On behalf of CottonConnect

Life Cycle Assessment of REEL Cotton

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

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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 Comission)
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.

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).

Executive Summary

Goal and Scope

The main purpose of this study is to assess the potential reduction in environmental impact of cotton farmed and ginned by small holder farmers operating under the REEL cotton program compared to a benchmark (control group of farmers operating in the same regions but not under the REEL program). The study will be disclosed to the public and has therefore been conducted according to the requirements of the ISO 14044 standard. Furthermore, the study has been reviewed by an external review panel. The functional unit assessed in this study is 1kg of cotton fibre at gin gate, with cradle-to-gin-gate system boundaries. Economic allocation was applied in order to allocate the burdens between the cotton seeds and the cotton fibre produced at the ginning stage.

Results in the main sections of the report are provided as an average of all countries considered in this study for the REEL cotton program titled ‘average project’ and the benchmark titled ‘average control’. Data were collected in the same regions for both project and control and results were then weighted by production shares to create a total average. All regions were the REEL programme is currently operational are included.

The following impact categories are assessed in this study:

- Climate change
- Water use
- Water consumption
- Acidification
- Eutrophication
- Abiotic depletion potential, fossil

In addition, the following impact categories are assessed on a screening level:

- Ecotoxicity
- Biodiversity impact

Inventory data

Four countries were assessed in this study. They are listed in the table below with the respective regions where data were collected for both ‘project’ and ‘control’ farmers.

Country	Region
Pakistan	Punjab, Sindh
Bangladesh	Chuadanga, Kushtia
India	Gujarat, Maharashtra, Madhya Pradesh
China	Hebei

The primary data was provided by CottonConnect and their partners who conduct sampling. The retrieved data represents an average from the cultivation years 2013/2014 to 2014/2015 as well as 2017/2018 to 2019/2020, both for the farm level and the ginning stage for all countries apart from Bangladesh which has only been collected for 2019/2020.

Inventory data and results are available in the main study on a total average level, weighted utilising production shares for REEL cotton. Inventory data and results are available on both a regional and country level in the annexes of this study and can be requested for viewing from CottonConnect.

For the life cycle inventory, the GaBi 10.6 software and databases, as well as Sphera's LeanAg Model, which is based on the latest version of the IPCC Guidelines for National Greenhouse Gas Inventories, has been used.

Results

The inventory data shows the REEL project to achieve higher yields, lower water consumption and an increased nitrogen use efficiency. As expected, this translates to the impact results, showing a clear benefit by implementation of the REEL program in the areas under study. For all impact categories apart from ecotoxicity and biodiversity, the REEL cotton project results show a clear improvement (>30% saving potential) versus the control results. Impacts on biodiversity are influenced heavily by the land use per FU of the system under study and the existing ecoregion factor of the region under study and show an improvement (>10%) predominantly driven by improved yields. Ecotoxicity results were dominated by a single substance, and the assessed increase (<2%) in the project vs. the control is considered to be of low relevance, but further investigation is recommended.

Climate change potential is dominated by field emissions with a large contribution from irrigation and the provision (production) of fertilizer. Acidification potential follows a similar pattern however, eutrophication potential is dominated solely by the impact of field emissions due to the application of the fertilizer. Water consumption and water use (scarcity) are dominated by the water used for irrigation on the field. Abiotic depletion potential is dominated by the utilisation of fossil-based resources which occurs most heavily in the provision of fertilizer, irrigation, and field work. Land use change only had a small contribution to the results in this study. Ecotoxicity potential shows no significant difference for the REEL cotton project. The ecotoxicity results are influenced by a few key crop protection substances that have high toxicity characterization factors. This might require an in-depth investigation on robustness of toxicity factors, substances of high concern and verification of application rates and fraction of farmers applying these. Impacts on biodiversity are influenced heavily by the land use per FU of the system under study and the existing ecoregion factor of the region under study and show a small improvement predominantly driven by improved yields.

Data quality was assessed to be good to very good, but there was uncertainty for some datapoints and related impact categories hence, improvement of data availability and consistency of collection would bring greater certainty to the environmental profile of cotton produced under the REEL project.

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 program
- 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 fertilizer use) were validated

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

- There was a different temporal scope between project regions
- 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
- Fertilizer production datasets were only available for India and had to be used as proxies for the other regions assessed
- No statistical testing of input parameters was carried out, so there is uncertainty around the significance of the reported differences between project and control

Therefore, absolute values need to be interpreted with care, especially when comparing to results of other studies.

Conclusions

Overall, the inventory data utilised in this study can be considered to be reliable. CottonConnect work with a second party to collect sample data from farmers and ginners which is then checked by CottonConnect and further third party verified. Hence, it is considered that the results of this study which show a clear improvement across the majority of indicators for the REEL cotton programme, demonstrate the clear benefits of the sustainable practices outlined by REEL cotton Code of Conduct 3.0. However, since no statistical testing of the significance of differences in the inventory data between project and control farms was made, some “uncertainty about the uncertainty” remains. It is recommended that CottonConnect continues to develop its LCA data collection scheme on a yearly basis. The continuation and expansion of data collection will allow CottonConnect to continuously measure the improvements against the control group but also within the REEL programme.

1. Goal of the Study

The CottonConnect REEL Project

The REEL (Responsible Environment Enhanced Livelihoods) flagship programme from CottonConnect is a business-driven initiative, in the form of a 3 year training programme for cotton farmers to enhance environmental and social benefits while improving the sustainability of cotton production. The private standard promotes equality and empowerment and improves labour conditions and the traceability of cotton. Amongst others, the considered practices are increased yield, reduced use of water, chemical pesticides and fertilizers (CottonConnect, 2021).

The CottonConnect REEL cotton Code of Conduct was first launched back in 2010 and was later revised in the years 2016 and 2021. The definition of sustainable cotton that is used for the programme is agreed on by the Cotton 2040 partners and represents social, environmental and economic sustainability. CottonConnect have reported increased yield, profit and income for farmers, supporting livelihoods and communities depending on smallholder farmers.

The programme is third party verified by FLOCERT, a global Fairtrade certification body. In total, 6 countries (India, Pakistan, China, Bangladesh, Egypt and Peru[1]) participated, with over 200,000 farmers.

Goal

The main purpose of this study is to assess the potential reduction in environmental impact of cotton farmed and ginned by small holder farmers operating under the REEL cotton program compared to a benchmark (control group of farmers operating in the same regions but not under the REEL program). By carrying out this study, the environmental burdens that are associated with lint cotton will be evaluated. By gaining more insight and a deeper understanding of the studied system, knowledge gaps can be closed, and weak points of the life cycle identified. The current and accurate LCI data for cotton cultivation and processing will enable an improvement of the environmental potentials of cotton cultivation under the REEL cotton programme.

This report provides insight into the changes that have already been implemented by CottonConnect and can provide guidance for decision making regarding the REEL cotton programme and for further research initiatives.

Comparative assertion

This study conducts a comparative assertion as defined in the ISO standard (14040 series) between REEL cotton project data and a ‘control’ cotton production average for the same countries and regions within those countries. The control values represent a benchmark that can be compared that does not implement the practices required by the REEL cotton project. Data for both the ‘REEL cotton project’ and ‘control’ values were collected and provided to Sphera by CottonConnect. As required by the ISO 14040 series, the present study is critically reviewed, including the comparative assertions.

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[1] Egypt and Peru are not included in the study, due to the very small number of farmers that are just in an initial stage of participating in the project, so that there was not sufficient data to include them in this study.

Intended application

The intended application of this study is to assess the environmental impact of the cotton production under the REEL project of CottonConnect. Four Countries are assessed (India, Pakistan, Bangladesh and China) and compared in this study however, as this study does not intend to compare different regions under the CottonConnect REEL project, the inventory data and results are presented as total averages. The total average is calculated based on the production shares of each region.

To understand the potential environmental savings that can be achieved by farms operating under the REEL project, data were also collected for farms in the same regions as the REEL project however not implementing the farming practices as outlined in the REEL project code of conduct. These results are referred to as ‘average control’ values (average is build with the same weighting factors based on production share used for the project group).

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

Intended audience

This study will be disclosed to the public and concerns therefore both, internal and external stakeholders. Included in the internal stakeholders are marketing and communications, business development as well as research and operations. The external stakeholders comprise the textile supply chain, importers, suppliers or other industry player as well as 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 China. Results are presented for an 'average project' and 'average control'[2]. The total average project results represent the farms that are operating under the REEL project program and the total average control results represent farms in the same regions as that of the REEL project program however, not implementing the required management practices under the REEL project. This study therefore indicates the potential environmental savings that have been achieved by farmers operating under the REEL project.

The following sections describe the general scope of the project to achieve the stated goals. This includes, but is not limited to, the identification of specific product systems to be assessed, the product function(s), functional unit and reference flows, the system boundary, allocation procedures, and cut-off criteria of 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 CottonConnect's REEL Cotton Code of Conduct 3.0 detailed in Annex F: (CottonConnect, 2021).

The Responsible Environment Enhanced Livelihoods cotton program was originally based on the Indian agriculture sector but is designed to be applicable worldwide, considering geographical differences and associated deviations. The program initiates a management system that allows for a reduced input cost, reduced use of chemicals, reduced use of fertiliser, reduced use of water, increased soil fertility and also establishes the habit of tracking profitability of farming. Please refer to CottonConnect REEL Cotton Code of Conduct 3.0 (CottonConnect, 2021) for a full description of the REEL cotton criteria. Beyond striving for environmental benefits, they prioritise social benefits which can also be found in the Code of Conduct.

The considered product systems are small scale farmers in the countries Pakistan, Bangladesh, India and China operating under irrigation. The regions within each country are detailed below.

Table 2-1: Regions under study

Country	Region
Pakistan	Punjab, Sindh
Bangladesh	Chuadanga, Kushtia
India	Gujarat, Maharashtra, Madhya Pradesh
China	Hebei

All the countries and regions where the REEL Cotton programme is currently operational are covered under the assessment (Egypt and Peru have some farmers participating at the initial stage of the program that were not included in this study for reasons of limited data availability, see also section 1). The sample

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

covered for this study represent approximately 50% of the farmers participating in the REEL programme. For the control, a group representing 10% of the sample of the REEL farmers sample (or 5% of the total programme farmers) was considered– with similar characteristics such as geography, irrigation pattern, land holding etc. See also section 3.1. on 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.

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).

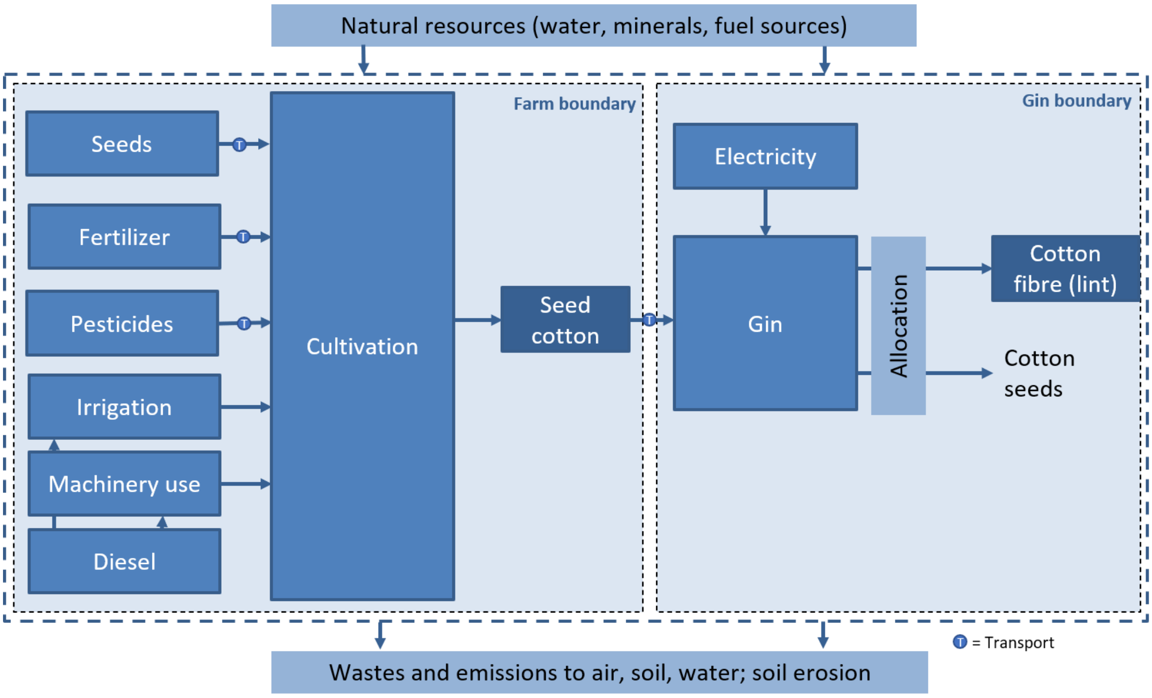

Figure 2-1: System boundaries

Table 2.2 summarizes the system boundaries used in this study. Included in the study are all material and energy flows required for the two phases of production (cultivation and ginning), as well as all associated waste and emissions. This includes fertilizer and pesticide production as well as field emissions (e.g. N_2O), emissions related to fire clearing (i.e. the combustion of biomass remaining on the field from previous cultivation period) (e.g. CH_4, SO_2), electricity for ginning and all transport (fertilizer to the field, seed cotton to gin). Also included in the study is an assessment of land use change (LUC) (see section 3.3.5).

Excluded from the study are the environmental impacts associated with draught animals. In general draught animals (oxen) are only used once per crop season, for ploughing. They are used in different fields no matter which crop is cultivated and they are used for other work such as transport to the market. Additionally, soil preparation is mostly done by service providers (the animal is only used for some hours on a single cotton field, i.e. its use in the cotton fields make up only a very small fraction of their useful life). This multipurpose use makes an allocation of environmental impact from the livestock system to the cotton cultivation system difficult and justifies the assumption that its contribution to the environmental impact of cotton cultivation will be marginal and can be neglected.

Impacts from production of organic fertilizer were also excluded. It is still under debate whether organic fertilizer can be considered a waste product with no burden coming from the animal husbandry system, or if it is a valuable co-product of milk and meat production and should carry an environmental burden. Most LCA models and studies assume that the fertilizer enters the plant production system free of burden. This approach was also followed in this study. Due to the low reported rates of organic fertilizer application, this approach is considered to have a low impact on the results. Emissions from application are considered.[3]

Furthermore, the End of Life of ginning waste was excluded, leaving the system burden free and without any benefits to the main product. Gin waste consists of broken seeds, fibres and plant remains (residues). In the worst case, it could be considered as waste that requires further treatment under specific consideration of pesticide remains. On the other hand, it is occasionally returned back to the land as organic fertilizer, sold to horticulture farms to improve physical soil conditions, or used for composting. Therefore, attributing no burdens to the gin waste is a neutral approach, neglecting a small potential environmental impact along with a similarly small environmental benefit (fertilizer use).

As customary in LCA studies, construction of capital equipment and maintenance of support equipment are excluded due to their minimal contribution and extreme difficulty to measure. Social aspects are beyond the scope of this study and therefore, human labour was also excluded from the study. At the same time, it should be noted that fair and safe human labour conditions are some of the prerequisites of the REEL project.

Table 2-2: System boundaries

Included	Excluded
✓ Seed production	✗ Animal draught
✓ Fertilizer and pesticide production	✗ Gin waste treatment
✓ Irrigation water consumption	✗ Human labour
✓ Energy required for irrigation	✗ Capital goods
✓ Machinery use	✗ Impacts from organic fertilizer supply chain (assumed to be allocated to animal system)
✓ Field emissions	
✓ Soil erosion	
✓ Electricity for ginning	
✓ Transports	
✓ Emissions from organic fertilizer application	
✓ LUC	

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[3] The LEAP guidelines provided by the FAO (Food and Agriculture Organization 2016) on allocation procedures of manure exported off-farm differentiate between the options co-product, waste and residual. While the exact source of the fertilizer was not trackied in the data collection, the chosen approach represents the “residual” option from these guidelines.

2.4. Temporal, technological and geographical coverage

Agricultural systems can show large year to year variation due to climatic conditions and biotic factors (e.g. infestation with pests). It is therefore good practice to work with multiple year averages however, the REEL program was not operating in all regions during all years hence, this could not be consistently applied across all regions. In order to maximize geographical coverage and to equal out seasonal differences, data from all years available was used, see Table 2-3. This means that for some regions, only data from one season was available, while other had continuous data for up to eight years. This approach introduces some temporal inconsistency, but it was considered to be the preferable approach to maximize geographical coverage and to equal out seasonal differences as stated above.

Data were averaged on a year by year basis and then averaged into an average per region. For the results calculation, results per regions were averaged into a country average and the country average into a total average based on production shares (see Table 2-4).

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

Country	Region	Years	Number of seasons covered
Pakistan	Punjab	2013-14 to 2014-15 AND 2017-18 to 2019-20	4
	Sindh	2013-14 to 2014-15 AND 2018-19 to 2019-20	4
Bangladesh	Chuadanga	2019-20	1
	Kushtia	2019-20	1
India	Gujarat	2011-12 to 2019-20	8
	Maharastra	2013-14 to 2014-15 2019-20	3
	Madhya Pradesh	2019-20	1
China	Hebei	2012-13 to 2019-20	7

Activity data from farmers participating in the programme is collected on a yearly basis. During the 3 year programme cycle, the farmer's data is verified by an external agency (2nd year of their attendance). In this study, data from all participating farmers was used, i.e. from farmers in their 1st, 2nd and 3rd year of the programme. It can be expected that farmers improve their management practices over the 3 year program cycle, but an investigation of farmers performance over the project cycle was not in scope of the study and the provided values are therefore an average of all the farmers participating in the programme. The sample size for the REEL farmers is 50% of all farmers participating in the program. Data from the control group is collected on the same temporal basis (every year). For the control, a group representing 10% of the size of the REEL farmers sample (or 5% of the total programme farmers) was considered. Control farmers are selected based on the field size, irrigation pattern and geography. The aim of the selection is that the control farmers meet the same criteria as the project farmers on the above-mentioned parameters. Control farmers are mostly selected from the near-by villages where the REEL programme is not running.

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 regional inventory data can be found in Annex B: which is available upon request to CottonConnect. Results are calculated on a regional basis and are then weighted into project and a control average utilising shares in production.

Table 2-4: Production shares

	Lint cotton production (tonnes)	Lint cotton country share of REEL total (%)
Pakistan	**121,841**	**45.35**
Punjab	16,470	6.13
Sindh	105,371	39.22
Bangladesh	**1,067**	**0.39**
Chuadanga	519	0.19
Kushtia	547	0.20
India	**138,693**	**51.64**
Gujarat	126,998	47.28
Maharashtra	5,442	2.03
Madhya Pradesh	6,252	2.33
China	**7,033**	**2.62**
Hebei	7,033	2.62
Total	**268,634**	**100**

Background data (fertilizer, electricity grid mix at gin) were used with the latest available reference year (e.g. 2018 for electricity, see section 2.11 and 3.4). The validity of the results is expected to be at least five years, as multiple year averages represent long term averages that only change slowly, as technological advances in agricultural systems, such as improved varieties or changed management practices, usually perforate slowly.

The REEL project and certification has a code of conduct (detailed in Annex F: for which farmers under working within the project comply with. Data were collected for representative technologies in each country considered, Pakistan, Bangladesh, India and China.

2.5. Allocation

When a system yields more than one valuable output, as is the case for cotton production (i.e. seed and lint after ginning), it has to be decided how “the partitioning (of) 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) can be achieved. If possible, allocation shall be avoided through e.g. product system expansion according to the ISO standard. If allocation cannot be avoided, the allocation method shall follow the physical relationships between the co-products (e.g. energy content, or weight). However, often these allocation methods will also not lead to meaningful results. In these cases, alternative allocation methods are used in LCA studies, such as economic allocation (splitting the burden based on monetary value of the different products).

It was determined that system expansion or allocation based on chemical properties were not functional for the cotton production system. The seeds are often used as animal feed. However, it is difficult to determine in which production systems they are used and what other feed supplies they could replace, especially since different countries are assessed in this study. The additional effort required to collect data outside the cotton production systems was assessed as too large for the scope of this study. Allocation based on physical relationship was also not applicable, as the seed represents the majority of the mass of the gin output (and therefore also the majority of the e.g. energy content or carbon content), but the fibre is clearly the more valuable product and the main product of the production system. Allocation based on physical properties would allocate the majority of environmental impacts to the seeds, which would misrepresent the purpose of the production system.

Therefore, economic allocation was regarded as the most suitable method to use for this study. Market value was chosen as the method of allocation as it describes best the demand that drives production of both products. Section 3.3.9 describes the allocation ratios used.

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 Sustainable Apparel Coalition (SAC) to be used for the Higg MSI (see Table 2-5).

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

Impact Category	LCIA Method	Unit	Reference
Climate Change	IPCC 2013 GWP 100a	kg CO_2 eq.	Intergovernmental Panel on Climate Change. 2013. IPCC Fifth 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 3.0 Water Scarcity method found under EF 3.0 (Environmental Footprint 3.0) is used.

The impact methods used in this study cover all impacts of the SAC's Higg MSI assessment framework[4]. Some impact assessment methods have been added to the assessment:

- Acidification was added to the assessment because it covers additional emissions of typical concern from agriculture, especially ammonia.
- Biodiversity was added to the assessment because together with climate change, it constitutes one of the most pressing environmental issues of our time (see Rockström & et al., 2009).

Table 2-6 and Table 2-7 describe 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. Biodiversity is not included in the list of impact methods assessed by the JRC but can be assumed to have a low robustness as well based on the assessment method presented by the JRC (ibid.).[5] These two impact categories should be interpreted with particular care as they are related to larger methodological uncertainty compared to the other assessed impacts. They are therefore highlighted as "screening level" impacts.

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

Impact Category	Description	Unit	Method
Climate change (global warming potential)	A measure of greenhouse gas emissions, such as CO_2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may in turn have adverse impacts on ecosystem health, human health and material welfare.	kg CO_2 equivalent	EF 3.0
Acidification Potential	A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H^+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline and the deterioration of building materials.	moles H^+ equivalent	EF 3.0

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

[5] E.g. assignin 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"

Impact Category	Description	Unit	Method
Eutrophication (terrestrial, freshwater, marine)	Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition.	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 accounting for the net intake and release of fresh water across the life of the product system considering the availability of water in different regions.	m^3 world equivalent	EF 3.0

Table 2-7: Environmental indicators used on screening level

Indicator	Description	Unit	Reference
Ecotoxicity	A measure of toxic emissions which are directly harmful to the health of the environment.	Comparative toxic units (CTU_h, CTU_e)	EF 3.0
Biodiversity	Biodiversity is defined as the variety of life on Earth at any level of organisation, ranging from molecules to ecosystems across all organisms and their populations. It includes the genetic variation among populations and their com-plex assemblages into communities and eco-systems. Biodiversity conservation is nowadays recognized as a global priority due to its essential contribution to human well-being and the functioning of ecosystems.	Biodiversity Impact (BVI m^2a)	(Lindner, et al., 2019)

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

The global warming potential impact category is assessed based on the IPCC characterisation factors taken as implemented in the EF 3.0 set of characterization factors for a 100 year timeframe (GWP100) as this is currently the most commonly used metric.

The project includes an evaluation of ecotoxicity using the EF 3.0 methodology, which is based on the USEtox™ characterisation model with some modifications[6]. USEtox™ is currently the best-available approach to evaluate toxicity in LCA and is the consensus methodology of the UNEP-SETAC Life Cycle Initiative. The precision of the current USEtox™ characterisation factors is within a factor of 10–100 for freshwater ecotoxicity (Rosenbaum, et al., 2008). This is a substantial improvement over previously available toxicity characterisation models, but still significantly higher than for the other impact categories noted above. Given the limitations of the characterisation model results need to be interpreted with particular care for this impact category, as stated above.

Assessment methods of biodiversity in an LCA context are comparatively new, and a single consensus method is not yet available. The method utilized in this study, proposed by Lindner et al. (2019), was used in the latest study on Cotton made in Africa (CmiA) conducted by Sphera. Whilst this method is less robust compared to the other impact assessment methods used in this study, the inclusion of the assessment shows a clear effort to include an important aspect of environmental impacts of agricultural systems into the study.

As this study intends to support comparative assertions to be disclosed to third parties, no grouping or further quantitative cross-category weighting has been applied. Instead, each impact is discussed in isolation, without reference to other impact categories, before final conclusions and recommendations are made.

While social impacts are outside the scope of this study, this does not imply, that these impacts are not assessed by CottonConnect. More details of this can be found on their 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:

- Identification of significant findings, such as the main process step(s), material(s), and/or emission(s) contributing to the overall results
- Evaluation of completeness, sensitivity, and consistency to justify the exclusion of data from the system boundaries as well as the use of proxy data.
- Conclusions, limitations and recommendations

Note that in situations where no product outperforms all of its alternatives in each of the impact categories, some form of cross-category evaluation is necessary to draw conclusions regarding the environmental superiority of one product over the other. Since ISO 14044 rules out the use of quantitative weighting factors in comparative assertions to be disclosed to the public, this evaluation will take place qualitatively and the defensibility of the results therefore depend on the authors' expertise and ability to convey the underlying line of reasoning that led to the final conclusion.

2.9. Data Quality Requirements

The data used to create the inventory model shall be as precise, complete, consistent, and representative as possible with regards to the goal and scope of the study under given time and budget constraints.

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[6] Modifications refer to some of the input data used in the calculation of the USEtox characterization factors. Most notable modification is that the characterization factors for heavy metals are much lower in EF 3.0 compared to the original USEtox factors. See Saouter et al. (2018) for details.

- Measured primary data are considered to be of the highest precision, followed by calculated data, literature data, and estimated data. The goal is to model all relevant foreground processes using measured or calculated primary data.
- Completeness is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. The goal is to capture all relevant data in this regard.
- Consistency refers to modelling choices and data sources. The goal is to ensure that differences in results reflect actual differences between product systems and are not due to inconsistencies in modelling choices, data sources, emission factors, or other artefacts.
- Reproducibility expresses the degree to which third parties would be able to reproduce the results of the study based on the information contained in this report. The goal is to provide enough transparency with this report so that third parties are able to approximate the reported results. This ability may be limited by the exclusion of confidential primary data and access to the same background data sources.
- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope. The goal is to use the most representative primary data for all foreground processes and the most representative industry-average data for all background processes. Whenever such data were not available (e.g., no industry-average data available for a certain country), best-available proxy data were employed.

An evaluation of the data quality with regard to these requirements is provided in Chapter 5 of this report. Please also refer to section 6.2 for a summary on limitations of this study including those related to data quality.

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 LCA model was created using the GaBi 10.6 Software system for life cycle engineering, developed by Sphera Solutions Inc. The GaBi 2022.1 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).

2.12. Critical Review

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

The methods used to carry out the LCA are consistent with the international standards ISO 14040 and ISO 14044,

- The methods used to carry out the LCA are scientifically and technically valid,
- The data used 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.

The critical review was conducted by a review panel of three experts:

- Dr. Ulrike Eberle, Managing Prtner at corsus – corporate sustainability GmbH (Chair)
- Eleni Thrasyvoulou Climate+ Impact Data, Senior Manager at Textile Exchange
- Dr. JagdishPrasad Yadavendra, Independent Consultant

The Critical Review Statement can be found in Annex A. The Critical Review Report containing the comments and recommendations by the independent expert(s) as well as the practitioner's responses is available upon request from the study commissioner in accordance with ISO/TS 14071.

3. Life Cycle Inventory Analysis

3.1. Data Collection Procedure

Primary data were collected using customised data collection templates created by Sphera. These data collection templates were sent out by email to CottonConnect who completed these for each region under study. Many data were readily available to CottonConnect as they already work with an independent party to conduct sample data collection of 50% of their REEL project programme farmers along with a benchmark value for farms in the same regions as that of the project (see section 2.4). Important farm data from the programme farmers are third party validated, including yields, fertilizer use, irrigation conducted (CottonConnect, 2021). This process adds strength to the quality of the input data and hence, results output of this 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 CottonConnects' farm teams. Parameters that are based on validated data are marked in Table 3-1.

Upon receipt, each questionnaire was cross-checked for completeness and plausibility using mass balance, as well as internal and external benchmarking. If gaps, outliers, or other inconsistencies occurred, Sphera and CottonConnect engaged with the data providers to resolve any open issues and in some cases further sample data were collected on farm level by CottonConnect's partners. The partners also carry out necessary checks and the final data sets are shared with CottonConnect. The CottonConnect team then carried out necessary validations and reviews to ensure the correctness of data. This means that neither Sphera nor the review panel verified data beyond plausibility checks and the responsibility for the correctness of the input data remains with CottonConnect.

Data were averaged on a year by year basis and then averaged into an average per region. For the results calculation, results per region were averaged into a country average and the country average into a total average based on production shares (see Table 2-4).

The averaged inventory data can be found in section 3.2 and regional inventory data can be found in Annex B: which is available upon request to CottonConnect. Note, as detailed in the scope of the study, results are calculated on a regional basis and weighted utilising the total production shares.

Electricity consumption at the gin was modelled based on primary data collected from all ginning locations. No differentiation between control and project was made for ginning. The electricity consumption, source and the ratio of by-products and waste (seed and fibre) were the key data collected. Transport distances from farm to gin were also collected but assumed to be the same for control and project as transport distance to gin is not influenced by the REEL programme. Assumptions were made for energy consumption from irrigation, for soil erosion rates, and ginning. These assumptions 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 regional minimum, maximum value. As detailed in section 2.4, calculations were carried out utilizing the regional life cycle inventory data and regional LCA results were then weighted according to the production shares. Therefore, the tables provide average values that are only indicative and do not display the data used in the model[7]. Minimum and maximum values help to understand the regional variation in the inventory data (see also section 4.4 on uncertainty and regional variability).

Annex B: includes inventory data for all regions (i.e. the data as used in the calculations), which is 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 and regions within countries.

Table 3-1: Overview of inventory data

	Unit	Project	Control	Regional minium	Regional maximum	Validated
Year	-	See Table 2-3	See Table 2-3			n.a.
Farmers applying field clearance	%	11.6 3)	28.5	0.0	73	no (additional data collection)
Farmers ploughing	%	78.77	79.07			no (additional data collection)
Diesel for field work	l/ha	45.9	54.2	2.38	113.53	no (additional data collection)
Seed	kg/ha	8.68	9.16	0.93	22.23	no (additional data collection
Yield (seed cotton)	kg/ha	2328	1969	1563	4557	yes
Irrigation	m^3/ ha	4,710	6,520	52	1129	yes
Diesel for Irrigation	kg/ha	117	219	1	384	no (estimated with pump model)
Total N applied		144	181	108	227	
Calcium ammonium nitrate	kg/ha	18.5	13.5	n.a.2)		yes
Diammonium phosphate	kg/ha	132	145			yes
NPK 15-15-15	kg/ha	41.6	54.8			yes
Potassium chloride	kg/ha	2.54	2.24			yes
Urea	kg/ha	225	304			yes
Organic fertilizer (as total N applied)	kg/ha	5.95	3.81			yes
Zinc	kg/ha	2.78	4.21	0.00	7.5	yes
Boron	kg/ha	0.028	0.029	0.00	8.9	yes
Crop protection (sum of active ingredients)1)	kg/ha	1.07	1.24	0.69	6.92	yes

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[7] 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 "buttom up" approach of aggregating regional impact assessment results. The shown inventory data are thus are good indicator to understand the contribution to the impact assessment results shown in section 4.

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. See Annex C for details.*
2) *Different fertilizer 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*

Table 3-2: Inventory data gin

	Unit	Project and control2)
Transport distance truck (average distance from farm to gin)	km	20
Output cotton fibre (ginning out turn, lints)	kg/1000 kg of seed cotton (input)	349
Output cotton seeds	kg/1000 kg of seed cotton (input)	617
Other (waste etc.)	kg/1000 kg of seed cotton (input)	33.3
Energy use (Electricity)	MJ/1000 kg of seed cotton (input)	120
Electricity source	-	Grid mix
Price fibre	monetary unit1)/ kg fibre	2.80
Price seeds	monetary unit1)/ kg seed	1.07

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*

As described in section 3.1 (data collection), most of the data was available through the regular assessment of the REEL cotton projects. Uncertainty remained regarding the energy use and energy sources of the irrigation pumps. To ensure consistency over the different regions assessed, it was decided to use the generic pump model included in the GaBi 10.6 DB. See section 3.3.7 for details.

The inventory data displayed in Table 3-1 shows yield increases of 18%, water reduction by 28% and reduction in pesticide use of 14% of project farmers compared to the control group. Yield increase and water use reduction numbers are higher in this inventory then the latest published impact results for real cotton for 2019-2020, which were 8.2% yield increase and 6.6% reduction in water use (pesticide use reduction is also reported with 14%). This is caused by the different temporal reference, where this study uses long term averages while the impact results refer to a single season. It should also be noted that the water reduction values were smaller than 15% in all regions except Gujarat, where water consumption values were high, the reported reduction potential was high, and that represents a large share in total production. The reported values are therefore strongly influenced by this region.

3.3. Model

3.3.1. Method

Sphera has developed a generic agricultural model (Lean AgModel) that can be used to assess the impacts of crop cultivation from cradle to field gate. It is a robust and tested model, based on agreed standards for agricultural modelling in LCA. Its two main guiding standards are:

- 2019 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 4, Agriculture, Forestry and Other Land Use)

- PEF method (Suggestions for updating the Product Environmental Footprint PEF method, chapter 4.4.1)

In combination with datasets from the GaBi 10.6 database, the model allows inclusion of all impacts from upstream processes, on the field and from downstream processing (in this case ginning). The contribution of each subprocess can be evaluated separately. The following table gives an overview of the different modules of the model and the emission modelling approach. Grey cells give the general description of the module, white cells provide the sub-modules and specific descriptions. The modules are also used to group the results in the contribution analysis (section 4).

Table 3-3: Overview of model modules and approaches

Module	Description	Approach
Field Clearance	**Emissions related to the combustion of biomass after cultivation to clear the field**	(see below)
Emissions from combustion of biomass	Methane, ammonia, nitrous oxide and other emissions related to the combustion process	Modelled based on the amount of biomass burned, its carbon and nitrogen content, based on emission factors from (Battye & Battye, 2002).
Field emissions	**Emissions from agricultural soil related to fertilizer application, crop residues and soil erosion**	(see below)
Emissions from fertilizer application (direct and indirect field emissions)	Nitrous oxide emissions to air from microbial nutrient turnover (denitrification), ammonia emissions to air from mineral and organic fertilizer, nitrate emissions to water through leaching, carbon dioxide emissions from carbon contained in fertilizer (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 GaBi 10.6

Module	Description	Approach
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 GaBi 10.6
Provision of Diesel	Upstream emissions in the fuel supply chain (e.g. refinery)	Based on energy provision datasets from GaBi 10.6 database (yearly updated)
Provision of fertilizer	**Emissions related to fertilizer production**	**(see below)**
Fertilizer production	Upstream emissions in the fertilizer supply chain (e.g. energy consumption of production)	Based on fertilizer production datasets from GaBi 10.6 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 GaBi 10.6 database
Pesticide application	Emission of pesticides into the environment	EF 3.0 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 GaBi 10.6 database (yearly updated)
Transports	**Transports of agricultural inputs (fertilizer and pesticides to the field**	**Based on transport distance, using the truck model in GaBi 10.6 and provision of diesel**
Transports to gin	**Transport of raw cotton**	**Based on transport distance, using the truck model in GaBi 10.6 and provision of diesel**

For all references to background data from GaBi 10.6 used, see section 3.4 on background data. The following sections provide additional information about assumptions made for model modules for which the specifications above are incomplete.

3.3.2. Field clearance

Combustion of biomass for field clearance was modelled based on the amount of biomass burned along with its carbon and nitrogen content. The amount of biomass burned was estimated based on values for crop residues from the IPCC 2019, which assumes a yield to above ground biomass ratio of 1:1. Nitrogen and carbon content of cotton stalks were based on the Phyllis database[8] and are assumed to be 38% for carbon and 1.1% for Nitrogen. All emission factors were modelled based on Battye & Battye (2002) which have been prepared for the US EPA. This source was used instead of the IPCC 2019 emission factors because more emissions than greenhouse gases are covered.

CottonConnect's code of Conduct (3.0) rules out combustion of field residues, but there are some farmerss still transitioning to adopting the new practice, so the field clearance values are not zero even for the project farms. Average adoption rate is in Table 3-1 and the regional adoption rates in Annex B: .

3.3.3. Emission from fertilizer application

The following emission factors were used according to IPCC 2006/2019 Guidelines for National Greenhouse Gas Inventories (Tier 1, aggregated). The IPCC guidelines also provide disaggregated emission factors for N_2O differentiating between wet and dry climate[9] Most regions in this study would qualify as dry climate (where a lower emission factor of 0.005 would apply). However, in all regions there is irrigation applied so that wet conditions would apply at least for some periods of the cultivation year. Therefore, the aggregated factor was used. At the same time, this ensured consistency with a larger range of LCA of cotton cultivation systems (see section 5.2) where also the aggregated factor was used.

Table 3-4. Emission factors for fertilizer 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. fertilizers	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 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" – "N_2 emissions to air" -" NO_3^- base loss".

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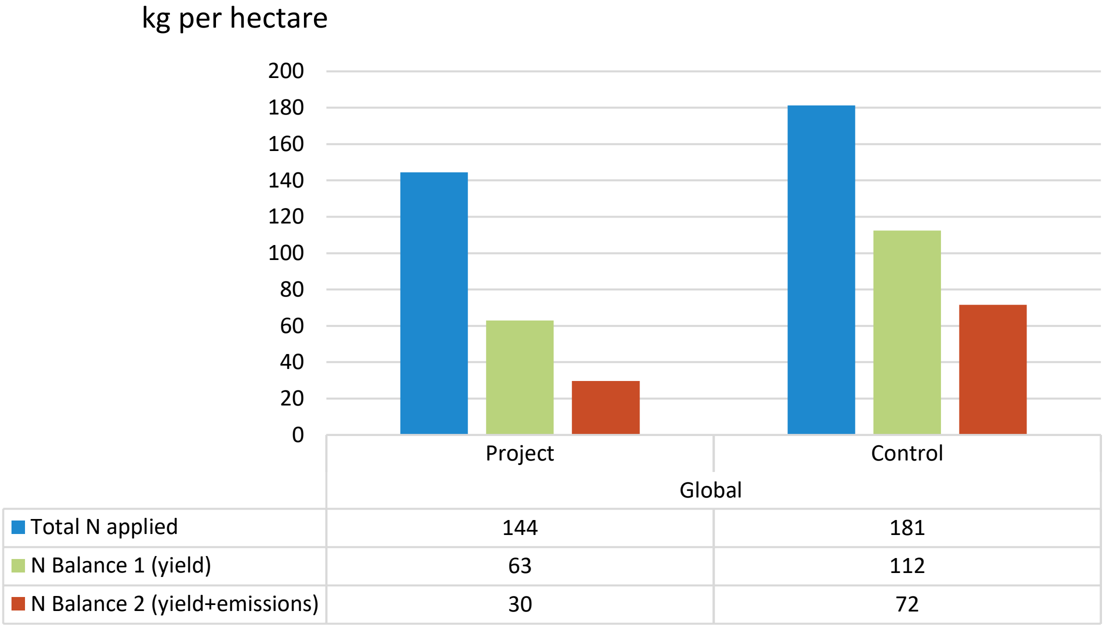
[8] https://phyllis.nl/Browse/Standard/ECN-Phyllis#cotton%20stalks

[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

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 fertilizer application. The usage of a fixed emission factor for nitrate is assessed in a scenario (see section **Error! Reference source not found.**).

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.



	Project	Control
🟦 Total N applied	144	181
🟩 N Balance 1 (yield)	63	112
🟥 N Balance 2 (yield+emissions)	30	72

Figure 3-1: Nitrogen balance, total average

3.3.4. Emission from crop residues

Emissions from crop residues were modelled according to IPCC 2006/2019 Guidelines for National Greenhouse Gas Inventories with default values provided in Table 11.1A, with cotton classified as “other crop”. Biomass burnt as field clearance was subtracted from the available above ground biomass.

3.3.5. 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). From all the region assessed, only Bangladesh reported occurrence of LUC, with approximately 20% of the area affected. For this fraction, a reference emission value calculated based on PAS 2050, using the latest available statistical land use data from FAO Stat. Using the same statistical data, the low probability of land use change occurring in the other countries under study was confirmed.

3.3.6. Emission from soil erosion

Soil erosion rates were assessed based on data from the Global Soil Erosion Modelling platform (GloSEM)[10], provided by the Joint Research Centre of the European Commission. Region averages from the provided 25 km raster data were calculated (see Table 3-5). It was assumed that 20% of total soil erosion eventually reaches surface water bodies (Prasuhn, 2006). The assumed P content of the soil was 500 mg/kg, a value on the lower end of the range reported in (Prasuhn, 2006). Management practices are known to reduce soil erosion significantly. Table 3-5 shows some reduction potentials of different management practices.

Table 3-5: Soil erosion reduction potential of different soil protection measures (own compilation based on (Blanco-Canqui, 2008))

Measure against soil erosion	Approx. soil erosion reduction potential
Crop rotation (instead of monoculture)	30%
Crop rotation with non-row crops (e.g. grass)	90%
No-tillage	90%
Filter stripes (field barriers)	70%
Cover Crops	90%
Application of organic fertilizer (increased SOM content)	80-95%
Crop residues remaining on the field	85-98%
Intercropping	>90%

Almost all regions reported the implementation of some measures against soil erosion. Therefore, an average management reduction rate of 50% was assumed. The adoption rate of no-till was considered separately (multiplied with a reduction factor of 90%, see Table 3-5). Table 3-4 gives the resulting soil loss to water.

Table 3-6: Soil loss to water

	Soil erosion rate	20% going to water	Management reduction rate	No-till reduction rate	Soil loss to water
Unit	t/ha	t/ha	%	%	t/ha
Average project	6.67	1.3	50%	80.9%	0.198
Average control	6.67	1.3	50%	81.2%	0.197

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[10] https://esdac.jrc.ec.europa.eu/content/global-soil-erosion

There is almost no difference in the erosion rate between the average and the control group. The very small difference in the reported adoption rate of no-till in the project group transfers to an even smaller difference in the soil erosion rate that can be considered to be neglectable.

3.3.7. Irrigation

The amount of irrigation water applied was reported consistently in the primary data collection (see Table 3-1). However, data for the energy consumption for pumping was not available. It was decided to use a pump model included in Sphera's Lean AgModel to estimate the energy consumption of irrigation. The documentation of the pump model can be found online[11]. The following assumption have been made in the calculations:

- All pumps were assumed to run on diesel (conservative estimate as related to larger environmental impacts compared to electricity driven pumps)
- Country averages available from FAO's Aquastat were used to specify the fraction of surface vs. ground water use[12]
- An average value of ground water depth of 11.5m was assumed to estimate pumping height for ground water use (Fan et al. 2013)

These assumptions were made to have a consistent approach applied to all assessed alternatives and to avoid distortion of the results by assuming differences in irrigation energy consumption between regions or between project and control that were not supported by robust data. However, the assumptions made represent a simplification and refined data collection in this regard could be considered for follow up studies (see section 6.2)

3.3.8. Crop protection

Primary data was collected for application rates of all reported active ingredients. Not all farmers used the same active ingredients, and application rates were averaged across all farmers. This means that even active ingredients rarely used were assessed, albeit with a very small average application rate. Many factors determine which fraction of a pesticide actually leaves the system boundary, i.e. is emitted to air and water. A detailed assessment of the emission pathways laid outside the scope of this study. Instead, generic emission factors to air, water and soil (90% to soil, 9% to air, 1% to water) were used according to the PEF method (European Commission, 2021). This is of course a simplification but applied consistently over all regions and between the project and control alternatives. Please also refer to the PEF method for further justification of these simplification.

The characterization factors provided for eco-toxicity from EF 3.0 were used to assess the toxicity of the actives used. For some active ingredients, no characterization factor was available in EF 3.0. For these, an average toxicity factor based on the 50 most commonly used pesticides (Maggi et al 2019) was used as a proxy.

3.3.9. Allocation at gin

Market prices reported in primary data collection have been used to determine the allocation of environmental burden between fibre and seeds. All the price data has been collected directly from farmers with

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[11] http://gabi-documentation-2022.gabi-software.com/xml-data/processes/15903a91-f76f-4535-aaf3-43d89962cfe4.xml

[12] Area equipped for irrigation by source of water, https://www.fao.org/aquastat/statistics/query/index.html

the same temporal reference as described in section 2.4, i.e. represents multiple year averages. The resulting allocation ratio was about 2/3 to fibre and 1/3 to seeds, quite consistently over the different regions assessed. However, previous studies found different allocation ratios, e.g. Cotton Inc. 2017 used an allocation ratio of 86% to fibre and 14% to seeds (Cotton Inc., 2017). In consequence, the allocation ratio used in this study leads to lower burdens allocated to fibre compared to other studies, which should be kept in mind when comparing the results. Since the same prices and allocation ratios where used for the project and the control group, the allocation does not influence the comparison between the two alternatives.

3.4. Background Data

The following table lists all background datasets used from the GaBi 2021 database. Documentation for all GaBi datasets can be found online (Sphera Solutions Inc., 2020).

Table 3-7: Background datasets

Material/ process	Location	Dataset	Data Provider	Reference Year	Comment
Urea fertilizer	India	IN: Urea (agrarian)	sphera	2020	Used as Proxy for all countries. Fertilizer production for China, Bangladesh and Pakistan are not available in GaBi 10.6. 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 fertilizer (DAP)	sphera	2020	see above
Calcium ammonium nitrate	India	IN: Calcium ammonium nitrate (CAN, solid)	sphera	2020	see above
NPK fertilizer	India	IN: NPK 15-15-15	sphera	2020	See above. While specific nitrogen content of different NPK fertilizer was considered in emission modelling, NPK 15-15-15 fertilizer is used as proxy for the production of NPK fertilizers with different nutrient concentrations

Material/ process	Location	Dataset	Data Provider	Reference Year	Comment
Pesticide production	GLO	Pesticide (average)	sphera	2020	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	2020	
Truck	GLO	GLO: Truck, Euro 0 - 6 mix, 14 - 20t gross weight / 11,4t payload capacity	sphera	2020	
Diesel provision	India	IN: Diesel mix at filling station	sphera	2018	Also used as proxy for Pakistan and Bangladesh
	China	CN: Diesel mix at filling station	sphera	2018	
Electricity	Bangladesh	BD: Electricity grid mix	sphera	2018	
	China	CN: Electricity grid mix	sphera	2018	
	Pakistan	PK: Electricity grid mix	sphera	2018	
	India	IN: Electricity grid mix	sphera	2018	

Country specific datasets were not always available, and the chosen datasets represent the best available proxies. This is especially relevant for the fertilizer production datasets because they are an important contributor to the assessed environmental impacts. Based on the shares of production (see Table 2-4), the most relevant proximation is the use of fertilizer datasets with reference to India for Pakistan. The application of proxy datasets applies to both, project and control, so that the comparison of the two alternatives should not be compromised. But this might have an impact on the absolute values and regional results (see section 5.3 on assessment of data quality and section 6.2 on limitations).

3.5. Life Cycle Inventory Analysis Results

ISO 14044 defines the Life Cycle Inventory (LCI) analysis result as the “outcome of a life cycle inventory analysis that catalogues the flows crossing the system boundary and provides the starting point for life cycle impact assessment”. The complete inventory comprises hundreds of flows and is only of limited informational value without the associated impact assessment. A summary of the inventory with the main flows contributing to impact assessment categories under study is given in Annex C: .

4. Results

This chapter contains the results for the impact categories and additional metrics defined in section 2.7. It shall be reiterated at this point that the reported impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach).LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

Due to the structure of data and models used in this study, no statistical testing was conducted in this study. This is common in most LCA studies. Based on expert judgement and results from previous studies (Cotton Inc 2017, CmiA 2021) the following wording is used to describe differences in results:

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

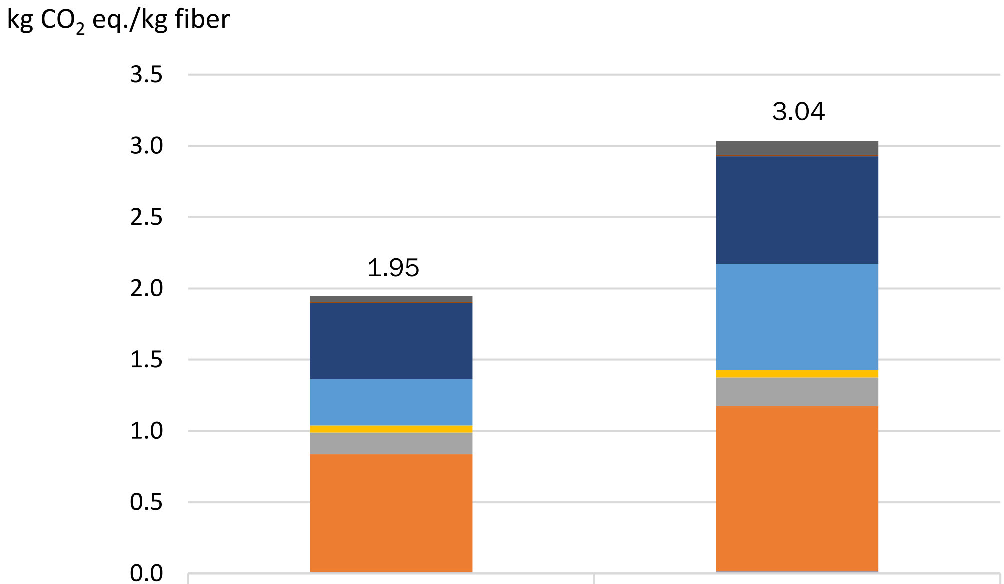
Please refer to section 4.4 on uncertainty and regional availability and section 6.2 on limitations for a better understanding of the robustness of the results.

4.1. Life cycle impact category results

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

4.1.1. Climate change

Figure 4-1 shows the average for climate change. Results show that the impact of the average for the REEL project is 1.95 kg CO_2 eq. per kg of fibre, in comparison with 3.04 kg CO_2 eq. per kg of fibre for the control group. This shows a saving potential of 1.1 kg CO_2 eq. or 35.9% per kg fibre. Climate change impacts for both the REEL project and the control results are dominated by (i) field emissions, (ii) irrigation, and (iii) provision of fertilizer, which together contribute to more than 80% of the total.



	Average Project	Average Control
■ Residue Combustion	0.042	0.099
■ Transports	0.008	0.010
■ Provision of Fertilizer	0.531	0.754
■ Land Use Change	0.000	0.001
■ Irrigation	0.325	0.746
■ Ginning	0.050	0.050
■ Field Work	0.152	0.200
■ Field Emissions	0.826	1.162
■ Crop Protection	0.010	0.013

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

Climate change results show potential savings for the REEL project across all life cycle steps compared to the average control except ginning where no differences were considered between the project and the control data. The main savings in absolute terms are resulting from irrigation (0.42 kg CO_2 eq./FU) and field emissions (0.34 kg CO_2 eq./FU).

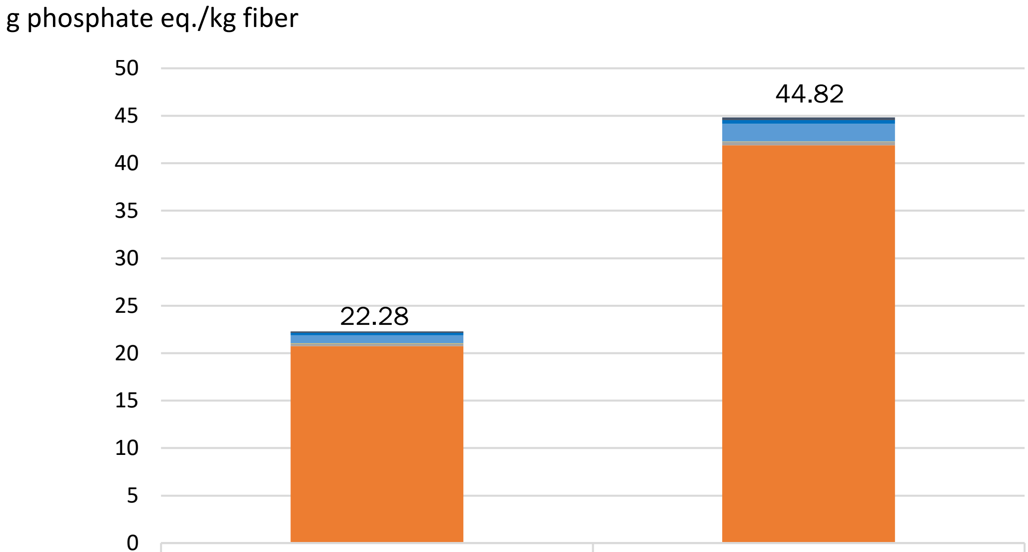
Field emissions are mainly related to fertilizer application, which in turn leads to the release of potent greenhouse gases such as N_2O and, in the case of urea application, CO_2. Since farms within the REEL project apply less fertilizer in the form of nitrogen or have a better nitrogen balance in general, field emissions are lower than the control group. In addition, the REEL project achieves higher yields, which in general scales emissions down on a per kg of product basis.

Irrigation’s impact on climate change can be explained by the fact that it not only requires water but also energy (for pumping) and thus the use of fossil energy carriers. The lower the water consumption the lower the energy use. Section 4.1.5 on water consumption provides additional details on the assessment of water consumption and water saving practices encouraged in the CottonConnect Code of Conduct.

The (biogenic) carbon content of the cotton fibre is assumed to be 42% (Cotton Inc., 2017) and thus 1540 kg CO_2 eq. per ton. However, it shall be noted that this uptake of carbon dioxide was not accounted for. As cotton is a short-lived consumer good, it can be considered as only a temporal sink. This approach is consistent with previous studies, as well as the PEF method.

4.1.2. Eutrophication

Figure 4-2 shows the average of eutrophication potential, EP. Results shows that the impact of the average for the REEL project is 22.3 g Phosphate (PO_4) eq. per kg of fibre, in comparison with 44.8 g Phosphate eq. per kg of fibre. This shows a saving potential of 22.5 g Phosphate eq. or 50.3% per kg of fibre. EP for both the REEL project and the control group results mainly from field emissions (94% in both cases).



	Average Project	Average Control
■ Residue Combustion	0.11	0.26
■ Transports	0.00	0.00
■ Provision of Fertilizer	0.29	0.41
■ Land Use Change	0.00	0.00
■ Irrigation	0.83	1.86
■ Ginning	0.02	0.02
■ Field Work	0.28	0.37
■ Field Emissions	20.74	41.89
■ Crop Protection	0.00	0.00

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

Results for EP shows savings for the REEL project across all life cycle steps compared to the average control (except ginning, see section above on climate change). The main savings in absolute terms are resulting from reduced field emissions (21.2 g phosphate eq.).

Field emissions are mainly related to the application of fertilizer. The higher the nitrogen surplus in the nitrogen balance, the more nitrogen compounds are released to soil, air, and water bodies and the higher the eutrophication potential becomes. Yield scales the results, i.e. higher yield leads to lower emissions per kg product. In addition, if less area is used per kg product, this may lead to lower impacts through soil erosion which is mainly scaled by area use.

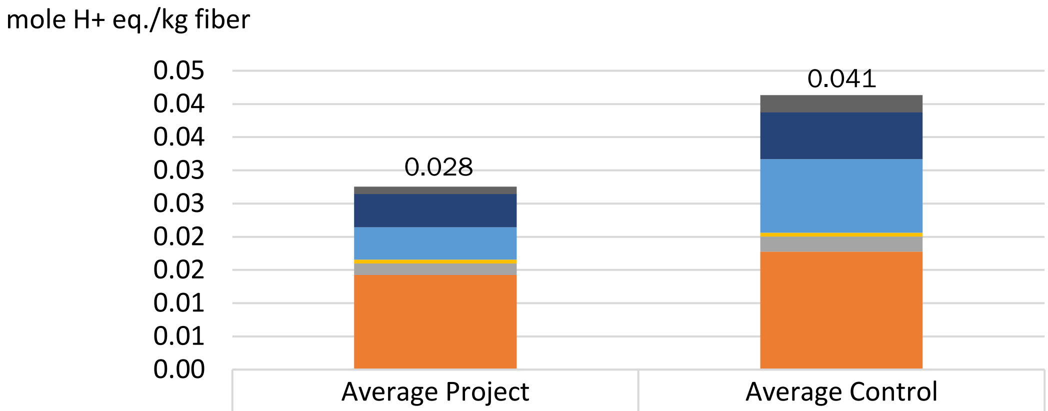
It should be noted that nitrate leaching is influenced by many factors (e.g. soil type, precipitation and application time). A detailed assessment is highly complex and laid beyond the scope of this study. In the baseline setting of this study, it is assumed that all surplus nitrogen is eventually leached into the environment (see section 3.3). This is not necessarily always the case, especially not in arid regions (IPCC, 2019). The reported values are therefore a conservative estimate and should be interpreted with care. Section 4.3, provides an alternative scenario regarding the assumed leaching rates.

Table 4-2: Contribution analysis of eutrophication potential

Inorganic emissions		Average project	Average control
To air			
	Total	**16%**	**12%**
	Ammonia	7%	5%
	Nitrogen Oxides	6%	5%
	Nitrous Oxide (Laughing Gas)	3%	2%
To freshwater			
	Total	**84%**	**88%**
	Nitrate leaching	77%	84%
	Soil Erosion	7%	4%

4.1.3. Acidification

Figure 4-3 shows the average of acidification potential, AP. Results shows that the impact of the average for the REEL project is 0.028 mol H+ eq. per kg of fibre, in comparison with 0.041 mol H+ per kg of fibre. This shows a saving potential of 0.014 mol H+ or 33.3% per kg of fibre. AP for both the REEL project and the control group results mainly from (i) field emissions, (ii) irrigation, and (iii) provision of fertilizer, which together contribute more than 80% to the total.



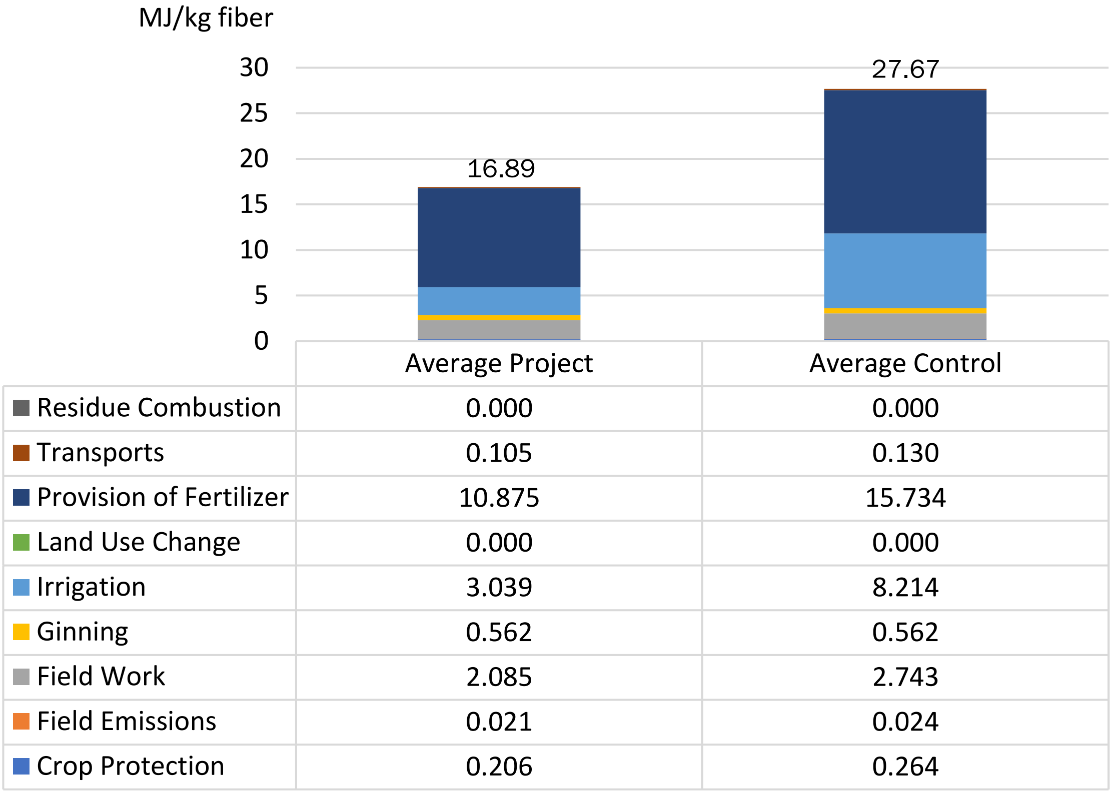
	Average Project	Average Control
⬛ Residue Combustion	0.001	0.003
🟫 Transports	0.000	0.000
🟦 Provision of Fertilizer	0.005	0.007
🟩 Land Use Change	0.000	0.000
🟦 Irrigation	0.005	0.011
🟨 Ginning	0.001	0.001
⬜ Field Work	0.002	0.002
🟧 Field Emissions	0.014	0.018
🟦 Crop Protection	0.000	0.000

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

Results for AP show savings for the REEL project across all life cycle steps compared to the average control (except ginning, see above). The main savings in absolute terms are resulting from reduced irrigation (0.006 mol H+ eq.) and field emissions (0.003 mol H+ eq.). Field emissions are an important contributor to AP, mainly due to ammonia emissions from fertilizer application, particularly from urea (see emission factors provided in Table 3-4).

4.1.4. Abiotic Depletion Potential

Figure 4-4 shows the average of abiotic depletion potential, ADP. Results show that the impact of the average for the REEL project is 16.9 MJ per kg of fibre, in comparison with 27.7 MJ per kg of fibre. This shows a saving potential of 10.7 MJ or 39% per kg fibre. ADP for both the REEL project and the control group results mainly from (i) provision of fertilizer and (ii) irrigation, which together contribute more than 80% to the total (for both the REEL project and the control group).



	Average Project	Average Control
■ Residue Combustion	0.000	0.000
🟫 Transports	0.105	0.130
🟦 Provision of Fertilizer	10.875	15.734
🟩 Land Use Change	0.000	0.000
🟦 Irrigation	3.039	8.214
🟨 Ginning	0.562	0.562
■ Field Work	2.085	2.743
🟧 Field Emissions	0.021	0.024
🟦 Crop Protection	0.206	0.264

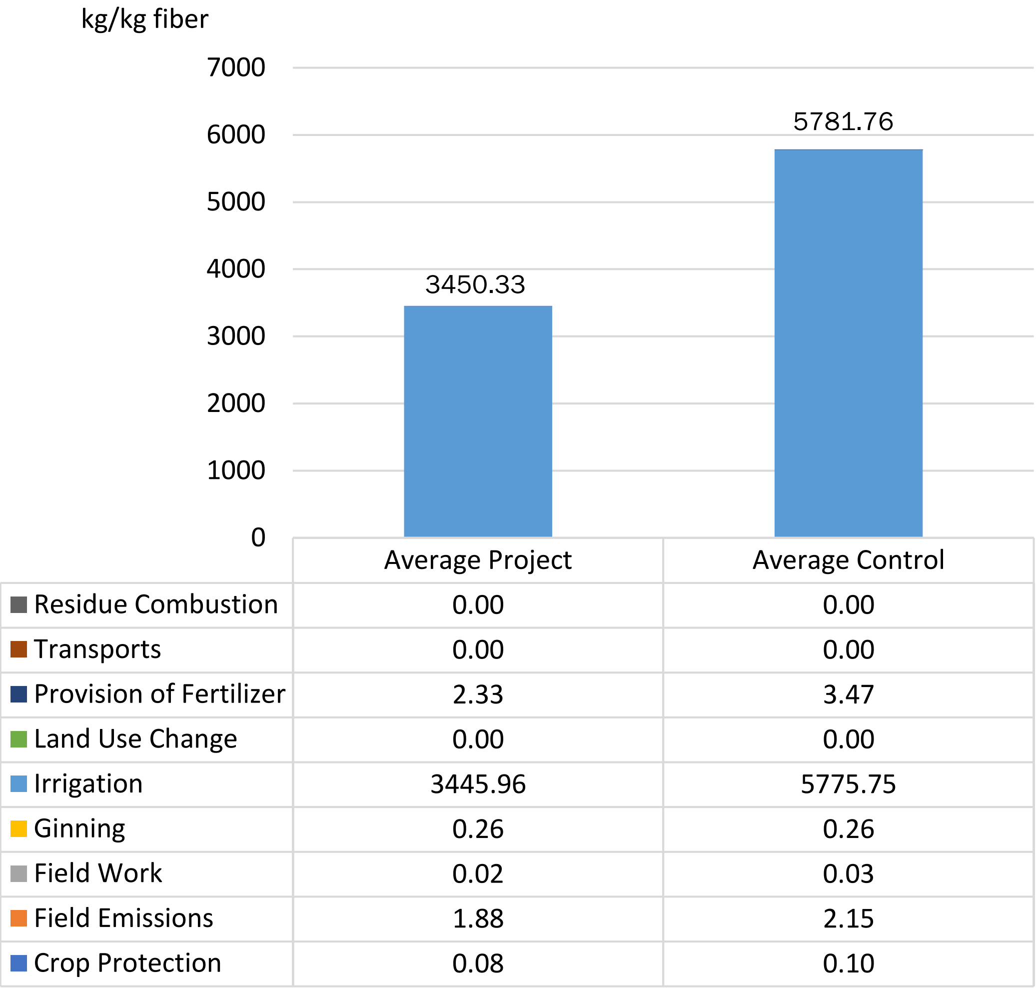
Figure 4-4: Abiotic depletion results, total production weighted average

Results for ADP show savings for the REEL project across all life cycle steps compared to the average control. The main savings in absolute terms are resulting from irrigation (5.2 MJ/FU) and provision of fertilizers (4.8 MJ/FU).

Similar to climate change results, irrigation requires energy (for pumping) which mostly relies on the combustion of fossil energy carriers (i.e. diesel). Additionally, the production of fertilizers depends on energy intensive processes as well. Improved irrigation and fertilizer practices thus lead to reductions in the results of the REEL project compared to the control group.

4.1.5. Water Consumption

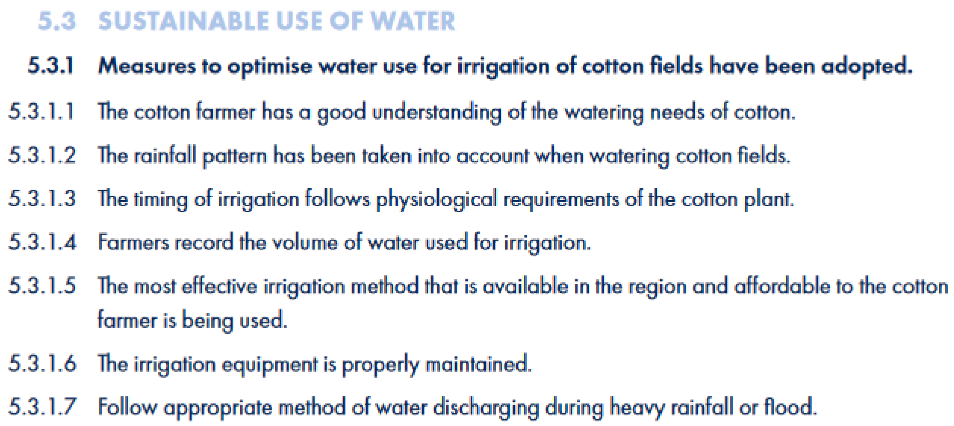
Figure 4-5 shows the average water consumption, without the consideration of region-specific scarcity factors. Water consumption for the REEL project is 3 450 kg water per kg fibre, whereas it is 5 781 kg water per kg fibre for the control group. This leads to a saving potential of 2 331 kg or 40.3% per kg cotton fibre. This is a larger reduction than the reduction on inventory level (see Table 3-1) because the results are shown per kg of fibre and therefore also include scaling effect caused by higher yields.



	Average Project	Average Control
■ Residue Combustion	0.00	0.00
■ Transports	0.00	0.00
■ Provision of Fertilizer	2.33	3.47
■ Land Use Change	0.00	0.00
■ Irrigation	3445.96	5775.75
■ Ginning	0.26	0.26
■ Field Work	0.02	0.03
■ Field Emissions	1.88	2.15
■ Crop Protection	0.08	0.10

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

Irrigation is practically the sole contributor (>99%) for this impact category. Differences between Project and Control could be associated with improved irrigation practices as described in the REEL project Code of Conduct (see Figure 4-6).



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 record 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.

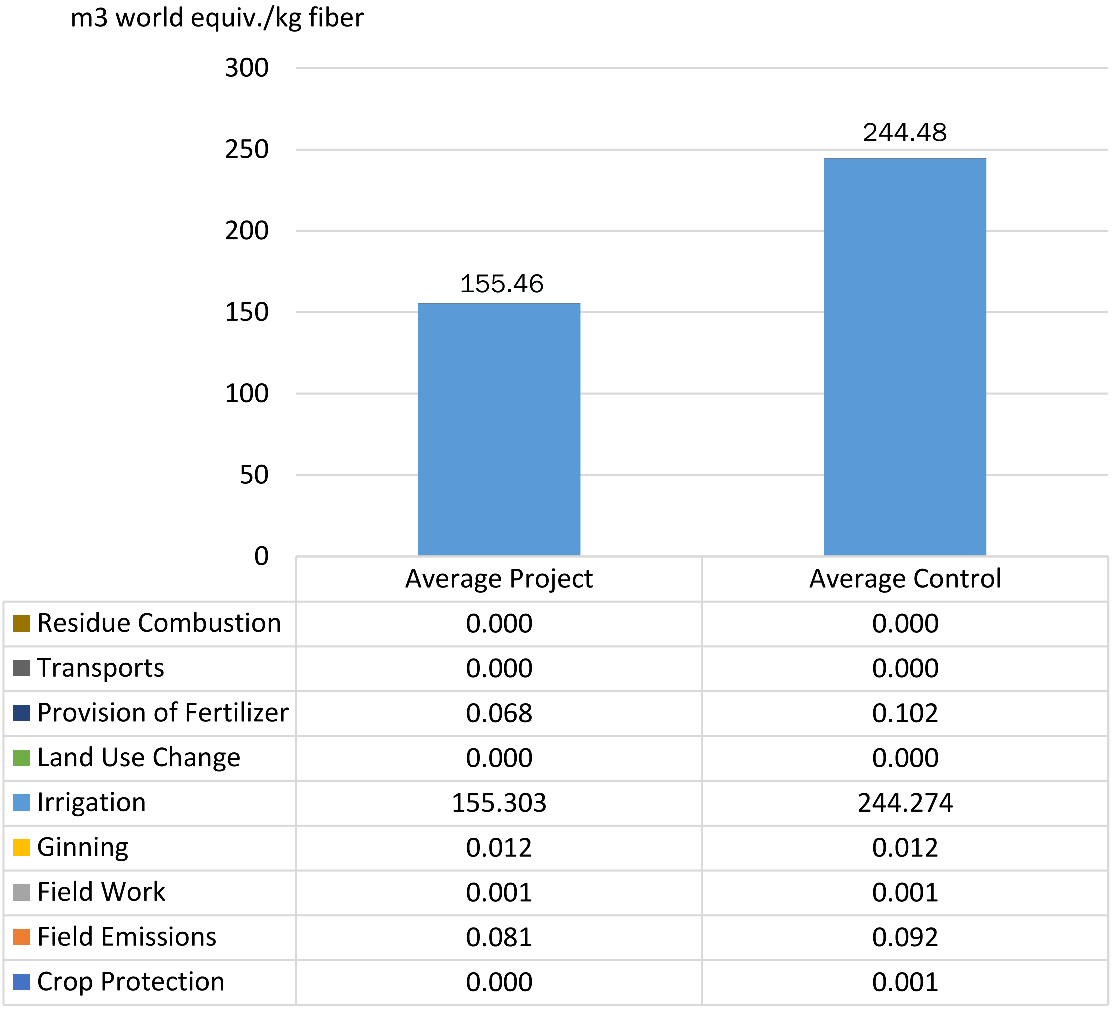
5.3.1.7 Follow appropriate method of water discharging during heavy rainfall or flood.

Figure 4-6: Measures to optimise water use for irrigation encouraged in the REEL project Code of Conduct (CottonConnect, 2021)

As mentioned in section 3.2, it should also be noted that the reported values are therefore strongly influenced by the region Gujarat, where water consumption values were high, the reported reduction potential was high, and that represents a large share in total production.

4.1.6. Water Use

Figure 4-7 shows the average water use. The impact category ‘Water use’ represents the results of water consumption multiplied with characterization factors which consider regional water scarcity, based on the impact assessment method ‘AWARE’ (Boulay, 2017), see also section 2.7. The water use for the REEL project is 155.46 m^3 world eq. per kg fibre, whereas water use for average control is 244.48 m^3 world eq. per kg fibre. This leads to a saving potential of 89 m^3 or 36.4% per kg fibre.



	Average Project	Average Control
🟫 Residue Combustion	0.000	0.000
⬛ Transports	0.000	0.000
🟦 Provision of Fertilizer	0.068	0.102
🟩 Land Use Change	0.000	0.000
🟦 Irrigation	155.303	244.274
🟨 Ginning	0.012	0.012
⬜ Field Work	0.001	0.001
🟧 Field Emissions	0.081	0.092
🟦 Crop Protection	0.000	0.001

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

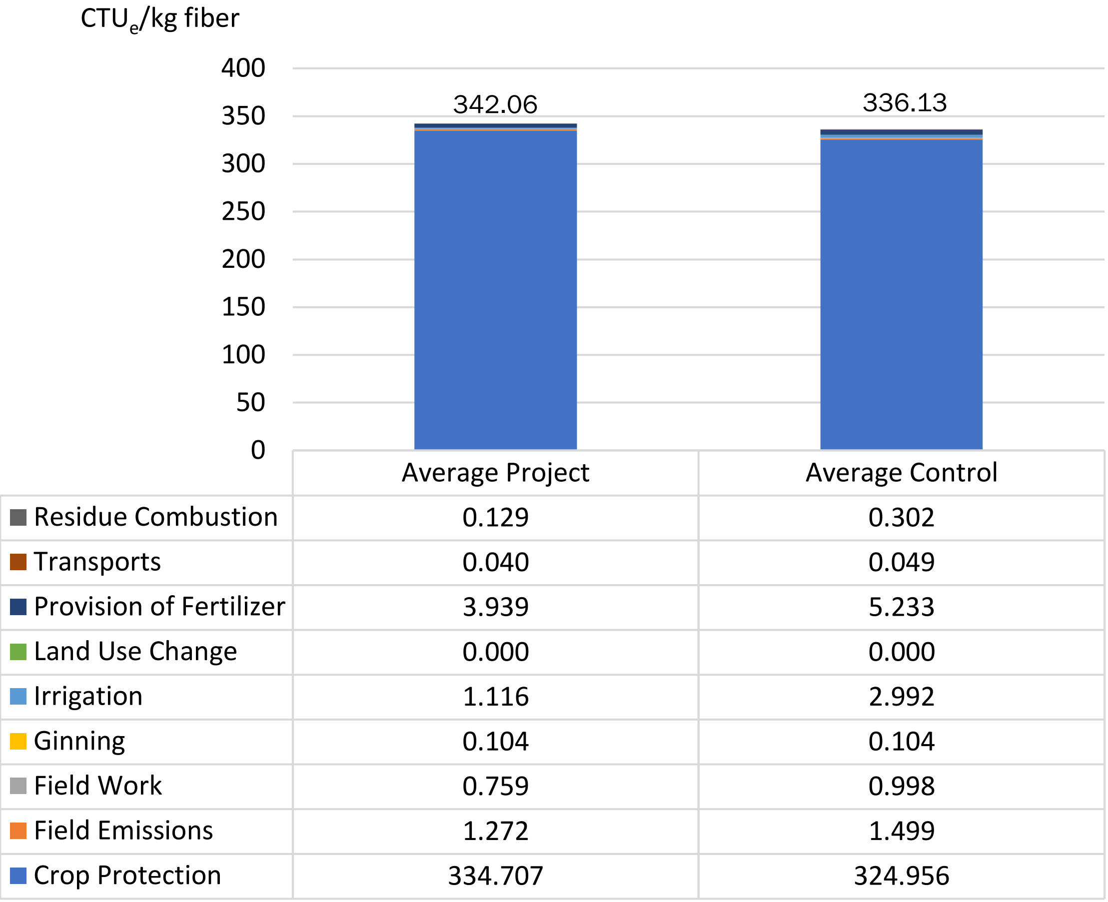
As expected, similar to water consumption, irrigation is practically the sole contributor (>99%) for this impact category. As already discussed, differences between Project and Control could be mainly considered as a result from improved irrigation practices.

It shall be noted that water use results are strongly influenced by the country where water is used. To illustrate this, characterization factors of water use are 2.43 for Bangladesh, compared 29.35 for India, 42.43 for China or 61.44 for Pakistan. Thus, water use in Pakistan leads to an 25-fold impact compared to Bangladesh. More precisely, for this study, sub-national-specific water scarcity factors (i.e. 7 different factors for Bangladesh, 31 for China, 35 for India, and 8 for Pakistan) were used to further increase precision. The applicable AWARE factor is 53 on average based on the share of regions (same for project and control).

However, since the share of regions to total results was the same for both average project and control farms, the selection of scarcity factors is not relevant for the comparison but important if results are compared to results from other studies.

4.1.7. Toxicity

Figure 4-8 shows the average of ecotoxicity. Results show that the impact of the average for the REEL project is 342.06 CTU_e per kg of fibre, in comparison with 336.13 CTU_e per kg of fibre. In contrast to other impact categories, the REEL cotton project does not show a saving potential but an increase of 5.9 CTU_e or 1.8% per kg cotton fibre over Average Control. Ecotoxicity is mainly a result (98%) from crop protection.



	Average Project	Average Control
■ Residue Combustion	0.129	0.302
■ Transports	0.040	0.049
■ Provision of Fertilizer	3.939	5.233
■ Land Use Change	0.000	0.000
■ Irrigation	1.116	2.992
■ Ginning	0.104	0.104
■ Field Work	0.759	0.998
■ Field Emissions	1.272	1.499
■ Crop Protection	334.707	324.956

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

The characterization factors for pesticides cover a span of several magnitudes, so that single substances can have a strong influence on the results even if used in small quantities. In general, pesticide use is lower in the project compared to the control (see Table 3-1). However, a slightly higher application rate of a single substance (bifenthrin) and a slightly increased fraction of farmers applying it in the project group in Pakistan lead to higher results for the average project vs. control, because the substance has a high toxicity factor.

Although the values are in this case higher for the average project, an interpretation of this should be taken cautiously. The underlying impact method is still not considered as very robust and the PEF guidance emphasizes that 'particular attention' should be paid to the improvement of toxicity-related impact assessment methods (European Commission, 2021). Thus, due to the low robustness of the method and the small differences[13] in results, the difference should be assumed as not significant. However, hotspot analysis could be used to investigate substances of large concern in follow up studies (see section 6.3).

The low contribution of other lifecycle phases to toxicity are mainly based on emissions to air with a toxicity factor, either in combustion of fuels (field work, irrigation) or in the upstream processes of energy supply and supply of other inputs (e.g. fertilizer).

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[13] According to the definition provided in Table 4-1, differences below 10% are considered to be small. However, as described above, the tox characterization factors used in this study cover a range of several magnitudes. Therefore, for toxicity, even differences smaller than one order of magnitude can be considered to be "small" and the reported difference of 2% can be considered to be insignificant.

4.2. Biodiversity

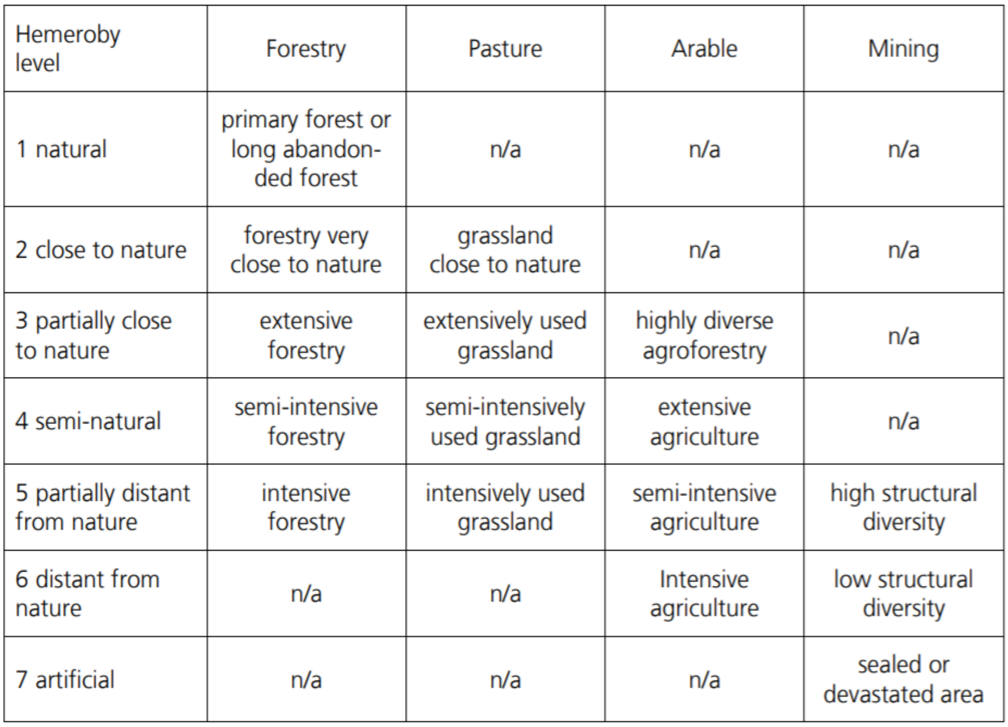
An approach for a biodiversity impact assessment method, proposed by Lindner, Fehrenbach, Winter, Bloemer, & Knuepffer (2019) was utilised in this study to quantitively assess the potential biodiversity impact of cotton production across Pakistan, Bangladesh, India and China. In this assessment, impacts on biodiversity were primarily influenced by the biodiversity value of the region under study, the land use type and the land use management practices. As defined by Lindner, Fehrenbach, Winter, Bloemer, & Knuepffer (2019), a biodiversity value can be estimated according to two approaches: a basic biodiversity calculation based on hemeroby categories or a detailed biodiversity calculation, which incorporates land management practices. Both approaches were considered for this study.

Whilst the results can be used as indicative to the relative improvements that could be achieved by the adjustment of management practices, the method is comparatively new and has not been broadly tested. There is one available benchmark for cotton production (CmiA) however, this still carries the same uncertainty of results. Hence, the results should not be taken as absolute but serve as a step towards including biodiversity assessments within LCA studies.

The detailed biodiversity method was developed and calibrated to accommodate a European context hence it may not be fully accurate for the biomes included in this study.

4.2.1. Estimated biodiversity

The hemeroby value for the less detailed calculation was estimated based on the land use type. The higher the hemeroby, the larger the distance the land is from a state of ‘naturalness’. The method outlines four land use types (forestry, pasture, arable and mining) that all have a range of hemeroby based on the intensity of land use as detailed in Figure 4-9.



Hemeroby level	Forestry	Pasture	Arable	Mining
1 natural	primary forest or long abandonded forest	n/a	n/a	n/a
2 close to nature	forestry very close to nature	grassland close to nature	n/a	n/a
3 partially close to nature	extensive forestry	extensively used grassland	highly diverse agroforestry	n/a
4 semi-natural	semi-intensive forestry	semi-intensively used grassland	extensive agriculture	n/a
5 partially distant from nature	intensive forestry	intensively used grassland	semi-intensive agriculture	high structural diversity
6 distant from nature	n/a	n/a	Intensive agriculture	low structural diversity
7 artificial	n/a	n/a	n/a	sealed or devastated area

Figure 4-9: Hemeroby level for land use types forestry, pasture, arable and mining (Lindner & Knüpffer 2020, page 6)

The REEL project and control farms were estimated to be semi-intensive agriculture systems resulting in a hemeroby value of 5, partially distant from nature. All the farms report substantial rates of fertilizer and pesticide use. This was considered to be a reason to classify them above level 4. At the same time, the farms are usually operated as small-scale farms (1 – 2 ha field size) and here is still a lot of manual labour employed compared to highly intensive systems (e.g. present in the US). This is why level 5 was used to differentiate these systems from such more intensively operated farms that were considered to be classified as level 6. please see also section 4.2.3 for an interpretation of the hemeroby value.

The hemeroby values were then equated to a local biodiversity value Bv_{local};; the lower the hemeroby value, the higher the local biodiversity value.

The ecoregion factor (EF) allows for weighting at a total study level as the reference quality level varies per ecoregion. It is utilised to determine BV_{total}, as detailed in Eq.1, which is representative of the extent to which the biodiversity potential is achieved for the specific land being assessed (Q) and entered into the final calculation for biodiversity impact per functional unit (FU):

Eq.1

$$BV_{total} = EF * BV_{local}$$

Ecoregion factors were determined for each region and the calculations carried out on a regional basis to determine the BVtotal.

The method is tied in with the Land Use Framework by the Life Cycle Initiative which defines ΔQ as the quality difference of a land surface area that deviates from a reference condition and is maintained for a determined period of time which is interpreted to be the impact of the process[14]. ΔQ is calculated by determining the difference from the ecoregion factor and Q, the study total biodiversity value (BV_{total}) as detailed in Eq.2.

Eq.2

$$\Delta Q = EF * (1 - BV_{local})$$

The calculation was carried out for each region and the results aggregated using the production values per region.

Table 4-3: Impact on biodiversity, hemeroby approach, averages

	Hemeroby	Local biodiversity value, BV_{local}	Ecoregion Factor, EF	Bv_{total} =Q	ΔQ	Land Use per FU	Biodiversity Impact per FU = Land Use * Delta Q
Unit		*BVI*		*BVI*	*BVI*	*m²a/FU*	*BVIm²a*
Project	5	0.754	0.200	0.151	0.049	4.468	0.220
Control	5	0.754	0.200	0.151	0.049	5.182	0.255

Since the same local biodiversity value and ecoregion factors are used for the project and the control, the results only differ based on the differences in yield, which transfers into a different land use factor (per kg of fibre).

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[14] This study only considers occupation impacts. Transformation impacts are omitted in consistency with the omission of LUC, see section 2.3.

4.2.2. Detailed biodiversity calculation

The calculation for the specific biodiversity value BV_{arable} was carried out using parameters based on (Fehrenbach, Grahl, Giegrich, & Busch, 2015) and the methodology defined by Lindner et al, (2019). The parameters considered were related to diversity of weeds, diversity of structures, soil conservation, material input and plant protection. The aspects considered are listed in table 4-3, the actual values used can be found in Annex B[15].

The baseline scenario parameters were determined based on the primary data gathered for each farming region to achieve the land use (arable) biodiversity value (BV_{arable}) as outlined by Lindner et al, (2019). While data availability was good for parameter group A3 to A5 (compare to Table 4-4), more vague assumptions needed to be made for parameter A1.1, A1.2. and A2.1.

Table 4-4: Parameters considered in detailed biodiversity calculation (based on (Fehrenbach, Grahl, Giegrich, & Busch, 2015))

Parameter group			Unit
A.1	**Diversity of weeds**		
	A.1.1	Number of weed species in the cultivation area	[species/ha]
	A.1.2	Existence of rarer species	[% time]
A.2	**Diversity of structures**		
	A.2.1	Elements of structure in the area	[% area]
	A.2.2	Field size	[ha]
A.3	**Soil conservation**		
	A.3.1	Intensity of soil movement (based on fuel use)	[L/ha]
	A.3.2	Ground cover	[% time]
	A.3.3	Crop rotation	[points]
A.4	**Material input**		
	A.4.1	Share of farmyard manure	[% mass]
	A.4.2	Share of manure/compost/fertilizers with low solubility	[% mass]
	A.4.3	share of artificial/liquid fertilizers	[% mass]
	A.4.4	Share of artificial/liquid fertilizers out of season	[% mass]
	A.4.5	Intensity of fertilizing	[kgN /ha*a]
A.5	**Plant protection**		
	A.5.1	Plant protection agents (input of pesticides)	[applications/a]
	A.5.2	Mechanical weed control (share of mechanical/biological pest control)	[% applications]

The value for BV_{arable} was further transformed into a normalised biodiversity value, BV_{norm} utilising maximum and minimum values for arable land use. The BV_{local} was then achieved using the calculations as laid out in (Lindner & Knüpffer, 2020).

The individual BV_{local} for each region was aggregated into an overall value for all regions using the production volumes per region. As per the initial calculation, Eq.1, the BV_{total} (Quality) was determined by utilising

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[15] Annex B includes inventory data for all regions (i.e. the data as used in the calculations), which is available upon request and at the discretion of CottonConnect.

the Ecoregion factors to determine the biodiversity impact per FU ($BV_{total} = BV_{local} * EF$). ΔQ was calculated using Eq,2.

The detailed biodiversity calculation was carried out on a regional basis for both REEL project and control project values. Regional results were then weighted by production % to determine the average detailed biodiversity value.

Table 4-5: Impact on biodiversity, detailed approach

	Local biodiversity value, BV_{local}	Ecoregion Factor, EF	Bv_{total} =Q	ΔQ	Land Use per FU	Biodiversity Impact per FU = Land Use * Delta Q
Unit	*BVI*		*BVI*	*BVI*	*m2a/FU*	*BVIm2a*
Project	0.829	0.200	0.166	0.034	4.468	0.151
Control	0.830	0.200	0.166	0.033	5.234	0.176

The local biodiversity value (that is calculated based on the parameters above) shows a negligible difference between the REEL project and control figures. This means that the reported differences e.g. in fertilizer or pesticide use does not lead to large differences in the impact on biodiversity. As the ecoregions under consideration are the same for both, the key driver in the difference of biodiversity impact is the land use (m^2a/ FU) recorded for the average REEL project and control farms. This difference resulted in a reduction in biodiversity impact per kg cotton fibre of 13% from the control to REEL project values.

4.2.3. Results summary

The less detailed biodiversity calculation, utilising the hemeroby scale, resulted in a higher biodiversity impact per FU than results for the detailed biodiversity calculation. This is in line with the CmiA study results.

The average project result was calculated to be 0.149 $BVIm^2a$ which is 42% lower than that of the calculation utilising the hemeroby scale. The average control result was calculation to be 0.172 $BVIm^2a$ which is also 42% lower than the calculation utilising the hemeroby scale. The calculated impact is 13% lower for the project vs. the control.

The following figure shows the hemeroby and local biodiversity value intervals for the land use types that can be assessed by the biodiversity method. As previously stated, arable land use is defined within the range of a hemeroby value 3 (partially close to nature) and 6 (distant from nature). This translates to a local biodiversity value of 0.950 and 0.500 respectively.

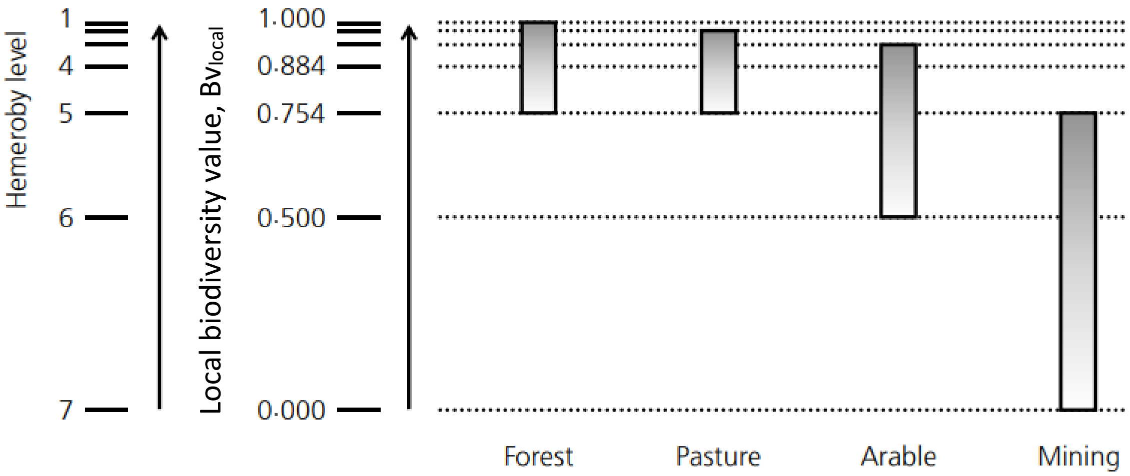


Figure 4-10: Value intervals of the land use types assessed by the biodiversity method (Lindner & Knüpffer 2020, page 7)

The local biodiversity value for the average project and control farms for the detailed local biodiversity calculation was calculated to be 0.833 and 0.834 respectively. These values lie between hemeroby level 4 (semi-natural) which represents an extensive agriculture system and 5 (semi-intensive agriculture). This confirms the assumption that the average project and control farms had a hemeroby level of 5.

Again, these values should be interpreted with care as some of the input data and the validity of the model calibration for the biomes under study is related to uncertainty.

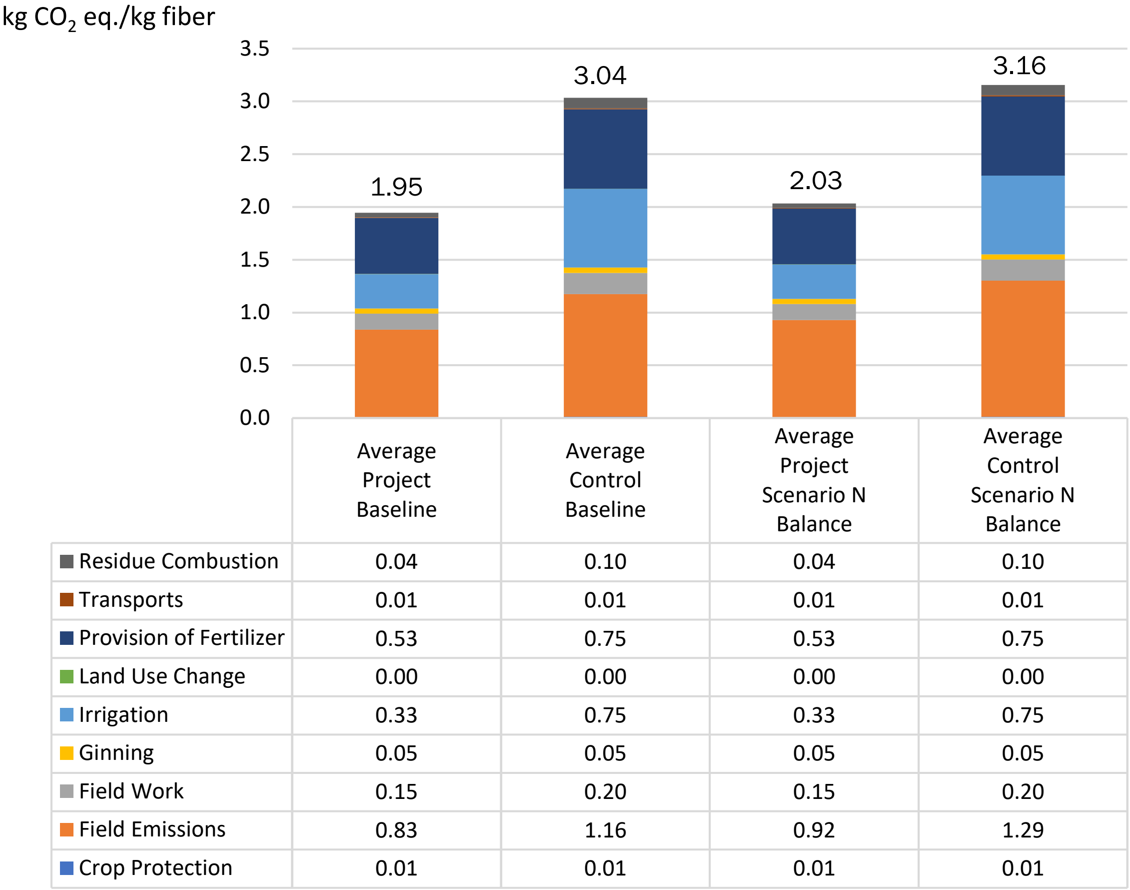
4.3. Scenario Analysis (N-balance)

In the baseline scenario used in this study, nitrate emissions were calculated based on a N balance (see section 3.3.3). As stated previously, this represents a conservative approach because it assumes that all surplus nitrogen is eventually leached. In addition, this means that the N content of the harvest influences leaching results as it is considered in the N balance, which leads to additional uncertainty regarding the calculated amount of N leached. Many studies use a simplified approach regarding N leaching with a fixed leaching factor applied to the total amount of N applied (i.e. 24%, see (IPCC, 2019)), even if this means that the assumed N balance of the modelled system is not closed. The following scenario shows the results using this fixed emission factor for N leaching (Figure 4-11 and Figure 4-12).

It can be seen that the assumption on N leaching had only a low impact on the climate change results. Only a small fraction of the N leached is assumed to be transformed into N_2O with its respective impact on climate change. Therefore, even large differences in the assumed leaching leads to only small differences in the climate change results.

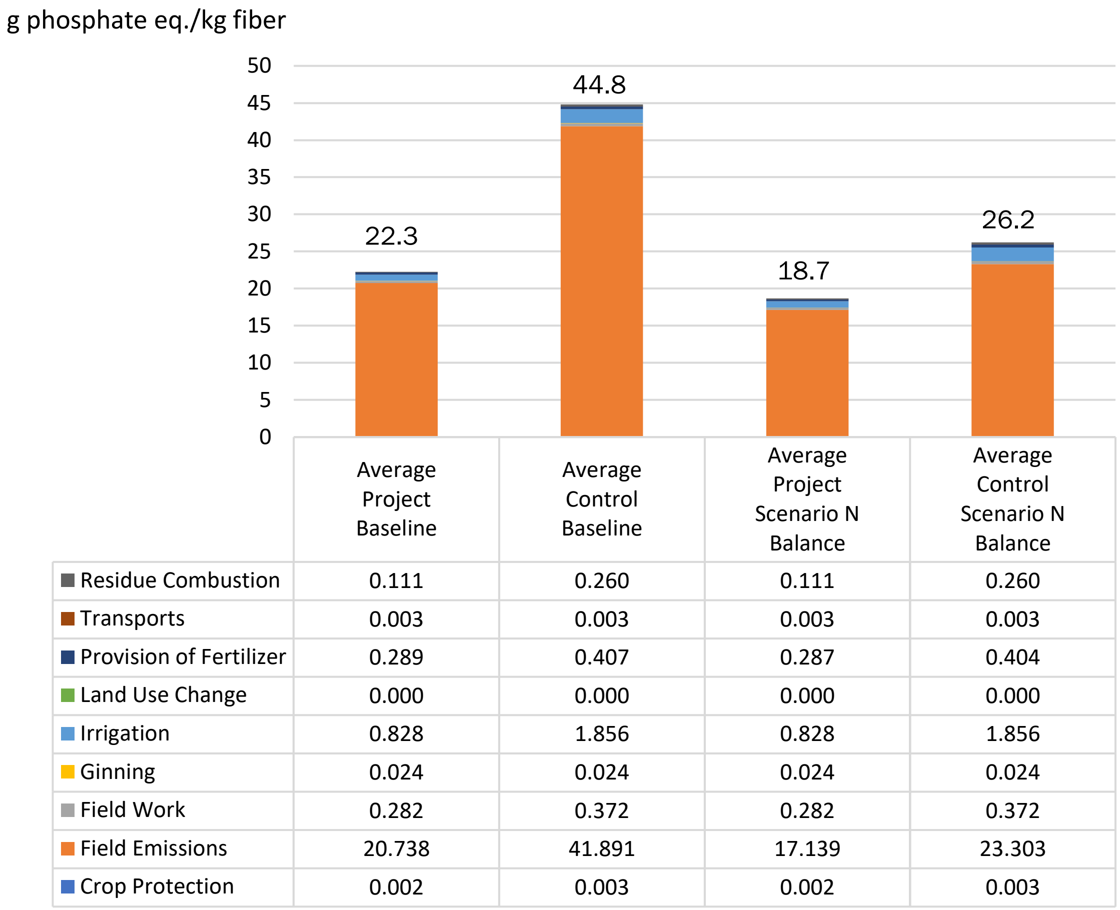
Eutrophication however is strongly influenced by leaching (see Table 4-2). It can be seen that using a fixed emission factor leads to lower results in the eutrophication impact category. The largest difference between the scenario and the baseline was found for the control. This is caused by the comparatively large N surpluses calculated in this group (see Figure 3-1). This surplus had a stronger impact on the results if an N balance approach was used as all surplus nitrogen is assumed to be leached.

Nitrate emission modelling is a complex issue and subject of an ongoing debate (see PEF method). It should be added here, that both approaches are a clear simplification (although one commonly used in most agricultural LCAs) as leaching is also influenced by soil type, climatic conditions and fertilization time, to just name the most important influencing factors. This means that without an in depth assessment of the above mentioned factors, the uncertainty of the results for both assessment should be considered.



	Average Project Baseline	Average Control Baseline	Average Project Scenario N Balance	Average Control Scenario N Balance
■ Residue Combustion	0.04	0.10	0.04	0.10
■ Transports	0.01	0.01	0.01	0.01
■ Provision of Fertilizer	0.53	0.75	0.53	0.75
■ Land Use Change	0.00	0.00	0.00	0.00
■ Irrigation	0.33	0.75	0.33	0.75
■ Ginning	0.05	0.05	0.05	0.05
■ Field Work	0.15	0.20	0.15	0.20
■ Field Emissions	0.83	1.16	0.92	1.29
■ Crop Protection	0.01	0.01	0.01	0.01

Figure 4-11: Climate change results for N balance scenario analysis



	Average Project Baseline	Average Control Baseline	Average Project Scenario N Balance	Average Control Scenario N Balance
Residue Combustion	0.111	0.260	0.111	0.260
Transports	0.003	0.003	0.003	0.003
Provision of Fertilizer	0.289	0.407	0.287	0.404
Land Use Change	0.000	0.000	0.000	0.000
Irrigation	0.828	1.856	0.828	1.856
Ginning	0.024	0.024	0.024	0.024
Field Work	0.282	0.372	0.282	0.372
Field Emissions	20.738	41.891	17.139	23.303
Crop Protection	0.002	0.003	0.002	0.003

Figure 4-12: Eutrophication potential results for N balance scenario analysis

4.4. 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 (16 alternatives considering project and control in 8 regions), a full Monte Carlo uncertainty analysis was considered to exceed the scope of the study. Regional variability was used to explore the variability and uncertainty surrounding the data to a certain extent, following an approach used in Cotton Inc. (2017). Standard deviation from the regional results (i.e. sub-country level, available on request from CottonConnect) are used as an indicator for the variability of the results (see Table 4-6).

Table 4-6: Relative regional variability (Standard deviation from median of regional results)

Impact	Standard deviation (%)
Climate change	44%
Eutrophication	91%
Acidification	50%
ADP	58%
Water consumption	179%
Water use	398%
Ecotoxicity	68%

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, fertilizer use, pesticide use). Impact categories that are influenced by many parameters (e.g. climate change that is influenced by yield, fertilizer 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. fertilizer application to field emissions and emissions from fertilizer 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 fertilizer application will lead to a 10% decrease in emissions related to fertilizer 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

For easy access, interpretations of the results that are necessary to understand differences between REEL project and control values and contributions are provided along with the results in the respective parts of section 4 of the report. This section summarises relevant findings on a larger scale and reviews them in relation to assumptions and limitations.

The inventory data shows the REEL project to achieve higher yields, lower water consumption and an increased nitrogen use efficiency. As expected, this translates to the impact results where a clear benefit is demonstrated by implementation of the REEL program in the areas under study.

Multiple year averages were used to equal out seasonal variation for data provided across all regions under study apart from Bangladesh which could only provide one year of inventory data. However, in the context of creating the average values utilising the production shares for each region under study, Bangladesh only contributed to 0.39% hence did not have a large impact on the average results. In addition, China data were only available for one region however, Hebei only contributed to 2.62% of the average production. Overall, results are most heavily influenced by production in Pakistan and India whereby availability of data were good and consistent over several production years.

Climate change potential is dominated by field emissions with a large contribution from irrigation and the provision (production) of fertilizer. Acidification potential follows a similar pattern however, eutrophication potential is dominated solely by the impact of field emissions due to the application of the fertilizer. Water consumption and water use (scarcity) are dominated by the water used for irrigation on the field. Abiotic depletion potential is dominated by the utilisation of fossil-based resources which occurs most heavily in the provision of fertilizer, irrigation, and field work.

Land use change only had a small contribution to the results in this study. However, it can have significant impacts on climate change results in systems where it occurs. It is therefore important to ensure it is tracked correctly, and continue efforts to prevent emissions from LUC.

The nitrogen balance indicates that there may still be opportunity for an improved fertiliser use efficiency even in the REEL systems which would benefit climate change results through reduced field emissions and reduced upstream impact from fertiliser production.

Irrigation is a significant contributor to the results, improvements to irrigation practices could lead to a lesser contribution to water scarcity in the project regions, as well as a reduction in climate change impact due to the diesel consumption required for irrigation. Cleaner sources of fuel could also be investigated (versus diesel).

Ecotoxicity potential shows no significant difference for the REEL cotton project. The ecotoxicity results are influenced by a single active ingredient with a high toxicity factor. This might require an in-depth investigation on robustness of toxicity factors of this substance, on substances of high concern in general and verification of application rates and fraction of farmers applying these.

Biodiversity impacts are most influenced by the ecoregion factor of the region under study which represents the existing state of the area and the land area utilised. Overall, a clear improvement is seen between project and control values, predominantly due to differences in area use.

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.

UNFCC

Following the launch of the Fashion Industry Charter for Climate action, they formed a Raw Material Working Group for signatories and other supporting organisations. As part of their work, they released a report 'Identifying Low Carbon Sources of Cotton and Polyester Fibres' (Action, 2021). The report aims to assess available life cycle assessment data from existing cotton studies and provide direction and a call to action from the industry to shift to more sustainable practices.

The following table shows key gaps identified by the UNFCC and details how this CottonConnect study considers them.

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 to CottonConnect.

Cotton Inc 2017.

The latest update to the Cotton Inc. study on the impact of cotton was conducted in 2017. The results of this showed an average to be 1.43 kg CO_2 eq./ kg lint cotton production, based on production shares from India, China, Australia, and the US. For most indicators, the contribution analysis is similar to this study. E.g. for climate change as with the CottonConnect results, field emissions, fertilizer production and irrigation dominate impact.

The Cotton Inc. study results are clearly lower than the REEL project results (e.g. 27% lower results in climate change). This is despite the fact that a lower allocation factor is used in this study compared to the cotton connect study (if the same allocation factor was used the difference would be >30%). If the averages are compared (although they cover different countries), the REEL project results are higher for irrigation, fertilizer provision and field emissions. Cotton Inc. includes regions of study with highly industrialised systems that produce higher yields versus the CottonConnect regions. From the contribution analysis, it can also be concluded that (on average) the amount if fertilizer applied per kg yield is lower in the

Cotton Inc study compared to the REEL project. The water consumption is lower in the Cotton Inc. study, which is understandable as CottonConnect regions dominating the results of this study in Pakistan and India tend to have high water use. This also transfers to lower impacts from irrigation in the Cotton Inc. study.

CmiA 2021

The LCA study update of Cotton made in Africa was conducted by Sphera and included a comparison of a total CmiA value with the total Cotton Inc 2017 results detailed above.

The results of the study showed CmiA to have an average climate change impact of 1.24 kg CO_2 eq./ kg cotton lint. These results are significantly lower than the REEL project results (e.g. 36% lower results in climate change). This is despite the fact that a lower allocation factor is used in this study compared to the cotton connect study (if the same allocation factor was used the difference would be almost 50%).

An important factor here is that CmiA cotton is not produced utilising irrigation hence, there is no contribution due to energy use for the irrigation pump (this accounts for more than half of the difference between the two systems). Similar to the comparison with the Cotton Inc study, the reported impacts from fertilizer use (fertilizer provision and field emissions) are lower than in this study. The CmiA systems are often limited by fertilizer use, and the reported N-Balances were close to zero (i.e. closed if accounting for losses). This might indicate an improvement potential in terms of fertilizer use efficiency for the REEL project farmers, where a larger N surplus was calculated (see section 3.3.3.)

Sphera utilised the biodiversity method as outlined in this study for the CmiA study in 2020. This is the only benchmark available that is known to Sphera. For the CmiA biodiversity calculation, the baseline scenario utilising the detailed biodiversity approach was calculated to be 0.558 BVIm^2a. Despite having a slightly higher local biodiversity value, due to the considerably higher ecoregion factor and land use per FU, the result is approximately 73% higher than the biodiversity value calculated for the average REEL project. The land use per FU for the average REEL project is 44% that of the land use per FU of the total CmiA value, which significantly impacts the biodiversity impact results. The ecoregion factor for the average REEL project is 57% that of the CmiA ecoregion factor which also influences the difference in biodiversity impact. Note again, these results should be interpreted with care. This method is new and more experience with its application to the biomes under consideration in this study or the CmiA study would help to better interpret the results.

BCI 2021

The Better Cotton Initiative recently published a study with a total average that includes various regions and countries similar to the CottonConnect REEL project (Better Cotton Initiative, 2021) . However, this study was conducted utilising the Cool Farm Tool (CFT).

The results of the BCI study showed a large difference in average results for climate change (3.6 vs. 1.95 kg CO_2 eq./ kg cotton fiber for BCI average vs. REEL project average) with a different pattern in contribution to the impact results. Most notably, the results show a much higher contribution due to fertilizer production. A detailed comparison would be required to understand the exact differences. However, possible explanations could be that the CFT includes Ecoinvent fertilizer datasets which are known to have different impact profiles compared to the datasets included in the Sphera Lean Ag model (used this study). In addition, the CFT utilises Ecoinvent energy datasets which could also drive differences in results.

Inventory data for the BCI study is not provided in detail hence, it is difficult to comprehensively interpret differences prior to the implementation in the different models. Also, the published results are limited to climate change hence, no further comparisons could be determined from blue water consumption or other LCA metrics. The BCI study confirmed the low relevance of LUC for the regions considered in this study.

5.3. Data Quality Assessment

Inventory data quality is judged by its precision (measured, calculated, or estimated) and representativeness (geographical, temporal, and technological). To cover the requirements outined in section 2.9 and to ensure reliable results, primary data in combination with consistent background LCA information from the GaBi 2022 database were used in this study. Overall, the inventory data utilised in this study can be considered as reliable. CottonConnect work with a second party to collect sample data from farmers and ginners which is then checked by CottonConnect and further third party validated. Only for some data points additional data had to be collected which were not certified (see section 3.1 and 3.2). However, it should be noted that neither Sphera not the review panel verified data beyond plausibility checks and the responsibility for the correctness of the input data remains with CottonConnect.

In reference to the PEF method (Suggestions for updating the Product Environmental Footprint PEF method, chapter 4.6.5), the following quality levels are used to assess the data quality of the aspects above. However, the assessment is done qualitatively, and no full calculation of a data quality indicator as required in PEF studies is conducted in this study.

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 aim of this study was to use multiple year averages to equal out seasonal differences. However, the REEL program was not operating in all regions in all years. In order to maximize geographical coverage and to equal out seasonal differences, data from all years available was used, see Table 2-3. This means that for some regions only data from one season was available, while other had continues data for up to eight years. This approach introduces some temporal inconsistency, but it was considered to be the preferable approach to maximize geographical coverage and to equal out seasonal differences as stated above. While multiple year averages were used where possible, with the mentioned inconsistencies temporal representativeness is assessed to be at least “good”.

5.3.3. Geographical representativeness

For the foreground system (i.e. the collected inventory data) it can be said that “the activity data reflects the exact geography where the process modelled (…) takes place” (ibid.), a criterion for excellent geographic representativeness. However, background data was not available on the same geographical level, with fertilizer datasets for India being used as proxies for the other countries assessed as the most noteworthy example. Electricity datasets however were available for each country assessed. This means that the geographical representativeness of background datasets is between level 3 (for fertilizer data) and level 1 (for electricity data). In total, it is assumed that the geographical representativeness is “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 program
- 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 fertilizer use) were validated

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

- There was a different temporal scope between project regions
- 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
- Fertilizer production datasets were only available for India and had to be used as proxies for the other regions assessed
- 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 study shows a comparison of cotton production under CottonConnect's REEL cotton programme versus a control baseline value that does not implement REEL cotton sustainable practices in the same regions. Inventory data and results are available in the main study on a study total average level, weighted utilising production shares for REEL cotton. Inventory data and results are available on both a regional and country level in the annexes of this study and can be requested for viewing from CottonConnect.

Overall, the inventory data utilised in this study can be considered as reliable. CottonConnect work with a second party to collect sample data from farmers and ginners which is then checked by CottonConnect and further third party verified. Hence, it is considered that the results of this study which show a clear improvement across the majority of indicators for the REEL cotton programme, demonstrate the clear benefits of the sustainable practices outlined by REEL cotton Code of Conduct 3.0. However, since no statistical testing of the significance of differences in the inventory data between project and control farms was made, some "uncertainty about the uncertainty" remains.

For all impact categories apart from ecotoxicity and biodiversity, the REEL cotton project results show a clear improvement (>30% saving potential) versus the control results. Impacts on biodiversity are influenced heavily by the land use per FU of the system under study and the existing ecoregion factor of the region under study and show an improvement (>10%) predominantly driven by improved yields. Ecotoxicity results were dominated by a single substance, and the assessed small increase (<2%) in the project vs. the control is considered to be of low relevance, but further investigation is recommended.

As Pakistan and India together make up approximately 97% of the total production shares of REEL cotton, the total average values for both project and control are largely dominated by the results from the inventory data collected for those countries. There was good consistency in data available for these regions whereby data were collected and averaged over a 3+ year time period. However, limitations in terms of data collected and data availability remain across these countries as well as the other contributing countries, China and Bangladesh hence, results should be interpreted with care in both the main study and annexes in relation to the limitations provided.

Sphera and CottonConnect echo the calls by many organisations in the space to focus on driving forward more sustainable sourcing and agriculture practices. This report demonstrates clearly that benefit can be sought across many impact categories by implementing projects such as CottonConnect's REEL cotton project.

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.

- Data for Bangladesh was only available for 2019/2020 however, both regions in Bangladesh only contribute to 0.39% of the total production values hence, not strongly influencing the LCA results of the study.

- Data were collected for the control values to represent approximately 5-10% of the REEL project production occurring in each region. Greater coverage could be beneficial to strengthen the comparison however, this covers a large value in absolute production value terms and can be taken as an indication of the baseline to compare vs. farms operating under the REEL cotton project.
- Data sampling was already conducted by a second party on behalf of CottonConnect and verified by a third party however there were some gaps in the data required for the LCA study hence, additional sampling was conducted by extension agents during the study. This data was not verified by a third party.
- No systematic assessment of uncertainty could be conducted for this study. The question if the reported differences in yield, fertilizer use and irrigation water use (that cause the differences in environmental performance) between project and control farms is significant could only be answered based on thorough statistical testing. Such testing was not performed neither previous to this study nor in this study. While most LCA studies do not include statistical testing due to the complex data structure, some systematic assessment of uncertainty at least on input data level would help to improve robustness of the results.
- 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.
- It is difficult to assess nitrate emissions as they are influenced by many factors however, the approach taken represents a conservative approach (surplus nitrogen is leached) hence the eutrophication potential may be overestimated.
- Ecotoxicity results were dominated by a single substance. This might require an in-depth investigation on robustness of toxicity factors, substances of high concern and verification of application rates and fraction of farmers applying these. In general, ecotoxicity results can vary over several orders of magnitudes, so absolute results should be interpreted with care.
- The biodiversity method utilised in this study is relatively new and was not developed for the biomes under consideration.

6.3. Recommendations

It is recommended that CottonConnect continues to develop its LCA data collection scheme on a yearly basis. CottonConnect may also seek to collect data for other countries and regions in which the REEL programme expands. The continuation and expansion of data collection will allow CottonConnect to continuously measure the improvements against the control group but also within the REEL programme. An additional assessment of farmers through the program (i.e. comparison of performance in the first year vs. the last year) could also be of interest.

Data quality was assessed to be at least good to very good for all critical aspects, but uncertainty remained for some datapoints and related impact categories hence, improvement of data availability and consistency of collection would bring greater certainty to the environmental profile of cotton produced under the REEL project. Statistical tests of significance of the most important inventory data parameters (i.e. yield, fertilizer use, irrigation) based on the disaggregated farmer data would also add more robustness to the results.

Energy consumption required for irrigation has been identified as a hotspot hence it is recommended to consider further investigation. CottonConnect may choose to intensify effort to include energy consumption in primary data collection at farms or refine approach to modelling/estimating the values (e.g. by differentiating by energy source, include ground water level etc.).

Eutrophication is included in the SAC Higg MSI score. If data from this study is submitted to the Higg MSI, further review might be required to ensure that the comparison to other materials is not compromised by different approaches to eutrophication modelling. If eutrophication results are found to be a hotspot in comparisons to results from other studies, a more detailed modelling of leaching rates with consideration of climate data could increase the robustness of the results from this study. However, all these aspects do not concern the comparison of REEL cotton vs. the control which is the main focus of this study.

The nitrogen balances calculated in this study give a good indication of increased nitrogen use efficiency in the REEL project farms. A more detailed regional assessment, potentially even on farm level, could indicate further improvement potentials to lower remaining surpluses as far as possible.

Ecotoxicity could be investigated further in depth to understand the key contributors to the impact and identify substances of high concern that could be monitored in CottonConnect's REEL cotton programme. If robustness of toxicity factors can be investigated further and application rates, as well as fraction of farmers applying substances confirmed, further recommendations could be made to replace harmful substances.

CottonConnect understands the importance and validity of calls for cotton LCA data to be made available at a country or regional level (and providing the highest level of disaggregation per the input data). Considering the current climate of data misuse and poorly informed decision making that can be carried out by companies sourcing cotton, CottonConnect and Sphera created the main report with the inventory including the values however as detailed previously, regional and country LCI & LCIA can be provided upon request to CottonConnect. CottonConnect may work with other organisations to determine ways to responsibly share this disaggregated data.

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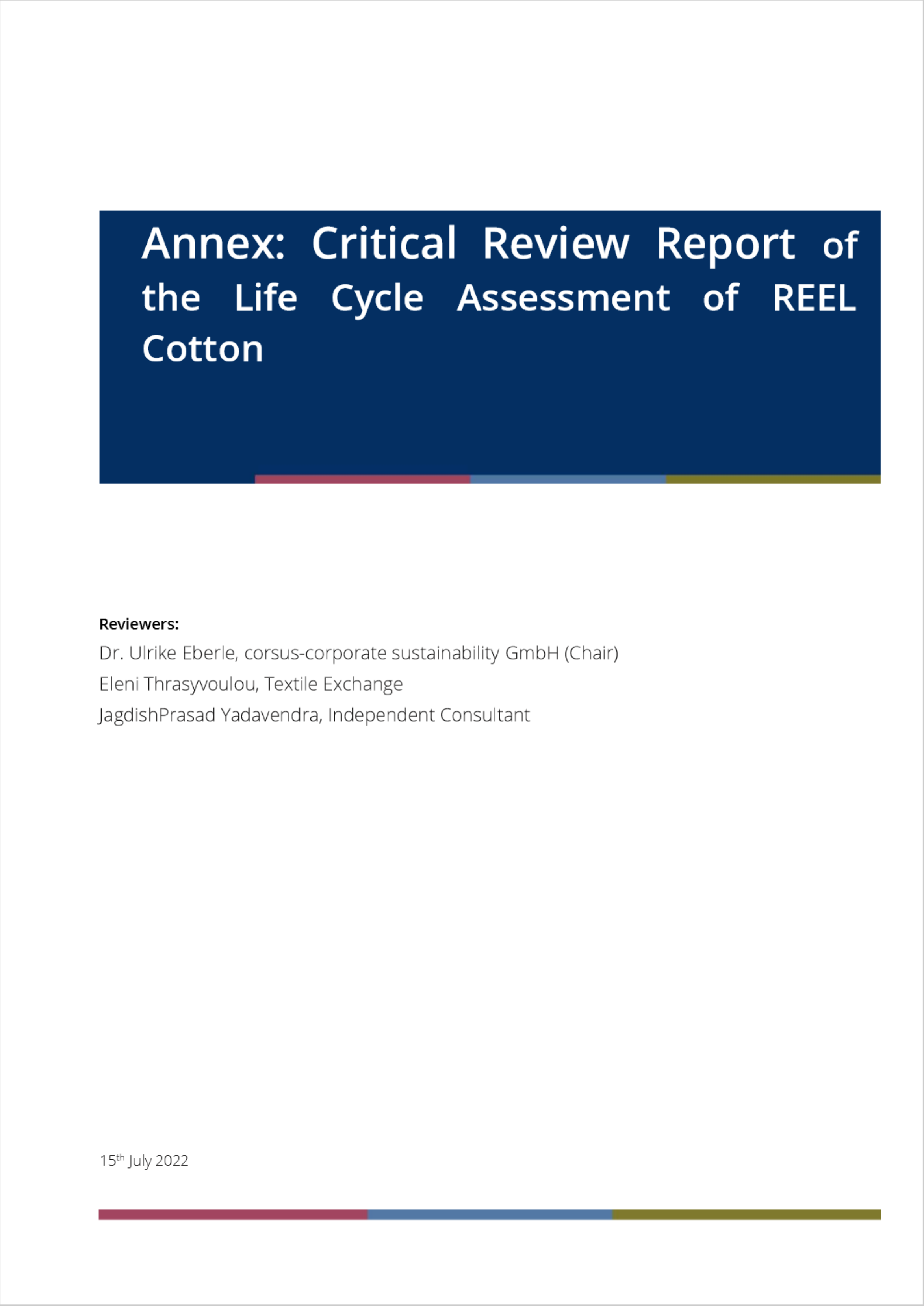
Annex A: Critical Review Statement



Annex: Critical Review Report of the Life Cycle Assessment of REEL Cotton

Reviewers:
Dr. Ulrike Eberle, corsus-corporate sustainability GmbH (Chair)
Eleni Thrasyvoulou, Textile Exchange
JagdishPrasad Yadavendra, Independent Consultant

15th July 2022

Content

1 Procedural Aspects

The Critical Review of the study “Life Cycle Assessment of REEL cotton” was commissioned by CottonConnect Ltd (thereafter referred to as CottonConnect) in April 2022. The LCA study was carried out by Sphera.

The Critical Review Panel (CRP) received a draft project report on 14th April 2022. A draft critical review report containing a detailed list of comments was submitted to the commissioner and the practitioners on 23rd May 2022. Thereafter, on 12 June 2022, the reviewers received the final draft of the LCA study report, which largely satisfactorily incorporated the reviewers' comments on the draft report. The statements and comments below are based on this final draft report. Checking the GABI model was not part of the critical review.

The critical review is a review by ‘interested parties’ (panel method) according to ISO 14040 section 7.3.3 [1] and ISO 14044 section 4.2.3.7 and 6.3 [2] due to the fact that comparative assertions of different systems are included in the LCA study.

The CRP is neutral with regard to and independent from particular commercial interests.

All members of the CRP are in agreement with the critical review report presented below.

2 Overview of the LCA study

In the LCA study “LCA of REEL cotton” two alternative cotton production systems have been studied:

- cotton farmed and ginned by small holder farmers operating under the REEL cotton program
- cotton farmed and ginned by a control group of farmers operating in the same regions but not under the REEL program (benchmark)

This LCA is important for CottonConnect as the organisation wishes to gain more insight and a deeper understanding of the system, to close knowledge gaps, and identify weak points of the life cycle. In this context, it is of interest in which environmental impact categories there are differences between the analysed options in order to be able to identify optimisation potentials.

In order to investigate the robustness of comparative results, scenario analyses were performed and evaluated.

3 Critical review statement

According to the LCA-framework standard ISO 14040 section 6.1 [1]:

"The critical review process shall ensure that:

- the methods used to carry out the LCA are consistent with the international Standard;
- 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;

- the study report is transparent and consistent."

In the following sections these items are discussed to our best judgement and considering the ISO standards 14040 [1] and 14044 [2].

3.1 Consistency of the methods with ISO 14040 & 14044

The study has been performed according to the international standards ISO 14040 and 14044. The methodological framework, goal and scope are described comprehensively. The life cycle inventory modelling follows the state-of-the-art practice and is presented in an understandable manner.

The inventory analysis methods applied are consistent with the ISO standards 14040 and 14044. The use of the GaBi LCA software facilitates an appropriate modelling of the systems under investigation.

The included impact categories and inventory level indicators are meaningful and their inclusion is explained. The most relevant impact categories have been selected. They are critically discussed, emphasising weaknesses and shortcomings. The impact assessment methods chosen are in line with the ISO 14044 standards.

The choices of analysed scenarios and of the parameters meet the objectives of the study.

Concluding, it can be stated that the methods used are consistent with the ISO 14040/44 standards.

3.2 Scientific and technical validity of the methods

The methods used are scientifically and technically state of the art. Some specific aspects of the study are highlighted below:

- The system boundaries are properly defined.
- A biodiversity impact assessment was included on a screening level, as biodiversity is one of the exceeded planetary boundaries.

Concluding, it can be stated that the methods used are scientifically and technically valid.

3.3 Appropriateness of data in relation to the goal of the study

Specific data provided by CottonConnect were used for the REEL cotton production system as well as the benchmark farms. Important data are third party validated, including yields, fertilizer use, and irrigation.

It was not part of this critical review to check the correctness of the primary data collected. However, the reviewers were able to check the correct selection of data modules for those data. Furthermore, a cross-check of certain data did not reveal any inconsistencies compared to similar studies, although there were differences in the impact that are within expected margins of error.

All data sets used for the included unit processes are sufficiently characterised 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 documented in the annex of the LCA report.

It can be stated that the data used that could be checked are appropriate and reasonable in relation to the goal of the study.

3.4 Assessment of interpretation referring to limitations and goal

The interpretation in the final report is based on the detailed data analysis performed. The interpretation is meaningful and limitations and recommendations are transparently stated.

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

Thus, it can be stated that the interpretation of the results is in accordance with the goal and scope of the study and reflects the identified limitations.

3.5 Transparency and consistency of the report

The report was revised in the final version according to the reviewers comments increasing the transparency and comprehensibility of the final report. The line of argument from inventory over impact assessment to interpretation and recommendations is transparent and comprehensible.

It can be stated that the report is transparent and consistent.

4 Conclusions and recommendations

It can be stated that this LCA study has been conducted in accordance with the ISO 14040 and 14044 standards.

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

The following recommendation is made by the CRP: Consideration should be given to building up such LCA studies based on, for example, three-year averages, in order to be able to better level out weather-induced deviations, for example. Especially when comparing different growing regions.

5 References

[1] DIN EN ISO 14040:2006: Environmental management - Life cycle assessment - Principles and framework

[2] DIN EN ISO 14044:2006: Environmental management - Life cycle assessment - Requirements and guidelines

Annex B: Regional Inventory Data

This section details the LCI data per region.

Pakistan

The following table details the inventory data on a regional level for Pakistan.

Table 0-1: Regional inventory data farm, Pakistan

	Unit	Punjab Project	Punjab Control	Sindh Project	Sindh Control
Year	-	2013-14 to 2014-15 and 2017-18 to 2019-20	2014-15 and 2017-18 to 2019-20	2013-14 to 2014-15 and 2018-19 to 2019-20	2013-14 to 2014-15 and 2018-19 to 2019-20
Farmers applying field clearance	%	0	0	0	23
Farmers ploughing	%	12	11	15	13
Diesel for field work	l/ha	93.3	114	93.3	114
Seed	kg/ha	14.9	22.2	15.6	16.3
Yield (seed cotton)	kg/ha	2246	2021	1845	1679
Water for Irrigation	m3/ ha	2685	2929	2164	2269
AWARE factor	m3 eq.	53.99	53.99	75.19	75.19
Diesel for Irrigation	kg/ha	112	123	63	71
CAN	kg/ha	63.0	74.9	36.0	22.0
DAP	kg/ha	83	153	117	135
NPK 15-15-15	kg/ha	106	52.3	25.9	34.5
KCl	kg/ha	0.00	0.00	0.00	0.00
Urea	kg/ha	303	372	233	251
Organic fertilizer (as total N)	kg/ha	3.16	0.30	4.87	2.75
Zinc	kg/ha	1.28	0.49	3.69	8.91
Boron	kg/ha	0.00	0.00	0.00	0.00
Crop protection (sum of active ingredients)	kg/ha	1.1	1.4	0.8	1.0

Table 0-2: Regional inventory data gin, Pakistan

	Unit	Punjab Project [2)]	Punjab Control [2)]	Sindh Project	Sindh Control
Transport distance truck (average distance from farm to gin)	km	14.5	16.1	14.5	16.1
Output cotton fibre (ginning out turn, lints)	kg/1000 kg of seed cotton (input)	337.8	342	337.8	342

Output cotton seeds	kg/1000 kg of seed cotton (input)	606.3	606.3	606.3	606.3
Energy use (Electricity)	MJ/1000 kg of seed cotton (input)	97.2	134.4	97.2	134.4
Electricity source	-	Grid mix	Grid mix	Grid mix	Grid mix
Price fibre	monetary unit[1]/ kg fibre	4.29	4.22	4.29	4.22
Price seeds	monetary unit[1]/ kg seed	1.73	1.72	1.73	1.72

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) *No values for Punjab available, Sindh used as proxy*

Bangladesh

The following table details the inventory data on a regional level for Bangladesh

Table 0-3: Regional inventory data farm, Bangladesh

	Unit	Chuadanga Project	Chuadanga Control	Kushtia Project	Kushtia Control
Year	-	2019-2020	2019-2020	2019-2020	2019-2020
Farmers applying field clearance	%	6	0	0	4
Farmers ploughing	%	0	0	0	0
Diesel for field work	l/ha	4.13	4.13	2.38	2.38
Seed	kg/ha	4.50	4.50	4.51	4.49
Yield (seed cotton)	kg/ha	3847	3596	3759	3543
Water for Irrigation	m3/ ha	1392	1632	1022	1620
AWARE factor	m3 eq.	3.54	3.54	3.54	3.54
Diesel for Irrigation	kg/ha	58.5	68.6	42.9	68.1
CAN	kg/ha	0.0	0.0	0.0	0.0
DAP	kg/ha	167	156	133	159
NPK 15-15-15	kg/ha	0.0	0.0	0.0	0.0
KCl	kg/ha	485	567	429	418
Urea	kg/ha	272	244	179	242
Organic fertilizer (as total N)	kg/ha	1.55	2.16	1.59	2.09
Zinc	kg/ha	0.00	0.00	0.00	0.00
Boron	kg/ha	7.13	7.50	7.27	7.49
Crop protection (sum of active ingredients)	kg/ha	2.6	3.2	2.0	2.6

Table 0-4: Regional inventory data gin, Bangladesh

		Chuadanga Project[2)]	Chuadanga Control[2)]	Kushtia Project[2)]	Kushtia Control[2)]
Transport distance truck (average distance from farm to gin)	km	115.6	53.8	67.5	43.7
Output cotton fibre (ginning out turn, lints)	kg/1000 kg of seed cotton (input)	337.8			
Output cotton seeds	kg/1000 kg of seed cotton (input)	606.3			
Energy use (Electricity)	MJ/1000 kg of seed cotton (input)	97.2			
Electricity source	-	Grid mix			
Price fibre	monetary unit[1)]/ kg fibre	4.29			
Price seeds	monetary unit[1)]/ kg seed	1.73			

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) *No differentiation between regions except for transport distances*

India

The following table details the inventory data on a regional level for India.

Table 0-5: Regional inventory data, India

	Unit	Gujarat Project	Gujarat Control	Maharashtra Project	Maharashtra Control	Madhya Pradesh Project	Madhya Pradesh Control
Year	-	2011-12 to 2019-20	2011-12 to 2019-20	2013-14 to 2014-15, 2019-20	2013-14 to 2014-15, 2019-20	2019-20	2019-20
Farmers applying field clearance	%	22.7	34.5	17.6	63.2	23.9	73.3
Farmers ploughing	%	20	23	31	29	82	49
Diesel for field work	l/ha	6.5	4.8	3.0	3.7	4.3	3.1
Seed	kg/ha	2.85	2.38	1.97	0.93	1.65	2.04
Yield (seed cotton)	kg/ha	2615	2073	2752	2193	1732	1563
Water for Irrigation	m3/ ha	7543	11285	3810	304	520	532
AWARE factor	m3 eq.	35.96	35.96	3.75	3.75	17.25	17.25

Diesel for Irrigation	kg/ha	175	384	122	86	2	1
CAN	kg/ha	0.84	0.32	1.71	1.94	4.13	3.15
DAP	kg/ha	156	158	30	64	182	192
NPK 15-15-15	kg/ha	11.5	30.2	239.5	304.0	3.1	2.7
KCl	kg/ha	0.00	0.00	0.00	0.00	0.00	0.00
Urea	kg/ha	216	355	164	313	230	272
Organic fertilizer	kg/ha	7.43	5.14	12.56	10.02	2.67	2.22
Zinc	kg/ha	2.65	1.46	0.00	0.00	0.00	0.00
Boron	kg/ha	0.00	0.00	0.00	0.00	0.00	0.00
Crop protection (sum of active ingredients)	kg/ha	1.0	1.0	0.7	2.2	1.4	1.6

Table 0-6: Regional inventory data gin, India

	Unit	Gujarat Project	Gujarat Control[2)]	Maharashtra Project	Maharashtra Control[2)]	Madhya Pradesh Project	Madhya Pradesh Control[2)]
Transport distance truck (average distance from farm to gin)	km	21.7	21.8	45.1	37.2	26.8	40.3
Output cotton fibre (ginning out turn, lints)	kg/1000 kg of seed cotton (input)	354.4	354.4	352	352	350	350
Output cotton seeds	kg/1000 kg of seed cotton (input)	627.1	627.1	636	636	635	635
Energy use (Electricity)[3)]	MJ/1000 kg of seed cotton (input)	114	114	114	114	114	114
Electricity source	-	Grid mix	Grid mix	Grid mix	Grid mix	Grid mix	Grid mix
Price fibre	monetary unit[1)]/ kg fibre	1.53	1.53	1.66	1.66	1.62	1.62
Price seeds	monetary unit[1)]/ kg seed	0.49	0.49	0.39	0.39	0.4	0.4

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) *Same data used for control and project except for transport distances*
3) *Missing data, values from Cotton Inc. 2017 used as proxy*

China

The following table details the inventory data on a regional level for China.

Table 0-7: Regional inventory data, China

	Unit	Hebei Project	Hebei Control
Year	-	2012-13 to 2019-20	2012-13 to 2019-20
Farmers applying field clearance	%	0	0
Farmers ploughing	%	56	0
Diesel for field work	l/ha	11.8	11.8
Seed	kg/ha	7.10	7.10
Yield (seed cotton)	kg/ha	4557	4263
Water for Irrigation	m3/ ha	1298	1437
AWARE factor	m3 eq.	89.47	89.47
Diesel for Irrigation	kg/ha	0	0
CAN	kg/ha	0.00	0.00
DAP	kg/ha	63.6	42.5
NPK 15-15-15	kg/ha	557.4	670.2
KCl	kg/ha	28.8	12.5
Urea	kg/ha	126	34.5
Organic fertilizer	kg/ha	0.41	0.76
Zinc	kg/ha	0.00	0.00
Boron	kg/ha	0.00	0.00
Crop protection (sum of active ingredients)	kg/ha	5.4	6.9

Table 0-8: Regional inventory data gin, China

	Unit	Hebei Project	Hebei Control [2]
Transport distance truck (average distance from farm to gin)	km	8	
Output cotton fibre (ginning out turn, lints)	kg/1000 kg of seed cotton (input)	390	
Output cotton seeds	kg/1000 kg of seed cotton (input)	604	
Energy use (Electricity)	MJ/1000 kg of seed cotton (input)	75.6	
Electricity source	-	Grid mix	
Price fibre	monetary unit[1]/ kg fibre	2.85	
Price seeds	monetary unit[1]/ kg seed	1.29	

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) *Same data used for control and project*

Biodiversity input data

Table 0-9: Biodiversity assessment input data

				Country	Pakistan						Bangladesh						India								China	
				Region	Punjab		Sindh		Average		Chuadanga		Kushtia		Average		Gujarat		Maharashtra		Madhya Pradesh		Average		Hubei	
		Project/Control			P	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C
	Metric	Unit	Min	Max																						
A.1	**Diversity of weeds**																									
A.1.1	Number of weed species in the cultivation area	[species/ha]	0	300	19	19	19	19	19	19	6	6	6	6	6	6	51	51	8	8	35	35	31	31	19	19
A.1.2	Existence of rarer species	[% time]	0	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
A.2	**Diversity of structures**			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A.2.1	Elements of structure in the area	[% area]	0	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
A.2.2	Field size	[ha]	0	10	1	1	1	1	1	1	0.45	0.17	0.23	0.14	0.34	0.15	1.24	1.15	1.06	0.96	1.06	1.54	1.1	1.2	0.64	0.65
A.3	**Soil conservation**			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A.3.1	Intensity of soil movement	[L/ha]	0	100																						
A.3.2	Ground cover	[% time]	0	1	0.5	0.5	0.5	0.5	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0	0.6	0.6	0.7	0.7	0.5	0.5	0.6	0.6	0.5	0.5
A.3.3	Crop rotation	[points]	0	13																						
A.4	**Material input**			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A.4.1	Share of farmyard manure	[% mass]	0	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.03	0.01	0.02	0.01	0.03	0.02	0.00	0.00
A.4.2	Share of manure/compost/fertilizers with low solubility	[% mass]	0	1	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00
A.4.3	share of artificial/liquid fertilizers	[% mass]	0	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.98	0.97	0.99	0.98	0.99	0.97	0.98	1.00	1.00
A.4.4	Share of artificial/liquid fertilizers out of season	[% mass]	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A.4.5	Intensity of fertilizing	[kgN /ha*a]	0	300	190	227	147	154	169	190	157	143	108	142	132	142	137	201	130	211	143	163	136	192	153	125

A.5	***Plant protection***																										
	A.5.1	*Plant protection agents (input of pesticides)*	*[applications/a]*	*0*	*12*	*8.4*	*8.4*	*8.4*	*8.4*	*8.4*	*8.4*	*6*	*6*	*6*	*6*	*6*	*6*	*12*	*12*	*12*	*12*	*12*	*12*	*12*	*12*	*10*	*10*
	A.5.2	*Mechanical weed control (share of mechanical/biological pest control)*	*[% applications]*	*0*	*1*	*0.35*	*0.25*	*0.05*	*0.00*	*0.20*	*0.12*	*1.00*	*1.00*	*1.00*	*1.00*	*1.0*	*1.0*	*0.8*	*0.7*	*0.3*	*0.3*	*0.1*	*0.1*	*0.4*	*0.3*	*0.5*	*0.5*

Annex C: Inventory flows

The following table provides the most important inventory flows of CottonConnect. GaBi 10.6. only provides water flows on country level. In order to use regional specific characterization factors, dummy flows were created that allowed to enter the AWaRe characterization factors as free parameters. These dummy flows are not shown. The water input flows and AWaRe characterization factors used can be deducted from the inventory data tables. Toxicity results were dominated by emission to fresh water, therefore, only this emission category is shown (emissions to air and soil omitted). For some reported pesticides, no matching elementary flows were available in GaBi 10.6. Similar to the water assessment, dummy flows were created that allowed to enter the USEtox characterization factors as free parameters. Again, these dummy flows are also not shown.

Table A-0-10: Inventory flows (kg/ kg fibre)

	Average project	Average control
Emissions to air		
Inorganic emissions to air		
Ammonia	4.50E-03	5.73E-03
Carbon dioxide	9.07E-01	1.53E+00
Carbon dioxide (LUC)	7.43E-04	8.43E-04
Nitrous oxide (laughing gas)	2.37E-03	3.28E-03
Sulphur dioxide	2.07E-03	3.04E-03
Organic emissions to air (group VOC)		
Methane	2.22E-03	4.16E-03
Emissions to fresh water		
Nitrate	1.75E-01	3.78E-01
Phosphorus	5.99E-06	7.17E-06
Pesticides to fresh water		
Acephate	1.6E-06	2.7E-06
Acetamiprid	1.08E-06	8.17E-07
Acetochlor	9.99E-09	5.79E-08
Alachlor	6.32E-09	7.4E-09
Aldicarb	1.88E-10	2.15E-10
Atrazine	8.17E-13	1.15E-12
Avermectin (Abamectin)	1.36E-08	6.48E-09
Azadirachtin	3.43E-07	2.22E-07
Benomyl	1.77E-11	2.06E-11
Bentazone	2.63E-14	3.73E-14
Bifenthrin	2.92E-07	5.4E-08
Carbendazim	1.95E-08	2.33E-08

Carbofuran	5.79E-14	8.15E-14
Chlormequat-chloride	2.19E-16	3.14E-16
Cypermethrin	1.82E-08	3.65E-08
Cyprodinil (CGA-219417)	5.97E-17	8.57E-17
Deltamethrin	1.63E-09	1.1E-08
Dicamba	2.26E-16	3.19E-16
Diflufenican	1.39E-17	2E-17
Dimethenamid	8.79E-24	1.13E-23
Dimethoate	1.13E-07	1.3E-07
Ethephon	2.21E-07	3.23E-07
Ethion	8.67E-08	6.87E-08
Fenvalerate	8.5E-10	1.04E-08
Fipronil	4.75E-09	6.8E-09
Glyphosate	7.67E-10	8.78E-10
Imidacloprid	4.16E-07	7.22E-07
Ioxynil	4.31E-17	6.19E-17
Isoproturon	5.64E-17	8.1E-17
Mancozeb	2.01E-08	3.66E-08
MCPA	9.29E-17	1.33E-16
Mecoprop	6.3E-17	9.05E-17
Methomyl	2.11E-14	2.93E-14
Novaluron	6.84E-10	3.01E-10
Parathion-methyl	1.49E-15	2.12E-15
Pendimethalin	2.32E-07	2.38E-07
Phoxim	5.19E-09	2.4E-09
Pymetrozine	0	6.19E-08
Terbufos	3.34E-24	4.28E-24
Thiram	1.68E-14	2.38E-14
Triazophos	1.26E-06	1.48E-06
Trichlorfon	2.65E-14	3.72E-14
Trifluralin	2.13E-10	2.48E-10

Annex D: Country level results

This section shows the country level average results for the REEL project vs. control. This annex should only be considered if accompanied by the main report for details on study scope and methodology.

The country level results are weighted per production % per region which can be found in Primary data were collected using customised data collection templates created by Sphera. These data collection templates were sent out by email to CottonConnect who completed these for each region under study. Many data were readily available to CottonConnect as they already work with an independent party to conduct sample data collection of 50% of their REEL project programme farmers along with a benchmark value for farms in the same regions as that of the project (see section 2.4). Important farm data from the programme farmers are third party validated, including yields, fertilizer use, irrigation conducted . This process adds strength to the quality of the input data and hence, results output of this 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 CottonConnects' farm teams. Parameters that are based on validated data are marked in Table 3-1.

Upon receipt, each questionnaire was cross-checked for completeness and plausibility using mass balance, as well as internal and external benchmarking. If gaps, outliers, or other inconsistencies occurred, Sphera and CottonConnect engaged with the data providers to resolve any open issues and in some cases further sample data were collected on farm level by CottonConnect's partners. The partners also carry out necessary checks and the final data sets are shared with CottonConnect. The CottonConnect team then carried out necessary validations and reviews to ensure the correctness of data. This means that neither Sphera nor the review panel verified data beyond plausibility checks and the responsibility for the correctness of the input data remains with CottonConnect.

Data were averaged on a year by year basis and then averaged into an average per region. For the results calculation, results per region were averaged into a country average and the country average into a total average based on production shares (see Table 2-4).

The averaged inventory data can be found in section 3.2 and regional inventory data can be found in Annex B: which is available upon request to CottonConnect. Note, as detailed in the scope of the study, results are calculated on a regional basis and weighted utilising the total production shares.

of the main study.

Table details the key inventory data on a country averaged level. Note, this is not the inventory data utilised to calculate the results as all calculations were carried out on a regional level as detailed in section 2.

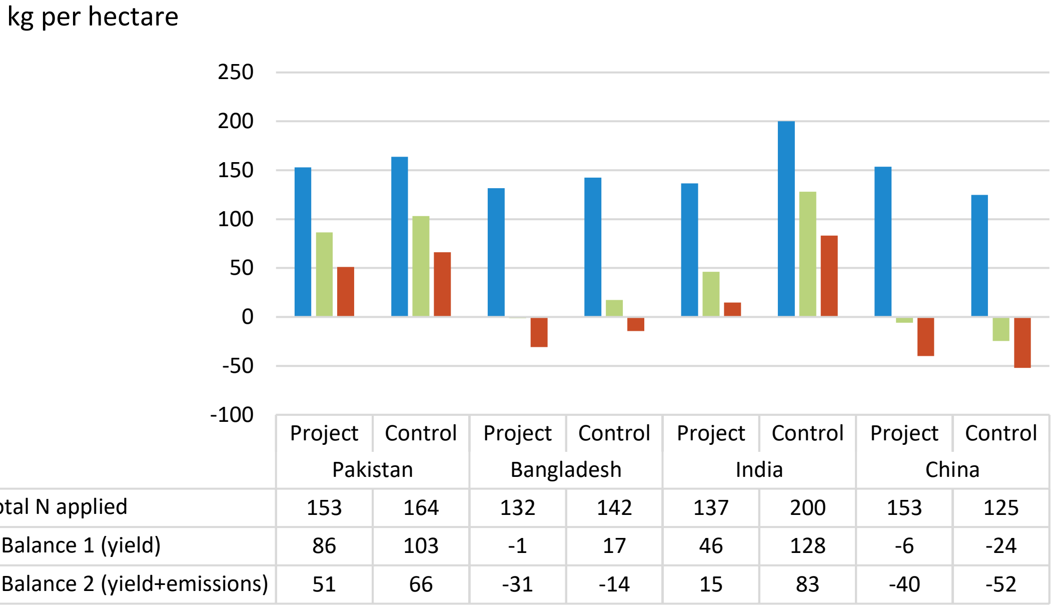
Table 0-11: Key data parameters, country average

Parameter	Pakistan		Bangladesh		India		China	
	Project	Control	Project	Control	Project	Control	Project	Control
Yield [kg/ha]	2045	1850	3803	3569	2366	1943	4557	4263
Total active ingredient [kg/ha]	2.7	3.8	4.5	5.8	3.1	4.8	5.3	7.5

Irrigation [mm]	242	259	120	162	395	495	129	143
AWARE [m3 equiv.]	64.6		3.5		18.9		89.5	
Diesel consumption for field work [l/ha]	93.3	113.5	3.3	3.3	4.6	3.9	11.8	11.8
Diesel demand for irrigation [kg/ha]	87.2	97.2	50.7	68.3	99.5	157.1	0	0
Electricity Use for Ginning [MJ/t]	115.8	115.8	33.9	33.9	114	114	75.6	75.6
Transport to Gin [km]	14.5	16.1	91.5	48.8	31.2	33.1	8	8

Country level N balance

The following figure includes the country level average nitrogen balance in kg per hectare.

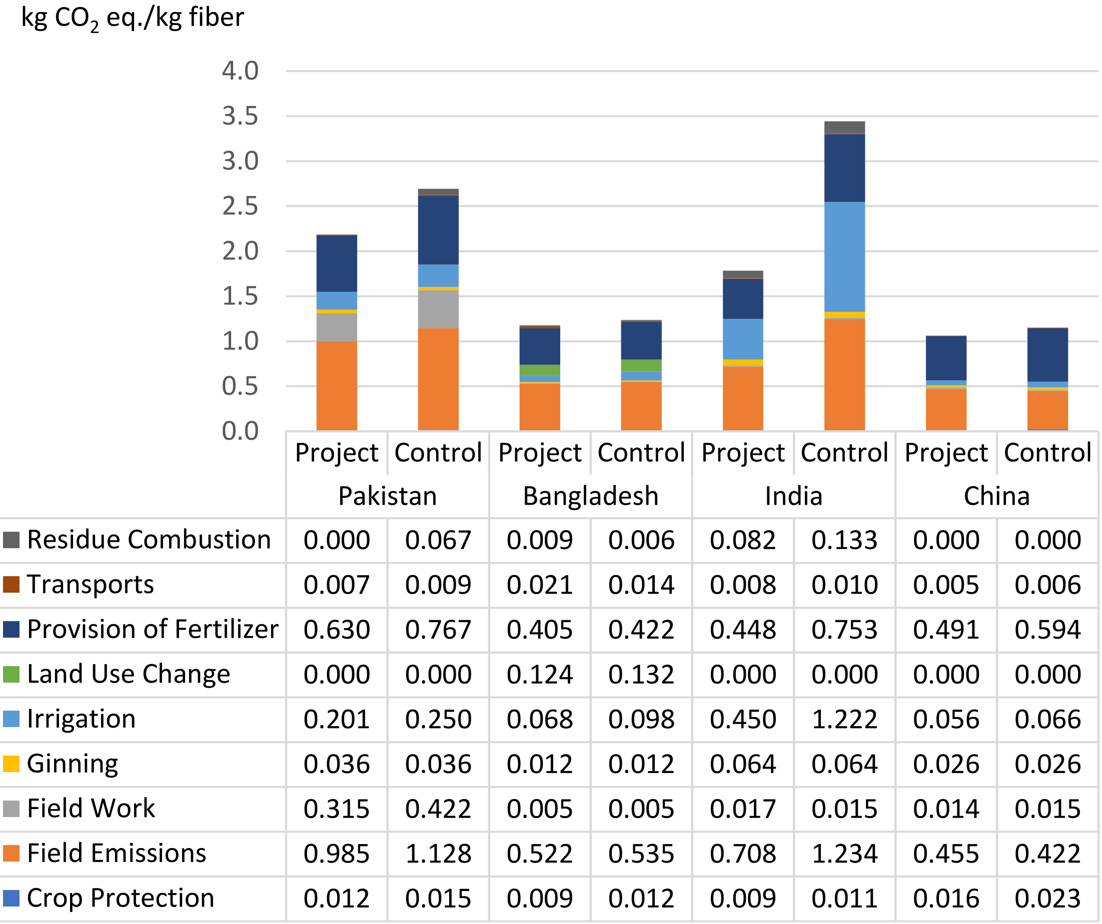


	Project	Control	Project	Control	Project	Control	Project	Control
	Pakistan		Bangladesh		India		China	
🟦 Total N applied	153	164	132	142	137	200	153	125
🟩 N Balance 1 (yield)	86	103	-1	17	46	128	-6	-24
🟥 N Balance 2 (yield+emissions)	51	66	-31	-14	15	83	-40	-52

Figure 0-1: N balance, country averages

Climate Change

The following figure shows the country results for climate change potential in kg CO_2 eq. per kg cotton fibre, with the largest total being India Control with 3.4 kg CO_2 eq./FU. The lowest climate change result was determined for China, with values of 1.06 and 1.15 kg CO_2 eq./FU for Project and Control respectively. Field emissions are the largest contributor to the total for each country.



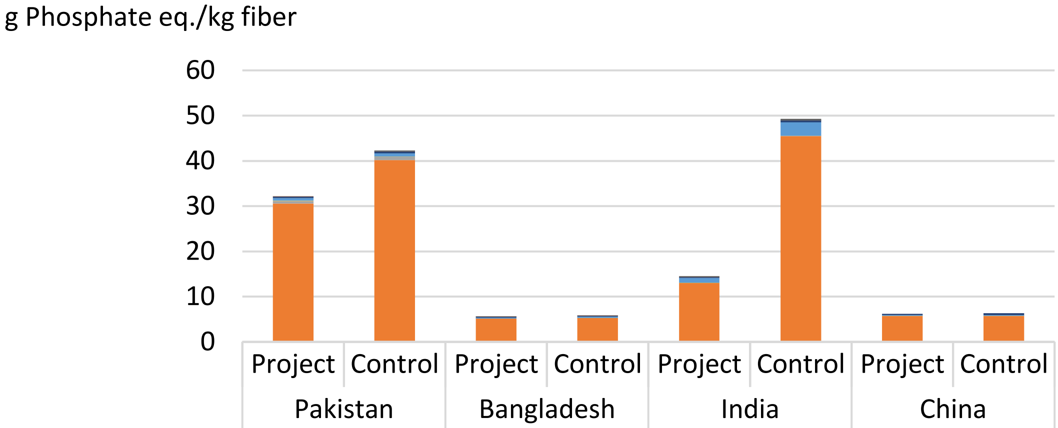
	Project	Control	Project	Control	Project	Control	Project	Control
	Pakistan		Bangladesh		India		China	
■ Residue Combustion	0.000	0.067	0.009	0.006	0.082	0.133	0.000	0.000
■ Transports	0.007	0.009	0.021	0.014	0.008	0.010	0.005	0.006
■ Provision of Fertilizer	0.630	0.767	0.405	0.422	0.448	0.753	0.491	0.594
■ Land Use Change	0.000	0.000	0.124	0.132	0.000	0.000	0.000	0.000
■ Irrigation	0.201	0.250	0.068	0.098	0.450	1.222	0.056	0.066
■ Ginning	0.036	0.036	0.012	0.012	0.064	0.064	0.026	0.026
■ Field Work	0.315	0.422	0.005	0.005	0.017	0.015	0.014	0.015
■ Field Emissions	0.985	1.128	0.522	0.535	0.708	1.234	0.455	0.422
■ Crop Protection	0.012	0.015	0.009	0.012	0.009	0.011	0.016	0.023

Figure 0-2: Climate change results, country average

The REEL cotton project shows savings across all countries compared to the control group, with 7.7% for China and 5% for Bangladesh, but 18.8% for Pakistan and 48.1% for India. The greatest savings are derived from differences in field emissions and for irrigation in India. It is particularly interesting that field work in Pakistan is associated with much higher emissions compared to the other countries, which is mainly a result from a significantly higher reported diesel consumption (see Table , p. 80) at the farms.

Eutrophication

The following figure shows the country results for eutrophication potential in g PO4 eq. per kg cotton fibre, with the largest total being India Control with 49.3 g PO4 eq./FU. The lowest results were determined for Bangladesh and China, both Project and Control, with values ranging from 5.5 – 6.3 g PO4 eq./FU. Field emissions contribute more than 90% to the total in each country.



	Project	Control	Project	Control	Project	Control	Project	Control
	Pakistan		Bangladesh		India		China	
■ Residue Combustion	0.000	0.175	0.024	0.017	0.215	0.350	0.000	0.000
■ Transports	0.003	0.003	0.006	0.004	0.003	0.004	0.000	0.000
■ Provision of Fertilizer	0.358	0.422	0.185	0.191	0.228	0.396	0.316	0.395
■ Land Use Change	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
■ Irrigation	0.575	0.716	0.196	0.282	1.089	2.955	0.141	0.167
■ Ginning	0.016	0.016	0.004	0.004	0.033	0.033	0.007	0.007
■ Field Work	0.586	0.785	0.009	0.010	0.031	0.029	0.027	0.029
■ Field Emissions	30.59	40.18	5.14	5.29	12.97	45.51	5.72	5.74
■ Crop Protection	0.003	0.003	0.002	0.003	0.002	0.003	0.004	0.005

Figure 0-3: Eutrophication potential results, country average

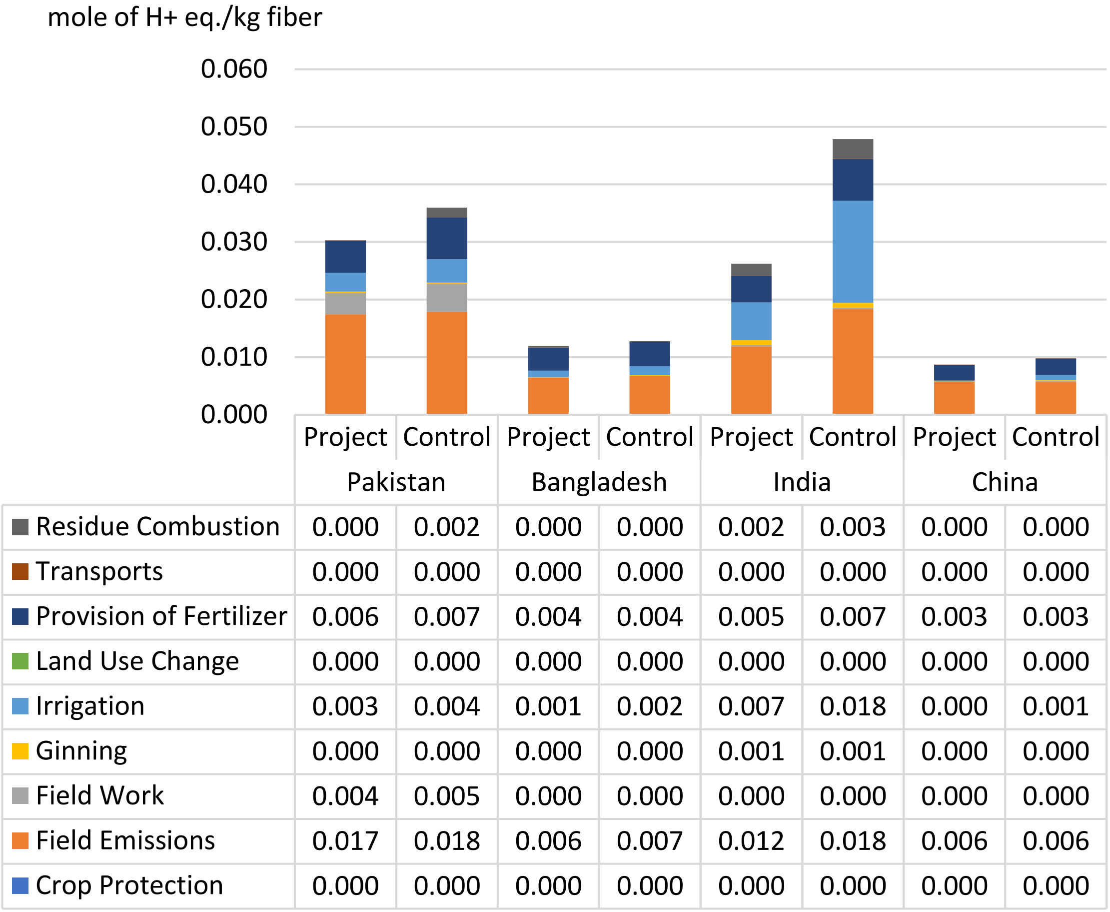
For every country, the REEL cotton project shows savings compared to the control group, with only 2.1% for China and 4% for Bangladesh, but 24.1% for Pakistan and 70.4% for India. The greatest savings are derived from differences in field emissions, since this is the dominant life cycle stage in all product systems.

Acidification

The following figure shows the country results for acidification potential in mole H+ eq. per kg cotton fibre, with the largest total being India Control with 0.048 g mole H+ eq./FU. The lowest results were determined for China, both Project and Control, with values 0.010 mole H+ eq./FU. Field emissions are the main contributor across all countries, with the exception of India Control, where irrigation is more dominant.

Figure 0-4: Acidification potential results, country average

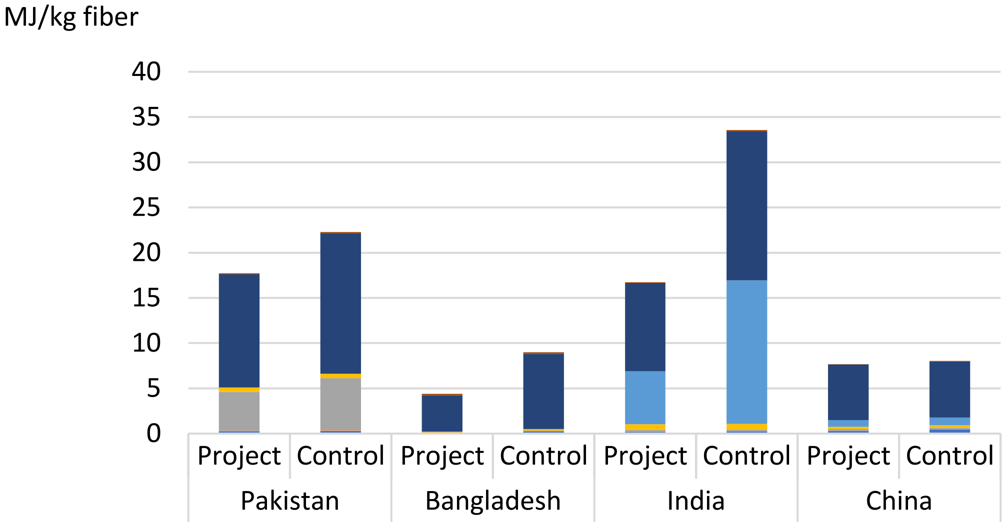
For every country, the REEL cotton project shows savings compared to the control group, with 3.1% for China and 6.7% for Bangladesh, but 15.8% for Pakistan and 45.2% for India. The greatest savings are derived from differences in field emissions, since this is the dominant life cycle stage in all product systems, with the exception of India.



	Project	Control	Project	Control	Project	Control	Project	Control
	Pakistan		Bangladesh		India		China	
Residue Combustion	0.000	0.002	0.000	0.000	0.002	0.003	0.000	0.000
Transports	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Provision of Fertilizer	0.006	0.007	0.004	0.004	0.005	0.007	0.003	0.003
Land Use Change	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Irrigation	0.003	0.004	0.001	0.002	0.007	0.018	0.000	0.001
Ginning	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
Field Work	0.004	0.005	0.000	0.000	0.000	0.000	0.000	0.000
Field Emissions	0.017	0.018	0.006	0.007	0.012	0.018	0.006	0.006
Crop Protection	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Abiotic Depletion Potential

The following figure shows the country results for abiotic depletion potential in MJ per kg cotton fibre, with the largest total being India Control with 33.6 MJ/FU. The lowest results were determined for Bangladesh Project, with a value of 4.4 MJ/FU. The provision of fertilizers is the main contributor to the total in all countries, with exception of India, where irrigation is more dominant. Field work can be considered relevant for this impact category only in Pakistan, where significantly more diesel in consumed on the field.



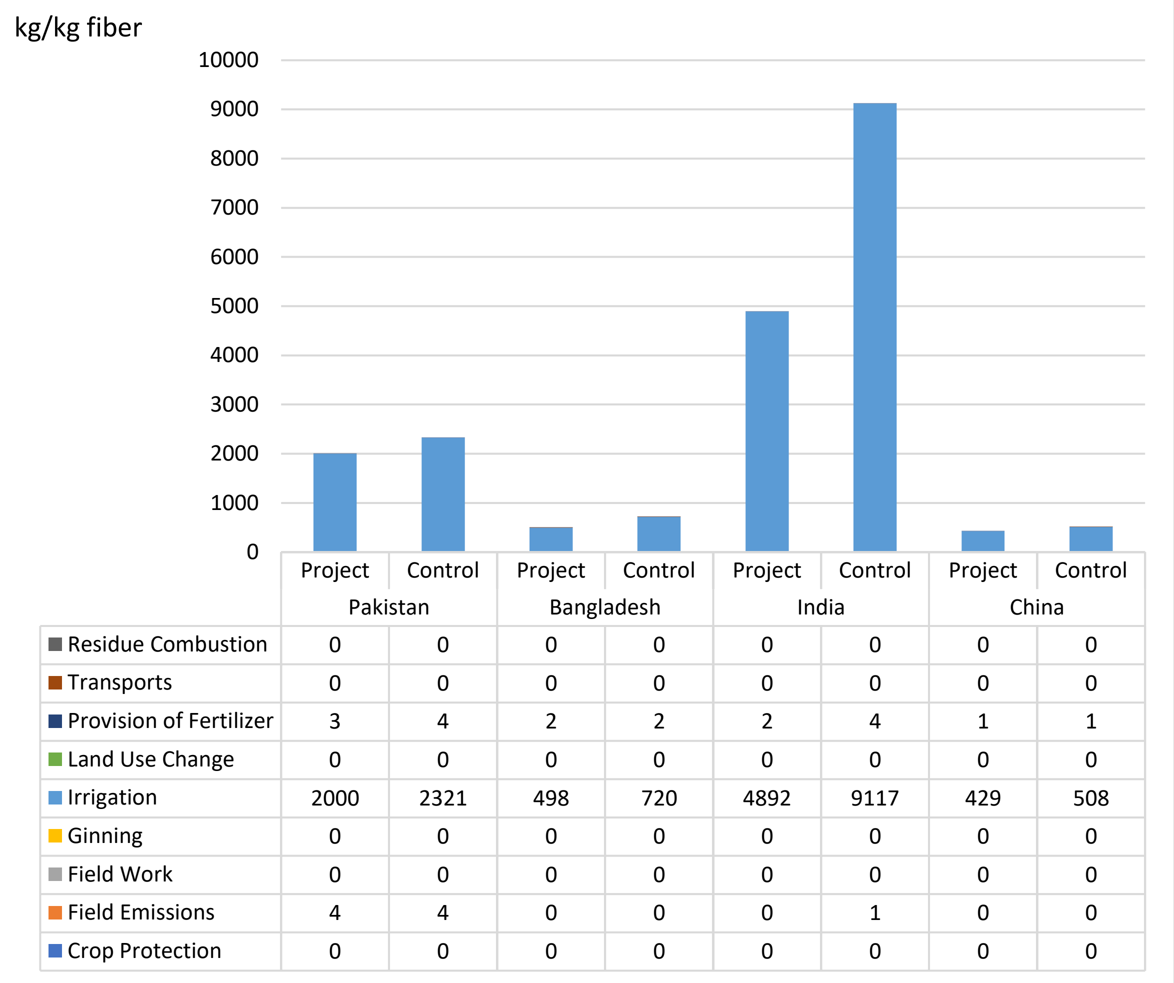
	Pakistan Project	Pakistan Control	Bangladesh Project	Bangladesh Control	India Project	India Control	China Project	China Control
■ Residue Combustion	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
■ Transports	0.102	0.118	0.169	0.185	0.110	0.143	0.067	0.076
■ Provision of Fertilizer	12.523	15.522	3.983	8.323	9.721	16.462	6.136	6.184
■ Land Use Change	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
■ Irrigation	0.000	0.000	0.000	0.000	5.849	15.865	0.737	0.872
■ Ginning	0.492	0.492	0.083	0.171	0.643	0.643	0.251	0.251
■ Field Work	4.327	5.796	0.043	0.074	0.227	0.211	0.196	0.210
■ Field Emissions	0.039	0.046	0.002	0.005	0.005	0.006	0.000	0.000
■ Crop Protection	0.238	0.300	0.098	0.239	0.173	0.224	0.308	0.453

Figure 0-5: Abiotic depletion potential results, country average

For every country, the REEL cotton project shows savings compared to the control group, with 4.4% for China and 51.3% for Bangladesh, but 20.4% for Pakistan and 50.1% for India. The greatest savings are derived from differences in field emissions, since this is the dominant life cycle stage in all product systems, but also for irrigation in India.

Water consumption

The following figure shows the country results for water consumption in kg per kg cotton fibre, with the largest total being India Control with 9121 kg/FU. The lowest results were determined for China Project and Control, with values of 430 and 501 kg/FU respectively. For water consumption, irrigation is practically the sole contributor to the total result.



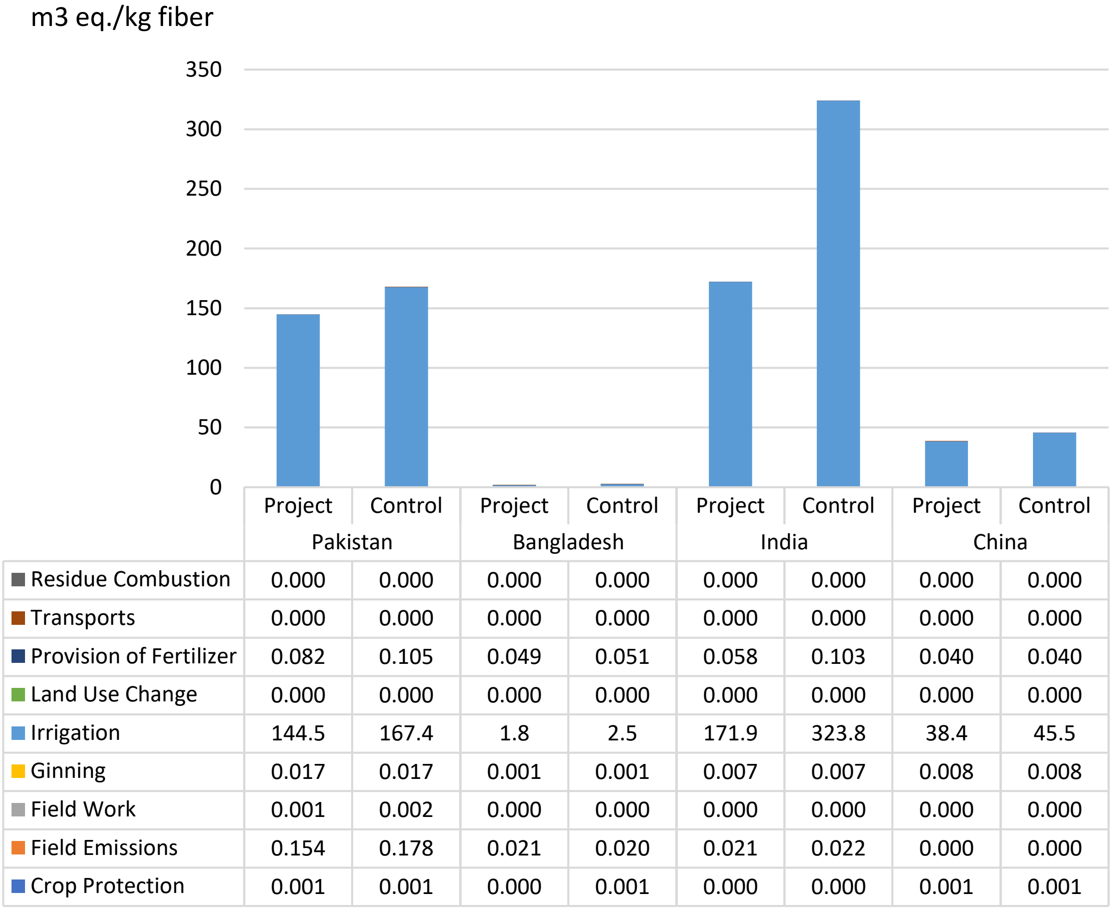
	Project	Control	Project	Control	Project	Control	Project	Control
	Pakistan		Bangladesh		India		China	
■ Residue Combustion	0	0	0	0	0	0	0	0
🟫 Transports	0	0	0	0	0	0	0	0
🟦 Provision of Fertilizer	3	4	2	2	2	4	1	1
🟩 Land Use Change	0	0	0	0	0	0	0	0
🟦 Irrigation	2000	2321	498	720	4892	9117	429	508
🟨 Ginning	0	0	0	0	0	0	0	0
⬜ Field Work	0	0	0	0	0	0	0	0
🟧 Field Emissions	4	4	0	0	0	1	0	0
🟦 Crop Protection	0	0	0	0	0	0	0	0

Figure 0-6: Blue water consumption results, country average

For every country, the REEL cotton project shows savings compared to the control group, with 13.8% for Pakistan, 15.5% for China, 30.6% for Bangladesh and 46.3% for India. The greatest savings are derived from differences in irrigation, since this is the dominant life cycle stage in all product systems. For this impact category, country or region-specific water scarcity is omitted. Thus, these results directly reflect the volume of irrigation water, which is highest in India and Pakistan.

Water use

The following figure shows the country results for water use in m^3 world eq. per kg cotton fibre, with the largest total being India Control with 323.92 m^3 world eq./FU. The lowest results were determined for Bangladesh Project and Control, with values of 1.84 and 2.62 m^3 world eq./FU respectively. For water use, irrigation is practically the sole contributor to the total result.



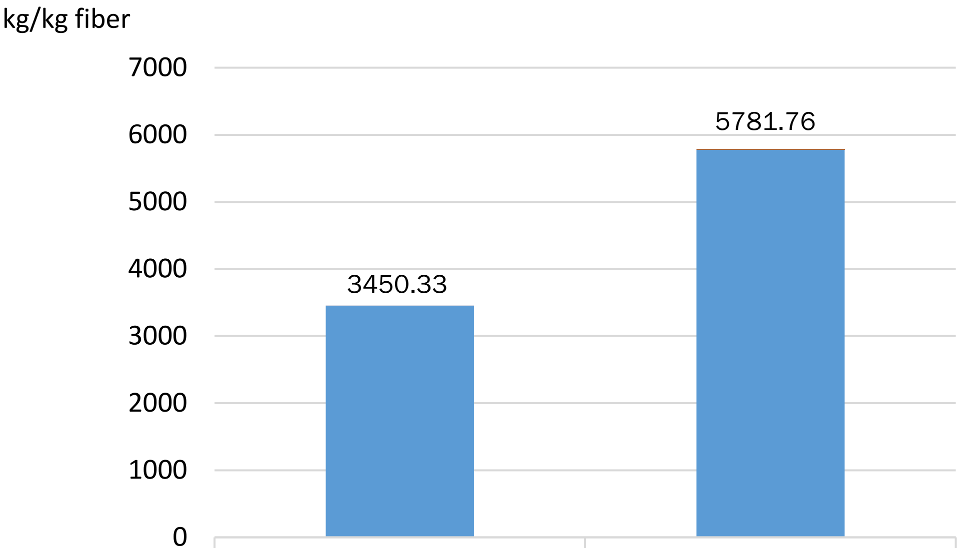
	Pakistan		Bangladesh		India		China	
	Project	Control	Project	Control	Project	Control	Project	Control
■ Residue Combustion	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
■ Transports	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
■ Provision of Fertilizer	0.082	0.105	0.049	0.051	0.058	0.103	0.040	0.040
■ Land Use Change	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
■ Irrigation	144.5	167.4	1.8	2.5	171.9	323.8	38.4	45.5
■ Ginning	0.017	0.017	0.001	0.001	0.007	0.007	0.008	0.008
■ Field Work	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000
■ Field Emissions	0.154	0.178	0.021	0.020	0.021	0.022	0.000	0.000
■ Crop Protection	0.001	0.001	0.000	0.001	0.000	0.000	0.001	0.001

Figure 0-7: Water use results, country average

For every country, the REEL cotton project shows savings compared to the control group, with 13.7% for Pakistan, 15.5% for China, 29.9% for Bangladesh and 46.9% for India. The greatest savings are derived from differences in irrigation, since this is the dominant life cycle stage in all product systems. The comparatively low result for Bangladesh is a result from its low AWARE characterization factor of 2.43 as a country average, while India (29.35), China (42.43) and Pakistan (61.44) have higher risks of water scarcity. Moreover, for this study region-specific AWARE factors were used (see also section 0

6.3.1. Water Consumption

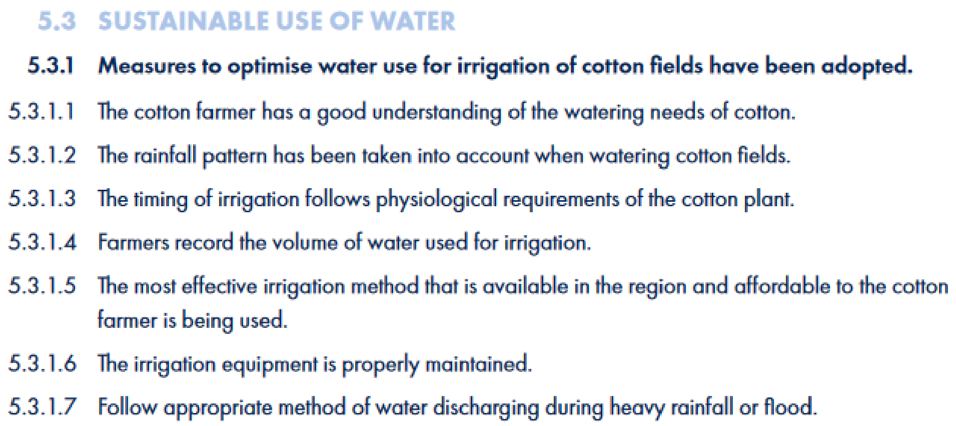
Figure 4-5 shows the average water consumption, without the consideration of region-specific scarcity factors. Water consumption for the REEL project is 3 450 kg water per kg fibre, whereas it is 5 781 kg water per kg fibre for the control group. This leads to a saving potential of 2 331 kg or 40.3% per kg cotton fibre. This is a larger reduction than the reduction on inventory level (see Table 3-1) because the results are shown per kg of fibre and therefore also include scaling effect caused by higher yields.



	Average Project	Average Control
■ Residue Combustion	0.00	0.00
■ Transports	0.00	0.00
■ Provision of Fertilizer	2.33	3.47
■ Land Use Change	0.00	0.00
■ Irrigation	3445.96	5775.75
■ Ginning	0.26	0.26
■ Field Work	0.02	0.03
■ Field Emissions	1.88	2.15
■ Crop Protection	0.08	0.10

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

Irrigation is practically the sole contributor (>99%) for this impact category. Differences between Project and Control could be associated with improved irrigation practices as described in the REEL project Code of Conduct (see Figure 4-6).



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 record 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 discharging during heavy rainfall or flood.

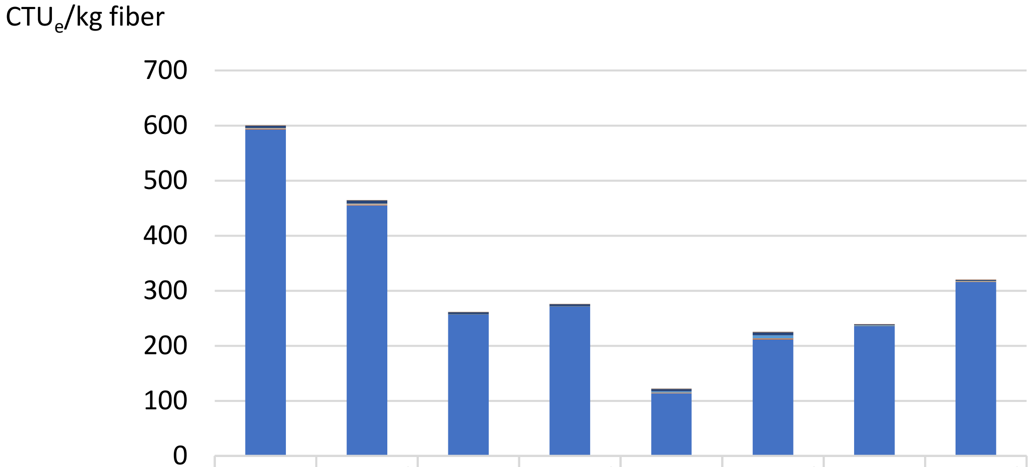
Figure 4-6: Measures to optimise water use for irrigation encouraged in the REEL project Code of Conduct

As mentioned in section 3.2, it should also be noted that the reported values are therefore strongly influenced by the region Gujarat, where water consumption values were high, the reported reduction potential was high, and that represents a large share in total production.

Water Use, p. 44).

Ecotoxicity

The following figure shows the country results for ecotoxicity freshwater in CTU$_e$ per kg cotton fibre, with the largest total being Pakistan Project with 599.7 CTU$_e$/FU. The lowest results were determined for India Project with a value of 121.5 CTU$_e$/FU. For ecotoxicity freshwater, crop protection is practically the sole contributor to the total result.



	Pakistan		Bangladesh		India		China	
	Project	Control	Project	Control	Project	Control	Project	Control
■ Residue Combustion	0.000	0.203	0.028	0.020	0.250	0.406	0.000	0.000
■ Transports	0.037	0.043	0.103	0.067	0.040	0.052	0.080	0.090
■ Provision of Fertilizer	4.037	5.276	3.365	3.421	3.985	5.406	1.424	1.341
■ Land Use Change	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
■ Irrigation	0.001	0.001	0.000	0.001	2.117	5.742	0.873	1.034
■ Ginning	0.110	0.110	0.019	0.019	0.102	0.102	0.050	0.050
■ Field Work	1.567	2.099	0.025	0.027	0.082	0.076	0.232	0.249
■ Field Emissions	1.362	1.423	0.585	0.606	1.231	1.616	0.610	0.636
■ Crop Protection	592.6	455.0	256.8	271.1	113.7	211.6	235.8	316.1

Figure 0-8: Ecotoxicity freshwater results, country average

The greatest savings are derived from differences in crop protection, since this is the dominant life cycle stage in all product systems. For every country except Pakistan, the REEL cotton project shows savings compared to the control group, with 5.2% for Bangladesh, 46.0% for India and 25.2% for China. For Pakistan, the REEL cotton project does not show savings, but yields 29.2% higher impact results than the control group. This impact category is affected by both amount and type of applied pesticide, which in turn may lead to the conclusion that REEL cotton farms in Pakistan apply less pesticides in general but products with higher ecotoxicity, or more pesticides with lower ecotoxicity.

Biodiversity

The following section details the biodiversity results on a country level. See section 4.2 of the main report for details of the calculation method.

Table 0-12: Biodiversity results, country average

	Local biodiversity value, BV_{local}	Ecoregion Factor, EF	BV_{total} =Q	ΔQ	Land Use per FU	Biodiversity Impact per FU = Land Use * Delta Q
Unit	*BVI*		*BVI*	*BVI*	*m2a/FU*	*BVIm2a*
Pakistan Average Project	0.835	0.199	0.166	0.033	4.890	0.161
Pakistan Average Control	0.838	0.199	0.167	0.032	5.406	0.175
Bangladesh Average Project	0.831	0.183	0.152	0.031	2.629	0.081
Bangladesh Average Control	0.834	0.183	0.152	0.030	2.802	0.085
India Average Project	0.831	0.199	0.166	0.034	4.226	0.142
India Average Control	0.830	0.199	0.166	0.034	5.146	0.174
China Average Project	0.830	0.246	0.204	0.042	2.194	0.092
China Average Control	0.830	0.246	0.204	0.042	2.346	0.098
Average project	0.833	0.200	0.167	0.034	4.468	0.149
Average control	0.834	0.200	0.167	0.033	5.182	0.172

Annex E: Regional level results

This annex provides the regional level results for key impact categories on a regional level. P represents the REEL project values and C represents the control values.

Climate change

The following table shows the regional results for climate change potential in kg CO_2 eq. per kg cotton fibre.

	Pakistan				Bangladesh				India						China	
	Punjab		Sindh		Chuadanga		Kushtia		Gujarat		Maharashtra		Madhya Pradesh		Hebei	
	P	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C
Total	2.31	3.01	2.17	2.64	1.22	1.24	1.13	1.23	1.77	3.50	1.68	2.91	2.13	2.75	1.06	1.15
Crop Protection	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02
Field Emissions	1.04	1.36	0.98	1.09	0.54	0.54	0.51	0.53	0.69	1.22	0.68	1.29	1.14	1.39	0.46	0.42
Field Work	0.27	0.36	0.32	0.43	0.01	0.01	0.00	0.00	0.02	0.02	0.01	0.01	0.02	0.01	0.01	0.02
Ginning	0.03	0.03	0.04	0.04	0.01	0.01	0.01	0.01	0.06	0.06	0.07	0.07	0.07	0.07	0.03	0.03
Irrigation	0.28	0.34	0.19	0.24	0.08	0.10	0.06	0.10	0.48	1.32	0.35	0.31	0.01	0.00	0.06	0.07
Land Use Change	0.00	0.00	0.00	0.00	0.12	0.13	0.13	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Provision of Fertilizer	0.67	0.89	0.62	0.75	0.41	0.43	0.40	0.42	0.43	0.74	0.48	0.94	0.77	0.95	0.49	0.59
Transports	0.01	0.01	0.01	0.01	0.03	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.00	0.01
Residue Combustion	0.00	0.00	0.00	0.08	0.02	0.00	0.00	0.01	0.08	0.12	0.07	0.25	0.09	0.28	0.00	0.00

Eutrophication

The following table shows the regional results for eutrophication potential in g phosphate eq. per kg cotton fibre.

	Pakistan				Bangladesh				India						China	
	Punjab		Sindh		Chuadanga		Kushtia		Gujarat		Maharashtra		Madhya Pradesh		Hebei	
	P	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C
Total	35.47	55.15	31.61	40.29	5.72	5.80	5.42	5.80	13.43	48.76	12.80	52.34	39.26	57.19	6.21	6.34
Crop Protection	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Field Emissions	33.74	52.96	30.10	38.19	5.23	5.30	5.05	5.28	11.78	44.79	11.41	50.30	38.53	55.88	5.72	5.74
Field Work	0.50	0.68	0.60	0.80	0.01	0.01	0.01	0.01	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.03
Ginning	0.01	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.03	0.03	0.04	0.04	0.04	0.04	0.01	0.01
Irrigation	0.80	0.98	0.54	0.68	0.22	0.28	0.17	0.28	1.15	3.19	0.84	0.75	0.02	0.01	0.14	0.17
Land Use Change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Provision of Fertilizer	0.41	0.52	0.35	0.41	0.19	0.19	0.18	0.19	0.22	0.38	0.30	0.57	0.39	0.48	0.32	0.40
Transports	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00
Residue Combustion	0.00	0.00	0.00	0.20	0.05	0.00	0.00	0.03	0.21	0.32	0.19	0.65	0.25	0.75	0.00	0.00

Acidification

The following table shows the regional results for acidification potential in mole H+ eq. per kg cotton fibre.

	Pakistan				Bangladesh				India						China	
	Punjab		Sindh		Chuadanga		Kushtia		Gujarat		Maharashtra		Madhya Pradesh		Hebei	
	P	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C
Total	0.031	0.039	0.030	0.035	0.012	0.013	0.011	0.013	0.026	0.049	0.025	0.041	0.028	0.038	0.010	0.010
Crop Protection	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Emissions	0.018	0.022	0.017	0.017	0.006	0.007	0.006	0.007	0.012	0.018	0.014	0.023	0.016	0.020	0.006	0.006
Field Work	0.003	0.004	0.004	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ginning	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000
Irrigation	0.005	0.006	0.003	0.004	0.001	0.002	0.001	0.002	0.007	0.019	0.005	0.005	0.000	0.000	0.000	0.001
Land Use Change	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Provision of Fertilizer	0.005	0.008	0.006	0.007	0.004	0.004	0.004	0.004	0.004	0.007	0.003	0.006	0.008	0.010	0.003	0.003
Transports	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Residue Combustion	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.002	0.003	0.002	0.006	0.002	0.007	0.000	0.000

Abiotic Depletion Potential

The following table shows the regional results for abiotic depletion potential in MJ per kg cotton fibre eq.

	Pakistan				Bangladesh				India						China	
	Punjab		Sindh		Chuadanga		Kushtia		Gujarat		Maharashtra		Madhya Pradesh		Hebei	
	P	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C
Total	16.77	23.48	17.87	22.08	8.99	9.14	8.58	8.86	16.79	34.60	13.00	21.33	18.75	22.90	7.70	8.05
Crop Protection	0.26	0.41	0.24	0.28	0.20	0.26	0.17	0.22	0.17	0.21	0.14	0.39	0.35	0.43	0.31	0.45
Field Emissions	0.03	0.05	0.04	0.04	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00
Field Work	3.68	5.00	4.43	5.92	0.09	0.09	0.05	0.05	0.23	0.21	0.11	0.17	0.26	0.20	0.20	0.21
Ginning	0.37	0.37	0.51	0.51	0.17	0.17	0.17	0.17	0.64	0.64	0.71	0.71	0.70	0.70	0.25	0.25
Irrigation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.19	17.15	4.53	4.03	0.13	0.06	0.74	0.87
Land Use Change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Provision of Fertilizer	12.32	17.51	12.55	15.21	8.18	8.41	7.96	8.24	9.46	16.25	7.32	15.81	17.15	21.29	6.14	6.18
Transports	0.11	0.13	0.10	0.12	0.35	0.20	0.22	0.17	0.10	0.14	0.19	0.21	0.16	0.22	0.07	0.08
Residue Combustion	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Water use

The following table shows the regional results for water use in m3 world eq. per kg cotton fibre.

	Pakistan				Bangladesh				India						China	
	Punjab		Sindh		Chuadanga		Kushtia		Gujarat		Maharashtra		Madhya Pradesh		Hebei	
	P	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C
Total	111.1	134.7	150.0	172.8	2.1	2.6	1.6	2.6	186.9	352.7	10.4	10.5	10.3	11.7	38.5	45.5
Crop Protection	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Field Emissions	0.1	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Field Work	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ginning	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Irrigation	110.8	134.4	149.7	172.5	2.0	2.5	1.5	2.6	186.8	352.6	10.4	10.4	10.2	11.6	38.4	45.5
Land Use Change	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Provision of Fertilizer	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Transports	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Residue Combustion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Water consumption

The following table shows the regional results for water consumption in kg per kg cotton fibre.

	Pakistan				Bangladesh				India						China	
	Punjab		Sindh		Chuadanga		Kushtia		Gujarat		Maharashtra		Madhya Pradesh		Hebei	
	P	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C
Total	2059	2498	1998	2302	574	719	431	724	5198	9809	2764	2770	597	677	431	510
Crop Protection	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Field Emissions	3	5	4	4	0	0	1	0	0	1	0	0	0	1	0	0
Field Work	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ginning	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Irrigation	2053	2489	1991	2294	571	717	429	722	5195	9805	2761	2766	593	672	429	508
Land Use Change	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Provision of Fertilizer	3	4	3	3	2	2	2	2	2	4	2	4	3	4	1	1
Transports	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Residue Combustion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Ecotoxicity

The following table shows the regional results for ecotoxicity freshwater in CTUe per kg cotton fibre.

	Pakistan				Bangladesh				India						China	
	Punjab		Sindh		Chuadanga		Kushtia		Gujarat	Maharashtra	Madhya Pradesh				Hebei	
	P	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C
Total	122.49	210.03	674.36	503.88	315.36	273.39	209.24	276.96	121.91	230.02	110.45	223.40	123.33	123.78	239.04	319.54
Crop Protection	116.95	201.37	667.00	494.65	311.27	269.23	205.09	272.80	114.11	216.32	105.25	215.70	113.29	111.54	235.77	316.14
Field Emissions	1.16	1.46	1.39	1.42	0.57	0.60	0.60	0.61	1.17	1.56	1.82	2.12	1.98	2.25	0.61	0.64
Field Work	1.33	1.81	1.60	2.14	0.03	0.03	0.02	0.02	0.08	0.08	0.04	0.06	0.09	0.07	0.23	0.25
Ginning	0.08	0.08	0.11	0.11	0.02	0.02	0.02	0.02	0.10	0.10	0.11	0.11	0.11	0.11	0.05	0.05
Irrigation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.24	6.21	1.64	1.46	0.05	0.02	0.87	1.03
Land Use Change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Provision of Fertilizer	2.91	5.26	4.21	5.28	3.29	3.43	3.44	3.41	3.93	5.34	1.31	3.11	7.47	8.84	1.42	1.34
Transports	0.04	0.05	0.04	0.04	0.13	0.07	0.08	0.06	0.04	0.05	0.07	0.08	0.06	0.08	0.08	0.09
Residue Combustion	0.00	0.00	0.00	0.24	0.06	0.00	0.00	0.04	0.25	0.37	0.22	0.76	0.29	0.87	0.00	0.00

Biodiversity

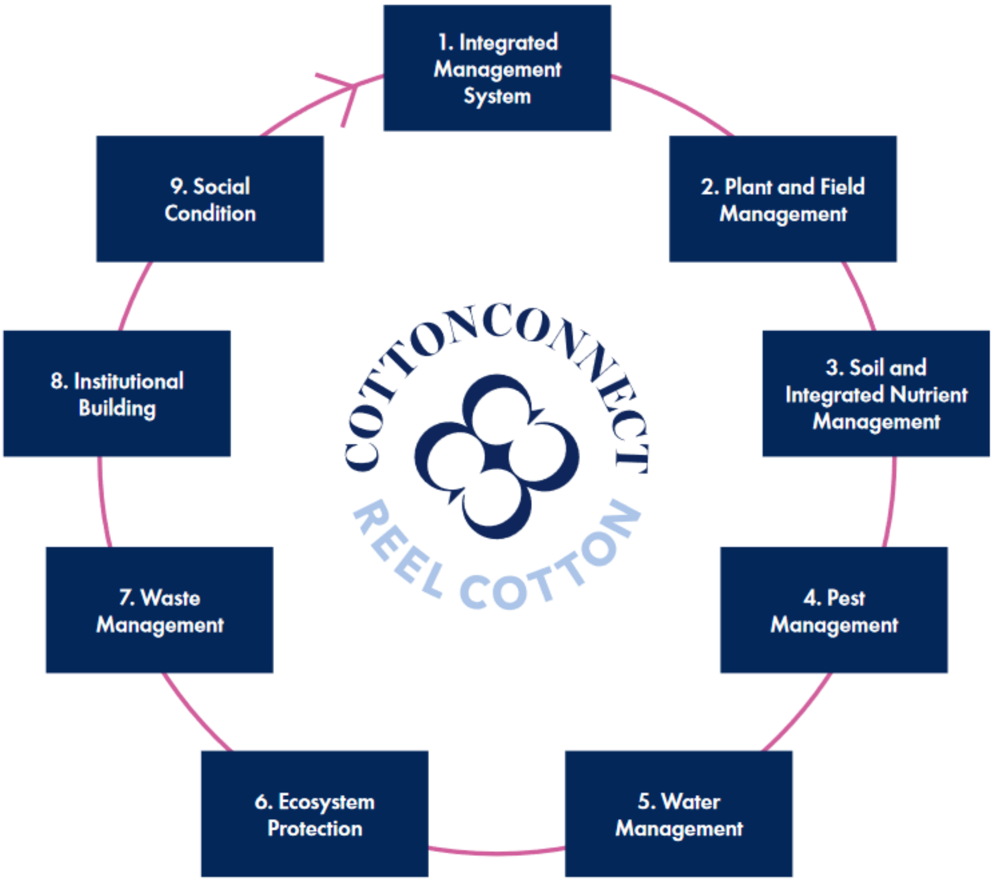
The following section details the biodiversity results on a regional level. See section 4.2 of the main report for details of the calculation method.

Table 0-13: Biodiversity results, regional level

			Local biodiversity value, BV_{local}	Ecoregion Factor, EF	Bv_{total} =Q	ΔQ	Land Use per FU	Biodiversity Impact per FU = Land Use * Delta Q
			BVI		*BVI*	*BVI*	*m^2a/FU*	*$BVIm^2a$*
Pakistan	**Punjab**	Project	0.830	0.198	0.164	0.034	4.453	0.150
		Control	0.833	0.198	0.165	0.033	4.948	0.164
	Sindh	Project	0.842	0.199	0.168	0.032	5.421	0.171
		Control	0.845	0.199	0.168	0.031	5.957	0.184
	Average	Project	0.835	0.199	0.166	0.033	4.890	0.161
		Control	0.838	0.199	0.167	0.032	5.406	0.175
Bangladesh	**Chuadanga**	Project	0.827	0.183	0.151	0.032	2.599	0.082
		Control	0.834	0.183	0.152	0.030	2.781	0.084
	Kushtia	Project	0.835	0.183	0.152	0.030	2.660	0.080
		Control	0.835	0.183	0.152	0.030	2.823	0.085
	Average	Project	0.831	0.183	0.152	0.031	2.629	0.081
		Control	0.834	0.183	0.152	0.030	2.802	0.085
India	**Gujarat**	Project	0.830	0.198	0.164	0.034	3.825	0.128
		Control	0.828	0.198	0.163	0.034	4.823	0.164
	Maharashtra	Project	0.830	0.215	0.179	0.036	3.634	0.133
		Control	0.833	0.215	0.179	0.036	4.560	0.164
	Madhya Pradesh	Project	0.847	0.224	0.189	0.034	5.774	0.198
		Control	0.843	0.224	0.189	0.035	6.397	0.225
	Average	Project	0.831	0.199	0.166	0.034	4.226	0.142
		Control	0.830	0.199	0.166	0.034	5.146	0.174
China	**Hebei/ Average**	Project	0.830	0.246	0.204	0.042	2.194	0.092
		Control	0.830	0.246	0.204	0.042	2.346	0.098

Annex F: 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.



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.

Figure 0-9: REEL Cotton Code of Conduct 3.0 principles

Table 0-14: 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