LIFE CYCLE ASSESSMENT OF REEL COTTON

COTTON CONNECT

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LIST OF ACRONYMS

ADP	Abiotic Depletion Potential
AP	Acidification Potential
CML	Centre of Environmental Science at Leiden
EP	Eutrophication Potential
GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
GHG	Greenhouse Gas
GWP	Global Warming Potential
ILCD	International Cycle Data System
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LUC	Land Use Change
NMVOC	Non-Methane Volatile Organic Compound
PEF	Product Environmental Footprint (initiative of the European Commission)
REEL	Responsible Environment Enhanced Livelihoods
VOC	Volatile Organic Compound

GLOSSARY

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 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)

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)

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

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)

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)

Foreground System
"Those processes of the system that are specific to it ... and/or directly affected by decisions analysed in the study." (JRC, 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.

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...." (JRC, 2010, pp. 97-98) As a general rule, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

External and 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).

INTRODUCTION

At CottonConnect, our mission has always been to demonstrate that sustainable cotton farming can create meaningful environmental and social benefits throughout the supply chain. While our annual Impact Report tracks the overall progress of our programmes, we also focus on understanding and measuring their direct impact on the environment—particularly in reducing greenhouse gas (GHG) emissions.

As part of this commitment, we took a significant step in 2022 by conducting our first Life Cycle Assessment (LCA) for the REEL Cotton Programme. This helped us assess the programme's environmental footprint and identify areas for improvement. Building on those insights, in 2023-24 we undertook our second LCA study for the programme in Pakistan, Bangladesh, India, and Egypt. The study evaluates the environmental impacts of the programme from the cultivation years 2020-21, 2021-22, and 2022-23, addressing both the agricultural production phase and ginning process, except for Egypt, where data was collected exclusively for the 2022-23 season.

This study strengthens our understanding with refined methodologies and expanded data, bringing us closer to our goal of a more sustainable cotton industry.

Why LCA matters?

A Life Cycle Assessment (LCA) gives us a holistic view – helping us understand the environmental impacts across all stages of our programme. It helps identify key problem areas, informs decision-making, and ensures we stay on track with programme's sustainability goals. By undertaking this LCA CottonConnect reinforces its commitment to transparency and responsible environmental stewardship and effective impact measurement.

This commitment aligns with the core objectives of the REEL Cotton Programme, which is to improve farm performance, reduce environmental impacts and improve cotton quality in the supply chain. The REEL Cotton Programme is a specially designed three- year agricultural training course that promotes sustainable cotton farming practices.

Key Insights

This LCA has provided valuable insights especially regarding carbon footprint of producing 1 kg of cotton fibre at the gin gate. The study has helped identify key emission hotspots across the cotton production processes – from Farm to Gin, enabling us to drive targeted mitigation strategies.

Furthermore, the finding confirm that the REEL Cotton Programme is making positive impact. The practices used under REEL Cotton Programme help farmers in reducing their environmental impact in measurable ways. This data-driven understanding helps us to monitor, quantify, track progress, and push optimise programme implementation while striving to minimise environmental footprints over time.

Putting these insights to action

- The findings will guide strategic improvements in REEL Cotton Programmes farming practices, focusing on emission hotspots.
- LCA results will be integrated into programme planning, aligning with science-based targets to ensure effectiveness.
- These results will help refining our GHG emissions in terms of CO_2eq. measurement framework for greater accuracy and transparency.
- To set measurable sustainability targets, ensuring that our programmes contribute to the long-term reduction of carbon emissions.
- This LCA will also serve as a foundation for ongoing monitoring and continuous improvement in our sustainability practices.

What next?

We continue to expand our approach – refining our processes based on LCA studies. We will continue to enhance the scope of assessment, engaging stakeholders, and leveraging innovative technologies. Collaboration is key—by working closely with farmers, brands, and partners, we aim to drive meaningful progress in all our programmes while sharing lessons learnt with the broader community.

Alison Ward
Chief Executive Officer,
CottonConnect

EXECUTIVE SUMMARY

Goal and Scope

The principal aim of this study is to assess the potential reduction in environmental impact attributable to cotton cultivated and processed by smallholder farmers engaged in the REEL Cotton programme, in contrast to a benchmark control group of farmers in the same regions who do not participate in the programme. This research will be publicly disseminated and has been conducted in full compliance with ISO 14044 standards. Furthermore, the study has undergone rigorous evaluation by an external panel of experts. The functional unit considered in this analysis is 1 kg of cotton fibre at the gin gate, with system boundaries established from cradle to gin gate. Economic allocation has been utilized to apportion the environmental burdens between the cotton seeds and the cotton fibre produced at the ginning stage.

The results presented in the main sections of the report are expressed as averages for all countries involved in the study of the REEL Cotton programme, referred to as the "average project," alongside a corresponding benchmark labelled as the "average control." Data were systematically collected from the same regions for both the project and control groups. Subsequently, data from various countries and programmes were weighted according to their production shares to generate a comprehensive average for the REEL project. All regions where data from the REEL programme were accessible have been included in this analysis.

The following impact categories are assessed in this study:

Climate change

Water use

Water consumption

Acidification

Eutrophication

Abiotic depletion potential, fossil

Inventory data

This study evaluated four countries, which are detailed in the table below, along with the corresponding regions from which data were collected for both the 'project' and 'control' farmers.

Country	Region
Pakistan	Punjab, Sindh
Bangladesh	Chuadanga, Kushtia
India	Gujarat, Maharashtra, Madhya Pradesh
Egypt	El gharbeya

The primary data was gathered by our team in collaboration with our partners responsible for sampling. This dataset includes information from the cultivation years 2020-2021, 2021-2022, and 2022-2023, addressing both the agricultural production phase and the ginning process across all countries, with the exception of Egypt, where data was exclusively collected for the 2022-2023 season. This study updates the previous report, with the primary objective of aligning with the scope of the original research to ensure consistency and continuity. By revisiting the initial framework, the update seeks to incorporate new findings, refine methodologies, and provide a more comprehensive understanding of the subject matter.

The main study provides a thorough presentation of inventory data and results, incorporating weighting based on production shares for REEL Cotton. Detailed inventory data and results specific to each country of this study will be available upon request and at the discretion of CottonConnect.

The life cycle inventory has been developed using Sphera's agricultural LCA model (Version 2.1) in Sphera's LCA calculator. The model is based on Sphera's LCA for expert software, version 10.9 and adheres to the latest version of the IPCC 2006 & refinement 2019 Guidelines for National Greenhouse Gas Inventories, the GHG protocol and the PEF method.

Results

The inventory data demonstrates that the REEL project achieves higher yields, reduced water consumption, and improved nitrogen use efficiency. These enhancements are reflected in the impact results, which clearly indicate the benefits of implementing the REEL programme in the studied regions. Across all impact categories, the REEL Cotton project exhibits significant improvements, with potential savings exceeding 30% compared to the control results.

Climate change potential is primarily influenced by field emissions, with substantial contributions from irrigation practices and fertiliser production. Acidification potential shows a similar trend; however, eutrophication potential is predominantly driven by field emissions associated with fertiliser application. Water consumption is largely attributable to irrigation efforts.

Abiotic depletion potential is significantly affected by the use of fossil-based resources, particularly evident in fertiliser production, irrigation activities, and field operations. Importantly, land use change did not emerge as a significant factor in this study's findings.

Ecotoxicity potential aligns with the observed trends in climate change, acidification, and abiotic depletion potential (ADP), with emissions primarily arising from crop protection measures, field applications, and fertiliser usage within the REEL Cotton project. The ecotoxicity results are particularly influenced by a select group of crop protection agents characterized by high toxicity factors. This observation underscores the need for a thorough evaluation of the robustness of these toxicity factors, the identification of substances of concern, and verification of application rates, as well as the prevalence of these substances among farmers.

The quality of the data was evaluated as good to very good; however, some data points and associated impact categories exhibited uncertainty. Thus, enhancing data availability and ensuring consistency in data collection would provide greater reliability in the environmental profile of cotton produced under the REEL project.

Positive aspects regarding data quality include the following:

- Primary data was utilized from a substantial sample size of farmers participating in the programme.
- Control data was also derived from primary sources, collected with the same temporal, geographical, and technological parameters as the project data.
- Where available, multi-year averages were employed to strengthen the analysis.
- Key data points, such as yields and fertiliser usage, were validated.

Conversely, the following limitations affected data quality:

- Not all data was readily accessible from routine data collection, necessitating additional efforts to gather certain data points.
- Estimates for irrigation energy use were generated using a pump model.
- Fertiliser production datasets representing production conditions in India have been used as proxies for the other regions
- Diesel consumption values for machinery (tractors) were not available, so a generic proxy had to be used for all regions
- Ginning energy data was not available, so that secondary data had to be used
- No statistical testing was performed on input parameters, leading to uncertainty regarding the significance of reported differences between the project and control groups.

As a result, absolute values should be interpreted cautiously, particularly when comparing them to findings from other studies.

This study builds upon a previous one conducted in the same area but includes several key differences that limit direct comparisons between the two. First, the scope of the current study has expanded to include a larger number of farmers, thereby broadening the dataset and offering a more comprehensive understanding of the agricultural landscape.

Additionally, there have been changes in the regional composition of the sample, with new regions being represented, leading to a shift in the geographical distribution compared to the earlier study.

Moreover, the climatic conditions during the two studies were notably different. Variations in weather patterns likely influenced agricultural outcomes and farming practices, further complicating direct comparisons.

Considering these factors, the results of the current study should not be interpreted as a "progress report" but rather as a comparison of two distinct periods under different circumstances.

Conclusions

The inventory data used in this study is considered to be reliable. We partnered with a second party to gather sample data from farmers and ginners, which was then verified internally by our experts and further validated by a third party. As a result, the findings demonstrate a notable improvement across most indicators for the REEL Cotton programme, underscoring the advantages of the sustainable practices detailed in the REEL Cotton Code of Conduct 3.0. However, the absence of statistical testing to evaluate the significance of differences in inventory data between project and control farms leaves some "uncertainty about the uncertainty."

We are dedicated to the ongoing development and enhancement of our LCA data collection scheme each year. Continuous and expanded data collection efforts will allow us to reliably measure improvements not only in comparison to the control group but also within the REEL programme itself.

1. GOAL OF THE STUDY

The CottonConnect REEL Project

The REEL (Responsible Environment Enhanced Livelihoods) flagship programme by CottonConnect is a business-oriented initiative designed as a three-year training course for cotton farmers. Its aim is to boost environmental and social advantages while enhancing the sustainability of cotton production. This private standard foster equality and empowerment, improves labour conditions, and enhances the traceability of cotton. Key practices included in the programme focus on increasing yield and minimizing the use of water, chemical pesticides, and fertilisers (CottonConnect, 2021).

Launched in 2010, the CottonConnect REEL Cotton Code of Conduct has been revised in 2016, 2021, and 2024. The programme's definition of sustainable cotton, agreed upon by the Cotton 2040 partners, encompasses social, environmental, and economic sustainability. Our reports indicate that farmers have experienced increased yields, profits, and incomes, thereby supporting the livelihoods of communities reliant on smallholder farming.

The programme is third-party verified by FLOCERT, a global Fairtrade certification body. It has engaged over 200,000 farmers across six countries: India, Pakistan, Bangladesh, China, Egypt, and Turkey.

Goal

The primary objective of this study is to evaluate the potential reduction in environmental impact of cotton produced and processed by smallholder farmers participating in the REEL Cotton Programme, compared to a benchmark control group of farmers in the same regions who are not part of the programme. This assessment will examine the environmental burdens associated with lint cotton production. By enhancing our understanding of the system under study, we can fill knowledge gaps and pinpoint weaknesses within the life cycle. The availability of current and precise life cycle inventory (LCI) data for cotton cultivation and processing will support enhancements in the environmental performance of cotton farming within the REEL programme. This report details the modifications we have implemented and offers critical insights for decision-making regarding the REEL Cotton Programme and future research initiatives.

Comparative assertion

This research performs a comparative analysis in accordance with the ISO 14040 series, examining data from the REEL Cotton initiative alongside an average control group of cotton production from the same geographical areas. The control values serve as a benchmark, demonstrating cotton production that does not follow the guidelines established by the REEL Cotton initiative. Data for both the REEL Cotton initiative and the control group were gathered by our team and our partner organizations. In alignment with ISO 14040 standards, the study has undergone a comprehensive review, including the comparative assertions made within it.

Intended application

The intended application of this study is to analyse the environmental implications of cotton production associated with the REEL project. The study focuses on four countries: India, Pakistan, Bangladesh, and Egypt. However, it does not aim to make direct comparisons among these regions. Consequently, the inventory data and results are reported as aggregate averages, calculated based on the production proportions of each country.

In order to assess the possible environmental benefits associated with farms participating in the REEL project, data was gathered from farms located in the same regions that do not adhere to the farming practices specified in the REEL project Code of Conduct. These findings are designated as 'average control' values, calculated using the same weighting factors based on production share as those used for the project group. Inventory data and results can be provided at the country level upon request.

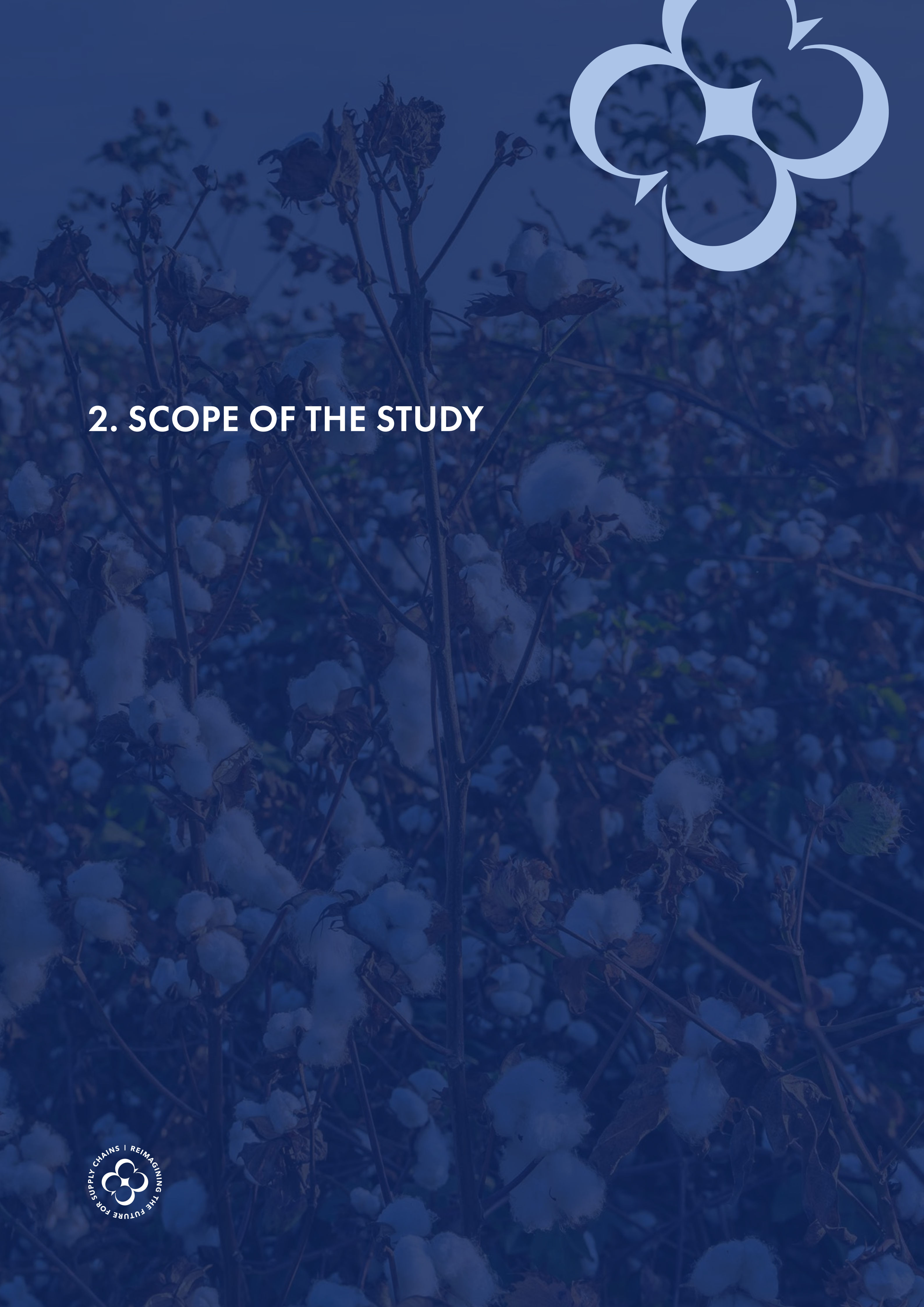
Intended audience

This study will be publicly available and pertains to both internal and external stakeholders. Internal stakeholders are represented by marketing and communications, business development, and research and operations. External stakeholders include the textile supply chain, importers, suppliers, other industry participants, and the general public.

ISO Compliance

This study is conducted according to the requirements of the ISO 14044 and critically reviewed (see section 2.12).

2. SCOPE OF THE STUDY



The presented study refers to cotton cultivation in Pakistan, Bangladesh, India and Egypt. Results are presented for an 'average project' and 'average control'[1]. The average results of the project encompass farms that are part of the REEL project programme, while the average control results pertain to farms in the same geographical areas that do not implement the requisite management practices associated with the REEL initiative. This research thus demonstrates the potential environmental advantages attained by farmers participating in the REEL project. The following sections will detail the overall scope of the project to meet the established objectives. This includes, but is not limited to, identifying specific product systems for analysis, the functions of those products, the functional unit and reference flows, the boundaries of the system, allocation procedures, and the cut-off criteria for the study.

2.1. Product System(s)

All of the considered 'project' product systems in this study are operating under the REEL Cotton Programme. The requirements for the programme are as described in the REEL Cotton Code of Conduct 3.0 detailed in Annex B: (CottonConnect, 2024).

The Responsible Environment Enhanced Livelihoods (REEL) Cotton programme was initially developed for the Indian agricultural sector but is structured to be relevant globally, taking into account regional variations and differences. This programme implements a management system aimed at lowering input costs, minimizing chemical usage, reducing fertiliser application, conserving water, enhancing soil fertility, and fostering a culture of monitoring farming profitability. For a comprehensive overview of the REEL Cotton criteria, please refer REEL Cotton Code of Conduct 3.0 (CottonConnect, 2024). In addition to its environmental goals, the programme emphasizes social benefits, which are also outlined in the Code of Conduct. The target product systems include small-scale farmers in Pakistan, Bangladesh, India, and Egypt who operate under irrigation, with specific regional details provided below.

Table 2-1: **Regions under study**

Country	Region
Pakistan	Punjab, Sindh
Bangladesh	Chuadanga, Kushtia
India	Gujarat, Maharashtra, Madhya Pradesh
Egypt	El gharbeya

The assessment encompasses all countries and regions where the REEL Cotton programme is currently active. The sample utilized for this study represents around 50% of the farmers involved in the REEL programme. For the control group, a subset comprising 10% of the REEL farmers' sample (equating to 5% of the total farmers in the programme) was selected, ensuring similar characteristics such as geography, irrigation methods, and land holdings. Additional details can be found in section 3.1. regarding data collection.

2.2. Product Function(s) and Functional Unit

The Cradle-to-gin-gate system for REEL Cotton covers raw material production from field to ginning.

The functional unit is:

1 kilogram of lint cotton at the gin gate

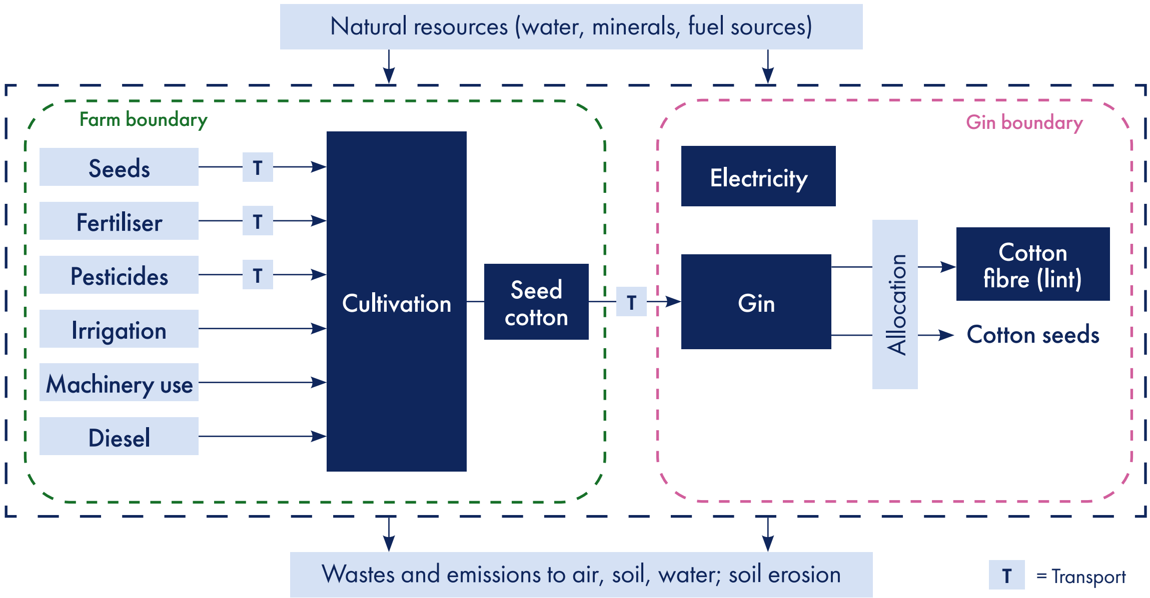
The system boundaries are shown in Figure 2-1. The function of the product is lint cotton for further processing in the textile industry. Potential differences in fibre quality (between regions, harvesting techniques or benchmark) are not considered in this study.

[1] Inventory data and results can be made available on a regional and country level upon request to CottonConnect

2.3. System Boundary

The system boundaries of the life cycle assessment include both, the cotton cultivation and the fibre production (ginning) in accordance with the REEL project (see Figure 2-1).

Figure 2-1: **System boundaries**



The system boundaries utilized in this study are summarized in Table 2-2. This includes all material, and energy flows necessary for the two production phases: cultivation and ginning, as well as all associated waste and emissions. The study takes into account the production of fertilisers and pesticides, field emissions such as N2O, and other emissions, which involve the combustion of leftover biomass from the previous cultivation period (e.g., CH4, SO2). Additionally, it includes the electricity required for ginning and all transportation activities, such as delivering fertilisers to the fields and transporting seed cotton to the gin. An evaluation of land use change (LUC) is also integrated into the study (see section 3.3.5).

The study excludes the environmental impacts associated with draft animals. Generally, draft animals, such as oxen, are utilized only once per crop season for ploughing. They are employed across various fields, regardless of the crop being cultivated, and are also used for other tasks, such as transporting goods to market. Furthermore, soil preparation is primarily conducted by service providers, with animals used for only a few hours on a single cotton field, meaning their use in cotton farming constitutes a very small portion of their overall utility. This multipurpose usage complicates the allocation of environmental impacts from the livestock system to the cotton cultivation system, justifying the assumption that their contribution to the environmental impact of cotton cultivation is minimal and can be disregarded.

The impacts from the production of organic fertiliser were also excluded from the study. There is ongoing debate about whether organic fertiliser should be considered a waste product with no associated burdens from animal husbandry or whether it is a valuable co-product of milk and meat production that should carry an environmental impact. Most life cycle assessment (LCA) models and studies treat this fertiliser as entering the plant production system free of burdens, and this study follows that approach. Given the low reported rates of organic fertiliser application, this method is thought to have a minimal impact on the results, although emissions from its application are considered.

Field clearance (combustion of crop residues) was also not considered in the study, due to low relevance and high data uncertainty. CottonConnect's Code of Conduct (3.0) prohibits the burning of field residues, however, some farmers might still be in the process of transitioning to this new practice, resulting in non-zero field clearance values. Since reliable data on the fraction of farmers field clearance was not available neither for project nor the control farms, the contribution was excluded from the study. In the previous LCA study from 2022 the values were included based on expert judgement but showed low contribution to overall impacts.

Additionally, the end-of-life impacts of ginning waste were excluded, resulting in a system that is burden-free without any benefits attributed to the main product. Gin waste, which consists of broken seeds, fibres, and plant residues, could potentially be viewed as waste requiring further treatment, particularly concerning pesticide residues. Conversely, it is sometimes returned to the land as organic fertiliser, sold to horticultural farms to improve soil conditions, or used in composting. Therefore, attributing no burdens to gin waste is a neutral approach that overlooks a minor potential environmental impact alongside a similarly small environmental benefit from fertiliser use.

As is customary in LCA studies, the construction of capital equipment and the maintenance of support equipment are excluded due to their minimal contribution and the difficulty of measurement. Social factors are beyond the scope of this study, which also excludes human labour from consideration. However, it is important to note that fair and safe labour conditions are fundamental prerequisites of the REEL project.

Table 2-2: **System boundaries**

Included	Excluded
✔ Seed production	✘ Animal draught
✔ Fertiliser and pesticide production	✘ Field clearance (combustion of crop residues)
✔ Irrigation water consumption	✘ Gin waste treatment
✔ Energy required for irrigation	✘ Human labour
✔ Machinery use	✘ Capital goods
✔ Field emissions	✘ Impacts from organic fertiliser supply chain (assumed to be allocated to animal system)
✔ Soil erosion	
✔ Electricity for ginning	
✔ Transports	
✔ Emissions from organic fertiliser application	
✔ LUC	

2.4. Temporal, technological and geographical coverage

Agricultural systems often experience significant fluctuations from year to year due to climatic variations and biotic influences, such as pest infestations. While it is advisable to utilize multi-year averages for analysis, the REEL programme was not consistently operational across all regions during every year, which limited the application of this practice. To enhance geographical representation and mitigate seasonal discrepancies, data from all available years were utilized, as shown in Table 2-3. Consequently, some regions had data from only one season, while others benefited from continuous data spanning up to eight years. Although this method introduces some temporal inconsistencies, it was deemed the most effective way to achieve broader geographical coverage and address seasonal variations. Data were aggregated globally to represent the overall REEL Project, as well as analysed on a country-specific basis to determine emissions related to each country's production shares (refer to Table 2-4).

Table 2-3: **Overview of the cultivation seasons considered in the study**

Country	Region	Years	Number of seasons covered
Pakistan	Punjab	2020-21 to 2021-22 and 2022-23	3
	Sindh	2020-21 to 2021-22 and 2022-23	3
Bangladesh	Chuadanga	2020-21 to 2021-22 and 2022-23	3
	Kushtia	2020-21 to 2021-22 and 2022-23	3
India	Gujarat	2020-21 to 2021-22 and 2022-23	3
	Maharastra	2020-21 to 2021-22 and 2022-23	3
	Madhya Pradesh	2020-21 to 2021-22 and 2022-23	3
Egypt	El gharbeya	2022-23	1

Data regarding the activities of farmers involved in the programme is gathered annually. Throughout the three-year programme cycle, the data of farmers is validated by an external agency during their second year of participation. This study utilized data from all farmers engaged in the programme, encompassing those in their first, second, and third years. While it is anticipated that farmers will enhance their management practices over the three-year cycle, the analysis of their performance throughout the project duration was not included in the study's scope. Consequently, the reported values represent an average across all participating farmers. The sample size for the REEL farmers constitutes 50% of the total farmer participants. Data from the control group is also collected annually, with a sample representing 10% of the REEL farmers (or 5% of the total programme participants). Control farmers are chosen based on criteria such as field size, irrigation methods, and geographical location, ensuring they align with the project farmers on these parameters. Most control farmers are selected from nearby villages where the REEL programme is not implemented.

More information about the data collection procedure is provided in section 3.1. Total average inventory data can be found in section 3.2 and country-level inventory data will be available upon request and at the discretion of CottonConnect. Results are calculated as overall REEL Project, as well as on a country-by-country basis to calculate emissions specific to each country.

Table 2-4:
Production shares

	Lint cotton production (tonnes)	Lint cotton country share of REEL total (%)
Pakistan	1,32,458	15.83
Bangladesh	20,050	2.40
India	6,84,343	81.76
Egypt	149	0.02
Total	**8,37,000**	**100**

The background data, including fertiliser usage and the electricity grid mix at the gin, were derived from the most recent reference year available, specifically 2020 for electricity (refer to sections 2.11. and 3.4.). The results are anticipated to remain valid for a minimum of three years, as three-year averages typically reflect long-term trends that evolve gradually. This slow change is often due to technological advancements in agricultural systems, such as the introduction of improved crop varieties or modifications in management practices. The REEL project has established a code of conduct, outlined in Annex B, which all participating farmers must adhere to. Data were gathered for representative technologies across the countries involved, namely Pakistan, Bangladesh, India, and Egypt.

2.5. Allocation

In scenarios where a system produces multiple valuable outputs, such as cotton production which yields both seed and lint post-ginning, it is essential to determine how to effectively partition the input or output flows between the primary product system and any additional product systems, as outlined in ISO 14040:2006, section 3.17. The ISO standard recommends avoiding allocation whenever feasible, potentially through the expansion of the product system. If allocation is unavoidable, the chosen method should reflect the physical relationships among the co-products, such as energy content or weight. However, these physical allocation methods may not always yield satisfactory results. In such instances, Life Cycle Assessment (LCA) studies may resort to alternative allocation methods, including economic allocation, which divides the environmental burden based on the monetary value of the various products.

The analysis revealed that system expansion or allocation grounded in chemical properties was not effective for the cotton production system. While the seeds are commonly used as animal feed, it remains challenging to ascertain the specific production systems utilizing them and the other feed alternatives they might substitute, especially considering the various countries involved in this study. The effort required to collect data beyond the cotton production systems was evaluated as too extensive for the study's scope. Additionally, allocation based on physical relationships was found to be inapplicable, as the seeds account for the majority of the mass of the gin output, which also encompasses significant energy and carbon content. However, the fibre is clearly the more valuable and primary product of the production system. Thus, allocating based on physical properties would misattribute most environmental impacts to the seeds, distorting the intended purpose of the production system.

As a result, economic allocation was deemed the most appropriate approach for this research. Market value was selected as the allocation method, as it most accurately reflects the demand influencing the production of both products. The allocation ratios utilized are detailed in Section 3.3.9.

2.6. Cut-off Criteria

No cut-off criteria are defined for this study. As summarized in section 2.3., the system boundary was defined based on relevance to the goal of the study. For the processes within the system boundary, all available energy and material flow data have been included in the model. In cases where no matching life cycle inventories are available to represent a flow, proxy data have been applied based on conservative assumptions regarding environmental impacts.

2.7. Selection of LCIA Methodology and Impact Categories

The impact assessment categories and other metrics considered to be of high relevance to the goals of the project are shown in Table 2-5 and Table 2-6. Various impact assessment methodologies are applicable for use in LCA studies e.g. Environmental Footprint v3.0 (EF 3.0), CML, ReCiPe, etc. The study aligns with the impact categories recommended by the Cascale to be used for the Higg MSI (see Table 2-5).

Table 2-5: **SAC Higg MSI Impact Assessment (Source: Cascale)**

Impact Category	LCIA Method	Unit	Reference
Climate Change	IPCC AR6 GWP 100a	kg CO_2 eq.	IPCC 6th Assessment Report. The Physical Science Basis.
Eutrophication	CML-IA baseline 2013	kg phosphate eq.	Center of Environmental Science of Leiden University (CML). 2013. CML-IA Baseline.
Abiotic Resource Depletion	CML-IA baseline 2013	MJ	Center of Environmental Science of Leiden University (CML). 2013. CML-IA Baseline.
Water Resource Depletion	AWARE*	m^3	http://www.wulca-waterlca.org
Chemistry	Semi-quantitative impacts (Usetox) + qualitative modifiers	Chemistry Units	Usetox (https://usetox.org) & SAC Chemistry Task Team. 2018.

* In the GaBi software there are multiple AWARE methods that represent different characterizations of the unknown geographics. For this project, the EF 3.1 Water Scarcity method found under EF 3.1 (Environmental Footprint 3.1) is used.

The impact methods used in this study cover all impacts of the Cascale Higg MSI assessment framework[2]. Acidification was added to the assessment because it covers additional emissions of typical concern from agriculture, especially ammonia. For toxicity, the EF 3.1.

Table 2-6 describes the impact categories used in the study. Table 2-7 separates the impact categories that are considered to be less robust than others. In context of the Product Environmental Footprint (PEF), the JRC provides robustness factors used in weighting sets to aggregate several midpoint impact categories into a single score (Sala S. et al. 2018). Ecotoxicity has a robustness factor of 17% compared to e.g. 87% for climate change or 67% for acidification(ibid.).[3] Therefore, this impact category should be interpreted with particular care as it is related to larger methodological uncertainty compared to the other assessed impacts.

[2] Data submission to the Cascale is not in scope of this study. The modification of the USEtox results with qualitative modifiers as requested by the Cascale for the assessment of chemistry is also not in scope of the study.

[3] E.g. assigning a Level III score to the categories inventory coverage completeness, inventory robustness and recommendation of Impact Assessment Method would yield a robustness factor of 20%, and lower if one was assumed to be "interim".

Table 2-6: **Summary of impact categories used in the study**

Impact Category	Description	Unit	Method
Climate change (global warming potential)	The release of greenhouse gases, such as CO_2 and methane, is resulting in greater absorption of radiation emitted by the Earth. This intensification of the natural greenhouse effect may adversely affect the health of ecosystems, human populations, and overall material welfare.	kg CO_2 equivalent	EF 3.1
Acidification Potential	The acidification potential is an indicator of emissions that negatively impact the environment by causing acidification. It evaluates how effectively a molecule can raise the concentration of hydrogen ions (H+) in water, which in turn lowers the pH level. The consequences of this process may include increased fish mortality, decline in forest health, and damage to building materials.	moles H+ equivalent	EF 3.1
Eutrophication (terrestrial, freshwater, marine)	Eutrophication encompasses the various effects resulting from elevated concentrations of macronutrients, primarily nitrogen (N) and phosphorus (P). The enrichment of these nutrients can trigger unfavourable changes in species diversity and an increase in biomass in both aquatic and terrestrial environments. In aquatic systems, this heightened biomass can result in reduced oxygen levels due to the increased oxygen demand during the decomposition of organic matter.	g phosphate equivalent	CML 2013
Abiotic Resource Depletion (fossil)	Abiotic Depletion Potential is a measure for the use of non-renewable energy carriers, comparable to the Cumulative Energy Demand (CED) of fossil fuels	MJ	CML 2013
Blue Water Consumption	A measure of the net intake and release of fresh water across the life of the product system. This is not an indicator of environmental impact without the addition of information about regional water availability (i.e. water use, see below).	kg of water	Inventory
Water Use	An assessment of water scarcity that accounts for the net intake and release of freshwater throughout the product system's lifecycle, taking into consideration the availability of water in various regions.	m3 world equivalent	EF 3.1
Ecotoxicity	A measure of toxic emissions which are directly harmful to the health of the environment.	Comparative toxic units (CTUh, CTUe)	EF 3.1

It is essential to understand that the aforementioned impact categories signify potential impacts; they serve as estimates of environmental effects that may arise if emissions (a) adhere to the specified impact pathway and (b) satisfy particular conditions in the environment where they are released. Additionally, the inventory reflects only that segment of the overall environmental burden that aligns with the functional unit (relative approach). Consequently, the results of the Life Cycle Impact Assessment (LCIA) are expressed in relative terms and do not forecast actual impacts, threshold exceedances, safety margins, or associated risks.

The global warming potential (GWP) impact category is evaluated using characterization factors derived from the IPCC, as incorporated in the EF 3.1 set of factors, which is based on a 100-year period (GWP100) and is currently the most prevalent metric used.

This project involves an ecotoxicity evaluation using the EF 3.1 methodology, which is based on a modified[4] version of the USEtox™ characterization model. USEtox™ is currently recognized as the leading method for toxicity assessment in Life Cycle Assessment (LCA) and is the agreed-upon methodology of the UNEP-SETAC Life Cycle Initiative. The precision of the current USEtox™ characterization factors for freshwater ecotoxicity is estimated to be within a factor of 10–100 (Rosenbaum et al., 2008). This represents a notable advancement over previous toxicity characterization models, although it is still significantly less precise than other impact categories mentioned earlier. Given the limitations of the characterization model, it is crucial to interpret results for this impact category with caution, as highlighted above.

This study is designed to facilitate comparative assertions regarding third-party disclosure, and as such, no grouping or quantitative cross-category weighting has been utilized. Each impact is analysed independently, without consideration of other categories, leading to the final conclusions and recommendations. While social impacts are not part of this study, this does not imply that they are not assessed. Additional information is available on our website.

2.8. Interpretation to be Used

The results of the LCI and LCIA were interpreted according to the Goal and Scope. The interpretation addresses the following topics:

- Recognition of critical findings, such as the essential process steps, materials, and emissions that contribute to the overall results.
- Analysis of the completeness, sensitivity, and consistency of the data to validate the exclusion of information from the system boundaries and the rationale for utilizing proxy data.
- Presentation of conclusions, limitations, and recommendations.

In cases where no product outperforms all alternatives in every impact category, a cross-category evaluation is necessary to assess the environmental superiority of one product over another. Since ISO 14044 disallows the use of quantitative weighting factors in public comparative claims, this evaluation will be performed qualitatively. The defensibility of the findings will depend on the authors' expertise and their capacity to clearly communicate the reasoning behind the final conclusions.

[4] Modified 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 3.0 compared to the original USEtox factors. See Saouter et al. (2018) for details.

2.9. Data Quality Requirements

The data utilized to construct the inventory model must be as precise, complete, consistent, and representative as possible, aligned with the study's goals and scope while adhering to time and budget constraints.

Precision Hierarchy: Measured primary data is deemed the most precise, followed by calculated data, literature-derived data, and estimated data. The objective is to model all relevant foreground processes using measured or calculated primary data.

Completeness: This criterion is assessed based on the thoroughness of inputs and outputs for each unit process, as well as the completeness of the unit processes themselves. The aim is to capture all pertinent data in this context.

Consistency: This aspect refers to the modelling choices and data sources employed. The goal is to ensure that variations in results accurately reflect differences between product systems, rather than discrepancies arising from inconsistent modelling choices, data sources, emission factors, or other artifacts.

Reproducibility: This concept indicates the extent to which third parties can replicate the study's results based on the information provided in this report. The objective is to offer sufficient transparency so that third parties can approximate the reported results. However, this capability may be limited by the exclusion of confidential primary data and the availability of the same background data sources.

Representativeness: This criterion reflects how well the data aligns with the geographical, temporal, and technological requirements established in the study's goals and scope. The aim is to utilize the most representative primary data for all foreground processes and the most representative industry-average data for all background processes. In cases where such data is unavailable (e.g., lack of industry-average data for a specific country), the best-available proxy data were employed.

An evaluation of data quality in relation to these requirements is presented in Chapter 5 of this report. For a summary of the study's limitations, including those related to data quality, please refer to Section 6.2.

2.10. Type and Format of the Report

In accordance with the ISO requirements (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.

2.11. Software and Database

The life cycle inventory has been developed using Sphera's agricultural LCA model (Version 2.1) in Sphera's LCA calculator. The model is based on Sphera's LCA for expert software, version 10.9 and adheres to the latest version of the IPCC 2006 & refinement 2019 Guidelines for National Greenhouse Gas Inventories, the GHG protocol and the PEF method. For further information please refer to the Documentation: Agricultural LCA Model – Part 1 – Model and Methods 2024 . The GaBi 2024.2 LCI database provides the life cycle inventory data for several of the raw and process materials obtained from the background system (see section 3.4.).

[5] https://lcadatabase.sphera.com/dataset-documentation-download/

2.12. External and critical review

When the findings of a Life Cycle Assessment (LCA) are intended for communication to external parties, such as stakeholders beyond the commissioner or the practitioner of the assessment, it can have implications for the interests of competitors and other stakeholders. In these instances, the standards ISO 14040:2009 and ISO 14044:2006 mandate the implementation of a Critical Review. The role of the reviewers is to evaluate whether the assessment meets the necessary criteria:

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 are appropriate and reasonable in relation to the goal of the study,
- The interpretations reflect the limitations identified and the goal of the study, and
- The study report is transparent and consistent.

External review details:

Textile Exchange
(Felicity Clarke, Debra Guo, Bowie Miles, Francesca Sartor, and Eleni Thrasyvoulou)

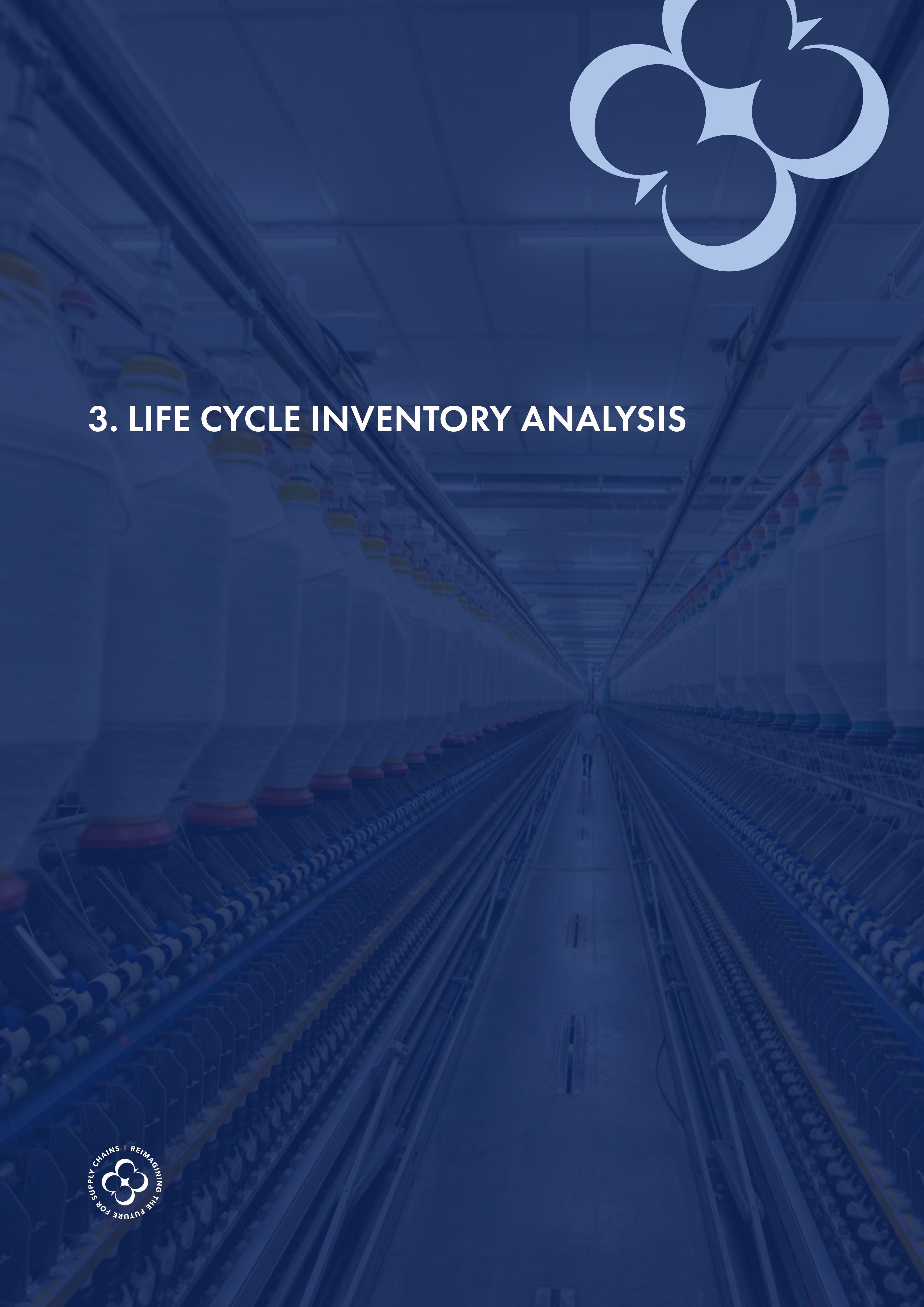
Dr. R. Santhi, Ph.D., FISSS
(Former Director, Directorate of Natural Resource Management and Professor & Head, Soil Science & Agricultural Chemistry, Tamil Nadu Agricultural University (TNAU), Coimbatore, Tamil Nadu)

Critical review details:

Dr. Keshav R. Kranthi, Ph.D.
(Chief Scientist, ICAC)

Joël Mertens
Director of Higg Product Tools, Cascale

The Critical Review Statement can be found in Annex A. The Critical Review Report containing the comments and recommendations by the independent expert(s) in accordance with ISO/TS 14071.



3. LIFE CYCLE INVENTORY ANALYSIS

3.1. Data Collection Procedure

We undertook the collection of primary data, leveraging existing partnerships with independent entities, from the farmers involved in the REEL project. This initiative also included the establishment of benchmark values for farms situated in the same geographical areas as those participating in the project, as detailed in section 2.4.. The data collected from the programme farmers are subject to multiple level of validation including first level of validation by farm team followed be second level of validation by MEL team and lastly third-party validation by an external agency encompassing critical metrics such as crop yields, fertiliser application, and irrigation practices. For validation purposes, a sample size is determined by the square root of the total number of farmers, this validation takes place after the harvest and selling season. During this process, the agency collects the FFB data from CottonConnect for the sampled farmers and conducts in-person interviews to validate the information. This validation process significantly enhances the reliability of the input data, thereby improving the overall outcomes of the study. Some datapoints required for the LCA were not available via the regular data collection scheme and had to be added based on additional data collection from farm teams. Parameters that are based on validated data are marked in Table 3-1.

Upon receipt, each questionnaire underwent cross-checking for completeness and plausibility through mass balance analysis and internal and external benchmarking. In cases where gaps, outliers, or inconsistencies were identified, we engaged with the data providers to address any outstanding issues. In some instances, additional farm-level sample data were collected by our partners, who also conducted necessary checks. The final datasets were then shared with us, which performed validations and reviews to ensure data accuracy. Consequently, the responsibility for the accuracy of the input data rests with us.

Data were averaged globally to represent the overall REEL project and also analysed on a country-by-country basis to calculate emissions specific to each country based on production shares (refer to Table 2-4). The averaged inventory data is presented in Section 3.2., while country-specific inventory data will be available upon request and at the discretion of CottonConnect. It is important to note that, as outlined in the study's scope, results are calculated as a total average for both the project and control groups across all countries, as well as for specific emissions in each country.

Electricity consumption at the gin was modelled using secondary data from all ginning locations, with no differentiation made between control and project groups for ginning activities. Key data collected included electricity consumption, source, and the ratio of by-products and waste (seed and fibre). Transportation distances from farm to gin were also gathered, with the assumption that they are the same for both control and project groups, as transport distances to the gin are not affected by the REEL programme. Assumptions regarding energy consumption from irrigation, soil erosion rates, and ginning processes are detailed in Section 3.3.

3.2. Farm and gin inventory data

The following inventory tables provide the averages (weighted by share in production, see Table 2-4) of the inventory data used, including the country minimum, maximum value. As detailed in section 2.4., calculations were carried out utilizing the country wise life cycle inventory data and global total LCA results were then calculated. Therefore, the tables provide average values that are only indicative and do not display the data used in the model[6]. Minimum and maximum values help to understand the country variation in the inventory data (see also section 4.4. on uncertainty and regional variability).

The inventory data for all regions (i.e., the data used in the calculations) will be available upon request and at the discretion of CottonConnect. As detailed in the scope of the study, the aim is to provide an indication of potential environmental savings that could be achieved under the REEL project and does not seek to compare results between countries.

[6] For testing purposes, the LCA model used in this study (see section 3.3.) was also run with the aggregated average data and the results are close (<10% deviation) to those obtained with the "bottom up" approach of aggregating regional impact assessment results. The shown inventory data are thus good indicator to understand the contribution to the impact assessment results shown in section 4.

Table 3-1: **Overview of inventory data**

	Unit	Project	Control	Country minimum	Country maximum	Validated
Year	-	See Table 2-3	See Table 2-3			n.a.
Diesel for field work	l/ha	33.9	36.6[4]	NA	NA	no (additional data collection)
Seed	kg/ha	4.72	6.00	2.23	19.45	no (additional data collection
Yield (seed cotton)	kg/ha	1946.91	1754.15	1679	3940	yes
Irrigation	m^3/ ha	1724.23	2436.23	1226	3478	yes
Diesel for Irrigation	kg/ha	0	0	0	0	no (estimated with pump model)
Total N applied		124.46	168.82	n.a.[2]		
Calcium ammonium nitrate	kg/ha	11.17	18.78	n.a.[2]		yes
Diammonium phosphate	kg/ha	75.95	203.50			yes
NPK 15-15-15	kg/ha	12.01	15.92			yes
Urea	kg/ha	198.16	238.22			yes
Organic fertiliser (as total N applied)	kg/ha	6.82	3.70			yes
Zinc	kg/ha	0.06	0.03	0	0.06	yes
Boron	kg/ha	0.31	0.03	0	0.27	yes
Crop protection (sum of active ingredients)[1]	kg/ha	0.61	0.81	0.75	0.81	yes

[1] Pesticide use was assessed based on active ingredients used (see section 4.1.7 Toxicity). Due to the long list of actives used they are summarized here into a single number.

[2] Different fertiliser profiles are used in different regions. Min values of zero and maximum values are therefore of limited meaningfulness and are therefore not shown.

[3] CottonConnect code of Conduct (3.0) rules out combustion of field residues, so this number is based on farms still transitioning to adopting the new practice.

[4] Diesel consumption in field work is assumed to be 29.637 L/Ha for reduced tillage and for high tillage 59.33 L/Ha for all the regions. Weighted average based on the proportion of farmers adopting different tillage practices was used. (Akbarnia A., Farhani F., 2014. Study of fuel consumption in three tillage methods. Res. Agr. Eng., 60: 142–147.)

Table 3-2: **Inventory data gin**

	Unit	Project and control[2]
Transport distance truck (average distance from farm to gin)	km	27
Output cotton fibre (ginning out turn, lints)	kg/ 1000 kg of seed cotton (input)	361
Output cotton seeds	kg/ 1000 kg of seed cotton (input)	616
Other (waste etc.)	kg/ 1000 kg of seed cotton (input)	33.3
Energy use (Electricity)	MJ/ 1000 kg of seed cotton (input)	316.67
Electricity source	-	Grid mix
Price fibre	monetary unit[1]/ kg fibre	3.14
Price seeds	monetary unit[1]/ kg seed	0.83

[1] Values were transferred from local currency to US$. However, for allocation, only the relative difference in prices matter. Therefore, the term "monetary unit" was used to avoid confusion around currencies and exchange rates

[2] Gin inventory data applies to both, project and control except energy use which are used separately for project & control based on the Cascale methodology report on energy calculation for ginning unit.

As outlined in Section 3.1. (Data Collection), the majority of the data was obtained through the regular assessment of the REEL Cotton projects. However, uncertainties persisted concerning the energy use and energy sources of the irrigation pumps. To maintain consistency across the various regions assessed, it was determined that the generic pump model included in the LCA FE 10.9 database would be utilized. For further details, please refer to Section 3.3.7.

According to the inventory data in Table 3-1, project farmers achieved a 10% increase in yield, along with a 27% decrease in both water consumption and pesticide usage compared to the control group. These improvements in yield, pesticide, and water usage do not match exactly with the latest published impact results for real cotton for the 2022-2023 period, which indicated an 18.5% yield increase and a 21.6% reduction in water use, with pesticide reduction reported at 17.1%. The differences arise from the varying temporal references, as this study employs long-term averages, while the impact results focus on a single season.

3.3. Inventory data update and relation to previous LCA study

This section outlines the updates to the inventory data used in the current study and examines its relationship to the data from the previous Life Cycle Assessment (LCA) study. The inventory has been revised to incorporate more recent information, including updated inputs, processes, and environmental impacts. These revisions were made to enhance accuracy and relevance compared to the earlier study.

The updated data remains aligned with the scope of the previous LCA, ensuring consistency in key parameters while benefiting from improvements in data quality and methodology. The revised inventory also integrates new findings and technological advancements, which may affect the results and impact categories. By comparing the updated data with that from the previous LCA study, this section highlights significant differences and explores their potential implications for the overall assessment.

In the previous study, the yield inventory was higher compared to this study. This discrepancy is mainly due to the large number of farmers included in this study and the fact that the earlier study considered data from eight seasons, whereas this study incorporates only three seasons. Additionally, this study includes data from Egypt for the 2022-2023 period, while China was excluded due to the unavailability of data for certain inputs.

Regarding energy and fuel consumption at the farm and ginning levels, this study used secondary data sources to estimate energy use at the ginning unit, based on the Cascale methodology[7] report. In contrast, the previous study relied on incomplete data, which likely led to an underestimation of energy consumption at the ginning unit. For fuel consumption in fieldwork, secondary data from a research paper was used to estimate diesel consumption for land management in both project and control groups. In the earlier study, fuel consumption was based on assumptions rather than empirical data.

When comparing water use results with the 2022 study, it was observed that water usage on the farm has decreased by over 50% for both the project and control groups. This reduction is attributed to targeted programmes that further minimized water consumption, including timely rainfall and the promotion of alternative furrow irrigation. Additionally, unseasonal rainfall during the 2022-2023 crop season, with medium to heavy rainfall from July to September, contributed to this improvement.

3.4. Model

3.4.1. Method

The life cycle inventory has been developed using Sphera's agricultural LCA model (Version 2.1) in Sphera's LCA calculator. The model is based on Sphera's LCA for expert software, version 10.9 and adheres to the latest version of the IPCC 2006 & refinement 2019 Guidelines for National Greenhouse Gas Inventories, the GHG protocol and the PEF method. For further information please refer to the Documentation: Agricultural LCA Model – Part 1 – Model and Methods 2024[8].

By integrating datasets from the GaBi 2024.2 database, the model facilitates the assessment of all impacts arising from upstream processes, field activities, and downstream processing, specifically ginning. Each subprocess's contribution can be analysed independently. The table below presents an overview of the various modules within the model and the approach to emission modelling. Grey cells contain general descriptions of the modules, while white cells detail the sub-modules and their specific characteristics. These modules are also utilized to categorize results in the contribution analysis (section 4.).

[7] Cascale, 2024, ICAC, 2023

[8] https://lcadatabase.sphera.com/dataset-documentation-download/

Table 3-3: **Overview of model modules and approaches**

Module	Description	Approach
Field emissions	**Emissions from agricultural soil related to fertiliser application, crop residues and soil erosion**	**(see below)**
Emissions from fertiliser application (direct and indirect field emissions)	Nitrous oxide emissions to air from microbial nutrient turnover (denitrification), ammonia emissions to air from mineral and organic fertiliser, nitrate emissions to water through leaching, carbon dioxide emissions from carbon contained in fertiliser (urea, lime)	Based on approach and emission factors provided in 2019 IPCC guidelines; fuel consumption considered under field work
Emissions from crop residues	Additional nitrogenous emissions due to nitrogen contained in crop residues	Based on approach provided in 2019 IPCC guidelines
Emissions from soil erosion	Nutrients contained in the soil reaching surface water bodies with soil erosion	Based on data from Global Soil Erosion Modelling platform (GloSEM) and default nutrient content in soil
Emissions from LUC	Carbon emissions related to the conversion of forest (or other land use type) to agricultural land	Based on primary data and FAO statistical data using approach from PAS 2050
Irrigation	**Emissions from water irrigation**	**(see below)**
Irrigation water requirement	Water used in irrigation	Based on collected primary data
Irrigation energy	Energy consumption from pumps, includes impacts of provision of energy and combustion emissions (in case of diesel pumps)	Based on pump model in LCA FE 10.9
Field work	**Emissions from tractor use and provision of fuel**	**(see below)**
Tractor use	Emissions from fuel combustion	Based on tractor and truck model in LCA FE 10.9
Provision of Diesel	Upstream emissions in the fuel supply chain (e.g. refinery)	Based on energy provision datasets from LCA FE 10.9 database (yearly updated)
Provision of fertiliser	**Emissions related to fertiliser production**	**(see below)**
Fertiliser production	Upstream emissions in the fertiliser supply chain (e.g. energy consumption of production)	Based on fertiliser production datasets from LCA FE 10.9 database
Crop protection	**Emissions related to production and application of crop protection agents**	**(see below)**
Pesticide production	Upstream emissions in the pesticide supply chain (e.g. energy consumption of production)	Based on pesticide production datasets from LCA FE 10.9 database
Pesticide application	Emission of pesticides into the environment	EF 3.1 characterization factors used for toxicity impact. Generic emission factors to air, water and soil used according to PEF method (90% to soil, 9% to air, 1% to water).
Ginning	**Additional module added to the LeanAg model. All emissions related to ginning (separation of seed and lint)**	**Based on energy consumption, seed-to-lint ratios, typical transport distances and prices for allocation**
Provision of electricity	Upstream emissions in the fuel supply chain (e.g. refinery)	Based on energy provision datasets from LCA FE 10.9 database (yearly updated)
Transports	**Transports of agricultural inputs (fertiliser and pesticides to the field**	**Based on transport distance, using the truck model in LCA FE 10.9 and provision of diesel**
Transports to gin	**Transport of raw cotton**	**Based on transport distance, using the truck model in LCA FE 10.9 and provision of diesel**

3.4.2. Emission from fertiliser application

The emission factors referenced in this report are in accordance with the IPCC 2006/2019 Guidelines for National Greenhouse Gas Inventories (Tier 1, aggregated). These guidelines also present disaggregated emission factors for N_2O, distinguishing between wet and dry climate[9]. Although the majority of regions analysed in this study are classified as dry climates, which would typically apply a lower emission factor of 0.005, the presence of irrigation in all regions results in wet conditions during certain times of the cultivation year. As a result, the aggregated factor was employed to ensure consistency with a broader spectrum of Life Cycle Assessments (LCA) for cotton cultivation systems, as outlined in section 5.2.

Table 3-4: **Emission factors for fertiliser application**

Compartment	Emission Factor	Unit
N_2O	0.01	kg N_2O-N/kg N
NH_3 from urea	0.15	kg NH_3-N/kg N
NH_3 from other min. fertilisers	0.02	kg NH_3-N/kg N
NO_3-	Based on N Balance (factor 0.24 used in scenario analysis)	kg NO_3—-N/kg N
CO_2 eq. direct from urea	0.2	kg CO_2-C/kg
P mineral	0.00048	kg P/kg P_2O_5

This study uses the N balance approach suggested in the PEF method (European Commission, 2017) to assess nitrate leaching to water:

"Total NO_3—-N emission to water" = "NO_3— base loss" + "additional NO_3—-N emissions to water",

with

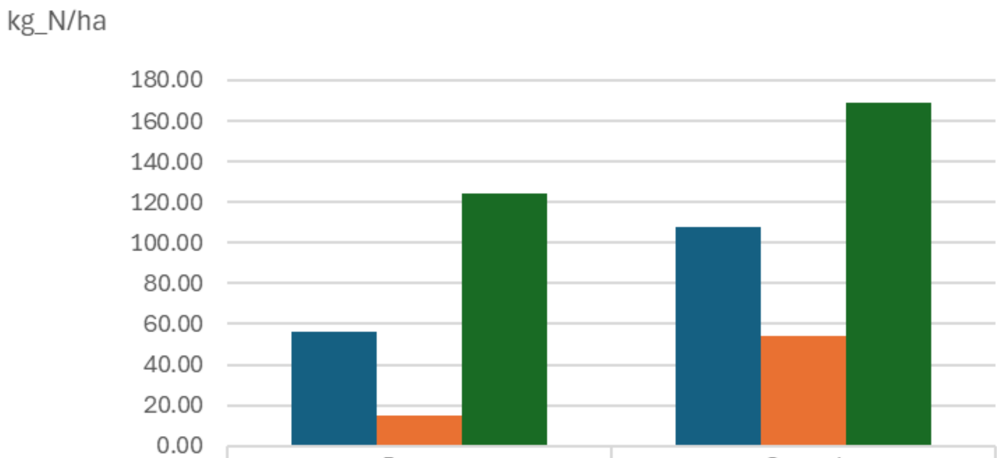
"Additional NO_3—-N emissions to water" = "N input with all fertilisers" – "N-removal with the harvest" – "NH_3 emissions to air" – "N_2O emissions to air" – "N2 emissions to air" - " NO_3— base loss".

The NO_3-base loss is assumed to be 10% (European Commission, 2017). If in certain low-input schemes the value for "additional NO_3—-N emissions to water" becomes negative, the value is to be set to "0". Moreover, in such cases the absolute value of the calculated "additional NO_3—-N emissions to water" is inventoried as additional N-fertiliser input into the system, using the same combination of N-fertilisers as employed to the analysed crop. This last step serves to avoid fertility-depletion schemes by capturing the N-depletion by the analysed crop that is assumed to lead to the need for additional fertiliser later on and to keep the same soil fertility level (European Commission, 2017). In addition, this serves as a conservative approach to ensure data consistency between reported yields and fertiliser application.

The resulting (simplified) N balance is shown in Figure 3 1. "N balance 1" is the N balance after subtracting nitrogen removed with the harvest. "N balance 2" is N balance 1 minus all the assumed gaseous emissions. This is the amount of nitrogen susceptible to leaching. The values again are an indicative total average, the N balance could differ from region to region, and some regions indeed showed negative N balances. On average, it can be seen that with the REEL project, fertilizer application per ha is lower, but also the N surplus after assumed losses (N balance 2). Considering that the REEL project also achieves higher yields, this is a clear indication of improved nitrogen use efficiency.

[9] 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 climate occur in temperate and boreal zones where the ratio of annual precipitation: potential evapotranspiration < 1, and tropical zones where annual precipitation < 1000 mm

Figure 3-1:
Nitrogen balance, total average



	Project	Control
N Balance 1	56.32	107.42
N Balance 2	14.98	54.05
Total N- Applied	124.46	168.82

3.4.3. Emission from crop residues

Emissions resulting from crop residues were estimated in accordance with the IPCC 2006/2019 Guidelines for National Greenhouse Gas Inventories, utilizing the default values outlined in Table 11.1A, where cotton is categorized as "other crop." The biomass used for field clearance was deducted from the total above-ground biomass available.

3.4.4. Emission from LUC

Emissions from LUC are calculated according to the approach outlined in PAS 2050. Primary data was used to assess whether LUC occurred, i.e. if the area studied has been under agricultural use for more than 20 years or not (reference time frame suggested by PAS 2050). The assessment revealed that no land use change has occurred in any of the countries examined

3.4.5. Emission from soil erosion

The assessment of soil erosion rates utilized data from the Global Soil Erosion Modelling platform (GloSEM)[10], supplied by the Joint Research Centre of the European Commission. Regional averages were computed from the provided 25 km raster data (see Table 3-5). It was posited that 20% of the total soil erosion eventually reaches surface water bodies (Prasuhn, 2006)). The phosphorus concentration in the soil was estimated at 500 mg/kg, which is on the lower end of the spectrum reported by (Prasuhn, 2006).

3.4.6. Irrigation

The quantity of irrigation water applied was systematically recorded in the primary data collection (see Table 3-1). However, data concerning the energy consumption for pumping was not available. As a result, a pump model from Sphera's Lean AgModel was utilized to estimate the energy consumption associated with irrigation. Documentation for this pump model can be accessed online[11]. The following assumptions were made during the calculations:

- It was presumed that all pumps operated on diesel, which is a conservative estimate given its greater environmental impact compared to electric pumps.
- Country averages from FAO's Aquastat were employed to delineate the proportion of surface water versus groundwater usage.
- An average groundwater depth of 11.5 meters was assumed to estimate the pumping height for groundwater extraction (Fan et al., 2013).

These assumptions were implemented to maintain a consistent approach across all assessed alternatives and to mitigate the risk of result distortion due to unsubstantiated differences in irrigation energy consumption among regions or between project and control groups. However, these assumptions do simplify the analysis, and more refined data collection in this area could be beneficial for subsequent studies (see section 6.2.).

[10] https://esdac.jrc.ec.europa.eu/content/global-soil-erosion
[11] http://gabi-documentation-2022.gabi-software.com/xml-data/processes/15903a91-f76f-4535-aaf3-43d89962cfe4.xml

3.4.7. Crop protection

Primary data was gathered regarding the application rates of all active ingredients reported. It is important to note that not all farmers utilized the same active ingredients, leading to an averaging of application rates across the entire farmer population. Consequently, even those active ingredients that were infrequently employed were included in the assessment, albeit with a minimal average application rate. Various factors influence the proportion of a pesticide that escapes the system boundary, resulting in emissions to air and water. A comprehensive evaluation of these emission pathways was beyond the scope of this study. Instead, generic emission factors were applied to air, water, and soil (90% to soil, 9% to air, and 1% to water) in accordance with the PEF method (European Commission, 2021). While this approach represents a simplification, it was consistently applied across all regions and between the project and control alternatives. For further justification of these simplifications, the PEF method should be consulted. The characterization factors for ecotoxicity from EF 3.0 were employed to evaluate the toxicity of the active ingredients utilized. In cases where no characterization factor was available in EF 3.0 for certain active ingredients, an average toxicity factor derived from the 50 most commonly used pesticides (Maggi et al., 2019) was utilized as a proxy.

3.4.8. Allocation at gin

The allocation of environmental burdens between fibre and seeds was determined using market prices obtained from primary data collection. Notably, the allocation ratio employed in this study assigns a lower environmental burden to fibre, aligning with other reports, and should be considered when reviewing the results. Data for the study was directly sourced from farmers and corresponds to the temporal reference specified in Section 2.4., representing averages over multiple years. Based on this data, the derived allocation ratio was computed to approximately 81% for fibre and 19% for seeds. An investigation by the Cascale Cotton LCA Methodology (2024) reported a similar allocation ratio of 82.7% for fibre and 17.3% for cotton seeds. Additionally, the same prices and allocation ratios were applied to both the project and control groups, ensuring that the allocation methodology does not impact the comparison between the two alternatives.

3.5. Background Data

Table 3-5: **Background datasets**

The following table lists all background datasets used from the LCA FE 2024.2 database. Documentation for all Sphera datasets can be found online (Sphera Solutions Inc., 2024).

Material/ process	Location	Dataset	Data Provider	Reference Year	Comment
Urea fertiliser	India	IN: Urea (agrarian)	sphera	2023	Used as Proxy for all countries. Fertiliser production for Egypt, Bangladesh and Pakistan are not available in LCA FE 10.9. Since India and Pakistan represent > 90% of production (and therefore weighted average), the approximation in considered to be fair.
Diammonium phosphate	India	IN: Diammonium phosphate granular fertiliser (DAP)	sphera	2023	see above
Calcium ammonium nitrate	India	IN: Calcium ammonium nitrate (CAN, solid)	sphera	2023	see above
NPK fertiliser	India	IN: NPK 15-15-15	sphera	2023	See above. While specific nitrogen content of different NPK fertiliser was considered in emission modelling, NPK 15-15-15 fertiliser is used as proxy for the production of NPK fertilisers with different nutrient concentrations
Pesticide production	GLO	Pesticide (average)	sphera	2023	Used as proxy for all countries and all active ingredients (no specific datasets available and low impact on results)
Tractor	GLO	GLO: Universal Tractor	sphera	2023	
Truck	GLO	GLO: Truck, Euro 0 - 6 mix, 14 - 20t gross weight / 11,4t payload capacity	sphera	2023	
Diesel provision	India	IN: Diesel mix at filling station	sphera	2020	Also used as proxy for Pakistan and Bangladesh
	Egypt	CN: Diesel mix at filling station	sphera	2020	
Electricity	Bangladesh	BD: Electricity grid mix	sphera	2020	
	Egypt	ZA: Electricity grid mix	sphera	2020	Proxy
	Pakistan	PK: Electricity grid mix	sphera	2020	
	India	IN: Electricity grid mix	sphera	2020	

The inconsistency in the availability of country-specific datasets has resulted in the necessity to utilize the best available proxies. This is especially critical for fertiliser production datasets, which are significant contributors to the evaluated environmental impacts. Based on the production shares presented in see Table 2-4, the fertiliser datasets from India are identified as the most pertinent proxy for Pakistan. The use of these proxy datasets is applicable to both the project and control groups, ensuring that the comparison between the two alternatives is not compromised. However, it is essential to recognize that this may influence the absolute values and regional results, as discussed in section 5.3. concerning data quality assessment and section 6.2. on limitations.

3.6. Life Cycle Inventory Analysis Results

According to ISO 14044, the results derived from Life Cycle Inventory (LCI) analysis are defined as the "outcome of a life cycle inventory analysis that catalogs the flows crossing the system boundary and establishes the basis for life cycle impact assessment." While the complete inventory encompasses a vast array of flows, its informational significance is limited without the accompanying impact assessment. A summary of the inventory data, highlighting the key flows that influence the impact assessment categories being examined, will be available upon request and at the discretion of CottonConnect. Detailed information about REEL programmes can be found https://www.cottonconnect.org/sustainable-practices.

4. RESULTS

This chapter presents the findings related to the impact categories and supplementary metrics outlined in section 2.7. It is important to emphasize that the impact categories reported here reflect potential environmental impacts, meaning they serve as estimates of the environmental consequences that may arise if emissions adhere to the specified impact pathway and satisfy particular conditions in the receiving environment. Furthermore, the inventory only accounts for that portion of the overall environmental burden that aligns with the selected functional unit (relative approach). Consequently, the results of the Life Cycle Impact Assessment (LCIA) are expressed in relative terms and do not forecast actual impacts, the surpassing of thresholds, safety margins, or associated risks.

Given the data structure and models employed in this study, statistical testing was not performed, which is a standard practice in many Life Cycle Assessment (LCA) studies. The following terminology is utilized to articulate differences in results, drawing on expert judgment and findings from prior research (Cotton Inc 2017, CmiA 2021).

Table 4-1: **Differences in results and corresponding wording**

Range of difference in results	Wording
<10%	small, slight, limited, insignificant
10% – 30%	visible, clear
>30%	large, strong, significant

Please refer to section 4.4. on uncertainty and regional availability and section 6.2. on limitations for a better understanding of the robustness of the results.

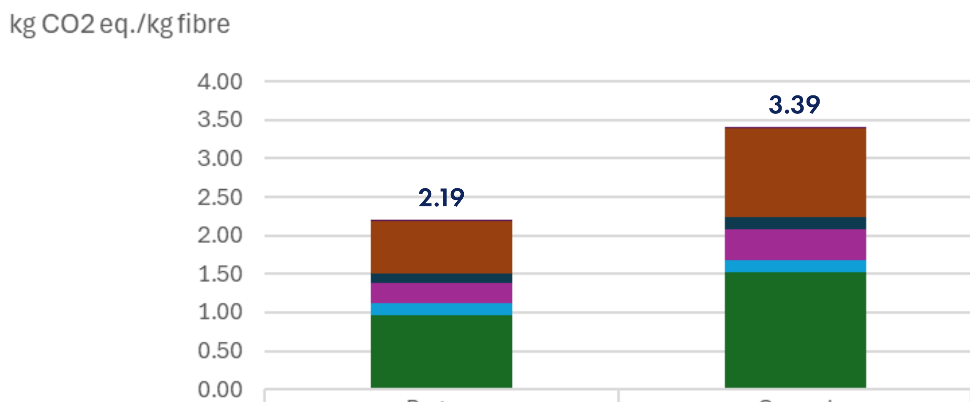
4.1. Life cycle impact category results

The following sections show the results for the average REEL project (total average project) environmental profile vs. the benchmark value (total average control).

4.1.1. Climate change

Figure 4-1 illustrates the effects related to climate change. The REEL Cotton Project impact shows 2.19 kg CO_2 per kilogram of cotton fibre produced, approximately 35.30% lower than the control region, where the production of one kilogram of cotton fibre emitted 3.39 kg CO_2. The climate change impacts for both the REEL project and the control group are primarily influenced by emissions from the fields, irrigation methods, and the use of fertilisers, which together account for more than 86% of emissions for farmers involved in the project and over 90% for those in the control group.

Figure 4-1: **Climate change results, total production weighted average**



	Project	Control
Transports	0.00	0.00
Transport to gin	0.01	0.01
Provision of fertilizer	0.68	1.14
Machinery	0.13	0.16
Irrigation	0.26	0.40
Ginning	0.16	0.15
Field	0.95	1.52
Crop protection	0.01	0.01

The findings regarding climate change indicate significant potential savings for the REEL project throughout all stages of its life cycle when compared to the average control, with the exception of ginning, where only minor discrepancies were noted between the project and control data. The most substantial savings, in absolute terms, arise from fertiliser provision (0.46 kg CO_2 eq./FU) and field emissions (0.57 kg CO_2 eq./FU). Compared to the previous study (2022), the project group shows a slight increase of 12.30% in carbon footprint, rising from 1.95 kg CO_2 per kilogram of cotton fibre. This increase is primarily attributed to the more than twofold rise in the number of participating farmers with per farmer fertiliser application was much higher than the previous report's farmers cohort, leads to increase application of fertiliser.

Field emissions primarily stem from fertiliser application, which contributes to the release of potent greenhouse gases such as N_2O and, particularly with urea, CO_2. The REEL project's farms utilize less nitrogen fertiliser or maintain a more favourable nitrogen balance overall, resulting in lower field emissions compared to the control group. Furthermore, the REEL project achieves superior yields, which effectively reduces emissions on a per kilogram basis.

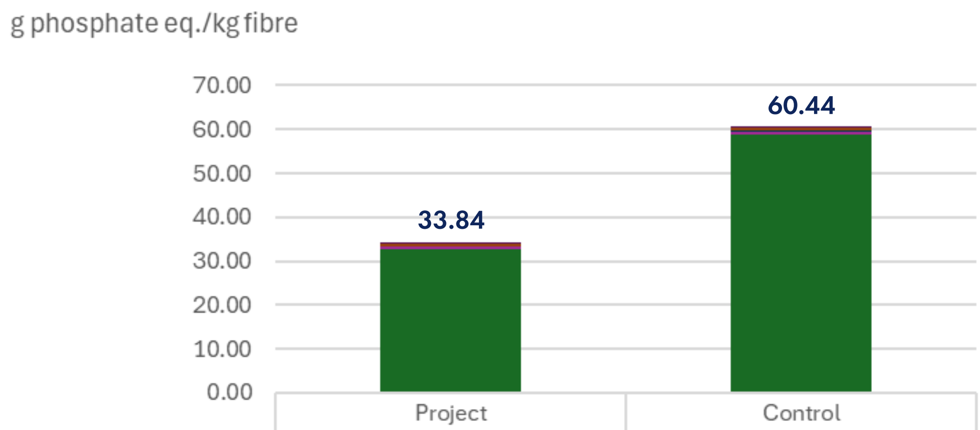
The influence of irrigation on climate change is noteworthy, as it necessitates not only water but also energy for pumping, thereby relying on fossil energy sources. A reduction in water consumption directly correlates with decreased energy usage. Additional insights into water consumption and the water-saving practices promoted by the CottonConnect Code of Conduct can be found in Section 4.1.5.

The (biogenic) carbon content of cotton fibre is estimated at 42% (Cotton Inc., 2017), equating to 1540 kg CO_2 eq. per ton. However, it is important to note that this carbon dioxide uptake has not been factored into the calculations. Given that cotton is a short-lived consumer product, it serves only as a temporary carbon sink. This perspective aligns with previous research (Cotton Inc., 2017) and adheres to the PEF methodology.

4.1.2. Eutrophication

Figure 4-2 presents the average eutrophication potential (EP) associated with the REEL Cotton Project impact shows 33.84 g of phosphate per kilogram of cotton fibre produced, approximately 44.01% lower than the control region, where the production of one kilogram of cotton fibre shows EP 60.44 g of phosphate. It is noteworthy that the EP for both the REEL project and the control group is predominantly influenced by field emissions, which account for 96% of the total impact in both scenarios.

Figure 4-2: **Eutrophication potential (EP) results, total production weighted average**



	Project	Control
Transports	0.00	0.00
Transport to gin	0.00	0.00
Provision of fertilizer	0.40	0.62
Machinery	0.24	0.29
Irrigation	0.49	0.76
Ginning	0.09	0.08
Field	32.62	58.68
Crop protection	0.00	0.00

The results for the EP indicate that the REEL project achieves savings across all life cycle stages when compared to the average control, with the exception of ginning, as discussed in the previous section on climate change. The primary savings, quantified in absolute terms, stem from a reduction in field emissions, amounting to 26.06 g phosphate. Comparing the results with the previous study (2022), it was observed that the eutrophication potential has increased. Specifically, the project group experienced an increase of 11.56 g of phosphate per kilogram of fibre, while the control group saw an increase of 15.62 g of phosphate per kilogram of fibre. This increase is primarily attributed to the more than twofold rise in the number of participating farmers with per farmer fertiliser application was much higher than the previous report's cohort, results to the increase in field emissions.

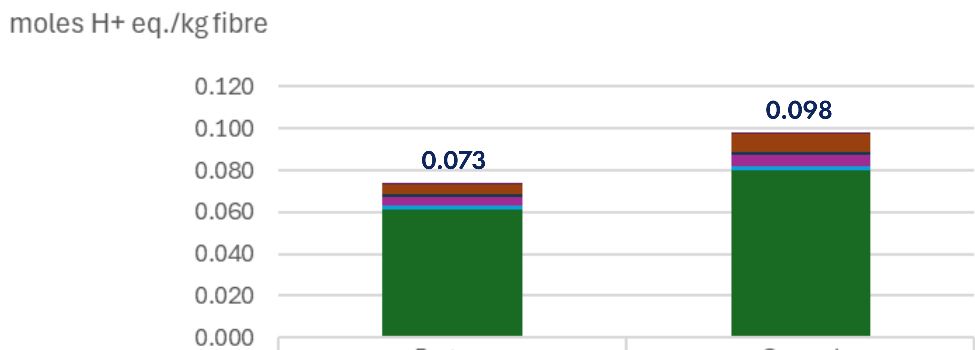
These field emissions are predominantly associated with fertiliser application. A higher nitrogen surplus in the nitrogen balance correlates with increased release of nitrogen compounds into soil, air, and water, thereby elevating the potential for eutrophication. Yield plays a crucial role in these results; specifically, greater yields result in lower emissions per kilogram of product. Furthermore, utilizing less land per kilogram of product can mitigate impacts related to soil erosion, which is primarily influenced by land use.

It is important to recognize that nitrate leaching is affected by various factors, including soil type, precipitation, and timing of application. A comprehensive evaluation of this issue is quite intricate and exceeds the scope of this study. In the baseline scenario, it is assumed that all surplus nitrogen ultimately leaches into the environment, as detailed in section 3.3. However, this assumption may not hold true in all contexts, particularly in arid regions (IPCC, 2019). Consequently, the values reported should be viewed as conservative estimates and interpreted cautiously.

4.1.3. Acidification

Figure 4-3 elucidates the average acidification potential (AP) associated with the REEL Cotton Project shows 0.07 mol H^+ eq. per kilogram of cotton fibre produced, approximately 25.17% lower than the control region, where the production of one kilogram of cotton fibre shows 0.098 mol H^+eq. Notably, the AP for both the REEL project and the control group is primarily driven by three factors: field emissions, irrigation, and fertiliser application, which collectively account for over 83.9% of the impact for project farmers and more than 81.6% for control farmers.

Figure 4-3:
Acidification potential results, total production weighted average



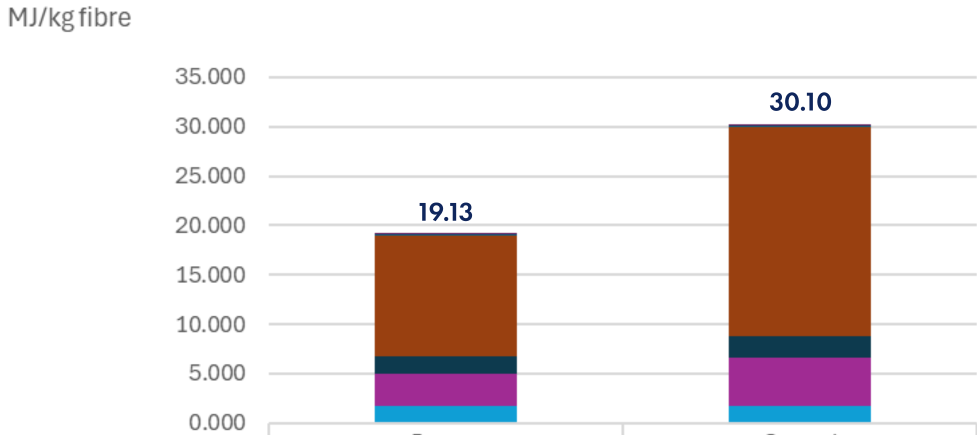
	Project	Control
Transports	0.000	0.000
Transport to gin	0.000	0.000
Provision of fertilizer	0.005	0.009
Machinery	0.001	0.002
Irrigation	0.003	0.005
Ginning	0.002	0.002
Field	0.061	0.080
Crop protection	0.000	0.000

The analysis of AP reveals that the REEL project achieves savings across all life cycle phases relative to the average control, with the notable exception of the ginning stage. The predominant savings, in absolute figures, stem from diminished irrigation (0.002 mol H^+ eq.), lower field emissions (0.018 mol H^+ eq.), and reduced fertiliser usage (0.004 mol H^+ eq.). Comparing the results with the previous study (2022), it was observed that the acidification potential has increased. Specifically, the project group experienced an increase of 0.042 mol H^+ eq. per kilogram of fibre, while the control group saw an increase of 0.059 mol H^+ eq. per kilogram of fibre. Similar to climate change and eutrophication potential, this rise in acidification potential is primarily due to increased number of participating farmers with per farmer fertiliser application was much higher than the previous report's cohort, leading to ammonia emissions from Urea, farmyard and livestock manure as outlined in the emission factors in Table 3-4.

4.1.4. Abiotic Depletion Potential

Figure 4-4 elucidates the average abiotic depletion potential (ADP) for the REEL Cotton Project shows 19.13 MJ per kilogram of cotton fibre produced, approximately 36.44% lower than the control region, where the production of one kilogram of cotton fibre shows 30.10 MJ. The ADP for both the REEL project and the control group is predominantly influenced by two key factors fertiliser provision and irrigation. Together, these elements account for 80.82% of the total ADP for the REEL project and 86.73% for the control group.

Figure 4-4: **Abiotic depletion results, total production weighted average**



	Project	Control
Transports	0.029	0.045
Transport to gin	0.069	0.069
Provision of fertilizer	12.328	21.235
Machinery	1.781	2.127
Irrigation	3.133	4.869
Ginning	1.669	1.612
Field	0.007	0.010
Crop protection	0.113	0.130

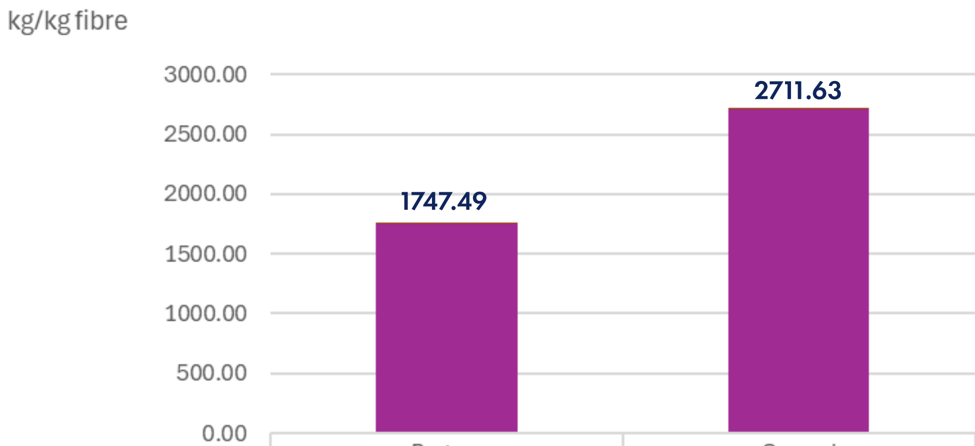
The findings for ADP indicate that the REEL project achieves savings throughout all stages of the life cycle when compared to the average control group. The most significant savings, in absolute terms, are attributed to irrigation (1.74 MJ/FU) and the provision of fertilisers (8.91 MJ/FU). As observed in the climate change results, irrigation necessitates energy for pumping, which predominantly relies on the combustion of fossil fuels, such as diesel. Furthermore, the production of fertilisers is characterized by energy-intensive processes. Consequently, enhancements in irrigation and fertiliser application practices contribute to the observed reductions in the outcomes of the REEL project relative to the control group.

Compared to the previous LCA study, there is slight increase of 2.01 MJ/FU in the ADP within the project group and 2.02 MJ/FU in the control group. However, this increase is largely attributed to the more than twofold increase in the number of participating farmers with per farmer fertiliser application was much higher than the previous report's cohort.

4.1.5. Water Consumption

Figure 4-5 elucidates the average water consumption, excluding region-specific scarcity factors. For the REEL project, water consumption is measured at 1747.49 kg of water per kilogram of fibre, in contrast to 2711.63 kg per kilogram of fibre for the control group. This difference signifies a savings potential of 964.14 kg, equating to a saving of 35.56% per kilogram of cotton fibre. Notably, this reduction exceeds that observed at the inventory level (see Table 3-1) as the results are expressed on a per-kilogram basis, thus incorporating the scaling effects associated with higher yields.

Figure 4-5:
Blue water consumption results, total production weighted average



	Project	Control
Transports	0.00	0.00
Transport to gin	0.00	0.00
Provision of fertilizer	2.71	4.11
Machinery	0.01	0.01
Irrigation	1743.97	2706.70
Ginning	0.69	0.68
Field	0.06	0.09
Crop protection	0.04	0.05

Almost the entirety of the contribution to this impact category, exceeding 99%, is derived from irrigation. The differences noted between the Project and Control may be related to the implementation of better irrigation practices as detailed in the REEL project Code of Conduct (see Figure 4-6).

It is important to highlight, as discussed in section 3.2, that the reported values are significantly affected by the countries of India and Pakistan. These nations exhibit high water consumption values, which in turn contribute to a substantial reduction potential, thereby representing a considerable portion of the overall production.

Figure 4-6:
Measures to optimise water use for irrigation encouraged in the REEL project Code of Conduct (CottonConnect, 2024)

5.3 SUSTAINABLE USE OF WATER

5.3.1 Measures to optimise water use for irrigation of cotton fields have been adopted.

5.3.1.1 The cotton farmer has a good understanding of the watering needs of cotton.

5.3.1.2 The rainfall pattern has been taken into account when watering cotton fields.

5.3.1.3 The timing of irrigation follows physiological requirements of the cotton plant.

5.3.1.4 Farmers recall to the volume of water used for irrigation.

5.3.1.5 The most effective irrigation method that is available in the region and affordable to the cotton farmer is being used.

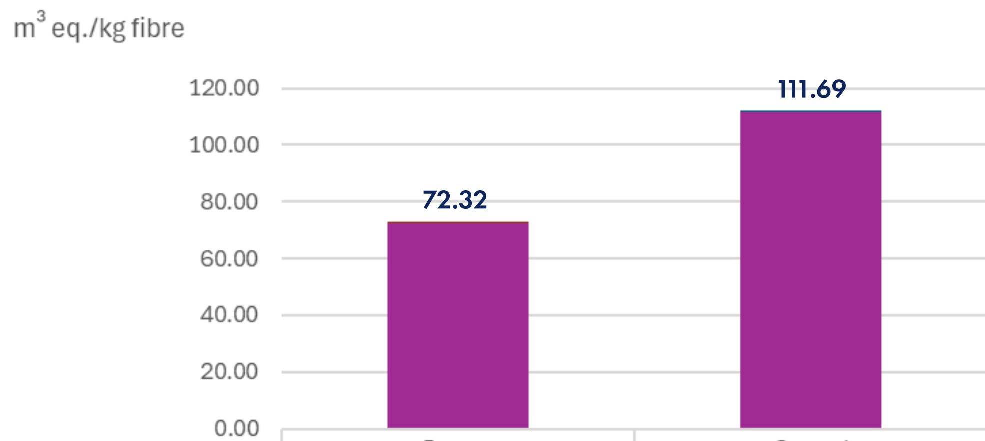
5.3.1.6 The irrigation equipment is properly maintained.

5.3.1.7 Follow appropriate method of water discharge/drainage during heavy rainfall or flood.

4.1.6. Water Use

The average water usage is depicted in the Figure 4-7. The impact category 'Water use' reflects the outcomes of water consumption, which are adjusted by characterization factors that account for regional water scarcity, following the AWARE impact assessment methodology (Boulay, 2017), as elaborated in section 2.7. The REEL project demonstrates a water use of 72.32 m³ world equivalent per kilogram of fibre, while the average control shows a higher usage of 111.69 m³ world equivalent per kilogram of fibre. Consequently, this indicates a potential water savings of 39.38 m³, representing a 35.26% reduction per kilogram of fibre.

Figure 4-7: **Water use results, total production weighted average**



	Project	Control
Transports	0.00	0.00
Transport to gin	0.00	0.00
Provision of fertilizer	0.08	0.12
Machinery	0.00	0.00
Irrigation	72.21	111.55
Ginning	0.02	0.02
Field	0.00	0.00
Crop protection	0.00	0.00

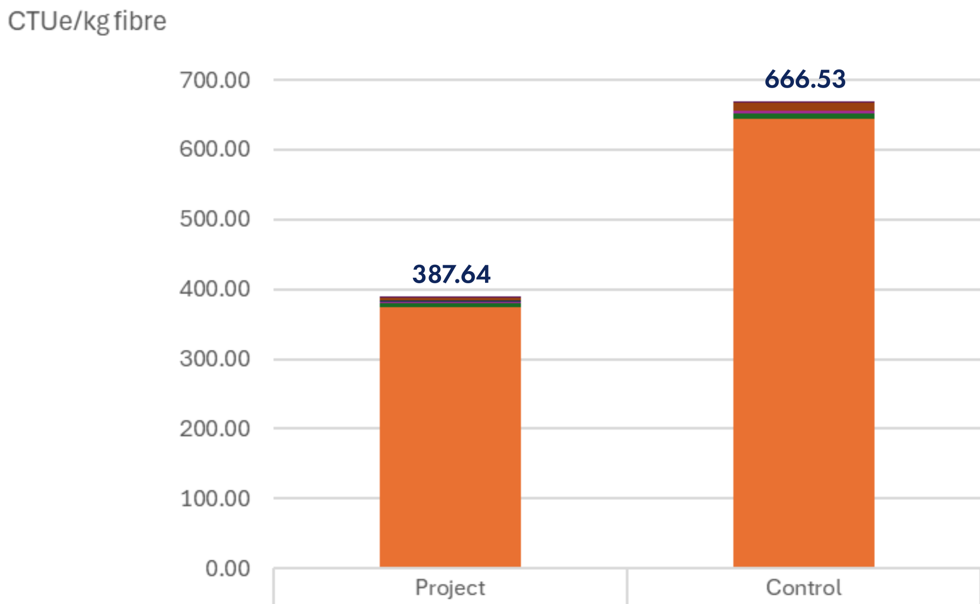
As anticipated, irrigation emerges as the predominant factor contributing to this impact category, accounting for over 99% of the total, much like water consumption. The disparities observed between the Project and Control can primarily be attributed to enhancements in irrigation methodologies. It is important to recognize that the outcomes related to water usage are significantly affected by the specific country in which the water is utilized. For example, the characterization factors for water use are 2.08 for Bangladesh, in contrast to 34.96 for India, 97.71 for Egypt, and 57.40 for Pakistan. Consequently, water use in Pakistan results in an impact that is 25 times greater than that in Bangladesh. However, since the regional distribution is identical for both average project and control farms, the choice of scarcity factors does not affect the comparison, although it is crucial when juxtaposing results with those from other studies.

When comparing water use results with the 2022 study, it was found that water usage on the farm has been reduced by over 50% for both the project and control groups. This improvement is largely due to targeted programmes that further reduced water consumption, including timely rainfall and the promotion of alternative furrow irrigation. Additionally, unseasonal rainfall during the 2022-23 crop season, with medium to heavy rainfall from July to September, also contributed to the reduction.

4.1.7. Toxicity

Figure 4-8 elucidates the average ecotoxicity, revealing that the REEL Cotton Project shows 387.64 CTUe per kilogram of cotton fibre produced, approximately 41.84% lower than the control region, where the production of one kilogram of cotton fibre shows potential saving of 278.89 CTUe. The ecotoxicity for both the REEL project and the control group is predominantly driven by crop protection.

Figure 4-8: **Ecotoxicity results, total production weighted average**



	Project	Control
Transports	0.01	0.02
Transport to gin	0.03	0.03
Provision of fertilizer	4.61	10.69
Machinery	0.80	0.96
Irrigation	1.62	2.52
Ginning	1.27	1.21
Field	4.90	7.03
Crop protection	374.40	644.06

The characterization factors associated with pesticides exhibit a wide range of magnitudes, indicating that individual substances can significantly impact the overall results, even when applied in minimal amounts. Generally, the usage of pesticides in the project is lower than that in the control group (refer to Table 3-1). Ecotoxicity results demonstrate that the REEL project achieves reductions across all life cycle stages when compared to the average control. The most substantial savings in absolute terms arise from crop protection (41.87 CTUe), field activities (30.29 CTUe), and the provision of fertilisers (56.88 CTUe). The limited contribution of other life cycle phases to toxicity is primarily attributed to emissions into the atmosphere with associated toxicity factors, which occur during fuel combustion (for field work and irrigation) or in the upstream processes related to energy supply and the provision of other inputs, such as fertilisers.

Comparing ecotoxicity results with previous LCA study there is a slight increase (13%) in project group and a 98% increase on control group. This increase is primarily due to unusual climatic variations. In 2022-2023, Pakistan experienced severe flooding, while India faced heavy rainfall from July to September and very little rain from September to April. These conditions led to a significant infestation of pests, such as thrips, whiteflies, aphids, and sooty mold, prompting farmers to use more pesticides throughout the crop cycle.

4.2. Scenario Analysis, uncertainty and regional variability

With all life cycle assessment studies, there is a significant amount of uncertainty within the results that can stem from several different causes. Data uncertainty is commonly explored through a Monte Carlo uncertainty analysis which can provide a range of results describing the environmental impacts. However, due to the complex structure of this study (several cultivation systems in different countries, interdependence of variables and input parameter) a full Monte Carlo uncertainty analysis was considered to exceed the scope of the study.

Country-specific results will be available upon request and at the discretion of CottonConnect. They can be interpreted as indicators for regional variability and provide an indication on how results could deviate from the average in specific regional contexts (and therefore as a substitute for scenario analysis and sensitivity analysis). It can be seen that there is considerable regional variability in the results (though it should be noted that it is not an indicator of limited data quality). However, such variability is to be expected since almost all inventory parameters are influenced by location (yield, irrigation, fertiliser use, pesticide use). Impact categories that are influenced by many parameters (e.g. climate change that is influenced by yield, fertiliser production, energy use etc.) vary less than impact categories that are influenced by one parameter only (i.e. water use and water consumption that are only influenced by the parameter irrigation water requirement). The variability can be expected to be similar for the control and the project. It becomes clear that variability in the results is large in agricultural systems due to their complex embedding in their natural surroundings. Hence, the results shown do not allow for drawing conclusions on the environmental performance of individual sites or farms. This also means that if a normal distribution of the results around the average with the standard deviation described above was assumed, there would be some overlap of the farms with higher results from the project average and the farms with lower results from the control. To measure the extent of this overlap would require statistical analysis (test of significance of the difference) for each single input parameter used in this study. It is appreciated that this would be the ideal assessment, and it is recommended to develop data collection further to allow such statistical testing to be carried out. Since statistical testing was not included in the scope of this study, the uncertainty about the uncertainty remains as a limitation. However, this limitation applies to most LCAs of Cotton (Cotton Inc. 2017, BCI 2021, CmiA 2021) or even to most agricultural LCA studies in general due to the large effort required to perform such analysis.

All relations in the model are linear. In combination with the detailed contribution analysis provided with the results, where inputs are related to emission categories (e.g. fertiliser application to field emissions and emissions from fertiliser production), it is easy to estimate the sensitivity of the results to changes in input parameters. If all other parameters remain constant, a 10% decrease in fertiliser application will lead to a 10% decrease in emissions related to fertiliser application and production. As the results are reported on a per kg basis, higher yields lead to lower emissions on a per kg basis. Again, these relations are directly correlated. Similar to that, changes in allocation show a direct change in the results on a 1:1 ratio. If the allocation ratio is changed, and seeds receive 5% more of the burden of total production, the results for lint will be reduced by 5%. Such calculations can also help to understand the variability and uncertainty of the results.

5. INTERPRETATION

5.1. Identification of Relevant Findings

To ensure ease of understanding, the interpretations required to differentiate between the REEL project and control values, as well as their contributions, are provided alongside the results in the appropriate sections of section 4 of the report. This section summarizes key findings on a broader scale and reviews them in relation to the assumptions and limitations. The inventory data demonstrates that the REEL project results in higher yields, lower water consumption, and increased nitrogen use efficiency. As anticipated, these results are reflected in the impact findings, which clearly indicate the benefits associated with the implementation of the REEL programme in the areas under investigation.

To mitigate seasonal fluctuations in the data collected from various regions, multiple year averages were employed, with the exception of Egypt, which was limited to a single year of inventory data. In the process of calculating the average values based on the production shares of each region, Egypt's contribution was a mere 0.02%, indicating that it had a negligible effect on the overall average outcomes. Consequently, the results were predominantly shaped by the production data from Pakistan and India, where data availability was robust and consistent across multiple production years.

The influence of climate change potential is largely attributed to emissions generated from agricultural fields, with irrigation and fertiliser production playing substantial roles. Acidification potential exhibits a similar trend, while eutrophication potential is uniquely influenced by emissions from fertiliser application. Water consumption and scarcity are primarily dictated by the irrigation water used in agricultural practices.

Additionally, the potential for abiotic depletion is chiefly linked to the consumption of fossil-based resources, particularly in relation to fertiliser production, irrigation, and field management activities. The findings of this study indicate that land use change did not influence the results. Nonetheless, it is important to recognize that land use change can exert considerable effects on climate change outcomes in systems where it is present. Consequently, accurate monitoring of land use change is essential, alongside ongoing initiatives aimed at mitigating emissions associated with it. The nitrogen balance suggests that there remains potential for enhancing fertiliser use efficiency, even within the REEL systems, which could lead to improved climate change outcomes by decreasing emissions from agricultural fields and minimizing the upstream environmental impact of fertiliser production. The contribution of irrigation to the observed results is substantial, and refining irrigation practices could alleviate the pressure on water resources in the project regions. This refinement may also contribute to diminishing the effects of climate change associated with diesel usage in irrigation. Investigating cleaner fuel options as alternatives to diesel is another avenue worth pursuing. The ecotoxicity potential associated with the REEL Cotton project reveals notable disparities, primarily driven by factors such as crop protection, fertiliser application, and field operations. The ecotoxicity findings are significantly affected by the presence of active ingredients with high toxicity levels. This situation may necessitate a comprehensive examination of the reliability of toxicity factors for these substances, a broader assessment of substances of high concern, and a verification of both application rates and the proportion of farmers utilizing these substances.

5.2. Comparison to other studies

An in-depth comparison of the findings of this study with findings from other studies was not in the scope of this study. However, to support the interpretation of the results, a high-level comparison with some key recent studies is provided below.

UNFCCC

In the wake of the introduction of the Fashion Industry Charter for Climate Action, a Raw Material Working Group was established, comprising signatories and various supporting organizations. This group has produced a report titled 'Identifying Low Carbon Sources of Cotton and Polyester Fibres' (Action, 2021). The objective of this report is to evaluate the life cycle assessment data derived from current cotton research and to offer guidance along with a call to action for the industry to transition towards more sustainable practices. The subsequent table outlines the significant gaps recognized by the UNFCCC and illustrates how this study addresses these issues.

Table 5-1: **Comparison of UNFCC identified gaps and CottonConnect LCA**

UNFCCC Identified Gaps	CottonConnect LCA
Inconsistencies in LCA modelling approach and field emissions	Latest available methods were utilised (e.g. IPCC 2019 guidelines), full transparency on methods included in ISO conformant report.
Outdated data	Latest available data utilised.
Background data and LCA software	Full transparency of each included in report as required by ISO.
Harmonised reporting requirements on biogenic carbon	Biogenic carbon is not included or assessed in this study. See section 3.3 for method utilised in this study.
Land use change (LUC) impacts	Included in system boundaries but low relevance.
Land use impacts	Full assessment is beyond the scope of this study however some important parameters were included (e.g. area use, soil erosion).
Organic fertiliser production	Low relevance in this study. Exclusion clearly stated in description of system boundary.
Regional resolution	Regional resolution is available in the annex of the report, upon request.

CottonConnect LCA Report 2022

The most recent update to CottonConnect's Life Cycle Assessment of cotton was carried out in 2022. The results reveal that the average emissions associated with the project amount to 1.95 kg CO_2 equivalent per kilogram, whereas the control emissions reach 3.04 kg CO_2 equivalent per kilogram of lint cotton produced, drawing from production data from India, Pakistan, Bangladesh, and China. Importantly, this study offers a more comprehensive contribution analysis for most indicators, with project emissions noted at 2.19 kg CO_2 equivalent and control emissions at 3.39 kg CO_2 equivalent specifically for climate change. The primary factors influencing climate change identified in this context include field emissions, fertiliser application, and irrigation practices.

The results from our 2022 study indicate significantly lower figures than those presented in the REEL project mentioned in this study, with reductions of 12.30% in project emissions and 11.51% in control emissions within the climate change category. This disparity is apparent even though the production levels in the 2022 study were lower than those in the current analysis.

The 2024 REEL project findings highlight a significant decrease in emissions related to irrigation and fertiliser use across different countries. However, emissions from field activities remain relatively high. An examination of the contributions reveals that the average fertiliser application per kilogram of yield is lower in our 2022 study compared to the 2024 REEL project. Additionally, the 2022 study indicates higher levels of water consumption. This difference can be explained by the fact that the earlier study aggregates data from three seasons, while the latter averages data from seven seasons. The regions that have a substantial impact on the results of the 2022 study are also noteworthy.

BCI 2021

The results of the current study are compared with a similar study conducted by BCI in 2021, which averaged emissions from multiple regions and countries to estimate emissions at the programme level. A comparison reveals a notable difference in the average climate change impacts, the BCI study reported 3.6 kg CO_2 equivalent per kg of cotton fibre, whereas to the REEL project average of 2.19 kg CO_2 equivalent per kg of cotton fibre. While the REEL project indicates a lower climate impact for cotton production compared to BCI, certain critical aspects must be considered before drawing definitive conclusions.

Firstly, the methodologies differ: BCI employed the Cool Farm Tool (CFT) for its assessments, whereas the REEL project used a life cycle assessment (LCA) approach with the Sphera tool. Secondly, to fully understand the differences in climate impact, a detailed comparative analysis is necessary, incorporating data from the same timeframe.

One possible reason for the observed differences could be the reliance of CFT on Ecoinvent fertiliser datasets, which have distinct impact profiles compared to those used in the Sphera Lean Ag model. Additional factors, such as the use of Ecoinvent energy datasets in CFT, the lack of inventory data for model applications, and the limitations of assessment indicators (e.g., climate change metrics in CFT versus comprehensive LCA indicators in Sphera), further complicate a holistic interpretation of the results.

5.3. Data Quality Assessment

The assessment of inventory data quality hinges on its accuracy—whether it is measured, calculated, or estimated—and its representativeness in terms of geographical, temporal, and technological factors. To fulfil the requirements delineated in section 2.9. and to ensure the reliability of results, this study utilized primary data in conjunction with consistent background Life Cycle Assessment (LCA) information from the GaBi 2022 database. As a result, the inventory data employed in this investigation can be regarded as reliable. We engage a second party to collect sample data from farmers and ginners, which is then verified inhouse by our experts and subsequently validated by a third party. For a limited number of data points, additional non-certified data had to be gathered (see sections 3.1 and 3.2). It is crucial to note that the responsibility for the accuracy of the input data rests with us. In relation to the Product Environmental Footprint (PEF) method (as discussed in chapter 4.6.5 of the suggestions for updating the PEF method), various quality levels are utilized to evaluate the data quality of the aforementioned aspects. However, this assessment is conducted qualitatively, and a comprehensive calculation of a data quality indicator, as mandated in PEF studies, is not performed in this analysis.

Data Quality Rating	Data Quality Level
1	Excellent
2	Very good
3	Good
4	Fair
5	Poor

5.3.1. Precision

All activity data is "measured/calculated and internally verified, plausibility checked by reviewer" (ibid.) which corresponds to a data quality rating of 2 (very good). As some of the input data is even externally validated (a criterion for a rating of excellent) the overall precision can be considered to be at least "very good".

5.3.2. Temporal representativeness

The objective of this research was to employ multi-year averages to mitigate seasonal variations. However, the REEL programme was not consistently operational across all regions during every year. To enhance geographical coverage and address seasonal discrepancies, data from India, Pakistan and Bangladesh for three years were utilized, as illustrated in Table 2-3. Consequently, for Egypt data from only one season, while others benefited from continuous data spanning up to three years. Although this methodology introduces some temporal inconsistencies, it was deemed the most effective strategy to optimize geographical representation and balance seasonal differences, as previously mentioned. While multi-year averages were applied wherever feasible, the noted inconsistencies led to an assessment of temporal representativeness as being at least "good."

5.3.3. Geographical representativeness

The collected inventory data, which constitutes the foreground system, is characterized by a commendable level of geographic representativeness, as indicated by the assertion that "the activity data reflects the exact geography where the process modelled (...) takes place" (ibid.). However, the background data does not possess the same geographic specificity, with fertiliser datasets from India utilized as proxies for other countries, which serves as a notable example of this limitation. In contrast, electricity datasets were available for each country under consideration. As a result, the geographic representativeness of the background datasets is assessed to be between level 3 for fertiliser data and level 1 for electricity data. In summary, the overall geographic representativeness is deemed to be "very good".

5.3.4. Technological representativeness

For the foreground system the technological representativeness can be considered to be "very good" to "excellent", as data is collected from the farmers that are assessed, and coverage in the sample size was high (see section 3.1). However, as an example, irrigation energy consumption had to be estimated. Also, all emission data is modelled and not measured (this is the usual approach in environmental impact assessment of agricultural products), and some simplifications are made in these models (e.g. in modelling N_2O or nitrate emissions that are all based on a Tier 1 approach). Therefore, overall technological representativeness is assumed to be "good" to "very good".

5.3.5. Data quality summary

The following points are considered to be positive aspects around data quality:

- Primary data was used with a large sample size among farmers participating in the programme
- Control data was also based on primary data collected with the same temporal, geographical and technological scope as the project data
- Multiple year averages were used where available
- Important datapoints (e.g. yields and fertiliser use) were validated

The following points are considered to be limitations in data quality:

- Not all data was readily available from regular data collection, therefore additional data collection had to be conducted for some datapoints
- Irrigation energy use had to be estimated using a pump model
- Fertiliser production datasets representing production conditions in India have been used as proxies for the other regions
- Diesel consumption values for machinery (tractors) were not available, so a generic proxy had to be used for all regions
- Ginning energy data was not available, so that secondary data had to be used
- No statistical testing of input parameters was carried out, so there is uncertainty around the significance of the reported differences between project and control

6. CONCLUSIONS, LIMITATIONS, AND RECOMMENDATIONS

6.1. Conclusions

This analysis compares cotton production outcomes under the REEL Cotton initiative with a control baseline that lacks the implementation of REEL Cotton's sustainable practices in the same geographical areas. The inventory data and results are presented at an overall average level in the main study, while country-specific data will be available upon request and at the discretion of CottonConnect. The reliability of the inventory data is affirmed, as it was gathered in partnership with a second party from farmers and ginners, subsequently verified by internal experts and further validated by a third party. The findings reveal notable enhancements across most indicators for the REEL Cotton programme, underscoring the benefits of the sustainable practices outlined in the REEL Cotton Code of Conduct 3.0. Nonetheless, the absence of statistical testing to evaluate the significance of differences in inventory data between project and control farms introduces a level of uncertainty.

The REEL Cotton project results indicate a clear enhancement across all impact categories, with a saving potential exceeding 35% compared to the control results. The ecotoxicity results were primarily influenced by a single substance, and the observed small increase of less than 2% in the project relative to the control is regarded as having low relevance; nonetheless, further investigation is warranted. With Pakistan and India contributing approximately 98% of the total REEL Cotton production, the average values for both the project and control are significantly influenced by the inventory data from these countries. Data consistency was strong, as it was collected and averaged over a three-year timeframe. However, limitations in data collection and availability still exist in these countries, as well as in Egypt and Bangladesh, which necessitates careful interpretation of the results in both the main study and its annexes.

We resonate with the initiatives advocated by many organizations in the field to enhance sustainable sourcing and agricultural practices. This report effectively demonstrates that by adopting projects like REEL Cotton project, we can realize advantages across a range of impact categories.

6.2. Limitations

In the following, the critical limitations of this study are listed. However, they apply to both project and control, so that the comparison of the two should not be compromised. Absolute values need to be interpreted with care, especially when comparing to results of other studies.

- The data for Egypt was limited to the 2022/2023 period. Egypt's contribution to total production values stands at only 0.02%, which limits its overall significance in the life cycle assessment (LCA) results of the REEL project. Although Egypt exhibits a much higher production rate per hectare than other countries, this does not greatly affect the overall findings of the REEL project. However, the high production rates do have a pronounced effect on the country-specific findings.
- Control values were derived from data collected to represent about 5-10% of the production from the REEL project in each region. While broader coverage could enhance the comparative analysis, the current dataset reflects a considerable absolute production value, which can serve as a foundational benchmark for comparing farms engaged in the REEL cotton project.
- Data sampling was initially performed by a second party on our behalf and subsequently verified by a third party. However, certain gaps in the data necessary for the LCA study were identified, prompting additional sampling by extension agents during the study. This subsequent data was not subject to third-party verification.
- A systematic assessment of uncertainty was not possible within the framework of this study. The determination of whether the differences in yield, fertiliser use, and irrigation water consumption—which influence the environmental performance disparities between project and control farms—are statistically significant could only be achieved through detailed statistical testing. Although numerous Life Cycle Assessment (LCA) studies typically omit statistical testing due to the complexity of the data involved, a systematic evaluation of uncertainty, particularly at the level of input data, would significantly bolster the robustness of the outcomes.
- Assumptions were made for irrigation energy use, which was estimated using the GaBi pump model, hence there is uncertainty remaining in relation to quantity of energy required. There is also uncertainty on the energy source (diesel). However, the chosen approaches can be assumed to be conservative estimates.
- Assessing nitrate emissions is inherently challenging due to the numerous factors that play a role in their dynamics. The approach utilized is conservative, positing that excess nitrogen is leached, which may lead to an overestimation of the eutrophication potential.
- Diesel consumption values for machinery (tractors) were not available, so a generic proxy had to be used for all regions (see section 3.2.)
- Ginning energy data was not available, so that secondary data had to be used.

6.3. Recommendations

We are committed to the ongoing development and enhancement of our LCA data collection scheme each year. Additionally, we may explore opportunities to gather data from other countries and regions as the REEL programme expands. The continuation and growth of our data collection efforts will enable us to consistently evaluate improvements both against the control group and within the REEL programme itself. Furthermore, conducting an additional assessment of farmers participating in the programme—comparing their performance from the first year to the last—could provide valuable insights. The quality of the data has been rated as at least good to very good across all critical aspects; however, some uncertainty persists regarding certain data points and their associated impact categories. Therefore, enhancing the availability and consistency of data collection would significantly improve the environmental profile of cotton produced under the REEL project. Implementing statistical tests to assess the significance of key inventory data parameters, such as yield, fertiliser use, and irrigation, based on disaggregated farmer data, would further strengthen the reliability of our findings.

The energy required for irrigation has been pinpointed as a significant area warranting further investigation. Consequently, we might consider intensifying our efforts to integrate energy consumption metrics into primary data collection on farms or to enhance our modelling and estimation strategies, such as distinguishing between energy sources and factoring in groundwater levels. Eutrophication is a component of the Cascale MSI score. If the findings from this study are submitted to the Higg MSI, it may necessitate a detailed review to ensure that comparisons with other materials are not affected by differing eutrophication modelling approaches. Should eutrophication be identified as a critical issue in relation to other studies, a more nuanced modelling of leaching rates, incorporating climate data, could bolster the reliability of this study's results. However, these considerations do not impact the comparison of REEL Cotton with the control, which is the central focus of this analysis.

The nitrogen balances calculated in this analysis reflect a promising increase in nitrogen use efficiency across the REEL project farms. A detailed regional evaluation, potentially at the individual farm level, could identify additional avenues for reducing any remaining nitrogen surpluses. Moreover, a comprehensive study of ecotoxicity could enhance understanding of the significant contributors to environmental impact and pinpoint substances that are of high concern for the REEL cotton programme. If the robustness of toxicity factors is further explored, alongside confirmation of application rates and the fraction of farmers applying these substances, it would enable the formulation of further recommendations aimed at replacing harmful agents.

We acknowledge the critical need for cotton Life Cycle Assessment (LCA) data to be available at the national level, with the utmost disaggregation according to the input data. In light of the current environment characterized by data misuse and uninformed decision-making by companies involved in cotton sourcing, we have developed a comprehensive report that includes the inventory values. As stated earlier, we can provide country-specific Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA) data upon request.

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ANNEX A: EXTERNAL AND CRITICAL REVIEW STATEMENT

Reviewer 1: Textile Exchange (Felicity Clarke, Debra Guo, Bowie Miles, Francesca Sartor and Eleni Thrasyvoulou)

Life Cycle Assessment of REEL Cotton – Review Statement by Textile Exchange

Specific data was gathered by the Cotton Connect team with their partners responsible for sampling as well as data for a benchmark control group of farmers in the same regions who are not part of the REEL program.

This study builds upon a previous one conducted in the same area but includes several key differences well described and stated in the report that limit direct comparisons between the two.

Some of the positive aspects are:

- the use of primary data from the farmers participating in the REEL program
- the use of primary sources for the benchmark control data
- consistency of the temporal, geographical and technological parameters coverage across REEL farmers and the control data
- when available, and in response to one of the limitations highlighted in the previous LCA study conducted, multi-year averages were analysed
- key data points such as yields and fertilizer usage, were validated

It was not part of this review to check the correctness of the primary data collected.

Furthermore, a cross-check of certain data did not reveal any inconsistencies compared to similar studies, although there was difference in the impact that are within expected margins of error.

All data sets used for the included unit processes are sufficiently characterized according to the system boundaries (technical, geographical and time related).

The handling of data and scenario analyses demonstrate a sufficient robustness of the calculated data.

Thus, the data can be seen appropriate regarding the goal of the study. The calculated inventory data for the compared product systems are accessible for review upon request.

Assessment of interpretation referring to limitation and goal

The interpretation in the final report is based on the detailed data analysis performed. The interpretation is meaningful, and limitations, recommendations, comparison with the previous study and with the control group are transparently stated.

The report's interpretation sections deal with all issues from the goal and scope sufficiently.

Conclusion and recommendations

It should be noted that this review statement is valid only for the final report as presented to the reviewer.

The following recommendation is made:

- Make the data points needed for the update of this LCA study part of the routine data collection to facilitate the process (e.g. diesel consumption for machinery, ginning energy data).
- Primary data for fuel consumption of tillage practices to be included in data collection requests, reducing the reliance on secondary data for this data type.
- Update the current study every 3 to 5 years to refine the approach and methodology, broaden the geographical and temporal coverage to avoid data to be deviated by seasonal changes or lack of data. This will also enable Cotton Connect to better assess the potential reduction in environmental impact attributable to cotton cultivated and processed by farmers in the REEL cotton program, informing the development of the program.

Reviewer 2: Dr. R. SANTHI, Ph.D., FISSS
Former Director, Directorate of Natural Resource Management and
Professor & Head (Soil Science & Agricultural Chemistry) (Retired),
Tamil Nadu Agricultural University (TNAU) Coimbatore-3, Tamil Nadu.

Life Cycle Assessment of REEL Cotton- Review Statement by Dr. R. Shanthi

The LCA report offers a comprehensive and methodologically sound analysis of third party validated primary data collected at the farm level. Key strengths include the utilization of primary data from farmers participating in the REEL programme and the employment of primary sources for benchmark control data. The consistency maintained in temporal, geographical, and technological parameters across both REEL farmers and control data ensures robust and reliable findings.

The analysis of multi-year averages, in response to limitations highlighted in previous study, adds significant value and depth to the assessment. Additionally, the validation of critical data points, such as yields, fertilizer usage, pesticide usage, irrigation pattern etc. enhances the credibility and accuracy of the presented results.

It should also be noted that verifying the correctness of the primary data collected was not part of this review. However, a cross-check of data inventory did not reveal any inconsistencies when compared to similar studies, although differences in the impact were within expected margins of error. Thus, the data can be considered appropriate with respect to the study's objectives. The calculated inventory data for the compared product systems are accessible for review upon request.

Overall, the report provides valuable insights into the environmental impacts of agricultural practices and serves as a solid foundation for future studies and policy recommendations. I commend the authors for their meticulous approach and thoroughness in addressing key aspects of farm-level agriculture in this LCA.

Reviewer 3: Dr. Keshav R. Kranthi, Ph.D. Chief Scientist (ICAC)

Comments Note on the LCA Study

The Life Cycle Assessment (LCA) study under review presents a comprehensive analysis of the environmental impacts of cotton production, particularly within the REEL project, across four countries. While the methodology appears robust and reflects significant effort, several points merit further clarification and discussion to enhance the study's transparency, accuracy, and relevance. Below is a cohesive commentary on the key points raised:

1. Methodology and Inputs

The study's methodology is well-structured, and the focus on key inputs—fertilizers, pesticides, irrigation, and machinery—provides a clear framework for understanding the environmental impacts of cotton production. The results highlight that these inputs (fertilizers, pesticides, irrigation) are the primary drivers of the environmental footprint, which aligns with established agricultural LCA practices. However, the study would benefit from a more detailed explanation of how these inputs were quantified and how their efficiencies were calculated, particularly in relation to the higher yields through reduction in the use of the inputs observed in the REEL project.

2. Efficiency of Inputs and Higher Yields

One of the most intriguing findings is that the REEL project achieved **higher yields with lesser use of fertilizers, pesticides, and irrigation water** compared to control units. This suggests improved input efficiency, which is a significant achievement. However, the study does not adequately explain the mechanisms behind this outcome. For instance:

- Were specific agronomic practices (e.g., precision farming, integrated pest management, or soil health improvements) employed in the REEL project?
- How did the REEL project optimize resource use to achieve higher yields with fewer inputs?

Providing this information would strengthen the study's credibility and offer valuable insights for scaling sustainable practices.

3. Field Emissions and Their Calculation

The study identifies **field emissions** as a major contributor to climate change, eutrophication, and acidification impacts. However, it does not clearly define what constitutes "field emissions" or how they are calculated independently of input use. For example:

- Are field emissions solely from soil processes (e.g., nitrous oxide from fertilizers, methane from waterlogged fields)?
- How are emissions from machinery, irrigation, and pesticide application accounted for?

Additionally, the study should confirm that there is **no double accounting** of emissions, particularly in relation to inputs like fertilizers and pesticides, to ensure the accuracy of the results.

4. Limitations of LCA in ignoring carbon capture (annual balance) and short-term biogenic sequestration in the fibers

The study touches on a critical issue: the **inherent limitations of LCA frameworks** when comparing bio-based fibers like cotton which would eventually be compared with synthetic fibers like polyester. Key points include:

- **Carbon Sequestration**: Cotton's ability to capture and store CO_2 during growth is not accounted for in standard LCA models, while polyester's fossil-based emissions are fully counted. This creates a bias against cotton.
- **End-of-Life Scenarios**: Cotton is biodegradable and can enrich soil through composting, whereas polyester contributes to microplastic pollution. Current LCA frameworks often overlook these long-term impacts.
- **Biogenic vs. Fossil Carbon**: LCA models treat biogenic carbon (from cotton) and fossil carbon (from polyester) as equivalent, ignoring the cyclical nature of biogenic carbon in natural systems.
- **Water and Land Use**: The study highlights the need to differentiate between rain-fed and irrigated cotton and to account for soil carbon improvements in regenerative farming systems.

These limitations suggest that **standard LCA frameworks are not well-suited** for comparing cotton and polyester. To address this, the study should advocate for:

- **Inclusion of biogenic carbon accounting** to recognize cotton's sequestration benefits. The LCA study mentions 42% biogenic sequestration in fibers but dismisses this as a short term sequestration. It is important to note that a fabric life of 10-20 years can be calculated within the 100 yrs GWP framework of the IPCC to be able to credit biogenic sequestration to offset the GHG emissions, which could lower down the emission values.
- **Differentiation of water use** based on sourcing (rain-fed vs. irrigated).
- **Expansion of end-of-life scenarios** to include biodegradability and soil enrichment.
- **Incorporation of microplastic pollution** as a long-term impact of synthetic fibers.

5. Recommendations for Improvement

To enhance the study's relevance and accuracy, the following steps are recommended:

- **Explain Mechanisms Behind Higher Yields**: Provide detailed insights into the agronomic practices that enabled the REEL project to achieve higher yields with fewer inputs.
- **Clarify Field Emissions**: Define and explain how field emissions are calculated, ensuring no double accounting of inputs and emissions.
- **Address Regional Variations**: Discuss the reasons for differences in cotton seed rates and other regional practices.

Reviewer 4: Joël Mertens, Director of Higg Product Tools, Cascale

Critical Review Statement

Life Cycle Assessment of REEL Cotton
Report version: v1.0
Report Date: 10/10/24

Commissioned by: CottonConnect

Reviewed by: Joël Mertens, Director of Higg Product Tools, Cascale

Review Summary

A review of the Life Cycle Assessment of Reel Cotton report was conducted, as provided by CottonConnect. The review focused on the described life cycle assessment methods, completeness of primary data, reasonableness of assumptions for data gaps, and interpretation of the results. The review was performed exclusively on the report and no software models or primary data sheets were validated as part of this review.

Conclusion

The methods and data collection procedures described in the report have sufficient scientific basis to justify the interpretation and conclusions of this life cycle assessment study. One suggestion for future improvement is to refine the ginning impact model and ginning data parameters, though it should be noted that this is not expected to change the conclusions of the report.

Joël Mertens
Director of Higg Product Tools
Cascale

Valid as of February 26, 2025

The reviewer signs this review statement as an individual expert and no endorsement of the report's scope or results shall be implied by the affiliated organization.

ANNEX B: **REEL COTTON CODE OF CONDUCT**

This annex provides an overview of the REEL Cotton Code of Conduct. For further details, please refer to CottonConnect's website. The REEL Cotton Code of Conduct is built around the nine principles detailed below.

Figure 0-1:
REEL Cotton Code of Conduct 3.0 principles

The REEL Cotton Code of Conduct specifically concerns sustainable agriculture practices. REEL Cotton Code of Conduct does not cover organic, food safety or other similar concerns.

Table 0-1: **Criteria of the REEL Cotton Code of Conduct 3.0**

Principle	Key aspects of principle
1 Integrated Management System	Contracts and Agreements Producer Group Set Up Documentation and Information Management Quality, Traceability and Terms of Trade Internal Verification Training
2 Plant and Field Management	Plant Field
3 Soil and Integrated Nutrient Management	Soil Fertility Soil Erosion Integrated Fertiliser Management
4 Pest Management	Integrated Pest Management Pesticide Use Safe Handling
5 Water Management	Sustainable Water Sources Quality of Irrigation Water Sustainable Use of Water
6 Ecosystem Protection	Forest Conservation Buffer Zones Ecological Compensation Agrobiodiversity
7 Waste Management	Recyclable Waste Hazardous Waste
8 Institutional Building	Progress towards a formalised organisation set up
9 Social Conditions	Freedom of association & Collective Bargaining Prohibition of Forced Labour Prohibition of Child Labour Warranty of Occupational Safety Employment Conditions No Discrimination Communal Development Projects

CottonConnect is a company with a social purpose to reimagine the cotton supply chains and help textile producers and farmers enjoy better livelihoods

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