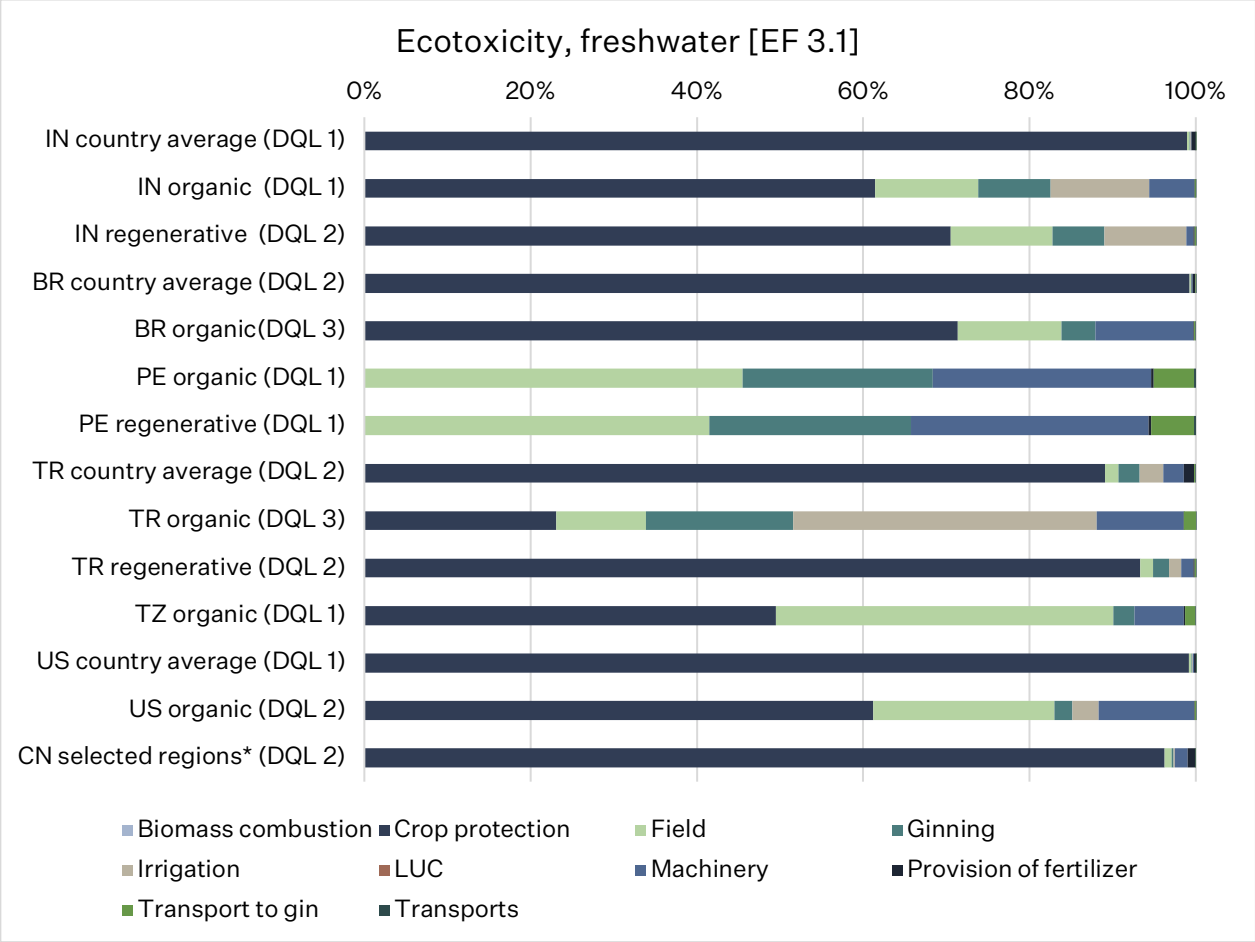

Figure 5-4: Ecotoxicity, freshwater—contribution analysis

*For regions included, see Table 3-1
DQL = Data quality level, see section 6.3, 1=good, 2=medium, 3=limited

Table 5-5: Ecotoxicity, freshwater [EF 3.1] (CTUe/kg fiber)

	DQL**	Biomass combustion	Crop protection	Field	Ginning	Irrigation	LUC	Machinery	Provision of fertilizer	Transport to gin	Transport	Total
IN country average	1	0.5	2796.5	8.8	2.1	2.9	0.0	1.0	14.9	0.0	0.0	2826.8
IN organic	1	0.0	14.7	3.0	2.1	2.8	0.0	1.3	0.0	0.0	0.0	23.9
IN regenerative	2	0.0	23.4	4.1	2.1	3.3	0.0	0.3	0.1	0.0	0.0	33.2
BR country average	2	0.0	1253.2	2.7	0.8	0.1	0.0	2.0	3.9	0.3	0.1	1262.9
BR organic	3	0.0	14.4	2.5	0.8	0.0	0.0	2.4	0.0	0.0	0.0	20.2
PE organic	1	0.0	0.0	1.6	0.8	0.0	0.0	0.9	0.0	0.2	0.0	3.6

	DQL**	Biomass combustion	Crop protection	Field	Ginning	Irrigation	LUC	Machinery	Provision of fertilizer	Transport to gin	Transport	Total
PE regenerative	1	0.0	0.0	1.4	0.8	0.0	0.0	1.0	0.0	0.2	0.0	3.4
TR country average	2	0.0	92.4	1.7	2.6	3.0	0.0	2.6	1.2	0.2	0.0	103.7
TR organic	3	0.0	3.4	1.6	2.6	5.5	0.0	1.6	0.0	0.2	0.0	14.9
TR regenerative	2	0.0	128.6	2.2	2.6	2.0	0.0	2.0	0.2	0.2	0.0	137.8
TZ organic	1	0.0	11.3	9.3	0.6	0.0	0.0	1.4	0.0	0.3	0.0	22.9
US country average	1	0.0	899.1	2.3	0.7	0.7	0.0	1.4	2.1	0.1	0.0	906.4
US organic	2	0.0	19.0	6.8	0.7	1.0	0.0	3.6	0.0	0.0	0.0	31.1
CN selected regions*	3	0.0	263.3	2.3	0.6	0.4	0.0	4.1	2.6	0.1	0.1	273.5

*For regions included, see Table 3-1
**DQL = Data quality level, see section 6.3, 1=good, 2=medium, 3=limited

Figure 5-4 and Table 5-5 presents the freshwater ecotoxicity impacts for different cotton cultivation systems across all countries included in this analysis. Pesticide use is the predominant contributor to this impact category, accounting for at least 90% of the total impact. It should be emphasized that toxicity-related results carry substantial uncertainty. First, pesticide application rates are often uncertain, particularly for country averages based on secondary data sources (see section 4.1.1). Second, the characterization factors for freshwater ecotoxicity span several orders of magnitude, meaning that a small quantity of a highly toxic substance can significantly affect the total impact. In addition to that, there is high uncertainty about the active ingredients used, especially for the country averages based on secondary data (see section 4.1.1). These uncertainties are discussed further in the scenario assessment in section 5.2.5 that compares pesticide application rates modelled as an unspecific pesticide rather than as specific active ingredients, and in the scenario provided in section 5.2.6 that compares results (including ecotoxicity) based on ICAC secondary data with those based on primary data (for US and IN). Given these limitations, differences in results smaller than one order of magnitude should not be interpreted as environmentally significant.

Impacts reported under "crop protection" for organic systems refer to the use of biopesticides, please refer to section 4.3.6. on how the use of biopesticides is considered in organic and regenerative systems. No impacts are reported for Peru, as the data provider provided details about applied substances, which did not include plant extracts but only microbial substances.

It should be noted that for regenerative systems in Türkiye, the use of synthetic pesticides was reported. Despite the small quantity, the use of a single substance classified as an “unspecific pesticide” in the regenerative system results in high impact due to its high toxicity characterization factor. However, the difference to the country average is not considered significant in the context of toxicity assessment, given the overall uncertainty in ecotoxicity assessments.

Pesticide application rates for the US country average are based on detailed data from the USDA National Agricultural Statistics Service (United States Department of Agriculture, 2025), and

considers both the average application rate and the area treated per active ingredient (see Table 4-9 and Annex L). Among the countries assessed, this represents one of the most comprehensive and granular datasets. In contrast to other regions where only class-level pesticide data were available based on ICAC data, the US inventory is built upon active ingredient-level data, increasing both representativeness and resolution. Despite the higher data quality, notable uncertainties remain. For some active ingredients, no substance-specific freshwater ecotoxicity characterization factors are available under the EF 3.1 method (based on USEtox). In such cases, generic average characterization factors had to be used. Moreover, it must be emphasized again that freshwater ecotoxicity potentials vary over several orders of magnitude between substances. As a result, a small number of substances can dominate the overall impact. In the US, where more robust active ingredient data is available, this effect is clearly observed: among the 90 pesticides included in the assessment, more than 90% of the ecotoxicity impact arises from just three active ingredients, abamectin, bifenthrin, and lambda-cyhalothrin (which are all applied with less than 0.1 kg ai/ha on country average level). This highlights that the results are highly sensitive to both the presence and the modeling of individual high-toxicity substances. Accordingly, ecotoxicity results should be interpreted with caution, and require careful consideration of underlying data quality and toxicity factor availability when interpreted. As mentioned above, these uncertainties are discussed further in the scenario assessments provided in section 5.2.5 and section 5.2.6.

5.1.2. Recycled cotton

Table 5-6 provides the definitions used for the contribution analyses in recycled cotton results.

Table 5-6: Contribution analyses used in recycled cotton results.

Contribution	Definition
Electricity from grid	Impacts associated with the consumption of grid electricity
Electricity from natural gas	Impacts associated with the consumption of electricity generated from natural gas
Electricity from photovoltaic	Impacts associated with the consumption of electricity generated from solar
Packaging, auxiliaries and EoL	Packaging including LDPE film, auxiliaries including lubricants and their EoL
Process and cooling water	Process water used in the recycling process
Process emissions	Emissions to air including water vapor and particles to air including <PM10 cotton fibers from recycling process, i.e., shredding
Shipping transport	International shipping of post-consumer cotton waste, including truck transportation at export and Import country as well as international shipping
Transport	Transport of cotton waste (all waste types) via truck transportation from tier 1 supplier warehouse to factory gate
Zippers, buttons, and label EoL	EoL treatment of zippers, buttons, and labels removed from cotton waste

Climate Change

The climate change impacts for the production of 1 kg of recycled cotton spinnable fiber from post-industrial yarn waste, post-industrial fabric waste, and post-consumer waste are shown below in

Figure 5-5. The chart highlights the contribution of energy and material inputs into the recycling process, as well as the process waste treatment, to the total climate change impacts for the different types of recycled spinnable fiber.

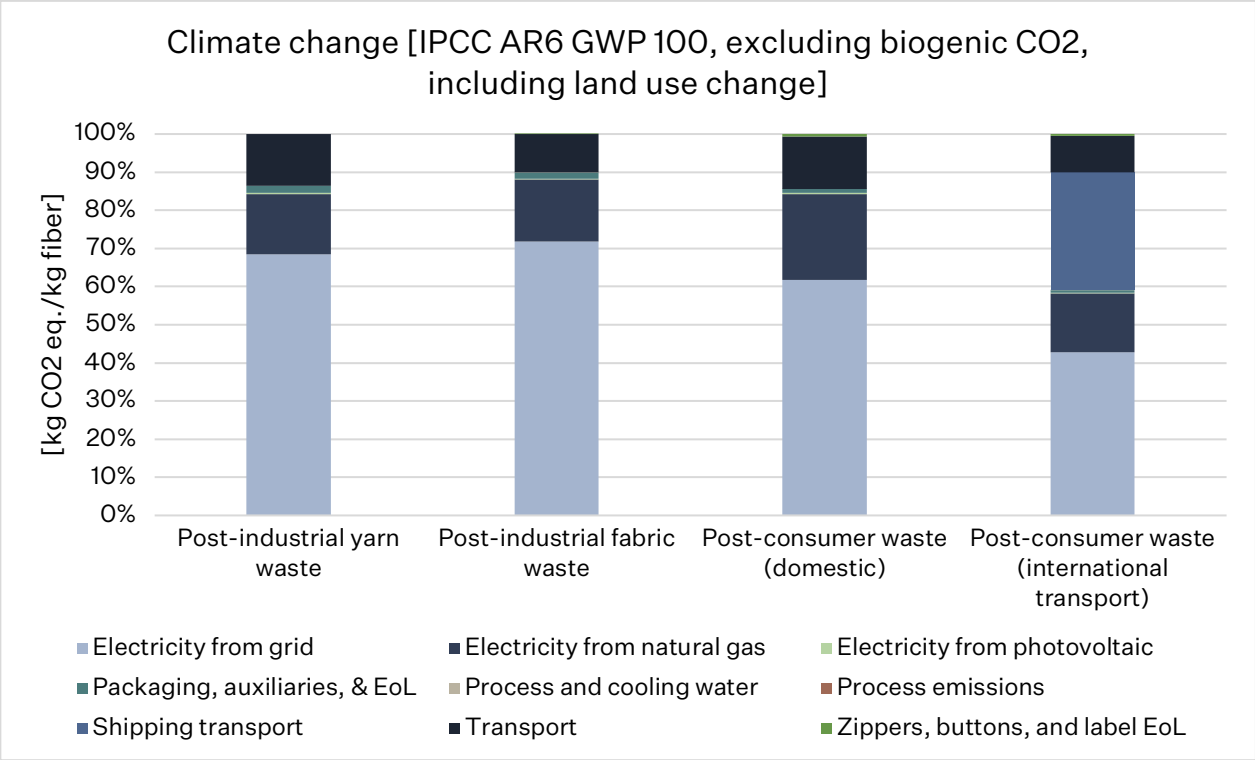

Figure 5-5: Climate change, global average recycled cotton

Table 5-7: Climate change, global average recycled cotton [kg CO_2 eq./kg fiber]

	Post-industrial yarn waste	Post-industrial fabric waste	Post-consumer waste (domestic)	Post-consumer waste (international transport)
Electricity from grid	3.02E-01	3.44E-01	4.86E-01	4.86E-01
Electricity from natural gas	6.94E-02	7.88E-02	1.76E-01	1.76E-01
Electricity from photovoltaic	1.41E-03	7.50E-04	2.94E-03	2.94E-03
Packaging, auxiliaries, and EoL	7.97E-03	7.97E-03	7.97E-03	7.97E-03
Process and cooling water	0.00E+00	1.09E-06	8.22E-06	8.22E-06
Process emissions	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Shipping transport	0.00E+00	0.00E+00	0.00E+00	3.51E-01
Transport	6.01E-02	4.80E-02	1.08E-01	1.08E-01
Zippers, buttons, and label EoL	0.00E+00	3.28E-05	5.21E-03	5.21E-03

	Post-industrial yarn waste	Post-industrial fabric waste	Post-consumer waste (domestic)	Post-consumer waste (international transport)
Total	0.441	0.48	0.786	1.138
DQL	Level 1	Level 1	Level 2	Level 2

Figure 5-5 highlights the IPCC AR6 GWP 100 results are 0.441 kg CO_2 equivalents for post-industrial yarn, 0.48 kg CO_2 equivalents for post-industrial fabric, and 0.786 kg CO_2 equivalents for post-consumer waste, pertaining to the production of 1 kg of recycled cotton spinnable fiber.

For all types of recycled cotton production, the main driver of climate change impacts is electricity consumption, which contributed between 84.5–88.3% of the total results. Transportation of cotton waste contributed between 10–13.8% of the total Impacts and all other inputs to the recycling process, including packaging, auxiliaries, and process waste treatment outputs had a negligible contribution at 1.6–1.8%.

On average post-industrial yarn waste consumed 0.63kWh/kg spinnable fiber, resulting in GWP impacts of 0.372 kg CO_2 equivalents. Post-industrial fabric waste consumed 0.7kWh/kg spinnable fiber, resulting in 0.424 kg CO_2 equivalents. Post-consumer waste required 1.075kWh/kg spinnable fiber, resulting in GWP impacts of 0.665kg CO_2 equivalents. Furthermore, for post-consumer waste, international transportation resulted in a further 0.35 kg CO_2 equivalents.

Post-consumer waste requires additional processing steps (i.e., trim removal, cutting[31]) prior to fiber opening driving the consumption of electricity, as well as having significant process waste (1.789 kg input cotton waste required for 1 kg spinnable fiber production), which also increases the impacts associated with transportation.

Eutrophication

The eutrophication impacts for the production of 1 kg of recycled cotton spinnable fiber from post-industrial yarn waste, post-industrial fabric waste, and post-consumer waste are shown below in Figure 5-6. The chart highlights the contribution of energy and material inputs into the recycling process, as well as process waste treatment, to the total eutrophication impacts for the different types of recycled spinnable fiber.

31 The cutting process step Is required for post-industrial fabric waste, but not for post-industrial yarn waste.

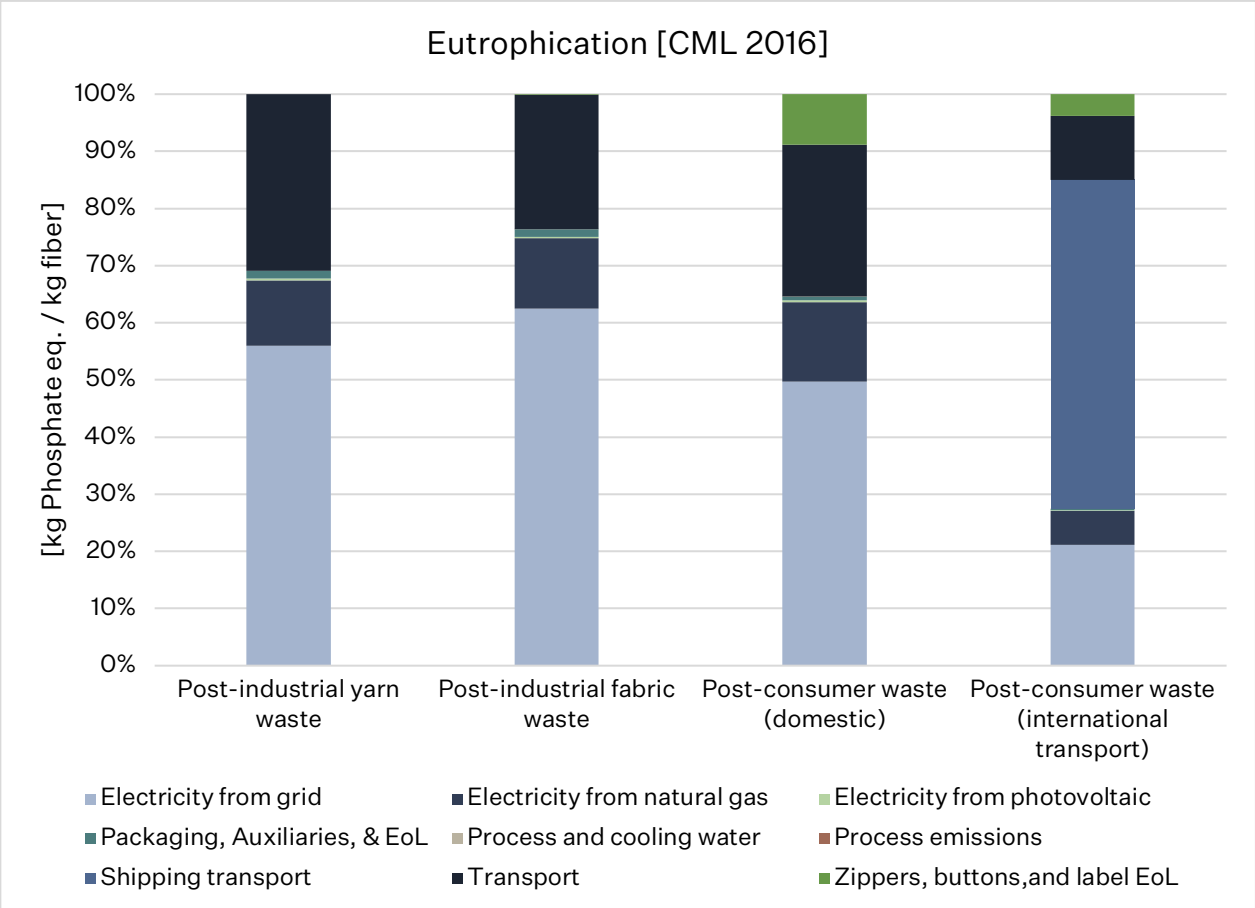

Figure 5-6: Eutrophication, global average recycled cotton

Table 5-8: Eutrophication, global average recycled cotton [kg phosphate equivalent/kg fiber]

	Post-industrial yarn waste	Post-industrial fabric waste	Post-consumer waste (domestic)	Post-consumer waste (international transport)
Electricity from grid	1.06E-04	1.24E-04	1.97E-04	1.97E-04
Electricity from natural gas	2.17E-05	2.46E-05	5.50E-05	5.50E-05
Electricity from photovoltaic	5.38E-07	2.83E-07	1.11E-06	1.11E-06
Packaging, auxiliaries and EoL	2.75E-06	2.75E-06	2.75E-06	2.75E-06
Process and cooling water	0.00E+00	1.14E-09	0.00E+00	0.00E+00
Process emissions	0.00E+00	0.00E+00	9.84E-09	9.84E-09
Shipping transport	0.00E+00	0.00E+00	0.00E+00	5.37E-04
Transport	5.84E-05	4.68E-05	1.05E-04	1.05E-04
Zippers, buttons, and label EoL	0.00E+00	2.20E-07	3.51E-05	3.51E-05

	Post-industrial yarn waste	Post-industrial fabric waste	Post-consumer waste (domestic)	Post-consumer waste (international transport)
Total	1.89E-04	1.99E-04	3.97E-04	9.34E-04
DQL	Level 1	Level 1	Level 2	Level 2

Figure 5-6 highlights that the CML 2016 eutrophication results are 1.89E-04 kg phosphate equivalents for post-industrial yarn, 1.99E-04 kg phosphate equivalents for post-industrial fabric and 3.97E-04 kg phosphate equivalents for post-consumer waste, pertaining to the production of 1 kg of recycled cotton spinnable fiber.

For all types of recycled cotton production, the main driver of eutrophication impacts is electricity consumption, which contributed between 63.9–75% of the total results. Transportation of cotton waste contributed between 23.5–30.9% of the total impacts. Additionally, for post-consumer waste the end-of-life treatment of process waste including zippers, buttons, and labels contributed 8.8%. All other inputs to the recycling process, including packaging, auxiliaries, and process waste treatment outputs, had a negligible contribution at 0.69–1.4%.

On average post-industrial yarn waste consumed 0.63 kWh/kg spinnable fiber, resulting in eutrophication impacts of 1.28E–04 kg phosphate equivalent. Post industrial fabric waste consumed 0.7 kWh/kg spinnable fiber resulting in 1.49E–04 kg phosphate equivalent. Post-consumer waste required 1.075 kWh/kg spinnable fiber resulting in GWP impacts of 2.53E–04 kg phosphate equivalent. Furthermore, for post-consumer waste, international transportation resulted in a further 5.37E–04 kg phosphate equivalent.

Blue water consumption

The blue water consumption for the production of 1 kg of recycled cotton spinnable fiber from post-industrial yarn waste, post-industrial fabric waste, and post-consumer waste is shown below in Figure 5-7. The chart highlights the contribution of energy and material inputs into the recycling process, as well as process waste treatment, to the total blue water consumption for the different types of recycled spinnable fiber.

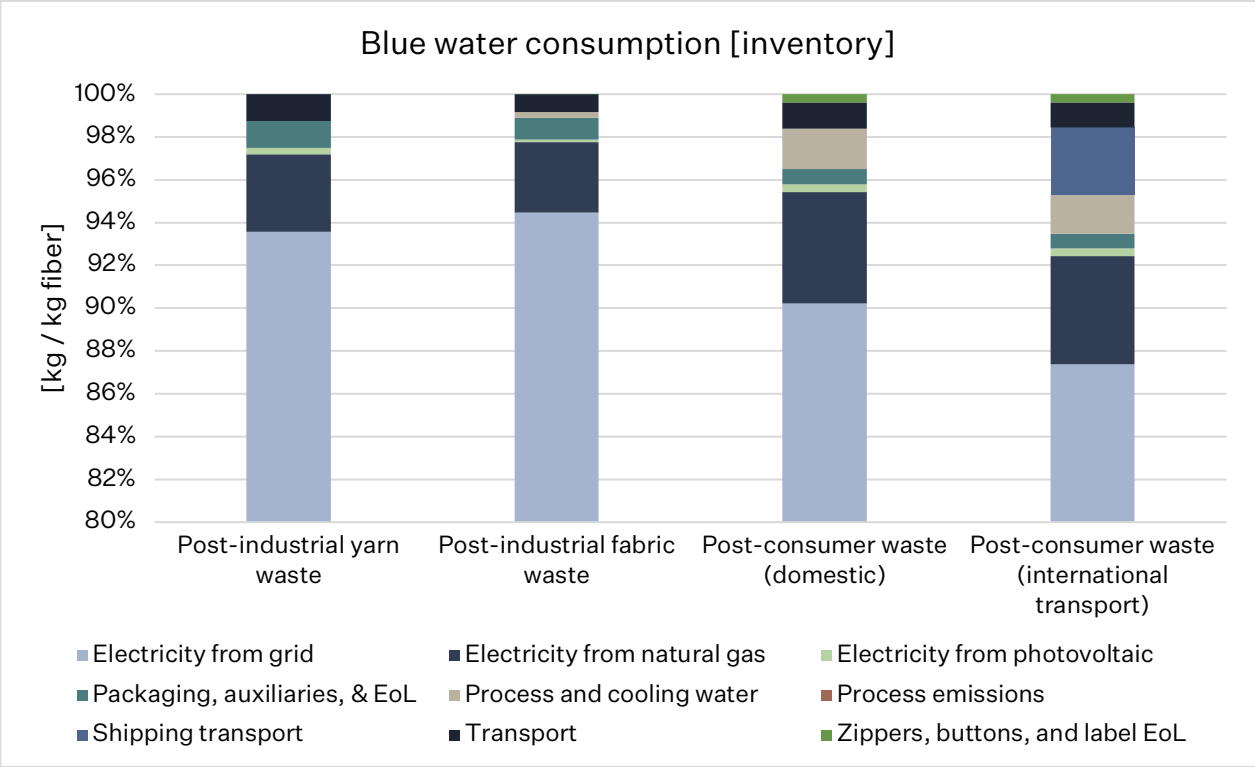

Figure 5-7: Blue water consumption, global average recycled cotton

Table 5-9: Blue water consumption, global average recycled cotton [kg/kg fiber]

	Post-industrial yarn waste	**Post-industrial fabric waste**	**Post-consumer waste (domestic)**	**Post-consumer waste (international transport)**
Electricity from grid	2.69E+00	3.39E+00	4.57E+00	4.57E+00
Electricity from natural gas	1.04E-01	1.18E-01	2.64E-01	2.64E-01
Electricity from photovoltaic	9.02E-03	4.61E-03	1.81E-02	1.81E-02
Packaging, auxiliaries, and EoL	3.63E-02	3.63E-02	3.63E-02	3.63E-02
Process and cooling water	0.00E+00	1.00E-02	9.50E-02	9.50E-02
Process emissions	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Shipping transport	0.00E+00	0.00E+00	0.00E+00	1.64E-01
Transport	3.58E-02	2.94E-02	6.16E-02	6.16E-02
Zippers, buttons, and label EoL	0.00E+00	1.26E-04	2.01E-02	2.01E-02
Total	2.88	3.59	5.06	5.23
DQL	Level 1	Level 1	Level 2	Level 2

Figure 5-7 highlights the blue water consumption inventory results are 2.88 kg for post-industrial yarn, 3.59 kg for post-industrial fabric and 5.06 kg for post-consumer waste, pertaining to the production of 1 kg of recycled cotton spinnable fiber.

For all types of recycled cotton production, the main consumption of blue water is associated with the electricity consumption which contributed 92.8-97.9% of the total blue water consumption. Process and cooling water inputs contributed between 0-1.9% of the total blue water consumption. For post-consumer waste, international shipping resulted in 3.1% contribution. All other inputs to the recycling process, including packaging, auxiliaries and process waste treatment outputs had a negligible contribution of 1.8-2.5%.

On average post-industrial yarn waste consumed 0.63 kWh/kg spinnable fiber, resulting in 2.81 kg of blue water consumption. Post industrial fabric waste consumed 0.7 kWh/kg spinnable fiber resulting in 3.51 kg of blue water consumption. Post-consumer waste required 1.075 kWh/kg spinnable fiber resulting in 4.85 kg of blue water consumption. Furthermore, for post-consumer waste, international transportation resulted in a further 0.164 kg of blue water consumption.

Ecotoxicity, freshwater

The ecotoxicity, freshwater impacts for the production of 1 kg of recycled cotton spinnable fiber from post-industrial yarn waste, post-industrial fabric waste, and post-consumer waste are shown below in Figure 5-8. The chart highlights the contribution of energy and material inputs into the recycling process, as well as process waste treatment, to the total ecotoxicity, freshwater impacts for the different types of recycled spinnable fiber.

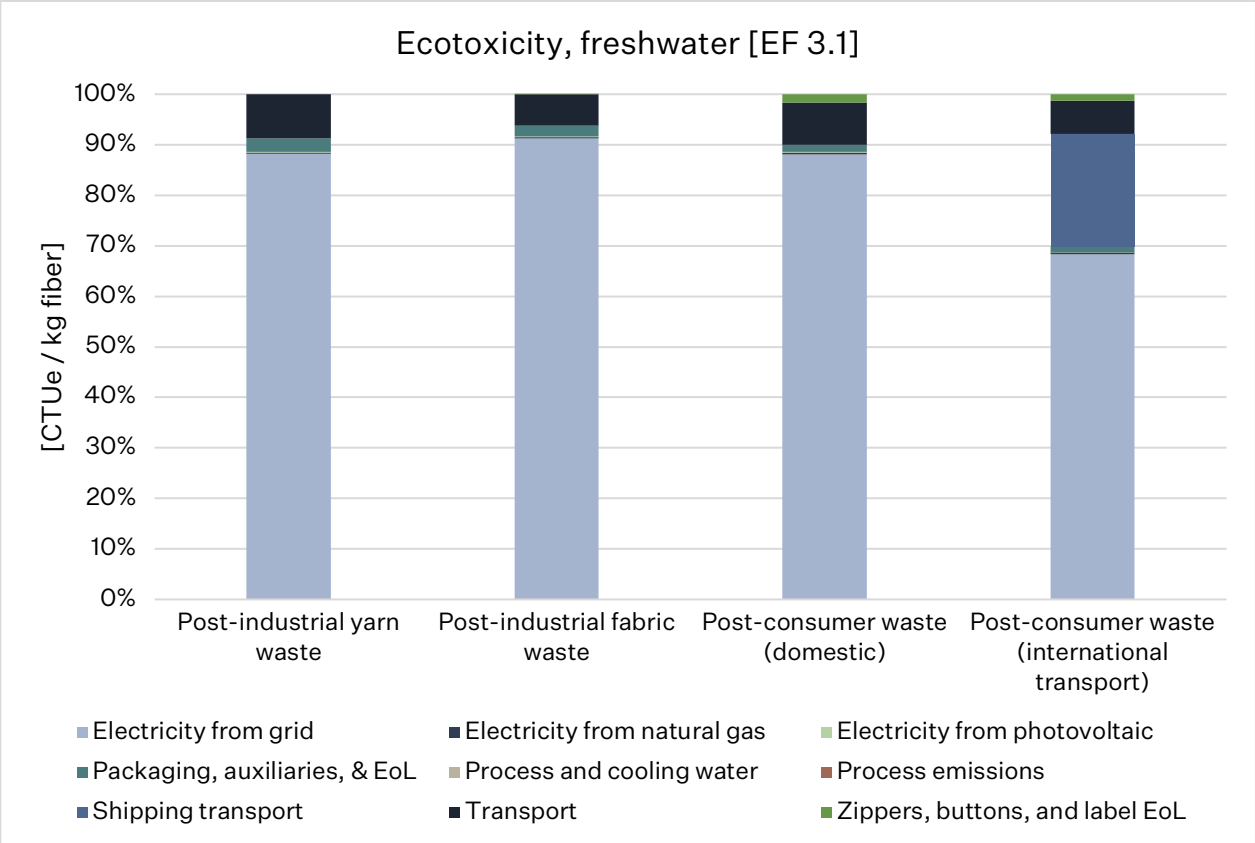

Figure 5-8: Ecotoxicity, freshwater, global average recycled cotton

Table 5-10: Ecotoxicity, freshwater, global average recycled cotton [CTUe/kg fiber]

	Post-industrial yarn waste	Post-industrial fabric waste	Post-consumer waste (domestic)	Post-consumer waste (international transport)
Electricity from grid	5.13E+00	6.27E+00	1.01E+01	1.01E+01
Electricity from natural gas	1.82E-02	2.06E-02	4.61E-02	4.61E-02
Electricity from photovoltaic	5.29E-03	2.76E-03	1.08E-02	1.08E-02
Packaging, auxiliaries, and EoL	1.54E-01	1.54E-01	1.54E-01	1.54E-01
Process and cooling water	0.00E+00	9.45E-06	7.55E-05	7.55E-05
Process emissions	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Shipping transport	0.00E+00	0.00E+00	0.00E+00	3.31E+00
Transport	5.11E-01	4.23E-01	9.65E-01	9.65E-01
Zippers, buttons, and label EoL	0.00E+00	1.20E-03	1.90E-01	1.90E-01
Total	5.82	6.88	11.48	14.80
DQL	Level 1	Level 1	Level 2	Level 2

Figure 5-8 highlights the EF 3.1 ecotoxicity, freshwater results are 5.82 kg CTUe for post-industrial yarn, 6.88 kg CTUe for post-industrial fabric, and 11.48 kg CTUe for post-consumer waste, pertaining to the production of 1kg of recycled cotton spinnable fiber.

For all types of recycled cotton production, the main driver of ecotoxicity, freshwater impacts, is electricity consumption, which contributed between 88.6–91.6% of the total results. Transportation of the cotton waste contributed between 6.2–8.8% of the total impacts. All other inputs to the recycling process, including packaging, auxiliaries, and process waste treatment outputs, had a negligible contribution at 2.2–3%.

On average, post-industrial yarn waste consumed 0.63kWh/kg spinnable fiber, resulting in 5.15 CTUe of ecotoxicity, freshwater impacts. Post-industrial fabric waste consumed 0.7kWh/kg spinnable fiber, resulting in 6.3 CTUe of ecotoxicity, freshwater impacts. Post-consumer waste required 1.075 kWh/kg spinnable fiber, resulting in 10.2 CTUe of ecotoxicity, freshwater impacts. Furthermore, for post-consumer waste, international transportation resulted in a further 3.31 CTUe of ecotoxicity, freshwater impacts.

It should be reiterated that chemical fumigants and auxiliary chemicals used to improve output fiber quality are excluded from this analysis and could have meaningful contributions, especially for post-consumer waste. Fumigation, however, was assessed in a separate scenario analysis, see section 5.2.11, where it was shown to have a negligible contribution in comparison to ecotoxicity, freshwater impacts associated with electricity consumption.

Moreover, as discussed in the cotton cultivation results, it must be emphasized again that freshwater ecotoxicity potentials vary over several orders of magnitude between substances. As a result, a small number of substances can dominate the overall impact. Accordingly, ecotoxicity results should be

interpreted with caution and require careful consideration of underlying data quality and toxicity factor availability when interpreted.

5.2. Scenario analysis

In a strict methodological sense, scenario analysis, sensitivity analysis, and uncertainty analysis are distinct approaches within life cycle assessment, each with its own objectives and techniques[32]. However, there is also conceptual and practical overlap between these methods, particularly in how they can be applied to explore variability and assess the robustness of results. In this study, especially for cotton cultivation results, the primary focus is on scenario analysis, as it was considered the most appropriate and transparent approach for addressing both uncertainty and sensitivity (interpreted here in a broader sense) in many of the cases examined.

5.2.1. Cotton cultivation—organic fertilizer provision impacts

As described in section 4.3.3, the default approach used in this study (in accordance with the Cascale Cotton LCA methodology) is to consider organic fertilizer (both farmyard manure (FYM) and compost) as a "residual" stream and not consider any provision impacts. However, the assumption of burden-free provision of organic fertilizer is a typical discussion point around cotton LCA studies (see section 1.1), potentially significantly affecting results. Therefore, the impact of including environmental burdens associated with the production of organic fertilizer is assessed through a scenario analysis.

The assumptions for constructing the scenario for assessing the environmental impacts associated with the provision of animal-derived organic and compost are documented in detail in Annex E1. Provision impacts for FYM were estimated based on FYM production rate, and animal live-weight impacts. FYM was used as proxy also for other animal-derived manures. Compost provision impacts were estimated by applying average methane and N2O emission rates reported for composting in the IPCC guidelines, and allocating them to the compost output product. Environmental impacts were assessed separately for FYM and compost, as well as in combination, to provide comprehensive insights into their potential contributions to the overall results, i.e., the following scenarios were assessed:

- Baseline: no provision impacts for organic fertilizer (see section 4.3.3)
- ORGFERT_COMBINED: Provision impacts for both compost and animal-derived organic fertilizer (FYM)
- ORGFERT_FYM: Only the provision impacts animal-derived organic fertilizer (FYM) considered
- ORGFERT_COMPOST: Only the provision impacts of compost considered

It is essential to highlight that this is a scenario-based approach, and actual assumptions and conditions may vary significantly across different production systems. The primary aim of this scenario is not to generate exact figures, but rather to provide a realistic estimation of the potential magnitude of the environmental contributions from the provision of organic fertilizers.

32 Scenario analysis is performed to compare results between different sets of assumptions or modeling choices. Sensitivity analysis is performed to test the sensitivity of the results towards changes in parameter values that are based on assumptions or otherwise uncertain. Uncertainty analysis is performed to test the robustness of the results towards the combined parameter uncertainty.

Findings

Detailed results per impact category are provided in Annex J. The approaches described above indicate that environmental impacts can substantially increase in production systems using significant amounts of organic fertilizers. The main impact areas where increases were observed are climate change and acidification. Impacts from compost provision were more relevant than those from farmyard manure (FYM). On average, impacts for the organic and regenerative systems increased by around 50% for climate change and 40% for acidification when both FYM and compost were considered. The compost-only scenario increased impacts on average by 37% for climate change and 38% for acidification. The minimum increase in the combined scenario was 15% for climate change, while the maximum reached more than a factor of two (124%). The higher the share of compost as an organic fertilizer, the greater the observed increase in impacts.

It is important to emphasize again that the presented results are based on a scenario approach, intended to provide a representative estimate of the potential order of magnitude of environmental impacts associated with the provision of organic fertilizers. Actual emissions and performance parameters can vary substantially depending on specific composting practices, feedstock composition, and system configurations. Notably, the estimate presented here reflects a conservative allocation, especially in the case of compost, in which the entire environmental burden of composting is attributed to the compost product. In practice, alternative allocation methods (for example, based on waste treatment services or multifunctionality) may yield lower results. Moreover, improvements in composting efficiency, such as optimized aeration, moisture control, or emission abatement, can significantly reduce process-related greenhouse gas emissions and, thereby, the overall carbon footprint of the compost. However, it should also be noted that while the scenario applied conservative allocation choices for organic fertilizer, the baseline scenario was not based on conservative assumptions, and thus the overall results should not be interpreted as a conservative estimate of organic fertilizer-related impacts.

5.2.2. Cotton cultivation—N_2O and NO3 emission factors—wet and dry climate

In the baseline modeling, direct N_2O emissions from nitrogen application were calculated using the aggregated Tier 1 emission factor provided in the IPCC Guidelines (IPCC, 2019), corresponding to 1% of all applied nitrogen. The IPCC also reports disaggregated emission factors of 1.6% for synthetic fertilizer in wet climates, 0.6% for other nitrogen inputs in wet climates, and 0.5% for all nitrogen inputs in dry climates[33]. It should also be noted that the classification into wet and dry conditions does not only affect direct N_2O emissions but also the emission factor for nitrate leaching. In the aggregated and wet scenario, a fixed value of 24% of applied nitrogen is assumed to leach as nitrate, whereas in the dry scenario the emission factor is set to 0%.

In this study, the use of the aggregated approach was chosen because it is consistent with country-level averaging and avoids methodological discontinuities. First, this study works with country-level averages, and agricultural production within a country often spans both dry and wet regions, such that a single classification into wet or dry is not possible. Second, the application of wet versus dry factors can introduce artificial thresholds: when a system crosses the climatic boundary, emission factors shift abruptly rather than reflecting a gradual change in conditions. Third, the treatment of

33 Climate definitions in the IPCC guideline: Wet climates occur in temperate and boreal zones where the ratio of annual precipitation: potential evapotranspiration >1, and tropical zones where annual precipitation >1000 mm. Dry climates occur in temperate and boreal zones where the ratio of annual precipitation: potential evapotranspiration <1, and tropical zones where annual precipitation <1000 mm. In wet climates, the EF1 is further disaggregated by synthetic fertilizer N inputs and other N inputs.

irrigation is not clearly specified in the guidelines, leaving uncertainty as to whether irrigated systems should be considered "wet."

To explore the potential variability introduced by these factors, a scenario analysis was conducted in which each cultivation system was alternatively modelled as entirely "wet" and entirely "dry." This provides an upper and lower boundary for nitrogen-based emissions in relation to climate classification, and highlights the sensitivity of results to the choice of emission factor specification.

The following scenarios were assessed:

- Baseline: Use of IPCC aggregated emission factors
- N_2O_DRY: All cultivation systems classified as dry
- N_2O_WET: All cultivation systems classified as wet

Findings

Detailed results per impact category are provided in Annex J. Two impact categories were directly influenced by the scenario analysis: climate change (via direct and indirect N_2O emissions) and eutrophication (via nitrate leaching emissions).

In the N_2O_DRY scenario, climate change impacts decreased across all cultivation systems, with an average reduction of 23%. The maximum decrease observed was 37%, while the minimum was 9%. Since nitrate emissions are set to zero under dry conditions, the effect on eutrophication was even more pronounced. On average, eutrophication impacts decreased by 50%, with reductions ranging from 29% to 63%.

In the N_2O_WET scenario, results were more differentiated. As the nitrate emission factor in wet conditions is identical to the aggregated baseline, eutrophication remained almost unchanged, and only climate change impacts were affected. Because the higher emission factor in wet climates applies specifically to synthetic fertilizer, cultivation systems with higher reliance on mineral fertilizers showed an increase in climate change impacts, averaging +11%. In contrast, systems dominated by organic fertilizer inputs showed a decrease in climate change impacts of 13% on average, with reductions ranging from 5% to 20%.

In conclusion, these scenarios confirm that the use of the aggregated emission factor represents a reasonable compromise when modeling at the country scale. It avoids artificial biases that could arise from a strict classification into wet or dry systems, which would otherwise favor specific fertilizer sources or production systems. At the same time, the analysis demonstrates that variability in N_2O emissions is substantial, and the reported baseline values should be interpreted as average-case estimates, recognizing that actual field emissions may be considerably higher or lower depending on local climatic and management conditions.

5.2.3. Cotton cultivation—nutrient content in organic fertilizer

As outlined in previous sections, there is considerable uncertainty regarding the nutrient content of organic fertilizers. While some data providers reported measured average nutrient concentrations, in many cases values had to be estimated from literature sources. Consequently, the actual amounts of nitrogen (N) and phosphorus (as P_2O_5) applied with organic fertilizers are subject to notable uncertainty.

To account for this, two sensitivity scenarios were developed:

- Baseline: Use nutrient content of organic fertilizer as reported (or as estimated based on secondary data)

- ORGFERT_200%: Assuming the nutrient content of all organic fertilizers is double the reported values, resulting in a doubling of nutrient application
- ORGFERT_50%: Assuming the nutrient content of all organic fertilizers is only half of the reported values, resulting in 50% of the nutrient application compared to the baseline

These scenarios provide a range for assessing the influence of uncertainty in organic fertilizer composition on the calculated environmental impacts.

Findings

Detailed results per impact category are provided in Annex J. This scenario only affected cultivation systems that rely primarily on organic fertilizer inputs (i.e., organic and regenerative systems). The impacts considered were climate change, acidification, and eutrophication.

In the ORGFERT_200% scenario, assuming doubled nutrient content and application rates, environmental impacts increased substantially: climate change impacts rose by an average of 46% over all organic and regenerative systems, ranging from +32% to +65%; acidification increased by an average of 87%, with a range of +74% to +93%, and eutrophication increased by an average of 70%, with a range of +52% to +92%.

In the ORGFERT_50% scenario, assuming halved nutrient content and application rates, the opposite effect was observed: climate change impacts decreased by an average of 23% over all organic and regenerative systems (−32% to −16%), acidification decreased by an average of 43% (−47% to −37%), and eutrophication decreased by an average of 35% (−46% to −26%).

As highlighted in earlier sections of this report, nutrient application rates strongly determine field emissions and, consequently, the associated impacts on climate change, acidification, and eutrophication. The large variations observed in this scenario analysis are, therefore, not unexpected.

For correct interpretation, the nitrogen balance of the systems (see Annex G.1.1) should be considered. Among the organic and regenerative systems, some already exhibit a nitrogen surplus under baseline assumptions, while others show a balanced situation or even a deficit. Against this background, the ORGFERT_200% scenario is likely more realistic for systems with a nitrogen deficit, whereas the ORGFERT_50% scenario may better reflect the potential impacts of systems that show a surplus in the reported data.

In general, the scenarios highlight the importance of nutrient application in relation to yield for a correct impact assessment. Specific care should, therefore, be given to these parameters in data collection and inventory data compilation.

5.2.4. Cotton cultivation—emission modeling and fertilizer inventory—N-balance approach

The IPCC provides a default emission factor for nitrate emissions, 24% of the nitrogen applied is being lost as emissions via leaching (aggregated and wet climate). This value represents a rough estimate and can lead to unrealistic emissions. As an example, systems that are running on low N-input and still report high yields might drain nitrogen from the soil, which would need to be replaced later, or such systems could not be maintained over long periods of time. A simple default value can also lead to unrealistically low emission results for crops that receive a substantial surplus. In any case, the approach using the IPCC default will lead to a nitrogen balance that is not closed (emissions + uptake <> input). Therefore, Sphera's Agricultural LCA Model can optionally consider the recommended N-balance approach as documented in the PEF method (European Commission, 2021):

- In case of a nitrogen surplus in the soil, the surplus of nitrogen is assumed to be lost via nitrate leaching
- In case of a nitrogen deficit, the missing nitrogen is inventoried as additional fertilizer input (incl. related emissions)[34]

This approach ensures a consistent and conservative estimation of leaching losses and avoids underreporting in low-input systems. The total nitrate emissions to water are calculated as:

Total NO_3^-–N emissions to water = Base NO_3^- loss + Additional NO_3^-–N emissions

Where:

Base NO_3^- loss is assumed to be a fixed 10% of the nitrogen input (from all fertilizers)

Additional NO_3^-–N emissions are calculated as:

N input (fertilizers) – N removed with harvest[35]. – NH_3 – N_2O – N_2 emissions – base NO_3^- loss

If the resulting additional NO_3^-–N emissions are negative, they are set to zero. Moreover, the equivalent amount of "missing" nitrogen is treated as an additional fertilizer input, using the same combination of N-fertilizers as employed to the analyzed crop. The N balance (N input of fertilizer minus crop uptake) of each product system under study is provided in Annex G.

The following two scenarios are assessed:

- Baseline: Using IPCC default emission factor of 24% of applied N for nitrate emissions
- N_BALANCE: using the N-balance-based approach as described above to estimate nitrate emissions

Findings

Detailed results per impact category are provided in Annex J. The N-balance scenario primarily affected the impact categories of climate change, acidification, and eutrophication, with additional effects observed in ADP in cases where mineral fertilizer use increased. In systems reporting a nitrogen deficit, additional fertilizer was inventoried to close the balance, which increased both field emissions and upstream provision impacts (including ADP). Systems with a large nitrogen surplus showed higher nitrate emissions than the fixed 24% assumed under the IPCC baseline, resulting in increased eutrophication impacts.

On average, across all cultivation systems, climate change impacts increased by 13%, with changes ranging from no change to an increase of 52%. Acidification impacts showed the strongest response, with an average increase of 31% and variations ranging from no change to a maximum increase of 121%. Eutrophication impacts were more balanced: on average, a small decrease of 1% was observed, but results ranged from decreases up to 29% to increases up to 37%.

As expected, increases were most pronounced in systems with a nitrogen deficit, where the N-balance approach inventories additional fertilizer and related emissions. Systems with a strong nitrogen surplus tended to show higher eutrophication impacts with the N-balance approach due to larger assumed nitrate losses compared to the IPCC fixed factor. Acidification impacts showed the highest increase in systems with organic fertilizer use and negative N-balance, as the N-balance approach leads to additional virtual fertilizer application (the fertilizer application rate of the applied

34 An additional argument to equal out a nitrogen deficit is that this is expected to occur in real practice, where additional nitrogen might be applied the following crop, compensating for the loss of N from the previous crop.

35 In this case: seed cotton (fiber and seed), assumed N content 3.3%, based on USDA. (2021). Plant Nutrient Tool.

fertilizers is increased). Since organic fertilizers show a larger contribution to acidification (see Annex G.1.2), the N-balance approach increases acidification impacts disproportionately in these systems.

This scenario offers an interesting additional option to assess impacts, addressing, at least to some extent, the uncertainty identified in the two previous scenarios (section 5.2.2 emission factor specification and section 5.2.3 nutrient content in organic fertilizer). It helps to avoid underestimating impacts in fertility-depletion schemes by explicitly accounting for nitrogen removed by the crop that would otherwise require replenishment to maintain soil fertility (European Commission, 2021). The method also supports consistency between reported yields and fertilizer-application data, offering a conservative approach that reduces the risk of underreporting emissions in systems that show negative N balances.

Another advantage of the N-balance approach is its practicality. Unlike more sophisticated Tier 2 nitrate emission models, it does not require additional soil or climate data. This makes it a feasible option for large-scale agricultural LCA studies where detailed site-specific information is unavailable. Sphera already applies this method in its dataset generation (Sphera Solutions Inc., 2024b), and its broader adoption could be considered to improve consistency and robustness in agricultural LCA studies.

5.2.5. Cotton cultivation—ecotoxicity characterization factors

As discussed in previous sections, several sources contribute to the uncertainty of ecotoxicity results. These include uncertainties at the inventory level (which active ingredients are applied and in what amounts), the emission factors to different environmental compartments (air, water, soil), and the characterization factors used for impact assessment. In this study, an effort was made to compile specific pesticide inventories and use specific characterization factors. However, to better understand the uncertainty associated with ecotoxicity characterization factors, the following scenario was assessed:

- Baseline: Specific active ingredients were modeled, each with its respective characterization factor.
- TOX_UNSPECIFIC: All active ingredients and their application rates were aggregated and represented as an "unspecific pesticide." For this, the average characterization factor of the 50 most widely used pesticides (according to CHEMGRIDS data, not cotton-specific) was applied.

Findings

Detailed results per impact category are provided in Annex J. On average, across all cultivation systems (including those with biopesticide application in organic and regenerative systems), ecotoxicity results decreased by around 20% when all pesticides were classified as unspecific. If only the country-average systems were considered, i.e., those using synthetic pesticides, the decrease was also approximately 20% compared to the baseline.

However, the range of results was large. In India and the US, where primary data was available for pesticide inventories, ecotoxicity impacts decreased strongly under the unspecific pesticide assumption, by 77% and 53%, respectively. As explained in section 5.1.1, ecotoxicity results, a single substance with a high characterization factor can dominate results even if applied at low rates. When such a substance is reported in primary data, the results are strongly influenced by it, and this effect disappears if all substances are aggregated as unspecific.

At the same time, given that ecotoxicity results can easily span several orders of magnitude, the scenario indicates that the approach applied in this study leads to results that are reasonably well

aligned and within a plausible range. For biopesticides, the results further show that the unspecific pesticide characterization factor is approximately 50% lower than the factor used for the proxy substance used for biopesticides (azadirachtin). This confirms that the current modeling of biopesticides follows a conservative approach for organic systems.

Overall, the scenario highlights the sensitivity of ecotoxicity results to both inventory detail and characterization factors. While the unspecific classification smooths out extreme values, it obscures the influence of single substances with high toxicity potentials and, therefore, reduces informational value. The baseline approach, which uses substance-specific inventories and characterization factors, provides a more transparent and differentiated picture, even though uncertainty remains high.

5.2.6. Cotton cultivation—comparing primary and secondary data collection approach for the US and India

As outlined in 4.1.1, secondary data for country averages were compiled for regions without primary data (notably for Brazil and Türkiye). This approach mainly relied on ICAC statistics, supplemented with additional literature sources (see section 4.1.1 for details). In contrast, country averages for the US and India were established based on primary data collection.

To test the robustness of the secondary data compilation approach, this scenario compares the outcomes for the US and India when modelled using the same secondary data compilation approach applied to Türkiye and Brazil. In other words, instead of primary data, country averages for the US and India were generated using ICAC data. The following scenarios were therefore assessed:

- Baseline: US and India country averages based on primary data (see section 4.2.2).
- ICAC data: US and India country averages based on the secondary data approach, using ICAC statistics and supporting literature.

Findings

Results for the scenarios are shown in Table 5-11.

Table 5-11: Comparing primary and secondary data collection approach for the US and India

	Unit	IN country average	IN ICAC	US country average	US ICAC
Results					
Climate change [IPCC AR6 GWP 100, excl biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.17	4.11	1.55	1.75
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.15	0.03	0.04
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.054	0.066	0.015	0.018
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.3	35.9	14.3	16.1
Blue water consumption [inventory]	kg/kg fiber	3177.4	3778.5	1118.2	2072.8

	Unit	IN country average	IN ICAC	US country average	US ICAC
Water resources depletion/scarcity [EF 3.1 Water use]	m^3 eq./kg fiber	111.0	111.1	37.8	70.0
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2826.8	507.0	906.4	507.0
Nitrogen balance	kg N/ha	99.6	96.5	23.0	23.6
Scenario vs. baseline (% increase or decrease)					
Climate change [IPCC AR6 GWP 100, excl biogenic CO_2, including Land Use Change]	%	-1%		13%	
Acidification [EF 3.1]	%	25%		20%	
Eutrophication [CML 2016]	%	22%		18%	
Abiotic Depletion Potential (ADP fossil) [CML 2016]	%	-11%		13%	
Blue water consumption [Inventory]	%	19%		85%	
Water resources depletion/scarcity [EF 3.1 Water use]	%	0%		85%	
Ecotoxicity, freshwater [EF 3.1]	%	-82%		-44%	
Nitrogen balance	%	-3%		3%	

For India, most categories remain well within range: climate change (−1%), abiotic resource/energy use (~+19%), blue-water consumption (+19%), water scarcity (~0%), and nitrogen balance (−3%). Two categories show moderate upward shifts: acidification (+25%) and eutrophication (+22%). Ecotoxicity shows a large decrease (−82%), consistent with the loss of substance-specific pesticide detail when moving from primary inventories to a generic secondary data compilation as discussed in the previous section (section 5.2.5). For the US, most categories are also well within range: climate change (+13%), eutrophication (+18%), nitrogen balance (+3%), acidification (+20%), and ADP (+ 13%). Large deviation is observed for blue-water consumption (+85%), and water scarcity (+95%). This can be traced directly back to the irrigation water data reported for the US in ICAC (ICAC, 2024), where, after the in-depth review of the US irrigation water values used in this study, it is assumed that the ICAC values might refer to NASS data, but does not consider the fraction of farmers that irrigate.

Ecotoxicity decreases substantially (−44%), again reflecting the use of a more generic pesticide use profile in the ICAC-based inventory.

Overall, the scenario shows that the secondary data approach can serve as a pragmatic proxy in the absence of detailed primary data. However, the extent of deviation observed is significant enough that particular care must be taken when using such data for decision-making. The variation identified in the US case, where statistical data compilation is comparatively advanced, suggests that even larger discrepancies may occur in regions where statistical data compilation is less developed or less consistent. Therefore, while the general trends remain consistent, the magnitude of differences should not be interpreted as negligible, and efforts to obtain more granular, locally representative inventory data remain strongly justified. Uncertainty is particularly high for pesticide inventories and the related ecotoxicity impacts, as discussed in the previous section. This uncertainty is partly due to the USEtox characterization method, in which single substances applied in small amounts, but with

very high toxicity factors, can significantly influence results, sometimes increasing impact scores by multiples or even by orders of magnitude.

At the same time, this underlines that ecotoxicity results for Brazil and Türkiye need to be interpreted with particular care. While the secondary datasets may represent average toxicity levels of pesticides typically applied in these cultivation systems, they cannot capture specific cases where highly toxic substances are used. If such substances were considered explicitly, toxicity impacts could increase substantially compared to the averages reported here for these countries.

5.2.7. Cotton cultivation—renewable energy at gin

Some data providers for regenerative and organic cotton in India reported the use of renewable energy at the gin. However, it was often unclear how the reported fraction of renewable energy was defined and how it related to the renewable energy share already present in the national grid mix. Furthermore, as noted in section 4.1.1, referring to secondary data use for ginning, the ginning process itself is not specific to the cultivation system. It was, therefore, uncertain whether the reported use of renewable energy should be applied only to those cultivation systems that mentioned it. As a conservative approach, in the baseline, the country-specific national grid mix was used to model electricity consumption for ginning. In this scenario, it is assumed that all electricity used in ginning is supplied from renewable sources (see section 4.5.1 on background data for the dataset applied). This scenario, therefore, illustrates the reduction potential achievable by decarbonizing the ginning step through a full switch to renewable electricity, and places these potential benefits in the context of the overall life cycle impacts of cotton fibers. The following scenarios were therefore assessed:

- Baseline: Country-specific grid mix used for electricity use at gin
- Renewable energy at gin: Electricity used in ginning is supplied from renewable sources

Findings

Detailed results per impact category are provided in Annex J. Assuming that all electricity used in ginning is supplied from renewable sources, this influenced all impact categories except eutrophication. On average across all cultivation systems, climate change impacts decreased by 9%, in direct relation to the impact of the ginning process on overall impacts in the baseline scenario. This also means that the highest reductions (up to 20% for climate change) were observed in systems where ginning electricity represents a relatively large share of the overall footprint.

Reductions were also visible for ADP, reflecting the relevance of fossil-based electricity generation for this impact category. In addition, small decreases in water scarcity were observed in systems without irrigation, where background processes such as electricity production are the only contributors to water scarcity. However, these absolute reductions were very low and of minor relevance compared to irrigation-related water consumption.

5.2.8. Recycled cotton—country-specific electricity characterization scenario and energy generation scenario

The mechanical recycling of cotton waste is an energy-intensive industrial process, and the electricity consumption is responsible for the most significant contribution to the environmental impacts of the production of recycled spinnable fibers. The environmental impacts associated with electricity consumption can vary significantly based on the generation method, or the country-

specific share of generation methods within the national grid. The influence of these factors is investigated in a scenario analysis.

Table 5-12 provides the LCI for each waste type for each electricity generation method used in the scenario analysis.

Table 5-12: Recycled cotton LCI, average electricity consumption by generation method

	Post-industrial yarn waste	Post-industrial fabric waste	Post-consumer waste (domestic/international transportation)	units
Electricity from grid	0.4663	0.5531	0.6825	kWh
Electricity from natural gas	0.0971	0.1103	0.2462	kWh
Electricity from solar	0.0666	0.0374	0.1464	kWh
Total electricity consumption	0.63	0.7008	1.0751	kWh

Country-specific electricity characterization analysis

A scenario analysis was undertaken to investigate the effect of how the country of production could impact the environmental impacts of the production of recycled spinnable fibers. This analysis assumes that the equivalent share of electricity consumption and generation methods as the global average LCI for each cotton waste type. Energy datasets were then changed from the global average regionalization mix to 100% regionalization to a low impact country of production (optimistic scenario) and 100% regionalization to a high impact country of production (pessimistic scenario). More information can be found in Annex E.3.

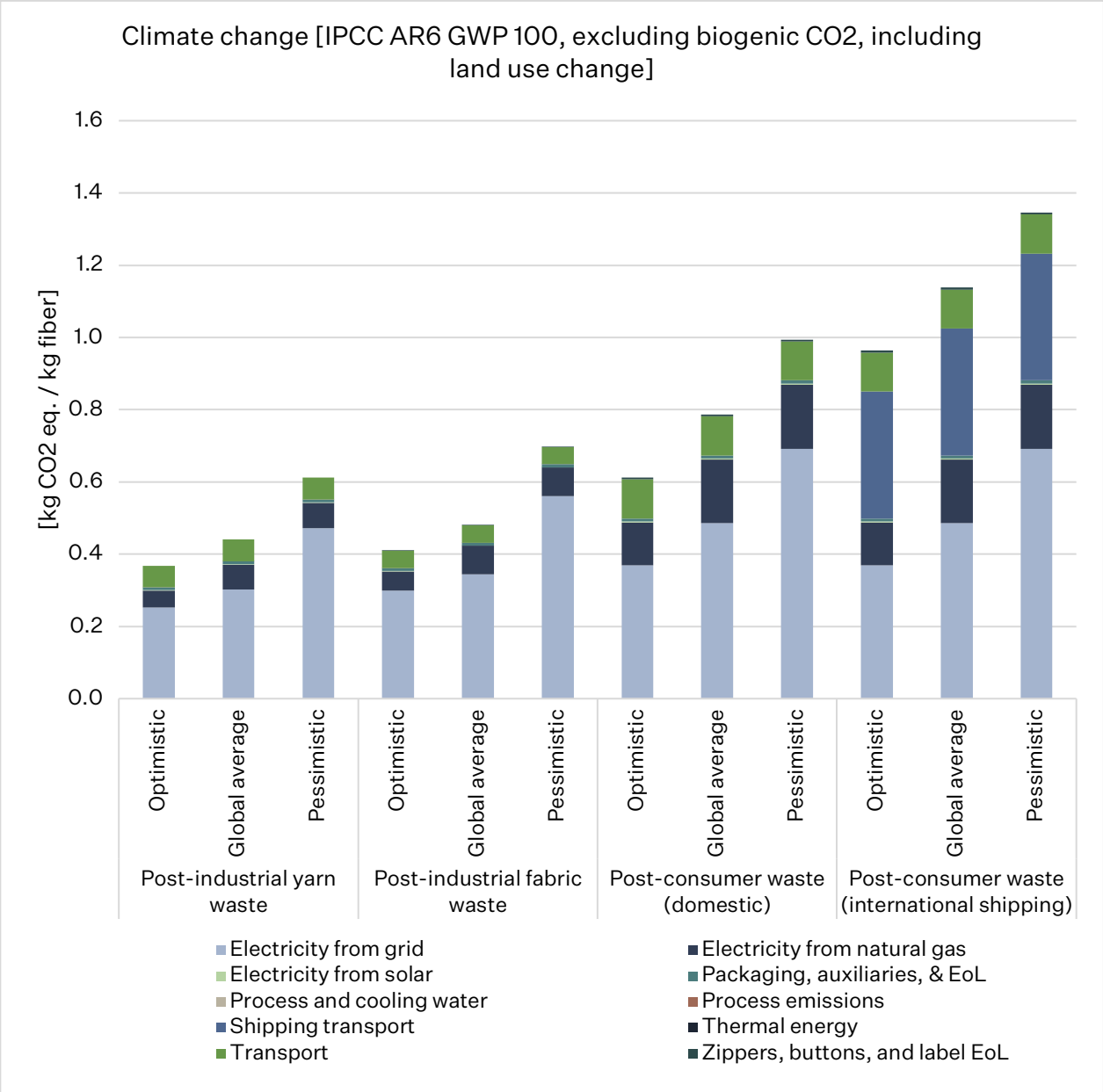

Figure 5-9: Climate change impacts of recycled cotton, including optimistic and pessimistic country-specific production impacts

The scenario analysis, as seen in Figure 5-9, highlights how a change from global average production, to the production of recycled spinnable fibers in an "optimistic" or "pessimistic" scenario, based on national variability in impacts associated with electricity generation methods, can affect potential environmental impacts.

In comparison with the respective global averages, impacts for the optimistic and pessimistic scenarios varied between 0.368–0.612 kg CO_2 equivalents for post-industrial yarn, 0.409–0.697 kg CO_2 equivalents for post-industrial fabric, 0.612–0.994 kg CO_2 equivalents for post-consumer waste (domestic), and 0.964–1.346 kg CO_2 equivalents for post-consumer waste (international transportation). Overall, for all cotton waste types, the optimistic scenario showed a reduction in GWP impacts of between 14.8%–22.2% compared to the global average while, conversely, in the pessimistic scenario there was a 18.3%–45.2% Increase in GWP impacts compared to the global average, highlighting how the intensity of electricity generation methods, particularly the country-

specific grid mix, is an important factor, along with the energy intensity of the production process, in regard to the overall impact of production.

Energy generation scenario analysis

A scenario analysis was undertaken to investigate the effect of a change in electricity generation methods to 100% solar (optimistic scenario), or 100% hard coal (pessimistic scenario), to highlight the change in potential environmental impacts from the choice of electricity generation sources. More Information can be found In Annex E.3.

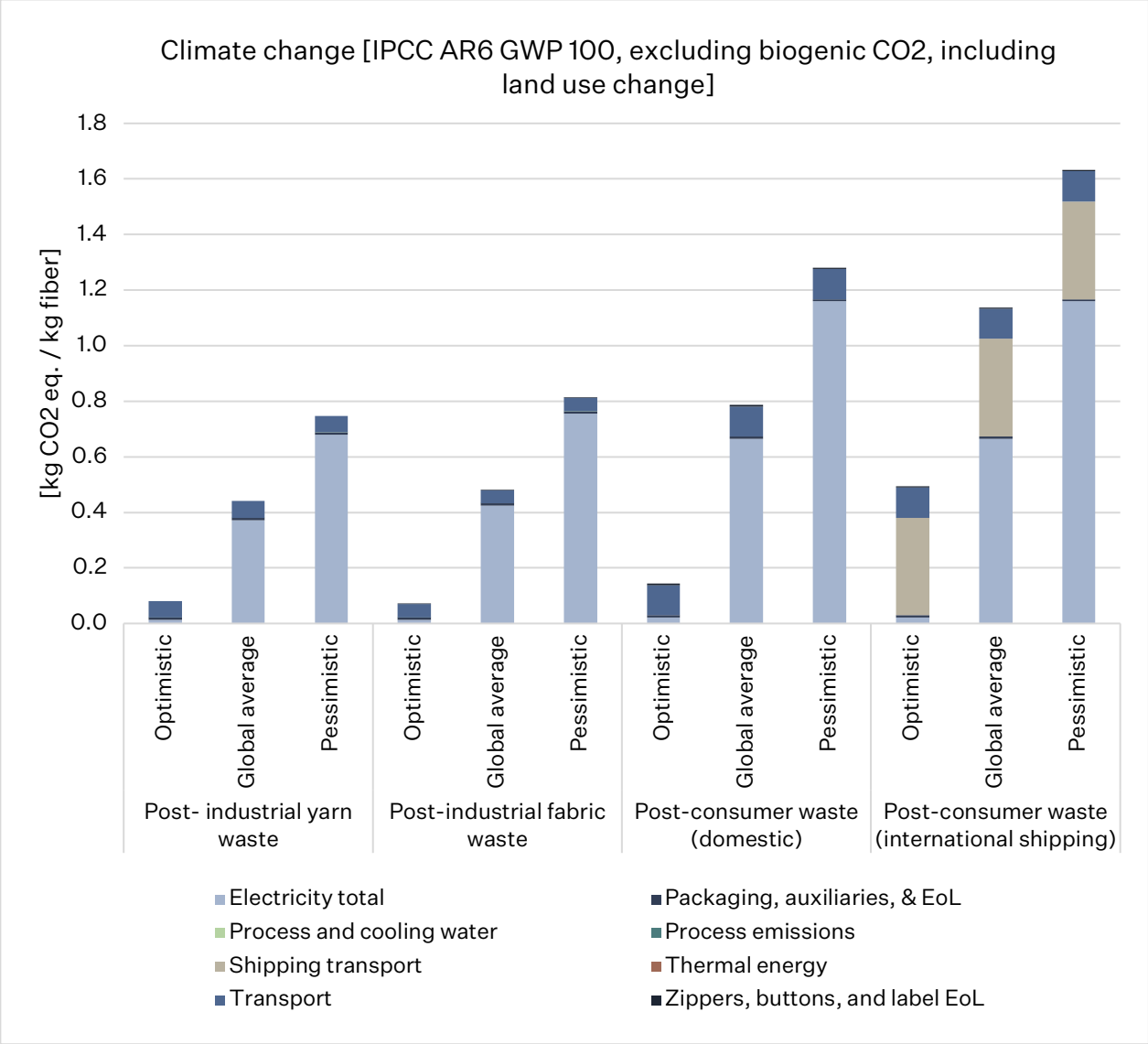

Figure 5-10: Climate change impacts of recycled cotton, including optimistic and pessimistic electricity generation scenarios

The scenario analysis, as seen in Figure 5-10, highlights how a change from global average electricity consumption from grid, natural gas, and solar generation methods, to production of recycled spinnable fibers from 100% electricity from photovoltaic or hard coal for the "optimistic" or "pessimistic" scenarios, respectively, can affect potential environmental impacts.

In comparison to the respective global averages, impacts for the optimistic and pessimistic scenarios varied between 0.081–0.748 kg CO_2 equivalents for post-industrial yarn, 0.07–0.812 kg CO_2 equivalents for post-industrial fabric, 0.143–1.281 kg CO_2 equivalents for post-consumer waste

(domestic), and 0.495–1.633 kg CO_2 equivalents for post-consumer waste (international transportation). This scenario highlights the significant decarbonization potential of switching to electricity generated from photovoltaics, which resulted in an 81.6–85.4% reduction of impacts for cotton-waste types (excluding the international transportation scenario).

5.2.9. Recycled cotton—international shipping of post-consumer waste

As part of the data collection process for all cotton-waste types, the truck transportation distance of the cotton waste from the domestic Tier 1 supplier to the recycling facility was collected. For post-consumer waste, specifically, no LCI was provided on international transportation distances. However, for this waste type, the impacts of international shipping are well documented and are a typical discussion point in both public discourse and in cotton LCA studies (see section 1.1), due to the potential significance of the inbound transportation impacts on the results. Therefore, the environmental burdens associated with the international shipping of post-consumer waste were assessed through a scenario analysis, and the results of this scenario were utilized to develop an additional baseline scenario for post-consumer waste (international transportation), which was informed by the "average" scenario. The scenario analysis evaluates the IPCC AR6 GWP impacts for three scenarios, including an "optimistic" and a "pessimistic" case, which assess the potential variation in impacts depending on the shipping distances considered.

The scenario for assessing the environmental impacts associated with the international shipment of post-consumer cotton waste was constructed using the following assumptions:

- COMM trade data, "used clothing" HS code 6309 (United Nations, 2025), was utilized to quantify the country-specific share of imported post-consumer waste for each of the countries and grouped by continent (Table 5-13). HS code 6310[36] was not included.
- Distances between major ports were calculated and used to derive a plausible range of distances for the scenarios (optimistic, average, and pessimistic) (Table E-4, Table 5-13).
- Each scenario considers truck transportation (import and export country) and shipping transportation.
- Fuel datasets have been regionalized for the export country (truck, ship) and import country (truck). A conservative assumption on exporting country fuel dataset regionalization was utilized (RER dataset for diesel and heavy fuel oil), whereas import country fuel datasets are specific to the country of import.

Table 5-13: International transportation scenario distances

	Post-consumer waste (international transportation)			
Transportation	**Unit**	**Optimistic**	**Average (baseline)**	**Pessimistic**
Truck distance (export country)	Km	250	500	1,000
Shipping distance (export country)	Km	5,000	10,000	20,000
Truck distance (import country)	Km	250	500	1,000

36 Since 2021, China has prohibited the import of post-consumer textile waste (European Commission, 2024), HS code 6310 "Used or new rags, scrap twine, cordage, rope and cables and worn-out articles of twine, cordage, rope or cables, of textile materials".

It is essential to highlight that this is a scenario-based approach, and actual assumptions and conditions may vary significantly across individual cotton recyclers, depending on the country of production and where they source their post-consumer waste. The primary aim of this scenario is not to generate exact figures, but rather to provide a realistic estimation of the potential magnitude of the environmental contributions from the international shipping of post-consumer textile waste, so that a clear distinction can be drawn between the potential environmental impacts of recycled spinnable cotton fibers produced from domestic post-consumer waste and internationally imported post-consumer waste. It is, therefore, the responsibility of the company procuring recycled spinnable fibers to engage directly with its supply chain to understand where post-consumer waste is sourced, to effectively estimate the potential magnitude of the environmental contributions from international shipping within its purchased recycled spinnable cotton fibers.

The climate change impacts for international inbound transportation of the post-consumer waste input for the production of 1 kg of recycled cotton spinnable fiber (excluding recycling impacts) are shown below in Figure 5-11. The chart highlights the potential climate change impacts associated with international shipping and truck transportation (import and export countries).

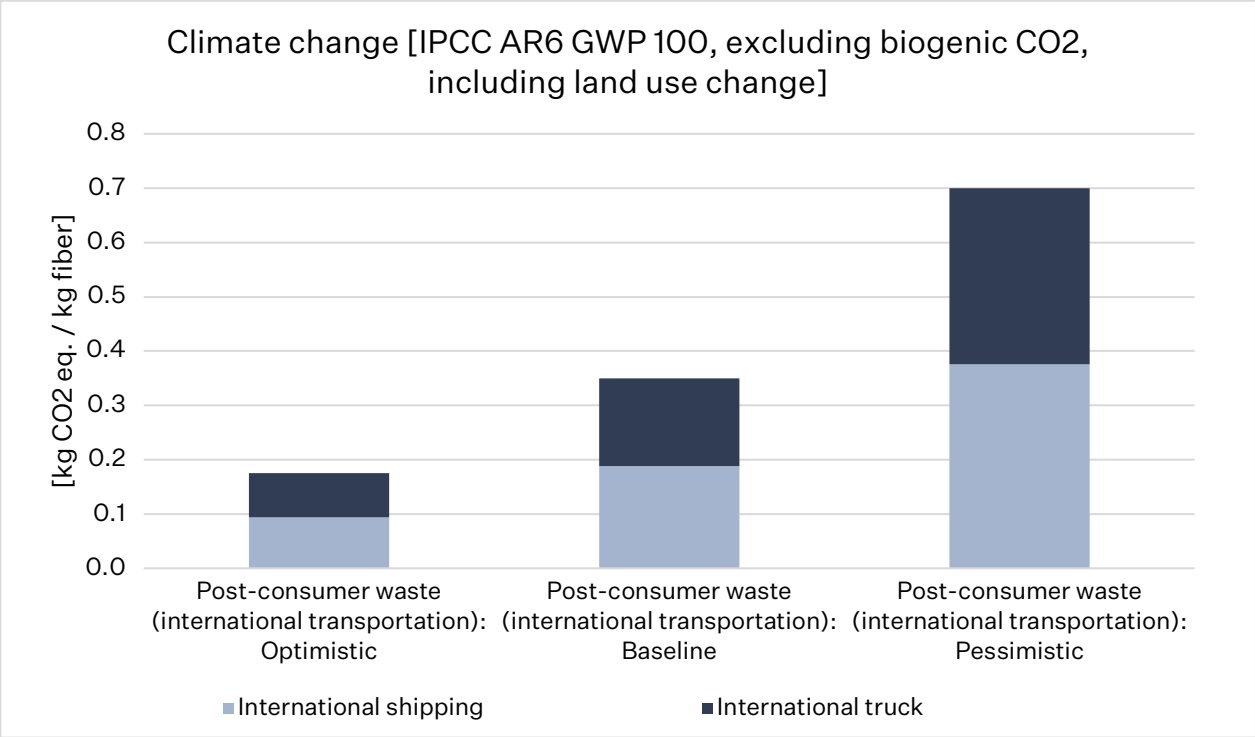

Figure 5-11: Climate change—international transportation of post-consumer waste

Figure 5-11 highlights that the IPCC AR6 GWP 100 results are 0.175 kg CO_2 equivalents for the best-case scenario, 0.35 kg CO_2 equivalents for the average scenario, and 0.7 kg CO_2 equivalents for the worst-case scenario, pertaining to the internationally shipped post-consumer waste required for the production of 1 kg of recycled cotton spinnable fiber.

For all three international shipping scenarios, the shipping impacts contributed 53.6% of the total results, and the truck transportation contributed 46.4% of the impacts.

The climate change impacts for the production of 1 kg of recycled cotton spinnable fiber from post-consumer waste, including international transportation, are highlighted in Figure 5-12. The chart highlights the contribution of the recycling process, as well as international shipping and truck transportation, to the impacts of climate change.

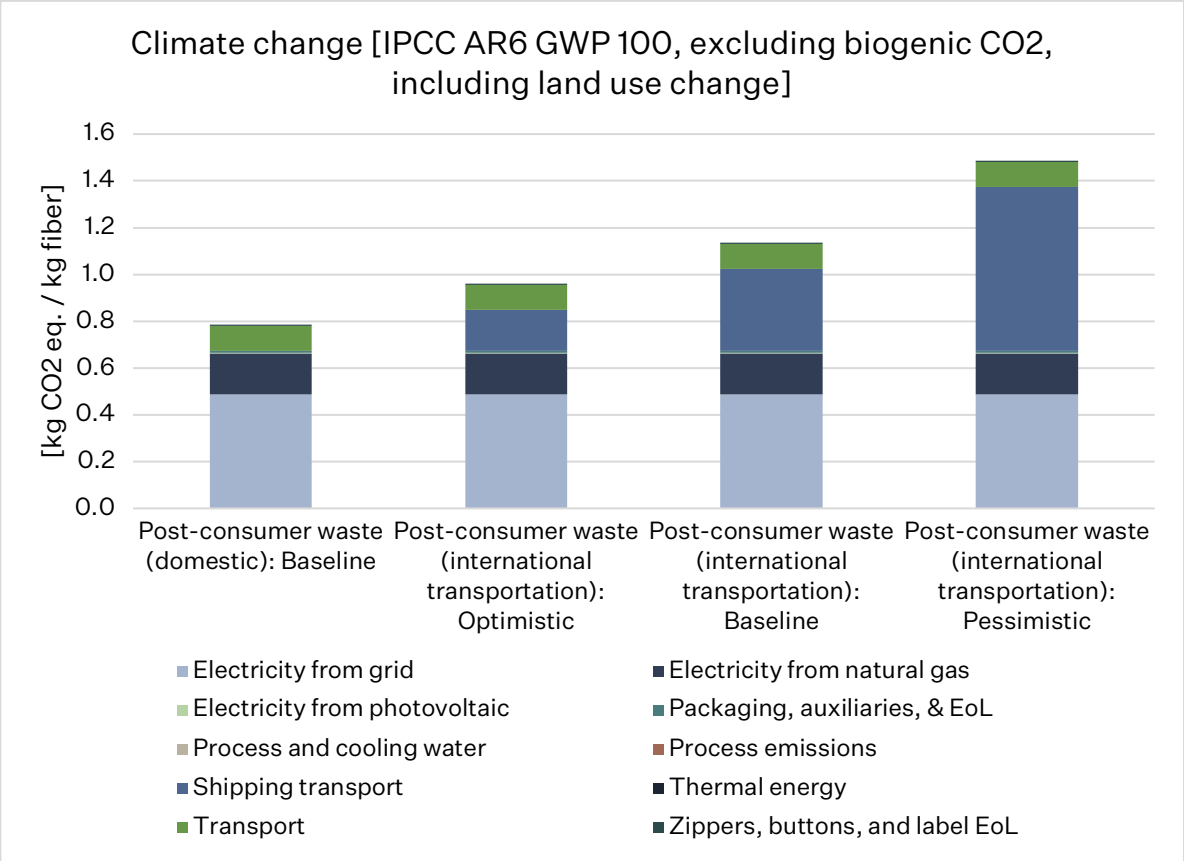

Figure 5-12: Climate change impacts, domestic and international post-consumer waste

Figure 5-12 highlights that the IPCC AR6 GWP 100 results are 0.786 kg CO_2 equivalents for the baseline domestic post-consumer waste scenario, 0.961 kg CO_2 equivalents for the optimistic international post-consumer waste scenario, 1.13 kg CO_2 equivalents for the average international post-consumer waste scenario, and 1.487 kg CO_2 equivalents for the pessimistic, international post-consumer waste scenario, pertaining to the production of 1 kg of recycled cotton spinnable fiber.

The chart clearly demonstrates the significance of international transportation to climate change results (18.2–47.1%) and the importance of the source of the post-consumer waste within the recycled cotton supply chain. In comparison to domestic post-consumer waste, international inbound transportation could increase the impacts of recycled spinnable fiber production by between 22.3% and 89.2%.

5.2.10. Recycled cotton—washing and drying of post-consumer waste

Post-consumer textiles can require washing and drying to remove contaminants, such as sweat and dirt. There are many points at which washing and drying can happen within the broader recycling system, however, many of these are outside the system boundaries; for example, downstream as part of the final textile finishing process, or upstream by the consumer, prior to processing and sorting at the recycling collection point, if necessitated as a requirement of the collection process[37]. Within the

37 Some consumers may choose to clean used textiles prior to recycling and, in some cases, washing and drying may be necessitated, if contaminated textiles would otherwise be rejected as part of the collection process. Typically, the "point of waste" within a mechanical recycling product system refers to the waste collection point or the sorting and processing center. In the case that a washing and drying step does occur, the impacts of washing and drying by the consumer prior to

system boundaries of the recycling process, washing and drying is very uncommon; for example, at the recycling collection center, the use of UV or ozone for sterilization[38] is a more common practice. Furthermore, at the mechanical recycling facilities, washing and drying is not a common practice. However, in rare circumstances, it can be necessary to remove unforeseen contaminants if, for example, it is deemed that contaminants could impair or damage the function of the recycling machinery. Therefore, despite the infrequency of this process step, given the significant potential environmental impacts, the scenario analysis is provided to highlight the importance of mitigating washing and drying where feasible.

The scenario concerns a conventional washing and machine drying process. Washing inventory includes electricity, water, and mild detergent containing surfactants. Drying inventory includes electricity. The electricity LCI is aggregated between both washing and drying. For more information on sources of LCI, please see Annex E.5. Due to challenges regarding the availability of washing and drying LCI data, and uncertainty regarding the representativeness, as well as the significant potential impacts identified from the scenario analysis, a sensitivity analysis was also undertaken and forms part of the scenario analysis.

It should be noted that Table 5-14 expresses the washing and drying inventory per kg of post-consumer cotton waste; however, on average, there was 1.788 kg of post-consumer cotton waste required to produce 1 kg of recycled spinnable fiber. An LCI table, according to the FU, is provided in Annex E.5.

Table 5-14: Washing and drying of post-consumer cotton waste LCI (domestic and international transportation)

	Washing and drying scenario—optimistic	**Washing and drying scenario—baseline**	**Washing and drying scenario—pessimistic**	**unit**
Inputs				
Post-consumer cotton waste (contaminated)	1	1	1	kg
Mild detergent	0.0085	0.017	0.0255	kg
Electricity	0.46	0.93	1.39	kWh
Water use	16.67	33.33	50	kg
Outputs				
Cotton waste (washed and dried)	1	1	1	kg
Water to WWTP	16.68	33.35	50.03	kg

delivery to the recycling collection point would be allocated to the use phase of the textile, rather than the upstream impacts of the recycling process.

38 Ozone and UV sterilization used to kill bacteria or other living microorganisms and is not functionally equivalent to washing, which is used to effectively remove contaminants such as dirt or stains.

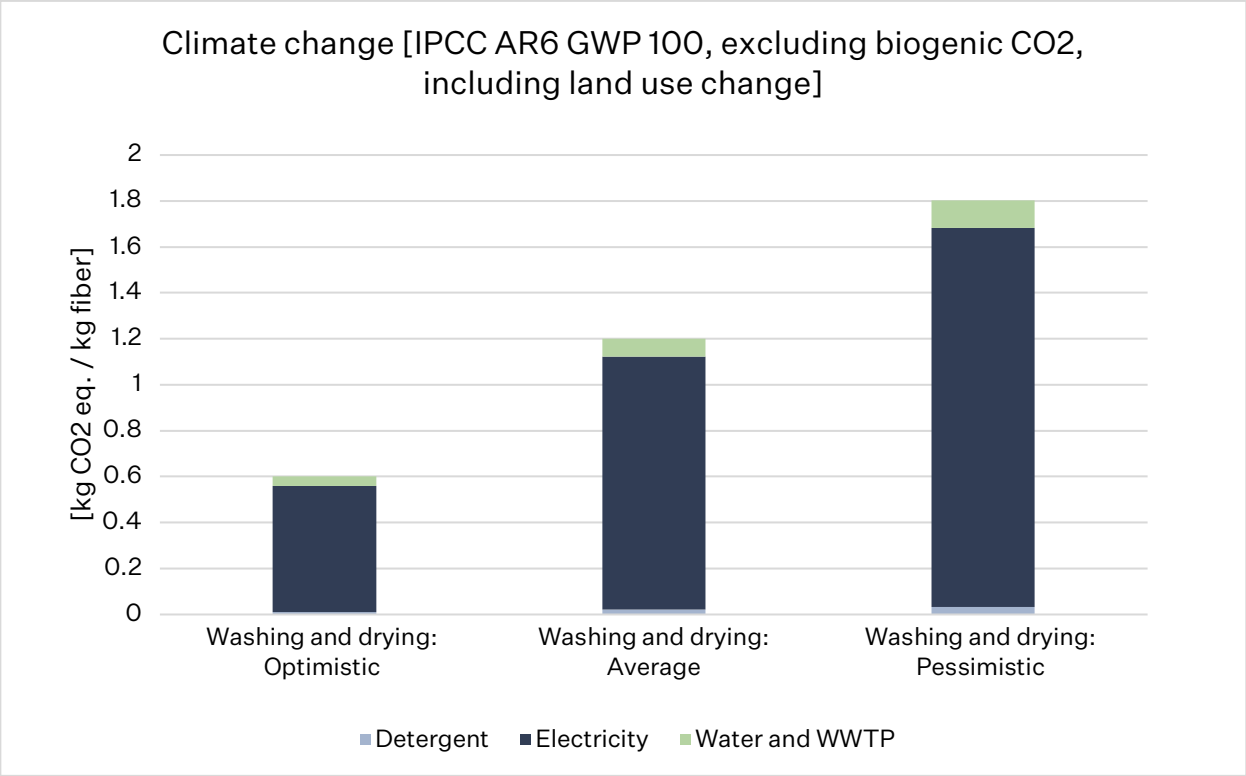

Figure 5-13: Climate change impacts associated with washing and drying post-consumer cotton waste

Figure 5-13 highlights the IPCC AR6 GWP 100 impacts for the different washing and drying scenarios. Climate change impacts are 0.601 kg CO_2 equivalents for the optimistic scenario, 1.201 kg CO_2 equivalents for the baseline scenario, and 1.802 kg CO_2 equivalents for the pessimistic scenario, pertaining to the production of 1 kg of recycled cotton spinnable fiber. Regarding the relative contribution of the washing and drying process, electricity used for washing and drying contributed 91.6%, water input and wastewater treatment contributed 6.6%, and detergent contributed 1.8%.

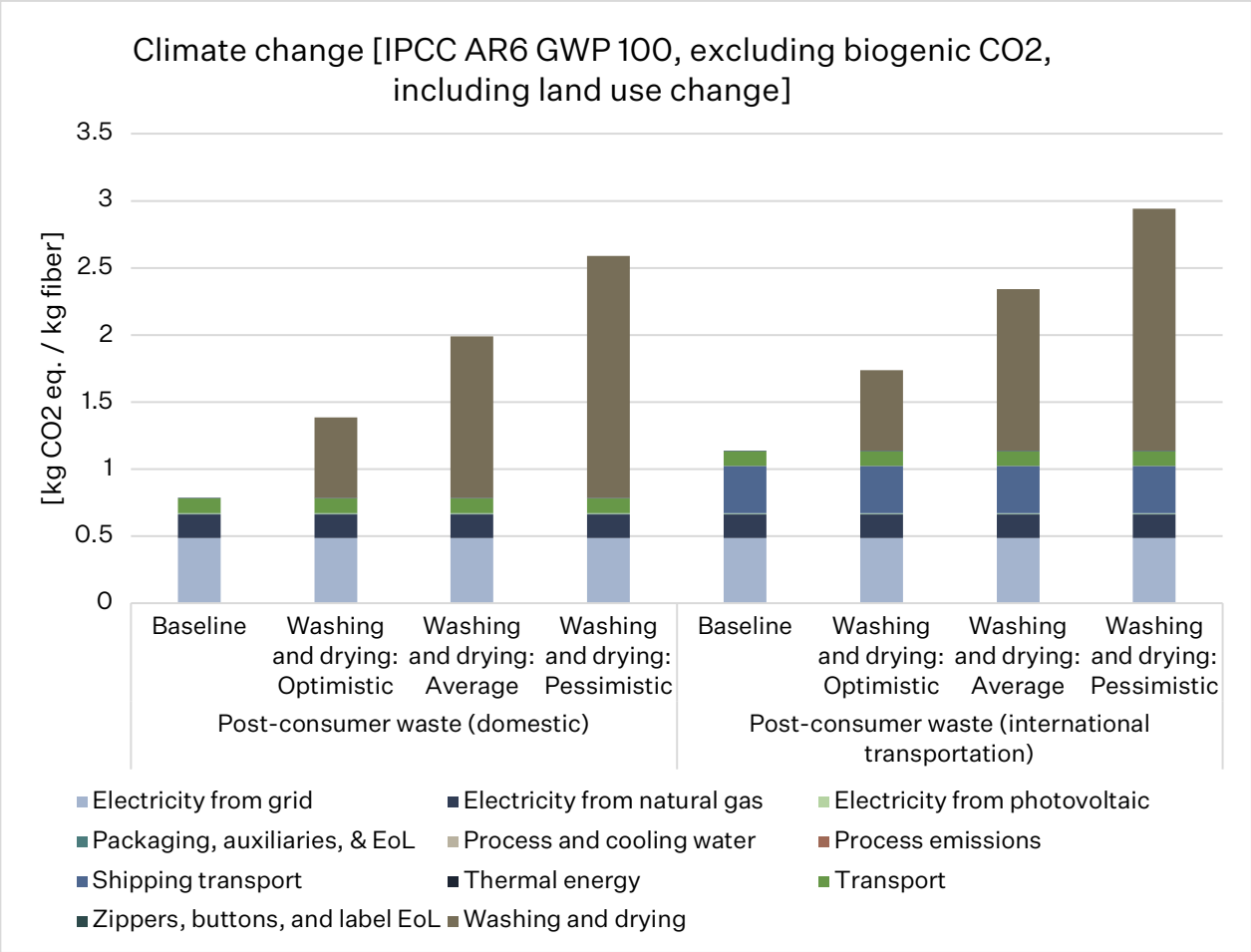

Figure 5-14: Climate change impacts of post-consumer cotton waste (domestic /international transportation) including washing and drying scenarios.

Figure 5-16 highlights the potential significant impact of the washing and drying process on the global average, post-consumer cotton waste (domestic/international transportation). For post-consumer waste (domestic), the washing and drying process can increase the GWP impacts by 76.4%–229.1% in comparison to the baseline global average. For post-consumer waste (international transportation) the washing and drying process can add between 52%–158%.

5.2.11. Recycled cotton—fumigation of post-consumer waste

Fumigation of post-consumer, cotton-textile waste containers at the exporting country is a legal requirement for shipped waste goods imported to certain countries, to ensure that pest species are not introduced. This country-specific legislation is applicable only to specified export countries, based on the identification of potential pest species. Additionally, in rare circumstances, fumigation of stored post-consumer cotton waste may occur as part of the foreground recycling process, if waste textiles are subject to pest infestation.

Phosphine gas was identified as the most common fumigant of post-consumer cotton waste. However, given the known variability of environmental impacts, including climate change and ecotoxicity, depending on the specific fumigant used, additional fumigants were analyzed to further contextualize how the choice of fumigant can affect the environmental burden of fumigation of post-consumer textile waste.

A scenario analysis is provided to highlight the potential climate change and ecotoxicity impacts of different fumigant chemicals using the following assumptions:

- For each fumigant, the inventory (kg fumigant/kg post-consumer waste), as seen in Table 5-16, was calculated from the target concentration, internal volume of the shipping container, and mass of baled post-consumer waste per container. More details can be found in Annex E.6.
- Each scenario considers the production and the use phase impacts of the chemical fumigant, assuming 100% of the gaseous chemical is released to the atmosphere, following the fumigation process, as emissions to the air.

It should be noted that Table 5-15 expresses the mass of fumigant per kg of post-consumer cotton waste; however, on average, there was 1.788 kg of post-consumer cotton waste required to produce 1 kg of recycled spinnable fiber.

Table 5-15: Fumigation of post-consumer waste (international transportation) shipping container LCI

Fumigant	kg fumigant/kg post-consumer waste
Phosphine	8.41E-06
Sulfuryl fluoride	1.02E-04
Methyl bromide	2.71E-04

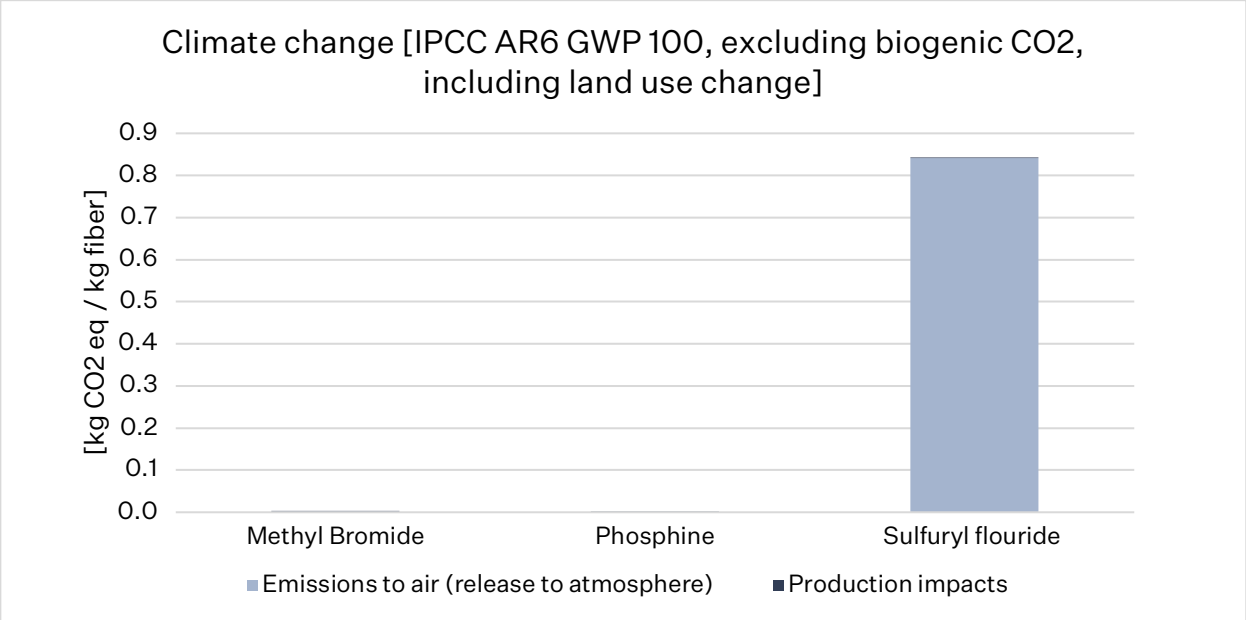

Figure 5-15: Climate change impacts of post-consumer cotton waste fumigation

Figure 5-15 highlights the significant variability in IPCC AR6 GWP 100 impacts for the different fumigation scenarios. Phosphine, the most commonly utilized fumigant for post-consumer textile waste fumigation, had negligible climate change impacts at 2.3E−05 kg CO_2 equivalents. For methyl bromide, the impacts are 0.0025 kg CO_2 equivalents; however, for sulfuryl fluoride, a potent greenhouse gas, the impacts were 0.841 kg CO_2 equivalents, of which >99.9% were from the emissions of sulfuryl fluoride to the air.

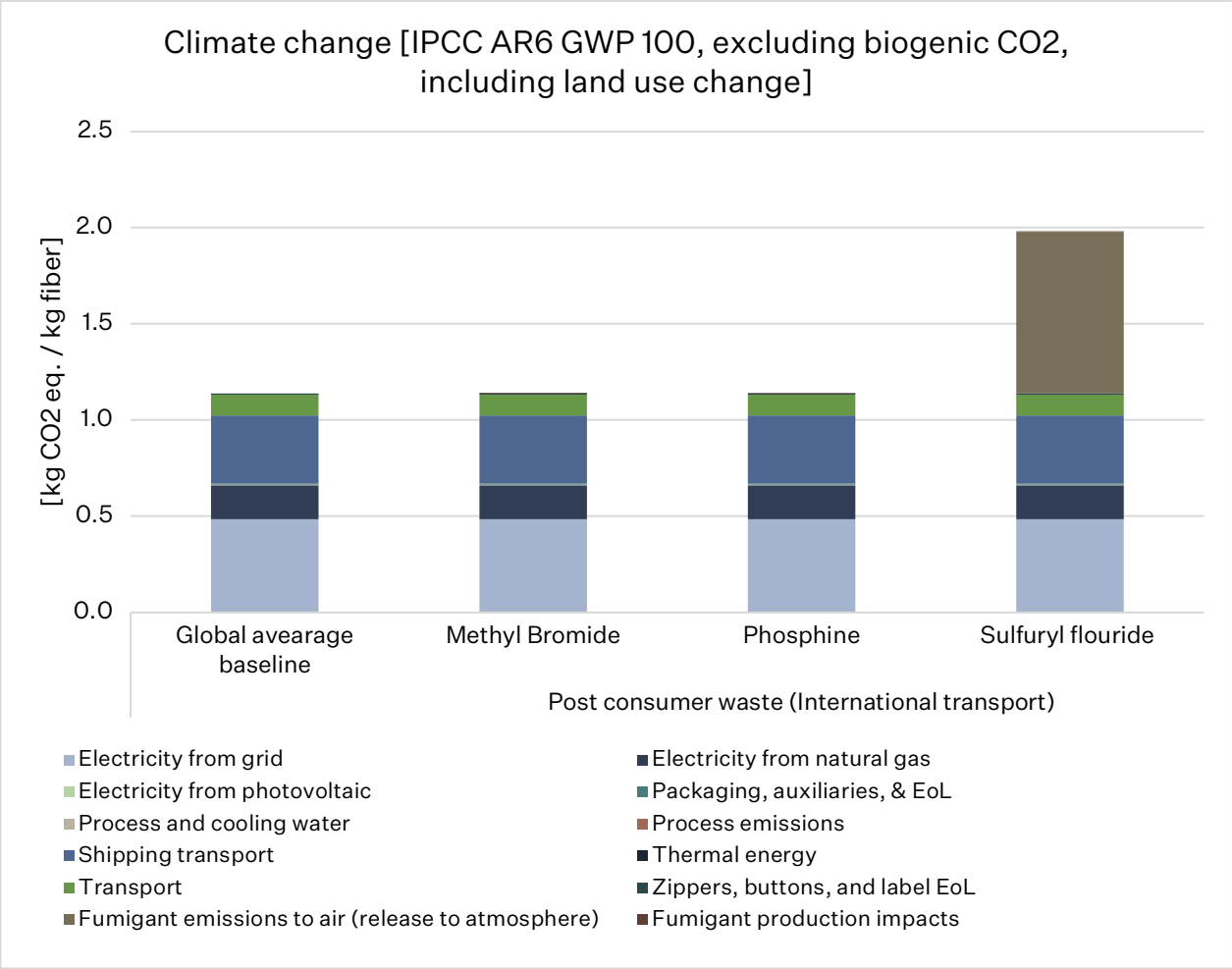

Figure 5-16: Climate change contribution analysis of post-consumer cotton waste (international transportation) fumigation scenarios.

Figure 5-16 highlights the negligible influence of the fumigation process on the global average, post-consumer cotton waste (international transportation) scenario, when phosphine is the selected fumigant. The use of methyl bromide within the fumigation process also has a negligible influence on the GWP impacts; however, the use of sulfuryl fluoride resulted in a 73.9% increase in climate change impacts.

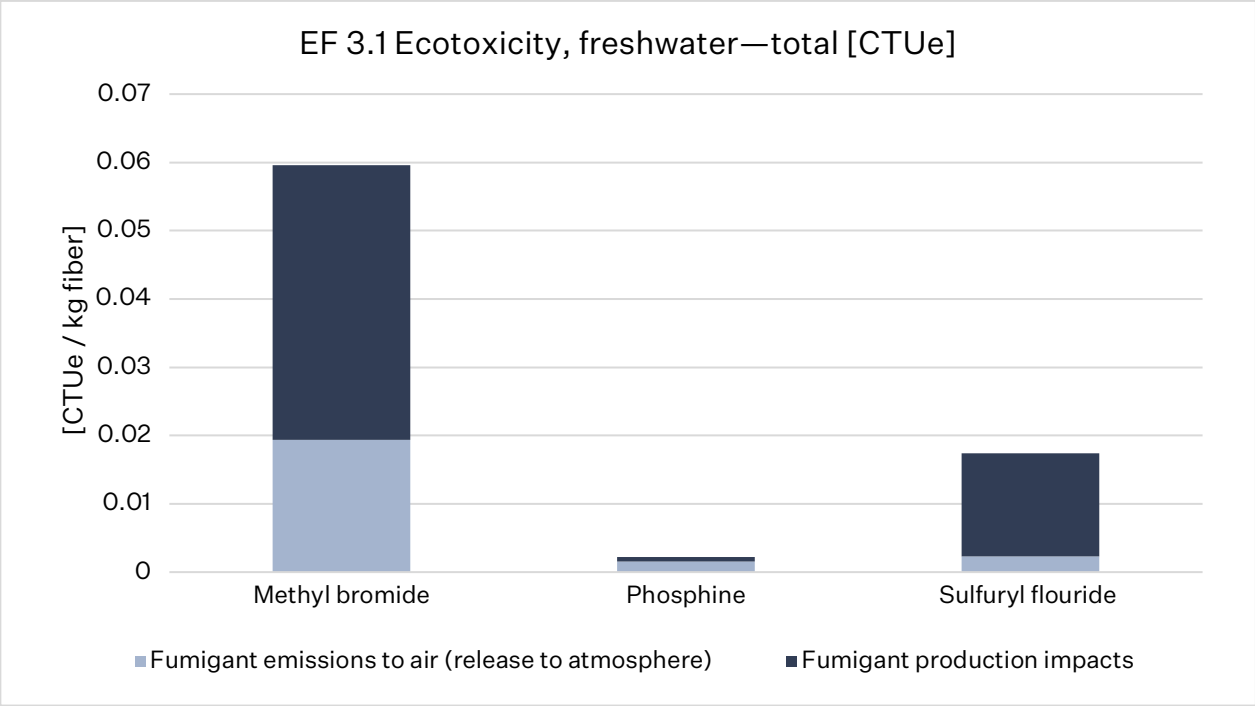

Figure 5-17: Ecotoxicity, freshwater impacts of post-consumer cotton waste fumigation

Figure 5-17 highlights the significant variability in EF 3.1 ecotoxicity, freshwater impacts for the different fumigation scenarios. Phosphine, the most commonly utilized fumigant for post-consumer textile waste fumigation, had a negligible ecotoxicity, freshwater impact at 2.22E-03CTUe. For methyl bromide, the impacts were 0.0596CTUe, and for sulfuryl fluoride, the impacts were 0.0174 CTUe. This analysis demonstrates that the fumigation process has a negligible effect on ecotoxicity, freshwater impacts for the global average, post-consumer cotton waste (international transportation) scenario. For all fumigants investigated, the fumigation process only resulted in a 0.015% - 0.403% increase in ecotoxicity, freshwater impacts.

5.3. Sensitivity analysis

5.3.1. Cotton cultivation

As stated above, this study focuses on scenario analysis for addressing uncertainty and sensitivity (interpreted here in a broader sense), as it was considered the most appropriate and transparent approach in many of the cases examined. Referring to sensitivity analysis specifically, the model used to assess cotton-cultivation-related impacts is mainly based on linear relationships. This, combined with the detailed contribution analysis provided, allows for a straightforward assessment of sensitivity, showing how changes in inputs affect specific emission categories. For instance, a 10% reduction in fertilizer use will result in a proportional 10% decrease in emissions associated with fertilizer production, assuming all other variables remain constant (field emissions, however, do not necessarily follow a linear trend 1:1 as they are composed of several components). Since results are expressed per kilogram of product, increasing yields result in lower emissions per kilogram. These relationships are directly proportional. Similarly, changes in allocation have a one-to-one effect on results: if the allocation to seeds increases by 5%, the emissions assigned to lint will decrease by the

same amount. These straightforward relationships can assist in interpreting the variability and uncertainty of the results.

Fertilizer provision impacts

A dedicated sensitivity analysis was conducted to assess the influence of fertilizer provision on overall results. The provision impacts of mineral fertilizers can vary considerably depending on the country of production. Key influencing factors are nitrous oxide emissions from nitric acid production, and the energy mix used in fertilizer manufacturing (IFS, 2019). As outlined in section 4.5.1, country-specific production datasets are available in the Sphera Agricultural LCA Model for Brazil, China, India, and the United States, while for Türkiye and Tanzania, a global production mix was applied (average of all available country-specific datasets). The sensitivity analysis was performed by comparing the global average provision dataset for each fertilizer type with the corresponding country-specific datasets (all from Sphera's MLC LCI database, see section 3.8), and calculating the unweighted average variation across fertilizer types. No weighting by relative production volumes or fertilizer use profiles was applied.

Across all fertilizer types, the variation between country-specific provision datasets is on the order of ±20% around the global average. Given that fertilizer provision contributes up to 40% of total cradle-to-gate climate change impacts in high-input systems (for example, India country average), this translates into a potential variation of up to ±8% in overall climate change results. As a general approximation, regionalization of fertilizer provision is, therefore, expected to influence climate change results within a range of ±10%. Another impact category significantly influenced by fertilizer provision is abiotic resource depletion (ADP). While country-to-country variation in fertilizer provision datasets is lower (around 10%), the relative contribution of fertilizer provision to total ADP impacts can reach up to 70%. Accordingly, overall ADP results may vary by about ±10%, similar in magnitude to the potential effect observed for climate change.

It should be emphasized that uncertainties in fertilizer provision are not limited to geographical differentiation. Comparative analyses of different LCA databases indicate that the results for the same fertilizer type may vary by more than 20%, depending on modeling choices and underlying data sources. A detailed review of fertilizer-provision datasets and cross-database comparison was outside the scope of this study. The present assessment is, therefore, intended as a high-level sensitivity check to indicate the order of magnitude of potential variation, rather than a full systematic evaluation. A more detailed assessment of the influence of background datasets on results is partly addressed in an upcoming Cotton LCA Model Comparison project initiated by Textile Exchange (see section 6.4.3).

5.3.2. Recycled cotton—economic allocation of valuable by-products (multi-output system)

A sensitivity analysis was conducted on the economic allocation of by-products for all recycled spinnable fiber scenarios to understand the influence of the allocation of the impacts, based on price data of all valuable outputs, on the results of the study. For this analysis, three scenarios (pessimistic, average, and optimistic) were analyzed in comparison with the baseline conservative assumption for the datasets that assumed 100% of the impacts were attributed to the recycled spinnable fiber.

Price data for the main product and by-products was collected from data providers and serves as the basis of the scenarios. In this case the "optimistic" scenario represents the maximum allocation of impacts to the by-products. More information on the price data can be found in Table E-5 and E-4 in the annex.

Table E-9: Post-industrial yarn and fabric economic allocation percentage

	Post-industrial yarn waste	**Post-industrial fabric waste**
	Allocation at factory gate (fluff, and filling material only)	Allocation at factory gate (fluff, and filling material only)
Global average baseline	100%	100%
Pessimistic	99.99%	99.99%
Average	99.59%	98.32%
Optimistic	97.5%	95%

Table E-10: Post-consumer waste (domestic/international transportation) economic allocation percentage

	Post-consumer waste (domestic/international transportation)	
	Allocation following sorting at factory (sold by-product, fluff, and filling material)	Allocation at factory gate (fluff, and filling material only)
Global average baseline	100.00%	100.00%
Pessimistic	95.0%	97.5%
Average	89.5%	94.5%
Optimistic	82.5%	90.0%

The climate change impacts for economic allocation of by-products for the production of 1 kg of recycled cotton spinnable fiber are shown below in Figure 5-18. The chart highlights the possible reduction in impacts compared to the baseline scenarios for each type of cotton waste, dependent on the allocation of impacts to by-products, calculated from price data provided by data providers.

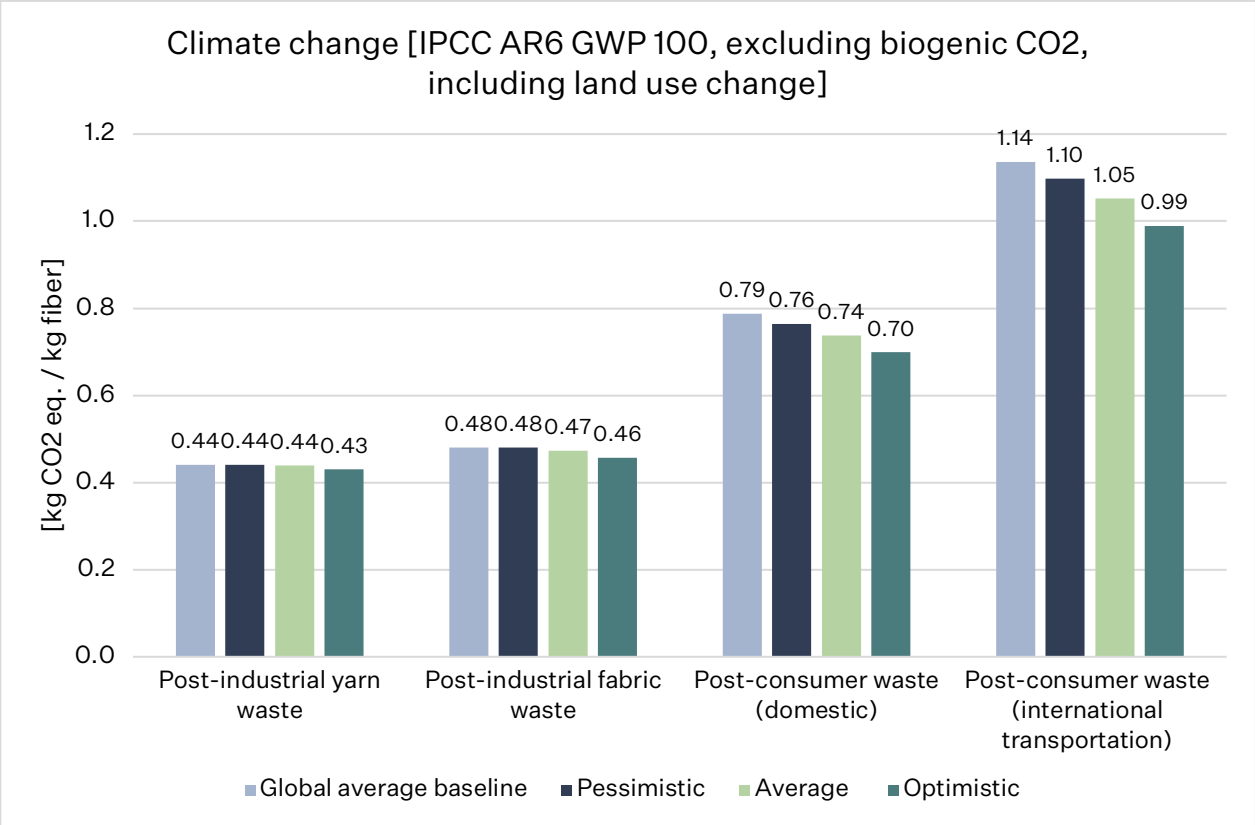

Figure 5-18: Parameter sensitivity—economic allocation of by-products (recycled cotton)

Post-industrial yarn waste shows the smallest reduction of the recycled spinnable fiber types, as data providers reported on average 99.6% allocation to the main product, which would account for a negligible reduction in impacts of 0.0018 kg CO_2 equivalents. For post-industrial fabric waste, data providers reported, on average, 98.3% allocation to the main product, which would account for a reduction in impacts of 0.0081 kg CO_2 equivalents. For post-consumer waste, there was the largest reported allocation of impacts to the by-products, where data providers reported, on average, 89.5%/94.5% allocation to the main product, which would account for a reduction in impacts of 0.05 and 0.0845 kg CO_2 equivalents for the domestic and international transportation scenarios, respectively[39].

For post-industrial yarn waste, the baseline impacts of 0.441 kg CO_2 equivalents (100% allocation), reduce in the optimistic scenario to 0.430 kg CO_2 equivalents (97.5% allocation). For post-industrial fabric waste, the baseline impacts of 0.481 kg CO_2 equivalents (100% allocation), reduce in the optimistic scenario to 0.456 kg CO_2 equivalents (95% allocation). For post-consumer waste (domestic), the baseline impacts of 0.788 kg CO_2 equivalents (100% allocation) reduce in the optimistic scenario to 0.7 kg CO_2 equivalents (82.5%/90% allocation)[39]. For post-consumer waste

39 For post-consumer waste, impacts associated with the production of recycled spinnable fibers are allocated at two separate points within the product system and have a separate allocation percentage applied. Similarly, to post-industrial waste types, the impacts of the recycling process are allocated to the recycled spinnable fibers (main product), and fluff and filling material (by-products). However, for post-consumer waste, a separate allocation is required to account for the sold low-quality post-consumer waste cotton (by-product) that leaves the product system following the sorting step, and is applied only to upstream impacts, i.e., transportation. More details can be found in Annex E.

(international transportation), the baseline impacts of 1.14 kg CO_2 equivalents (100% allocation) reduce in the optimistic scenario to 0.99 kg CO_2 equivalents (82.5%/90% allocation)[39].

5.4. Uncertainty analysis

As with all LCA studies, the findings presented here are subject to a degree of uncertainty arising from various sources. A common approach to addressing this uncertainty is through Monte Carlo simulation[40], which can yield a distribution of possible outcomes for environmental impacts. However, given the intricate nature of this study, including multiple cultivation systems across different countries, and the interrelated nature of many variables and input parameters, a full Monte Carlo analysis was deemed beyond the scope of the current work. As stated above, this study focuses on scenario analysis for addressing uncertainty and sensitivity (interpreted here in a broader sense), as it was considered the most appropriate and transparent approach in many of the cases examined. Nevertheless, the next sections provide some additional context to assess and interpret the uncertainty of the results of the study.

5.4.1. Cotton cultivation

Section 5.1 provides country-specific results, and Annex K provides the ranges of key input parameters and results for cultivation systems that are assessed based on primary data and where more than one data provider provided data. These indicated ranges (both inter- and intra-country variations) offer a sense of the variability between locations and can serve as proxies for scenario or sensitivity analyses, and provide context for how local conditions may cause deviations from the overall average. Significant differences between regions or data providers are apparent, although these should not be interpreted as evidence of poor data quality. Such variability is expected, as nearly all inventory data, such as yield, irrigation, fertilizer use, and pesticide application, are influenced by geographic and environmental conditions.

Impact categories affected by multiple variables (for example, climate change, which depends on yield, fertilizer production, and energy use) tend to show less variation than categories influenced primarily by a single inventory factor (for example, water scarcity and water consumption, which are driven by irrigation water applied). The extent of variability is anticipated to be similar across different cultivation systems. This highlights a broader challenge in assessing agricultural systems, which are inherently shaped by complex natural environments. Hence, the results shown do not allow for drawing conclusions on the environmental performance of individual sites or farms.

5.4.2. Recycled cotton

Key recycled cotton LCI inventory data

A high degree of variability in the primary data LCI values collected from recycled cotton data providers was observed in this study. Table 5-16 and Table 5-17 below highlight the minimum and maximum values for key LCI inventory data, including electricity consumption (kWh) and truck and

40 A Monte Carlo simulation is a way to test how uncertain input data affect the final results. The calculation is run many times while input values are varied within predefined ranges, usually following an expected statistical distribution such as a normal distribution, so the results show a range of possible outcomes instead of one single number.

ship transportation distances (km), and comparatively assess the percentage deviation compared to the global average values for all waste types.

Table 5-16: Key recycled cotton LCI inventory data variation

	Post-industrial yarn waste			**Post-industrial fabric waste**			**Post-consumer waste** (domestic)			**Post-consumer waste** (international transportation)		
	Min	**Global average**	**Max**	**Min**	**Global average**	**Max**	**Min**	**Global average**	**Max**	**Min**	**Global average**	**Max**
Electricity (kWh)	0.32	0.63	1.36	0.38	0.70	1.80	0.43	1.08	1.81	0.43	1.08	1.81
Transport distance (km)	1	379	500	14	275	500	20	370	500	20	370	500
International shipping (km)										5000	10000	20000
International truck (km)										500	1000	2000

Table 5-17: Key recycled cotton LCI Inventory data percentage deviation compared to global average

	Post-industrial yarn waste			**Post-industrial fabric waste**			**Post-consumer waste** (domestic)			**Post-consumer waste** (international transportation)		
	Min	**Global average**	**Max**	**Min**	**Global average**	**Max**	**Min**	**Global average**	**Max**	**Min**	**Global average**	**Max**
Electricity (kWh) % deviation	-49%	0%	116%	-46%	0%	157%	-60%	0%	68%	-60%	0%	68%
Transport distance (km) % deviation	-100%	0%	32%	-95%	0%	82%	-95%	0%	35%	-95%	0%	35%
International shipping (km) % deviation										-50%	0%	100%
International truck (km) % deviation										-50%	0%	100%

Recycled cotton impact category absolute results and inventory values

Figure 5-19 highlights the supplier specific variation (lowest impact supplier, global average, highest impact supplier) of absolute climate change impacts for individual recycled cotton data providers.

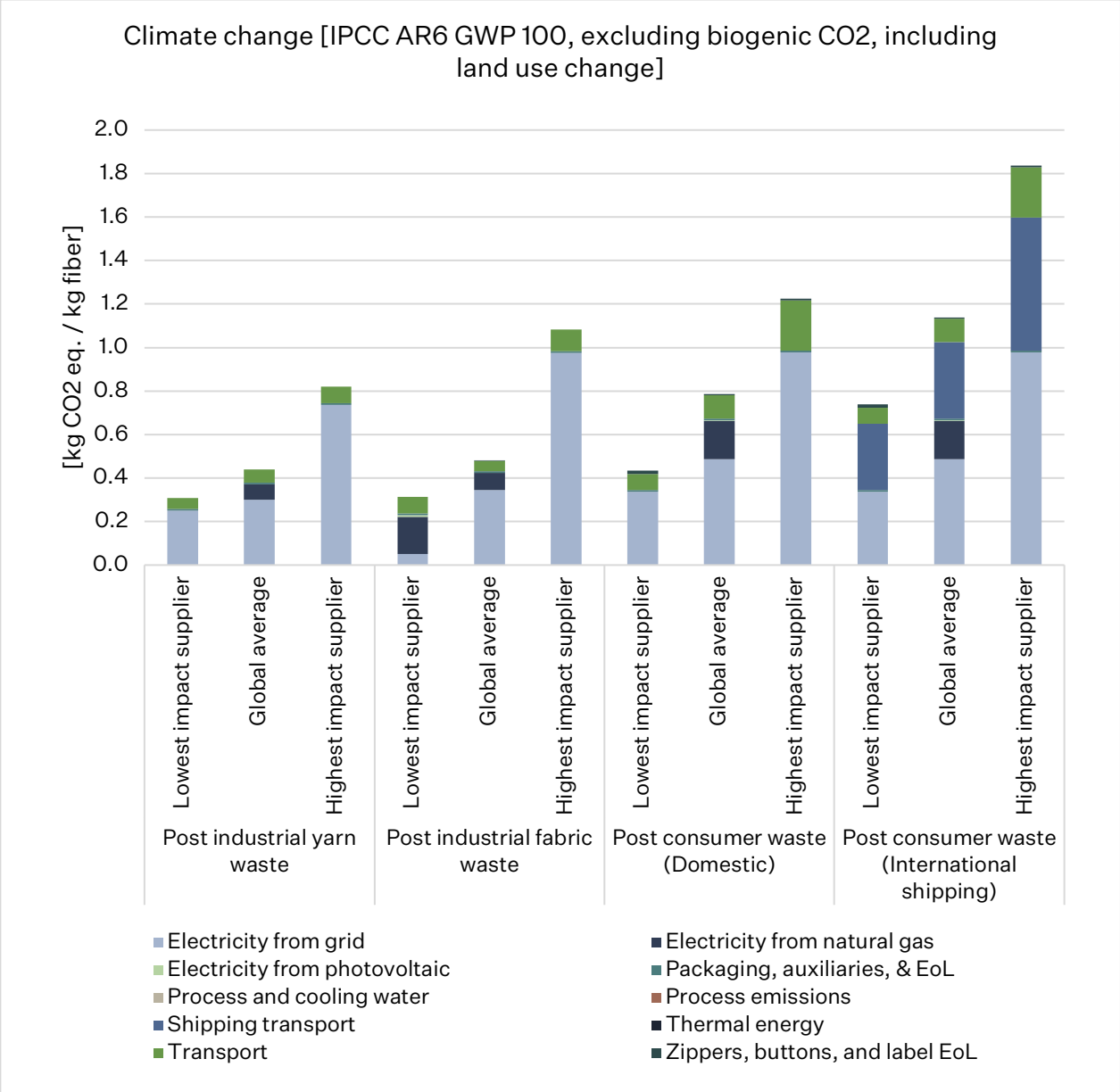

Figure 5-19: Recycled cotton uncertainty analysis of supplier specific impacts—Climate Change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]

As seen in Figure 5-19, there is significant variability in absolute climate change impacts for supplier-specific recycled cotton data providers across all waste types, demonstrating the high uncertainty associated with the global averages. The high degree of climate change impact variability between suppliers is clearly evidenced, where the highest impact post-industrial waste supplier (0.81 kg CO_2 equivalent) has a higher climate change impact than the post-consumer waste (domestic) global average (0.78 kg CO_2 equivalent). Conversely, the lowest impact post-consumer waste (domestic) supplier (0.43 kg CO_2 equivalent) has a lower climate change impact than the post-industrial yarn

global average (0.44 kg CO_2 equivalent). This uncertainty analysis demonstrates the need for textile brands to assess the impacts of recycled spinnable fiber production on a supplier-specific basis.

Table 5-18 and Table 5-19 highlight the variation (lowest impact supplier, global average, highest impact supplier) of impact category absolute results and inventory values, for all recycled cotton waste types, and comparatively assess the percentage deviation compared to the global average. Further impact categories and inventories can be found in Annex G.2.

Table 5-18: Recycled cotton impact category and inventory absolute value variation

	Post-industrial yarn waste			**Post-industrial fabric waste**			**Post-consumer waste** (domestic)			**Post-consumer waste** (international transportation)		
	Lowest impact supplier	**Global average**	**Highest impact supplier**	**Lowest impact supplier**	**Global average**	**Highest impact supplier**	**Lowest impact supplier**	**Global average**	**Highest impact supplier**	**Lowest impact supplier**	**Global average**	**Highest impact supplier**
Climate change	0.16	0.44	0.82	0.31	0.48	1.08	0.43	0.79	1.22	0.74	1.14	1.85
Eutrophication	1.08E-04	1.89E-04	2.95E-04	1.24E-04	1.99E-04	3.91E-04	1.67E-04	3.97E-04	5.78E-04	7.41E-04	9.34E-04	1.52E-03
Blue water consumption	0.72	2.88	11.64	0.74	3.59	15.41	0.8	5.06	16.02	0.96	5.23	16.19
Ecotoxicity	0.78	5.82	31.92	0.31	6.88	42.25	0.32	11.48	43.89	2.35	14.80	49.55

Table 5-19: Recycled cotton impact category and inventory percentage deviation compared to global average

	Post-industrial yarn waste			**Post-industrial fabric waste**			**Post-consumer waste** (domestic)			**Post-consumer waste** (international transportation)		
	Lowest impact supplier	**Global average**	**Highest impact supplier**	**Lowest impact supplier**	**Global average**	**Highest impact supplier**	**Lowest impact supplier**	**Global average**	**Highest impact supplier**	**Lowest impact supplier**	**Global average**	**Highest impact supplier**
Climate change	-63%	0%	86%	-35%	0%	126%	-45%	0%	56%	-35%	0%	62%
Eutrophication	-43%	0%	56%	-37%	0%	96%	-58%	0%	46%	-21%	0%	63%
Blue water consumption	-75%	0%	304%	-79%	0%	330%	-84%	0%	217%	-82%	0%	210%
Ecotoxicity	-87%	0%	449%	-95%	0%	515%	-97%	0%	282%	-84%	0%	235%

6. Interpretation

6.1. Identification of relevant findings

6.1.1. Cotton cultivation

Data availability and quality

The scope of this study included assessing data availability for cotton cultivation, revealing that comprehensive and readily accessible datasets for farm activity data remain limited. Reliable and complete datasets were found only in a select number of cases. The process of data collection continues to pose significant challenges, demanding substantial time, resources, and organizational effort. Furthermore, the experience level of data providers varied widely, significantly influencing the quality and consistency of the collected data. It should also be recognized that data providers are frequently confronted with multiple requests for information. Demonstrating the benefits of participation in studies of this kind is, therefore, an important element of any data-collection strategy. Regional representation was identified as a notable limitation, often due to the small number of data providers available or restricted sample sizes, ultimately impacting the representativeness and reliability of the data collected.

In terms of data quality (assessed based on geographical, temporal, and technological representativeness and precision, see section 6.3.1), the study identified several cases with good data quality. These include country average and organic cotton production systems in India, regenerative and organic systems in Peru, organic cultivation in Tanzania, and conventional practices in the US. Conversely, data collected from regenerative systems in India, as well as organic production in Brazil, Türkiye, and the United States, exhibited potential limitations due to lower data-quality ratings. Secondary data had to be employed for country average datasets in Brazil, Türkiye, and selected regions of China. While efforts were made to compile secondary data consistently, using published statistical sources, uncertainty remains regarding the representativeness of these datasets.

Environmental impact analysis

Climate change impacts are primarily driven by field emissions of nitrous oxide, resulting from nitrogen fertilizer application, closely linked to the nitrogen balance. High nitrogen surpluses result in particularly elevated impacts. The impacts are also strongly influenced by fertilizer provision. For mineral fertilizers, the upstream provision processes contribute substantially to overall impacts. Organic fertilizers are considered residues or by-products of other systems, and their provision is typically not allocated to the cultivation system under study, i.e., their upstream burdens are excluded. As this assumption is subject to methodological debate and no single “correct” approach exists, its influence on the results is examined in a dedicated scenario (see section 5.2.1), where it was found to have a notable effect on overall outcomes. In any case, both differences in nitrogen application rates, and fertilizer types (mineral or organic), lead to distinct profiles of climate change impacts. An additional hotspot is irrigation energy use, which depends on several factors, including the intensity of irrigation water application, the irrigation technique applied, and local conditions such as groundwater table depth (see the section below on blue water consumption, see also section 5.1.1 blue water consumption results).

Eutrophication impacts are dominated by field emissions as well, contributing at least 90% of the total. Nitrogen application rates and the resulting N balance are the primary drivers, leading to nitrate leaching and ammonia volatilization, while phosphorus emissions contribute to a lesser extent via leaching and erosion-related runoff. Yield levels play an important role in scaling the impacts, as higher yields dilute fixed emissions across more output, while lower yields and higher land requirements increase soil erosion-related contributions. Uncertainty in nitrate-leaching estimates remains, as a fixed IPCC emission factor was applied that may overestimate emissions in low-input or arid systems. A scenario analysis explores the influence of modeling based directly on nitrogen balance.

Blue water consumption impacts are almost entirely determined by irrigation water applied, which accounts for 99–100% of blue water consumption in irrigated systems. Predominantly rainfed systems show minimal impacts, limited to background processes. The irrigation water requirement of a crop is primarily determined by local climatic conditions, though actual water consumption also depends on irrigation techniques and management practices. Results vary not only with irrigation volume but also with yield, as higher yields can offset high water consumption when expressed per kilogram of fiber.

Ecotoxicity impacts are dominated by pesticide use, accounting for at least 90% of total impacts. Ecotoxicity results are often shaped by a few substances that dominate overall outcomes. This category, however, carries substantial uncertainty, and results must be interpreted with caution. Uncertainties stem from the limited reliability of application rate data (especially for country averages), very high variability in characterization factors across active ingredients, and incomplete knowledge of the actual substances applied.

Results vary considerably across regions and impact categories, reflecting the complexity of assessing cultivation practices under diverse agroecological conditions. Yield levels emerge as a critical factor, as lower yields can increase impacts per unit of output even when input use is reduced. In such cases, the benefits of input reduction (for example, lower fertilizer or pesticide use) may be offset by yield penalties, for instance, when pesticide avoidance leads to substantial yield losses (see also section 6.4.3, 7.2 and footnote 44).

The scenario analysis demonstrates that several modeling choices and data uncertainties can substantially influence the calculated environmental impacts of cotton cultivation and processing:

- Organic fertilizer provision impacts: The scenario analysis conducted specifically on organic fertilizer provision found that the contribution of organic fertilizer provision to overall impacts could potentially be significant. Nevertheless, these impacts may vary widely depending on multiple factors, including the type and source of organic fertilizer, handling practices, and local conditions in the processing of organic manure. Emissions from composting organic material were identified as a potential hotspot. The findings underscore the importance of responsible composting and manure management practices to reduce emissions and minimize the environmental impact of organic fertilizers. Currently, considerable uncertainty remains regarding how much of these potential impacts should be allocated to the cotton cultivation system. However, it is noteworthy that the Cascale Cotton LCA Methodology, representing industry-aligned approaches for cotton LCA modeling, also supports the assumption that organic fertilizers enter cultivation systems burden-free.
- Nitrogen-related emissions: Assumptions on N_2O emission factors (aggregated vs. wet/dry classification) and nitrate leaching are influential for climate change and eutrophication results. The aggregated IPCC factor provides a reasonable compromise for country-level modeling, but scenarios showed that actual field emissions could be significantly higher or lower depending on climatic conditions.

- Nutrient content of organic fertilizers: Variations in assumed nutrient content clearly affect results for organic and regenerative systems, especially for acidification and eutrophication. In general, the scenarios highlight the importance of nutrient application in relation to yield for a correct impact assessment. Specific care should, therefore, be given to these parameters in data collection and inventory data compilation.
- N-balance approach: Applying the PEF-recommended N-balance method to inventory fertilizer inputs and estimate nitrate emissions helps ensure consistency between reported yields and fertilizer use, and to assess the emissions more realistically in relation to the calculated N balance. While average changes across all systems were moderate, individual systems with large deficits or surpluses showed substantial deviations.
- Ecotoxicity impacts: Results are highly sensitive to both pesticide inventories and characterization factors. Aggregating all substances into an unspecific pesticide reduced ecotoxicity impacts by ~20 percent on average but obscured the influence of single, highly toxic active ingredients, which can dominate results even at low application rates. The overall robustness of ecotoxicity results remains limited due to large uncertainties in available pesticide inventories, and the use of generic characterization factors as proxies where specific CFs for active ingredients were missing. These limitations restrict the interpretability and comparability of results. Consequently, differences should only be interpreted at the level of orders of magnitude, as smaller variations fall within the range of methodological uncertainty.
- Primary versus secondary data: Comparison of US and India results based on primary versus ICAC-derived secondary data shows that the secondary approach can be a reasonable proxy for some categories, but deviations are large for others, especially ecotoxicity. This underscores both the utility of secondary data for gap-filling and the need for caution when interpreting results, particularly for pesticide-related impacts.
- Renewable energy at gin: Decarbonizing electricity use in ginning through renewable energy can reduce climate change impacts by ~9 percent on average (up to 20 percent for some systems), and also lower abiotic depletion potential. While the relative effect on total cotton fiber impacts is moderate, the scenario illustrates the clear reduction potential of renewable energy in post-harvest processing stages.

In addition to impact assessment methods commonly used in LCA, the study applied an LCA+ approach to include indicative assessments of soil health and biodiversity, together with an assessment of social impacts. These assessments should be considered high-level screening approaches and are assessed in a separate section (section 7) to distinguish them from the core LCA impact categories and to emphasize their role as complementary, exploratory analyses.

The soil health assessment in this study applies the IPCC Tier 1 methodology as a proxy, focusing on soil organic carbon (SOC) dynamics, while acknowledging that soil health is a broader concept involving physical, chemical, and biological dimensions. The analysis evaluates potential SOC sequestration from reduced tillage and increased organic inputs, including cover crops, green manure, and animal manure applications. Results show that reduced tillage and increased organic inputs, especially manure application, can substantially enhance SOC stocks. However, these potentials are generalized and must be interpreted cautiously: they rely on default factors, assume linear accrual over 20 years, and do not capture local soil, climate, or management heterogeneity. The findings should, therefore, be seen as indicative scenarios but they are not robust enough for reporting removals. Still, given the link between SOC and broader soil-health indicators, these results underline the role of organic inputs and reduced disturbance in building long-term soil resilience.

For biodiversity, impacts were assessed indirectly by interpreting existing environmental impact categories such as land use change, eutrophication, pesticide use, and water consumption as proxy indicators (see section 7.2). However, these indicators were not designed to measure biodiversity, and their correlation with actual biodiversity outcomes is limited, and can be inconsistent or even inverse depending on local ecological conditions. While reductions in these pressures are generally expected to lower biodiversity risks, outcomes remain highly site-specific, and no direct one-to-one relationship can be assumed. Some potential benefits of specific farming practices develop gradually over time and may fall outside the resolution of this LCA. This study, therefore, does not constitute a biodiversity assessment and should not be used as such by third parties. A meaningful evaluation of biodiversity impacts would require more detailed, spatially explicit, and locally grounded data, which goes beyond the screening level possible with the LCA+ approach.

In addition, while this study provides valuable insights into the environmental impacts of cotton cultivation systems, it also recognizes that certain potential benefits are inherently site-specific and manifest over extended timeframes. These dynamic effects often lie beyond the spatial and temporal scope of conventional LCA methods and are, therefore, only partially captured in this assessment. To complement the LCA+ approach and better reflect long-term, system-level improvements, outcome-based monitoring frameworks such as Textile Exchange's *Regenerative Agriculture Outcome Framework* (Textile Exchange, 2025) can be employed to track progress on a more granular and site-specific level.

Despite the identified limitations, especially regarding data quality, this study represents a clear advancement over most previously available data sources. A significant step forward is achieved through the improved transparency of data collection methodologies, assumptions, and analysis (see also the context and challenges section in 6.4.1).

6.1.2. Recycled cotton

Data availability and quality

The scope of this study included assessing data availability for recycled spinnable fiber production. For recycled spinnable fiber production, no universally accepted PCR document exists. Therefore, as available LCA data does not adhere to a consistent methodological approach, and transparency on the methodological choices is inconsistent for many studies, this limits the use of existing available LCA and LCI data. Furthermore, no LCA results are available that address the differences in impacts between the production of recycled spinnable fiber from post-industrial yarn, post-industrial fabric, and post-consumer waste, or provide a country- specific assessment.

Regarding the data quality of available LCA studies, reliable and complete data sets were found only in a select number of cases and, while high-quality data exists, the lack of transparent documentation of LCI data and consistency of methodological choices impacts the comparability of available studies. Moreover, the companies that have commissioned these studies also tended to be corporations with advanced proprietary recycling technologies that, while providing accurate supplier-specific LCA results, are not necessarily representative of the global recycled spinnable fiber supply chain, with the availability of representative high-quality LCA data limited to supplier-specific fibers. These findings clearly highlight the importance of a sector-wide accepted methodological approach on the quantification of potential environmental impacts of recycled cotton fibers to improve the availability of high-quality LCA data representative of global recycled spinnable cotton fiber production.

Similar to cotton cultivation, the process of data collection for recycled cotton posed significant challenges, requiring considerable time, coordination, and resources. While variability in experience and data infrastructure among providers influenced the consistency and detail of the collected LCI

data, many contributors demonstrated strong engagement and provided valuable insights. However, some concerns regarding the quality and consistency of the collected data remained. Furthermore, without reliable benchmark data, plausibility checks on the data collected were of limited effectiveness, highlighting the need for onsite external verification of key LCI Inventories, such as electricity consumption. Limited, or inconsistent reporting, on packaging, auxiliaries, and transportation distances beyond Tier 1 suppliers also significantly affected data quality.

The challenges of quantifying the representativeness of LCI were most prevalent for post-consumer waste, due to the higher number of process steps both upstream and in the recycling processes, differences in national legislation, and significantly more diverse waste streams, representing a more complex and variable product system than post-industrial waste. LCI for upstream processes associated with post-consumer waste were extremely limited. In addition, the small sample size and prevalence of data gaps within this waste type ultimately impacted on the representativeness and reliability of the data collected, resulting in lower DQR scores. Further stratification of post-consumer waste types is required to better define expected LCI within this product system, based on aspects such as waste feedstock types and/or the quality of output fibers to reduce the reliance on conservative assumptions and scenario analysis to fill data gaps.

Despite the identified limitations, especially regarding data quality, this study represents a clear advancement over previously available data sources, providing LCA data disaggregated for post-industrial and post-consumer cotton waste types used in the production of recycled spinnable fibers. Furthermore, similar to cotton cultivation, a significant step forward is achieved through the improved transparency of data-collection methodologies, assumptions, and analysis. This enhanced transparency contributes substantially to the credibility and reliability of environmental impact assessments within the cotton sector.

Environmental impact analysis

The environmental impact analysis identified electricity consumption as the key driver of potential environmental impacts. For climate change, electricity consumption contributed between 58.4–88.3% of the total impacts for all waste types, or 84.5–88.3% excluding post-consumer waste (international transportation). Transportation of cotton waste had the second most significant contribution, with domestic transportation contributing between 9.5–13.8% of the total impacts for all waste types. In the post-consumer waste (international transportation) scenario, international transportation was responsible for 30.9% climate change impacts. All other inputs to the recycling process, including packaging, auxiliaries, and waste treatment outputs, had a negligible contribution of 1.2–1.8%.

For all impact categories and inventories analyzed, electricity consumption was identified as the most important parameter with a contribution of >60% for all waste types, excluding the international transportation scenario. In this scenario, the impacts of international transportation also had a significant contribution of 22.4–57.5% for all impact categories and inventories, excluding blue water consumption and water scarcity.

The IPCC AR6 GWP 100 impacts are 0.44 kg CO_2 equivalents for post-industrial yarn, 0.48 kg CO_2 equivalents for post-industrial fabric, 0.78 kg CO_2 equivalents for post-consumer waste (domestic), and 1.14 kg CO_2 equivalents for post-consumer waste (international transportation), pertaining to the production of 1 kg of recycled cotton spinnable fiber. For all cotton waste types, impacts are most significantly influenced by the intensity of the recycling process and electricity consumed in the production of recycled spinnable fibers. Post-industrial yarn waste required 0.63 kWh/kg spinnable fiber, post-industrial fabric waste required 0.7 kWh/kg spinnable fiber, and post-consumer waste required 1.08 kWh/kg spinnable fiber. For post-consumer waste, there are additional processing

steps (sorting, trim removal, cutting[41]) required prior to fiber opening and high process waste losses (1.79 kg input cotton waste required for 1 kg spinnable fiber production), contributing to high electricity consumption and impacts associated with the transportation of post-consumer cotton waste to the recycling facility, which is evident in the impacts of this waste type.

Despite these findings, the uncertainty assessment identified that supplier-specific impacts are highly variable, due to the significant variability of key inventories across all waste types. For example, some post-industrial waste suppliers have a higher climate change Impact than the post-consumer waste global average, demonstrating the need for brands to assess impacts of recycled spinnable fiber production on a supplier- specific basis.

Additional sensitivity and scenario analysis provided additional context to the interpretation of the quantified potential environmental impacts, including the following:

- A sensitivity analysis was conducted on the economic allocation of by-products for all recycled spinnable fiber scenarios to understand the influence of the allocation of the impacts based on price data of all valuable outputs on the results of the study. For post-industrial yarn and post-industrial fabric, the mass and economic value of fluff and filling material was negligible in comparison to the main product, therefore, applying the economic allocation only accounted for reductions of <0.025 kg CO2 equivalent. However, for post-consumer waste, economic allocation is more relevant due to the considerably higher by-product mass, where impacts could be reduced by 0.08–0.15 kg CO2 equivalent.
- The scenario analysis conducted on international shipping of post-consumer waste provided further insights into the potential variance of environmental impacts depending on the shipping distances. The analysis identified that international transportation of post-consumer cotton waste could result in 0.177–0.707 kg CO_2 equivalents (optimistic and pessimistic scenarios), increasing the impacts of recycled spinnable fiber production by between 22.5% and 89.9% compared to domestic post-consumer waste. These findings highlight the need for the increased development of domestic end-of-life recycling facilities for post-consumer waste, to ensure recycled spinnable fiber is available to the textile sector without the significant environmental burden associated with international transportation.
- Additional scenario analysis of post-consumer waste also highlighted the potential for other significant impacts associated with upstream processes. Conventional washing and drying could result in a 0.55–1.65 kg CO_2 equivalents (optimistic and pessimistic scenarios) increase in GWP impacts. Analysis of fumigation highlighted that potential ecotoxicity impacts were negligible, at most contributing 0.4% to total impacts. However, for climate change, there is significant variance in impacts between chemical fumigants, with the most common fumigant, phosphine, having an insignificant contribution of 8.3E–07 kg CO_2, whereas the use of sulfuryl fluoride could result in 0.84 kg CO_2 equivalent, highlighting the need for phasing out the use of this potent GHG where possible.
- The scenario analysis of electricity generation methods highlighted the significant decarbonization potential of switching recycled spinnable fiber production to electricity generated from renewable energy, in this case photovoltaics, which resulted in an 81.6–85.4% reduction of impacts for waste types, excluding the international transportation scenario.

41 The cutting process step is required for post-industrial fabric waste, but not for post-industrial yarn waste.

From the identification of the relevant findings, two recommendations were identified regarding their potential to effectively decarbonize the recycled spinnable fiber supply chain. The first is a switch to 100% electricity generated by photovoltaics, or an equivalent low impact renewable electricity generation method, which was demonstrated to reduce impacts of recycled spinnable fiber production by 81.6–85.4% to 0.07-0.143 kg CO_2 equivalents (excluding post-consumer waste international transportation). Secondly, domestic treatment of post-consumer waste should be prioritized where possible over international transportation of post-consumer waste as this transportation has been demonstrated to Increase Impacts of post-consumer waste by 44.7% to 1.138 kg CO_2 equivalent. A comprehensive list of recommendations is provided in section 7.3.13.

6.2. Assumptions and limitations

The present LCA study is subject to several limitations and assumptions that impact the accuracy and applicability of the results. These limitations arise from data availability, methodological constraints, and the inherent complexity of agricultural systems. While efforts have been made to ensure methodological consistency, the following aspects should be considered when interpreting the findings.

6.2.1. Cotton cultivation

Definition of product systems

- Country average datasets include program-specific data from cotton programs in some cases (see section 3.1.1). As a result, interpreting country-average data in this study as baseline or control values could lead to inconsistencies. Therefore, these datasets should not be used to make comparative assertions about the performance of specific cotton programs or production systems (see section 2.4).
- The definition of "regenerative" agriculture is not standardized across data providers. Some categorize organic farming under regenerative practices, while others include systems that use mineral fertilizers (see section 3.1.1). This lack of uniformity makes the interpretation of results more difficult. However, reported mineral fertilizer application rates were low in the regenerative production systems concerned.
- Fiber quality is not assessed in this LCA, despite its potential significance for farmer income and sourcing decisions. It should be noted that fiber quality can influence not only the market value of cotton but also the energy requirements and efficiency of subsequent processing stages, as well as the quality and durability of the final textile products.

Data collection constraints

- Primary data collection requires significant resources. The study prioritized assessing the availability and quality of existing primary data already being collected, rather than immediately initiating new data-collection infrastructures. However, high-quality primary data was not uniformly available for all product systems, resulting in variability and lower DQR in certain cases (see section 4.1.1 and section 6.3.1).
- With only limited primary-data collection conducted in selected cases, implementing effective stratification to ensure all climatic and social-economic variability in farming systems represented in the country averages proved difficult. Efforts to indirectly address stratification limitations by differentiating major cotton-production regions were constrained

by data availability and incomplete reference data. While sampled production volumes were substantial enough to achieve general country-level representativeness in most cases, the representativeness of specific sub-regions or strata could not be clearly assessed (see section 4.1.1 and section 6.3.1).

- The data collected for this study primarily represents snapshots of current cultivation practices, rather than longitudinal datasets that capture systems in transition or how agricultural systems evolve over time. As such, the analysis does not fully reflect the dynamic nature of practice changes, such as the gradual build-up of soil organic matter or reduced reliance on synthetic inputs over multiple seasons. This limits the ability to assess the long-term impacts and benefits of regenerative or transitional farming approaches (see also section 2.1). In addition, the analysis does not account for temporal variability, such as changes in weather conditions or pest pressures between years, which can influence yields, input requirements, and resulting emissions and, thereby, contribute to variability in real-world outcomes.
- The disclosure of more granular, provider-level data was constrained by confidentiality agreements, limiting the level of detail that could be included in the public documentation of results.
- The cultivation data used in this study was provided directly by participating organizations and is, therefore, self-reported. With the exception of internal plausibility checks conducted by the project team, the Technical Advisory Group, and the independent critical review panel, the data has not been externally audited or independently verified. As a result, there remains a risk of inaccuracies, inconsistencies, or unrecognized biases in the underlying datasets.

Specific data uncertainties

- Certain data points within the inventories were identified as having higher uncertainty. These uncertainties are reflected in the respective DQRs, which highlight limitations associated with specific datasets.
- Water-consumption data for cotton production in India is generally uncertain. Water consumption is often not directly metered but, instead, is estimated based on pump usage duration or energy consumption. This was explicitly the case for a major data provider of organic cotton, making water-related impact assessments particularly uncertain for this production system. The absence of exact water metering is also expected in other regions, especially where cotton is produced by smallholder farmers.
- The nitrogen content in organic fertilizers is typically estimated rather than measured, leading to potential discrepancies in nutrient balance calculations.
- The study aimed to include direct LUC within its data collection framework. However, no data provider explicitly reported LUC associated with their cotton production systems. Verification of actual LUC impacts was not possible, so some uncertainty remains in this regard. Nonetheless, this absence aligns with findings from statistical assessments of land use change (statistical LUC or SLUC), suggesting minimal or no significant LUC impacts within most of the production regions studied. As a result, LUC impacts are only included for the Brazil country average, utilizing available statistical LUC data (BRLUC).
- The application rates of pesticides in secondary datasets are highly uncertain, affecting the accuracy of toxicity impact assessments.

Modeling assumptions

- The study primarily employs IPCC Tier 1 emission modeling for consistency and in alignment with the Cascale Cotton LCA methodology. However, for some of the assessed countries, country-specific emission factors are available, and their use could potentially increase precision in more detailed assessments.
- Nitrate emission modeling remains a challenge in agricultural LCA studies, with different approaches varying in data intensity and modeling complexity. Some methods incorporate climate and soil data, while others rely on generic emission factors. In the baseline of this study, a fixed emission factor for nitrate was used, and the nitrogen balance approach described in the PEF method was assessed in a scenario, which accounts for nitrogen balance but does not consider climatic or soil characteristics. While these approaches align with standard practice, significant uncertainty remains, particularly regarding eutrophication impacts.
- The nitrogen balance does not account for all potential nitrogen inputs, such as carry-over from previous crops, nitrogen in irrigation water, and atmospheric deposition. Particularly in irrigated systems, this may lead to an underestimation of total nitrogen inputs and related impacts.
- Pesticide emissions were modeled using simplified emission rates from the PEF method. Emissions depend on various environmental factors and may diverge significantly from estimated values, particularly for impacts on freshwater toxicity.
- Toxicity factors for biological pesticides used in organic farming are not available; although they are expected to have low toxicity, their exact impact remains unquantified.
- The baseline scenario excludes organic fertilizer production impacts in accordance with the Cascale Cotton LCA methodology. However, this assumption could significantly influence impact assessment results (see section 5.2.1).
- Uncertainty and potential limitations in data quality may not only apply to foreground inventory data but also to background datasets. In this study, this is particularly relevant for fertilizer production datasets. There is uncertainty regarding whether regional variations in provision impacts between sourcing countries are adequately captured, and additional uncertainty arises from the fact that the origin of fertilizers is usually unknown. As a result, fertilizer provision impacts are mapped to the country of consumption, which may not reflect actual sourcing patterns.

Additional general limitations

- It should be mentioned here that this life cycle assessment focuses on environmental impact indicators (and assesses social impacts at screening level as part of the LCA+ approach), but no economic analysis has been included. Incorporating robust financial metrics would require a dedicated study, complete with detailed cost modeling, market-data collection, and stakeholder validation, which was beyond the scope of this study. However, the economic dimension is considered a central pillar of holistic sustainability assessments, and complementary economic assessments would be necessary before any conclusions about potential sustainability benefits of specific production systems or measurements discussed in this study can be drawn.
- This study applies an attributional life cycle assessment approach, which quantifies environmental impacts based on actual material and energy flows within the product's life cycle. Attributional approaches do not account for potential changes in these flows resulting

from shifts in supply or demand, nor do they assess whether demand could exceed supply. Consequently, an assessment of possible market-driven effects and their implications (such as dilution or illegal circumvention of production standards) are outside the scope of this study.

While this LCA study provides a structured and methodologically aligned assessment of cotton production impacts, the outlined limitations must be considered when interpreting the results. Data gaps, uncertainties in secondary datasets, and modeling assumptions introduce uncertainty in the data that needs to be considered in the interpretation of the results. Guidance on how DQR should be considered in the use of the data is given in section 2.3 and in section 6.3.1. Section 6.4.3 outlines some potential future refinements in data collection and modeling approaches that could help mitigate these limitations and improve the robustness of LCA results of cotton cultivation systems.

6.2.2. Recycled cotton

Definition of product systems

- Recycled spinnable fibers can be produced from a wide range of cotton textile wastes. Although post-industrial yarn, post-industrial fabric, and post-consumer waste types are clearly defined and clear guidance on quality of output fibers is provided in the GRS standard (see section 3.1.2), additional guidance is needed to distinguish cotton waste inputs based on key technical properties, as well as to classify recycling technology types. This will help ensure that the most relevant production systems are represented, improve the assessment of representativeness, and support more robust stratification strategies in future studies of recycled spinnable fiber production.
- Cotton waste textile structure, fiber thickness, and other parameters that can influence the expected electricity consumption of the recycling process are not assessed in this LCA.
- Fiber quality is not assessed in this LCA; however, given that mechanical shredding results in a reduced fiber length and quality, this can increase reject rates and downstream energy usage, as well as end-use applications and sourcing decisions.

Data collection constraints

- As no published LCI data was readily available for recycled cotton, the study relied on primary data collection for all LCI data. High-quality primary data was not uniformly available for all product systems, resulting in variability and lower DQR in certain cases (see section 4.1.1 and section 6.3.2).

Specific data uncertainties

- Certain data points within the inventories were identified as having higher uncertainty. These uncertainties are reflected in the respective DQRs, which highlight limitations associated with specific datasets.
- The global average was not calculated using a weighted average based on sampled production volumes. This is due to the lack of information on country-specific production volumes, the absence of a classification system for recycling technology types, and uncertainty around the representativeness of the sampled data.
- Data on packaging and auxiliaries was not consistently reported by data providers; the study applied conservative assumptions on LDPE film and lubricants for all datasets. Assumptions were selected from the most conservative values reported (Table 4-14).

- Data on transportation was not consistently reported by data providers; the study utilized primary data where possible, and applied a conservative assumption of 500 km (domestic transportation to recycling facilities from Tier 1 suppliers) to all datasets without specified transportation. The 500 km was selected as the most conservative value reported (Table 4-14).
- For post-consumer waste, no international transportation distances were reported, although, in some cases, data providers were able to identify the country of origin. An international transportation scenario was developed and included as a baseline scenario, despite the known data-quality issues, given the significance of international transportation impacts and the likelihood of international sourcing.
- The reporting of price data for valuable outputs of all recycled cotton fibers was also inconsistent. To address this uncertainty, a conservative assumption with 100% allocation of impacts to the main product was taken for the global datasets, and a sensitivity analysis was utilized to understand the influence of this allocation on the results.

Modeling assumptions

- The input of cotton waste into the system is burden free, as is the output of the main product and by-products. As this is a multi-output system, allocation is typically utilized to allocate a share of production impacts to the by-products. However, due to uncertainty with price data reported, the baseline scenario assigned 100% of impacts to the main product, and economic allocation was utilized as a sensitivity analysis.
- Country-specific regionalization was applied to all energy and fuel inputs. However, for packaging, auxiliaries, and end-of-life treatment of process waste, European datasets were used across all countries. Due to the negligible impact of geographical proxies, this approach was not considered to affect the study's conclusions (Table 4-15).
- Of the packaging materials listed by data providers, most materials, such as fabric, iron wire, and packaging rope, are reusable and were cut off due to negligible impacts resulting from allocation per lifetime uses. Single-use LDPE stretch film was commonly reported as included in the LCA FE model.
- A plastic waste on landfill dataset was used to model the end-of-life treatment for zippers, buttons, and associated waste. This was based on the assumption that nylon coil zippers and plastic buttons are the most common types, and that labels are negligible by mass. Landfilling was chosen as a conservative assumption, reflecting typical practices in the countries studied.

6.3. Data quality assessment

The Product Environmental Footprint (PEF) method, developed by the European Commission, provides a standardized approach for assessing data quality in Life Cycle Assessment studies (European Commission, 2021). The standard PEF approach evaluates data quality based on five key criteria: technological representativeness (TeR), geographical representativeness (GeR), temporal representativeness (TiR), precision (P), and completeness and consistency. Each data point is rated on a scale from 1 (very high quality) to 5 (very low quality), with the final DQR score calculated as an aggregated weighted average. Under this framework, data quality is assessed at the elementary flow level by evaluating its contribution to a single score across 16 Environmental Footprint (EF) 3.1

impact categories. The DQR is then weighted based on the relative contribution of each parameter to the environmental impacts, ensuring that the most influential data points receive greater scrutiny.

Given the scope and specific requirements of the current LCA study, several limitations of the standard PEF approach were identified. The standard PEF methodology weights DQR according to each parameter's contribution to a weighted single score across environmental impacts. This method can lead to inconsistent DQR results when applied across agricultural datasets, since different parameters influence environmental impacts in varying ways. For instance, irrigation can significantly impact the environmental footprint in irrigated systems and thus would heavily influence the DQR. Conversely, in non-irrigated systems, although the absence of irrigation is typically very certain data, this high certainty would not be adequately reflected in the DQR, as irrigation would not contribute to the weighted single score at all. Similarly, fertilizer use or pesticide application parameters, crucial for accurately determining agricultural impacts, could become underrepresented or distorted due to this weighting approach.

Furthermore, the PEF DQR rating scale is not directly applicable to agricultural data, as it was developed with a broader industrial LCA focus rather than for systems where crop yield, fertilizer efficiency, and land use management play crucial roles in environmental performance. Another limitation is that not all 16 EF 3.1 impact categories are assessed in detail in the main section of this report (see section 3.6), making it impractical to apply the full weighting system from the PEF method. Most of the limitations were also found to apply to recycled cotton. Therefore, for practical reasons, a more consistent and structured DQR methodology was required to ensure comparability between datasets while still aligning with the core principles of the PEF method.

To address these challenges, this study adopted a modified DQR approach that is aligned with the PEF framework but not fully in accordance with it. The modifications ensure that data quality is assessed using criteria relevant to cotton cultivation and processing, and cotton recycling, while still maintaining transparency, consistency, and comparability across datasets.

6.3.1. Cotton cultivation

Modified DQR approach

The DQR methodology applied to assess cotton cultivation in this study was designed to prioritize key inventory categories that significantly influence environmental impacts in agricultural systems. Rather than assessing data at the elementary flow level, the evaluation focused on five primary data categories, each contributing differently to the overall DQR:

- Yield and fertilizer data (50%)
- Irrigation (12.5%)
- Pesticide use (12.5%)
- Fuel use (12.5%)
- Ginning (12.5%)

Technological representativeness (TeR), temporal representativeness (TiR), and precision (P) were assessed for each of the categories above and weighed with the stated weighting factor into a DQR score per data provider. The scoring system followed a structured rating scale (based on the rating scales provided in the PEF method) that classified data points based on completeness, verification status, and representativeness:

- TeR was evaluated based on the completeness and consistency of yield, fertilizer, irrigation, pesticide, and fuel-use data.
- P was determined based on whether data had been externally verified, internally reviewed, or derived from secondary sources.
- TiR was assessed based on the time span covered by the data, with three-year averages scoring highest and datasets older than five years receiving lower scores.
- GeR was rated according to the share of production volume represented and the extent to which key production regions were covered.

The rating scales used are provided in Annex C.

The DQR was then aggregated into the country average, based on production volume similar to all the inventory data parameters (see section 4.1.1). Yield was not assessed separately, as it is always reported in agricultural LCA studies. Instead, the robustness of the combination of yield and fertilizer input was emphasized, given its strong influence on nutrient balance, GHG emissions, and overall environmental performance. Geographical representativeness (GeR) was assessed at the country level, with aggregated DQR based on the assessment of representatives (see section 4.2.1). For datasets that relied entirely on secondary data sources (for example, Brazil country average, Türkiye country average), a default DQR of 3 was assigned to all categories to reflect the inherent uncertainty in such data.

A simple average is built to aggregate TeR, P, TiR and GeR into the final DQR score based on the PEF method:

$$\mathbf{DQR} = \frac{\mathbf{TeR+GeR+TiR+P}}{\mathbf{4}}$$

DQR interpretation and scoring system

Based on the weighting approach described above, the results of the DQR do not span a very wide range. Most individual scores fall between 1 and 3, with occasional ratings of 4 in exceptional cases, resulting in overall values typically ranging from 1.5 to 3.5. Consequently, differences may appear small, yet they can represent important variations in the DQR (see also (Edelen & Ingwersen, 2018)). To highlight differences in DQR, a simplified DQR interpretation framework was developed to categorize datasets based on their reliability and completeness:

Table 6-1: DQR - Levelling and interpretation

Level	DQR	Interpretation	PEF rating
Level 1	<2.2	**good** quality, represents good LCA standard	Excellent and very good
Level 2	≥2.3; <3.1	**medium** quality primary data, or secondary validated data, fit for purpose, but limitations apply	Very good, good
Level 3	≥3.2	**limited** data quality, proxy data, estimate, indicative value	Fair

While ratings above 3.5 were deemed unacceptable, values exceeding 3.1 were already considered problematic, as datasets with large data gaps were excluded from the analysis at an earlier stage.

Datasets based entirely on secondary data received a default DQR of 3, ensuring that transparency was maintained in data evaluation.

Results of the DQR

The following tables (Table 6-2 to Table 6-7) provide the results of the data quality assessment for the different cultivation systems and regions. The rating scales used are provided in Annex C. Despite these criteria, it should be highlighted here that the rating remains subjective to a certain extent, a common criticism around DQR approaches (Edelen & Ingwersen, 2018). The numbers provided here should be interpreted in relation to the inventory tables (Table 4-5 to Table 4-10) and the assessment of representativeness (Table 4-4). It should also be noted that the four categories are assessed independently from one another. For example, a dataset may receive a high score for time representativeness but a low score for geographical representativeness, resulting in a mixed DQR outcome. It could be argued that if the score in one category is low, it should determine the overall DQR (i.e., the overall DQR should not exceed the lowest individual category score). However, these are inherent limitations of the DQR (ibid.). To maintain consistency with the approach proposed in the PEF method, and to avoid developing an entirely new rating system, the method outlined in the PEF guidance was retained to the largest extent possible.

Table 6-2: DQR—India

	India country average	**India organic**	**India regenerative**
TeR	1.8	1.4	1.6
TiR	1.5	2.9	3.0
P	1.8	2.0	2.0
GeR	2.0	1.0	3.0
DQR	**1.8 (Level 1)**	**1.8 (Level 1)**	**2.4 (Level 2)**
Comment	Primary data, three years average, data complete except fuel and ginning, main production regions covered, yield and fertilizer data externally validated for main data provider	Five data providers, most of them with complete datasets; however, largest data provider has only one year of data, and uncertainty remains to N content of organic fertilizer	Four data providers, GeR default 3 because main production regions unknown

Table 6-3: DQR—South America

South America	**Brazil country average** (secondary)	**Brazil organic**	**Peru organic**	**Peru regenerative**
TeR	3	3.3	2.0	2.0
TiR	3	3	1.5	1.5
P	3	3.5	2.3	2.3
GeR	3	3	1	1
DQR	**3 (Level 2)**	**3.2 (Level 3)**	**1.9 (Level 1)**	**1.9 (Level 1)**
Comment	Secondary data default score 3	~20 farmers, very high variability in	One data provider, but good	One data provider, but good

South America	**Brazil country average** (secondary)	**Brazil organic**	**Peru organic**	**Peru regenerative**
		yield and fertilizer data	coverage, inventory parameters were reviewed in several iterations	coverage, inventory parameters were reviewed in several iterations

Table 6-4: DQR—Tanzania

	Tanzania organic
TeR	2.5
TiR	1.3
P	2.1
GeR	1.0
DQR	**1.7 (Level 1)**
Comment	Low input, low output system, organic fertilizer input uncertain but low, GeR high

Table 6-5: DQR—Türkiye

	Türkiye country average (secondary)	**Türkiye organic**	**Türkiye regen**
TeR	3	2.6	2.3
TiR	3	2.5	1.4
P	3	3.0	2.2
GeR	3	4.5	4.0
DQR	**3 (Level 2)**	**3.2 (Level 3)**	**2.5 (Level 2)**
Comment	Secondary data default score 3	Two data providers; one did not share sampling information, other 20ha, i.e. small sample size	Four data providers; however, represented production volume is small

Table 6-6: DQR—US

	US country average (Cotton Incorporated)	**US organic**
TeR	1.0	3.0
TiR	2.0	1.3
P	1.7	3.0
GeR	1.0	2.0
DQR	**1.4 (Level 1)**	**2.3 (Level 2)**
Comment	Combination of US survey report (Bayramova, et al., 2024), survey data from national agricultural statistics service (NASS, (United States Department of	Five farmers from one cooperative, but comparatively large area cultivated; multiple year averages available, data on organic fertilizer

	US country average (Cotton Incorporated)	**US organic**
	Agriculture, 2025)), and additional information provided by Cotton Incorporated based on its upcoming LCA study (unpublished). Yield, fertilizer, and irrigation data considered as verified since part of peer-reviewed journal publication. Survey results represent single cultivation year, but consistency with values from previous assessments is demonstrated in the relevant publications.	input uncertain, irrigation water estimated

Table 6-7: DQR—China (selected regions)

	China (selected regions, secondary)[1)]
TeR	3
TiR	3
P	3
GeR	3
DQR	**3 (Level 2)**
Comment	Secondary data, mainly based on official Chinese statistics.

1) For regions included, see section 3.1.1, Table 3-1

6.3.2. Recycled cotton

Similar to the modified DQR approach described in the previous cotton-cultivation section, recycled cotton has also adopted a modified DQR approach that is aligned with the PEF framework but is not fully in accordance with it. The modifications ensure that data quality is assessed using criteria relevant to cotton recycling, while still maintaining transparency, consistency, and comparability across datasets.

Modified DQR approach

The DQR methodology applied to recycled cotton in this study was designed to prioritize key inventory categories that significantly influence environmental impacts. Rather than assessing data at the elementary flow level, the evaluation focused on electricity and transportation (domestic/international) data, as these data points were identified as having the most significant contribution for all impact categories analyzed.

Post-industrial yarn waste, post-industrial fabric, and post-consumer waste (domestic)

For Technological representativeness (TeR), precision (P), and geographical representativeness (GeR), electricity and transportation contributed the following percentages to the overall DQR:

- Electricity (86.5%)
- Transportation (13.5%)

For temporal representativeness (TiR), transportation distances were not considered and, therefore, contributed the following percentage to the overall DQR:

- Electricity (100%)

Post-consumer waste (international transportation)

For technological representativeness (TeR), precision (P), and geographical representativeness (GeR), electricity and transportation contributed the following percentages to the overall DQR:

- Electricity (60%)
- International transportation (30%)
- Transportation (10%)

For temporal representativeness (TiR), transportation distances were not considered and, therefore, contributed the following percentage to the overall DQR:

- Electricity (100%)

Technological representativeness (TeR) and precision (P) were assessed for each of the categories above, and weighed with the stated weighting factor into a DQR score per the global, recycled spinnable fiber dataset. The scoring system followed a structured rating scale (based on the rating scales provided in the PEF method) that classified data points based on completeness, verification status, and representativeness:

- TeR was evaluated based on the completeness of electricity and transportation data, as well as the alignment of electricity data to the available benchmarks.
- P was determined based on whether data had been externally verified, internally reviewed, or derived from secondary sources.
- TiR was assessed based on the reference year and average time period, with data <3 years old and >1 year average scoring highest, and data with time coverage <6 months and >5 years old, or no time reference provided, receiving lower scores.
- GeR was rated once on the global dataset level, according to the number of data points that were provided for each dataset.

The rating scales used are provided in Annex B.

Unlike cotton cultivation, the DQR was not aggregated based on a weighted average. This was due to the high uncertainty regarding the representativeness of any one data provider, given the total production volume sampled was ~8% of global annual production, and there was no available breakdown of annual production per country or per recycling technology. Therefore, a non-weighted average was taken for the DQR values calculated per datapoint. A simple average is built to aggregate TeR, P, TiR, and GeR into the final DQR score based on the PEF method:

$$\mathbf{DQR} = \frac{\mathbf{TeR+GeR+TiR+P}}{\mathbf{4}}$$

DQR interpretation and scoring system

The same leveling system as for cotton cultivation was used (see Table 6-1).

Results of the DQR

Table 6-8 provides the results of the data-quality assessment for the different recycled spinnable fiber cotton waste types.

Table 6-8: DQR—recycled spinnable fibers (post-industrial yarn waste, post-industrial fabric waste, and post-consumer waste)

Weighting	DQR	Post-industrial yarn waste	Post-industrial fabric waste	Post consumer waste
	TeR	**1.9**	**1.9**	**1.8**
86.50%	Energy consumption	1.7	1.8	1.6
13.50%	Transport	3.1	2.7	3.2
	P	**2.1**	**2.2**	**2.2**
86.50%	Energy consumption	2.0	2.0	2.0
13.50%	Transport	2.6	3.3	3.6
	TiR	**2.3**	**1.8**	**2.4**
100%	Energy consumption	2.3	1.8	2.4
	GeR	**2.5**	**2.0**	**3.5**
86.50%	Energy consumption	2.0	2.0	3.0
13.50%	Transport	3.0	2.0	4.0
	DQR	**2.2**	**2.0**	**2.5**
	DQL	**Level 1**	**Level 1**	**Level 2**

Table 6-9: DQR—recycled, spinnable fibers (post-consumer waste international transportation)

Weighting	DQR	**Post-consumer waste** (international transportation)
	TeR	**2.5**
60%	Energy consumption	1.6
30%	International transportation	4.0
10%	Transport	3.2
	P	**3.1**
60%	Energy consumption	2.0
30%	International transportation	5.0
10%	Transport	3.6
	TiR	**2.4**
100%	Energy consumption	2.4
	GeR	**3.1**
60%	Energy consumption	3.0
30%	International transportation	3.0
10%	Transport	4.0

Weighting	DQR	**Post-consumer waste** (international transportation)
	DQR	**2.8**
	DQL	**Level 2**

6.3.3. Model completeness and consistency

All relevant process steps for each product system were considered and modeled to represent each specific situation. The process chain is considered sufficiently complete and detailed with regard to the goals and scope of this study. All assumptions, methods, and data are consistent with each other and with the study's goals and scope. Differences in background data quality were minimized by using LCI data from Sphera's MLC databases (2024.2). System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

6.4. Conclusions and recommendations

6.4.1. Conclusions

Context and challenges

When assessing the findings of this study, it is important to consider the context and limitations that existed before its initiation. Previously, stakeholders in the fashion, textile, and apparel industry faced significant challenges related to the availability and quality of life cycle assessment data for cotton. These challenges included outdated information, aggregation of data to global averages that obscured important regional variations, inconsistent modeling approaches, and incomplete representation of environmental impacts.

This study was initiated with the awareness that numerous data collection efforts were already underway within the cotton industry (for example, LCA studies initiated by cotton programs, umbrella organizations, data submissions to Higg MSI via the Cotton LCA framework). Building on this assumption, the research proactively initiated an extensive stakeholder dialogue, thoroughly assessed the existing availability of cultivation data, and undertook significant preparatory and background work as part of a dedicated project-scoping phase prior to commencing the LCA. In the process, valuable discussions and exchanges among stakeholders were facilitated, which represents an important achievement of the project.

A key achievement of this study is the transparent mapping of cause and effect chains across the assessed systems. Unlike some of the datasets currently available in LCA databases which present results without providing detailed life cycle inventory data or a clear description of methodological assumptions, this work explicitly documents the specific aspects of cotton cultivation and recycling that drive environmental impacts, the types and quality of data required to robustly assess these impacts, the influence of methodological choices on the outcomes, and how these choices translate into the reported results.

While it was not possible to compile high quality LCI datasets for all production systems under investigation, the study, nonetheless, serves as a comprehensive demonstration of the practical implications of compiling LCA results for cotton cultivation and recycling. By making all methodological building blocks available, it enables users to explore scenarios, test assumptions, and understand the sensitivity of results to both data inputs and modeling decisions. This approach

not only strengthens the interpretability and reproducibility of the findings but also provides a practical reference for stakeholders seeking to apply LCA in the textile sector with greater methodological transparency.

However, it also became evident that the most systematic and robust data collection currently occurs at the program level (for cotton cultivation). In contrast, data that reflects regional averages (either at the country or sub-country level) and is suitable for use as benchmark datasets, or to represent production systems not covered by cotton programs, remains scarce and is often fragmented. While this study made considerable efforts to compile such datasets, it also highlights that significant gaps remain, and further targeted efforts are needed to improve the availability and representativeness of regionally aggregated data.

Inventory data development

The study made considerable efforts to compile inventory data for cotton cultivation and recycled cotton in a consistent and transparent manner. It prioritized the use of available primary data, carefully assessing both representativeness and overall data quality. Where primary data was unavailable or insufficient, secondary data was incorporated as supplementary information, with associated limitations clearly reflected in the data-quality ratings. Additionally, benchmarking analyses were conducted to enhance transparency and credibility. Although the resulting inventory data still contains limitations and uncertainties, the work represents an important baseline upon which future data improvements can be systematically developed.

Despite these efforts, for cotton-cultivation data, availability and quality varied considerably across regions and cultivation systems, impacting the overall representativeness of the study. Comprehensive and reliable datasets were primarily found in country-average and organic cotton systems in India, regenerative and organic systems in Peru, organic cultivation in Tanzania, and conventional practices in the US. However, data from regenerative systems in India, and organic production in Brazil, Türkiye, and the United States showed limitations due to lower-quality ratings. The reliance on secondary datasets, particularly for Brazil, Türkiye, and selected regions of China, further introduced uncertainties regarding data representativeness.

For recycled cotton, previously, no industry-wide LCA studies were available that differentiated the production of recycled spinnable fibers from post-industrial yarn, post-industrial fabric, and post-consumer waste, increasing the textile sector's reliance on the use of supplier-specific LCIA with inherent uncertainties regarding representativeness. Within this study, reporting on inventories such as packaging, auxiliaries, and transportation distances beyond Tier 1 suppliers was inconsistent, necessitating the use of secondary data and scenario analysis to address data gaps. The lack of publicly available benchmark inventory data also caused issues with the validation of reported data. Furthermore, given the lack of information on the breakdown of global annual production of recycled spinnable cotton fiber to country-specific production volumes, waste types, and recycling technologies, it was not possible to assess the representativeness of the primary data collected. Despite these challenges, this study has significantly improved the representativeness of available LCA data for recycled spinnable cotton fibers, providing publicly available, global-average LCIA disaggregated into respective cotton waste types with transparent documentation of LCI; as well as improving the outlook for future studies by providing improved transparency of data-collection methodologies, assumptions, and analysis, and recommendations to address identified challenges.

Environmental hotspots in cotton cultivation

Environmental impacts associated with cotton cultivation are shaped by a small set of systemic drivers that cut across impact categories. Field emissions related to the nitrogen balance are central for climate change and eutrophication modeling; fertilizer provision impacts further condition results,

with mineral fertilizer production contributing to upstream burdens, while organic fertilizers are usually treated as residues or by-products whose upstream burdens are not allocated to cultivation. Irrigation influences both blue-water consumption and energy-related emissions, and its relevance depends on water-use efficiency, technique, and local hydrogeological conditions. Pesticide inventories and characterization factors strongly affect ecotoxicity modeling, where a limited number of active ingredients can have a disproportionate influence. Yield levels act as a scaling parameter across categories because inventory flows are expressed per unit of output. Post-harvest energy supply (for example, electricity for ginning) also contributes to the overall profile.

Scenario explorations indicate that results are sensitive to methodological choices, including the handling of organic fertilizer provision, selection of nitrous oxide and nitrate leaching factors, nutrient contents assumed for organic materials, the use of an N-balance approach for emission modeling and fertilizer inventories, aggregation versus substance-specific pesticide modeling, and the electricity mix used in ginning.

In addition to standard LCA impact categories, this study applied an LCA+ approach to provide indicative assessments of soil health and biodiversity. These are presented in a separate section as high-level screening analyses, together with an assessment of social impacts, to highlight their exploratory nature and avoid confusion with core results.

For soil health, the study used soil organic carbon (SOC) as a proxy, applying the IPCC Tier 1 methodology. Results suggest that reduced tillage and especially increased organic inputs, such as cover crops or manure, can enhance SOC stocks and strengthen long-term soil resilience. However, these estimates rely on default factors, assume linear trends, and do not capture site-specific variation. They should, therefore, be interpreted as indicative scenarios, not as robust or reportable removals.

For biodiversity, impacts were assessed indirectly by interpreting existing environmental-impact categories such as land use change, eutrophication, pesticide use, and water consumption as proxy indicators (see section 7.2). While reductions in these pressures are generally expected to lower biodiversity risks, the outcomes depend on local conditions, and no direct one-to-one correlation can be assumed. Some potential benefits of specific farming practices are highly site-specific and develop gradually over time, and may, therefore, fall outside the resolution of this LCA. Since the LCA+ approach primarily relies on screening methods, more granular and site-specific assessments are necessary to fully capture long-term and localized environmental impacts and benefits.

Environmental hotspots in recycled cotton production

The environmental impact analysis identified electricity consumption and transportation as the key drivers of potential environmental impacts for all impact categories and inventories analyzed for the production of recycled spinnable fibers. Post-industrial yarn waste was identified as having the lowest potential impacts, and post-consumer waste as having the most significant potential impacts for all impact categories and inventories analyzed, with electricity consumption, on average, considerably higher for this waste type due to the additional processing steps required prior to fiber opening and higher process waste losses. Additionally, post-consumer waste international transportation, along with other potential upstream impacts such as washing and drying or fumigation, was identified as a significant potential source of additional environmental impact.

Despite these findings, due to the significant variation observed in key inventories between data providers, high uncertainty remains regarding the potential environmental impacts of individual suppliers of recycled cotton fibers, and it cannot be assumed that one waste type is inherently more impactful than another. Therefore, for companies procuring recycled, spinnable fibers, the collection of supplier-specific, externally validated inventory data, including electricity consumption and

transportation (including international transportation from source), should be prioritized when analyzing the supply chain-specific impacts of fibers, or to inform data-driven environmental impact reduction strategies.

Limitations affecting cotton-cultivation findings

Despite the progress achieved, this study is subject to several limitations that impact the interpretation and application of its findings. For cotton cultivation, the limitations stem primarily from data-availability constraints, methodological assumptions, and the inherent complexity of agricultural systems. Key limitations include variability and uncertainty in primary data quality, and challenges related to the representativeness of regional data. Specific uncertainties affecting inventory data include yield data for organic and regenerative systems, estimated irrigation water consumption, nutrient content estimations for organic fertilizers, and pesticide application rates in secondary datasets. Beyond foreground data, background datasets, such as those for fertilizer production, also carry significant uncertainty, as regional sourcing patterns are often unknown and provision impacts are approximated by the country of consumption. Furthermore, the study applies an attributional LCA approach focused on environmental indicators; it does not account for market-mediated effects or include an economic analysis, which would require separate, dedicated studies. Such limitations must be explicitly considered in interpreting the study's outcomes, and further refinements in data collection and modeling approaches are recommended to enhance the robustness and applicability of cotton LCA data in the future (see section 6.4.3 on recommendations).

Limitations affecting recycled cotton findings

For recycled cotton, the limitations stem primarily from the availability of benchmark LCI data, data availability constraints, and validation of primary data collection. Key limitations included variability and uncertainty in primary data quality, and challenges related to quantifying the representativeness of supplier-specific data. Specific uncertainties affecting inventory data include assumptions on packaging, auxiliaries, and transportation distances, as well as electricity-data validation. Additionally, for post-consumer waste, given the variability of input waste types and output fiber qualities, future studies would benefit from more granular classification of post-consumer waste to more effectively benchmark expected LCI and address uncertainty regarding representativeness. Furthermore, as an assessment of representativeness was not conducted for any recycled, spinnable fibers, it is imperative for LCA practitioners to review the studies documenting LCI in comparison to their own supplier-specific LCI, to ensure representativeness of global average datasets is considered when utilizing the LCIA.

Similarly to cotton cultivation, such limitations must be explicitly considered in interpreting the study's outcomes, and further refinements in methodological alignment and data collection are recommended to enhance the robustness and representativeness of recycled cotton LCA data in the future (see section 6.4.3 on recommendations).

Overall significance and future outlook

In conclusion, this study represents a considerable advancement in the state of LCA data for cotton and related fibers, including recycled cotton. While the study has clearly outlined limitations, particularly relating to data availability, representativeness, and methodological constraints, it has, nonetheless, delivered significant improvements compared to previous datasets. Notably, by systematically compiling transparent inventory data, adhering to industry-aligned methodologies such as the Cascale Cotton LCA Methodology, and providing comprehensive documentation, this study marks a clear step toward higher transparency and robustness in cotton LCA results.

Nevertheless, to ensure accurate and meaningful assessments, users should prioritize supply chain-specific data over generic datasets. The LCA results presented in this study are intended to serve as default values only when more specific data, such as farm- or program-level inventories, are not available. In addition, LCA results remain sensitive to assumptions and contextual factors; thus, the results should be interpreted within their limitations, and simplistic rankings, comparisons, or claims based on these should not be completed. When interpreting and reporting results, the robustness of the underlying data should be given equal or greater weight than the numerical value of the impact itself. Transparent documentation of data quality and uncertainty is essential to ensure the responsible communication of results. For datasets identified with lower data quality, particular attention should be paid to the uncertainty ranges reflected in scenario and sensitivity analyses. In such cases, more detailed data collection and improved representativeness can lead to substantial changes in results. Although conservative estimates were applied in this study wherever necessary, the inherent uncertainty of lower-quality datasets implies that impacts will not necessarily decrease as data quality improves but could also increase.

Finally, it should be reiterated that this study is non-comparative in nature. The datasets are intended for use as defined in section 2.3 and section 2.4. For guidance on responsible interpretation and application, users should refer to Textile Exchange's position paper *Ensuring Integrity in the Use of Life Cycle Assessment* (Textile Exchange, 2025).

The study outlines targeted recommendations to enhance data quality, and reduce environmental impacts, across cotton cultivation and recycled cotton systems. For cultivation, key actions include improving nitrogen management, optimizing irrigation, and enhancing methodological consistency. For recycled cotton, priorities include better classification of waste types, improved electricity metering, and reduction of transport-related impacts. Continued stakeholder engagement and coordinated data collection are emphasized, along with a proposed Phase 2 follow-up to address remaining data gaps. A more detailed overview of all recommendations is provided in section 6.4.3.

6.4.2. LCA data challenges: positioning and outlook

LCA is a widely used tool for quantifying the environmental impacts of textile materials, including cotton cultivation and recycled cotton. However, LCA applications in this context have drawn recurring concerns around data quality, methodological consistency, and the way results are communicated and interpreted, especially in relation to product claims and global fiber comparisons. This section reviews common criticisms of LCA data use in the cotton and fashion, textile, and apparel industries. These concerns were collected through stakeholder feedback, the 2021 report *Identifying Low Carbon Sources of Cotton and Polyester Fibers by the Fashion Industry Charter for Climate Action* (FICCA, 2021), and recent publications that have critically examined LCA methodologies and their use in sustainability communication (Kassatly & Pauly, 2021), (Kassatly & Pauly, 2022). Table 6-10 presents a selection of these concerns, alongside the study's response or position, and references recommended next steps as outlined in the next section (section 6.4.3). Textile Exchange recently published a position paper titled *Ensuring Integrity in the Use of Life Cycle Assessment – Data-Responsible Impact Measurement for the Fashion, Textile, and Apparel Industry* (Textile Exchange, 2025), which provides additional context around LCA data and challenges.

Table 6-10: LCA Data Challenges—positioning and outlook

LCA challenge/criticism	Criticism description	How this LCA study addresses the challenge	Relevant sections	Related recommendations (see section 6.4.3)
Inconsistent and non-standardized methodologies	LCA results are highly sensitive to assumptions, LCA methods vary (system boundaries, allocation, functional units), making comparisons unreliable (wide ranges in GHG estimates reflect inconsistent methods more than real-world differences).	This study follows the Cascale Cotton LCA Methodology (Cascale, 2024b), which provides industry-aligned guidance on key methodological aspects such as system boundaries, allocation procedures, functional units, and default secondary data values. By adhering to this framework, the study ensures consistency with widely accepted modeling approaches used for cotton LCA studies in the fashion, textile, and apparel industries. Where possible, assumptions and data align with those defined by the methodology, helping to improve the comparability and credibility of the results.	2.2	Model comparison and methodological alignment.
Misuse of LCA results for simplistic rankings, comparisons, or claims	LCA results are oversimplified into scores or rankings that mislead consumers and mask nuance.	The study clearly outlines its intended use and limitations, emphasizing that LCA results are context-dependent and not suited for simplified product comparisons. The results of this study should not be used for consumer-facing claims; see section 2.3 for further information on the intended uses.	2.3 2.4	Alignment with LCA guidance and transparent communication, see also Textile Exchange's position paper *Ensuring Integrity in the Use of Life Cycle Assessment – Data-Responsible Impact Measurement for the Fashion, Textile, and Apparel Industry* (Textile Exchange, 2025).
Lack of transparency and public access to data	LCA data and assumptions are often not publicly available, making claims unverifiable.	This study ensures a high degree of transparency by publishing the inventory data used in the LCA modeling, along with comprehensive documentation of the data sources, system boundaries, and modeling assumptions. Limitations in data quality are explicitly communicated (however, the constraint that more granular data on provider-level could not be disclosed due to confidentiality agreements is a limitation). All key assumptions are clearly stated and accompanied by sensitivity or scenario assessments to evaluate their influence on results. A DQR approach was applied to assess the quality of data for each cotton system.	4.1 4.2 5.2-5.4 6.2	Alignment with LCA guidance and transparent communication; improved and ongoing primary data collection.
Use of outdated or non-representative data	Many LCA studies rely on data that is 10–20 years old, not	The goal of this study is to use the most recent and representative data available. Primary data was collected directly from cotton-production systems,	3.3	Improved and ongoing primary data collection.

LCA challenge/criticism	Criticism description	How this LCA study addresses the challenge	Relevant sections	Related recommendations (see section 6.4.3)
	reflecting current practices or technologies.	primarily covering the 2023/2024 season and, where available, previous cultivation years. For secondary data, a strict cut-off was applied to exclude sources older than 10 years. The DQR of the study considers time representativeness.		
Data collection bias and small sample sizes	Small, unrepresentative samples and vested-interest data collection skew LCA outcomes.	The study recognizes the importance of ensuring representative primary data to support robust and credible results. While high representativeness in the data compiled for this study could not always be achieved due to practical constraints, the intention to capture representative data guided the evaluation of data quality. To support transparency, the study includes a detailed assessment of representativeness for each dataset, in alignment with established statistical approaches. This enables users to understand the extent to which results can be generalized. Representativeness is formally considered within the DQR framework, ensuring that any related limitations are communicated and factored into the interpretation of results.	4.1 4.2.1 6.3	Improved and ongoing primary data collection; development of national and regional data coordination models.
Regional and practice-based variability ignored	Global averages mask local variation in cotton-production impacts, leading to inaccurate conclusions.	The study addresses this challenge by providing country-specific datasets rather than relying on global averages. The primary goal was to develop country-level averages. While the study acknowledges that regional and farm-level variation exists and can significantly influence environmental impacts, such granular assessments were beyond the scope of this assessment. More detailed (for example, supply chain-specific) studies are encouraged, and this study provides a transparent foundation that can support such follow-up analyses. Where regional LCA data exists that aligns with a brand's or user's sourcing regions, its use is strongly recommended and should be prioritized over the use of national averages, to ensure the representativeness of results (see also 2.3).	2.3 3.1	Improved and ongoing primary data collection; development of national and regional data-coordination models.

LCA challenge/criticism	Criticism description	How this LCA study addresses the challenge	Relevant sections	Related recommendations (see section 6.4.3)
Cherry-picking data to support pre-set narratives	Selective data use to favor certain fibers undermines credibility of comparative results.	This study does not support or encourage comparative assertions between different cotton-cultivation systems (or with other fibers). Its focus is on generating transparent and representative inventory data for cotton-production systems. To further safeguard against bias or pre-set narratives, the study was guided by a multi-stakeholder Technical Advisory Group (TAG) and underwent external review by a critical review panel that represented different views in the cotton sector. These structures were designed to ensure that diverse perspectives were considered.	2.4 3.9	Independent oversight and multi-stakeholder engagement.
Scope: Lack of use-phase and end-of-life consideration; functional performance not considered	Cradle-to-gate LCA studies exclude garment use and disposal, skewing fiber impact comparisons. Garment durability or wear count is ignored, undervaluing long-lasting natural fibers.	This is a question of scope. All Textile Exchange LCA studies are designed as cradle-to-gate studies. Users are encouraged to integrate this data into broader cradle-to-grave assessments where use-phase and end-of-life impacts are relevant to their goals.	2.3 3.1	Alignment with LCA guidance and transparent communication.
Poor representation of sustainable and regenerative practices	Low-carbon practices (for example, no-till, intercropping) are often omitted, underestimating mitigation potential.	This study explicitly focuses on capturing organic and regenerative cotton production practices. While not every factor or practice is assessed separately, the study allows for an overall picture of the environmental impact of such systems.	3.3.1	Improved and ongoing primary data collection; independent oversight and multi-stakeholder engagement.
Exclusion of key emission sources	Important sources (for example, soil carbon changes, irrigation energy) are inconsistently included.	See also the comment above: this study follows the Cascale Cotton LCA Methodology, which defines a consistent set of emission sources to be included. No arbitrary cut-offs were applied, and all relevant inputs were accounted for.	3.3	Alignment with LCA guidance and transparent communication.
LCA studies are not comprehensive measures of sustainability	LCA studies only measure environmental impacts, not social or economic factors; they cannot support broad "sustainable" claims on their own.	This study is designed as an environmental Life Cycle Assessment and does not claim to capture the full spectrum of impact areas relevant for to cotton production. Following Textile Exchange's LCA+ approach, additional impacts beyond conventional LCA metrics are considered; for example, a review of potential social impacts is included, though relevant	3.6 Annex B	Alignment with LCA guidance and transparent communication; independent oversight and multi-stakeholder engagement.

LCA challenge/criticism	Criticism description	How this LCA study addresses the challenge	Relevant sections	Related recommendations (see section 6.4.3)
		limitations apply in this area as well. Economic dimensions remain outside the scope of this assessment. Users are advised not to interpret the results as comprehensive sustainability ratings. Instead, the findings are intended to inform decision-making as one element within a broader assessment framework.		
Concerns over industry-led studies	Private corporations should not unilaterally determine the environmental impact of materials; independent oversight and public accountability are necessary.	This study was supported by a formal critical review process and guided by a multi-stakeholder Technical Advisory Group (TAG) composed of independent experts to ensure independent verification. These measures follow—and through the addition of the TAG, go beyond—the requirements set out in international standards, such as ISO 14044 for third-party reviewed LCA studies. While the study was industry-funded and conducted by a private consultancy, these third-party verification structures were implemented to ensure transparency, methodological integrity, and overall credibility. The study acknowledges that greater independence in data collection and verification, particularly by public or academic institutions, would significantly strengthen the credibility and robustness of LCA results. However, public investment in such efforts has so far been limited. In this context, the aim of this study is to work transparently with the best available data, ensure stakeholder engagement and external review, and make results accessible for broader scrutiny and discussion. This approach is intended as a constructive step forward, while recognizing the need for more publicly governed holistic assessments in the future.		Independent oversight and multi-stakeholder engagement; development of national and regional data-coordination models.

6.4.3. Recommended next steps

Several opportunities to enhance future cotton LCA efforts have emerged from the findings of this study. The recommendations presented below are structured into two main categories:

- Recommendations to improve data quality (further research)
- Recommendations to reduce environmental impacts

Where possible, the focus has been placed on recommendations that are directly derived from this study's findings, in order to avoid repeating general best practices regarding data collection and reporting (for example, (European Commission, 2021), (GHG Protocol, 2022)), or agricultural practices (Textile Exchange, 2022), commonly discussed elsewhere. Nonetheless, these general requirements and widely accepted recommendations remain relevant and should be considered when implementing the specific actions proposed in this study.

This study emphasizes the importance of aligning with established methodological frameworks, and clearly communicating the scope and limitations of LCA results. Recommendations on how to interpret and use LCA results are, therefore, not repeated here. Textile Exchange is also engaged in ongoing work to strengthen integrity in the use of LCA results across the apparel, fashion, and textile industries. For further details, refer to the position paper titled *Ensuring Integrity in the Use of Life Cycle Assessment – Data-Responsible Impact Measurement for the Fashion, Textile, and Apparel Industry* (Textile Exchange, 2025).

Recommendations to improve data quality (further research)

Target groups: Research institutions, LCA method developers, NGOs coordinating cotton initiatives, data platform operators, LCA practitioners, and sustainability managers in the fashion, textile, and apparel industries.

What?

- Improve methodological harmonization of data collection and impact assessment:
  - For cotton cultivation, Textile Exchange has initiated a parallel project to compare the outputs of different LCA model providers using the same input data. The goal is to better understand variation in results and to support further alignment in modeling approaches across the cotton LCA community. This will help improve the credibility and interpretability of future LCA outcomes and their correct use.
  - For recycled cotton, methodological alignment is the most imperative next step. While there is less uncertainty around modeling aspects, methodological alignment is necessary to improve the definition of product systems and data-collection approaches (see next section). The setup of a recycled cotton-industry working group will be required to develop a consistent approach for the quantification of environmental impacts, encompassing the views of key industry stakeholders.
- Address temporal and spatial data gaps in cotton-cultivation data: Expand LCI datasets to capture multi-year trends and regional variability; develop a sampling strategy to increase granularity and to reflect production system diversity across countries, climate zones, and farm types.
- Improve granularity in recycled fiber inventories: future data collection efforts should focus on the following aspects:
  - Stratify recycled, spinnable fiber-waste types: differentiate between post-industrial yarn, post-industrial fabric, and post-consumer waste; discuss if differentiation of

cotton waste based on key technical properties affecting electricity consumption and/or fiber output quality needs to be considered.
  - Classify key recycling technologies to benchmark and validate electricity consumption across systems.
  - Identify key inventory data required for each waste type (for example, transportation, packaging, auxiliaries).
  - Develop a secondary inventory data repository to support consistent reporting when primary data is missing.
  - Prioritize primary data collection for electricity use and transportation, as these are critical impact drivers:
    - Installation of appropriate electricity metering in recycling facilities, especially when other non-recycling processes (for example, spinning) are co-located, to avoid data allocation issues[42].
    - Encouragement of collaboration with recyclers early in the LCA study to ensure relevant metering is in place.
  - Improve traceability of transportation data, particularly for post-consumer waste, by tracking cotton waste supply chains to their origin[43]:
    - Textile Exchange's ongoing collaboration with Fashion for Good (FFG) on the Tracing Textile Waste project (Fashion For Good, 2024) will help to address this through improved transparency and traceability of textile waste through updates to the Reclaimed Material Declaration Form. This form was published in July 2025, and informed updates to existing GRS and RCS schemes and set a new standard for traceability.

How?

- Build stakeholder capacity: The study introduced LCA methodologies to several organizations for the first time, and continued engagement could help these stakeholders enhance their data collection capacities. In return, the study has provided participating organizations with supplier-specific LCIA results, fostering mutual learning and transparency. With further guidance, many of these organizations could contribute more structured, representative, and supply chain specific LCA datasets, ultimately enriching the landscape of cotton LCA data.
- Maintaining momentum: Given the momentum generated through stakeholder engagement, increased data transparency, and growing awareness of the study's findings, a timely follow-up effort is recommended. A Phase 2 of this study would provide an opportunity to address remaining limitations in a targeted manner, informed by the lessons learned during the initial assessment. Careful planning should be undertaken to prioritize critical data gaps and improve representativeness, and to align data collection efforts with specific use case (for example, provide generic data where program specific data is missing).

42 For electricity, most, if not all, companies have metering installed. However, as many factories also include processes outside the system boundaries of the study, such as the spinning process, it is recommended to work with recycling companies prior to the initiation of LCA studies to install appropriate metering to avoid allocation of aggregated electricity data.

43 Most recycling companies were not able to provide specific transportation modes and distances beyond their local Tier 1 suppliers. However, to accurately quantify the environmental burden of transportation, particularly for post-consumer waste, it is imperative to track the supply of cotton waste back through the supply chain to its source.

- Long-term engagement: Several data providers and potential contributors have already indicated the availability of updated or additional data, which could significantly strengthen future assessments if captured in a timely manner. Maintaining continuity with engaged stakeholders and leveraging the established dialogue will be key to sustaining engagement, ensuring consistency across study iterations, and supporting the implementation and monitoring of environmental-impact reductions over time.
- Encourage national data-coordination models: This study demonstrated the feasibility of using secondary data to develop country-level averages, but the credibility of country-average reference data will increase when derived from officially recognized sources and endorsed by country-representative organizations. As an example, the approach adopted by Cotton Incorporated, in which a national organization compiles inventory data on behalf of producers, presents a good case study for others to follow.
- Encourage cooperation with independent bodies for data governance: To enhance methodological rigor, transparency, and credibility, data-collection initiatives should aim to involve independent institutions (such as academic or public-sector bodies) either through consultation, oversight, or review. Such cooperation can help minimize bias and facilitate external validation where appropriate.
- Reduce data-provider fatigue and ensure incentives: Incentivize participation in data collection by aligning efforts with existing frameworks, minimizing redundancies, and ensuring that the data providers benefit from their involvement.
- Recommend that sustainability managers in the fashion, textile, and apparel industries include supply chain traceability requirements for recycled, spinnable fibers in their procurement practices to drive upstream data availability.

Recommendations to reduce environmental impacts

Target groups: cotton farmers, agricultural extension services, regenerative/organic cotton programs, supply chain sustainability teams, and sustainability managers in in the fashion, textile, and apparel industries.

Cotton cultivation systems

It should be noted that most of the recommendations presented in this section are already generally known and not exclusively derived from the findings of this study. At the same time, it is acknowledged that various socio-economic conditions often act as barriers to the practical implementation of such measures. A detailed investigation of these hurdles, and potential ways to overcome them, lies beyond the scope of this study. Nevertheless, the results presented here provide additional emphasis on the potential benefits of these measures by demonstrating that they can lead to measurable reductions in environmental impacts, and that these impacts can be quantified and reported within sustainability reporting frameworks along the supply chain. In this way, the study may contribute to strengthening the motivation to overcome existing hurdles to their implementation.

- **Improve use efficiency of inputs**
  - Reduce nitrogen surplus through better matching of fertilizer inputs to crop uptake, using tools such as precision nutrient management or decision support systems.
  - Encourage practices that reduce losses of nitrogen to air and water (for example, split applications, use of nitrification or urease inhibitors).
  - Promote farmer training on optimal fertilizer types, rates, and timing.

  - Reduce pesticide use intensity and promote integrated pest management (IPM) strategies to decrease ecotoxicity impacts[44].
  - Focus on improving yields through agronomic best practices without increasing external inputs, thereby reducing the impacts per kg of fiber.
  - Use of low-carbon fertilizers[45].
- **Prioritize organic fertilizer strategies with low provision impacts**
  - Compost and manure provision must be managed to reduce CH_4 or N_2O emissions.
  - Where organic fertilizers are used, explore supply chain partnerships to ensure that their production and transport impacts are minimized (for example, proximity sourcing, aerobic composting methods).
  - Consider including provision impacts in hotspot assessments to avoid underestimating total impacts.
- **Reduce irrigation-related energy use and water demand**
  - Encourage water metering and monitoring to improve transparency of water consumption and enable more precise management.
  - Promote efficient irrigation systems (for example, drip, sensor-controlled systems) to reduce both water and energy demand, while acknowledging that such technologies can be costly and not equally accessible to all farmers.
  - Support capacity strengthening and training to optimize irrigation practices and water scheduling, enabling farmers to achieve efficiency gains with existing systems.
  - Improve soil health and water retention (for example, through organic matter management, mulching, or cover crops) to reduce irrigation needs.
  - Invest in energy-efficient pumps and renewable-powered irrigation where financially and contextually feasible.
- **Adoption of renewable energy sources at ginning facilities:** the use of renewable energy (for example, solar or wind) at ginning facilities represents a readily available option to reduce environmental impacts (although local considerations such as uninterrupted availability and infrastructure conditions may influence feasibility)**.** Since a single gin typically processes cotton from several hundred to several thousand growers, improvements at the ginning stage can yield system-wide benefits that could be more efficient to achieve than comparable changes at the farm level.

Recycled cotton fiber production

Similar to cultivated cotton fibers, the recommendations provided for recycled spinnable fibers are already generally known. However, the quantitative insights derived from this study can support environmental impact reduction strategies within the textile sector by demonstrating that these recommendations can lead to measurable reductions in environmental impacts, and that these impacts can be quantified and reported within sustainability reporting frameworks. It is also

44 It should be noted that reductions in pesticide use do not universally lead to lower overall environmental impacts. In some cases, moderate increases in pesticide application, when guided by integrated pest management principles, can improve yields and thereby reduce impacts per unit of product across several impact categories (for example, climate change, eutrophication, land use, see (Thoma, Matlock, Lawrence, Taylor, & Hickman, 2024)). The objective of IPM is therefore not necessarily to minimize pesticide use, but to optimize it, achieving a balance between agronomic performance, economic returns, and environmental outcomes.

45 Low-carbon or "green" fertilizers refer to fertilizers produced with reduced greenhouse gas emissions compared to conventional production routes. This can be achieved through the use of renewable energy (for example, green hydrogen from electrolysis instead of natural gas for ammonia synthesis), carbon capture and storage during production, or efficiency improvements in manufacturing processes.

acknowledged that barriers to practical implementation of these recommendations must also consider aspects such as technical feasibility and cost of implementation, which were outside the scope of this study, to ensure an effective transition to lower impact production of recycled spinnable fibers.

- **Prioritize low-impact electricity sources**
  - Encourage recycling facilities to use certified electricity from renewable sources, or invest in renewable energy solutions (for example, rooftop PV).
  - Prioritize process improvements, i.e., advancements in mechanical recycling technologies that reduce electricity demand per kg of spinnable fiber.
- **Reduce transportation distances and optimize logistics**
  - Source cotton waste materials from nearby suppliers where possible to reduce transport-related impacts.
  - For post-consumer waste, promote the development of localized recycling infrastructure to minimize the impacts associated with international shipping.
- **Allocation of impacts to valuable by-products**
  - Explore market development for by-products, including low-quality post-consumer waste that does not meet quality requirements, as well as fluff and filling material. Improving the economic value of by-products and using economic allocation reduces impacts assigned to the main product and more accurately reflects the allocation of impacts within the production process.

7. Results of the LCA+ approach

7.1. Results of soil health assessment

As described in section 3.6.1, this study provides an assessment of removal potentials based on the IPCC Tier 1 approach as a proxy indicator for soil health. It should be acknowledged that soil health encompasses a broader set of regenerative agricultural practices, including cover cropping, crop rotation, agroforestry, and reduced pesticide use, which may contribute to long-term improvements in soil structure, biology, and resilience, but are not captured in detail in this simplified SOC-focused assessment. Please refer to Textile Exchange's *Regenerative Agriculture Landscape Analysis* (Textile Exchange, 2022) and Textile Exchange's *Regenerative Outcomes Framework* (Textile Exchange, 2023) for a more nuanced discussion of such impacts.

It should also be reiterated that this analysis addresses sequestration potentials, and the assessment should be seen as additional scenario analysis; the results are not robust enough to include the calculated removals in the impact assessment results or to claim these removals in reporting (see section 3.6.1).

The assessment of potential carbon stock changes follows the IPCC Tier 1 methodology, which relies on default carbon stock values and change factors available in the IPCC guidelines. The approach applied in this study compares two scenarios:

1. Reference System: This represents the baseline condition against which changes are assessed.
2. Assessed System: This represents the agricultural system under evaluation, incorporating specific management practices.

Both systems apply IPCC-derived land-use factors, management factors, and carbon input factors to estimate the carbon stock.

- Land Use Factor: A multiplier reflecting the impact of different land use types (for example, cropland, pasture) on carbon stocks.
- Management Factor: A factor accounting for the management practices used, such as tillage methods, crop rotation, and fertilization practices.
- Carbon Input Factor: A factor that considers the amount of organic and inorganic carbon inputs, such as the use of organic fertilizers.

The change in carbon stock is then calculated as:

$$\Delta C\ (t\ C\ ha^{-1}\ yr^{-1}) = \frac{C_{\text{stock, reference}} - C_{\text{stock, assessed}}}{20}$$

where $C_{stock,\ reference}$ represents the estimated carbon stock under the reference system, and $C_{stock,\ assessed}$ represents the estimated carbon stock under the assessed system. The difference is divided by 20 years to determine the annualized carbon stock change.

For the assessment in this study, for each cultivation system, a reference system was assumed that does not consider any regenerative practices:

- The system is considered as in a steady state, with no net carbon accumulation

- The carbon input intensity is classified as medium (factor = 1), i.e., this would be a system without significant organic inputs (for example, via organic fertilizer or cover crops)[46]
- Full tillage is assumed (factor =1)

The following scenarios were assessed.

- SOC_TILLAGE: Switching from full tillage to no tillage
- SOC_INPUT_HIGH: Switching from medium organic input intensity (baseline, see above) to high carbon input intensity. This would represent the use of green manure or cover crops, but without manure applied (IPCC, 2019).
- SOC_INPUT_HIGH_WITH_MANURE: Represents significantly higher C input over medium C input cropping systems due to an additional practice of regular addition of animal manure (ibid). [47]
- SOC_COMBINED: Combination of no tillage and high input with manure (best case SOC scenario).

In consequence, the assessment primarily estimates the potential impact of increasing soil carbon sequestration with organic inputs and reduced tillage practices, in comparison to the same cultivation system not using these practices. It is, therefore, applied to all cultivation systems. Limitations of this assessment are discussed in the following interpretation of the results.

The reference soil carbon stock and relative carbon stock change factors are specific to the climate zone and are provided in table E-1 in Annex E.

Results

Detailed results for the different soil carbon sequestration scenarios are provided in Annex J. The results highlight that systems incorporating organic inputs exhibit a clear potential for increasing SOC and, thus, lowering net GHG emissions per kilogram of cotton fiber, in some cases even leading to net-negative carbon footprint results (see Annex J).

The change of tillage from full tillage to no-tillage systems alone results in a moderate potential for SOC sequestration. On average, 0.80 kg CO_2 equivalent/kg fiber is sequestered, with a range between 0.09 and 2.34 kg CO_2 equivalent/kg fiber across production systems. Increasing organic inputs (for example, through cover crops or green manure) without manure application leads to sequestration potentials similar to changing the tillage practice. The average sequestration is 0.95 kg CO_2 equivalent/kg fiber (range 0.04–2.83). When regular animal manure addition is assumed, SOC sequestration potentials increase substantially. The average is 3.87 kg CO_2 equivalent/kg fiber, with values ranging from 0.39 to 11.33. The combined scenario represents the upper bound of the

46 The classification of cotton cultivation systems in terms of input intensity is not entirely clear. In the 2019 IPCC Guidelines, cotton is explicitly mentioned as an example of "crops yielding low residues" and would, therefore, fall under the category of low-input systems. At the same time, cotton residues are commonly returned to the field, and cotton is often grown in rotation with nitrogen-fixing crops, which would support a classification as medium-input. In this scenario, sequestration potentials of high-input systems are assessed relative to the reference system, assuming the latter to be medium-input results in lower additional sequestration estimates than if a low-input reference were used. The medium-input classification was, therefore, applied as a conservative assumption.

47 Although the IPCC guidelines do not explicitly address compost, following the logic of the Tier 1 approach for estimating SOC changes, this study recommends not classifying compost as a "very high" organic input. The composting process entails substantial carbon losses, resulting in a lower carbon content in the final product compared to raw organic materials such as fresh manure. Accordingly, compost should probably be classified as a "high" organic input in Tier 1 assessments, implying a more moderate SOC sequestration potential than unprocessed organic matter.

sequestration potential. Here, an average of 4.67 kg CO_2 equivalent/kg fiber is sequestered, with values ranging from 0.48 to 13.68. This "best case" represents the synergistic effects of reduced tillage and higher organic matter input, including manure.

It is important to note that the results are expressed per unit of product. In systems with lower yields, a greater land area is required to produce the same output. When organic inputs are applied across these larger areas, the potential for SOC sequestration increases, resulting in more pronounced reductions in emissions per kilogram of cotton fiber. By contrast, when results are considered on a per-hectare basis, the variation between scenarios is less pronounced. Specifically, the sequestration potential ranges from 0.06 to 0.22 t C per ha per year for a change in tillage practice alone, and up to 3.7 to 4.6 t C per ha per year in the combined scenario (per ha results are also provided in Annex J).

Limitations

There are several limitations to consider when interpreting the results. The soil carbon sequestration estimates rely on the IPCC Tier 1 methodology, which applies generic factors and does not account for site-specific carbon dynamics[48]. The approach does not consider variations in soil types, climate conditions, or historical land management practices, all of which can significantly affect carbon sequestration rates. The methodology assumes a linear accrual of soil carbon over a 20-year period, after which a new equilibrium in soil carbon stocks is assumed. In practice, sequestration cannot continue indefinitely at these rates, and the actual dynamics may deviate from the assumed trend. Moreover, all sequestration potentials are calculated relative to a baseline without mitigation measures. If practices such as reduced tillage or manure application have already been implemented for extended periods, the additional sequestration potential may, in reality, be substantially lower. It should also be emphasized that any SOC gains are reversible (for example, if practices are discontinued or land is disturbed, see section 3.6.1). Finally, the IPCC Tier 1 approach applies only to the upper 30 cm of soil. Carbon dynamics in deeper soil layers can be more complex and may alter sequestration outcomes, but these processes are not captured within the Tier 1 framework (Ogle et al., 2019).

Therefore, it should also be reiterated that the results provided in this study are not robust enough to claim any of these removals in reporting (see section 3.6.1). As noted above, the uncertainty and contextual factors surrounding soil carbon sequestration are discussed in detail in Textile Exchange's *Biogenic Carbon* guidelines (Textile Exchange, 2024a) and Textile Exchange's *Regenerative Agriculture Landscape Analysis* (Textile Exchange, 2022) and are, therefore, not repeated here in detail. These guidelines also provide detailed context for the conditions under which removals, including those related to soil carbon sequestration, can be reported and claimed.

Conclusion

Soil health is a multifaceted concept that extends well beyond soil carbon alone. Nevertheless, practices that increase soil organic carbon (SOC) are often also expected to improve broader soil health indicators. The assessment presented here should therefore be understood as an indicative scenario analysis rather than a definitive quantification. Given the prominence of soil carbon in research, policy, and sustainability debates, it is valuable to include a screening-level perspective within this study.

48 Tier 2 or Tier 3 methods were not applied due to data constraints because such approaches are generally impractical for large spatial units like regional or country averages; moreover, their application is resource-intensive and was considered outside the scope of this study.

The analysis applied the IPCC Tier 1 methodology and focused on two primary levers for SOC enhancement: reducing tillage intensity and increasing organic carbon inputs. The latter can be achieved through several pathways, with cover crops and the application of animal manure representing two prominent examples.

The results indicate that these measures can substantially increase soil carbon stocks compared to a reference system without them. Reduced tillage alone can already lead to moderate SOC gains, while the addition of animal manure represents a high-input scenario with considerably larger sequestration potential. The combination of no-till practices and high organic inputs consistently yielded the highest carbon sequestration potentials.

At the same time, these findings represent generalized potentials rather than site-specific outcomes. Actual sequestration depends on local conditions and management history, and rigorous methodological requirements must be followed before any sequestration can be claimed in formal reporting.

7.2. Results of biodiversity assessment

As described in 3.6.2, this section reflects on the relation of LCA impact indicators to reduced impacts on biodiversity. Most assessed categories correspond to pressures that can affect biodiversity directly (for example, chemical toxicity, habitat loss, resource depletion) or indirectly (for example, climate instability, soil degradation). However, as outlined in the following, the linkage between lower indicator scores and real biodiversity outcomes is context-dependent and often non-linear. LCA impact assessment results can be interpreted as indicators of potential risk to biodiversity, but while correlations may exist, they neither imply a universal cause-and-effect chain nor substitute for dedicated biodiversity assessments (A Senior, et al., 2024).

To begin with, local ecological conditions play a decisive role. For example, a reduction in fertilizer application that curbs nutrient runoff may only marginally benefit biodiversity in watersheds with resilient or already-adapted aquatic communities. The baseline level of ecosystem degradation also matters; an action that represents a minor improvement in a relatively intact landscape could yield pronounced biodiversity benefits in an area that has suffered historical overuse or pollution.

Moreover, species and ecosystem responses to agricultural pressures are highly variable. For instance, lowering pesticide use is likely to support the recovery of generalist pollinators and soil invertebrates, but the return of more specialized or rare species may require not just reduced toxicity but also restoration of habitat structure, connectivity, and food resources. Biodiversity is multidimensional, encompassing genetic, species, and ecosystem diversity, and each dimension may respond differently to the same intervention (Nyström, 2003). Some taxa are particularly sensitive to chemical residues, while others are more affected by physical changes such as tillage or irrigation practices.

The comprehensiveness and integration of interventions further influence biodiversity outcomes. Isolated changes (such as switching to a less harmful pesticide) may deliver limited benefits if not accompanied by broader shifts in land management, such as the introduction of buffer strips, maintenance of semi-natural habitats, or diversified crop rotations (Sutherland, Dicks, Petrovan, & Smith, 2021). These landscape-level features often serve as refugia and corridors, supporting a broader array of species and enabling recolonization after disturbances. For example, research has shown that fields bordered by hedgerows or wildflower strips tend to host higher numbers of pollinators and natural enemies, bolstering both biodiversity and crop resilience.

There is also the issue of trade-offs and unintended consequences. Some measures that reduce a particular LCA impact can inadvertently create new pressures. For instance, reducing tillage to lower soil erosion and improve carbon retention can, in some cases, lead to increased herbicide use, affecting non-target species and potentially undermining gains for biodiversity. Similarly, intensifying production on existing land to avoid expansion into natural habitats ("land sparing") may result in higher input use, with mixed consequences for local biodiversity. However, when compared to land conversion or deforestation, such intensification often results in substantially lower overall biodiversity losses. Conversely, "land-sharing" approaches, which integrate biodiversity-friendly practices across the agricultural matrix, can benefit a wider range of species, but might not achieve the same yield levels, raising questions about overall land use efficiency (Grau, Kuemmerle, & Macchi, 2023). Likewise, reducing or eliminating crop protection measures may benefit certain species in the short term, but if yields decline substantially and greenhouse gas emissions per unit of product increase, such outcomes could offset or even counteract the intended environmental impact and biodiversity benefits (Thoma, Matlock, Lawrence, Taylor, & Hickman, 2024).

Another dimension to consider is the scale and duration of impact reductions. Biodiversity responses are typically lagged and may not manifest immediately after management changes. Soil microbial communities and invertebrate populations, for example, can recover relatively quickly from reduced chemical input, but the restoration of plant communities or vertebrate populations may take years or even decades, especially if local extinctions have occurred (N. Daskalova, et al., 2020). The temporal aspect is critical, as short-term reductions in impacts may not be sufficient to support long-term recovery or the stability of complex ecological networks.

Regional climate and hydrology further modulate outcomes (Junjun, et al., 2018). In arid regions, irrigation often enables vegetation growth in otherwise sparsely vegetated landscapes, which can increase habitat availability and species richness compared to bare or degraded land locally. However, the broader biodiversity implications depend on the source and management of irrigation water. When withdrawals occur from surface or groundwater systems that support natural aquatic habitats, excessive extraction can reduce environmental flows and stress dependent ecosystems. In more humid areas, the biodiversity effects of irrigation efficiency improvements will be smaller, while water quality improvements, such as reducing runoff, are more impactful where downstream ecosystems are especially sensitive, such as riverine wetlands that support endemic fish or amphibians.

In some cases, legacy effects and historical land use set the boundaries for possible biodiversity recovery (E. Turley, Bell-Dereske, E. Evans, & A. Brudvig, 2020). Soils heavily degraded by decades of monoculture or chemical use may harbor altered microbial communities or persistent contaminants, limiting the extent to which biodiversity can rebound even after impact reductions. Conversely, areas with a history of polyculture or low-intensity management may show rapid recovery when pressures are alleviated.

Socio-economic context also shapes the effectiveness of interventions (Rahman, Al Mahmud, & Shahidullah, 2016). Where smallholder farmers have limited resources, the adoption of biodiversity-friendly practices may hinge on external incentives, technical support, or market access. Without these enabling conditions, even scientifically sound recommendations may fail to be implemented at scale, blunting potential biodiversity gains.

Finally, monitoring and adaptive management are crucial. Because biodiversity responses are often context-specific and unpredictable, ongoing assessment is needed to detect both intended and unintended outcomes. Adaptive management, whereby interventions are adjusted in response to monitoring results, can help maximize positive impacts and minimize new or unforeseen pressures (Franklin, Helinski, & Manale, 2007). At the same time, the lack of standardized and scalable

biodiversity metrics remains a major challenge for systematic monitoring. Current approaches range from field-based species surveys to remote-sensing indicators and model-derived habitat quality indices, each with differing data requirements and levels of ecological resolution. The development and harmonization of biodiversity indicators suitable for farm- and landscape-scale application is an active area of research (Garcia Herrero et al., 2025). Importantly, the costs and responsibilities for data collection should not fall solely on farmers, particularly in smallholder systems. Coordinated efforts among supply-chain actors, certification programs, and policy frameworks are needed to ensure that biodiversity monitoring is both scientifically robust and economically equitable.

In summary, reducing impacts in the reported impact categories is a necessary but not always sufficient condition for enhancing biodiversity in agricultural systems. The actual outcomes depend on the starting ecological state, the types and integration of interventions, the landscape context, and legacy effects from past land use. To maximize biodiversity benefits, it is essential to tailor strategies to local conditions, combine multiple complementary actions, and commit to long-term monitoring and adaptability. However, it should also be recognized that agricultural landscapes, including cotton-growing regions, can also contribute to biodiversity relative to alternative land uses such as residential or industrial development. In many producing countries, farmers are legally required to conserve native vegetation or forest buffers, and large portions of cotton-growing areas are embedded within or adjacent to mosaics of semi-natural habitats. Under such conditions, cotton farms can also contribute to important ecosystem functions.

While LCA metrics provide critical guidance for reducing environmental harm, translating these reductions into real-world biodiversity gains requires a nuanced, context-aware approach that recognizes the complexity and variability of ecosystems.

With these considerations in mind, the following analysis aims to tentatively interpret the assessed impact categories through a biodiversity lens, drawing on established frameworks and recent literature to provide context. It should be emphasized again that the results represent potential risks to biodiversity. While the assessed impacts may correlate with biodiversity outcomes, as outlined above, it cannot be concluded that a direct cause-and-effect relationship always exists, that the impacts necessarily translate into actual biodiversity impacts, or that they can replace a more detailed biodiversity impact assessment.

Land use change: Land Use Change (LUC) represents a significant pressure on biodiversity. Cotton's adaptability to arid conditions makes it a candidate for expansion into grasslands and savannahs, ecosystems that are often rich in endemic species (Solidaridad, 2025). The conversion of these landscapes to cropland fragments habitats, reduces connectivity, and alters ecological processes. The Science-Based Targets Network's *Biodiversity Short Paper* (Hawkins, et al., 2023) identifies land conversion as the dominant driver of terrestrial biodiversity loss, while Solidaridad (2025) emphasizes the need for high-conservation-value assessments to guide sustainable expansion. According to the data provided, there were no explicit reports of direct LUC (see section 4.3.5), except for Brazil. However, if LUC was evident (for example, Brazil country average system based on statistical data), potential biodiversity loss risks are inherently greater. Avoiding land conversion and restoring degraded habitats are essential strategies for maintaining biodiversity in cotton-growing regions.

Climate change: Climate change alters temperature and precipitation regimes, thereby impacting biodiversity through habitat alteration, shifts in species distribution, phenology changes, and increased vulnerability of species to extreme weather events. The provided LCA results indicate that reduced application of mineral fertilizers, i.e., by increasing fertilizer use efficiency or by use of organic fertilizers, or use of low-carbon fertilizers (see footnote 45), can lower climate impacts, potentially mitigating biodiversity losses associated with climate-induced habitat changes. The Field

to Market WILD Index (Coronel, Pearce, & Pilchak, 2023) lists practices like reduced tillage or cover cropping as a strategy to improve habitat and soil cover and increase other biodiversity benefits, strategies that might also have benefits on climate change (see section 7.1).

Eutrophication: Eutrophication, driven by surplus nitrogen and phosphorus from fertilizers entering aquatic systems through runoff, degrades freshwater ecosystems by promoting algal blooms and oxygen depletion, leading to declines in aquatic species richness and ecosystem function. This study highlights field emissions as the major contributor (≥90%) to eutrophication. Practices with efficient nutrient management and reduced fertilizer inputs per kilogram of product harvested demonstrated lower eutrophication impacts (per kilogram of fiber produced), indicating their potential to reduce biodiversity threats from eutrophication. Furthermore, the WILD Index (ibid) advocates for practices that reduce runoff, like buffer strips and grassed waterways.

Ecotoxicity: The use of pesticides introduces ecotoxicological risks that can correlate with an impact on biodiversity. Pesticides are designed to disrupt biological systems, and their effects on non-target organisms like pollinators, beneficial insects, and soil organisms are well documented. This study identifies pesticide use as almost exclusively driving freshwater ecotoxicity impacts. Integrated Pest Management (IPM) represents a science-based framework for reducing pesticide reliance while maintaining crop health. Definitions and implementation guidance are provided by various organizations and initiatives, including the IPM Institute of North America, Field to Market's WILD Index (Coronel, Pearce, & Pilchak, 2023), and Solidaridad's "Cotton & Biodiversity" program (Solidaridad, Organic Cotton Accelerator, 2025).

Soil health: Soil health, while often underrepresented in biodiversity assessments, plays a foundational role in supporting belowground biodiversity and ecosystem services. Healthy soils support diverse microbial communities, invertebrates, and root-associated organisms that facilitate nutrient cycling, pest regulation, and plant resilience. Agrochemical use, particularly inorganic fertilizers and herbicides, can degrade soil structure and reduce biological activity (Pahalvi, et al., 2021). The study indicates that practices involving organic fertilizer applications or cover crops have the potential to enhance SOC sequestration (see section 7.1).

However, it is important to acknowledge that SOC is only one proxy for soil health, and this study focuses primarily on carbon dynamics due to methodological constraints. Other regenerative practices, such as reduced tillage, cover cropping, diversified crop rotations, integration of perennial or deep-rooting species, and the reduction of synthetic inputs, also play critical roles in improving soil structure, biological activity, nutrient cycling, and water retention (see section 7.1 above on soil health).

Blue water consumption: The results indicate substantial variability in blue water consumption across cotton cultivation systems, driven primarily by regional climate, irrigation practices, and yield levels. As discussed above, water consumption from surface and groundwater resources in irrigated cotton systems interacts with biodiversity in complex ways. The direction and magnitude of impacts depend strongly on the water source, management practices, and local hydrological context. In general, improving water-use efficiency helps reduce pressure on increasingly scarce water resources and can mitigate potential risks to aquatic and riparian ecosystems. Effective water resource management can, therefore, help to sustain both efficient and economic production and biodiversity outcomes. This includes efficient irrigation technologies, vegetative cover[49], and optimized application timings. Retention ponds and similar infrastructure can play a dual role by

49 The influence of vegetative cover on water consumption varies by context. While it can reduce evaporative losses and improve soil moisture retention over time, it may also increase water demand in some cases due to additional evapotranspiration.

improving water availability and providing new aquatic habitats that support amphibians, birds, and other wildlife.

7.3. Results of human rights impact assessment

7.3.1. About this assessment

Important disclaimer

This study provides a foundational overview of some of the most common social impacts associated with cotton production. It is intended to serve as a general reference, highlighting key themes, and offering useful resources for further exploration. It does not represent an in-depth assessment and should not be treated as such.

For those seeking to understand the social impacts of a specific supply chain or location, a more detailed human rights impact assessment should be conducted. This should include direct stakeholder engagement on the ground, as social impacts can vary significantly by geography and site. These variations depend on a range of factors, including socio-political context, the demographics of local workers and communities, and the extent of human rights due diligence in place.

The textile industry has historically been plagued by risks to human rights and concerns regarding the well-being of people involved across all tiers of its production value chain. Textile Exchange, as well as its project partners, believes it is important to consider the impacts of fiber and material production more holistically. This is linked to Textile Exchange's LCA+ approach, where impact measurement goes beyond "carbon tunnel vision", to also account for biodiversity, soil health, animal welfare, and social livelihoods. For the cotton LCA study, the most relevant LCA+ impact areas were identified as biodiversity, soil health, social impact, and livelihoods. While soil health and biodiversity are included in a qualitative way in the LCA report, this document has been developed to capture some essential human rights impact elements related to cotton production.

It is important to highlight that the LCA+ portion of this work does not go into the same level of depth in assessing human rights impacts as the LCA study does with environmental impacts. While there are well-established social life cycle assessment methodologies similar to environmental LCA, this assessment does not follow these methodologies fully and does not aim to provide a comprehensive analysis of the social footprint of cotton. Rather, this assessment aims to highlight the importance of understanding the social impacts alongside the environmental impacts and to provide a foundational understanding of key human rights impact areas related to this production system.

While the importance of evaluating the social aspect is generally well acknowledged, practical challenges remain in effectively carrying out such an assessment. One of the key difficulties lies in identifying relevant indicators and establishing appropriate methods for measuring them. Social indicators often lack a clear linear scale; for example, employee contractual working hours should be neither 24 hours nor zero hours each day. Instead, context-specific, socially accepted norms need to be applied. Another major barrier is obtaining reliable data on a scale required to make unequivocal claims. The willingness of stakeholders to share sensitive data, and the ability to verify it, are critical aspects when it comes to assessing and reporting on human rights impacts.

In light of this, and because the scope of the LCA+ study spans a variety of countries and cotton types, the human rights assessment portion of this study casts a wide net via a high-level screening

approach, aiming to explore potential risks and benefits of the main cotton farming approaches considered within the project, as well as cotton recycling. These findings provide a starting point for future work, where additional resources can be dedicated to exploring identified hotspots in greater detail, and developing more targeted results and recommendations for stakeholders.

A number of studies and resources already exist that look at the human rights impacts of the textile industry, particularly cotton production. These include completed risk assessments and social evaluations already performed within the context of Textile Exchange projects, some social LCA (sLCA) literature of the cotton industry, and a wealth of information produced by government agencies, academic institutions, or the industry that is not controlled by commercial publishing.

The goal of the LCA+ approach and its social aspects is to carry out a qualitative screening and hotspot analysis. However, human rights issues in the apparel industry and the cotton supply chain are numerous and wide-ranging. Therefore, the focus of the human rights topics under investigation in this assessment was limited to certain social stakeholder groups, as defined by the *Guidelines for Social Life Cycle Assessment of Products and Organizations* (United Nations Environment Programme, 2020), as described below.

7.3.2. Definitions

Child labor

The International Labor Organization (ILO) defines child labor as "work that deprives children of their childhood, their potential, and their dignity, and that is harmful to physical and mental development". The ILO refers to work that is (a) mentally, physically, socially, or morally dangerous and harmful to children and/or (b) interferes with their schooling by depriving them of the opportunity to attend school, obliging them to leave school prematurely, or requiring them to attempt to combine school attendance with excessively long and heavy work (International Labour Organization, 2025).

Fair salary

Fair salary (often also referred to as "fair wage" or "fair pay") refers to a rate of compensation that allows workers to meet their basic needs, including housing, food, healthcare, education, and other essentials (The OR briefings, people & organisational research, 2025). Going beyond living wages, the concept of fair salaries also addresses factors such as equity, sustainability, and dignity (Fairwage Network, 2025).

Grievance mechanisms

Grievance mechanisms are processes that allow individuals or communities who believe they have been harmed by a business activity to raise their concerns and seek remediation (UNODC, 2024).

United Nations Office on Drugs and Crime (2024). Cash in the trash: The role of corruption, organized crime, and money laundering in waste trafficking.

Human rights

Human rights are basic rights and freedoms belonging to every human being to ensure people can live their lives in dignity. There are 30 human rights outlined in the Universal Declaration of Human Rights by the United Nations (United Nations, 1948) and embedded in the Bill of Human Rights, an international law instrument. Human rights cover different aspects of our lives, from the most basic, such as the right to life or freedom, to economic rights, including labor rights, and political rights, such as the right to vote.

Human rights due diligence

This is a continuous process carried out by businesses that involves setting clear human rights policies; identifying, addressing, and preventing the potential and actual human rights impacts associated with their own operations or value chain; ensuring the effectiveness of their actions; and communicating openly about their progress (United Nations, 2011)

Human rights impacts

In line with the United Nations Guiding Principles on Business and Human Rights (UNGPs) global terminology framework (United Nations, 2011), this study report defines human rights impacts as any potential or actual infringements on the rights of individuals or groups negatively affected by cotton production. This includes formal and informal workers across the supply chain, as well as communities near production sites.

Note that the scope of this study only covers a part of the cotton value chain, from cultivation or purchase of wastes (recycled cotton) to fiber production. There may be other demographics of people who may be affected in other stages out of scope for this study.

Informal workers

Informal workers are those who are not formally registered as workers and therefore lack legal status and social protection, in jobs that are not regulated, monitored, or taxed by governments. Often, they are also migrants (internal or cross-border) or otherwise disadvantaged in the job market and therefore particularly vulnerable. Due to the lack of protection, informal workers cannot easily exercise their rights and are often found working in the most disadvantaged and low-paid jobs (International Labour Organization, 2015).

Land grabbing

While the FAO states that no current definition fully captures the issue of land grabbing (Food and Agriculture Organization, 2016), a publication by Eco Ruralis presents a review of existing definitions from different societal sectors, such as civil society, governments, and financial institutions (Baker-Smith & Szocs Boruss, 2016). However, this study on human rights impacts in the cotton supply chain mainly refers to the definition of the International Platform on Biodiversity and Ecosystem Services (IPBES) that defines land grabbing as “large-scale acquisition of land (especially in developing countries), driven primarily by concerns about the food and energy security of high-income countries and often executed by the private sector” (Intergovernmental Platform on Biodiversity and Ecosystem Services, 2025).

Living wage

A living wage is commonly defined as the wage level necessary to afford a decent standard of living for workers and their families. It considers country circumstances and is calculated for work performed during normal working hours. A living wage should be sufficient to cover basic needs such as food, housing, healthcare, education, transport, and clothing. It should be set using robust data and in consultation with workers’ and employers’ organizations (Fairwage Network, 2025). The ILO emphasizes that living wages should reflect local or regional differences and be regularly adjusted for changes in the cost of living (International Labour Organization, 2022).

Minimum wage

According to the ILO, a minimum wage is defined as a minimum amount of compensation an employer is required to pay a worker for work performed during a certain period. It cannot be reduced by collective agreement or individual contracts (International Labour Organization, 2025).

Rightsholders

This term includes groups and individuals whose human rights have been or may be affected by a company's operations, products, or services ("affected people"). Rightsholders represent a subset of stakeholders (Oxfam Business Advisory Services, 2023).

7.3.3. Scope

The scope of the human rights assessment includes the same life cycle stages as the LCA part of the study: from cradle-to-gate.

For cotton cultivation, field workers were the main target group. A graphical display of the system boundaries of the study in general can be found in Figure 3-1. Scope exclusions are listed in detail in Table 3-3.

The human rights assessment for recycled cotton includes all processing steps within recycling facilities up to the stage at which the recycled spinnable fiber leaves the factory gate. The main target group is factory workers. Detailed figures of the processes in scope for cotton recycling, as well as scope exclusions (Table 3-4), can be seen in Figure 3-2, Figure 3-3, and Figure 3-4.

7.3.4. Methodology

For the collection of data, a multi-step approach using different sources of information was applied.

First, a human rights survey covering specific aspects of human rights issues in cotton cultivation and cotton recycling was developed jointly by experts from Textile Exchange and the project team. The survey was designed to attain a high-level overview of relevant social topics. This survey was then sent to data providers who had already been involved in the collection of environmental data. They were encouraged not only to give answers on behalf of their own company but also to report general observations from their region. Although this study did not involve direct engagement with farmers or workers, the aim was to gather insights from stakeholders within the supply chain who have visibility of human rights impacts in the field or at recycling facilities—ideally, those with perspectives as close to the beginning of the supply chain as possible.

After an initial quantitative analysis of all answers by the project team, interviews were carried out with highly experienced human rights experts in the cotton sector. In those consultations, a review and discussion of the answers given by the data providers, and also more general questions on human rights aspects in cotton fiber production, were discussed. An overview of the methodology is illustrated in Figure 7-1. Where necessary, literature sources were also reviewed to provide supporting information.

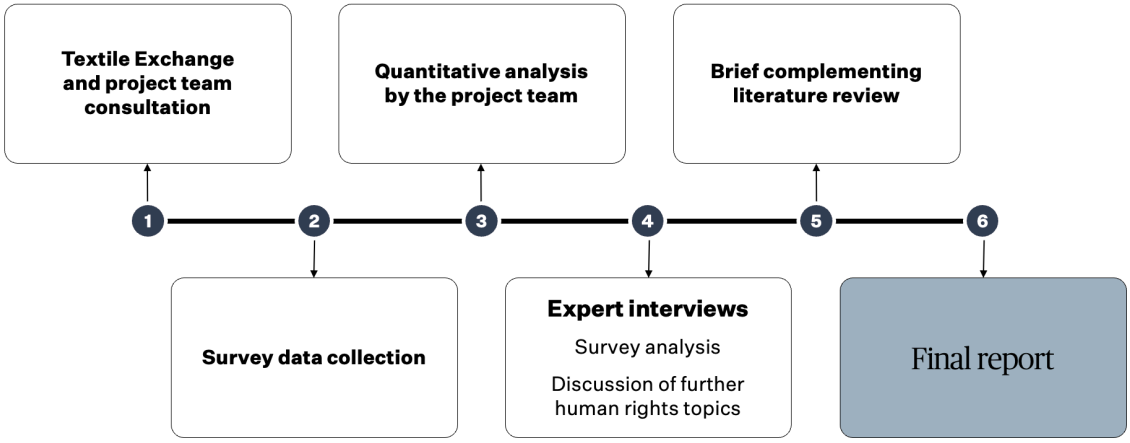

Figure 7-1: Methodology of human rights assessment.

7.3.5. Human rights assessment survey

The human rights assessment survey took into consideration the UNEP Guidelines for Social Life Cycle Assessment of Products and Organizations (United Nations Environment Programme, 2020). The guidelines provide lists of potential stakeholders and social impacts tailored to them. The complete stakeholder and impact list can be found in Table 7-1.

Table 7-1: List of stakeholder categories and social impact categories as defined by UNEP (United Nations Environment Programme, 2020).

Stakeholder categories	Subcategories
Worker	1. Freedom of association and collective bargaining 2. Child labor 3. Fair salary 4. Working hours 5. Forced labor 6. Equal opportunities/discrimination 7. Health and safety 8. Social benefits/social security 9. Employment relationship 10. Sexual harassment 11. Smallholders, including farmers
Local community	1. Access to material resources 2. Access to immaterial resources 3. Delocalization and migration 4. Cultural heritage 5. Safe and healthy living conditions 6. Respect for Indigenous People 7. Community engagement 8. Local employment 9. Secure living conditions
Value chain actors (not including consumers)	1. Fair competition 2. Promoting social responsibility

Stakeholder categories	Subcategories
	3. Supplier relationships 4. Respect for intellectual property rights 5. Wealth distribution
Consumer	1. Health and safety 2. Feedback mechanism 3. Consumer privacy 4. Transparency 5. End-of-life responsibility
Society	1. Public commitments to sustainability issues 2. Contribution to economic development 3. Prevention and mitigation of armed conflicts 4. Technology development 5. Corruption 6. Ethical treatment of animals 7. Poverty alleviation
Children	1. Education provided in the local community 2. Health issues for children as consumers 3. Children's concerns regarding marketing practices

For the high-level screening, the list of stakeholder categories focused on workers and local communities, as it was already defined by Textile Exchange in an internal risk review of human rights risks to rightsholders. Regarding the topics addressed, human rights experts from Textile Exchange and Sphera focused on those that were identified as substantial to the cotton fiber supply chain, and developed a set of 20 questions. The questions, including potential answers, are listed in the annex in Table B-1, sorted according to their corresponding subcategories. For this study, these questions related to actual and potential human rights impacts within the cotton supply chains; as such, the impacts will be referred to as “human rights impacts” throughout this report. For all questions, it was also possible to add individual comments to the answers, such as detailed numbers or examples. Most questions were addressed to data providers involved in cotton cultivation as well as in cotton recycling; however, there were a few that were specific to only one type of cotton production. In some cases, the content of one question could be found in a different question with a slight variation and a different context. This was done intentionally to achieve a greater range of answers from different angles for a more holistic view of the topic.

Human rights surveys were sent to all data providers who contributed LCI data for cotton cultivation and recycled cotton production for the study. Taking part was voluntary, and not all data providers participated in the survey. In one exception, a survey respondent was an independent data collection partner not directly affiliated with a company responsible for the production/cultivation of cotton fibers. In Table 7-2, an overview of the sample sizes can be seen, according to the number of respondents per country and type of cotton fiber. The definitions of cotton fiber types can be found in Chapter 3.1.1

Table 7-2: Number of respondents per country and type of cotton fiber.

	Country average	Organic	Regenerative	Recycled
China (selected regions) *	1	1	-	1
India	1	3	4	1
Pakistan**	1	1	1	2
Brazil	1			
Türkiye	1	-	2	4
US	-	1	-	-
Peru	-	1	1	-
Bangladesh	-	-	0	3
Total	**5**	**7**	**8**	**11**

*For regions included, please refer to section 3.1.1.

**Pakistan was included in the human rights assessment covering all cotton types, but is not included in the cotton cultivation part of this report for reasons of data availability.

The surveys were then consolidated and analyzed quantitatively and qualitatively (for the comments). There was no second round of iteration for the data collection to clarify questionable or unclear points. This assessment was then shared with experts to further discuss in subsequent interviews (see Table 7-3).

7.3.6. Expert interviews

To validate the feedback from the data providers and to discuss additional topics, interviews with selected sector experts were carried out. The list of interview partners can be found in Table 7-3.

Table 7-3: Human rights experts for interviews.

Name	Institution	Background
Simon Ferrigno	Freelance consultant, researcher, and writer	Freelance researcher and writer on cotton and sustainability. Active in sustainability since 1998, and on cotton since 2001, with global experience across Africa, India, Latin America, Türkiye, Central Asia, and the US. Contributes to Ecotextile News and Cotton Diaries.
Emma Dennis	Better Cotton Initiative	Senior manager for global impacts at Better Cotton Initiative. Expert in sustainable development, agronomy, rural development, and natural resource management.
Patricia Jurewicz	Responsible Sourcing Network (RSN)	Founder and CEO of RSN, which manages YESS: Yarn Ethically & Sustainably Sourced, and co-founder of the Cotton Campaign, a multi-stakeholder coalition focused on addressing forced labor in Uzbekistan and Turkmenistan.
Richa Mittal	Fair Labor Association	Executive Vice President and Chief Innovation Officer at Fair Labor Association. Expert in innovation for

Name	Institution	Background
		upstream human rights impacts across agricultural programs.

In addition to the questions from Table B-1, the experts were also asked for their input on more general issues such as:

- Whether differences in human rights impacts among different cotton production systems exist, and if so, why?
- The extent to which the findings seem representative of all cotton-producing countries, based on the expert's experience and expertise.
- Impacts on human rights that the survey does not cover.
- The most significant recent improvements in human rights issues within the cotton supply chain and their driving forces.
- Human rights issues worsening within the cotton supply chain and their main challenges.
- Main concerns for social issues in the future, and where companies can make the biggest impact to mitigate these.

The interviews were scheduled for one hour. After the interviews, experts also sent back a written summary of their feedback, including literature recommendations. Those additional literature sources were used to complement the findings and to contextualize relevant and critical points. It needs to be mentioned that the experts were mainly focusing on agricultural aspects due to their backgrounds.

7.3.7. Limitations

Although the human rights assessment methodology combines different sources of information, the current approach is affected by limitations that should be considered when interpreting the results.

Survey participants

- This high-level human rights assessment relied on self-reporting by management-level stakeholders already participating in the project as intermediaries, rather than direct communication with field or factory workers. This introduces potential issues with the accuracy of reported information.

Representativeness of data

- When disaggregating survey responses to individual countries and cotton production types, the total sample size was limited. Sample sizes were also variable on individual human rights topics[50], introducing uncertainty regarding the representativeness of the survey results.
- Given the significant regional variations for some human rights issues, aggregation of survey responses at a country level is not appropriate, as issues and their drivers are location specific.
- Furthermore, aggregation of data at a regional level still risks overlooking small-scale regional differences in drivers of human rights issues, such as farm size and socio-economic conditions. For example, medium-sized farms were identified by experts as facing unique challenges of being too small for large machinery and too big to be managed by families. Therefore, they have to hire potentially high numbers of temporary workers, which may result in an increased chance of human rights issues.

Selection of human rights survey questions

- Survey questions were partly identified as very broad by human rights experts, lacking clear definitions.
- The list of human rights issue questions was selected from the UNEP Guidelines for Social Life Cycle Assessment of Products and Organizations, but did not cover all the included human rights issues comprehensively. This was done to ensure the time taken by respondents to complete the survey did not adversely affect return rates or the detail of comments provided.
- There are large differences in the production steps of cotton cultivation and recycled cotton fibers. While cotton cultivation covers mainly agricultural aspects, cotton recycling is a purely industrialized process, limiting the comparability of supply chain issues between those two types of cotton fibers.

The human rights assessment part of this LCA study is intended to serve as a high-level screening according to Textile Exchange's LCA+ approach. The outcomes should not be used for any claims or external communication, but rather to support the identification of the most relevant fields of action.

7.3.8. Human rights impact assessment results

The following paragraphs summarize the feedback received from the data providers in the surveys as well as the findings of the expert interviews. Since a large part of the content was verbally communicated by the experts, not every aspect is linked to a reference. For confidentiality reasons, not all answers are directly linked to their source (person, cotton production type, and country), since, for some countries and cotton production types, only one data point was available. Wherever possible, answers were provided with the respective reference. All impact categories presented refer to the UNEP classification mentioned in section 7.3.5 Table 7-1, focusing on workers and local communities. The conclusions drawn from the result analyses can be found in the conclusions in section 7.3.11.

Please note that statements given by data providers were directly included in this report, and are not considered to be representative of the sector due to the limitations summarized in 7.3.13. Answers

50 Respondents only answered questions that they had knowledge of, resulting in individual human rights topics and/or countries having a lower sample size than the total number of relevant respondents.

were, therefore, triangulated with expert interviews and literature sources to attain a more holistic picture.

7.3.9. Survey results

Child labor

The survey questions addressing child labor were the following:

1. How often do you see under-18s working on cotton farms/cotton recycling facilities in your region?
   (Answers: Never, Rarely, Sometimes, Often, Always)
2. What is the youngest age of children you see working on cotton farms/cotton recycling facilities in your region? (Answers: Less than 10—10 to 12 years old, 13 to 15 years old, 16 to 18 years old)
3. Are you aware of under-18s ever doing work that could be considered hazardous in your region? (Answers: Yes, No)

For cotton cultivation, the answers to the first question ranged from "sometimes" to "never", with the majority of answers being "never" (~60–70%). For recycled cotton, the share of data providers stating "never" was very high for all countries (> 90%).

Many providers of data on cotton cultivation explicitly commented that, in their regions, children go to school and are not involved in any field work. They noted that there is an exception for children or grandchildren of farmers who support family business, particularly during harvesting season, but only when the children are free from school (for example, in the evenings). If data providers stated that minors are involved in field work, they commented that the minors are either part of contract labor teams, with harvesting and weeding as their main tasks, or working on their family's farm.

For recycled cotton, all data providers from India and Bangladesh stated that it is very uncommon to see minors in recycling facilities. Particularly, data providers from Bangladesh stated that they have strict child labor policies in place with strong discouragement of child labor.

Looking at these answers from data providers, one expert commented that the figures, especially for the cotton cultivation reference system, seem rather low, in particular because the ILO does allow work for minors under certain circumstances. In general, child labor is a known issue in cotton cultivation across multiple countries, particularly in regions with low mechanization and high economic reliance on cotton production (Fair Labor Association, 2017). Cotton cultivation is one of the most common commodities produced with child labor in many countries [(FAO, 2023), (International Labour Organization, 2018)]. Child workers in cotton cultivation are exposed to risks such as tasks that are hazardous to their health and safety (for example, pesticide handling, physical stress, or long working hours) as well as abuse and coercion (Environmental Justice Foundation, 2007). According to the ILO, children above the minimum age for employment (typically ~15 years) can engage in work that does not harm their health, personal development, or interfere with their education (International Labour Organization, 2025). However, the ILO strictly prohibits hazardous work that could harm the health, safety, or morals of children.

Regarding the ages of children involved in cotton cultivation, most answers gave a range of 16–18 years (67%), and only a few stated ages between 13–15 years. One data point mentioned children under 10 years working on farms. For recycled cotton, all data providers stated the ages of children working in recycling facilities to be between 16 and 18 years (100%). For organic and regenerative cotton in India, it was stated that youths aged 16–18 can occasionally be involved in light activities

such as the delivery of food for workers in the fields or collecting biomass for the preparation of organic fertilizer. However, most of the time workers are over 18 years of age.

The involvement of minors in hazardous work yielded mixed answers. Some data providers marked this question with "yes" without giving further comments so, unfortunately, additional detailed analysis is not possible at this point. However, Indian data providers for organic and regenerative cotton stated that they have training and awareness sessions for communities to promote no child labor, child protection, and educational rights, which, according to them, helps to reduce child labor. Data providers from other countries, such as Türkiye (conventional and regenerative cotton), and Bangladesh (recycled cotton), mentioned that their working practices are fully compliant with legal requirements and that the involvement of minors in hazardous work is strictly prohibited.

When reflecting on the answers to this question, one expert shared that the involvement of children in hazardous work could be explained by certain types of bonded labor, such as debt bondage, where children are hired to pay off the debts of their parents (Environmental Justice Foundation, 2007). Debt bondage is considered the most common form of modern slavery (Anti-Slavery International, 2025) and is a known problem in cotton cultivation.

Fair salary

The following questions focusing on fair salary were included in the survey:

1. How often do workers on cotton farms/cotton recycling facilities earn at least the local minimum wage in your region?
   (Answers: Never, Rarely, Sometimes, Often, Always)
2. How often do workers earn a living wage (enough to cover their basic needs for themselves and their families, including unexpected expenses) in your region?
   (Answers: Never, Rarely, Sometimes, Often, Always)

All participants in the survey stated that workers on cotton farms often or always receive the local minimum wage. Some data providers also stated that labor is in such shortage in their area that wages are often up to twice as high as the minimum wage. The increasing lack of workforce, potentially resulting in better conditions for wage negotiations of workers, was also confirmed by experts (see B.2.2.). One data provider from India producing regenerative cotton also shared that they carried out a social baseline survey in 2024 and found that although a large percentage (~80%) of farmers weren't aware of respective legislation and the absolute value of the minimum wage, 73% claimed values that were above the local minimum wage. The data provider further stated that they usually see that workers are paid "fairly".

For recycled cotton, all data providers answered that minimum wages are always paid. They stated that most workers are aware of minimum wages and will refuse to work for less. The recycling facilities stated that wages for all regular hours are paid out fully and on time. If deductions of benefits occur, all processes are in line with legal requirements.

Regarding the living wage, for cotton cultivation, the answers covered the full range of possibilities, showing large differences between countries. For conventional cotton, out of the five data providers, one answered that living wages are "never" earned, one stated they are "rarely", and three answered they are always reached. It was commented that living wages are usually earned during the sowing and harvesting seasons, but outside of those periods, earnings can drop significantly. This creates the need for workers to complement their wages from working in cotton fields with other sources of income. For regenerative cotton in India, it was commented that living wages are always met and that, additionally, many expenses are covered under governmental schemes, such as free health insurance, free education, maternity care, and monthly cash benefits for women aged 20–55.

All data providers of the recycled cotton industry stated that minimum wages are always paid, and living wages are often (30%) or always (70%) attained. One data provider in Bangladesh abstained from answering because they were not aware of any living wage calculations available. It is not clear whether they were not aware of sources such as the Global Living Wage Coalition (Global Living Wage Coalition, 2025) providing such calculations, or whether they were located in a region where there were no figures available.

The information provided by the participants was only partly confirmed in expert interviews and was often questioned. For minimum wages, statements covering cotton communities in India in general were given that stated that they are often not met and can be lacking by up to 50%. While they agreed with the statement that the competitive situation for companies to find suitable workforce positively affects wages, it was also shared that living wages may often only be achieved over certain (short) time periods, but rarely over months or a year. Their experience indicated that many smallholders struggle to earn a living income themselves, making it unlikely that they can afford to pay living wages to their workers. When analyzing the status of living incomes, the importance of looking at not only worker incomes, but also farming households' incomes should be investigated. It was also highlighted that in the last few years, increased inflation has put a lot of additional financial pressure on farmers. This is because rising costs are not reflected in the price being paid for cotton, meaning that their living income is not met.

When cotton farming is not the sole source of income, and workers rely on additional jobs to earn a living income, it becomes important to recognize and account for these multiple income streams. Addressing this issue, however, requires clear agreements and strong collaboration across different sectors.

A study conducted by the Better Cotton Initiative investigated the attainment of living income amongst different groups of farmers (Better Cotton Initiative, 2024). The groups were categorized by state and farm size. The results revealed that in two states in India (Maharashtra and Telangana), five out of eight groups of farmers do not meet the living income benchmark. The majority of cotton farmers in India are smallholders with rainfed farms smaller than five acres, and, on average, none of the farmers meet the living income benchmark. This example shows the urgency needed to address human rights aspects regarding income and wages.

Working hours

The field of working hours was addressed with the following questions:

1. For cotton cultivation only: How often do workers on cotton farms get days off in your region?
   (Answers: At least 2 days/week off, At least 1 day/week off, At least 1 day/every 2 weeks off, At least 1 day/month off)
2. How often do workers on cotton farms/cotton recycling facilities exceed 40 hours per week in your region?
   (Answers: Never, Rarely, Sometimes, Often, Always)
3. Do you feel that workers are able to freely refuse working overtime in your region?
   (Answers: Yes, No)
4. What are the peak season working hours like in your region?
   (Answers: 60 to 70 hours/week, 70 to 80 hours/week, 80 to 90 hours /week, >90hours/week)

The first question was addressed to data providers from cotton cultivation only. All answers indicated that workers get one or two days off in a week, while the majority of answers (68%) stated one day off. Since many employment relationships in this sector are based on non-formal employment (see also the paragraph on employment relationship), it was also stated that people can decide not to work on

a certain day, but that means they are not paid for that day. This practice is reinforced by the fact that workers are often hired on a daily basis, resulting in employees who have no entitlement to vacation. In those sites in which formal contracts exist, those contracts entitle them to one to two days off work per week.

When it comes to working hours per week, most of the data providers referring to cotton cultivation answered that they "never" or "rarely" exceed 40 hours per week in their region. Two data providers stated that 40 hours of work per week are exceeded "often" or "sometimes" depending on seasonal activities. It was mentioned that exceeding this time is "unlikely". During harvesting season (peak season), work is usually required for about two to three hours in the morning and in the evening. For organic and regenerative cotton cultivation in India, no working in excess of 40 working hours was reported, which was underlined by the comment that they are providing training on decent work practices.

On this issue, experts expressed doubts about the rate participants stated they "never" see workers exceed 40 working hours per week. Some contradictory information supplied indicates the need to focus on this topic in more detail (for example, some data providers stating that they "never" see workers exceeding 40 hours/week, but also sharing that maximum working hours can reach 60–80 hours/week. Similarly, some reported that cotton picking only requires a few hours of work, but they also noted that overtime can happen during peak seasons).

In general, overtime work is a significant human rights issue in cotton cultivation (Fair Wear Foundation, 2021). Studies by the Fair Labor Association focusing on cotton production in Türkiye, for example, revealed that seasonal workers often work over eight hours a day, seven days a week. They observed that weekly working times, particularly during peak seasons, often exceed the 45 hours per week that is prescribed by law (Fair Labor Association, 2019). As one of the possible levers to mitigate the risk of excessive working hours, the Fair Wear Foundation recommends improving collaborative planning between the cotton supply chain and the brands. This could potentially lead to an increase in supply chain partners, including farmers, meeting the agreed deadlines within decent working hours (Fair Wear Foundation, 2021).

In the recycled sector, all potential answers except for "often" could be found for this question. The answers were equally distributed. Many data providers mentioned that in their regions, weekly working hours are usually as high as 45 to 48 hours, which is above the threshold given in the question itself. Many recycling facilities base their work schedules on shifts of eight hours and six working days. It was further mentioned that small recycling facilities, working mainly for the domestic market, may be less compliant with national labor laws, with workers working up to 12-hour shifts on six working days.

All data providers for both cotton cultivation and recycled cotton answered "yes" to the question regarding whether workers can refuse to work overtime. However, differences in the consequences became obvious in the comments. While some of the data providers explained that workers are aware of their rights and can take legal action in case of mistreatment, one participant stated that the worker might not be hired again if overtime is refused. Another data provider added more context to their answer by stating that a worker can decide to just not come back if they are not treated according to legal requirements as a measure of "refusing" overtime. One data provider from a rural area explained that workers and employers usually live in the same community and, therefore, being perceived as having a bad reputation is an issue, so workers try to avoid this.

For recycled cotton, just as in the question before, it was mentioned that in smaller recycling facilities, legislative compliance may not be met, with workers potentially being forced to do overtime or being removed from their position if they refuse.

Peak seasons in cotton cultivation are mainly the phases of sowing and harvesting. During those phases, weekly working hours were stated to mostly be around 60 to 70 hours per week, but can go up to 90 hours per week. This was found to be contradictory to the answers that were given to the question on overtime, which is discussed above.

In the recycled cotton sector, peak seasons can be determined by, for example, cotton waste availability or recycled cotton fiber demand. However, some of the participants from the recycled cotton industry mentioned that they see no peak seasons throughout the year. Others stated that when there is an increased workload, working times are extended in compliance with national laws. However, in smaller, less compliant companies, working times can go up to 90 weekly hours for periods of two or three consecutive months.

Equal opportunities/discrimination

In the section covering equal opportunities and discrimination, the survey included three questions:

1. What is the approximate ratio of women and men working on cotton farms/cotton recycling facilities in your region? Please elaborate.
   (Answers: Women [%], Men [%])
2. Are the workers mostly local or migrant in your region?
   (Answers: Local, Internal migrants, Cross-border migrants)
3. How often do women and men who do the same job in the context of cotton farming/cotton recycling facilities earn the same money in your region?
   (Answers: Never, Rarely, Sometimes, Often, Always)

Throughout all the different cultivation types, rather equal ratios between women and men working on farms were seen in the analysis of the results. Several participants mentioned that there are often gender differences in the types of work. While activities such as weeding, sowing, and cotton-picking are often carried out by women and men, other activities, such as land preparation, irrigation, nutrient, pest management, and post-harvest activities, are often exclusively carried out by men. Those findings were largely confirmed by experts. Also, according to self-generated figures from a participant in the regenerative sector in India, only 42% of farmers consistently involve women in their decision-making processes. It was mentioned that, due to the trend of rural exodus, certain societal groups are left behind in rural areas, such as the elderly, children, and women, and these groups consequently shoulder more responsibilities on their farms.

In the recycling sector, a stronger trend could be seen toward more men working in recycling facilities (overall, approximately 30% women, 70% men). However, several comments indicated that they would like to increase the rate of women in the sector. It was emphasized by one participant that women have some advantages regarding the types of work in recycling facilities. The degree of manual work is high during sorting and grading activities, and women were stated to have advantages because of a higher tactile sensitivity compared to men. Also, stripping activities such as removing buttons or zippers were stated to be carried out more successfully by women. The data provider emphasized that an increase in the demand for recycled fibers by the brands, and a simultaneous increase in the proportion of women in the workforce, could have a positive effect on creating employment opportunities for women.

The rate of answers negating a gender pay gap in the recycling sector was high (>90%). It was mentioned that, in smaller recycling facilities with less pressure on legislative compliance, it can be seen that women earn lower wages overall because they work shorter shifts (for example, eight hours instead of 12 hours per day).

In cotton cultivation, the rate of participants answering that there is no pay gap was high, but it was indicated that they did see inequalities in payments in some areas. However, as mentioned in the

paragraph above, it is often the case that women and men carry out different types of work, so no direct comparison is possible. It was also indicated that structural changes can be seen, since physically challenging parts of the field work which were usually carried out by men in the past are increasingly mechanized, meaning that they can now be done by women and men with the same result. According to one self-conducted baseline survey that was conducted by a data provider in the regenerative sector in India, the majority (~80%) of the 464 participants confirmed that they always pay women and men equally.

On this topic, experts suggested that besides payments, other major differences in gender equality can be found in cotton cultivation. According to their observations, women are often disadvantaged when it comes to land ownership. They described how, in smallholder structures, which can be fostered by tax regulations, officially land is passed on to women but, in reality, this does not happen. This results in women being landowners but not farmers, and, therefore, having few rights in decision-making processes. However, it is observed that in many cases, most of the work on farms is done by women. Additionally, if husbands or elders also own land, women often have to work on their land first before they can take care of their own fields. As a positive development, it was also mentioned that in certain geographical regions (for example, Africa), structural changes can be seen with increasing numbers of women being farmers as well. Programs such as Cotton made in Africa actively work toward gender equality in the cotton sector. The initiative reported that up to 160,000 female cotton farmers have participated in their programs in sub-Saharan Africa (Cotton made in Africa, 2019).

Regarding the origin of workers (local or migrant), throughout all cotton cultivation types, it was stated that the majority of the workforce is local (~90–95%). In many cases, this was underlined by specific statements which said that many farmers are smallholders managing their own farms, occasionally with the help of relatives and neighbors. Even during peak seasons, when additional workforce is needed, sourcing often takes place in local communities or by hiring internal migrants from different regions or provinces. The possibility of hiring external workers is also limited by the economic boundary conditions of the farms.

Only 5–7% of the workforce were stated as internal migrants for all cotton types, and <5% of cross-border migrants for conventional cotton. As one of the issues accompanying migration, it was highlighted that, in the case of migratory movements of whole families, the human rights of children might be strongly affected due to difficult and irregular school attendance. The probability of migrants working informally was also stated to be higher.

The expert interviews commented that this issue can show very high regional differences. Therefore, it was recommended to follow up on this topic with more granular investigations at a regional level (for example, regions close to national borders might show higher numbers of cross-border migrants, such as migrant workers from Central/South America in Southeast Texas/US).

For recycled cotton, the results were shifted slightly to ~70% stating only local workers and ~30% stating migrant workers. While for some companies a large number of workers were internal migrants, some mentioned that there is such high availability in the local workforce that the hiring of migrant workers is not necessary. Internal migrants were stated to mainly fill positions requiring more experience, such as supervisory or managerial-level employees.

Health and safety

To get insights on the status of health and safety issues in the cotton sector, study participants were asked to provide information on two questions:

1. How would you rate the health and safety on cotton farms/cotton recycling facilities within your region?

(Answers: Good (no issues), Satisfactory (minor issues), Poor (many issues), Dangerous (serious issues))

2. For cotton recycling only:
   Are there any social welfare and safety requirements that need to be met during the sorting of recycled materials in your region? Please provide examples in the comment.
   (Answers: Free text)

During the analysis of the responses to the first question, answers between "poor/many issues" (conventional cotton) and "good/no issues" (all cotton types) were found. None of the data providers stated that it was negligible, and it was commented that respective training courses are carried out to raise awareness, as well as technical assistance and a close monitoring of practices. A survey carried out by a regenerative cotton producer in India revealed there are still gaps that need to be filled in relation to safe working conditions, personal protective equipment, and the provision of first aid. Experts mainly confirmed the plausibility of those answers. Many literature sources confirm that there is a range of health and safety risks in cotton cultivation. Pesticide exposure can lead to acute poisonings and long-term health effects [(Environmental Justice Foundation, 2007) (Koussé, et al., 2023)]. Cotton dust generated during farming (Safe AG Systems, 2024), (TDI, 2024) or ginning (Derso, et al., 2021) can negatively affect air quality and cause respiratory problems. There are also additional health risks that are commonly associated with work in the fields, such as risk of injuries (Franklin, Fragar, Houlahan, Brown, & Burcham, 2001) as well as further ergonomic and psychosocial risks. Particularly for children, cotton picking can lead to significant health issues due to, for example, exposure to pesticides and prolonged stooping or carrying heavy loads, dehydration, heat stress, and more (International Labour Organization, 2025).

Producers of recycled cotton fibers answered the question with approximately a ratio of 50:50 between "good" and "satisfactory". Some data providers gave explicit examples of positive efforts they undertake in addition to personal protective measures, such as ventilation, water availability, restrooms, subsidized canteens, fire extinguishers and alarms, first aid kits, and emergency exit lights.

On the question of social welfare and safety requirements, which was specifically addressed to recycled cotton providers only, three out of eleven data providers explicitly stated that they have social welfare programs in effect. It needs to be mentioned that some did not comment on this specific part of the question, while a few stated they do not have any additional welfare programs besides work safety. The rate of participants confirming they take care of providing adequately safe working conditions by implementing the measures mentioned in the paragraph above was very high (eight out of eleven, with three abstentions).

Social benefits/social security

A topic within social benefits and social security was addressed in the question:

- Where workers on conventional cotton farms/cotton recycling facilities are provided with accommodation by their employer, what are the conditions of the accommodation in your region?
  (Answers: Good (no issues), Satisfactory (minor issues), Poor (many issues), Dangerous (serious issues))

The question was not answered by all data providers, with some stating that accommodation is not an issue for them, as all workers are family members or sourced from local communities. If the question was answered, accommodation was mostly rated "good" or "satisfactory" for cotton cultivation, complying with regulations and covering basic needs such as water, electricity, and sanitary facilities. One data provider reported they have seen poor conditions in accommodation,

such as sleeping in tents, community facilities (such as schools), or even under open skies. This was accompanied by problems such as access to drinking water, a lack of education for children, the quality of food, insufficient medical facilities, and social discrimination.

The majority of data providers in the recycling sector did not answer this question, as it is also not applicable to them because they only hire regional workers. Of those who did answer this question, there was a 50/50 split between "good" and "satisfactory" without further comments.

It should be mentioned here that one expert indicated that the accommodation mainly affects men because migrant workers were usually men or whole families, but not single women.

UNEP impact subcategory: Employment relationship (UNEP stakeholder category: Local community)

Regarding topics around employment relationships, the following questions were included in the survey:

1. Are the workers mostly permanently employed or seasonal in your region?
   (Answers: Formal permanent employment—Formal seasonal or temporary employment—Informal permanent employment— Informal seasonal or temporary employment)
2. Do workers on cotton farms/cotton recycling facilities have contracts or work informally in your region?
   (Answers: Most have contracts with benefits, Most have contracts but no benefits, Some work informally, Some have contracts, Only informal work)
3. To what extent can workers working on cotton farms (or their surrounding communities) or cotton recycling facilities advocate for themselves if they are negatively impacted in any way in your region? (such as labor issues or water scarcity)
   (Answers: Concerns or grievances are usually effectively resolved in the workplace, or through a worker union or another grievance channel, Concerns or grievances are sometimes effectively resolved in the workplace, or through a worker union or another grievance channel, Although there are channels available, concerns or grievances are never effectively resolved in the workplace, or through a worker union or another grievance channel, There is NO channel in the workplace, a worker union or external grievance channel for workers or communities to use to resolve grievances or concerns)
4. How often do you hear about things like workers working on cotton farms/cotton recycling facilities being required to pay recruitment fees, or being unable to terminate employment due to owing money to their employer in your region?
   (Answers: Never, Rarely, Sometimes, Often, Always)

For cotton cultivation, almost all answers possible could be found for the first question, with the highest rates of answers stating that workers are mostly employed informal seasonal/temporary (~50–70% of answers throughout all cultivation types). Informal permanent employment was only reported in the cotton cultivation reference system. The majority of the comments emphasized that, in the fields, the hiring of permanent workers is not common. Workers were mostly hired informally on a seasonal or, often, a daily basis. For smallholder farmers, family members contributed mostly to field work.

The data providers active in the recycling sector showed a clear tendency to have "formal permanent employments" (~90%) and only few cases of "formal seasonal/temporal employment" or "informal permanent employment". It was, furthermore, mentioned that, due to regular audits, it is mandatory to only have formal contracts in place.

The second question was asking for similar content, but with the inclusion of benefits. The shares of the different contract types (formal/informal) reflected responses in the first question, and individual

comments confirmed the information that was already given. Only a rather small share of answers (~2–10%) stated that benefits were associated with contracts. One participant from the organic sector in India stated that benefits are not directly provided by farmers, but that the government offers beneficial schemes such as pregnancy/maternity care, health insurance, or monthly cash benefits for women aged 20–55. Some data providers also confirmed that workers are granted paid vacation and an additional salary besides the regular 12 monthly salaries ("13th salary"), as well as social security payments.

Experts drew attention to inconsistencies when comparing answers to the first and second questions, which partly had overlapping content. Also, the number of contracts with benefits was questioned. One expert shared a different clustering of types of workers than mentioned in the question. According to their expertise, they typically see five types of workers: family workers, permanently hired, temporarily hired, seasonally hired, and a small proportion of migrant workers in some regions. However, they are all treated as informal without documented contracts. Regarding benefits, it was mentioned that workers can also receive other types of "payment" besides money, such as food.

For recycled cotton fiber production, the shares of formal contracts were similar in the answers to this question as in the first question. The figures were assessed to be plausible by experts. Many companies commented that they also provide benefits such as health insurance, bonuses paid on holidays and during sickness, and food aid. One data provider from Bangladesh also listed additional benefits, such as talent awards for children of workers at school, green transport for all long-distance female employees, and scholarships for talented students in local communities, as well as plans to establish community schooling.

When it comes to the question assessing the availability of grievance channels, the answer that was chosen most often throughout all agricultural production systems was that grievances are "usually effectively resolved in the workspace, through a worker union or another grievance channel" (~70%). However, several times. it was also mentioned that there are no grievance channels available. However, some comments explained that problems are solved informally between parties without official grievance channels. In rural areas in India, community structures in villages exist that provide support in solving problems (such as Gram Panchayat[51] or Kisan Sangh[52]).

In the recycling industry, all data providers stated that they have channels for resolving grievances or for raising concerns.

The question about the payment of recruitment fees or the issue of workers being unable to terminate employment due to owing money to their employers was most often answered with "never" from data providers of all cultivation types. Only one data provider stated that this can be observed "sometimes". In two comments from two different data providers from the conventional and the organic/regenerative sector, participants explained that workers and farmers are mostly from the same community and have good relationships and, therefore, such practices are not common.

Although the participants of the survey in general stated no issues with labor violations, several literature sources state that this is a common human rights issue in cotton cultivation. A transparent review of labor conditions on 90 cotton farms in India showed that debt bondage can often be seen, for money and also for child labor (Transparentem, 2025). Mechanisms can, for example, be that parents receive advantages of loans from cotton seed producers in exchange for their child's labor. Debt bondage can also be enhanced by the payment of recruitment fees (University of Nottingham,

51 Basic political institution in Indian villages.

52 Apolitical Indian farmers' organization promoting agricultural self-reliance.

2019). Debts may be passed down through generations, forcing entire families into servitude and poverty [(World Vision Action, 2012), (Environmental Justice Foundation, 2007)].

While the majority of the data providers from the recycling sector stated that they never observe this, a few participants also answered, "rarely" or "sometimes". The companies stating that recruitment fees and debts do not occur also mentioned that they have respective regulations in place that they have to comply with.

Access to material resources

To cover aspects of land grabbing and related issues, one question was included in the survey (only for cotton cultivation):

- Do you see any issues specifically related to illegal adoption of land, deforestation, or land grabbing (from Indigenous or Local Communities who may have customary land rights without formal ownership) related to cotton farming within your region?
  (Answers: Yes, No)

All data providers of all sectors answered this question with a clear "no". One participant mentioned that in their region, land is either rented or owned, and that land contract rights have been clearly defined for three decades by local authorities. Data providers from the organic and regenerative sector in India stated that most of their farmers are cultivating the same lands they have been working on for more than 20 years. However, it was also mentioned that this is a regional issue, and that there might be regions where the situation needs to be monitored closely.

Experts raised concerns about the plausibility of the answers to this question. According to literature, land grabbing in cotton cultivation has been documented in several major cotton-producing regions and is, besides human rights violations, also associated with environmental destruction and the displacement of local communities. A recent report revealed significant issues in Brazil's Cerrado, where land was taken from traditional and Indigenous communities and transformed into cotton cultivation land (Earthsight, 2024). The communities have, thereby, lost access to grazing lands and water resources, and have experienced intimidation and violence. In Uzbekistan, land grabbing is also a known issue. Since 2017, Uzbekistan has implemented land "optimization" policies, resulting in mass seizures and redistribution of farmland to facilitate large-scale private developments, which is described in a study published by the Centre for Public Administration of the University of Ulster (Centre for Public Administration, University of Ulster, 2024). The study report states that the mechanisms behind this are connected to abuses of public power and critical rights. So far, no meaningful actions have been taken to improve the situation, although the facts were brought to public attention.

7.3.10. General findings from expert interviews and human rights survey

As mentioned in chapter 7.3.6, a range of questions were discussed with the experts in the interviews. The following paragraphs summarize the information from human rights expert interviews, sorted into respective topic clusters.

Influence of production systems on human rights impacts

For cotton cultivation, all experts agreed that, in general, the production systems are not the main drivers for differences in human rights impacts. However, notable distinctions in certain human rights aspects can be observed between organic and conventional farming.

Organic farming tends to provide higher incomes resulting from higher prices and lower costs to farmers due to lower operating costs (MacRae, Frick, & Martin, 2007). In a farming program led by

OCA, organic cotton farmers' average net profits were 21% higher per hectare than their conventional counterparts (OCA, 2022). The success of sustainability programs heavily depends on staff training in communities, the integration of inclusive structures, and the involvement of women, youth, and minority groups in governance. According to the experts consulted in the interviews, organic farming also results in better school attendance and higher education, as well as healthier diets for workers and farmers. The literature supports better education for children in organic cotton cultivation. A study investigating the impacts of organic cotton farming on the livelihoods of smallholders includes interviews in which organic farmers state that they invest in the higher education of their children, so that the chances to access off-farm incomes are increased. This can lead to a diversification of income and, as a result, to poverty reduction (Eyhorn, Mäder, & Ramakrishnan, 2005). Another publication focusing on the social, economic, and environmental impacts of cotton farming in India found some evidence that children of cotton farmers licensed by the Better Cotton Initiative have slightly higher levels of school enrolment than children of conventional cotton farmers, lower incidences of missed school days due to work on other (non-family owned) farms or other businesses and, in general, lower numbers for children working on farms (however, no statistically significant differences were seen in the number of missed school days due to working on the household farm) (De Hoop, et al., 2018).

Furthermore, an increased awareness of human rights issues was recognized in the organic sector.

These expert statements confirmed some of the answers that were listed in the comments of the survey participants. It was mentioned that working in organic cotton production contributes to higher employment rates due to a high degree of manual labor, supporting rural livelihoods, and farming communities. This thesis is supported by several publications on organic farming in general. A study analyzing the differences in employment opportunities between different farming types in the US indicates that organic farms employ more workers per acre. The workers also face an increased workload compared to workers on conventional cotton farms, which the authors interpret as a potential indication for more secure employment (Mette, et al., 2017). Other studies also support these findings [(Soil Association, 2006), (FAO, 1999)].

Furthermore, data providers stated that, according to their observations, workers feel more connected to their work due to a high degree of "social harmony, improved ecology, and better soil health". They feel safer, and are aware of social topics such as decent work and child labor, as well as environmental issues such as biodiversity and the hazardous impacts of chemicals. However, according to an expert statement, the increased need for manual labor can not only lead to increased employment opportunities in rural areas, but can also raise concerns about potential exploitation risks.

Other parameters influencing human rights aspects in cotton cultivation: time, technology, governance, and infrastructure

Structural changes affecting human rights aspects in farming communities often require time to manifest, as economic benefits need to filter through the system. Farmers typically need confidence and security before making investments, or coming up with their own ideas, or experimenting with new techniques learned from training or recommended by standards.

Social issues can have a high level of temporal dynamics compared to potentially slower-changing environmental dynamics, for example, the seasonality of a required workforce impacting local employment rates.

Technological aspects, such as the shift from hand-harvesting to machine-harvesting, can also strongly impact labor dynamics and skill requirements. In areas with a high proportion of machine-harvesting, there is often a higher share of full-time workers who are highly educated. It was also

observed that mechanical operations are more often carried out by men than by women, which can affect incomes and gender equality (see also paragraph B.3.1 on equal opportunities/discrimination). In general, a higher degree of mechanization can lead to higher efficiency and productivity, with decreasing labor costs at the same time. In regions where labor scarcity prevails, mechanization can reduce the dependency on seasonal workers (Swinkels, Kochkin, & Romanova, 2016). In some cotton-growing regions, mechanization has reduced the need for state-mobilized labor, which would often include children and government employees such as teachers and doctors, allowing schools and hospitals to remain operational during harvest season (Swinkels, Kochkin, & Romanova, 2016). This shift also presents opportunities for landscape diversification through smaller, robotic, and AI-supported machines, as was mentioned by an expert. On the other hand, increased machine work can result in high investment costs and can reduce employment opportunities for workers, potentially affecting livelihoods.

It was mentioned that, overall, establishing local structures and national legislation is crucial for the protection of workers, to improve livelihoods, labor practices, and community dynamics. Laws and regulations can have significant influences on, for example, subsidies, labor practices, human rights, social and gender inclusion, training, and child labor.

A last point explicitly mentioned in one interview was the influence of the local infrastructure. The more production facilities (for example, ginning facilities) are available for farmers, the more power they have to negotiate prices and options. In less industrialized areas, farmers might need to accept the conditions of sale without room for negotiations.

Effects of climate change

Climate change is having a significant impact on farming communities, affecting both the quantity and the quality of cotton yields. The main impacts of climate change on human rights aspects of cotton production include the following (Owain, Pal, Rycerz, & Linares, 2021) (Routh, 2017):

- Rising temperatures create a need for early warning systems, the provision of shade, and improved medical systems to help workers cope with increasing heat.
- Both water scarcity and extreme rainfall can potentially lead to crop failures and financial losses. Furthermore, with limited water availability, a shift to food crops rather than fiber crops might happen, influencing local community structures.
- Extreme weather events, such as wildfires, storms, droughts, and extreme rainfall, can impact health and safety.
- Growing seasonal changes, such as shorter growing seasons, lead to temperatures above the optimum cotton growth temperatures and changes in rainfall patterns. This can lead to yield losses and increased risks of income losses.
- Increasingly favorable conditions for insects and diseases, due to higher temperatures, can threaten plant health while, at the same time, chemical control methods might become less effective due to potentially faster decomposition rates, leading to increased costs and the risk of income losses.

Although negative impacts on cotton cultivation through climate change might prevail, it should also be mentioned that there might also be parameters that can positively influence cotton cultivation in general. Increasing temperatures could, for example, lead to benefits in cotton yields in cooler regions due to longer growing season (Routh, 2017). While it is well-known that increased atmospheric CO_2 levels can positively stimulate cotton growth, it needs to be considered that enhanced growth will require more water as well as nutrients. Besides that, the growth of weeds

profits from higher CO_2 concentrations, which is assumed to reduce the effectiveness of weed control measures (Routh, 2017).

Overall, ecosystem resilience was generally recognized to be a key factor in adapting to climate change. The resilience of ecosystems can be improved by agroecological practices such as crop rotation or cover cropping, but also by measures such as diversifying income sources (Agroecology Knowledge Hub: Resilience: enhanced resilience of people, communities and ecosystems is key to sustainable food and agricultural systems, 2025).

Recent trends in human rights impacts

In the expert interviews, several aspects were mentioned that are currently seen as improving, such as:

- Increased awareness of gender inequality, and the creation of more job opportunities for women, particularly in Africa and Latin America.
- Growing awareness of human rights issues in general, through campaigns and inclusion in standards.
- Efforts to address child labor (though challenges remain, such as migrant children's access to education in some countries such as India, Pakistan, and Türkiye, for example (US. Department of state, 2023).
- Potentially positive effects on wages due to a lack of workers in rural areas caused by urban movements.

It was also emphasized that increasing awareness must be followed by concrete actions to remediate and resolve these issues. Several initiatives actively drive forward the training of staff in human rights issues, such as programs from OCA and the Better Cotton Initiative, or the Harvesting the Future program of the Fair Labor Association, a cooperation with global apparel companies, Indian garment and textile producers, and several local implementing partners, to improve conditions for cotton producers, harvesters, and their families in Madhya Pradesh. (Fair Labor, 2024).

Another tool to improve situations can be audits, but they must be carried out in an effective manner (for example, not online). Third-party certifications and audits were also mentioned by participants of the human rights survey several times, noting that these are part of their daily business and require strong compliance.

However, some issues are seen to have worsened, including:

- Instances of forced labor, in some locations state-sponsored
- Geopolitical risks, such as populism and rollbacks on workers' rights
- Economic pressures from inflation and rising costs of living
- Persistent gender-based discrimination in task allocation and wages

7.3.11. Conclusions

7.3.12. Main findings of human rights survey and expert interviews

Despite the limitations of the sample size, the human rights survey results and accompanying comments provided interesting insights into human rights issues in the cotton supply chain. They also gave stakeholders the opportunity to demonstrate the positive work they are doing to identify and mitigate these issues. While self-reporting can be a useful tool for gathering information on

human rights, it is not a substitute for independent verification and broader engagement with diverse stakeholders. Due to the associated limitations, expert interviews and accompanying literature reviews were utilized to assess the plausibility of the responses.

Data providers engaged well with questions, with most stakeholders answering all questions and contextualizing their answers with comments highlighting specific examples and how issues have been addressed. This demonstrates a clear awareness of, and engagement with, the respective issues. In multiple cases, experts commenting on the information given by data providers confirmed their answers. However, there were occasions when inconsistencies in the responses were detected, and experts challenged the plausibility of these responses. As it was not possible to carry out a second iteration to clarify open points, the reasons for those inconsistencies could not be further analyzed. Not all questions were answered by all participants. In some cases, a reason was given (for example, the question not being applicable), but this was not always the case.

Overall, in almost all social impact subcategories, answers indicated that there are human rights issues affecting workers in the cotton supply chain that still require improvement. This was particularly apparent for cotton cultivation, where answers showed high variability, and most subcategories included at least one data point indicating potential human rights issues.

In addition to reviewing survey responses, interviews with sector experts focused on additional topics, such as recent improvements, challenges, and the future outlook of human rights issues in the cotton supply chain. There was consensus among social experts that the type of cotton cultivation system has a minor influence on most social impacts. However, regional differences—sometimes even at the community level—were considered more significant in shaping social impacts than the type of production system. The importance of the existence and enforcement of national legislation for the protection of workers was highlighted. Laws and legislation are powerful tools that can be used to influence human rights aspects, such as subsidies. Besides legislative aspects, local infrastructure, and mechanization were mentioned as having a strong influence on human rights issues.

Regarding general improvements in the human rights aspects of cotton fiber production, experts listed gender equality, awareness-building, child labor, and structural changes in rural areas as key areas to focus on. However, issues with forced labor, geopolitical risks, rising costs, and persistent gender-based discrimination in task allocations and wages were mentioned as worsening areas. The impact of climate change on human rights issues in the cotton supply chain was also heavily emphasized during the interviews. Given that climate change will be one of the most significant risks over the next few years, focusing on adequate warning systems to guarantee the protection of workers, as well as securing incomes for farmers and workers, is crucial.

7.3.13. Recommendations

The following recommendations summarize potential improvement opportunities of the human rights assessment for further studies as well as for brands, retailers, and manufacturers.

Recommendations for further research

Data sources

Since self-reporting by management-level stakeholders might lead to less accurate and less detailed results compared to answers from field or factory workers, direct communication with workers in an anonymized way, without fear of reprisal, is key to ensuring impartial and accurate information on human rights issues.

Data representativeness
The small size and variation of sample sizes led to difficulties in interpreting and displaying results. To increase the representativeness of the survey results, a larger number of participants (including those from different geographies) would be helpful. Regarding geographical representativeness, individual human rights questions must be first assessed at the level that is appropriate for the aggregation of data. Certain issues can be analyzed at the country level, but most need to be assessed regionally, or at a community level. The identification of key drivers for each human rights issue is needed to facilitate further disaggregation and grouping of survey responses. This would increase the representativeness of data.

Selection of human rights survey questions
To better define the questions from the survey, more specific and more detailed inquiries with clearer definitions of wording or employment types (formal, informal, seasonal, permanent) are recommended to ensure the answers provided are consistent and specific. Less direct question techniques could also lead to respondents sharing more information. Financial provisions could be utilized to ensure high return rates.

Regarding the differences in the production steps between cultivated and recycled cotton, human rights issues in both cotton fiber types should be investigated with separate surveys. This approach would enable each survey to better address specific topics related to the different fiber production systems.

Furthermore, the human rights assessment could be extended to include additional topics such as Indigenous Peoples, poverty, labor coercion, and corruption. Further research is also recommended to assess in more detail subjects like gender equality, child labor, migrant labor, and prison labor, and to cover all of the value chain steps, not only harvesting. More questions related to climate risks, such as extreme weather conditions, could be included, given their impact on yields and living wages. However, looking at the vast amount of data points that can potentially be collected in a human rights survey, it might make sense to limit the broadness of topics and, rather, focus on a smaller geographical scale with fewer topics, depending on the resources available.

Recommendations for brands, retailers, and manufacturers

Human rights due diligence
For the identification and mitigation of human rights issues, comprehensive risk assessments and due diligence are crucial across all tiers of the supply chain. Companies should engage in continuous monitoring and independent verification or audits of labor practices at every stage of the cotton supply chain, from cotton farming to finished textiles. Geographical significance, and the local contexts of identified risks, need to be considered as well as impacted groups or worker types in the supply chain. Those measures, in combination with field-based research, can improve the quality of assessments and lead to effective measures to address human rights issues.

Transparency and traceability
Suppliers should be required to provide clear and reliable documentation, demonstrating their compliance with human rights requirements. This can support the identification of risks, gaps, and improvement potentials for companies regarding human rights violations. Cotton sourcing from regions with known human rights abuses should be avoided unless robust monitoring and remediation mechanisms are in place.

Compliance with international standards
It is highly recommended that all business processes, including sourcing, are in alignment with international frameworks such as the UN Guiding Principles on Business and Human Rights (United Nations, 2011), ILO conventions (International Labour Organization, 2025), and OECD guidelines

(OECD, 2018). Supplier certifications to high social standards, including strict human rights and social criteria, should be incorporated in sourcing requirements. Programs need to be developed to support suppliers in achieving certifications. Respective human rights and sourcing policies need to be checked for compliance and updated regularly in line with evolving regulations.

Stakeholder engagement and collaboration

For risk assessments and when developing and reviewing policies, companies should continuously engage and collaborate with stakeholders. This includes rightsholders and affected communities as well as governments and other brands, so that high-quality information can be obtained to help develop effective and meaningful strategies for improvements.

Training and worker empowerment

Companies should invest in training staff and suppliers on the identification and prevention of human rights abuses and how to comply with human rights standards. Workers should be supported in exercising their rights to freedom of association and collective bargaining throughout the supply chain. To ensure effective remediation of human rights issues, confidential channels such as helplines and grievance mechanisms should be established.

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Annex A: Critical Review Statement

Critical Review Statement

Title of Study: "Life Cycle Assessment of Cotton (Country average, organic, regenerative, recycled)"

Commissioned by: Textile Exchange

Conducted by: Sphera Solutions, Inc

Critical Review Panel: Joël Mertens (Panel Chair)
Director, Cascale
Dr. Jesse Daystar
Chief Sustainability Officer, Cotton Incorporated
Allan Williams
Executive Director, Cotton Research and Development Corporation
Miguel Gómez-Escolar Viejo
Head of MEL, Better Cotton Initiative

Date: 7 January 2026

Scope of the Critical Review:
The critical review was carried out in accordance with the following reference standards:

- ISO 14040: 2006
  Environmental management — Life cycle assessment — Principles and framework
- ISO 14044: 2006
  Environmental management — Life cycle assessment — Requirements and guidelines
- ISO 14071: 2024
  Environmental management — Life cycle assessment — Critical review processes and reviewer competencies

The review considered:

- the appropriateness and clarity of the goal, scope, functional unit, and system boundaries
- the methods used to carry out the LCA relative to ISO 14040:2006 and ISO 14044:2006
- the adequacy and representativeness of the data in relation to the goal of the study
- the suitability of the life cycle impact assessment (LCIA) methods and impact categories
- the documentation and description of results, assumptions, and limitations
- the interpretation and conclusions relative to the limitations and the goal of the study
- the overall transparency, consistency, and legibility of the final study report

Review comments were collected in two rounds, with the LCA practitioners updating the report in response after each round. The review period took place between June and December 2025.

Conclusion:

It is the opinion of the review panel that this study is consistent with ISO 14040 and ISO 14044. The scope, system boundaries, and functional unit are appropriate and reasonable to achieve the defined goals. The inventory data, LCIA methods, and impact category selection are all suitable for the purpose of the report. The report is transparent and consistent with clear explanation of limitations and conclusions.

The reviewers did not have direct access to the LCA calculations, LCI data collection templates, or LCA models. This review is therefore primarily limited to the summary data and model results included in the report. Completing the critical review does not imply the reviewers endorse the results of the LCA study, nor any of the assessed products. Opinions of the reviewers are their own and do not necessarily represent the position or policy of their respective organizations.

Signed:

Joël Mertens	Dr. Jesse Daystar

Allan Williams	Miguel Gómez-Escolar Viejo

Annex B: Social Assessment

B.1. Human rights impact assessment survey

The following table shows the human rights impact assessment survey that was sent out for data collection.

Table B-1: Human rights assessment survey

UNEP stakeholder categories	UNEP impact subcategories	Questions (including options for answers)
Worker	Child labor	How often do you see under 18s working on cotton farms/cotton recycling facilities in your region? (Answers: Never, Rarely, Sometimes, Often, Always)
		What is the youngest age of children you see working on cotton farms/cotton recycling facilities in your region? (Answers: Less than 10, 10 to 12 years old, 13 to 15 years old, 16 to 18 years old)
		Are you aware of under 18s ever doing work that could be considered hazardous in your region (please provide specifics in the comment section)? (Answers: Yes, No)
Worker	Fair salary	How often do workers on cotton farms/cotton recycling facilities earn at least the local minimum wage in your region (please state the local minimum wage in the comments)? (Answers: Never, Rarely, Sometimes, Often, Always)
		How often do workers earn a living wage (enough to cover their basic needs for themselves and their families, including unexpected expenses) in your region? Please state the local minimum wage in the comments. (Answers: Never, Rarely, Sometimes, Often, Always)
Worker	Working hours	For cotton cultivation only: How often do workers on cotton farms get days off in your region? Please give more detail in the comments. (Answers: At least 2 days/week off, At least 1 day/week off, At least 1 day/every 2 weeks off, At least 1 day/month off)
		How often do workers on cotton farms/cotton recycling facilities exceed 40 hours per week in your region? (Answers: Never, Rarely, Sometimes, Often, Always)
		Do you feel that workers are able to freely refuse working overtime in your region? If not, please explain what happens in a situation where they refuse overtime. (Answers: Yes, No)

UNEP stakeholder categories	UNEP impact subcategories	Questions (including options for answers)
		What are the peak season working hours like in your region? What is the highest overtime you have seen? (Answers: 60–70 hours/week, 70–80 hours/week, 80–90 hours/week, >90 hours/week)
Worker	Equal opportunities/ discrimination	What is the approximate ratio of women and men working on cotton farms/cotton recycling facilities in your region? Please elaborate. (Answers: Women [%], Men [%])
		Are the workers mostly local or migrant in your region? (Answers: Local, Internal migrants, Cross-border migrants)
		How often do women and men who do the same job in the context of cotton farming/cotton recycling facilities, earn the same money in your region? (Answers: Never, Rarely, Sometimes, Often, Always)
Worker	Health and safety	How would you rate the Health & Safety on cotton farms/cotton recycling facilities within your region? Please provide examples in the comments. (Answers: Good (no issues), Satisfactory (minor issues), Poor (many issues), Dangerous (serious issues))
		For cotton recycling only: Is there any social welfare and safety requirements that need to be met during the sorting of recycled materials in your region? Please provide examples in the comments. (Free text answer)
Worker	Social benefits/social security	Where workers on cotton farms/cotton recycling facilities are provided with accommodation by their employer, what are the conditions of the accommodation in your region? Please give more detail in the comments. (Answers: Good (no issues), Satisfactory (minor issues), Poor (many issues), Dangerous (serious issues))
Worker	Employment relationship	Are the workers mostly permanently employed or seasonal in your region? (Answers: Formal permanent employment, Formal seasonal or temporary employment, Informal permanent employment, Informal seasonal or temporary employment)
		Do workers on cotton farms/cotton recycling facilities have contracts or work informally in your region? Please give more detail in the comments (benefits can include sick pay, maternity pay, pension, etc.,). (Answers: Most have contracts with benefits, Most have contracts but no benefits, Some work informally, Some have contracts, Only informal work)

UNEP stakeholder categories	UNEP impact subcategories	Questions (including options for answers)
		To what extent can workers working on cotton farms (or their surrounding communities) or cotton recycling facilities, advocate for themselves if they are negatively impacted in any way in your region (such as labor issues or water scarcity)? (Answers: Concerns or grievances are usually effectively resolved in the workplace, or through a worker union or another grievance channel, Concerns or grievances are sometimes effectively resolved in the workplace, or through a worker union or another grievance channel, Although there are channels available, concerns or grievances are never effectively resolved in the workplace, or through a worker union or another grievance channel, There is NO channel in the workplace, a worker union or external grievance channel for workers or communities to use to resolve grievances or concerns)
		How often do you hear about things like workers working on cotton farms/cotton recycling facilities being required to pay recruitment fees, or being unable to terminate employment due to owing money to their employer in your region? (Answers: Never, Rarely, Sometimes, Often, Always)
Local community	Access to material resources	For cotton cultivation only: Do you see any issues specifically related to illegal adoption of land, deforestation or land grabbing (from indigenous or local communities who may have customary land rights without formal ownership) related to cotton farming within your region? If yes, please give more detail in the comments. (Answers: Yes, No)

Annex C: DQR criteria

C.1. Cotton cultivation

C.1.1. Technological representativeness

Technological representativeness (TeR) is interpreted as the completeness and consistency of collected data. It was assessed on the data-provider level, then aggregated to the country average.

Table C-1: Technological representativeness criteria for cotton cultivation

	1	**2**	**3** *(Default for datasets based on statistical data)*	**4**	**5**
Yield and fertilizer data	Complete; N content of organic fertilizer specified (if applicable); N balance closed	Complete, negative N balance; N content of organic fertilizer specified (if applicable)	N content of organic fertilizer estimated or based on secondary data	Fertilizer data incomplete (for example, states that organic fertilizer applied) but no inputs are stated	Fertilizer data missing
Irrigation	Water consumption and irrigation energy specified	Water consumption known irrigation energy use modelled	Water consumption modelled or based on secondary data	Water consumption based on proxy data (i.e., fraction of farmers that irrigate unclear)	Unknown (no suitable proxy available, estimated)
Pesticide use	Complete list of active ingredients (AI) provided	AI (active ingredient) application based on cotton specific country averages/ statistical data (1)	AI application based on secondary data (ICAC + Chemgrids)	AI application based on secondary data (Chemgrids only)	Unknown (no suitable proxy available, estimated)
Fuel use	Provided	Estimated based on reported activities	Estimated based on secondary data (country averages)	Estimated based on FAO energy intensity values	Unknown (no suitable proxy available, estimated)
Ginning	Seed to lint ratios and energy provided	Seed to lint or energy estimated	Cascale default data on energy use in gin		Unknown (no suitable proxy available, estimated)

C.1.2. Precision

Table C-2: Precision criteria for cotton cultivation

	1	**2**	**3** *(Default for datasets based on statistical data)*	**4**	**5**
Precision	Measured/ calculated AND externally verified	Measured/ calculated and internally verified, plausibility checked by reviewer	Measured/ calculated/ literature and plausibility not checked by reviewer OR qualified estimate based on calculations plausibility checked by reviewer.	Qualified estimate based on calculations; plausibility not checked by reviewer	Rough estimate with known deficits

C.1.3. Temporal representativeness (TiR) and Geographical representativeness (GeR)

- TiR (temporal representativeness) is assessed on the supplier level as well, and aggregated into the country average
- GeR (geographical representativeness) is assessed on the level of the aggregated country average

Table C-3: Temporal representativeness criteria for cotton cultivation

	1	**2**	**3** *(Default for datasets based on statistical data)*	**4**	**5**
Temporal representativeness (TiR)	Three years average, most recent cultivation season	Two years coverage, or three years not recent but not older than five years	One-year average	Any data older than five years	n.a. (proxy data older than 10 years)
Geographical representativeness (GeR)	Production volume sampled >SQRT of total production volume, main production regions covered	Production volume represented >SQRT of total production volume, main production regions covered	Production volume represented >SQRT of total production volume, some production regions missing; or volume represented < SQR of total production main production regions covered	Production volume represented < SQRT of total production volume, some production regions missing	Proxy data from other geographical context

C.2. Recycled cotton

C.2.1. DQR representativeness

Technological representativeness (TeR), precision (P), and temporal representativeness (TiR), are assessed on a data-provider level, then aggregated to the global average. Geographical representativeness (GeR) is assessed on the global level.

Table C-4: DQR representativeness criteria for recycled cotton

Technological representativeness (TeR)		**1**	**2**	**3**	**4**	**5**
	Energy	Data complete. Data in accordance with benchmarks.	Data complete, but not in accordance with benchmarks.	Energy consumption estimated or based on existing literature.	Data incomplete (for example, stating energy source, but no inputs are stated)	Energy data missing.
	Transport (domestic /international)	Data complete. All transportation distances are reported.	Incomplete. Some transportation distances are estimated.	All transportation distances are estimated based on information from data providers.	All transportation distances are estimated. No further information was provided.	Transportation data missing.
Precision (P)		**1**	**2**	**3**	**4**	**5**
	Energy, transport (domestic/international)	Measured/ calculated AND externally verified	Measured/ calculated and internally verified, plausibility checked by reviewer	Measured/calculated/ literature and plausibility not checked by reviewer OR qualified estimate based on calculations plausibility checked by reviewer.	Qualified estimate based on calculations; plausibility not checked by reviewer	Rough estimate with known deficits

Time representativeness (TiR)		**1**	**2**	**3**	**4**	**5**
	Energy	One year average, data is not older than three years.	One year average, data is older than three years.	one year average, data older than five years.	Time coverage 6–12 months	Time coverage <six months, or no time reference provided.
Geographical representativeness (GeR)	**Energy, transport (domestic/international)**	**1**	**2**	**3**	**4**	**5**
		No. of data points >10	No. of data points between 6–10	No. of data points between 3–5	No. of data points 1–2	No. of data points unknown

Annex D: Regenerative practices

Table D-1: Practices considered to classify regenerative systems*

Practice	Description	Expected impact (with relevance to considered LCIA categories)[1]
Yield	Not a management practice, but data collection should be clear if yield increases or decreases are experienced, or are to be expected compared to conventional baseline	None/increase/decrease [3]
Integrated nutrient management*	Farmers are aware of nutrient balance, and avoid large nutrient surplus application with fertilizer; farmers use efficient application techniques	Increased nutrient efficiency, lower leaching rates, lower field emissions per kg product
Use of organic fertilizer*	A certain fraction of mineral fertilizer is substituted with organic fertilizer	Increased carbon input, potentially higher ammonia emissions (acidification), lower provision impacts from mineral fertilizer (see section 3.11.2 on provision impacts of organic fertilizer)
Tillage*	Farmers apply reduced or no-tillage [4]	Higher soil carbon sequestration potential, lower diesel consumption, potentially increased use of herbicides
Integrated pest management*	Farmers apply principles of integrated pest management	Substitution of substances of high concern, lower pesticide application rates
No LUC*	No primary forest, and no secondary forest older than 10 years is deforested with the purpose to gain new land for cultivation [5]	No emissions from LUC
Irrigation	Farmers adopt measures to optimize water consumption for irrigation (awareness of watering needs of cotton, consideration of rainfall pattern, measure of volume applied, use of effective irrigation methods)	Reduced water consumption (per ha and per kg of crop)
Cover crops	Farmers introduce cover crops between vegetation periods	Increased input of carbon, reduced leaching, reduced soil loss.
Intercropping	Cultivation of two or more crops in a field simultaneously (whether legume, cash crop, or cover crop)	Reduced leaching, split of burden between crops if cash crops are cultivated as intercrops [6]
Combustion of crop residues	Farmers do not combust crop residues prior to vegetation period	Increased input of carbon, lower emissions (especially relevant for acidification)
Crop rotation	Planting alternate crops with different characteristics, sequentially, on the same plot of land [7]	Potential impacts (need to be assessed case specific): reduced pesticide use, reduced water consumption and increased carbon sequestration potential, transfer of nutrients from previous crop to succeeding crop
Agroforestry	Combination of trees or shrubs with agricultural crops	Increased carbon stock in biomass

*Based on Textile Exchange's *Regenerative Agriculture Landscape Analysis* (Textile Exchange, 2022).

(1) It should be noted that the table does not intend to mention all potential benefits of a regenerative cultivation system, but only those directly related to any of the assessed impact categories, (see section 3.9). For example, potential improvements in soil health in general or biodiversity are not assessed directly, but impacts that are easier to quantify can be used as proxy indicators (see section 2.3).
(2) See section 3.1 on included geographies.
(3) It should be noted that decreases in yield do not necessarily mean that the system is performing worse in environmental or economic terms (for example, if yield is assessed as yield/production cost). However, an economic assessment of regenerative cultivation systems is outside the scope of the LCA study. Since environmental impacts are calculated on a per-kilogram basis, yield decreases can still lead to reduced environmental impacts if associated with disproportionately larger decreases in emissions. Differences in fiber quality are not assessed (see section 3.3).
(4) Based on (IPCC, 2019): No-till = direct seeding without primary tillage and only minimal soil disturbance in the seeding zone herbicides are typically used for weed control; Reduced tillage = primary and/or secondary tillage but with reduced soil disturbance that is usually shallow and without full soil inversion; normally leaves surface with >30% coverage by residues at planting; Full tillage = substantial soil disturbance with full inversion and/or frequent, within year tillage operations, while leaving <30% of the surface covered by residues at the time of planting.
(5) No LUC criterion also applies to the conversion of wetland and peatland, even though it is expected to have low relevance for cotton cultivation.
(6) Economic allocation might be applicable (see also section 2.2).
(7) Crop rotation is not explicitly defined in the Regenerative Agriculture Landscape Analysis, but an example refers to three- to four-year rotations.

Dimension of regenerative agriculture (Processes) Sorted by frequency in Practitioner Websites	N	%
Use no or low external inputs; maximize on-farm inputs	32	26.4
Integrate livestock	23	19
Use no synthetic pesticides	15	12.4
Use no synthetic fertilizers	15	12.4
Reduce tillage (or no-, minimal-, conservation-)	14	11.6
Use crop rotations	12	9.9
Use crop plant diversity (including intercropping)	11	9.1
Use compost, mulch, green manure, or crop residues	11	9.1
Use cover crops	10	8.3
Use organic methods	10	8.3
Use ecological or natural principles or systems	9	7.4
Use organic fertilizers	8	6.6
Incorporate perennials and trees	7	5.8
Use natural pest control	7	5.8
Protect/cover the soil	6	5
Focus on localism and/or regionality	6	5
Other	4	3.3
Restore natural habitats	3	2.5
Focus on small scale systems	3	2.5
Rely on farm labor, including for local knowledge	3	2.5

Dimension of regenerative agriculture (Processes) Sorted by frequency in Journal Articles	N	%
Integrate livestock	9	40.9
Reduce tillage (or no-, minimal-, conservation-)	9	40.9
Use cover crops	8	36.4
Use no or low external inputs; maximize on-farm inputs	7	31.8
Use crop rotations	7	31.8
Use compost, mulch, green manure, or crop residues	6	27.3
Incorporate perennials and trees	6	27.3
Use no synthetic fertilizers	5	22.7
Use no synthetic pesticides	4	18.2
Protect/cover the soil	4	18.2
Use crop plant diversity (including intercropping)	3	13.6
Use organic methods	3	13.6
Use ecological or natural principles or systems	3	13.6
Use organic fertilizers	2	9.1
Use natural pest control	2	9.1
Other	1	4.5
Restore natural habitats	1	4.5
Focus on localism and/or regionality	0	0
Focus on small scale systems	0	0
Rely on farm labor, including for local knowledge	0	0

Table 1 (opposite): Summary of "processes" (practices) and outcomes included in definitions or descriptions of regenerative agriculture within journal articles and practitioner websites. Adapted from Newton et al. (2020)

Green highlights indicate terms in the top 5 for both Journal Articles and Practitioner Websites

Figure D-1: Regenerative practices referred to in practitioner websites and journal articles (Textile Exchange, 2022)

Table D-2: Selection of minimum requirements

Definition in *Regenerative Agriculture Landscape Analysis*	Consideration in definition of regenerative practices (Table D-1)
Use no or low external inputs, maximize on-farm inputs	Integrated nutrient management, integrated pest management, use of organic fertilizer
Integrate livestock	Use of organic fertilizer
Reduced tillage	Tillage
Avoidance of deforestation (see page 17)	No LUC

Annex E: Additional documentation for scenario and sensitivity analysis

E.1. Organic fertilizer provision impacts

The scenario for assessing the environmental impacts associated with the provision of organic fertilizer, FYM, and compost, was constructed using the following assumptions. It is essential to highlight that this is a scenario-based approach, and actual assumptions and conditions may vary significantly across different production systems. The primary aim of this scenario is not to generate exact figures, but rather to provide a realistic estimation of the potential magnitude of the environmental contributions from the provision of organic fertilizers.

Estimating provision impacts for farmyard manure (FYM)

For this scenario, organic fertilizer derived from animal production systems was considered as FYM. To estimate the environmental impacts, a linkage between FYM production and animal live-weight impacts was established. It was assumed that each animal in an extensive production system generates approximately 3.8 tons of FYM annually (Pandey, et al., 2021), with a lifetime of about five years and achieving a final live weight of approximately 480 kg (Sphera dataset documentation[53]). Consequently, over a five-year lifetime, an animal produces around 20 tons of FYM and 480 kg live weight. This corresponds to roughly 39.6 kg of FYM produced per kg of live weight.

A simplified economic allocation method was applied, attributing 10% of the animal's environmental burden to manure production, estimated based on (Leip, et al., 2019). With this assumption, the environmental burden per kilogram of FYM was calculated as follows: 1 kg live weight × 0.1 allocation factor ÷ 39.6 kg FYM = 0.0025 kg live weight-equivalent impact per kg FYM. To quantify these impacts, a Sphera dataset representing extensive cattle production was employed.[53]

Estimating provision impacts for compost

For compost, all reported application rates originating from diverse source materials were normalized to an "average compost", characterized by a nutrient content of 2.7% (Sultana, et al., 2021). A standard compost yield assumption of 50% was used, indicating that producing 1 kg of compost output requires 2 kg of input material (IPCC V5_4).

Emission factors for composting processes were sourced from the IPCC guidelines, and are as follows (IPCC V5_4, table 4.1):

- Methane (CH_4): 4 g/kg input material (equivalent to 0.004 kg/kg)
- Nitrous Oxide (N_2O): 0.24 g/kg input material (equivalent to 0.00024 kg/kg)

As a conservative approach for this scenario, all composting impacts were fully allocated to the compost output product. It is important to note that the IPCC guidelines indicate a wide variability in CH_4 emissions from composting processes, ranging from 0.3 to 8 g CH_4 per kg of input material.

53 The following dataset was used as a proxy: beef cattle pasturing, 1 kg live weight, BR (Sphera Solutions Inc., 2025). Although it refers to Brazil as production region, it was assumed to be a suitable proxy as it represents a low-intensity, pasture-based production system.

Therefore, actual environmental impacts could be substantially higher or lower than the figures presented here.

Environmental impacts were assessed separately for FYM and compost, as well as in combination, to provide comprehensive insights into their potential contributions to the overall results (see section 5.2.1).

Under the current scenario settings, the GWP contribution from FYM is notably lower than that from compost. An additional analysis helps set these findings into perspective:

- Considering cattle with a GWP of 8.21 kg CO_2-equivalent per kg live weight[53], and with 0.0025 kg liveweight allocated to each kilogram of FYM, results in approximately 0.021 kg CO_2-equivalent per kg FYM. Assuming a nitrogen content of 1%, this translates to 2.1 kg CO_2-equivalent per kg nitrogen provided. In comparison, mineral nitrogen fertilizer (urea), according to the Sphera dataset for India (Sphera Solutions Inc., 2025), has a GWP of approximately 3.1 kg CO_2-equivalent per kg nitrogen. Thus, under these assumptions, FYM's impact is about 66% of that of mineral fertilizers.
- With the premise that 2 kg of biowaste are needed to obtain 1 kg of stabilized compost (≈ 50 % wet-mass loss), the IPCC Tier 1 default emission factors for composting—4 g CH_4 per kg and 0.24 g N_2O per kg fresh matter feedstock—scale to 8 g CH_4 and 0.48 g N_2O per kilogram of product. Applying the AR6 100-year GWPs for non-fossil methane (27.2 kg CO_2 equivalent kg^{-1}) and nitrous oxide (273 kg CO_2 equivalent kg^{-1}) yields contributions of 0.22 kg CO_2 equivalent from CH_4 and 0.13 kg CO_2 equivalent from N_2O, giving a direct process footprint of 0.35 kg CO_2 equivalent per kilogram of compost applied. Given the assumed nitrogen content of 2.7%, this equates to around 13kg CO_2 equivalent per kg nitrogen. This GWP per unit nitrogen is significantly higher than for mineral fertilizers (see above).

E.2. Reference soil carbon stock and relative carbon stock change factors

Table E-1: Reference soil carbon stock and relative carbon stock change factors (IPCC, 2019)

Country	Dominant IPCC climate zone	Reference SOC stock (t C/ha)	FLU	FI_high_org	FI_high	FI_low	FI_medium	FMG_full	FMG_no_till	FMG_reduced
Brazil	Tropical wet	52	0.83	1.44	1.11	0.92	1	1	1.10	1.04
China	Warm temperate dry	19	0.76	1.37	1.04	0.95	1	1	1.04	0.99
India	Tropical wet	52	0.83	1.44	1.11	0.92	1	1	1.10	1.04
Peru	Tropical wet	52	0.83	1.44	1.11	0.92	1	1	1.10	1.04
Tanzania	Tropical wet	52	0.83	1.44	1.11	0.92	1	1	1.10	1.04
Türkiye	Warm temperate dry	19	0.76	1.37	1.04	0.95	1	1	1.04	0.99
US	Warm temperate moist	55	0.69	1.44	1.11	0.92	1	1	1.10	1.05

E.3. Recycled cotton—country-specific electricity characterization scenario and energy-generation scenario

Country-specific electricity characterization analysis

A scenario analysis was undertaken to investigate the effect of how the country of production could impact the environmental impacts of the production of recycled spinnable fibers. This analysis assumes that the equivalent share of electricity consumption and generation methods is the global average LCI for each cotton waste type. Energy datasets were then changed from the global average regionalization mix to 100% regionalization to a low-impact country of production (optimistic scenario) and 100% regionalization to a high-impact country of production (pessimistic scenario). The choice of country regionalization for the scenario was chosen specifically from the countries sampled within the study and does not extend to all countries. Chosen countries for scenarios are:

- Optimistic scenario—Turkey (electricity from grid, natural gas, and photovoltaic)
- Pessimistic scenario—India (electricity from grid, natural gas, and photovoltaic)

Individual energy dataset characterization factors cannot be shared due to confidentiality.

Table 5-12 provides the LCI for each waste type for each electricity generation method.

Table E-2: Recycled cotton LCI, average electricity consumption by generation method

	Post-industrial yarn waste	Post-industrial fabric waste	Post-consumer waste (domestic/international transportation)	units
Electricity from grid	0.4663	0.5531	0.6825	kWh
Electricity from natural gas	0.0971	0.1103	0.2462	kWh
Electricity from solar	0.0666	0.0374	0.1464	kWh
Total electricity consumption	0.63	0.7008	1.0751	kWh

Energy-generation scenario analysis

A scenario analysis was undertaken to investigate the effect of a change in electricity generation methods to 100% solar (optimistic scenario), or 100% hard coal (pessimistic scenario), to highlight the change in potential environmental impacts from the choice of electricity generation sources. This analysis assumes that the equivalent share of electricity consumption is the global average LCI for each cotton waste type. However, energy generation datasets were changed from the global average regionalization (mixture of grid, solar, and natural gas) to 100% solar from a low-impact country of production (optimistic scenario) and 100% hard coal from a high-impact country of production (pessimistic scenario). The choice of country regionalization for the scenario was chosen specifically from the countries sampled within the study and does not extend to all countries. Chosen countries for scenarios are:

- Optimistic scenario—Turkey (100% electricity from photovoltaic)
- Pessimistic scenario—India (100% electricity from hard coal)

Table 5-12 provides the LCI for each waste type for each electricity generation method.

Table E-3: Recycled cotton LCI, average electricity consumption by generation method

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Total electricity consumption	0.63	0.7008	1.0751	kWh

E.4. Recycled cotton—international shipping of post-consumer waste

COMM trade data (code 6309[54]) was utilized to quantify the country-specific share of imported post-consumer waste for each of the four importing countries under study and grouped by continent (European Commission, 2024). A shipping distance calculator was used to calculate the distances from the major ports of the export and import countries (EcoTransIT World, 2025). These distances were used to establish a plausible range of transportation distances for the international transportation scenarios, and can be found below in Table E-5.

Table E-4: Weighted average exports of post-consumer waste per import country

	Import country			
Continent (export)	**China**	**Pakistan**	**Türkiye**	**India**
North America	91.97%	18%	2%	49%
Europe (including UK)	7%	64%	95%	28%
Asia	0.96%	13%	4%	22%
Australasia (Oceania)	0.08%	5%	0%	1%

Table E-5: International transportation distance examples

	China	**Pakistan**	**Türkiye**	**India**
North America	10714 km Shanghai, China to Los Angeles, US 19809.2 km Shanghai, China to New York, US 27419.9 km Shanghai, China to Chicago, US 10719.5 km Shanghai, China to Canada	23188.4 km Karachi to Los Angeles, US 17015.5 km Karachi to New York, US 21145.5 km Karachi to Canada	9680.6 km Istanbul to New York, US 19432.7 km Istanbul to Los Angeles, US 25950.9 km Istanbul to Canada	22889.7km Nhava Sheva, India to New York, US 21567.4 km Nhava Sheva, India to Los Angeles, US 20193.8 km Nhava Sheva, India to Canada
Europe (including UK)	25884.4 km Shanghai, China to Rotterdam, the Netherlands 26765.1 km Shanghai to	13163.8 km Karachi, Pakistan to Rotterdam, the Netherlands 13707.4 km Karachi Pakistan	6982.6 km Istanbul to Rotterdam, the Netherlands 6814.8 km Istanbul to	13559.8 km Nhava Sheva, India to Rotterdam, the Netherlands 14113.7 km

54 Since 2021 China has prohibited the import of post-consumer textile waste (European Commission, 2024), HS code 6310: Used or new rags, scrap twine, cordage, rope and cables, and worn-out articles of twine, cordage, rope or cables, of textile materials.

	China	Pakistan	Türkiye	India
	Antwerp, Belgium	to Hamburg, Germany 13148.3 km Karachi Pakistan to Antwerp, Belgium	Hamburg, Germany	Nhava Sheva, India to Hamburg, Germany
Asia		9920.1 km Karachi, Pakistan to Shanghai, China	17289.7 km Istanbul to Shanghai, China	10364.1 Nhava Sheva, India to Shanghai, China
Australasia (Oceania)	9646.5 km Shanghai, China to Sydney, Australia	13775.9 km Karachi, Pakistan to Sydney, Australia	19411 km Istanbul, to Sydney, Australia	12875.2 km Nhava Sheva, India to Sydney, Australia

E.5. Recycled cotton—washing and drying of post-consumer waste

Post-consumer textiles can require washing and drying to remove contaminants such as sweat and dirt. There are many points at which washing and drying can happen within the broader recycling system; however, many of these are outside of the system boundaries, for example downstream as part of the final textile finishing process, or upstream by the consumer prior to processing and sorting at the recycling collection point[55]. Within the system boundaries of the recycling process, washing and drying are very uncommon. Furthermore, at the mechanical recycling facilities, washing and drying are not common practice; however, in rare circumstances, it can be necessary to remove unforeseen contaminants if, for example, it is deemed that contaminants could impair or damage the function of the recycling machinery. Therefore, despite the infrequency of this process step, given the significant potential environmental impacts, the scenario analysis is provided to highlight the importance of mitigating washing and drying where feasible.

The scenario concerns a conventional washing and machine-drying process. Washing inventory includes electricity, water, and mild detergent containing surfactants. Drying inventory includes electricity. The electricity LCI is aggregated between both washing and drying.

Available literature was utilized to attain LCI for the washing and drying processes and detergent use. A meta study was utilized to assess a multitude of LCI from industrial washing and drying studies, which was used to derive a plausible scenario for washing and drying representative of the most robust, temporally, and technologically representative studies concerning washing and drying of cotton. LCI for electricity and water use is aggregated for both the washing and drying processes. A separate study was utilized to obtain LCI for detergent use, and references for both are provided in the table.

55 Typically, the "point of waste"

within a mechanical recycling product system refers to the waste collection point or sorting and processing centre. Therefore, the impacts of washing and drying by the consumer prior to delivery to the recycling collection point would be allocated to the use phase of the textile, rather than the upstream impacts of the recycling process.

Due to challenges regarding the availability of washing and drying LCI data, and uncertainty regarding the representativeness, as well as the significant potential impacts identified from the scenario analysis, a sensitivity analysis was also undertaken and forms part of the scenario analysis. The "optimistic" and "pessimistic" scenarios are calculated as +/- 50% of the LCI within the baseline scenario.

Table E-4 provides more information on the LCI used for the washing and drying scenarios.

Table E-6: LCI for washing and drying scenarios' analysis of post-consumer waste

	Energy use kWh/kg recycled cotton fiber*	**Water use L/kg recycled cotton fiber***	**Detergent use kg/kg recycled cotton fiber****
Optimistic	0.8277	29.8	0.01519
Baseline	1.655	59.59	0.03039
Pessimistic	2.483	89.39	0.04559

* (Munasinghe, Druckman, & Dissanayake , 2021)

** (Mezzanotte et al., 2025)

E.6. Recycled cotton—fumigation of post-consumer waste

For post-consumer cotton waste that is imported via international transportation, a fumigation step can be a legal requirement, depending on the import country. A scenario analysis has been undertaken to understand the effect of the fumigation process on the impacts of the recycling process.

For the analysis, phosphine was Identified as the most commonly utilized fumigant. However, as impacts, especially for ecotoxicity, freshwater can be highly dependent on the individual chemical, additional fumigants that can be used for stored-textile fumigation were additionally analyzed to understand their potential environmental impacts[56].

For each fumigant, a target concentration was established from available literature. It should be stated that the target concentration is variable, dependent on abiotic conditions such as temperature, as well as the pest species being targeted. A conservative assumption was taken where a range of target concentrations were identified, see references for more detailed information. The fumigant mass per fumigated standard large (40 ft) shipping container was calculated with the target concentration (g/m3) and the container's internal volume (m3). Following this, the mass per kg of post-consumer cotton waste was calculated according to the total post-consumer waste that can be typically stored within a large, standard shipping container. Finally, the mass of fumigant was scaled to the input mass of post-consumer cotton waste required to fulfill the FU of 1 kg of recycled

[56] Because the previously popular fumigant, methyl bromide, has been phased out in some countries under the Montreal Protocol, phosphine is the only widely used, cost-effective, rapidly acting fumigant that does not leave residues on the stored product. However, this fumigant can still be used in certain countries and, additionally, certain pests with high levels of resistance toward phosphine have become common in Asia, Australia, and Brazil and, in turn, sulfuryl fluoride's use has increased as a replacement for methyl bromide and as an alternative to the use of phosphine, which, during the fumigation process, can be acutely toxic.

spinnable fiber, which, for post-consumer waste, was a mass of 1.788 kg. Information pertaining to the calculation can be found in table E-5.

Table E-7: Calculation of mass of fumigant chemicals required for the fumigation process of post-consumer cotton waste

	Phosphine	Sulfuryl fluoride	Methyl bromide	units
Target concentration	1.39*	30**	80***	g/m3
Container volume	67.7	67.7	67.7	m3
Calculated fumigant mass per container.	0.09410	2.031	5.416	kg
Post-consumer cotton waste per standard large container (40 ft)	20	20	20	tons
kg fumigant/kg post-consumer waste	4.71E-06	1.02E-04	2.71E-04	kg
kg fumigant/kg recycled spinnable fiber	8.41E-06	1.82E-04	4.84E-04	kg

* (Somiahnadar, 2016)

** (Drinkall, Dugast, Reichmuth, & Schöller, 1996)

*** (Fumigation service PVT LTD, 2025)

E.7. Recycled cotton—economic allocation of valuable by-products (multi-output system)

Price data was collected from data providers for recycled spinnable fiber (main product), fluff, and filling material (by-products) for each cotton waste type, as well as sorted post-consumer waste (by-product post-consumer waste only). The default analysis utilizes an assumption of 100% allocation to the main product; however, sensitivity analysis was utilized to understand the influence of this allocation on the results of the study. An average was calculated for each cotton waste type from the price data provided, and this was utilized, along with the minimum and maximum reported values, to develop a realistic range of scenarios for the sensitivity analysis (pessimistic, average, and optimistic). Here, the optimistic scenario represents the most significant allocation of impacts to by-products.

For post-consumer waste, when the baled post-consumer waste arrives at the factory gate, a sorting step happens and, for some data providers, some of the post-consumer cotton waste that does not meet quality standards is then sold on, prior to the recycling process. Therefore, as seen in table E-7, the allocation of the impacts is separated, with one economic allocation percentage applied following sorting at factory (sold by-product, fluff, and filling material) and one applied at factory gate (fluff and filling material only). The recycled, spinnable fiber production valuable output price data can be found in table E-6, and the economic allocation percentage for each of the pessimistic to optimistic scenarios can be found in tables E-6 and E-7.

Table E- 8: Recycled, spinnable fiber production valuable output price data

Output	Post-industrial yarn	Post-industrial fabric	Post-consumer waste
Recycled spinnable fiber (main product)	99.59%	98.32%	89.47%
Fluff (by-product)	0.20%	0.84%	4.37%
Filling/dust material (by-product)	0.20%	0.84%	1.17%
Sorted post-consumer waste (by-product)			5%

Table E-9: Post-industrial yarn and fabric economic allocation percentage

	Post-industrial yarn waste	Post-industrial fabric waste
	Allocation at factory gate (fluff, and filling material only)	Allocation at factory gate (fluff, and filling material only)
Global average baseline	100%	100%
Pessimistic	99.99%	99.99%
Average	99.59%	98.32%
Optimistic	97.5%	95%

Table E-10: Post-consumer waste (domestic/international transportation) economic allocation percentage

	Post-consumer waste (domestic/international transportation)	
	Allocation following sorting at factory (sold by-product, fluff, and filling material)	Allocation at factory gate (fluff, and filling material only)
Global average baseline	100.00%	100.00%
Pessimistic	95.0%	97.5%
Average	89.5%	94.5%
Optimistic	82.5%	90.0%

Annex F: Cotton cultivation global average results

It is in the scope of the study to build a global average production dataset from the country averages and for organic cotton production. The available countries are weighted, based on production volume, into a global average (see Table F-1 and table F-2). It is important to note that this global average should be used with caution. Some key cotton-producing regions are not represented, particularly in the global-average reference system, and the quality of data varies between countries (see section 6.3.1). The use of global-average datasets is a well-recognized limitation in LCA studies, and has been the subject of criticism (see section 1.1 and 6.4.2). These global averages are provided solely for indicative, high-level use (for example, as preliminary inputs where no country- or supplier-specific data is available). They must not be used for comparative assertions, sourcing decisions, or to claim differences between cotton production systems or countries. Users are strongly encouraged to replace global averages with country- or supplier-specific data whenever possible.

Note that no global average is calculated for regenerative systems, because no reliable production data is available for weighting into a global average. Additionally, many of the assessed systems were new and covered small sample sizes (see section 4.2.1), so that the data was also not considered robust enough to be aggregated into a global average.

Table F-1: Weighting factors for global-average dataset cotton cultivation country averages

Country averages	**Production volume ('000 tons)** (ICAC, 2024) **for 2023**	**Weighting factor**	**DQR**
Brazil	2552	20%	3.0
India	5722	44%	1.8
US	3150	24%	1.4
Türkiye	887	7%	3.0
China selected regions*	628	5%	3.0
Total	12939		**Level 3****
Total all countries	24420		
Coverage	53%		

* For regions included, see table 3-1.

** Since not all geographies are covered, and key production regions are missing, the global-weighted dataset can only be classified as having limited data quality. It should also be noted that a production-weighted average does not necessarily correspond to a market average, which may differ across countries or regions.

Table F-2: Weighting factors for global-average cotton dataset cultivation organic

Organic	**Production volume ('000 tons)** (Textile Exchange, 2024) **for 2023***	**Weighting factor**	**DQR**
Brazil	0.1	0.0%	3.2
India	270.7	69.9%	1.8

Organic	**Production volume ('000 tons)** (Textile Exchange, 2024) **for 2023***	**Weighting factor**	**DQR**
Peru	1.3	0.3%	1.9
Tanzania	22.3	5.7%	1.7
Türkiye	83.4	21.5%	3.2
US	9.7	2.5%	2.3
Total	387.4		Level 3**
Total all countries	560.0		
Coverage	69%		

* Disclaimer from Textile Exchange's *Materials Market Report* (Textile Exchange, 2024): Due to the complex landscape of organic certification, accurately calculating global organic cotton production volumes is extremely challenging. Organic cotton is often certified to multiple standards, complicating the aggregation process. Moreover, significant data gaps exist, necessitating the use of modeling and proxies in several countries, including India, the world's largest organic cotton producer. As a result, global data should be considered very rough estimates and should only be used as such.

** As noted above, given the uncertainty of the weighting factors and the limited data quality for Türkiye, despite its significant contribution to the global dataset, the global-weighted dataset can only be classified as having limited data quality. It should also be noted that a production-weighted average does not necessarily correspond to a market average, which may differ across countries or regions.

The tables below (table F-3 and table F-4) show the global-average production results from the country averages and for organic cotton production.

Table F-3: Global-average results (production weighted average of country averages)

	Biomass combustion	**Crop protection**	**Field**	**Ginning**	**Irrigation**	**LUC**	**Machinery**	**Provision of fertilizer**	**SOC**	**Transport to gin**	**Transports**	**Total**
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change] (kg CO_2 eq./kg fiber)	7.4E-03	4.6E-02	1.0E+00	1.7E-01	2.7E-01	2.5E-01	1.5E-01	9.4E-01	0.0E+00	8.9E-03	4.7E-03	2.9E+00
Acidification [EF 3.1] (moles H+ eq./kg fiber)	5.7E-04	9.9E-05	5.6E-02	1.7E-03	3.3E-03	0.0E+00	1.6E-03	6.3E-03	0.0E+00	1.8E-05	1.2E-05	7.0E-02
Eutrophication [CML 2016] (kg phosphate eq./kg fiber)	5.9E-05	1.0E-05	3.0E-02	8.0E-05	4.5E-04	0.0E+00	2.8E-04	4.9E-04	0.0E+00	3.2E-06	2.1E-06	3.2E-02
Abiotic Depletion Potential (ADP fossil) [CML 2016] (MJ/kg fiber)	0.0E+00	8.7E-01	1.1E-02	2.0E+00	3.2E+00	0.0E+00	2.0E+00	1.7E+01	0.0E+00	1.1E-01	6.1E-02	2.5E+01

	Biomass combustion	Crop protection	Field	Ginning	Irrigation	LUC	Machinery	Provision of fertilizer	SOC	Transport to gin	Transports	Total
Blue water consumption [inventory] (kg/kg fiber)	0.0E+00	3.2E-01	1.9E+00	1.3E+00	1.9E+03	0.0E+00	4.1E-02	3.8E+00	0.0E+00	3.1E-03	1.4E-03	1.9E+03
Water resources depletion/scarcity [EF 3.1 water use] (m^3 eq./kg fiber)	0.0E+00	1.7E-03	1.1E-02	2.8E-02	6.8E+01	0.0E+00	8.5E-04	9.3E-02	0.0E+00	5.4E-05	2.7E-05	6.8E+01
Ecotoxicity, freshwater [EF 3.1] (CTUe/kg fiber)	2.2E-01	1.7E+03	5.2E+00	1.5E+00	1.7E+00	0.0E+00	1.5E+00	8.1E+00	0.0E+00	1.1E-01	5.0E-02	1.7E+03

Table F-4: Global-average results country averages (production weighted average of country averages)

	Biomass combustion	Crop protection	Field	Ginning	Irrigation	LUC	Machinery	Provision of fertilizer	SOC	Transport to gin	Transports	Total
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change] (kg CO_2 eq./kg fiber)	0.0E+00	1.0E-03	5.4E-01	2.2E-01	3.6E-01	0.0E+00	1.9E-01	1.3E-04	0.0E+00	8.5E-03	9.6E-05	1.3E+00
Acidification [EF 3.1] (moles H+ eq./kg fiber)	0.0E+00	2.1E-06	3.4E-02	2.5E-03	3.9E-03	0.0E+00	2.1E-03	1.6E-06	0.0E+00	1.8E-05	2.7E-07	4.2E-02
Eutrophication [CML 2016] (kg phosphate eq./kg fiber)	0.0E+00	2.2E-07	2.1E-02	1.2E-04	1.9E-04	0.0E+00	3.5E-04	6.3E-08	0.0E+00	3.0E-06	4.6E-08	2.2E-02
Abiotic Depletion Potential (ADP fossil) [CML 2016] (MJ/kg fiber)	0.0E+00	1.9E-02	1.0E-02	2.6E+00	3.7E+00	0.0E+00	2.5E+00	3.4E-03	0.0E+00	1.1E-01	1.2E-03	9.0E+00
Blue water consumption [inventory] (kg/kg fiber)	0.0E+00	7.0E-03	3.4E-01	1.1E+00	2.9E+03	0.0E+00	2.9E-02	6.2E-04	0.0E+00	2.2E-03	3.4E-05	2.9E+03

	Biomass combustion	Crop protection	Field	Ginning	Irrigation	LUC	Machinery	Provision of fertilizer	SOC	Transport to gin	Transports	Total
Water resources depletion/scarcity [EF 3.1 water use] (m^3 eq./kg fiber)	0.0E+00	3.6E-05	1.5E-02	4.0E-02	1.0E+02	0.0E+00	6.1E-04	2.6E-05	0.0E+00	2.9E-05	4.4E-07	1.0E+02
Ecotoxicity, freshwater [EF 3.1] (CTUe/kg fiber)	0.0E+00	1.2E+01	3.1E+00	2.1E+00	3.2E+00	0.0E+00	1.4E+00	2.7E-03	0.0E+00	9.1E-02	1.2E-03	2.2E+01

Annex G: Additional impact category results

G.1. Supplementary impact categories for cotton cultivation

G.1.1. Nitrogen balance

The nitrogen (N) balance is calculated as the difference between total nitrogen applied (via fertilizers) and the nitrogen taken up in the harvested part of the crop[57], and the result may be a surplus or a deficit (see also section 5.2.4). Strictly speaking, the N balance is an inventory-level indicator. However, it is included under results because it is an output of the model, generated during the impact assessment phase, rather than being directly collected as input data. It provides valuable interpretive context for the impact-assessment categories that directly depend on the ratio of nitrogen application and yield, i.e., climate change, eutrophication, and acidification.

It should be noted that several nitrogen input sources are not included in this calculation. Specifically, nitrogen carried over from previous crop rotations, nitrogen contained in irrigation water, and atmospheric nitrogen deposition are excluded. Among these, nitrogen in irrigation water may represent a particularly substantial input in some systems; however, not considering N input from irrigation water is in alignment with Cascale Cotton LCA methodology.

Inclusion of these additional nitrogen sources could potentially reduce or eliminate the observed negative N balances, providing a more complete and accurate representation of nitrogen dynamics in the cultivation systems. Nevertheless, a negative N balance may still reflect a genuine nutrient deficit, suggesting that nitrogen availability could be a limiting factor for crop growth in certain systems.

To assess the potential underestimation of nitrate emissions or soil fertility depletion, a scenario where any calculated nitrogen deficits are compensated for by adding a virtual fertilizer input equivalent to the missing nitrogen is provided (see section 5.2.4).

In addition, as outlined in previous sections, there is considerable uncertainty regarding the nutrient content of organic fertilizers. While some data providers reported measured average nutrient concentrations, in many cases, values had to be estimated from literature sources. Consequently, the actual amounts of nitrogen (N) and phosphorus (as P_2O_5) applied with organic fertilizers are subject to notable uncertainty (see scenario provided in section 5.2.3.

Table G-1 represents the N-balance results for the country average, organic, and regenerative cotton cultivation for all the countries. In cases where a negative N balance is observed in cotton cultivation systems, this may be due to certain nitrogen inputs not being fully accounted for in the analysis (see above). Nevertheless, a negative balance may also indicate a true deficit, suggesting that nitrogen availability could be a limiting factor for crop growth in those systems.

57 Seed cotton, assumed N content 3.3%, based on USDA. (2021). Plant Nutrient Tool.

Table G-1: N balance [inventory] (kg N/ha)

	DQL**	N balance (N-input fertilizer—net crop uptake) [kg/ha]
IN country average	1	99.6
IN organic	1	3.7
IN regenerative	2	41.6
BR country average	2	2.2
BR organic	3	-20.2
PE organic	1	-26.0
PE regenerative	1	-23.0
TR country average	2	-9.9
TR organic	3	-18.2
TR regenerative	2	-16.3
TZ organic	1	4.7
US country average	1	23.0
US organic	2	43.8
CN selected regions*	3	0.4

*For regions included, see Table 3-1
** DQL = Data quality level, see section 6.3, 1=good, 2=medium, 3=limited

In India, the country average shows a very high nitrogen surplus. This aligns with findings that can be found in international fertilizer statistics (IFA 2024), and ICAC data (ICAC, 2024). One likely explanation for this large surplus is the subsidization of fertilizers in India, which can lead to over-application beyond what crops can absorb. Other contributing factors include the timing of fertilizer application, which must align with crop nutrient demand, as well as weather conditions that can strongly influence nutrient availability and uptake. Furthermore, limited farmer training, and extension services on integrated nutrient management practices, may contribute to inefficiencies, highlighting the importance of capacity-building initiatives (see section 6.4.3 and (CottonConnect, 2025)).

Organic systems in India show a nitrogen input roughly balanced by crop uptake. This is realistic, as organic fertilizers (for example, compost, manure) are often not available in sufficient quantities, limiting the overall N input and surplus. Regenerative systems show a moderate nitrogen surplus (41.6 kg N/kg fiber). This may reflect a more balanced nitrogen input-output ratio that accounts for losses. The integration of animals into regenerative farming systems, where applicable, might increase the availability of organic fertilizer in these systems. However, the result could also be influenced by the specific situation of the regenerative systems included in the data collection, which may not fully represent the broader diversity of such practices (see section 4.2.1).

The negative nitrogen balance observed in organic and regenerative cotton systems in Brazil and Peru could reflect uncertainties associated with estimating the nitrogen content of organic fertilizers. Additionally, as explained above, certain nitrogen inputs, for example, atmospheric deposition and residual nitrogen from crop rotations, are not accounted for in this N balance (N-input fertilizer – net crop uptake), which can further contribute to the underestimation of total nitrogen inputs. However, low fertilizer input to organic systems in the regions under study was confirmed by local experts. In

addition, fertilizer input values for Peru were reviewed multiple times in collaboration with the data provider, suggesting that the results are not due to simple reporting or estimation errors.

The N-balance result for Tanzania's organic cotton reflects the estimated nitrogen input from organic fertilizer applications, which, in this case, was approximated based on expected crop nitrogen uptake. Tanzania is characterized as a low-input, low-output cotton production system, with very low fertilizer application rates, a pattern that is also supported by national statistics such as those from ICAC (ICAC, 2024). The modest nitrogen surplus is consistent with these conditions and suggests that nutrient inputs are, in the best case, just high enough to meet crop demand.

All three cultivation systems assessed in Türkiye show moderately negative nitrogen balances, with the lowest value observed in the organic system. For organic and regenerative systems, these negative values are likely due to uncertainties in estimating the nitrogen content of organic fertilizers. Moreover, as noted earlier, certain nitrogen inputs (mineralization of soil organic matter, residual nitrogen from previous crops, and atmospheric deposition) are not accounted for in this calculation. In addition, irrigation rates in Türkiye are relatively high, and irrigation water can carry dissolved nitrogen, which is not reflected in the N-balance calculation. In reality, these unaccounted inputs may offset the negative balances, suggesting that actual nitrogen dynamics at the field level could be more balanced than the current figures imply. Please refer to scenarios in section 5.2.3 for N content in organic fertilizer and 5.2.4 for compensation of negative N balance in the modeling.

In the US, a clear N surplus is reported for the organic system, which could be influenced by several factors. The organic data carries high uncertainty, due to estimated application rates and variable nitrogen content in organic fertilizers. However, a possible explanation for the surplus could be that organic farmers may apply higher amounts of nutrients with organic fertilizer to compensate for the lower nutrient availability of organic inputs compared to mineral fertilizers. It should also be noted that the organic data represents a single regional context (Texas, where most organic cotton is grown), whereas the country average reflects a range of farming systems across diverse climate zones.

G.1.2. Acidification

Table G-2: Acidification [EF 3.1] (moles H+ eq./kg fiber)

	DQL**	Biomass combustion	Crop protection	Field	Ginning	Irrigation	LUC	Machinery	Provision of fertilizer	Transport to gin	Transport	Total
IN country average	1	0.001	0.000	0.092	0.003	0.007	0.000	0.002	0.012	0.000	0.000	0.117
IN organic	1	0.000	0.000	0.030	0.003	0.005	0.000	0.002	0.000	0.000	0.000	0.041
IN regenerative	2	0.000	0.000	0.062	0.003	0.006	0.000	0.001	0.000	0.000	0.000	0.071
BR country average	2	0.000	0.000	0.026	0.001	0.000	0.000	0.001	0.002	0.000	0.000	0.030
BR organic	3	0.000	0.000	0.025	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.027
PE organic	1	0.000	0.000	0.013	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.014

	DQL**	Biomass combustion	Crop protection	Field	Ginning	Irrigation	LUC	Machinery	Provision of fertilizer	Transport to gin	Transport	Total
PE regenerative	1	0.000	0.000	0.014	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.015
TR country average	2	0.000	0.000	0.024	0.001	0.002	0.000	0.002	0.001	0.000	0.000	0.029
TR organic	3	0.000	0.000	0.028	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.031
TR regenerative	2	0.000	0.000	0.037	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.040
TZ organic	1	0.000	0.000	0.062	0.003	0.000	0.000	0.001	0.000	0.000	0.000	0.066
US country average	1	0.000	0.000	0.031	0.000	0.001	0.000	0.002	0.001	0.000	0.000	0.035
US organic	2	0.000	0.000	0.118	0.000	0.001	0.000	0.004	0.000	0.000	0.000	0.123
CN selected regions*	3	0.000	0.000	0.022	0.001	0.001	0.000	0.003	0.002	0.000	0.000	0.028

*For regions included, see Table 3-1
DQL = Data quality level, see section 6.3, 1=good, 2=medium, 3=limited

Table G-2 represents the acidification impacts for the different types of cotton cultivation systems with respect to the different countries considered in this analysis. Acidification impacts are closely linked to Nitrogen application and eutrophication potential, with field emissions being the primary hotspot and the main driver of differences across cultivation systems in all countries. This means that most of the context provided to explain eutrophication results (see section 5.1.1) and N-balance results (see Annex G.1.1) also apply to acidification. Specific aspects to take into account are that urea is associated with higher ammonia emissions during application than other mineral fertilizers, see (IPCC, 2019) (for example, acidification potential in India is high because of the large N surplus as described in the previous section, and the fact that most of the nitrogen is applied via urea (Table 4-5). Organic fertilizers are also related to higher acidification impacts per kg N applied than most mineral fertilizers (IPCC, 2019).

It should also be noted that the scaling effects observed for eutrophication (see section 5.1.1) can also be observed for acidification. For example, for Tanzania, acidification impacts are relatively low because this is a low-intensity system with low yields and minimal fertilizer use, resulting in lower nutrient inputs. However, some baseline emissions still occur and are scaled according to the area used.

G.1.3. Abiotic Depletion Potential (ADP) fossil

Table G-3: Abiotic Depletion Potential (ADP fossil) [CML 2016] (MJ/kg fiber)

	DQL**	Biomass combustio	Crop protection	Field	Ginning	Irrigation	LUC	Machinery	Provision of fertilizer	Transport to gin	Transport	Total
IN country average	1	0.0	0.8	0.0	2.8	5.8	0.0	2.2	28.5	0.1	0.1	40.3
IN organic	1	0.0	0.0	0.0	2.8	4.1	0.0	3.0	0.0	0.1	0.0	10.1
IN regenerative	2	0.0	0.0	0.0	2.8	4.8	0.0	0.7	0.1	0.1	0.0	8.5
BR country average	2	0.0	1.7	0.0	0.8	0.0	0.0	1.2	7.7	0.2	0.1	11.7
BR organic	3	0.0	0.0	0.1	0.8	0.0	0.0	1.4	0.0	0.0	0.0	2.3
PE organic	1	0.0	0.0	0.0	0.8	0.0	0.0	0.6	0.0	0.1	0.0	1.5
PE regenerative	1	0.0	0.0	0.0	0.8	0.0	0.0	0.6	0.0	0.1	0.0	1.6
TR country average	2	0.0	0.2	0.0	1.8	2.1	0.0	2.0	5.0	0.2	0.0	11.4
TR organic	3	0.0	0.0	0.0	1.8	3.5	0.0	1.2	0.0	0.2	0.0	6.7
TR regenerative	2	0.0	0.3	0.0	1.8	1.4	0.0	1.5	0.9	0.2	0.0	6.0
TZ organic	1	0.0	0.0	0.1	2.5	0.0	0.0	1.0	0.0	0.2	0.0	3.9
US country average	1	0.0	0.6	0.0	1.8	1.5	0.0	1.9	8.3	0.1	0.1	14.3
US organic	2	0.0	0.0	0.0	1.8	2.4	0.0	4.9	0.0	0.1	0.0	9.3
CN selected regions*	3	0.0	0.3	0.0	1.5	2.7	0.0	3.5	7.7	0.1	0.1	15.9

*For regions included, see Table 3-1
DQL = Data quality level, see section 6.3, 1=good, 2=medium, 3=limited

Table G-3 represents the abiotic depletion impacts for the different cotton cultivation systems involved with respect to the countries considered in this analysis. The primary hotspot and key driver of differences in impacts across the cultivation systems are the provision of mineral fertilizer (mainly applicable to country average systems), and irrigation impacts, based on background data (mineral fertilizer production, and provision of energy).

G.1.4. Water resources depletion/scarcity

Table G-4: Water resources depletion/scarcity [EF 3.1 water use] (m^3 eq./kg fiber)

	DQL**	Biomass combustio	Crop protection	Field	Ginning	Irrigation	LUC	Machinery	Provision of fertilizer	Transport to gin	Transport	Total
IN country average	1	0.0	0.0	0.0	0.0	110.8	0.0	0.0	0.2	0.0	0.0	111.0
IN organic	1	0.0	0.0	0.0	0.0	98.7	0.0	0.0	0.0	0.0	0.0	98.7
IN regenerative	2	0.0	0.0	0.7	0.0	92.0	0.0	0.0	0.0	0.0	0.0	92.7
BR country average	2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
BR organic	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PE organic	1	0.0	0.0	0.0	0.0	126.6	0.0	0.0	0.0	0.0	0.0	126.6
PE regenerative	1	0.0	0.0	0.0	0.0	130.3	0.0	0.0	0.0	0.0	0.0	130.3
TR country average	2	0.0	0.0	0.1	0.1	93.1	0.0	0.0	0.0	0.0	0.0	93.3
TR organic	3	0.0	0.0	0.1	0.1	134.3	0.0	0.0	0.0	0.0	0.0	134.4
TR regenerative	2	0.0	0.0	0.0	0.1	71.6	0.0	0.0	0.0	0.0	0.0	71.7
TZ organic	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
US country average	1	0.0	0.0	0.0	0.0	37.7	0.0	0.0	0.1	0.0	0.0	37.8
US organic	2	0.0	0.0	0.0	0.0	51.6	0.0	0.0	0.0	0.0	0.0	51.7
CN selected regions*	3	0.0	0.0	0.0	0.0	76.2	0.0	0.0	0.1	0.0	0.0	76.3

*For regions included, see Table 3-1
DQL = Data quality level, see section 6.3, 1=good, 2=medium, 3=limited

Table G-3 presents the water scarcity impacts for different cotton cultivation systems across all countries included in this analysis. This impact category reflects regionalized water scarcity, calculated by multiplying blue water consumption with characterization factors derived from the AWARE method (Boulay, et al., 2017), see table G-5. As the results are primarily driven by blue water consumption weighted by local scarcity, the underlying differences across the systems are consistent with those discussed in the respective blue water consumption figures. For detailed interpretations, please refer to section 5.1.1, Table 5-4 ff., as the analysis is not repeated here.

Table G-5: AWARE country average values (1.2)[58]

Country	AWARE characterization factor (m^3 world eq./m^3 consumed)
Brazil	2.3
China	42.5
India	29.8
Peru	27.8
Tanzania	13.7
Türkiye	56.5
United States of America	33.1

G.1.5. Green water consumption and land occupation

Green water consumption and land occupation are additional inventory metrics, and not impact-assessment methods in a strict sense, see Table 3-8. Green water consumption refers to the rainwater use of crops (Hoekstra, Chapagain, Aldaya, & Mekonnen, 2011). Green water consumption is usually not measured. These values are, therefore, always modeled with a lot of uncertainty. The University of Twente has published an updated dataset on blue and green water consumption for important crops with global coverage (Mialyk et al., 2023). Their country-specific green water consumption values are used in this study, not differentiating crop systems. Land occupation refers to area use, i.e., the reciprocal of the crop yield. The amount of land occupation does not include any information on the quality, intensity, or impact of the land use and has, therefore, limited informational value. Since the two mentioned categories are directly referring to inventory data and are mainly differentiated by yields, no additional analysis is provided here.

Table G-6: Green water consumption and land occupation impacts cotton cultivation

	Green water use	Land occupation
	[m^3/kg fiber]	[m^2/kg fiber]
IN country average	6.8	14.7
IN organic	6.8	15.6
IN regenerative	6.8	15.7
BR country average	2.2	4.5
BR organic	2.4	15.3
PE organic	1.7	6.8
PE regenerative	1.7	7.0
TR country average	1.5	4.6
TR organic	1.2	3.6
TR regenerative	1.2	4.0
TZ organic	19.7	29.6

[58] In line with the study scope to aggregate data at country level, country-average factors are applied; no bottom-up weighting of regional scarcity factors was conducted.

	Green water use	Land occupation
	[m^3/kg fiber]	[m^2/kg fiber]
US country average	3.5	8.2
US organic	3.7	20.2
CN selected regions*	1.4	6.9

*For regions included, see Table 3-1

G.1.6. Climate change including biogenic carbon

Table G-7 shows the impacts on climate change results, excluding and including biogenic carbon (see section 4.3.4). Biogenic carbon contained in the product is calculated based on an assumed carbon content of 42% (Cotton Incorporated, 2016).

Table G-7: Climate change including biogenic carbon (IPCC AR6)

	Climate change excluding biogenic carbon (IPCC AR6)	Climate change including biogenic carbon (IPCC AR6)
	[kg CO_2 equivalent/kg fiber]	[kg CO_2 equivalent/kg fiber]
IN country average	4.17	2.63
IN organic	1.46	-0.08
IN regenerative	1.72	0.18
BR country average	2.46	0.92
BR organic	0.44	-1.10
PE organic	0.48	-1.06
PE regenerative	0.49	-1.05
TR country average	1.29	-0.25
TR organic	0.95	-0.59
TR regenerative	0.89	-0.65
TZ organic	0.89	-0.65
US country average	1.55	0.01
US organic	1.77	0.23
CN selected regions*	1.72	0.18

*For regions included, see Table 3-1

G.2. Supplementary impact categories for recycled cotton

G.2.1. Acidification [EF 3.1]

The acidification impacts for the production of 1 kg of recycled, cotton spinnable fiber from post-industrial yarn waste, post-industrial fabric waste, and post-consumer waste, are shown below in Figure G-1. The chart highlights the contribution of energy and material inputs into the recycling process, as well as process waste treatment, to the total acidification impacts for the different types of recycled spinnable fiber.

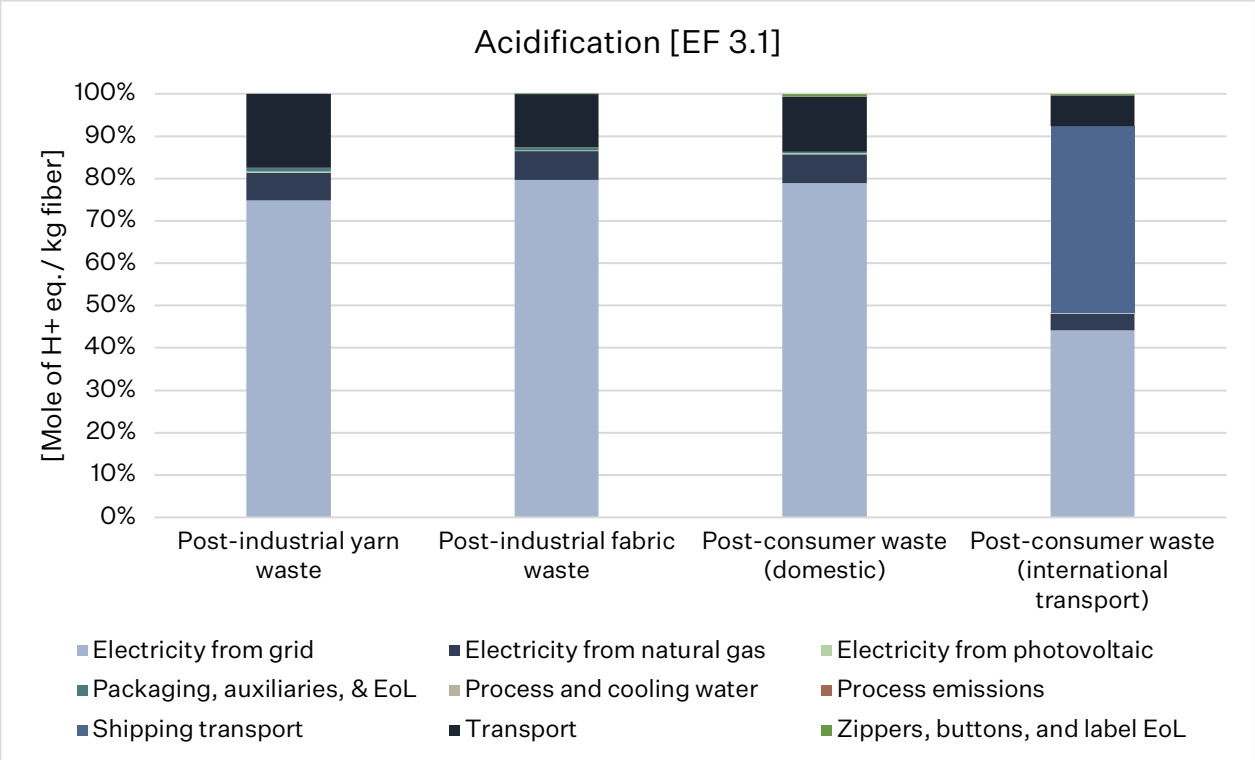


Figure G-1: Acidification, global-average recycled cotton

Table G-8: Acidification, global-average recycled cotton [Mole of H+ equivalent/kg fiber]

	Post-industrial yarn waste	**Post-industrial fabric waste**	**Post-consumer waste** (domestic)	**Post-consumer waste** (international transport)
Electricity from grid	1.47E-03	1.73E-03	3.76E-03	3.76E-03
Electricity from natural gas	1.30E-04	1.47E-04	3.29E-04	3.29E-04
Electricity from photovoltaic	6.26E-06	3.26E-06	1.28E-05	1.28E-05
Packaging, auxiliaries, and EoL	1.68E-05	1.68E-05	1.68E-05	1.68E-05

	Post-industrial yarn waste	**Post-industrial fabric waste**	**Post-consumer waste** (domestic)	**Post-consumer waste** (international transport)
Process and cooling water	0.00E+00	4.47E-09	1.85E-08	1.85E-08
Process emissions	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Shipping transport	0.00E+00	0.00E+00	0.00E+00	3.74E-03
Transport	3.43E-04	2.74E-04	6.18E-04	6.18E-04
Zippers, buttons, and label EoL	0.00E+00	1.95E-07	3.11E-05	3.11E-05
Total	0.00197	0.00217	0.00476	0.0085
DQL	Level 1	Level 1	Level 2	Level 2

Figure G-1 highlights the EF 3.1 acidification results are 0.00197kg Mole of H+ equivalent for post-industrial yarn, 0.00217kg Mole of H+ equivalent for post-industrial fabric, and 0.00476kg Mole of H+ equivalent for post-consumer waste, pertaining to the production of 1kg of recycled cotton spinnable fiber.

For all types of recycled cotton production, the main driver of acidification impacts is electricity consumption which contributed between 81.7–86.6% of the total results. Transportation of cotton waste contributed between 12.6–17.4% of the total impacts. All other inputs to the recycling process, including packaging, auxiliaries and process waste treatment outputs had a negligible contribution at 0.8–1%.

G.2.2. Abiotic Depletion Potential (ADP fossil) [CML 2016]

The ADP fossil impacts for the production of 1 kg of recycled cotton spinnable fiber from post-industrial yarn waste, post-industrial fabric waste and post-consumer waste are shown below in Figure G-2. The chart highlights the contribution of energy and material inputs into the recycling process, as well as process waste treatment, to the total ADP fossil impacts for the different types of recycled spinnable fiber.

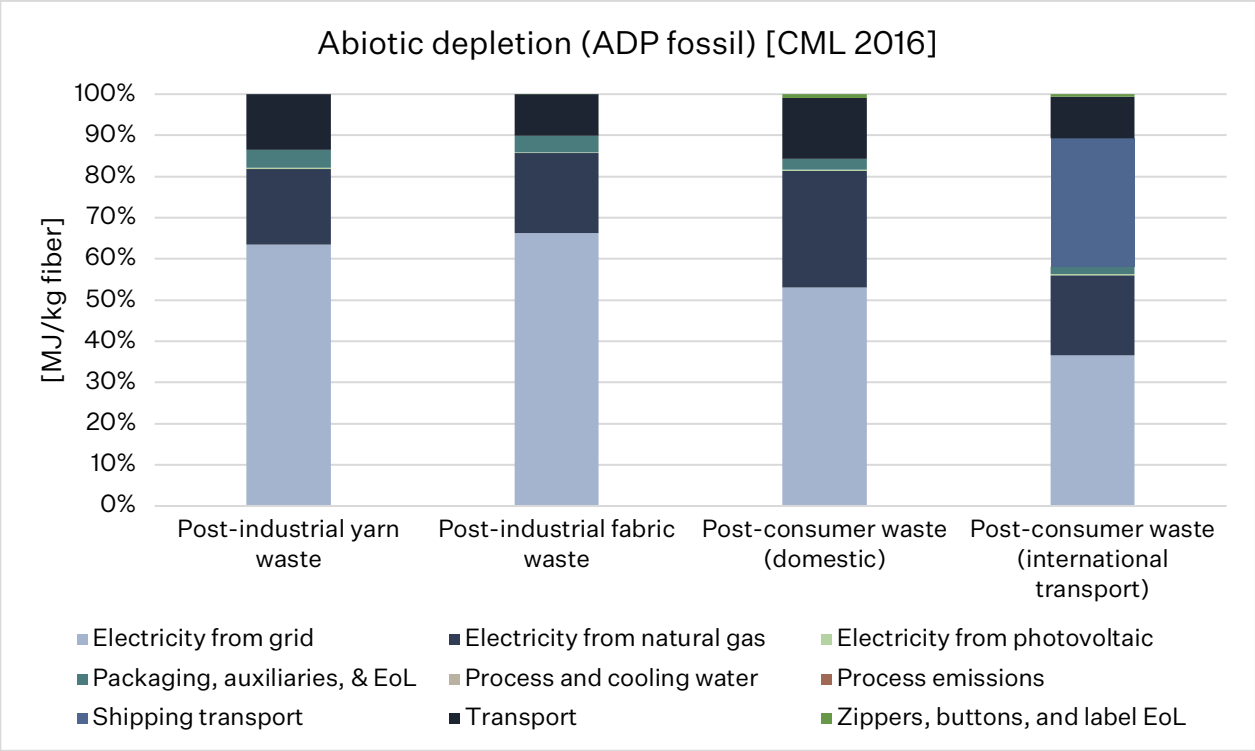


Figure G-2: Abiotic Depletion Potential (ADP fossil), global-average recycled cotton

Table G-9: Abiotic Depletion Potential (ADP fossil), global-average recycled cotton [MJ/kg fiber]

	Post-industrial yarn waste	Post-industrial fabric waste	Post-consumer waste (domestic)	Post-consumer waste (international transport)
Electricity from grid	3.72E+00	4.15E+00	5.13E+00	5.13E+00
Electricity from natural gas	1.07E+00	1.22E+00	2.73E+00	2.73E+00
Electricity from photovoltaic	1.49E-02	7.96E-03	3.12E-02	3.12E-02
Packaging, auxiliaries, and EoL	2.59E-01	2.59E-01	2.59E-01	2.59E-01
Process and cooling water	0.00E+00	1.26E-05	1.05E-04	1.05E-04
Process emissions	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Shipping transport	0.00E+00	0.00E+00	0.00E+00	4.36E+00
Transport	7.89E-01	6.30E-01	1.42E+00	1.42E+00
Zippers, buttons, and label EoL	0.00E+00	5.30E-04	8.42E-02	8.42E-02
Total	5.86	6.27	9.65	14.02
DQL	Level 1	Level 1	Level 2	Level 2

Figure G-2 highlights the CML 2016 Abiotic Depletion Potential (ADP fossil) results, which are 5.86 MJ for post-industrial yarn, 6.27 MJ for post-industrial fabric and 9.65 kg Mole of H+ equivalent for post-consumer waste, pertaining to the production of 1 kg of recycled, cotton spinnable fiber.

For all types of recycled cotton production, the main driver of ADP fossil impacts is electricity consumption, which contributed between 81.7–85.8% of the total results. Transportation of cotton waste contributed between 10–14.8% of the total impacts. Packaging, auxiliaries, and their EoL also contributed 2.7–4.4% to the total impacts.

G.2.3. Green water consumption [inventory]

For recycled cotton, green water consumption is reported solely for consistency across all cotton systems. It does not result from the recycling process itself, but is entirely attributable to background processes; for example, biomass contributions in electricity grid mixes used in upstream supply chains. The green water consumption for the production of 1 kg of recycled, cotton spinnable fiber from post-industrial yarn waste, post-industrial fabric waste, and post-consumer waste is shown below in Figure G-3. The chart highlights the contribution of energy and material inputs into the recycling process, as well as process waste treatment, to the total green water consumption for the different types of recycled, spinnable fiber.

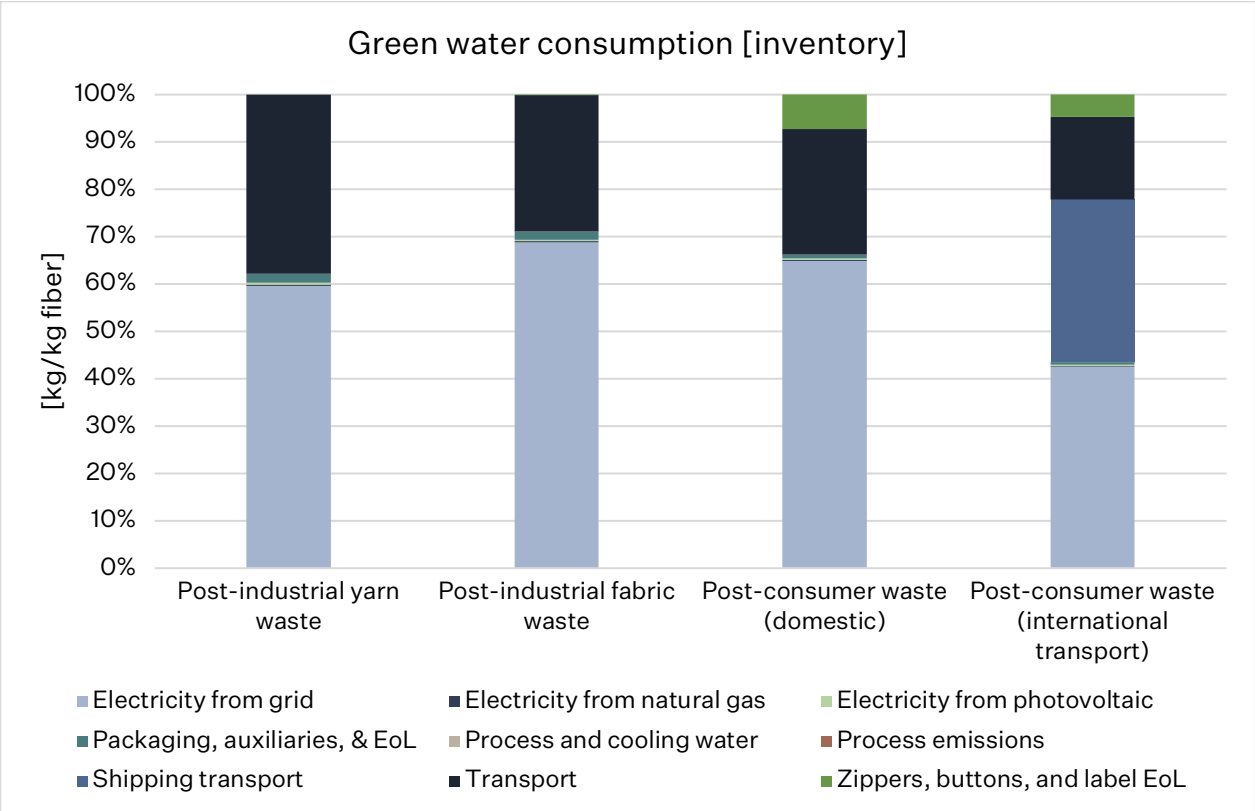


Figure G-3: Green water consumption, global-average recycled cotton

Table G-10: Green water consumption, global-average recycled cotton [kg/kg fiber]

	Post-industrial yarn waste	**Post-industrial fabric waste**	**Post-consumer waste** (domestic)	**Post-consumer waste** (international transport)
Electricity from grid	8.01E-01	9.99E-01	2.11E+00	2.11E+00
Electricity from natural gas	3.47E-03	3.95E-03	8.81E-03	8.81E-03
Electricity from photovoltaic	4.90E-03	2.82E-03	1.11E-02	1.11E-02
Packaging, auxiliaries, and EoL	2.66E-02	2.66E-02	2.66E-02	2.66E-02
Process and cooling water	0.00E+00	5.20E-06	6.60E-05	6.60E-05
Process emissions	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Shipping transport	0.00E+00	0.00E+00	0.00E+00	1.71E+00
Transport	5.07E-01	4.17E-01	8.65E-01	8.65E-01
Zippers, buttons, and label EoL	0.00E+00	1.48E-03	2.35E-01	2.35E-01
Total	1.34	1.45	3.26	4.97
DQL	Level 1	Level 1	Level 2	Level 2

Figure G-3 highlights the green water consumption inventory results, which are 1.34 kg for post-industrial yarn, 1.45 kg for post-industrial fabric, and 3.26 kg for post-consumer waste, pertaining to the production of 1 kg of recycled cotton spinnable fiber.

For all types of recycled cotton production, the main consumption of green water is associated with the electricity consumption, which contributed 60.3–69.3% of the total green water consumption. Transportation impacts contributed 26.5–37.8% of the total impacts, and the treatment of process waste, including zippers, buttons, and labels, contributed 7.2% to the post-consumer waste.

G.2.4. Water resources depletion/scarcity [EF 3.1 water use]

The water scarcity impacts for the production of 1 kg of recycled, cotton spinnable fiber from post-industrial yarn waste, post-industrial fabric waste, and post-consumer waste are shown below in Figure G-4. The chart highlights the contribution of energy and material inputs into the recycling process, as well as process waste treatment, to the total water-use impacts for the different types of recycled, spinnable fiber.

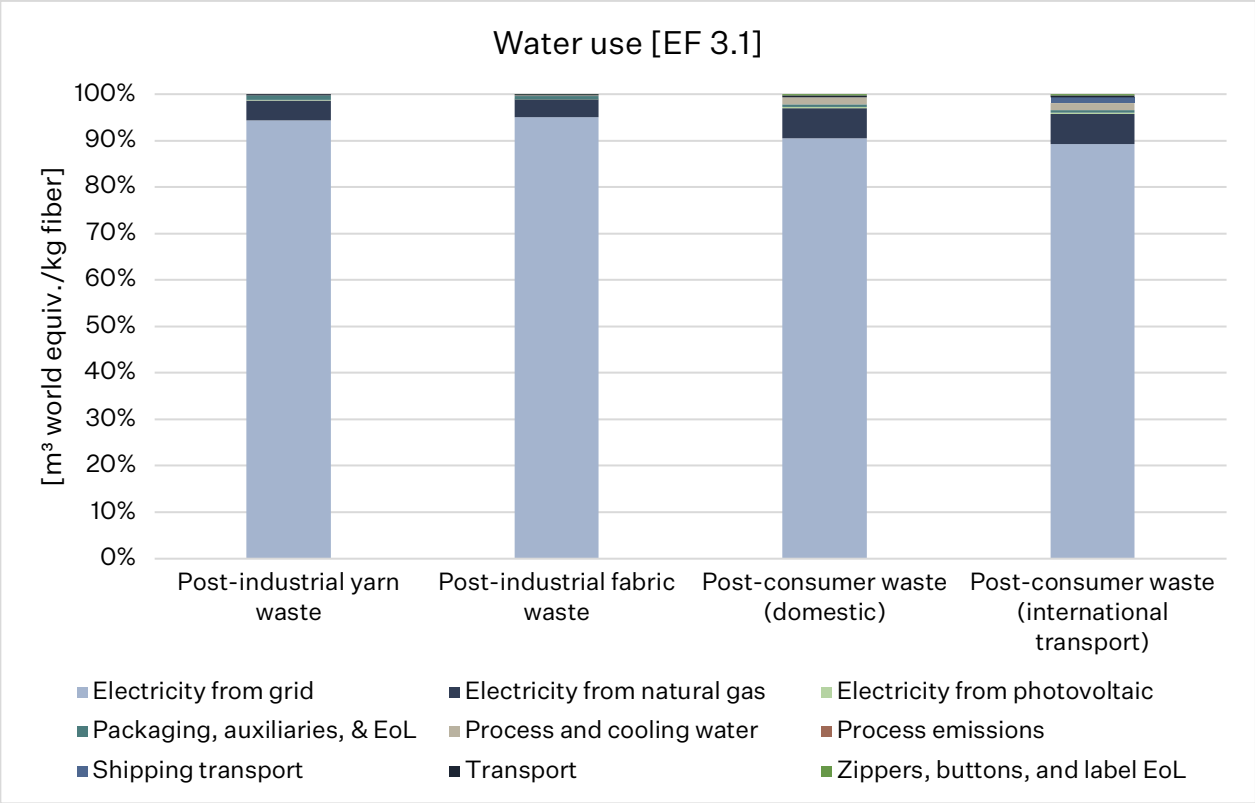


Figure G-4: Water use, global average recycled cotton

Table G-11: Water scarcity, global average recycled cotton [m³ world equivalent/kg fiber]

	Post-industrial yarn waste	**Post-industrial fabric waste**	**Post-consumer waste** (domestic)	**Post - consumer waste** (international transport)
Electricity from grid	1.38E-01	1.79E-01	2.21E-01	2.21E-01
Electricity from natural gas	6.30E-03	7.15E-03	1.60E-02	1.60E-02
Electricity from photovoltaic	3.21E-04	1.66E-04	6.51E-04	6.51E-04
Packaging, auxiliaries, and EoL	1.27E-03	1.27E-03	1.27E-03	1.27E-03
Process and cooling water	0.00E+00	2.94E-04	3.84E-03	3.84E-03
Process emissions	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Shipping transport	0.00E+00	0.00E+00	0.00E+00	3.24E-03
Transport	4.90E-04	4.02E-04	8.61E-04	8.61E-04
Zippers, buttons, and label EoL	0.00E+00	4.22E-06	6.71E-04	6.71E-04
Total	0.147	0.189	0.244	0.247
DQL	Level 1	Level 1	Level 2	Level 2

Figure G-4 highlights the EF 3.1 water scarcity results are 0.147m³ world equivalent for post-industrial yarn, 0.189m³ world equivalent for post-industrial fabric and 0.244m³ world equivalent for post-consumer waste, pertaining to the production of 1kg of recycled cotton spinnable fiber.

For all types of recycled cotton production, the main driver of water scarcity impacts is electricity consumption which contributed between 96–99% of the total results.

G.2.5. Land occupation [inventory]

For recycled cotton, land occupation is reported solely for consistency across all cotton systems. It does not result from the recycling process itself, but is entirely attributable to background processes; for example, biomass contributions in electricity grid mixes used in upstream supply chains. The land occupation for the production of 1 kg of recycled, cotton spinnable fiber from post-industrial yarn waste, post-industrial fabric waste, and post-consumer waste is shown below in Figure G-5. The chart highlights the contribution of energy and material inputs into the recycling process, as well as process waste treatment, to the total land occupation for the three types of recycled, spinnable fiber.

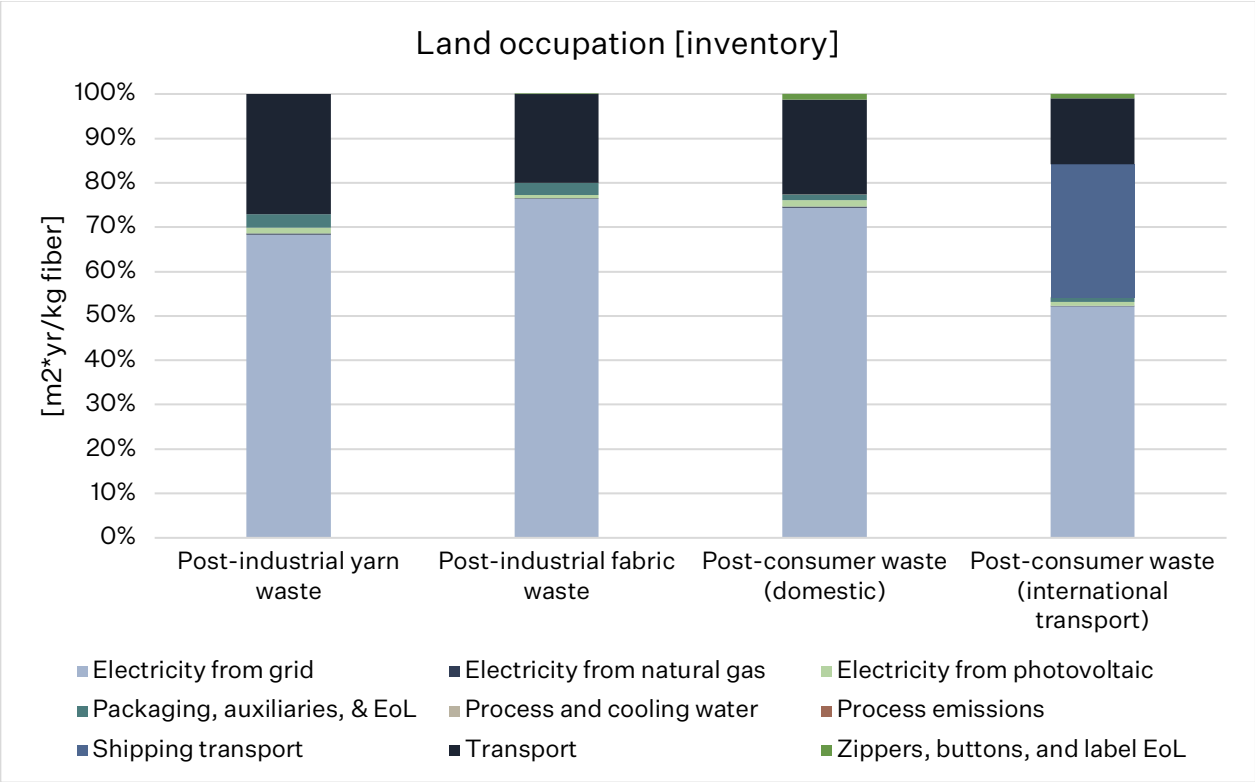


Figure G-5: Land occupation, global-average recycled cotton

Table G-12: Land occupation, global-average recycled cotton [m2*yr/kg fiber]

	Post-industrial yarn waste	**Post-industrial fabric waste**	**Post-consumer waste** (domestic)	**Post-consumer waste** (international transport)
Electricity from grid	4.35E-03	5.42E-03	1.03E-02	1.03E-02
Electricity from natural gas	1.48E-05	1.68E-05	3.75E-05	3.75E-05
Electricity from photovoltaic	8.38E-05	4.81E-05	1.88E-04	1.88E-04
Packaging, auxiliaries, and EoL	1.96E-04	1.96E-04	1.96E-04	1.96E-04
Process and cooling water	0.00E+00	1.49E-08	2.38E-07	2.38E-07
Process emissions	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Shipping transport	0.00E+00	0.00E+00	0.00E+00	5.94E-03
Transport	1.73E-03	1.42E-03	2.94E-03	2.94E-03
Zippers, buttons, and label EoL	0.00E+00	1.13E-06	1.80E-04	1.80E-04
Total	0.00638	0.00710	0.0139	0.0198
DQL	Level 1	Level 1	Level 2	Level 2

Figure G-5 highlights the land occupation inventory results, which are 0.00638 m^2*yr for post-industrial yarn, 0.0071 m^2*yr for post-industrial fabric, and 0.0139 m^2*yr for post-consumer waste, pertaining to the production of 1 kg of recycled, cotton spinnable fiber.

For all types of recycled cotton production, the land occupation is driven by electricity consumption, which contributed 69.8–77.2% of the total land occupation. Transportation impacts contributed 20–27.1% of the total inventory, and packaging, auxiliaries, and their EoL also contributed 1.4–3.1% to the total impacts.

G.2.6. Climate change including biogenic carbon

Table G-9 shows the impacts of climate change results, excluding and including biogenic carbon (see section 4.3.4). Biogenic carbon contained in the product is calculated based on an assumed carbon content of 42% (Cotton Incorporated, 2016).

Table G-13: Climate change including biogenic carbon (IPCC AR6)

	Climate change excluding biogenic carbon (IPCC AR6)	**Climate change including biogenic carbon (IPCC AR6)**
	[kg CO_2 eq. /kg fiber]	[kg CO_2 eq. /kg fiber]
Post-industrial yarn waste	0.441	-1.10
Post-industrial fabric waste	0.48	-1.06

	Climate change excluding biogenic carbon (IPCC AR6)	**Climate change including biogenic carbon (IPCC AR6)**
	[kg CO_2 eq. /kg fiber]	[kg CO_2 eq. /kg fiber]
Post-consumer waste (domestic)	0.786	-0.75
Post-consumer waste (international transport)	1.138	-0.40

G.3. EF 3.1 All impact categories

G.3.1. Cotton cultivation

Table G-14: EF 3.1 Impact categories cotton cultivation

	IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions	GLO country averages	GLO organic average
DQL*	**1**	**1**	**2**	**2**	**3**	**1**	**1**	**2**	**3**	**2**	**1**	**1**	**2**	**3**	**3**	**3**
EF 3.1 Acidification [Mole of H+ eq.]	1.17E-01	4.13E-02	7.15E-02	2.95E-02	2.67E-02	1.43E-02	1.47E-02	2.93E-02	3.11E-02	3.99E-02	6.56E-02	3.47E-02	1.23E-01	2.81E-02	6.96E-02	4.24E-02
EF 3.1 Climate change, total [kg CO_2 eq.]	4.17E+00	1.46E+00	1.72E+00	2.46E+00	4.44E-01	4.81E-01	4.92E-01	1.29E+00	9.51E-01	8.93E-01	8.93E-01	1.55E+00	1.77E+00	1.72E+00	2.88E+00	1.33E+00
EF 3.1 Climate change, biogenic [kg CO_2 eq.]	4.56E-02	5.68E-03	6.29E-03	1.63E-02	9.08E-03	8.97E-03	8.97E-03	4.24E-03	1.72E-03	1.43E-03	1.85E-03	1.17E-03	4.84E-04	4.71E-03	2.42E-02	4.49E-03
EF 3.1 Climate change, fossil [kg CO_2 eq.]	4.12E+00	1.46E+00	1.71E+00	1.14E+00	4.25E-01	4.67E-01	4.77E-01	1.28E+00	9.48E-01	8.89E-01	8.90E-01	1.55E+00	1.77E+00	1.71E+00	2.59E+00	1.32E+00

	IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions	GLO country averages	GLO organic average
EF 3.1 Climate change, land use and land use change [kg CO_2 eq.]	3.32E-03	2.43E-03	2.65E-03	1.30E+00	1.04E-02	5.36E-03	5.47E-03	3.78E-03	2.20E-03	2.33E-03	1.30E-03	7.16E-04	6.80E-04	1.73E-03	2.59E-01	2.28E-03
EF 3.1 Ecotoxicity, freshwater —total [CTUe]	2.83E+03	2.39E+01	3.32E+01	1.26E+03	2.02E+01	3.61E+00	3.42E+00	1.04E+02	1.49E+01	1.38E+02	2.29E+01	9.06E+02	3.11E+01	2.74E+02	1.74E+03	2.20E+01
EF 3.1 Ecotoxicity, freshwater inorganics [CTUe]	3.04E+01	9.12E+00	9.68E+00	1.01E+01	5.17E+00	3.12E+00	2.91E+00	9.06E+00	1.06E+01	7.96E+00	9.88E+00	6.95E+00	1.10E+01	9.97E+00	1.82E+01	9.50E+00
EF 3.1 Ecotoxicity, freshwater organics [CTUe]	2.80E+03	1.48E+01	2.35E+01	1.25E+03	1.50E+01	4.93E-01	5.05E-01	9.47E+01	4.33E+00	1.30E+02	1.30E+01	8.99E+02	2.01E+01	2.64E+02	1.72E+03	1.25E+01
EF 3.1 Eutrophication, freshwater [kg P eq.]	5.02E-03	3.32E-03	1.78E-03	5.20E-04	1.88E-03	1.29E-03	5.91E-04	5.01E-04	1.91E-04	1.79E-04	1.36E-02	3.89E-04	3.35E-04	1.92E-03	2.57E-03	2.59E-03
EF 3.1 Eutrophication, marine [kg N eq.]	6.31E-02	2.41E-02	3.86E-02	1.76E-02	9.65E-03	1.39E-02	1.43E-02	1.75E-02	1.57E-02	1.64E-02	2.30E-02	2.35E-02	4.48E-02	1.94E-02	3.92E-02	2.27E-02

	IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions	GLO country averages	GLO organic average
EF 3.1 Eutrophication, terrestrial [Mole of N eq.]	4.76E-01	1.61E-01	2.91E-01	1.26E-01	1.19E-01	6.28E-02	6.46E-02	1.30E-01	1.37E-01	1.78E-01	2.86E-01	1.53E-01	5.54E-01	1.21E-01	2.87E-01	1.72E-01
EF 3.1 Human toxicity, cancer —total [CTUh]	6.85E-09	1.04E-09	9.68E-10	5.79E-09	6.70E-10	4.88E-10	3.56E-10	2.55E-09	3.59E-10	3.47E-09	3.24E-09	3.53E-09	1.03E-09	1.22E-09	5.26E-09	9.09E-10
EF 3.1 Human toxicity, cancer inorganics [CTUh]	2.62E-09	9.96E-10	8.94E-10	4.02E-09	6.47E-10	4.67E-10	3.34E-10	2.39E-09	3.00E-10	3.08E-09	3.23E-09	3.00E-09	9.98E-10	7.02E-10	5.26E-09	1.02E-09
EF 3.1 Human toxicity, cancer organics [CTUh]	4.23E-09	4.49E-11	7.36E-11	1.77E-09	2.34E-11	2.16E-11	2.16E-11	1.61E-10	5.98E-11	3.94E-10	9.84E-12	5.30E-10	3.28E-11	5.17E-10	2.88E-09	9.71E-10
EF 3.1 Human toxicity, non-cancer—total [CTUh]	7.44E-07	1.08E-07	1.65E-07	7.17E-07	7.24E-08	5.71E-08	5.47E-08	3.05E-07	6.93E-08	4.15E-07	2.23E-07	3.96E-07	2.67E-07	7.29E-08	2.38E-09	4.57E-11
EF 3.1 Human toxicity, non-cancer inorganics [CTUh]	3.51E-07	1.07E-07	1.65E-07	4.94E-07	7.23E-08	5.70E-08	5.46E-08	2.79E-07	6.91E-08	4.05E-07	2.23E-07	3.61E-07	2.67E-07	5.21E-08	5.92E-07	1.10E-07

	IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions	GLO country averages	GLO organic average
EF 3.1 Human toxicity, non-cancer organics [CTUh]	3.94E-07	1.49E-10	8.79E-10	2.23E-07	1.26E-10	1.06E-10	1.08E-10	2.61E-08	1.78E-10	1.09E-08	2.20E-10	3.57E-08	2.90E-10	2.08E-08	3.62E-07	1.09E-07
EF 3.1 Ionising radiation, human health [kBq U235 eq.]	1.42E-02	8.53E-03	9.29E-03	1.49E-02	1.39E-03	1.29E-03	1.30E-03	7.26E-03	1.18E-03	2.32E-03	3.66E-03	3.60E-02	2.87E-02	1.00E-02	2.30E-07	1.62E-10
EF 3.1 Land Use [Pt]	1.15E+03	1.22E+03	1.23E+03	4.96E+02	1.65E+03	7.34E+02	7.55E+02	6.61E+01	5.09E+01	5.59E+01	1.36E+03	5.26E+02	1.28E+03	4.91E+02	7.63E+02	9.74E+02
EF 3.1 Ozone depletion [kg CFC-11 eq.]	1.96E-07	2.98E-12	3.24E-12	5.02E-11	2.89E-11	2.87E-11	2.87E-11	4.58E-12	3.63E-12	2.46E-12	3.87E-13	2.46E-12	1.64E-12	3.21E-12	8.68E-08	3.01E-12
EF 3.1 Particulate matter [disease incidences]	1.83E-06	4.07E-07	6.00E-07	2.45E-07	2.04E-07	1.07E-07	1.10E-07	2.56E-07	2.45E-07	3.07E-07	4.71E-07	2.89E-07	9.20E-07	2.59E-07	9.59E-07	3.87E-07
EF 3.1 Photochemical ozone formation, human health [kg NMVOC eq.]	1.85E-02	6.62E-03	4.26E-03	2.82E-03	2.07E-03	9.82E-04	1.00E-03	5.86E-03	2.32E-03	3.16E-03	2.43E-03	4.21E-03	7.44E-03	6.11E-03	1.05E-02	5.46E-03

	IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions	GLO country averages	GLO organic average
EF 3.1 Resource use, fossils [MJ]	4.08E+01	1.03E+01	8.80E+00	1.21E+01	2.39E+00	1.60E+00	1.62E+00	1.16E+01	6.76E+00	6.09E+00	3.98E+00	1.55E+01	1.02E+01	1.63E+01	2.58E+01	9.18E+00
EF 3.1 Resource use, mineral and metals [kg Sb eq.]	2.26E-06	5.08E-08	7.08E-08	4.30E-06	3.12E-08	1.47E-08	1.49E-08	9.04E-07	4.01E-08	4.09E-07	2.68E-08	1.26E-06	1.17E-07	9.35E-07	2.26E-06	6.63E-08
EF 3.1 Water use [m^3 world equiv.]	1.11E+02	9.87E+01	9.27E+01	1.14E-01	2.35E-02	1.27E+02	1.30E+02	9.33E+01	1.34E+02	7.17E+01	5.45E-02	3.78E+01	5.17E+01	7.63E+01	6.84E+01	9.96E+01

* DQL = Data quality level, see section 6.3, 1=good, 2=medium, 3=limited

G.3.2. Recycled cotton

Table G-15: EF 3.1 Impact categories for recycled cotton

	Post-industrial yarn waste	**Post-industrial fabric waste**	**Post-consumer waste (domestic)**	**Post-consumer waste (international transportation)**
EF 3.1 Acidification [Mole of H+ equivalent]	1.97E-03	2.17E-03	4.76E-03	8.50E-03
EF 3.1 Climate change, total [kg CO_2 equivalent]	4.41E-01	4.81E-01	7.88E-01	1.14E+00
EF 3.1 Climate change, biogenic [kg CO_2 equivalent]	3.94E-04	4.34E-04	6.89E-04	1.03E-03
EF 3.1 Climate change, fossil [kg CO_2 equivalent]	4.40E-01	4.80E-01	7.86E-01	1.14E+00
EF 3.1 Climate change, land use and land use change [kg CO_2 equivalent]	5.32E-04	4.76E-04	1.14E-03	2.42E-03
EF 3.1 Ecotoxicity, freshwater, total [CTUe]	5.82E+00	6.88E+00	1.15E+01	1.48E+01
EF 3.1 Ecotoxicity, freshwater inorganics [CTUe]	5.81E+00	6.87E+00	1.13E+01	1.46E+01
EF 3.1 Ecotoxicity, freshwater organics [CTUe]	8.89E-03	9.39E-03	1.48E-01	1.71E-01
EF 3.1 Eutrophication, freshwater [kg P equivalent]	3.76E-07	4.08E-07	3.68E-06	4.17E-06
EF 3.1 Eutrophication, marine [kg N equivalent]	5.07E-04	5.23E-04	9.78E-04	2.55E-03
EF 3.1 Eutrophication, terrestrial [Mole of N equivalent]	5.78E-03	5.99E-03	1.11E-02	2.84E-02
EF 3.1 Human toxicity, cancer—total [CTUh]	9.28E-11	1.04E-10	1.49E-10	2.07E-10
EF 3.1 Human toxicity, cancer inorganics [CTUh]	2.94E-11	3.15E-11	5.79E-11	1.14E-10
EF 3.1 Human toxicity, cancer organics [CTUh]	6.34E-11	7.25E-11	9.09E-11	9.29E-11
EF 3.1 Human toxicity, non-cancer, total [CTUh]	1.69E-09	1.91E-09	3.80E-09	5.55E-09

	Post-industrial yarn waste	**Post-industrial fabric waste**	**Post-consumer waste (domestic)**	**Post-consumer waste (international transportation)**
EF 3.1 Human toxicity, non-cancer inorganics [CTUh]	1.62E-09	1.84E-09	3.68E-09	5.37E-09
EF 3.1 Human toxicity, non-cancer organics [CTUh]	6.98E-11	7.34E-11	1.20E-10	1.76E-10
EF 3.1 Ionising radiation, human health [kBq U235 equivalent]	5.10E-03	7.74E-03	6.63E-03	7.36E-03
EF 3.1 Land use [Pt]	5.11E-01	5.59E-01	1.23E+00	1.79E+00
EF 3.1 Ozone depletion [kg CFC-11 equivalent]	6.94E-12	4.34E-12	1.42E-11	1.43E-11
EF 3.1 Particulate matter [disease incidences]	2.51E-08	3.03E-08	6.91E-08	1.65E-07
EF 3.1 Photochemical ozone formation, human health [kg NMVOC equivalent]	1.32E-03	1.39E-03	2.60E-03	6.89E-03
EF 3.1 Resource use, fossils [MJ]	6.01E+00	6.51E+00	9.86E+00	1.42E+01
EF 3.1 Resource use, mineral and metals [kg Sb equivalent]	2.88E-08	2.73E-08	6.94E-08	8.92E-08
EF 3.1 Water use [m^3 world equivalent]	1.47E-01	1.89E-01	2.44E-01	2.47E-01

Annex H: Soil erosion rates

Table H-1: Soil erosion rates[1]

	Baseline [2]	Adoption rate reduced tillage	Reduction potential reduced tillage [3]	Rate 1	Adoption rate no tillage	Reduction potential no tillage [3]	Rate 2	Adoption rate cover crops [4]	Reduction potential cover crops [3]	Rate 3 (final)	Combined reduction
	kg/ha	%	%	kg/ha	%	%	kg/ha	%	%	kg/ha	%
IN country average	1932	1%	33%	1925	5%	44%	1887	0%	50%	1887	2%
IN organic	1903	50%	33%	1592	31%	44%	1374	15%	50%	1271	33%
IN regenerative	1903	96%	33%	1302	0%	44%	1302	72%	50%	833	56%
BR country average	857	8%	33%	836	68%	44%	588	0%	50%	588	31%
BR organic	857	60%	33%	687	0%	44%	687	0%	50%	687	20%
PE organic	1130	20%	33%	1056	0%	44%	1056	0%	50%	1056	7%
PE regenerative	1130	60%	33%	907	0%	44%	907	80%	50%	544	52%
TR country average	599	1%	33%	597	0%	44%	597	0%	50%	597	0%
TR organic	599	100%	33%	401	0%	44%	401	50%	50%	301	50%
TR regenerative	599	80%	33%	440	20%	44%	402	50%	50%	302	50%
TZ organic	2594	61%	33%	2071	0%	44%	2071	100%	50%	1035	61%
US country average	434	23%	33%	400	54%	44%	305	22%	50%	271	37%
US organic	358	91%	33%	250	0%	44%	250	100%	50%	125	65%
CN country average[5]	1736	23%	33%	1608	8%	44%	1554	0%	50%	1554	10%

1) Calculated as: Rate 1 = Baseline * % adoption 1 * Reduction potential 1; Rate 2 = Rate 1 * % adoption 2 * Reduction potential 2; Rate 3 = Rate 2 * % adoption 3 * Reduction potential 3; combined reduction = 1- (Baseline/Rate 3).

2) Based on GIS data from European Soil Data Centre—Global Soil Erosion (Joint Research Centre, 2019), sub-country level values were used where appropriate.

3) Estimates based on (Gideon, Nasir Ahmad, Mustafa, & Yusoff, 2020), (Chen, Zhongwu, Xiao, Ning, & Tang, 2021), (García-Ruiz, et al., 2015).

4) Assumed zero where no data.

Annex J: Scenarios and uncertainty assessment

J.1.Cotton cultivation inventory data variation

Table J-1: Cotton cultivation inventory absolute value variation—India country average

		Minimum	Average	Maximum
Yield (seed cotton)	kg/ha	1307.5	1678.9	2526.9
N mineral	kg N/ha	121.2	138.5	162.2
N organic	kg N/ha	0.0	4.5	51.3
Pesticides	kg ai/ha	0.9	3.6	6.7
Irrigation water	m^3/ha	0.0	2155.9	5572.0
Fuel use	l/ha	11.5	29.6	42.0

Table J-2: Cotton cultivation inventory absolute value variation—India organic

		Minimum	Average	Maximum
Yield (seed cotton)	kg/ha	1130.0	1585.5	1850.0
N mineral	kg N/ha	0.0	0.0	0.0
N organic	kg N/ha	32.0	56.0	222.1
Pesticides (excluding biopesticides)	kg ai/ha	0.0	0.0	0.0
Irrigation water	m^3/ha	0.0	2154.1	5171.0
Fuel use	l/ha	0.0	37.4	46.3

Table J-3: Cotton cultivation inventory absolute value variation—India regenerative

		Minimum	Average	Maximum
Yield (seed cotton)	kg/ha	937.6	1571.0	1750.0
N mineral	kg N/ha	0.0	0.9	13.4
N organic	kg N/ha	1.9	92.6	145.3
Pesticides (excluding biopesticides)	kg ai/ha	0.0	0.04	9.5
Irrigation water	m^3/ha	0.0	1989.6	4500.0
Fuel use	l/ha	0.0	8.3	40.3

Table J-4: Cotton cultivation inventory absolute value variation—Brazil organic

		Minimum	Average	Maximum
Yield (seed cotton)	kg/ha	400	1276	3000
N mineral	kg N/ha	0.0	0.0	0.0
N organic	kg N/ha	5	22	80
Pesticides (excluding biopesticides)	kg ai/ha	0.0	0.0	0.0
Irrigation water	m^3/ha	0.0	0.0	0.0
Fuel use	l/ha	n.a.	20	n.a.

Table J-5: Cotton cultivation inventory absolute value variation—Tanzania organic

		Minimum	Average	Maximum
Yield (seed cotton)	kg/ha	673.0	716	754.0
N mineral	kg N/ha	0.0	0.0	0.0
N organic	kg N/ha	26.7	28.3	29.9
Pesticides	kg ai/ha	0.0	0.0	0.0
Irrigation water	m^3/ha	0.0	0.0	0.0
Fuel use	l/ha	n.a.	7.3	n.a.

Table J-6: Cotton cultivation inventory absolute value variation—Türkiye organic

		Minimum	Average	Maximum
Yield (seed cotton)	kg/ha	5250.0	5400.0	5550.0
N mineral	kg N/ha	0.0	0.0	0
N organic	kg N/ha	120.0	160.0	200.0
Pesticides	kg ai/ha	0.0	0.0	0.0
Irrigation water	m^3/ha	5000.0	6615.0	8230.0
Fuel use	l/ha	47.5	68.0	88.5

Table J-7: Cotton cultivation inventory absolute value variation—Türkiye regenerative

		Minimum	Average	Maximum
Yield (seed cotton)	kg/ha	4030.0	4949.6	5600.0
N mineral	kg N/ha	0.0	33.3	45.9
N organic	kg N/ha	0.1	121.5	200.0
Pesticides	kg ai/ha	0.0	3.9	5.5
Irrigation water	m^3/ha	2238.7	3234.6	7750.0
Fuel use	l/ha	47.5	79.8	88.5

Table J-8: Cotton cultivation inventory absolute value variation—US organic

		Minimum	Average	Maximum
Yield (seed cotton)	kg/ha	470.0	1079.2	1345.0
N mineral	kg N/ha	0.0	0.0	0.0
N organic	kg N/ha	34.6	79.4	99.0
Pesticides	kg ai/ha	0.0	0.0	0.0
Irrigation water	m^3/ha	0.0	757.1	784.6
Fuel use	l/ha	18.7	49.8	84.3

J.2. Cotton cultivation scenarios

Table J-9: Cotton cultivation organic fertilizer provision impacts scenario [ORGFERT_COMBINED]

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Baseline															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.17	1.46	1.72	2.46	0.44	0.48	0.49	1.29	0.95	0.89	0.89	1.55	1.77	1.72
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.04	0.07	0.03	0.03	0.01	0.01	0.03	0.03	0.04	0.07	0.03	0.12	0.03
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.054	0.024	0.030	0.012	0.013	0.012	0.010	0.012	0.011	0.012	0.029	0.015	0.034	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.3	10.1	8.5	11.7	2.3	1.5	1.6	11.4	6.7	6.0	3.9	14.3	9.3	15.9
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.6	3152.1	47.9	3.4	4326.2	4453.4	1679.0	2418.2	1290.0	2.0	1118.2	1528.6	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2826.8	23.9	33.2	1262.9	20.2	3.6	3.4	103.7	14.9	137.8	22.9	906.4	31.1	273.5
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.26	2.24	2.84	2.46	0.51	1.07	1.10	1.29	1.33	1.05	1.07	1.55	2.10	1.72
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.06	0.10	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.07	0.03	0.13	0.03
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.055	0.028	0.035	0.012	0.013	0.015	0.013	0.012	0.012	0.012	0.029	0.015	0.034	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.4	10.3	8.9	11.7	2.5	1.6	1.6	11.4	6.9	6.2	4.3	14.3	10.1	15.9
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.9	3152.7	47.9	3.6	4326.3	4453.5	1679.0	2418.4	1290.3	2.6	1118.2	1529.7	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2827.0	25.3	35.5	1262.9	20.5	4.6	4.4	103.7	15.8	138.4	23.7	906.4	32.9	273.5
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4
Baseline vs. scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	%	102%	153%	165%	100%	115%	223%	224%	100%	140%	117%	119%	100%	119%	100%

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Acidification [EF 3.1]	%	102%	157%	146%	100%	102%	231%	231%	100%	134%	107%	102%	100%	102%	100%
Eutrophication [CML 2016]	%	101%	115%	117%	100%	101%	124%	130%	100%	115%	104%	101%	100%	101%	100%
Abiotic Depletion Potential (ADP fossil) [CML 2016]	%	100%	102%	105%	100%	108%	105%	105%	100%	103%	104%	112%	100%	109%	100%
Blue water consumption [inventory]	%	100%	100%	100%	100%	107%	100%	100%	100%	100%	100%	130%	100%	100%	100%
Water use [EF 3.1]	%	100%	100%	100%	100%	102%	100%	100%	100%	100%	100%	102%	100%	100%	100%
Ecotoxicity, freshwater [EF 3.1]	%	100%	106%	107%	100%	101%	128%	129%	100%	106%	100%	104%	100%	106%	100%
Nitrogen balance	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table J-10: Cotton cultivation organic fertilizer provision impacts scenario [ORGFERT_FYM]

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Baseline															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.17	1.46	1.72	2.46	0.44	0.48	0.49	1.29	0.95	0.89	0.89	1.55	1.77	1.72
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.04	0.07	0.03	0.03	0.01	0.01	0.03	0.03	0.04	0.07	0.03	0.12	0.03
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.054	0.024	0.030	0.012	0.013	0.012	0.010	0.012	0.011	0.012	0.029	0.015	0.034	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.3	10.1	8.5	11.7	2.3	1.5	1.6	11.4	6.7	6.0	3.9	14.3	9.3	15.9
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.6	3152.1	47.9	3.4	4326.2	4453.4	1679.0	2418.2	1290.0	2.0	1118.2	1528.6	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2826.8	23.9	33.2	1262.9	20.2	3.6	3.4	103.7	14.9	137.8	22.9	906.4	31.1	273.5
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4
Scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2,	kg CO_2 eq./kg fiber	4.18	1.54	1.88	2.46	0.51	0.51	0.52	1.29	1.03	0.98	1.07	1.55	2.10	1.72

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
including Land Use Change]															
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.04	0.07	0.03	0.03	0.01	0.01	0.03	0.03	0.04	0.07	0.03	0.13	0.03
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.054	0.024	0.030	0.012	0.013	0.012	0.010	0.012	0.011	0.012	0.029	0.015	0.034	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.4	10.3	8.9	11.7	2.5	1.6	1.6	11.4	6.9	6.2	4.3	14.3	10.1	15.9
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.9	3152.7	47.9	3.6	4326.3	4453.5	1679.0	2418.4	1290.3	2.6	1118.2	1529.7	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2826.9	24.3	34.1	1262.9	20.5	3.8	3.6	103.7	15.3	138.3	23.7	906.4	32.9	273.5
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4
Baseline vs. scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	%	100%	105%	109%	100%	115%	106%	106%	100%	108%	109%	119%	100%	119%	100%
Acidification [EF 3.1]	%	100%	101%	101%	100%	102%	101%	101%	100%	101%	101%	102%	100%	102%	100%
Eutrophication [CML 2016]	%	100%	100%	101%	100%	101%	100%	100%	100%	101%	101%	101%	100%	101%	100%

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Abiotic Depletion Potential (ADP fossil) [CML 2016]	%	100%	102%	105%	100%	108%	105%	105%	100%	103%	104%	112%	100%	109%	100%
Blue water consumption [inventory]	%	100%	100%	100%	100%	107%	100%	100%	100%	100%	100%	130%	100%	100%	100%
Water use [EF 3.1]	%	100%	100%	100%	100%	102%	100%	100%	100%	100%	100%	102%	100%	100%	100%
Ecotoxicity, freshwater [EF 3.1]	%	100%	102%	103%	100%	101%	106%	106%	100%	103%	100%	104%	100%	106%	100%
Nitrogen balance	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table J-11: Cotton cultivation organic fertilizer provision impacts scenario [ORGFERT_COMPOST]

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Baseline															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.17	1.46	1.72	2.46	0.44	0.48	0.49	1.29	0.95	0.89	0.89	1.55	1.77	1.72
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.04	0.07	0.03	0.03	0.01	0.01	0.03	0.03	0.04	0.07	0.03	0.12	0.03

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.054	0.024	0.030	0.012	0.013	0.012	0.010	0.012	0.011	0.012	0.029	0.015	0.034	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.3	10.1	8.5	11.7	2.3	1.5	1.6	11.4	6.7	6.0	3.9	14.3	9.3	15.9
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.6	3152.1	47.9	3.4	4326.2	4453.4	1679.0	2418.2	1290.0	2.0	1118.2	1528.6	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2826.8	23.9	33.2	1262.9	20.2	3.6	3.4	103.7	14.9	137.8	22.9	906.4	31.1	273.5
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4
Scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.25	2.17	2.68	2.46	0.44	1.04	1.07	1.29	1.25	0.96	0.89	1.55	1.77	1.72
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.06	0.10	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.07	0.03	0.12	0.03
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.055	0.028	0.034	0.012	0.013	0.015	0.013	0.012	0.012	0.012	0.029	0.015	0.034	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.3	10.1	8.5	11.7	2.3	1.5	1.6	11.4	6.7	6.0	3.9	14.3	9.3	15.9
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.6	3152.1	47.9	3.4	4326.2	4453.4	1679.0	2418.2	1290.0	2.0	1118.2	1528.6	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2826.9	24.9	34.7	1262.9	20.2	4.5	4.3	103.7	15.3	137.9	23.7	906.4	31.1	273.5
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4
Baseline vs. scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	%	102%	148%	156%	100%	100%	217%	218%	100%	132%	108%	100%	100%	100%	100%
Acidification [EF 3.1]	%	102%	156%	144%	100%	100%	230%	230%	100%	132%	106%	100%	100%	100%	100%
Eutrophication [CML 2016]	%	101%	115%	116%	100%	100%	124%	130%	100%	114%	103%	100%	100%	100%	100%
Abiotic Depletion Potential (ADP fossil) [CML 2016]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Blue water consumption [inventory]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Water use [EF 3.1]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Ecotoxicity, freshwater [EF 3.1]	%	100%	104%	105%	100%	100%	125%	126%	100%	103%	100%	104%	100%	100%	100%
Nitrogen balance	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table J-12: Cotton cultivation N_2O and NO_3 emission factors, dry-climate scenario [N_2O_DRY]

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Baseline															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.17	1.46	1.72	2.46	0.44	0.48	0.49	1.29	0.95	0.89	0.89	1.55	1.77	1.72
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.04	0.07	0.03	0.03	0.01	0.01	0.03	0.03	0.04	0.07	0.03	0.12	0.03
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.054	0.024	0.030	0.012	0.013	0.012	0.010	0.012	0.011	0.012	0.029	0.015	0.034	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.3	10.1	8.5	11.7	2.3	1.5	1.6	11.4	6.7	6.0	3.9	14.3	9.3	15.9
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.6	3152.1	47.9	3.4	4326.2	4453.4	1679.0	2418.2	1290.0	2.0	1118.2	1528.6	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2826.8	23.9	33.2	1262.9	20.2	3.6	3.4	103.7	14.9	137.8	22.9	906.4	31.1	273.5
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4
Scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	3.42	1.18	1.24	2.24	0.34	0.30	0.31	1.09	0.76	0.70	0.62	1.26	1.25	1.49
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.04	0.07	0.03	0.03	0.01	0.01	0.03	0.03	0.04	0.07	0.03	0.12	0.03

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.029	0.015	0.014	0.005	0.009	0.006	0.004	0.005	0.004	0.005	0.020	0.006	0.016	0.009
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.3	10.1	8.5	11.7	2.3	1.5	1.6	11.4	6.7	6.0	3.9	14.3	9.3	15.9
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.6	3152.1	47.9	3.4	4326.2	4453.4	1679.0	2418.2	1290.0	2.0	1118.2	1528.6	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2826.8	23.9	33.2	1262.9	20.2	3.6	3.4	103.7	14.9	137.8	23.7	906.4	31.1	273.5
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4
Baseline vs. scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	%	82%	80%	72%	91%	75%	63%	63%	85%	80%	79%	69%	82%	70%	87%
Acidification [EF 3.1]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Eutrophication [CML 2016]	%	54%	61%	46%	42%	71%	49%	38%	45%	41%	46%	68%	37%	48%	56%
Abiotic Depletion Potential (ADP fossil) [CML 2016]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Blue water consumption [inventory]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Water use [EF 3.1]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Ecotoxicity, freshwater [EF 3.1]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Nitrogen balance	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table J-13: Cotton cultivation N_2O and NO_3 emission factors wet-climate scenario [N_2O_WET]

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Baseline															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.17	1.46	1.72	2.46	0.44	0.48	0.49	1.29	0.95	0.89	0.89	1.55	1.77	1.72
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.04	0.07	0.03	0.03	0.01	0.01	0.03	0.03	0.04	0.07	0.03	0.12	0.03
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.054	0.024	0.030	0.012	0.013	0.012	0.010	0.012	0.011	0.012	0.029	0.015	0.034	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.3	10.1	8.5	11.7	2.3	1.5	1.6	11.4	6.7	6.0	3.9	14.3	9.3	15.9
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.6	3152.1	47.9	3.4	4326.2	4453.4	1679.0	2418.2	1290.0	2.0	1118.2	1528.6	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2826.8	23.9	33.2	1262.9	20.2	3.6	3.4	103.7	14.9	137.8	22.9	906.4	31.1	273.5

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4
Scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.73	1.31	1.47	2.62	0.39	0.39	0.40	1.44	0.85	0.85	0.75	1.77	1.50	1.89
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.04	0.07	0.03	0.03	0.01	0.01	0.03	0.03	0.04	0.07	0.03	0.12	0.03
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.055	0.024	0.029	0.013	0.013	0.012	0.010	0.012	0.011	0.012	0.029	0.015	0.033	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.3	10.1	8.5	11.7	2.3	1.5	1.6	11.4	6.7	6.0	3.9	14.3	9.3	15.9
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.6	3152.1	47.9	3.4	4326.2	4453.4	1679.0	2418.2	1290.0	2.0	1118.2	1528.6	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2826.8	23.9	33.2	1262.9	20.2	3.6	3.4	103.7	14.9	137.8	23.7	906.4	31.1	273.5
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4
Baseline vs. scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	%	113%	90%	86%	107%	87%	81%	80%	112%	89%	95%	84%	115%	84%	110%
Acidification [EF 3.1]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Eutrophication [CML 2016]	%	101%	99%	99%	101%	100%	99%	99%	101%	99%	100%	100%	101%	99%	101%
Abiotic Depletion Potential (ADP fossil) [CML 2016]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Blue water consumption [inventory]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Water use [EF 3.1]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Ecotoxicity, freshwater [EF 3.1]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Nitrogen balance	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table J-14: Cotton cultivation nutrient content in organic fertilizer scenario [ORGFERT_200%]

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Baseline															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.17	1.46	1.72	2.46	0.44	0.48	0.49	1.29	0.95	0.89	0.89	1.55	1.77	1.72
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.04	0.07	0.03	0.03	0.01	0.01	0.03	0.03	0.04	0.07	0.03	0.12	0.03

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.054	0.024	0.030	0.012	0.013	0.012	0.010	0.012	0.011	0.012	0.029	0.015	0.034	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.3	10.1	8.5	11.7	2.3	1.5	1.6	11.4	6.7	6.0	3.9	14.3	9.3	15.9
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.6	3152.1	47.9	3.4	4326.2	4453.4	1679.0	2418.2	1290.0	2.0	1118.2	1528.6	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2826.8	23.9	33.2	1262.9	20.2	3.6	3.4	103.7	14.9	137.8	22.9	906.4	31.1	273.5
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4
Scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.21	1.97	2.58	2.46	0.66	0.79	0.81	1.29	1.30	1.18	1.42	1.55	2.78	1.72
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.07	0.13	0.03	0.05	0.03	0.03	0.03	0.06	0.07	0.13	0.03	0.24	0.03
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.056	0.038	0.053	0.012	0.019	0.019	0.018	0.012	0.021	0.021	0.046	0.015	0.066	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.3	10.1	8.5	11.7	2.3	1.5	1.6	11.4	6.7	6.0	3.9	14.3	9.3	15.9
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.6	3152.1	47.9	3.4	4326.2	4453.4	1679.0	2418.2	1290.0	2.0	1118.2	1528.6	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2827.0	25.2	35.9	1262.9	21.3	4.2	4.0	103.7	16.1	139.3	23.7	906.4	36.3	273.5
Nitrogen balance	kg N/ha	104.1	59.7	134.2	2.2	1.7	54.2	57.3	-9.9	141.8	97.6	33.0	23.0	123.3	0.4
Baseline vs. scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	%	101%	135%	150%	100%	147%	165%	165%	100%	137%	132%	159%	100%	157%	100%
Acidification [EF 3.1]	%	104%	174%	185%	100%	192%	191%	191%	100%	191%	182%	193%	100%	195%	100%
Eutrophication [CML 2016]	%	103%	155%	180%	100%	152%	165%	180%	100%	192%	175%	158%	100%	195%	100%
Abiotic Depletion Potential (ADP fossil) [CML 2016]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Blue water consumption [inventory]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Water use [EF 3.1]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Ecotoxicity, freshwater [EF 3.1]	%	100%	105%	108%	100%	105%	117%	118%	100%	108%	101%	104%	100%	117%	100%
Nitrogen balance	%	105%	1616%	322%	100%	-9%	-209%	-249%	100%	-779%	-600%	700%	100%	281%	100%

Table J-15: Cotton cultivation nutrient content in organic fertilizer scenario [ORGFERT_50%]

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Baseline															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.17	1.46	1.72	2.46	0.44	0.48	0.49	1.29	0.95	0.89	0.89	1.55	1.77	1.72
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.04	0.07	0.03	0.03	0.01	0.01	0.03	0.03	0.04	0.07	0.03	0.12	0.03
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.054	0.024	0.030	0.012	0.013	0.012	0.010	0.012	0.011	0.012	0.029	0.015	0.034	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.3	10.1	8.5	11.7	2.3	1.5	1.6	11.4	6.7	6.0	3.9	14.3	9.3	15.9
Blue water consumption [Inventory]	kg/kg fiber	3177.4	3356.6	3152.1	47.9	3.4	4326.2	4453.4	1679.0	2418.2	1290.0	2.0	1118.2	1528.6	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2826.8	23.9	33.2	1262.9	20.2	3.6	3.4	103.7	14.9	137.8	22.9	906.4	31.1	273.5
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4
Scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.15	1.21	1.29	2.46	0.34	0.33	0.33	1.29	0.78	0.75	0.63	1.55	1.27	1.72
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.11	0.03	0.04	0.03	0.01	0.01	0.01	0.03	0.02	0.02	0.03	0.03	0.06	0.03

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.053	0.018	0.018	0.012	0.009	0.008	0.006	0.012	0.006	0.007	0.021	0.015	0.018	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.3	10.1	8.5	11.7	2.3	1.5	1.6	11.4	6.7	6.0	3.9	14.3	9.3	15.9
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.6	3152.1	47.9	3.4	4326.2	4453.4	1679.0	2418.2	1290.0	2.0	1118.2	1528.6	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2826.7	23.2	31.8	1262.9	19.6	3.3	3.1	103.7	14.2	137.1	23.7	906.4	28.5	273.5
Nitrogen balance	kg N/ha	97.3	-24.3	-4.7	2.2	-31.1	-66.1	-63.1	-9.9	-98.2	-73.2	-9.4	23.0	4.1	0.4
Baseline vs. scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	%	100%	83%	75%	100%	76%	68%	68%	100%	82%	84%	71%	100%	72%	100%
Acidification [EF 3.1]	%	98%	63%	57%	100%	54%	55%	55%	100%	54%	59%	53%	100%	52%	100%
Eutrophication [CML 2016]	%	99%	72%	60%	100%	74%	68%	60%	100%	54%	63%	71%	100%	53%	100%
Abiotic Depletion Potential (ADP fossil) [CML 2016]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Blue water consumption [inventory]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Water use [EF 3.1]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Ecotoxicity, freshwater [EF 3.1]	%	100%	97%	96%	100%	97%	92%	91%	100%	95%	99%	104%	100%	92%	100%

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Nitrogen balance	%	98%	-658%	-11%	100%	154%	254%	275%	100%	540%	450%	-200%	100%	9%	100%

Table J-16: Cotton cultivation Emission modeling and fertilizer inventory—N-balance approach scenario [N_BALANCE]

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Baseline															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.17	1.46	1.72	2.46	0.44	0.48	0.49	1.29	0.95	0.89	0.89	1.55	1.77	1.72
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.04	0.07	0.03	0.03	0.01	0.01	0.03	0.03	0.04	0.07	0.03	0.12	0.03
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.054	0.024	0.030	0.012	0.013	0.012	0.010	0.012	0.011	0.012	0.029	0.015	0.034	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.3	10.1	8.5	11.7	2.3	1.5	1.6	11.4	6.7	6.0	3.9	14.3	9.3	15.9
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.6	3152.1	47.9	3.4	4326.2	4453.4	1679.0	2418.2	1290.0	2.0	1118.2	1528.6	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2826.8	23.9	33.2	1262.9	20.2	3.6	3.4	103.7	14.9	137.8	22.9	906.4	31.1	273.5

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4
Scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.38	1.52	1.72	2.64	0.68	0.61	0.62	1.51	1.06	1.05	0.95	1.57	1.79	1.93
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.05	0.07	0.04	0.06	0.02	0.02	0.04	0.04	0.06	0.08	0.04	0.12	0.03
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.074	0.021	0.030	0.011	0.017	0.011	0.009	0.011	0.010	0.012	0.027	0.011	0.035	0.015
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.3	10.1	8.5	13.7	2.3	1.5	1.6	13.2	6.7	6.4	3.9	14.9	9.3	17.8
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.6	3152.1	48.9	3.4	4326.2	4453.4	1679.5	2418.2	1290.1	2.0	1118.4	1528.6	1801.3
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.4
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2826.8	24.3	33.2	1264.4	21.9	4.1	3.9	104.7	15.5	138.9	23.7	906.7	31.1	274.4
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4
Baseline vs. scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	%	105%	104%	100%	107%	152%	127%	125%	118%	111%	118%	107%	102%	101%	113%
Acidification [EF 3.1]	%	100%	117%	100%	127%	221%	153%	150%	132%	141%	145%	122%	107%	100%	123%

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Eutrophication [CML 2016]	%	137%	87%	100%	86%	134%	97%	94%	91%	96%	102%	93%	71%	104%	88%
Abiotic Depletion Potential (ADP fossil) [CML 2016]	%	100%	100%	100%	117%	100%	100%	100%	117%	100%	107%	100%	104%	100%	112%
Blue water consumption [inventory]	%	100%	100%	100%	102%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Water use [EF 3.1]	%	100%	100%	100%	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Ecotoxicity, freshwater [EF 3.1]	%	100%	102%	100%	100%	108%	114%	115%	101%	104%	101%	104%	100%	100%	100%
Nitrogen balance	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table J-17: Cotton cultivation ecotoxicity characterization factors [TOX_UNSPECIFIC]

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Baseline															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.17	1.46	1.72	2.46	0.44	0.48	0.49	1.29	0.95	0.89	0.89	1.55	1.77	1.72
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.04	0.07	0.03	0.03	0.01	0.01	0.03	0.03	0.04	0.07	0.03	0.12	0.03

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.054	0.024	0.030	0.012	0.013	0.012	0.010	0.012	0.011	0.012	0.029	0.015	0.034	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.3	10.1	8.5	11.7	2.3	1.5	1.6	11.4	6.7	6.0	3.9	14.3	9.3	15.9
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.6	3152.1	47.9	3.4	4326.2	4453.4	1679.0	2418.2	1290.0	2.0	1118.2	1528.6	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2826.8	23.9	33.2	1262.9	20.2	3.6	3.4	103.7	14.9	137.8	22.9	906.4	31.1	273.5
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4
Scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.17	1.46	1.72	2.46	0.44	0.48	0.49	1.29	0.95	0.89	0.89	1.55	1.77	1.72
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.04	0.07	0.03	0.03	0.01	0.01	0.03	0.03	0.04	0.07	0.03	0.12	0.03
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.054	0.024	0.030	0.012	0.013	0.012	0.010	0.012	0.011	0.012	0.029	0.015	0.034	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.4	10.1	8.5	11.8	2.3	1.5	1.6	11.4	6.7	6.0	3.9	14.3	9.3	15.9
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.6	3152.1	47.9	3.4	4326.2	4453.4	1679.0	2418.2	1290.0	2.0	1118.2	1528.6	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	659.8	15.1	21.4	1330.1	11.5	3.6	3.4	146.5	12.8	187.2	23.3	429.5	19.6	244.2
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4
Baseline vs. scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Acidification [EF 3.1]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Eutrophication [CML 2016]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Abiotic Depletion Potential (ADP fossil) [CML 2016]	%	100%	100%	100%	101%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Blue water consumption [inventory]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Water use [EF 3.1]	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Ecotoxicity, freshwater [EF 3.1]	%	23%	63%	64%	105%	57%	100%	100%	141%	86%	136%	102%	47%	63%	89%
Nitrogen balance	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table J-18: Cotton cultivation renewable energy at gin scenario

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Baseline															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.17	1.46	1.72	2.46	0.44	0.48	0.49	1.29	0.95	0.89	0.89	1.55	1.77	1.72
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.12	0.04	0.07	0.03	0.03	0.01	0.01	0.03	0.03	0.04	0.07	0.03	0.12	0.03
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.054	0.024	0.030	0.012	0.013	0.012	0.010	0.012	0.011	0.012	0.029	0.015	0.034	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	40.3	10.1	8.5	11.7	2.3	1.5	1.6	11.4	6.7	6.0	3.9	14.3	9.3	15.9
Blue water consumption [inventory]	kg/kg fiber	3177.4	3356.6	3152.1	47.9	3.4	4326.2	4453.4	1679.0	2418.2	1290.0	2.0	1118.2	1528.6	1800.7
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.7	0.1	0.0	126.6	130.3	93.3	134.4	71.7	0.1	37.8	51.7	76.3
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2826.8	23.9	33.2	1262.9	20.2	3.6	3.4	103.7	14.9	137.8	22.9	906.4	31.1	273.5
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4
Scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	3.93	1.23	1.49	2.42	0.41	0.44	0.46	1.17	0.83	0.77	0.71	1.48	1.70	1.61
Acidification [EF 3.1]	moles H+ eq./kg fiber	0.11	0.04	0.07	0.03	0.03	0.01	0.01	0.03	0.03	0.04	0.06	0.03	0.12	0.03

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Eutrophication [CML 2016]	kg phosphate eq./kg fiber	0.054	0.024	0.029	0.012	0.013	0.012	0.010	0.012	0.011	0.012	0.029	0.015	0.034	0.017
Abiotic Depletion Potential (ADP fossil) [CML 2016]	MJ/kg fiber	38.0	7.7	6.2	11.3	2.0	1.2	1.2	10.0	5.4	4.7	1.9	13.5	8.5	14.8
Blue water consumption [inventory]	kg/kg fiber	3176.5	3355.8	3151.2	45.2	0.7	4323.5	4450.7	1677.7	2416.8	1288.7	1.2	1117.8	1528.2	1800.0
Water use [EF 3.1]	m^3 eq./kg fiber	111.0	98.7	92.6	0.1	0.0	126.6	130.3	93.2	134.4	71.6	0.0	37.8	51.6	76.3
Ecotoxicity, freshwater [EF 3.1]	CTUe/kg fiber	2825.2	48.9	58.4	1262.5	46.0	3.2	3.0	101.6	19.0	142.5	42.8	906.2	65.4	273.4
Nitrogen balance	kg N/ha	99.6	3.7	41.6	2.2	-20.2	-26.0	-23.0	-9.9	-18.2	-16.3	4.7	23.0	43.8	0.4
Baseline vs. scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	%	94%	84%	86%	99%	92%	92%	93%	91%	87%	87%	80%	96%	96%	94%
Acidification [EF 3.1]	%	97%	93%	96%	99%	99%	98%	98%	99%	99%	99%	96%	100%	100%	99%
Eutrophication [CML 2016]	%	100%	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Abiotic Depletion Potential (ADP fossil) [CML 2016]	%	94%	77%	72%	97%	84%	76%	76%	88%	80%	77%	48%	95%	91%	93%
Blue water consumption [inventory]	%	100%	100%	100%	94%	21%	100%	100%	100%	100%	100%	58%	100%	100%	100%
Water use [EF 3.1]	%	100%	100%	100%	92%	59%	100%	100%	100%	100%	100%	41%	100%	100%	100%
Ecotoxicity, freshwater [EF 3.1]	%	100%	97%	97%	100%	99%	89%	89%	98%	90%	98%	100%	100%	100%	100%

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Nitrogen balance	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table J-19: Soil organic carbon—switch from full tillage to no tillage [SOC_TILLAGE]

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Baseline															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO2 eq./kg fiber	4.17	1.46	1.72	2.46	0.44	0.48	0.49	1.29	0.95	0.89	0.89	1.55	1.77	1.72
Scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	3.00	0.23	0.48	2.10	-0.76	-0.06	-0.06	1.18	0.86	0.80	-1.45	0.98	0.37	1.43
SOC sequestration potential															
SOC	kg CO_2 eq./kg fiber	1.16	1.23	1.24	0.36	1.21	0.54	0.55	0.11	0.09	0.09	2.34	0.57	1.40	0.29
SOC	t C/ha	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.06	0.06	0.06	0.22	0.19	0.19	0.11

Table J-20: Soil organic carbon—high carbon input [SOC_INPUT_HIGH]

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Baseline															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.17	1.46	1.72	2.46	0.44	0.48	0.49	1.29	0.95	0.89	0.89	1.55	1.77	1.72
Scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	2.76	-0.03	0.22	2.02	-1.02	-0.17	-0.18	1.23	0.91	0.85	-1.94	0.86	0.07	1.33
SOC sequestration potential															
SOC	kg CO_2 eq./kg fiber	1.41	1.49	1.50	0.43	1.46	0.65	0.67	0.05	0.04	0.05	2.83	0.69	1.70	0.39
SOC	t CO_2 eq./ha	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.12	0.12	0.12	0.96	0.84	0.84	0.56

Table J-21: Soil organic carbon—high carbon input with manure [SOC_INPUT_HIGH_WITH_MANURE]

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Baseline															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.17	1.46	1.72	2.46	0.44	0.48	0.49	1.29	0.95	0.89	0.89	1.55	1.77	1.72
Scenario															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	-1.46	-4.50	-4.30	0.72	-5.41	-2.12	-2.18	0.80	0.56	0.47	-10.44	-1.21	-5.02	0.18
SOC sequestration potential															
SOC	kg CO_2 eq./kg fiber	5.63	5.96	6.02	1.74	5.85	2.60	2.67	0.49	0.39	0.42	11.33	2.76	6.79	1.54
SOC	t CO_2 eq./ha	3.83	3.83	3.83	3.83	3.83	3.83	3.83	1.07	1.07	1.07	3.84	3.37	3.37	2.23

Table J-22: Soil organic carbon—combined [SOC_COMBINED]

		IN country average	IN organic	IN regenerative	BR country average	BR organic	PE organic	PE regenerative	TR country average	TR organic	TR regenerative	TZ organic	US country average	US organic	CN selected regions
Baseline															
Climate change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	4.17	1.46	1.72	2.46	0.44	0.48	0.49	1.29	0.95	0.89	0.89	1.55	1.77	1.72
Scenario															
Climate Change [IPCC AR6 GWP 100, excluding biogenic CO_2, including Land Use Change]	kg CO_2 eq./kg fiber	-2.63	-5.73	-5.54	0.36	-6.62	-2.65	-2.73	0.69	0.48	0.37	-12.78	-1.78	-6.42	-0.11
SOC sequestration potential															
SOC	kg CO_2 eq./kg fiber	6.79	7.19	7.26	2.09	7.06	3.13	3.23	0.60	0.48	0.52	13.68	3.33	8.19	1.83
SOC	t CO_2 eq./ha	4.62	4.62	4.62	4.62	4.62	4.62	4.62	1.31	1.31	1.31	4.63	4.06	4.06	2.65

J.3. Recycled cotton production

Table J-23: Recycled cotton impact category and inventory absolute value variation

	Post-industrial yarn waste			**Post-industrial fabric waste**			**Post-consumer waste** (domestic)			**Post-consumer waste** (international transportation)		
	Lowest impact supplier	**Global average**	**Highest impact supplier**	**Lowest impact supplier**	**Global average**	**Highest impact supplier**	**Lowest impact supplier**	**Global average**	**Highest impact supplier**	**Lowest impact supplier**	**Global average**	**Highest impact supplier**
Acidification potential	7.42E-04	1.97E-03	3.51E-03	1.04E-03	2.17E-03	3.84E-03	9.85E-04	4.76E-03	1.40E-02	3.45E-03	8.50E-03	1.64E-02
Abiotic resource depletion	2.11	5.86	9.35	3.91	6.27	12.2	4.88	9.65	14	8.73	14.02	21.49
Green water consumption	0.05	1.34	5.33	0.14	1.45	7.05	0.07	3.26	9.85	0.82	4.97	15.07
Water use	3.40E-02	1.47E-01	6.23E-01	2.99E-02	1.89E-01	2.42E-01	4.72E-02	2.44E-01	8.47E-01	5.05E-02	2.47E-01	8.5E-01
Land occupation	2.93E-04	6.38E-03	2.80E-02	3.11E-04	7.10E-03	3.71E-02	3.18E-04	1.39E-02	4.56E-02	2.93E-03	1.98E-02	6.35E-02

Table J-24: Recycled cotton impact category and inventory percentage deviation compared to global average

	Post-industrial yarn waste			**Post-industrial fabric waste**			**Post-consumer waste** (domestic)			**Post-consumer waste** (international transportation)		
	Lowest impact supplier	**Global average**	**Highest impact supplier**	**Lowest impact supplier**	**Global average**	**Highest impact supplier**	**Lowest impact supplier**	**Global average**	**Highest impact supplier**	**Lowest impact supplier**	**Global average**	**Highest impact supplier**
Acidification potential	-62%	0%	78%	-52%	0%	77%	-79%	0%	194%	-59%	0%	93%
Abiotic resource depletion	-64%	0%	60%	-38%	0%	94%	-49%	0%	45%	-38%	0%	53%
Green water consumption	-96%	0%	297%	-91%	0%	386%	-98%	0%	202%	-84%	0%	203%
Water use	-77%	0%	324%	-84%	0%	28%	-81%	0%	247%	-80%	0%	244%
Land occupation	-95%	0%	339%	-96%	0%	422%	-98%	0%	229%	-85%	0%	221%

Annex K: Background datasets used in Sphera's Agricultural LCA model

The following table lists all the background datasets used in Sphera's Agricultural LCA model (see section 4.5.1 for regional proxies. Background data used for the recycled product system is provided in section 4.5.2).

Table K-1: Background datasets used in Sphera's Agricultural LCA model

Region	Dataset name	Source	Object group	GUID
GLO	Pesticide (average)	Sphera	Pesticides	{e2ae08d0-05cf-4b2a-a334-e8b42b796b3d}
IN	Diammonium phosphate granular fertilizer (DAP)	Sphera	Fertilizers	{1e0eeb88-ea73-434b-8be0-a2d7ee37b572}
US	Ammonium nitrate (AN, solid)	Sphera	Fertilizers	{b9de2c53-5b7f-45c2-9241-18bcab357fe7}
US	Urea (agrarian)	Sphera	Fertilizers	{a034a4cb-5091-489a-952c-ec34c01d95ff}
RU	Potassium chloride (agrarian) (economic allocation)	Sphera	Fertilizers	{bf70511a-7ecd-4d7f-80c3-468cb94326e0}
BR	Urea ammonium nitrate (UAN)	Sphera	Fertilizers	{b79eb807-37e0-4994-9d0b-a379dd099a65}
CN	Urea ammonium nitrate (UAN)	Sphera	Fertilizers	{66667083-0b01-43d4-aac6-9a09807154a9}
RU	Calcium ammonium nitrate (CAN, BAT, solid)	Sphera	Fertilizers	{b95d802b-1766-41a8-86c6-ec725ba85d6c}
RU	Diammonium phosphate granular fertilizer (DAP)	Sphera	Fertilizers	{106699d6-c19c-4a22-9bfa-2068043b33ec}
US	Urea ammonium nitrate (UAN)	Sphera	Fertilizers	{8aad4bf6-4c56-4f94-9d13-c86fab06b0cb}
IN	Urea ammonium nitrate (UAN)	Sphera	Fertilizers	{d08b4fa2-e5c5-4f2b-8d4e-8b177f8347f4}
CN	Monoammonium phosphate (MAP)	Sphera	Fertilizers	{401abd30-31fb-4914-882b-bfc7b54cc2d5}
BR	Triple superphosphate (TSP)	Sphera	Fertilizers	{e792a2d6-225e-4da8-8b0f-4b81643c5ba5}
RU	Phosphoric acid (54% P_2O_5, agrarian, BAT) (economic allocation)	Sphera	Fertilizers	{54a071a9-bdb4-4b5c-b77e-40516fe86159}
IN	NPK 15-15-15 fertilizer (BAT) (mass allocation)	Sphera	Fertilizers	{5414fd60-49b5-4955-bb18-369aaff12693}

Region	Dataset name	Source	Object group	GUID
CN	NPK 15-15-15 (BAT) (mass allocation)	Sphera	Fertilizers	{1ad0e86e-3205-4b7c-8bea-a5fe52ba4995}
US	Triple superphosphate (TSP)	Sphera	Fertilizers	{c684ff99-5662-4cd1-b28d-d6b3053c3cb6}
BR	Potassium chloride (agrarian) (economic allocation)	Sphera	Fertilizers	{8d6a7695-b10e-469d-90d4-758d1376fc7d}
RU	Urea (agrarian, BAT) (approximation)	Sphera	Fertilizers	{614387bd-d041-4a9f-9454-7e561e53d14b}
BR	Ammonium nitrate (AN, BAT, solid)	Sphera	Fertilizers	{6f0af798-6388-4c08-8854-dc5129a88761}
BR	Calcium ammonium nitrate (CAN, BAT, solid)	Sphera	Fertilizers	{3290e1a3-9d75-4683-9890-f4d908a64e70}
US	Calcium ammonium nitrate (CAN, solid)	Sphera	Fertilizers	{0129673d-8cbd-49d3-990b-c90795e2a168}
BR	Urea (agrarian, BAT) (approximation)	Sphera	Fertilizers	{fc018434-f94d-43e4-95d4-21325397709e}
BR	NPK 15-15-15 (BAT) (mass allocation)	Sphera	Fertilizers	{cdcf05a2-d07d-42b6-9314-33adc6df5dd7}
RU	NPK 15-15-15 (BAT) (mass allocation)	Sphera	Fertilizers	{4d7aa2fc-5dca-4f59-921d-6811b0a21505}
RU	Triple superphosphate (TSP)	Sphera	Fertilizers	{caa861c3-3719-4c8c-a45b-dbe9d1d7cbe8}
CN	Urea (agrarian, BAT)	Sphera	Fertilizers	{9910ae87-3cc9-4854-8388-a056639d3bd3}
US	NPK 15-15-15 fertilizer	Sphera	Fertilizers	{6e463987-7963-4d6d-a5d3-0e50b93c592c}
CN	Calcium ammonium nitrate (CAN, BAT, solid)	Sphera	Fertilizers	{c2e71abc-0824-4903-ad6c-fe3aa790ce8d}
RU	Monoammonium phosphate (MAP)	Sphera	Fertilizers	{b765b21a-ead0-4e3c-a678-5a80581a0bce}
RU	Ammonium nitrate (AN, BAT, solid)	Sphera	Fertilizers	{fd99c521-dee8-4817-9895-2de2491857bd}
US	Diammonium phosphate granular fertilizer (DAP)	Sphera	Fertilizers	{1d5a5838-3ec7-42f7-8baf-f67fc400d65f}
RU	Urea ammonium nitrate (UAN)	Sphera	Fertilizers	{35de82b1-7271-4662-87d5-a0ce114008e2}
IN	Triple superphosphate (TSP)	Sphera	Fertilizers	{f1d7c4a9-0591-4248-87bd-670b7b5e5e39}
CN	Triple superphosphate (TSP)	Sphera	Fertilizers	{7651313c-e90c-48ee-8c06-98f3e0675d94}
BR	Monoammonium phosphate (MAP)	Sphera	Fertilizers	{4d1850a2-37ec-40b2-8030-55bd1dfaf5e4}

Region	Dataset name	Source	Object group	GUID
IN	Ammonium nitrate (AN, BAT, solid)	Sphera	Fertilizers	{5a4e8242-0ab7-4886-82ca-6d482e3089d1}
IN	Monoammonium phosphate (MAP)	Sphera	Fertilizers	{4fcc7eb6-b60a-483d-b790-29f43b02c90b}
CN	Diammonium phosphate granular fertilizer (DAP)	Sphera	Fertilizers	{be5c0495-ec8e-416e-a9f2-86afc5e8b089}
US	Monoammonium phosphate (MAP)	Sphera	Fertilizers	{d7e35f18-407f-45f2-843d-76d7852167c9}
US	Potassium chloride (agrarian)	Sphera	Fertilizers	{8494b096-e9c1-4b12-959e-46d23d9da53f}
BR	Diammonium phosphate granular fertilizer (DAP)	Sphera	Fertilizers	{912f690e-0318-453e-9471-578a393c8720}
CN	Phosphoric acid (54% P_2O_5, agrarian, BAT) (economic allocation)	Sphera	Fertilizers	{d070253f-9da7-49f8-bb4a-6298b20934ac}
CN	Ammonium nitrate (AN, BAT, solid)	Sphera	Fertilizers	{16b2e445-a316-4581-8856-82c98f029db2}
IN	Phosphoric acid (54% P_2O_5, agrarian, BAT) (economic allocation)	Sphera	Fertilizers	{68eeee92-4d85-4849-81a3-8aea1f293f72}
BR	Phosphoric acid (54% P_2O_5, agrarian, BAT) (economic allocation)	Sphera	Fertilizers	{4daeedcc-0798-4bc9-817e-771ab0f3ee70}
IN	Urea (agrarian)	Sphera	Fertilizers	{b44b34b8-7949-4bab-bfb4-fb119b02d353}
CN	Potassium chloride (agrarian) (economic allocation)	Sphera	Fertilizers	{ad3e1722-9712-421c-8d34-778f4a5dddbf}
US	Phosphoric acid (54% P_2O_5, agrarian)	Sphera	Fertilizers	{f248cd05-a7f5-4954-97e0-b581355af9cb}
IN	Potassium chloride (agrarian)	Sphera	Fertilizers	{0190da7c-f4d2-4da0-8399-c60ec26bf998}
IN	Calcium ammonium nitrate (CAN, solid)	Sphera	Fertilizers	{edf83046-a26d-49ca-afef-e4ddad7f8b93}
GLO	Rock phosphate mix (32,4 % P_2O_5)	Sphera	Fertilizers	{a9a40f47-b00c-48d9-9f96-ce44e6b7e6f7}
CN	Polyethylene film (PE-LD) (without additives) (approximation)	Sphera	Plastic production	{605c0765-253b-4fa3-8fcd-39fcc87b39d3}
CN	Plastic foil (Polyethylene, PE)	Sphera	Plastic production	{074ba79d-a427-4c21-9e36-0e162f1a6928}
US	Ammonia liquid (NH_3) with CO_2 recovery, by-product carbon dioxide (economic allocation)	Sphera	Inorganic intermediate products	{c25e44cb-6c70-468e-bc76-0931fb8a9140}

Region	Dataset name	Source	Object group	GUID
CN	Ammonia liquid (NH_3) with CO_2 recovery, by-product carbon dioxide (economic allocation)	Sphera	Inorganic intermediate products	{a2738244-f346-447e-8a24-7d6461becf1f}
RU	Ammonia liquid (NH_3) with CO_2 recovery, by-product carbon dioxide (economic allocation) (BAT)	Sphera	Inorganic intermediate products	{d8a671e9-4a58-4eb5-805f-7934652cecb9}
BR	Ammonia liquid (NH_3) with CO_2 recovery, by-product carbon dioxide (economic allocation) (BAT)	Sphera	Inorganic intermediate products	{8961f879-a9c0-4949-b794-4134cdf46e39}
IN	Ammonia liquid (NH_3) with CO_2 recovery, by-product carbon dioxide (economic allocation) (BAT)	Sphera	Inorganic intermediate products	{735dce8d-a2c0-41db-8e32-76b503b546aa}
RER	Potassium chloride (KCl/MOP, 60% K_2O)	Fertilizers Europe	Fertilizers Europe	{a2a8695e-968c-4341-922c-a007c8a8c56d}
RER	Diammonium phosphate (DAP, 18% N, 46% P_2O_5)	Fertilizers Europe	Fertilizers Europe	{3e10ae2e-01f5-4e91-b098-8f9b4b44e119}
RER	Urea ammonium nitrate (UAN, 30% N)	Fertilizers Europe	Fertilizers Europe	{c19713df-4bb3-4b84-ade8-49a244c24882}
RER	Ammonium phosphate (AP, 52% P_2O_5, 8.4% N)	Fertilizers Europe	Fertilizers Europe	{d27713d1-a464-44f4-8585-1481870847d1}
RER	Raw phosphate (32% P_2O_5)	Fertilizers Europe	Fertilizers Europe	{709cd7af-c2ee-4314-aea6-828fb9f295c5}
RER	Ammonia (NH_3)	Fertilizers Europe	Fertilizers Europe	{f1c2e4cd-0d6c-40d2-a518-c0bf1ce39ce5}
RER	Ammonium nitrate (AN, 33.5% N)	Fertilizers Europe	Fertilizers Europe	{c2c4ebba-358f-493e-83ba-71bffe847e9a}
RER	Urea (46% N)	Fertilizers Europe	Fertilizers Europe	{a03a1819-f679-41e9-a6cb-c02ce874e6f8}
RER	NPK 15-15-15 (nitrophosphate route, 15N-15P_2O_5-15K_2O)	Fertilizers Europe	Fertilizers Europe	{327e2d94-14c0-4610-9b19-dd776a6a85ad}
RER	Calcium ammonium nitrate (CAN, 27% N)	Fertilizers Europe	Fertilizers Europe	{d069ee25-aebc-4cb5-a3b6-2b976e859d21}
RER	Triple superphosphate (TSP, 46% P_2O_5)	Fertilizers Europe	Fertilizers Europe	{8d0007f0-9ad8-43b0-86e4-ebe6e9f9d0e6}
RER	Phosphoric acid (H_3PO_4, 54% P_2O_5)	Fertilizers Europe	Fertilizers Europe	{fefe1855-2fb9-4bc0-874d-a72c3f54de71}
US	Thermal energy from natural gas	Sphera	Thermal energy from natural gas	{885a8641-0eae-4f2f-b191-cec7335325bc}

Region	Dataset name	Source	Object group	GUID
US	Thermal energy from LPG	Sphera	Thermal energy from LPG	{a592f6d8-bc7e-40e8-9bdd-a331afe00fc4}
CN	Diesel mix at filling station	Sphera	Filling station	{97539829-e5d9-4278-b69b-de66133a94f2}
IN	Diesel mix at filling station	Sphera	Filling station	{6c2c293e-ee47-4383-a385-c80f7f7d8bde}
BR	Diesel mix at filling station	Sphera	Filling station	{ec3ec538-9f53-432a-bb54-54a7fb042dc4}
US	Diesel mix at filling station	Sphera	Filling station	{a3ce3c6c-7b55-45e5-9f93-a202ad50622b}
RAF	Electricity, medium voltage, consumption mix	Sphera	Electricity grid mix 1 kV-60kV	{224fc9a9-6595-4aaa-b644-93e912055195}
IN	Electricity grid mix	Sphera	Electricity grid mix	{b9f24581-2fe8-4393-810c-4789a92b9c3b}
CN	Electricity grid mix	Sphera	Electricity grid mix	{124e9246-9e84-4352-86b5-c08837e8cf92}
US	Electricity grid mix	Sphera	Electricity grid mix	{6b6fc994-8476-44a3-81cc-9829f2dfe992}
BR	Electricity grid mix	Sphera	Electricity grid mix	{ceb36eee-1612-4101-81a8-0fb8aeac9032}
GLO	Green electricity grid mix (production mix)	Sphera	Electricity grid mix	{d5035db8-986c-43ab-aa4a-73b4b82ffb0c}
BR	Beef cattle (pasturing, 1 kg live weight)	Sphera	Raising of cattle and buffaloes	{09e0f5ac-cdbd-4e79-9567-817a19513d4f}

Annex L: Detailed pesticide use inventory data

Table L-1 Detailed pesticide use inventory data

Active ingredient (all values provided as kg active ingredient per ha)	**IN country average**	**IN organic**	**IN regenerative**	**BR country average**	**BR organic**	**PE organic**	**PE regenerative**	**TR country average**	**TR organic**	**TR regenerative**	**TZ organic**	**US country average**	**US organic**	**CN selected regions**
2,4-dichlorophenoxyacetic acid (2,4-d)	0.0E+00	0.0E+00	0.0E+00	1.4E+00	0.0E+00	0.0E+00	0.0E+00	8.1E-01	0.0E+00	0.0E+00	0.0E+00	6.0E-02	0.0E+00	1.1E-01
Acephate	1.1E+00	0.0E+00	0.0E+00	1.8E+00	0.0E+00	0.0E+00	0.0E+00	3.0E-01	0.0E+00	0.0E+00	0.0E+00	8.3E-02	0.0E+00	9.7E-02
Acetamiprid	5.2E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.6E+00	0.0E+00	1.9E-03	0.0E+00	0.0E+00
Acetochlor	0.0E+00	0.0E+00	0.0E+00	9.2E-01	0.0E+00	0.0E+00	0.0E+00	7.7E-02	0.0E+00	0.0E+00	0.0E+00	1.4E-01	0.0E+00	9.7E-02
Avermectin (abamectin)	1.0E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Azadirachtin	0.0E+00	3.2E-02	3.2E-02	0.0E+00	3.2E-02	0.0E+00	0.0E+00	0.0E+00	3.2E-02	3.2E-02	1.3E-02	7.2E-07	3.2E-02	0.0E+00
Azoxystrobin	1.5E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.7E-04	0.0E+00	0.0E+00
Bifenthrin	7.9E-03	0.0E+00	0.0E+00	3.3E-01	0.0E+00	0.0E+00	0.0E+00	3.0E-02	0.0E+00	0.0E+00	0.0E+00	3.3E-02	0.0E+00	5.9E-02
Buprofezin input	3.7E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	6.0E-03	0.0E+00	0.0E+00
Captan	0.0E+00	0.0E+00	0.0E+00	7.6E-01	0.0E+00	0.0E+00	0.0E+00	3.8E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Carbendazim	1.3E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Active ingredient (all values provided as kg active ingredient per ha)	**IN country average**	**IN organic**	**IN regenerative**	**BR country average**	**BR organic**	**PE organic**	**PE regenerative**	**TR country average**	**TR organic**	**TR regenerative**	**TZ organic**	**US country average**	**US organic**	**CN selected regions**
Carfentrazone-ethyl	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.9E-03	0.0E+00	0.0E+00
Chlorantraniliprole input	6.2E-03	0.0E+00	0.0E+00	7.6E-01	0.0E+00	0.0E+00	0.0E+00	3.8E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Chlorfenapyr input	3.3E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Chloropyrifos	1.7E-01	0.0E+00	0.0E+00	7.7E-04	0.0E+00	0.0E+00	0.0E+00	2.8E-04	0.0E+00	0.0E+00	0.0E+00	3.7E-04	0.0E+00	1.5E-03
Copper hydroxide	0.0E+00	0.0E+00	0.0E+00	7.6E-01	0.0E+00	0.0E+00	0.0E+00	3.8E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Copperoxychloride (59,5% cu)	5.8E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cyclanilide	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.8E-03	0.0E+00	0.0E+00
Cyfluthrin	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.7E-04	0.0E+00	0.0E+00
Cypermethrin	1.1E-01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	6.1E-03	0.0E+00	0.0E+00
Deltamethrin	1.1E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dicamba	0.0E+00	0.0E+00	0.0E+00	7.2E-02	0.0E+00	0.0E+00	0.0E+00	1.8E-02	0.0E+00	0.0E+00	0.0E+00	3.9E-01	0.0E+00	5.0E-02
Dichlorprop	0.0E+00	0.0E+00	0.0E+00	3.4E+00	0.0E+00	0.0E+00	0.0E+00	1.6E-01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.9E-01
Dicrotophos	0.0E+00	0.0E+00	0.0E+00	6.5E+00	0.0E+00	0.0E+00	0.0E+00	5.3E-02	0.0E+00	0.0E+00	0.0E+00	7.7E-02	0.0E+00	2.2E-01
Difenoconazole input	3.7E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dimethenamid	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.0E-03	0.0E+00	0.0E+00

Active ingredient (all values provided as kg active ingredient per ha)	**IN country average**	**IN organic**	**IN regenerative**	**BR country average**	**BR organic**	**PE organic**	**PE regenerative**	**TR country average**	**TR organic**	**TR regenerative**	**TZ organic**	**US country average**	**US organic**	**CN selected regions**
Dimethoate	2.3E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Diuron	0.0E+00	0.0E+00	0.0E+00	8.7E-02	0.0E+00	0.0E+00	0.0E+00	4.9E-02	0.0E+00	0.0E+00	0.0E+00	2.3E-01	0.0E+00	2.0E-01
Ethephon input	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	8.0E-01	0.0E+00	0.0E+00
Ethion	9.2E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Etoxazole	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.5E-05	0.0E+00	0.0E+00
Fenvalerate	2.1E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Fipronil	1.7E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Flonicamid input	6.6E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Flumioazin	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.5E-02	0.0E+00	0.0E+00
Fluometuron	0.0E+00	0.0E+00	0.0E+00	3.4E-04	0.0E+00	0.0E+00	0.0E+00	3.7E-04	0.0E+00	0.0E+00	0.0E+00	2.0E-03	0.0E+00	1.5E-03
Fomesafen	0.0E+00	0.0E+00	0.0E+00	3.0E-01	0.0E+00	0.0E+00	0.0E+00	1.6E-02	0.0E+00	0.0E+00	0.0E+00	3.2E-02	0.0E+00	3.9E-02
Glyphosat	5.3E-03	0.0E+00	0.0E+00	3.7E+00	0.0E+00	0.0E+00	0.0E+00	7.0E-01	0.0E+00	0.0E+00	0.0E+00	1.4E+00	0.0E+00	5.3E-01
Hexaconazole input	1.1E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Imidacloprid	4.6E-01	0.0E+00	0.0E+00	1.1E+00	0.0E+00	0.0E+00	0.0E+00	1.3E-02	0.0E+00	0.0E+00	0.0E+00	4.9E-03	0.0E+00	6.4E-02
Iprodione	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.5E-05	0.0E+00	0.0E+00
Lambda-cyhalothrin	6.8E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.8E-02	0.0E+00	0.0E+00

Active ingredient (all values provided as kg active ingredient per ha)	**IN country average**	**IN organic**	**IN regenerative**	**BR country average**	**BR organic**	**PE organic**	**PE regenerative**	**TR country average**	**TR organic**	**TR regenerative**	**TZ organic**	**US country average**	**US organic**	**CN selected regions**
Malathion	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.4E-03	0.0E+00	0.0E+00
Mancozeb	4.3E-02	0.0E+00	0.0E+00	7.6E-01	0.0E+00	0.0E+00	0.0E+00	3.8E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Mepiquat chloride	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.5E-02	0.0E+00	0.0E+00
Methomyl	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.9E-05	0.0E+00	0.0E+00
Metolachlor	0.0E+00	0.0E+00	0.0E+00	9.1E-01	0.0E+00	0.0E+00	0.0E+00	6.4E-02	0.0E+00	0.0E+00	0.0E+00	5.7E-04	0.0E+00	3.6E-01
Msma	0.0E+00	0.0E+00	0.0E+00	3.4E-04	0.0E+00	0.0E+00	0.0E+00	1.9E-04	0.0E+00	0.0E+00	0.0E+00	1.2E-04	0.0E+00	1.1E-03
Naled	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.5E-02	0.0E+00	0.0E+00
Novaluron	1.9E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.5E-03	0.0E+00	0.0E+00
Oxamyl	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.4E-02	0.0E+00	0.0E+00
Oxyfluorfen	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.7E-03	0.0E+00	0.0E+00
Paraquat	0.0E+00	0.0E+00	0.0E+00	2.2E-01	0.0E+00	0.0E+00	0.0E+00	6.4E-02	0.0E+00	0.0E+00	0.0E+00	1.6E-01	0.0E+00	2.1E-01
Pendimethalin	7.3E-05	0.0E+00	0.0E+00	8.0E-02	0.0E+00	0.0E+00	0.0E+00	5.2E-02	0.0E+00	0.0E+00	0.0E+00	5.4E-02	0.0E+00	1.2E-01
Phorate	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.1E-03	0.0E+00	0.0E+00
Profenofos	4.8E-01	0.0E+00	3.3E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Prometryne	0.0E+00	0.0E+00	0.0E+00	3.0E-02	0.0E+00	0.0E+00	0.0E+00	1.8E-02	0.0E+00	0.0E+00	0.0E+00	1.6E-02	0.0E+00	5.5E-02
Propiconazole input	1.4E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Active ingredient (all values provided as kg active ingredient per ha)	**IN country average**	**IN organic**	**IN regenerative**	**BR country average**	**BR organic**	**PE organic**	**PE regenerative**	**TR country average**	**TR organic**	**TR regenerative**	**TZ organic**	**US country average**	**US organic**	**CN selected regions**
Pyraflufen-ethyl	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.0E-04	0.0E+00	0.0E+00
Pyrithiobac-sodium salt	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.8E-05	0.0E+00	0.0E+00
Quinalphos	1.6E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
S-metolachlor	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.1E-01	0.0E+00	0.0E+00
Sodium chlorate	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.4E-02	0.0E+00	0.0E+00
Spinosad input	4.9E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Spiromesifen input	7.3E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tebuconazole input	2.0E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Thiamethoxam	6.4E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.1E-02	0.0E+00	0.0E+00
Thidiazuron	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.5E-02	0.0E+00	0.0E+00
Thifensulfuron methyl	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.9E-02	0.0E+00	0.0E+00
Thiophanate-methyl input	0.0E+00	0.0E+00	0.0E+00	7.6E-01	0.0E+00	0.0E+00	0.0E+00	3.8E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Triazophos	1.2E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Trifluralin	0.0E+00	0.0E+00	0.0E+00	7.4E-02	0.0E+00	0.0E+00	0.0E+00	7.6E-02	0.0E+00	0.0E+00	0.0E+00	9.9E-02	0.0E+00	2.7E-01
Unspecific pesticide	8.9E-01	0.0E+00	4.1E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.3E+00	0.0E+00	4.0E-01	0.0E+00	0.0E+00

Application rate documentation for biopesticides (Azadirachtin)

The reported biopesticide formulation contains 6% azadirachtin (US EPA, 2020). Label guidance specifies rates between 1–4 teaspoons (tsp) per 1,000 ft^2, equivalent to approximately 0.07 oz product ≈ 2 tsp. Each teaspoon, therefore, contains about 0.992 g product (28.35 g/oz × 0.035 oz/tsp).

Per-application load calculation

1. Active ingredient per teaspoon: 0.992 g product × 0.06 = 0.0595 g ai

2. Active ingredient per 1,000 ft^2 at 2.5 tsp rate: 2.5 × 0.0595 = 0.149 g ai/1,000 ft^2

3. Scale to one acre (43.56 × 1,000 ft^2): 0.149 × 43.56 = 6.49 g ai/acre

4. Convert to per hectare: 6.49 ÷ 0.4046856 = 16.0 g ai/ha

Hence, one application equals approximately 0.016 kg ai per hectare.

Seasonal total (two applications): 0.016 × 2 = 0.032 kg ai/ha per season.

Annex M: Fertilizer mapping approach

Context: classification of fertilizer type considered in Sphera's agricultural LCA model

- Nutrient content is considered to model N emissions and nitrogen balance.
- NH_3 emissions are modelled specific to fertilizer type (IPCC emission factors).
- N_2O emissions are modelled based on N input, but not specific to fertilizer type.
- NO_3^- emissions are modelled based on nutrient balance, but also not specific to fertilizer type.
- Micronutrients: no environmental impact except provision (where contribution is low)—cut-off possible.
- Fertilizer provision—for all fertilizers included in the input parameter list, specific provision datasets are available (from LCA FE DB).
- Provision of (generic) NPK fertilizer with variable N, P, and K content is estimated based on the separated, (and adjustable) provision of ammonia, potassium chloride, and phosphate datasets.

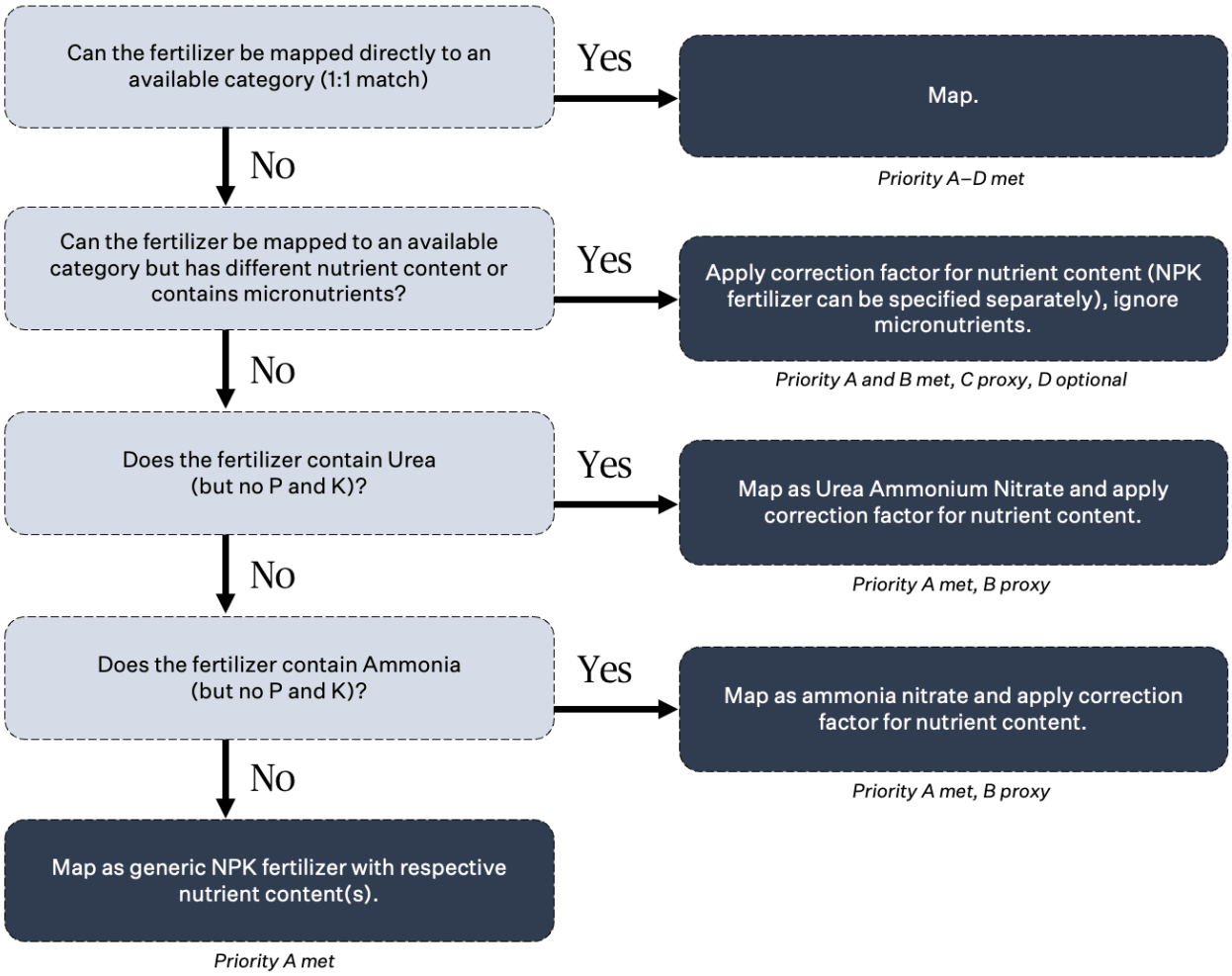
Focus areas

- Most important is to get the amount of nitrogen entered into the system correct, as this has the largest impact on the assessed results (climate change, eutrophication, and N balance).
- NH_3 emissions are mainly influencing acidification results—but also influence climate change and eutrophication results—simplifications and proxies can be used here if need be.

Conclusions for the mapping approach

Priority	Aspect	Description
A	Nutrient content	Especially nitrogen (N)
B	NH_3 emission classification	Based on fertilizer type
C	Provision profile	Dataset mapping
D (optional)	Micronutrients	Optional consideration

Decision tree



Use of correction factors

Divide the nutrient content of fertilizer by the default nutrient content used in Sphera's agricultural LCA model → correction factor.

Multiply the total amount applied by the correction factor before transfer to Sphera's agricultural LCA model → the amount applied will be corrected so that the amount of nutrient applied is correct.

Use of the correction factor—example

100 kg of "Alzon Liquid S 25/6" is reported (11% Urea-N, 5% Nitrate-N, 9% Ammonium-N, 25% total N).

The mapping approach results in mapping this fertilizer to UAN (urea ammonium nitrate).

Nutrient content of UAN fertilizer in Sphera's agricultural LCA model = 30%, while reported fertilizer = 25% → correction factor = 0.25 / 0.30 = 0.83.

In Sphera's agricultural LCA model, enter 83 kg/ha UAN (100 kg/ha × 0.83).

Mixed nutrient fertilizer

In case of a multi-nutrient fertilizer, the approach is:

1. Try to map to the existing fertilizer per the approach above, and add the missing nutrient (P or K) per the generic NPK fertilizer.
2. If that is not possible, enter N, P, K, under generic NPK fertilizer (N, P, and K can be specified separately).