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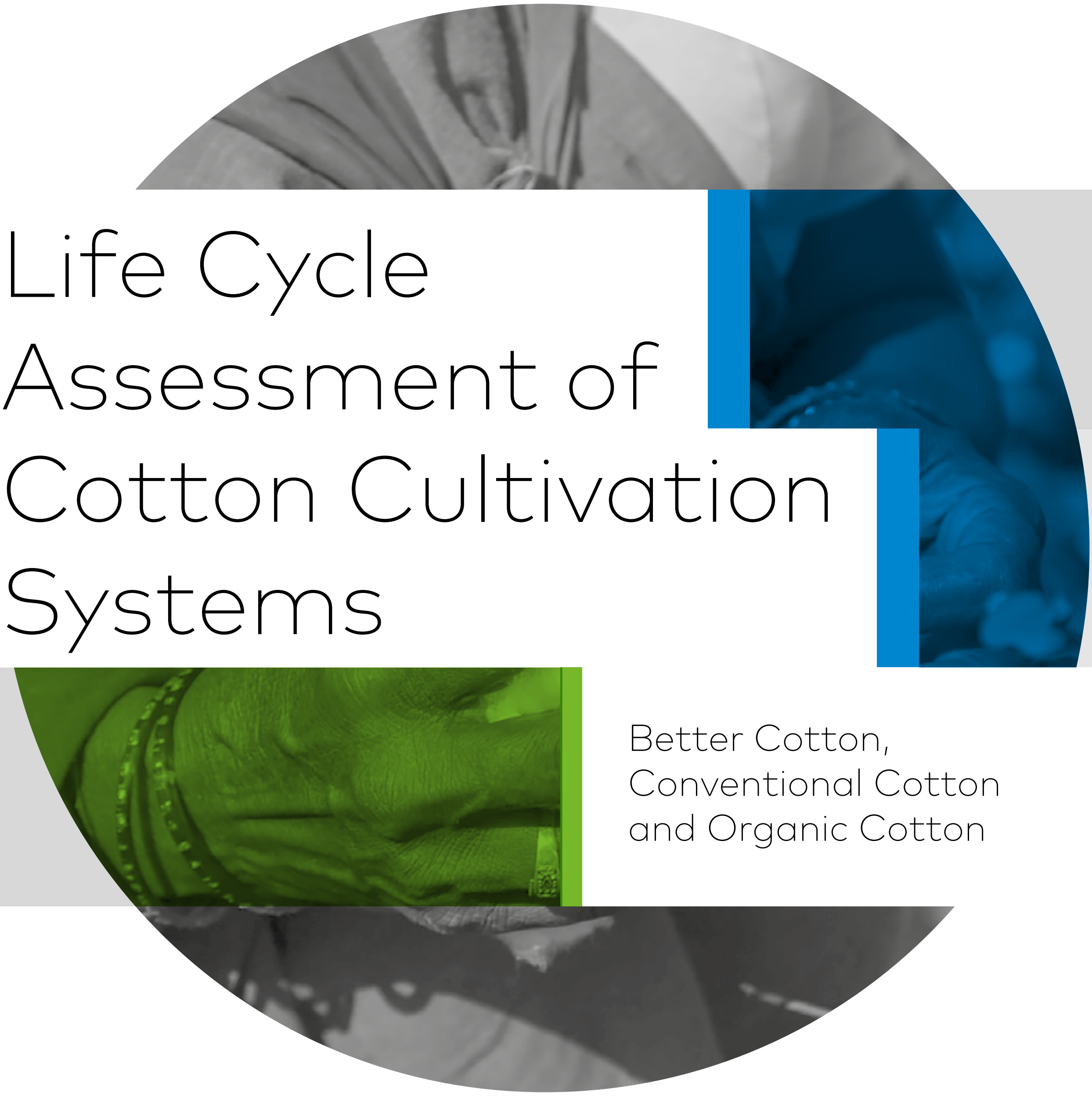

Life Cycle Assessment of Cotton Cultivation Systems

Better Cotton, Conventional Cotton and Organic Cotton

Study commissioned by

C&A Foundation

Critical Review Panel Members

Review Panel Chair
Mr. Matthias Fischer,
Fraunhofer Institute for Building Physics

Panel Members
Dr. Senthilkannan Muthu,
Head of Sustainability, SgT group & API, Hong Kong

Mr. Simon Ferrigno,
Cotton and Sustainability Expert

Mr. Rajeev Verma,
Project Manager, Cotton Connect, India

Advisory Panel Members
Textile Exchange
Ms. Liesl Truscott, Mr. Amish Gosai

Better Cotton Initiative
Ms. Kendra Pasztor

C&A
Ms. Charline Ducas

Internal Review Panel Members
C&A Foundation
Ms. Anita Chester, Ms. Ipshita Sinha,
Mr. Litul Baruah

Study Author
Thinkstep Sustainability Solutions Pvt. Ltd.
(100% subsidiary of thinkstep AG)

Authors
Dr. Rajesh Singh
Ritesh Agrawal
Ulrike Bos
Hiranmayee Kanekar

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Erratum

Thinkstep would like to acknowledge there were three typos in the original Life Cycle Assessment of Cotton Cultivation Systems: Better Cotton, Conventional Cotton and Organic Cotton study report, published in May 2018.

Typo #1:
Section 4.3.3 Table 11, p. 48 – Previously it showed the value as 615 cubic meters per hectare, which has been rectified to the correct value of 244 cubic meters per hectare for organic cotton cultivation.
Section 8.4 Table 27 p.79 – It had the value of 615 cubic meters per hectare, which should be 244 cubic meters per hectare for organic cotton cultivation.

Typo #2:
Section 4.3.3 Table 12, p. 50
The rain water contribution is shown as 79%, but should have been 93%.

Typo #3:
Section 8.5 Table 28, p. 81
The irrigation water use values given for conventional cotton are given as 35.8 m3/ha and 4.8 m3/ ha. The decimal point was misplaced. The values should be 358 m3/ha and 48 m3/ ha, respectively.

All of these errors have been amended in the revised version of the report.

Please note: the LCA models used the right data and all results are therefore correct.

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Acronyms

AP	Acidification Potential (also referred as Acidification)
BCI	Better Cotton Initiative
Bt	Bacillus thuringiensis
CML	Centre of Environmental Science at Leiden
CTUe	Comparative Toxic Unit for Ecosystems
CTUh	Comparative Toxic Unit for Humans
EP	Eutrophication Potential (also referred as Eutrophication)
ETP	Eco-toxicity potential (also referred as Eco-toxicity)
FAO	Food and Agriculture Organization of the United Nations
Fm	Fresh matter
FU	Functional unit
FYM	Farm Yard Manure
GHG	Greenhouse Gas
GWP	Global Warming Potential (also referred as Climate Change)
HTP	Human toxicity potential (also referred as Human Toxicity)
IABP	Institute for Acoustics and Building Physics, University of Stuttgart
ILCD	International Life Cycle Data System
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
ODP	Ozone Depletion Potential (also referred as Ozone Depletion)
PAF	Potentially affected fraction
PED	Primary Energy Demand (also referred as Total Primary Energy Demand)
PEF	Product environmental footprint
POCP	Photochemical Ozone Creation Potential (also referred as Photochemical Ozone Creation)
TE	Textile Exchange
TS	Thinkstep AG
UNEP-SETAC	United Nations Environmental Program (UNEP) – Society of Environmental Toxicology and Chemistry (SETAC)

Executive summary

C&A Foundation is a corporate foundation here to transform the fashion industry. They work with change-makers all over the world, giving them financial support, expertise and networks so they can make the fashion industry work better for every person it touches. The foundation collaborates with a variety of stakeholders, including NGOs and industry partners, and work closely with smallholder farmers and garment workers. In all their work, C&A Foundation places a specific emphasis on women and girls, as they are disproportionately affected by the issues affecting the industry. Currently, they are concentrating their efforts in five key areas: accelerating sustainable cotton, improving working conditions, eliminating forced and child labour, fostering a transition to circular fashion, and strengthening communities.

In order to broaden the understanding of environmental impacts and achieve the above focus areas, C&A Foundation decided to conduct Life Cycle Assessment (LCA) of Better Cotton, conventional cotton and organic cotton cultivation systems, according to the principles of the ISO 14040/44 and to document the results. LCA is a recognized tool to measure and quantify the environmental impacts of production systems or products, also aid to discover improvement potentials. The method allows to objectively and scientifically evaluate the resource requirements of a product and its potential impact on the environment during every phase of its production, use, and disposal. This study focused only on the cultivation phase of seed cotton and is representative of the state of Madhya Pradesh in India. The outcomes of this study are intended to give a better perspective of the environmental footprint of cotton cultivation in the region of Madhya Pradesh, India.

C&A Foundation commissioned Thinkstep Sustainability Solutions Private Limited, India, subsidiary of thinkstep AG, Germany for this study. To allow credible communication based on the results of this study, a third party critical review panel was commissioned to peer review the work and ensure compliance with the ISO 14040 /44 standards. In addition to critical review panel, an advisory panel was constituted to provide guidance and oversight to the study.

LCA studies of cotton are available in the public literature. These studies provide environmental impacts for global averages as well as country averages. But there was a need to conduct LCA for the cotton cultivation specific to Madhya Pradesh region in India where C&A Foundation has a presence.

The data collection for the cultivation systems were done with the help of C&A Foundation. 100 farmers of each type of cotton cultivation systems were selected from Khargone District of Madhya Pradesh. The selection of the cotton farms was based on criteria such as conversion maturity of more than 3 years for Better Cotton cultivation and organic cotton cultivation along with type of irrigation, mechanization of farming, farm size, etc. for Better Cotton, conventional cotton and organic cotton farms.

The data which were related to geographical aspects of the region such as average rainfall, soil conditions, rate of erosion, rate of evaporation, etc. were considered specific to the region of Madhya Pradesh, India. For the raw materials and fuels consumption, primary data were collected from field. The data collection questionnaires finalized by the advisory panel were used to collect data from farmers.

The information gathered from field observations and data collected from farmers were used to develop a model in the GaBi 8 Software released in 2017. The functional unit considered for the study was 1 metric ton of seed cotton at farm gate, for all the three systems viz. Better Cotton, conventional cotton and organic cotton. The reference flow for all the three types of cotton cultivation systems was 1 metric ton of seed cotton.

Results of Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA)

The average Better Cotton yield was 1888 kg per hectare. The LCIA results of Better Cotton for 1 metric ton of seed cotton were as follows-

Impact Category	Unit	Impact Value
Acidification	kg SO_2 eq.	12.41
Eutrophication	kg phosphate eq.	1.66
Climate Change	kg CO_2 eq.	688.00
Ozone Depletion	kg R11 eq.	7.18E-09
Photochemical Ozone Creation	kg ethene eq.	0.17
Total Primary Energy Demand	MJ	2.56E+04
Blue Water Consumption	kg	3.67E+05
Blue Water Consumption (including rain water)	kg	1.75E+06
Eco-toxicity	CTUe	1.17E+04
Human Toxicity	CTUh	3.13E-07

It was observed that emissions occurring in the field, such as ammonia and nitrogen monoxide, had the highest contribution to impact categories of acidification, eutrophication and climate change. Energy consumption in irrigation had higher contribution to ozone depletion and photochemical ozone creation impacts. Non-renewable primary energy consumption was maximum in irrigation, but the total energy demand was dominated by the field as the solar energy consumed by cotton for its growth was also accounted. Pesticide emissions to air, soil and water lead to toxicity impacts. Water consumption in production of raw materials and energy were also accounted but the irrigated water used for cultivation had the highest contribution to blue water consumption.

The average conventional cotton yield was 1938 kg per hectare. The LCIA results for 1 metric ton of seed cotton were as follows-

Impact Category	Unit	Impact Value
Acidification	kg SO_2 eq.	12.68
Eutrophication	kg phosphate eq.	1.92
Climate Change	kg CO_2 eq.	680.20
Ozone Depletion	kg R11 eq.	6.90E-09
Photochemical Ozone Creation	kg ethene eq.	0.15
Total Primary Energy Demand	MJ	2.55E+04
Blue Water Consumption	kg	3.44E+05
Blue Water Consumption (including rain water)	kg	1.71E+06
Eco-toxicity	CTUe	9.00E+03
Human Toxicity	CTUh	1.82E-06

Highest contribution to impact categories of acidification, eutrophication and climate change was from field emissions of ammonia and nitrogen monoxide. Ozone depletion and photochemical ozone creation impacts were dominated by energy used in irrigation. Non-renewable primary energy consumption was maximum in irrigation, but the total energy demand was dominated by the field as the solar energy consumed by cotton for its growth was also accounted. Toxicity was due to pesticide emissions to air, soil and water. Water consumption in production of raw materials and energy were also accounted but the irrigated water used for cultivation had highest contribution in blue water consumption.

The average organic cotton yield was 1755 kg per hectare. The LCIA results of organic cotton for 1 metric ton of seed cotton were as follows-

Impact Category	Unit	Impact Value
Acidification	kg SO_2 eq.	0.57
Eutrophication	kg phosphate eq.	-0.02
Climate Change	kg CO_2 eq.	338.50
Ozone Depletion	kg R11 eq.	1.85E-09
Photochemical Ozone Creation	kg ethene eq.	0.05
Total Primary Energy Demand	MJ	2.09E+04
Blue Water Consumption	kg	1.40E+05
Blue Water Consumption (including rain water)	kg	1.88E+06
Eco-toxicity	CTUe	1.41E-01
Human Toxicity	CTUh	1.99E-10

Highest contribution to impact categories of acidification was from tractor operations due to emission of nitrogen monoxide. The absence of chemical fertilizers helped in reducing the excess field emissions of ammonia. In eutrophication and climate change emissions of nitrate to water and carbon dioxide to air, occurring in field dominated to the respective impacts. Ozone depletion and photochemical ozone creation impacts were dominated by energy used in irrigation. Total primary energy demand and blue water consumption were dominated by the field requirements of the organic cotton cultivation. Eco-toxicity was due to tractor operations while human toxicity was dominated by energy consumption in irrigation.

Interpretation

Field emissions – encompassing the emissions from nutrient transformation processes taking place in the soil - stand out in several impact categories. They dominate the impact on climate change due to nitrous oxide emissions and were an important contributor to acidification potential via ammonia release. Apart from field emissions, use of fossil fuels contributed to the several impact categories, most notably, energy used in irrigation and tractor operations.

Acidification was mainly due to fuel consumption in tractors, electricity consumption for irrigation, soil erosion, fertilizer and pesticide production.

Nutrient leaching and soil erosion caused eutrophication. Use of chemical fertilizers increased the amount of nutrients in the soil, which gets washed. Soil fertility and protection measures helped in reducing soil erosion. These measures also help in preserving soil moisture content available for plant uptake. The amount of rainfall, availability of fresh water and ground water depended on geography of the cultivation systems. Thus, the amount of blue water consumption would differ from region to region for same crop.

Production of electricity used in irrigation and production of chemicals such as fertilizers, pesticides and insecticides contributed to Ozone Layer Depletion Potential and Photochemical Ozone Creation Potential.

In Better Cotton and conventional cotton, the eco-toxicity was mainly due to use of pesticides having Profenofos as active ingredient. The eco-toxicity potential of Profenofos was 1.61E+07 CTUe per kg of element emitted.

In organic cotton, no chemical fertilizers and pesticides are applied, hence, the results were mainly contributed by energy used in irrigation and emissions from tractor operations. The field emissions of Nitrogen led to Ozone Layer Depletion Potential, Photochemical Ozone Creation Potential impacts.

The conclusion of this study is that all three cotton cultivation systems in Madhya Pradesh, a region in India resulted in environmental impacts and distinct hot spots could be identified within their system boundaries. Selective scenarios were also evaluated to quantify the variability of environmental impacts.

1. Introduction

Cotton is a natural plant fibre which grows around the seed of the plant. Fibres are used in the textile industry, where they are the starting point of the production chain. Cotton fibres are usually spun into yarn and further processed to make fabrics. It is also utilized in the manufacturing of several industrial products such as cordage and paper. Cottonseeds are used to produce oil for human consumption. The cottonseed meal is rich in protein and therefore is used as animal feed. Cotton cultivation in India amounted to around 5.88 million metric tons in 2016-2017[1]. India has occupied top position in the World cotton production since 2015-16.

Cotton contributing to 6-7% of the net sown area, is the second largest kharif crop (crop grown during rainy season) in India, after Rice. Cotton is cultivated in the states of Punjab, Haryana, Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Andhra Pradesh, Telangana, Karnataka & Tamil Nadu, besides in small areas in Uttar Pradesh, Orissa, West Bengal, Assam and Tripura states. [COTTONSTAT, 2017].

A need for higher yield, due to industrial development, led to intensive use of pesticides and fertilisers from the 1940s. As yield was the focus, environmental and social impacts were overlooked, leading to a need to assess environmental impacts of cotton cultivation.

The vast majority of the LCA studies have diverse goals, methodologies and coverage of issues related to cotton cultivation. Most of these studies were about contribution and hotspot analysis of environmental impacts in the agricultural practices. This diversity meant that there was limited similarity in the coverage and therefore, it was difficult to draw conclusions. However, some consensus could be drawn.

Few of the notable studies were:

- Life Cycle Assessment of cotton fibre & fabric by Cotton Incorporated, published in 2012, with the objective to develop and publish detailed global average Life Cycle Inventories (LCIs) for cradle-to-gate production of cotton fibre and fabric. The regions included in this study were from India, China, and USA
- Life Cycle Assessment (LCA) of organic cotton fibre by Textile Exchange, published in 2014, with the objective to build an updated and well-documented Life Cycle Inventory (LCI) for organic cotton fibre (ginned and baled), representative of worldwide global production. The regions included in this study were from India, Turkey, China, Tanzania and USA.
- Cherrett et al, 2005 reported the ecological Footprint and Water Analysis of conventional cotton, organic cotton, conventional hemp, organic hemp and polyester fibres cultivated in the regions of United Kingdom, USA and India (only Punjab)
- Muthu et al 2011, reported the development of a model to quantify the environmental impact made by various textile fibres produced in India

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[1] https://www.statista.com/statistics/263055/cotton-production-worldwide-by-top-countries/

- Sandin et al. 2013, reported the assessments of water and land used in bio-based textile fibre specific to the region of North West China
- Shen et al 2010, described the environmental impact of man-made cellulose fibres i.e. Viscose, Modal and Tencel produced in USA and China
- Babu and Selvadas, 2013, reported the environmental impact due to cultivation of the conventional and organic seed cotton fibres cultivated in India
- Comparative assessment of Better Cotton, conventional cotton and cotton cultivated in Akola region of Maharashtra, India was reported by Arvind 2014

This Life Cycle Assessment study intends to build a credible database for cotton cultivation systems in the region of Madhya Pradesh, India.

C&A Foundation is a corporate foundation here to transform the fashion industry. They work with change-makers all over the world, giving them financial support, expertise and networks so they can make the fashion industry work better for every person it touches. The foundation collaborates with a variety of stakeholders, including NGOs and industry partners, and work closely with smallholder farmers and garment workers. In all their work, C&A Foundation places a specific emphasis on women and girls, as they are disproportionately affected by the issues affecting the industry. Currently, they are concentrating their efforts in five key areas: accelerating sustainable cotton, improving working conditions, eliminating forced and child labour, fostering a transition to circular fashion, and strengthening communities.

In order to understand the environmental impacts of various cotton cultivation systems, C&A Foundation decided to conduct this life cycle assessment study in Khargone region of Madhya Pradesh, focusing on Better Cotton, conventional cotton and organic cotton cultivation systems.

C&A Foundation commissioned Thinkstep Sustainability Solutions Private Limited, India to perform the Life Cycle Assessment study according to the principles of ISO 14040/44 and to document the results. The goal of the study was to quantify the environmental impacts associated with production of Better Cotton, conventional cotton and organic cotton using LCA approach and also identify the environmental hotspots over a range of impact categories.

Specific questionnaires were adapted for primary data collection from the 100 selected farms for each of the three cultivation systems in the identified geography. The primary data was collected by Thinkstep team members visiting the various identified farms and one to one interaction with the farmers during the month of October to November 2017. The selection of the cotton farms was based on criteria such as conversion maturity of more than 3 years (for Better Cotton cultivation and organic cotton cultivation), type of irrigation, mechanization of farming, farm size, etc. The information about the farmers (names, farm detail, locations) were provided by C&A Foundation. The questionnaires were designed to capture 2016-17 cultivation data for all three types of cultivation systems.

Farmers have adopted mostly manual farming practices. However, tractors were the only machinery used by most of the farmers in the initial land preparation activity. Crop rotation was dependent on the availability of water, with wheat or gram being cultivated in rotation. The cotton crop grown had two sub-types based on the cultivation period. May-December crop, also called Summer Cotton, the sowing for which started before monsoon and June-January crop, also called Rainy Cotton for which sowing started during monsoon. Harvest period was from October to January. The monsoon in the region lasts from late June to October.

The organic inputs prepared by farmers were from home made products such as garlic, onion, ginger and chilli paste, fresh/ rotten Buttermilk, Neem dust, Panch Patti kadha (natural tonic -made from five types of leaves of custard apple, Neem, Indian Beech (Karanj), devil's trumpets (Dhatura) and Ipomoea carnea), etc. Cow dung was the most common organic input used for all three types of cotton cultivation.

Preparation of organic inputs, application of such inputs, fertilizer and pesticides as well as harvesting were done manually by Better Cotton and conventional Cotton cultivators. Seed cotton was cultivated and then sent to local markets for sale.

All the observations and the data collected using specifically adapted questionnaires were consolidated and used in this LCA study.

The results and conclusions of the study were completely and accurately reported without bias to the intended audience. The data, methods, assumptions and limitations were transparently presented in the report. The report allows the results and interpretation to be used in a manner consistent with the goals of the study.

2. Goal and scope

2.1 Goal of the study

The study presented in this report intended to conduct a life cycle assessment of cotton cultivation systems specific to the state of Madhya Pradesh, in India. The objectives of this study were:

- Quantifying the environmental impacts associated with production of Better Cotton, conventional cotton and organic cotton using LCA approach.

- Identifying the environmental hotspots over a range of environmental impact categories.

- Seeking additional reliable scientific information to communicate the environmental performance of organic cotton and Better Cotton to various stakeholders including government, retailers, suppliers, and non-governmental organizations.

- Use of LCI/LCIA results internally by C&A Foundation.

To the effect of achieving these goals, the relevant ISO standards (ISO 14040 and ISO 14044) were followed. This assessment of impacts was based on scientific approach and provides reliable information to various stakeholders.

To allow credible communication based on the results of this study, a third party critical review panel was commissioned to peer review the work and ensure compliance with the ISO 14040[2]/44[3] standards. This panel comprised of four independent experts:

- **Mr. Matthias Fischer**, Fraunhofer Institute for Building Physics – Review Panel Chair

- **Dr. Senthilkannan Muthu**, Head of Sustainability, SgT group & API, Hong Kong

- **Mr. Simon Ferrigno**, Cotton and Sustainability Expert – Panel Member

- **Mr. Rajeev Verma**, Project Manager, Cotton Connect, India – Panel Member

In addition to critical review panel, an advisory panel was constituted to provide guidance and oversight to the study. The advisory panel consisted of:

- **Textile Exchange** – Ms. Liesl Truscott, Mr. Amish Gosai

- **Better Cotton Initiative** – Ms. Kendra Pasztor

- **C&A** – Ms. Charline Ducas

The Internal review team members involved in this study were

- **C&A Foundation** – Ms. Anita Chester, Mr. Litul Baruah, Ms. Ipshita Sinha

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[2] ISO 14040: Environmental management – Life cycle assessment – Principles and framework (ISO 14040:2006)
[3] ISO 14044: Environmental management – Life cycle assessment – Requirements and guidelines (ISO 14044:2006)

2.2 Scope of the study

2.2.1 System description

Cotton, a soft, fluffy staple fibre that grows in a boll, or protective capsule, around the seeds of cotton plants. It belongs to the genus Gossypium in the family of Malvaceae. The plant is a shrub native to tropical and subtropical regions around the world, including the Americas, Africa, and India.

2.2.1.1 Better Cotton Cultivation

The Better Cotton Standard System is a holistic approach to sustainable cotton cultivation which covers all three pillars of sustainability: environmental, social and economic. Each of the elements – from the Production Principles and Criteria to the monitoring mechanisms which show results and impact – work together to support the Better Cotton Standard System, and the credibility of Better Cotton. The system was designed to ensure the exchange of good practices, and to encourage the scaling up of collective action to establish Better Cotton as a sustainable mainstream commodity. The Better Cotton Production Principles and Criteria lay out the global definition of Better Cotton, by upholding the following 6 principles:

- Better Cotton is produced by farmers who minimize the harmful impact of crop protection practices.
- Better Cotton is produced by farmers who use water efficiently and care for the availability of water.
- Better Cotton is produced by farmers who care for the health of the soil.
- Better Cotton is produced by farmers who conserve natural habitats.
- Better Cotton is produced by farmers who care for and preserve the quality of the fibre.
- Better Cotton is produced by farmers who promote Decent Work.

The concept is to grow cotton with very carefully controlled application of water, chemical and organic fertilizers and pesticides, aiming to reduce the environmental footprint of cotton farming. To ensure compliance, Better Cotton cultivation was closely monitored and supervised for the farming practices carried out.

2.2.1.2 Conventional Cotton Cultivation

In conventional cotton farming the common practices observed are use of synthetic fertilizers, mono-cropping, use of genetically modified seeds which are treated with fungicides, insecticides and herbicides to defoliate the plants which makes picking easier.

2.2.1.3 Organic Cotton Cultivation

Organic cotton is cotton that is produced and certified to organic agricultural standards.1 Its production sustains the health of soils, ecosystems and people by using natural processes rather than artificial inputs. Importantly organic cotton farming does not allow the use of toxic chemicals or GMOs (genetically modified organisms). Instead, it combines tradition, innovation and science to benefit the shared environment and promote a good quality of life for all involved. It includes a number of factors like site selection, crop rotations, variety, weed control, non-chemical means of insect control and skill to manage organic crop. Most commonly used organic fertilizers are farmyard manure, compost and cow dung. Another common practice is application of organic mix of cow dung, cow urine, and chickpea flour.

2.2.2 System Boundaries

The typical system under consideration was a cradle-to-gate Life Cycle Inventory including the cultivation of the cotton till farm gate as shown in Figure 1, Figure 2 and Figure 3, for Better Cotton, conventional cotton and organic cotton, respectively.

Figure 1 System Boundary for Better Cotton Cultivation

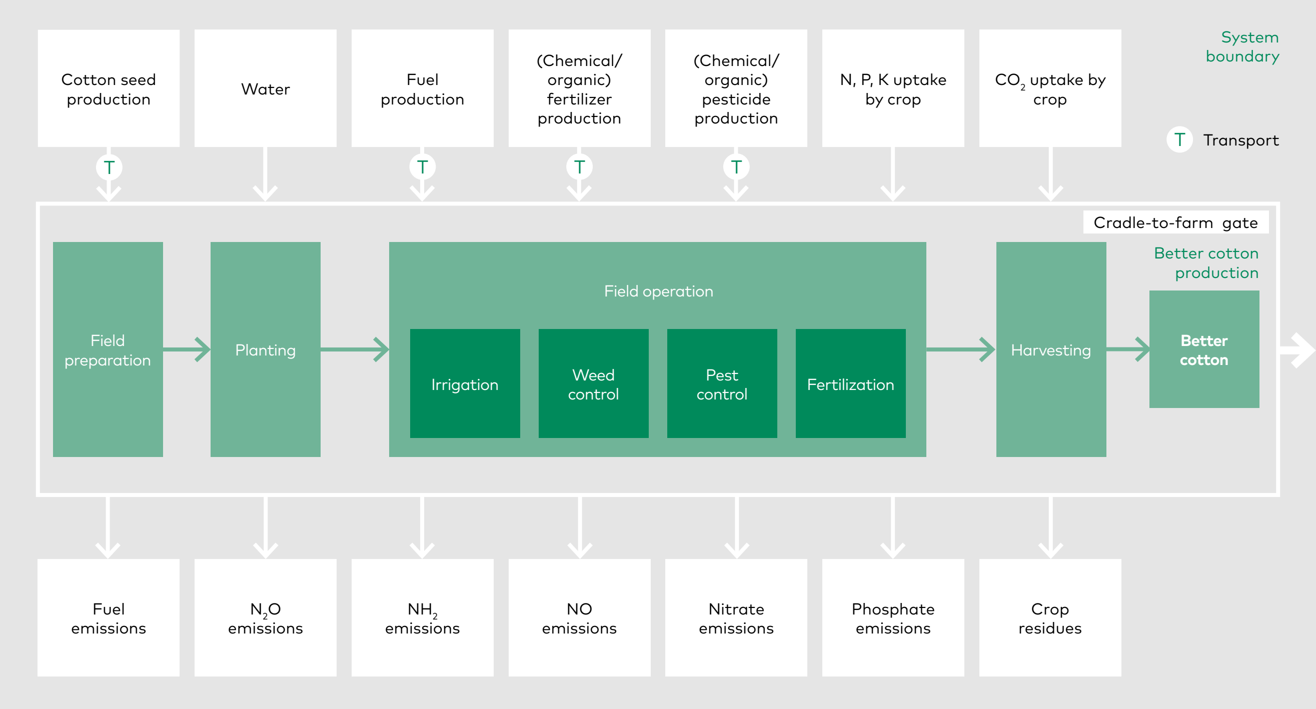


Figure 2 System Boundary for Conventional Cotton Cultivation

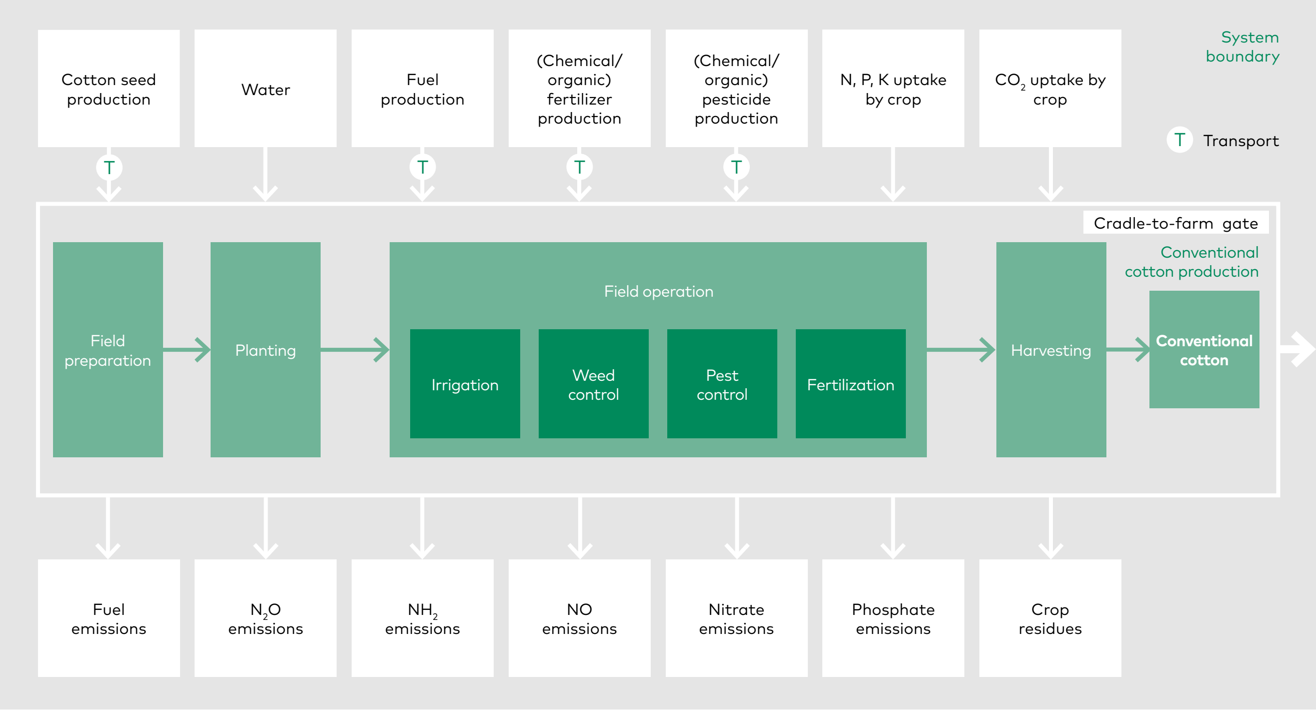
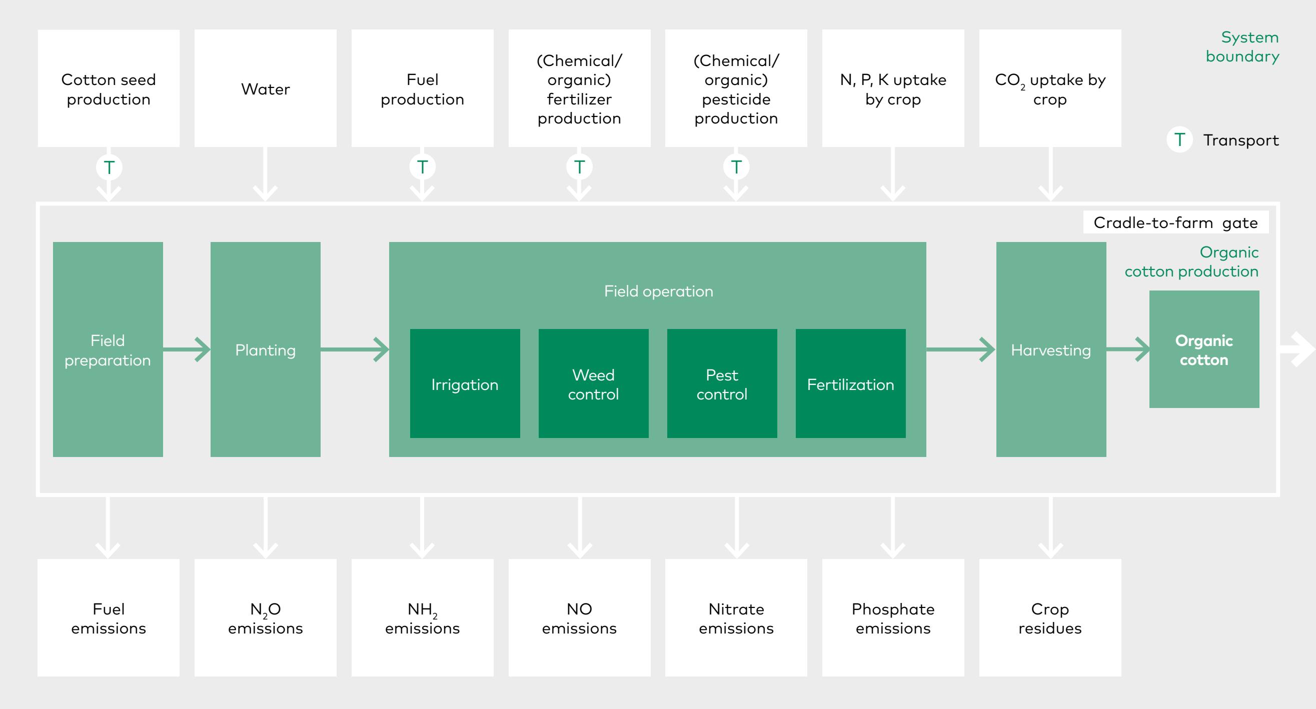


Figure 3 System Boundary for Organic Cotton Cultivation



Cotton cultivation includes four main tasks: field preparation, planting, field operations, and harvesting. Under the collective term field operations, irrigation, weed and pest control, and fertilization was included. These tasks consume energy (electricity and fuel), require inputs (seeds, fertilizers, water, etc.) and crop residues and emissions – all of which form part of the present system.

Table 1 Life Cycle Stages considered in the LCA study

Life Cycle stages	Life Cycle stages	Life Cycle stages
Cotton Cultivation	Field preparation	Collecting the stubble (land cleaning) and ploughing and harrowing the land i.e. land to be prepared for the planting.
	Planting	Input Preparation (compost, fruit enzymes) and seed sowing, spraying of organic or inorganic inputs like manures, composts, fertilizers, pesticides and other nutrients and irrigation (if available & needed)
	Field operations	In this sub-stage of life cycle irrigation, weed and pest control, and application of fertilizers were included
	Harvesting	Harvesting the cotton crop

2.2.3 Functional Unit

The functional unit allows quantification of the environmental impacts of the procedures involved in cotton cultivation. These environmental impacts were calculated based on the functional unit wherein each flow related to material consumption, energy consumption, emissions, effluent and waste were scaled to the reference flow.

The Functional unit for this study was 1 metric ton of seed cotton at farm gate, for all the three systems viz. Better Cotton, conventional cotton and organic cotton.

The reference flow for all the three types of cotton was 1 metric ton of seed cotton.

2.2.4 Selection of LCIA Methodology and type of impacts

To conduct a credible LCA, it is critical to use good quality, current data on all raw materials, energy, and processing aids used as well as the environmental outputs associated with producing a product because this information becomes the platform for performing the life cycle inventories (LCIs) which are the basis for the LCA.

The life cycle assessment was carried out following the ISO 14040 and ISO 14044 guidelines by modelling different scenarios of cotton cultivation using GaBi ts software. (http://www.gabi-software.com/)

The initial phase of LCA involves collection and calculation of Life Cycle Inventory (LCI) data which quantify the material, energy and emission data associated with a functional system. This stage precedes the Life Cycle Impact Assessment (LCIA) which involves classifying, characterizing and evaluating these data in relation to ecological impacts. A further possible stage is the interpretation of data and the potential for improvement through modification of the functional systems.

CML 2001 (January 2016) method developed by Institute of Environmental Sciences, Leiden University, Netherlands and USEtox method endorsed by the UNEP/SETAC Life Cycle Initiative have been selected for evaluation of environmental impacts. These indicators are scientifically and technically valid.

Environment impacts indicators considered for evaluation are listed in Table 2.

Table 2 Environmental impacts indicators

Impact Indicator	LCIA Method	Unit
Acidification	CML	kg SO_2 equivalent
Eutrophication	CML	kg phosphate equivalent
Climate Change	CML	kg CO_2 equivalent
Ozone Depletion	CML	kg R11 equivalent
Photochemical Ozone Creation	CML	kg ethene equivalent
Total Primary Energy Demand (including non-renewable and renewable PED)	-	MJ
Blue Water Consumption	-	m^3 or kg
Blue Water Consumption (including rain water)	-	m^3 or kg
Eco-toxicity	USEtox	CTUe
Human Toxicity	USEtox	CTUh

2.2.5 Inclusion, exclusion and cut-off criteria

In the study, all material and energy flows were required for the cultivation phase, as well as all associated wastes and emissions. This was included but was not limited to: fertilizer and pesticide production as well as field emissions (e.g. N_2O), electricity for pumps and all transports (fertilizer to the field).

The specific cut-off criteria for including or excluding materials, energy and emissions data of the study were as follows:

Mass – If a flow is less than 1% of the cumulative mass of the model it may be excluded, providing its environmental relevance is not a concern.

Energy – If a flow is less than 1% of the cumulative energy of the model it may be excluded, providing its environmental relevance is not a concern.

Environmental relevance – If a flow meets the above criteria for exclusion yet is thought to potentially have a significant environmental impact, it is included. Material flows which leave the system (by emissions) and whose environmental impact is greater than 1% of the whole impact of an impact category that has been considered in the assessment must be covered.

In the assessment, all available data from production processes were considered, i.e. all raw materials use, utilize thermal energy, and electric power consumption using best available LCI datasets. In these cases, even material and energy flows contributing less than 1% of mass or energy were considered. In case of human labor, social issues were outside the scope of this study.

Table 3 Components included within and excluded from the system boundaries

Included items	Excluded items
Cultivation of cotton relevance)	Human and livestock labour (complexity and low
Production of operating materials as manual labour involved)	Construction of capital equipment (low relevance
Energy production and utilization (complexity and low relevance)	Maintenance and operation of support equipment
Fuel production and utilization (low relevance and data intensity)	Production and transport of packaging materials
Water supply, use and consumption	
Transportation of operating materials and product	

2.2.6 Data Collection

Primary data for Better Cotton, conventional cotton and organic cotton cultivation were collected for 100 farms each for the three cotton cultivation systems through a dedicated data collection team of thinkstep with the support of C&A Foundation. Specifically, adapted questionnaires for agrarian systems were used to collect inventory data for agricultural systems. These questionnaires were filled in by representatives of producer groups. Upon completion of data collection, quality checks against literature and other primary cultivation data to ensure reliable results, were done by thinkstep. To ensure data quality, data were collected only on international standards (kg/hectares).

Technological-, geographical- and time reference as well as an assessment of data quality were described in the following paragraphs.

2.2.7 Temporal Coverage

Agricultural data were collected for the year 2016-2017. Additional data necessary to model base material production and energy use were adopted from the GaBi 8 software system database.

2.2.8 Technological and geographical reference

Data were collected for representative samples in Khargone district in the state of Madhya Pradesh in India. Cotton cultivation was modeled in great detail with the proprietary agricultural model of thinkstep AG to appropriately consider all the parameters.

Ancillary materials, process materials and energy, such as the production of chemicals, fuels, and electricity were adopted as average industry mixes from the GaBi 8 software system database (http://www.gabi-software.com).

The geographical coverage was an average cotton cultivation in Madhya Pradesh State of India.

2.2.9 Assessment of data quality

2.2.9.1 Completeness

All relevant process steps were considered and modelled to represent each specific situation, i.e. cultivation in various farms in different locations were modelled separately. The process chain was considered sufficiently complete with regard to the goal and scope of this study.

2.2.9.2 Reliability

Primary data were collected using a specifically adapted questionnaire for agrarian systems. Cross-checks concerning the plausibility of mass and energy flows were carried out on the data received. Similar checks were made on the software model during the study. The agricultural model itself was part of the GaBi 2017 database. Overall the data quality with regard to the goal and scope of this study was intended to reach a good level.

2.2.9.3 Consistency

To ensure consistency, all primary data were collected with the same level of detail, while all background data were sourced from the GaBi databases. Allocation and other methodological choices were made consistently throughout the model.

2.2.10 Allocation

Allocation in the foreground data

When a system yields more than one valuable output as co-products, environmental burden needs to be allocated, i.e. split between them. Several allocation methods were used in LCA studies: mass-based (the heavier product was assigned more burden), substitution (subtracting off the environmental impact of a product that was replaced by the co-product, for example, accounting for the amount of soybeans replaced by cotton seed), and economic (splitting the burden based on monetary values) (Cotton Inc. 2012).
It is observed that most of the studies reported economic allocation as the most suitable method in case of cotton LCA studies.

During cotton cultivation, the environmental impact was allocated to the two products i.e. lint cotton and seed cotton with 16% of the economic value of the harvested crop coming from seed. Allocation was done between cotton seed and cotton residue, as the cotton stalk was considered to be a by-product and could be utilized as compost in the field. The amount of nitrogen content in the cotton stalk was about 1% and the weight ratio of cotton seed to cotton stalk was 1:3.5.

2.2.11 Software and database

The LCA models were created using the GaBi ts software system for life cycle engineering, developed by thinkstep AG. The GaBi LCI database provides the life cycle inventory data for several of the raw and process materials obtained from the background system. The most recent update of the database was in 2017.

2.2.12 Interpretation

The results of the LCI/LCIA were interpreted according to the goal and scope. The interpretation addresses the following topics:

- Identification of significant findings in line with the goal of the study
- Understanding the environmental impacts of cotton – focusing on cradle-to-gate assessment
- Evaluation of completeness, sensitivity and consistency, to justify the inclusion or exclusion of data from the system boundaries as well as the cut-off criteria and data quality checks as described
- Conclusions, limitations and recommendations, stating the appropriateness of the definitions of the system functions, the functional unit and system boundary
- Influence of “non-Indian” datasets in the overall results (if any)

2.2.13 Critical Review

To decrease the likelihood of misunderstandings or negative effects on external interested parties, a panel of interested parties conducted critical reviews on LCA studies where the results were intended to be used and disclosed to the public. Because the study was intended to support external communications, a critical review was conducted.

The critical review panel had the task to assess whether:

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

- The methods used to carry out the LCA were scientifically and technically valid

- The technological coverage of the cotton producers in the prevalent LCA study was representative of the current practice

- The data used were 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 was transparent and consistent

- The review was performed according to ISO 14040 and ISO 14044 in their strictest sense as the data provided by the study were intended to be disclosed to the public. The analysis of individual datasets was outside the scope of this review.

In addition to the above, the following items in the report were considered for third-party review:

- Modifications to the initial scope together with their justification
- System boundary
- Description of the unit processes, including decision about allocation
- Data, including decision about data, details about individual data, and data quality requirements
- Choice of impact categories and category indicators.

The critical review statement and report can be found in section 8.8.

3. Life cycle inventory (LCI) analysis

The data collated from field were adapted in the agricultural model of GaBi software for deriving the environmental impacts. The description of this model is presented in the sections below.

3.1 Agricultural Model [4]

Agrarian systems belong to the most complex production systems within LCA due to their dependence on environmental conditions that were variable in time (e.g. within a year, from year to year) and in space (e.g. varies by country, region, site conditions). The following factors contribute to the complexity of agricultural modelling:

- The variety of different locations,
- High variability of soil characteristics within small scale,
- The large number and diversity of farms in terms of size, cropping patterns, and so on,
- The variety of agricultural management practices applied,
- No determined border to the environment,
- Complex and indirect dependence of the output (harvest, emissions) from the input (fertilizers, location conditions, etc.),
- Variable weather conditions within and between different years,
- Variable pest populations (insects, weeds, disease pathogens, etc.)
- Different crop rotations
- The difficulty to directly measure emissions from agricultural soils due to the time and resource intensity of such measurements

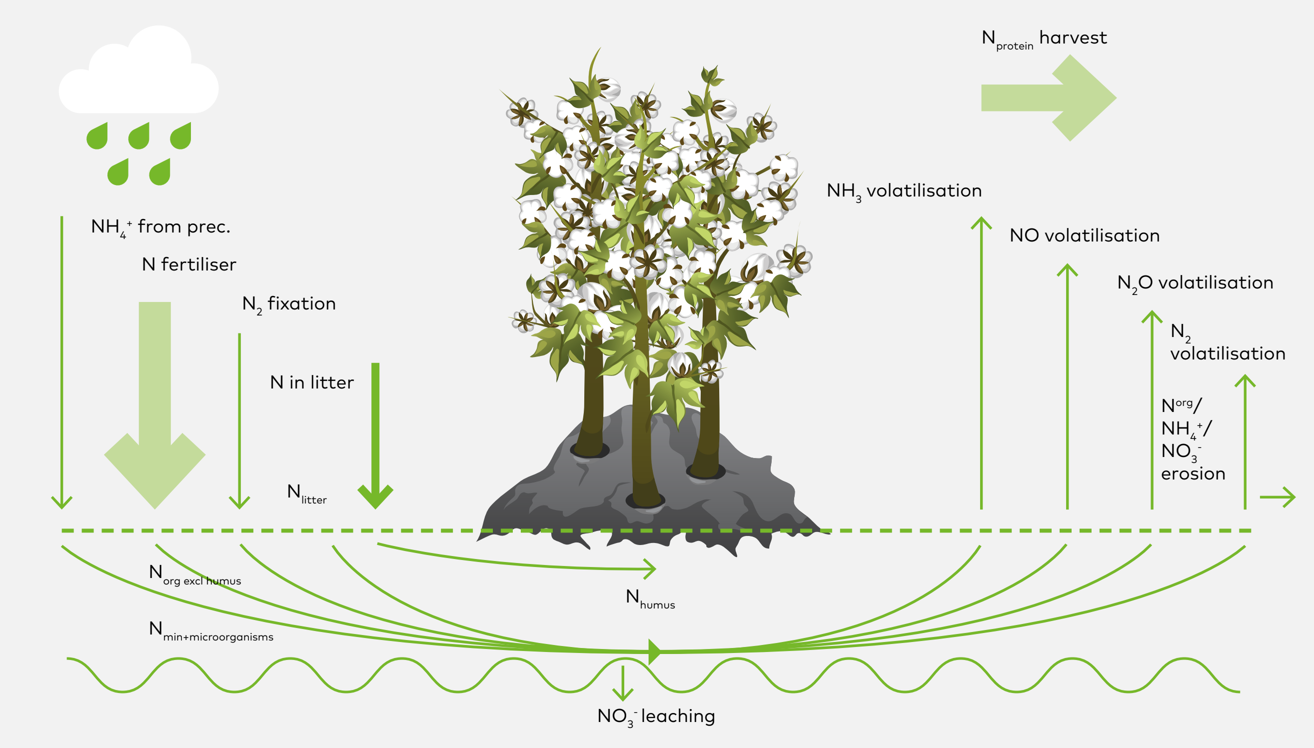
Due to the inherent complications characterizing an agricultural system, a nonlinear agrarian calculation model was applied displaying plant production (developed by thinkstep); this software model covers a multitude of input data, emission factors and parameters. The GaBi model was used for cradle-to-gate (seed-to-bale) environmental impact assessment associated with planting, growing, harvesting, processing, handling, and distribution of cotton. For annual crops, a cultivation period starts immediately after the harvest of the preceding crop and ends after harvest of the respective crop.

3.2 Nutrient Modelling

Nitrogen plays a fundamental role for agricultural productivity and is also a major driver for the environmental performance of an agricultural production system. For these reasons it is essential to evaluate all relevant nitrogen flows within, to and from the agricultural system. The agricultural model accounts for the nitrogen cycle in agricultural systems. Atmospheric deposition of nitrogen is considered as an input into the system based on the values provided in GALLOWAY ET AL. 2004. The model includes emissions of nitrate (NO_3^-) in water and nitrous oxide (N_2O), nitrogen oxide (NO_x) and ammonia (NH_3) into air. The model ensures that emissions from erosion, the reference system (comparable non-cultivated land area) and nutrient transfers within crop rotations are modelled consistently. Figure 4 shows sinks (black arrows) and sources (blue arrows) of the nitrogen cycle.[5]

[4] http://www.gabi-software.com/fileadmin/Documents/The_Agricultural_LCA_model_V1.3_02.pdf
[5] http://www.gabi-software.com/fileadmin/Documents/The_Agricultural_LCA_model_V1.3_02.pdf

Figure 4 Nitrogen system flows



The different N-based emissions are calculated as follows:

- NH_3 emissions to air from organic inputs like cow dung and chemical fertilizers were adapted from the model of BRENTRUP ET AL. 2000 and modelled specifically for the cropping system dependent on the fertilizer-NH_4+ content, the soil-pH, rainfall and temperature. As no mineral nitrogen fertilizer were used in the organic cultivation system under study, the selection of specific NH_3 emission factors for different mineral fertilizers does not apply. It applies in case of Better Cotton and conventional cotton cultivation systems.

- NO is an intermediate product of denitrification. Denitrification is a process of microbial nitrate reduction that ultimately produces molecular nitrogen (N_2) through a series of intermediate gaseous nitrogen oxide products. NO emissions were calculated as 0.43% of the N-fertilizer input specific for the cultivation system as NO according to BOUWMAN ET AL. 2002.

- N_2O is another intermediate product of denitrification, with a large global warming potential. According to IPCC 2006, N_2O emissions were calculated as 1% of all available nitrogen including nitrogen applied with fertilizers, atmospheric deposition, microbial nitrogen fixation, nitrogen available from previous crop cultivation and indirect emissions.

- NO_3- emission to groundwater is calculated based on available nitrogen derived from a nitrogen balance (N not lost in gaseous form or taken up by the plant, stored in litter, storage in soil, etc.). Depending on the leaching water quantity and soil type, a fraction of this available nitrogen is calculated to be leached as nitrate. Water available for leaching is estimated as Potential leaching = Precipitation + Irrigation – Evapotranspiration – Runoff, where evapotranspiration is estimated using the formula described in Thornthwaite 1948. The actual amount of water leached depends on the water retention capacity of the soil.

- Norg and NO_3- emissions to water occur due to erosive surface run-off. Please see section 3.4 below for a description of soil erosion modelling.

The nitrogen balance in the model is closed: Ninput = Noutput for the examined cultivation crop. If any cultivation processes are to yield a net nitrogen reduction or accumulation in the soil, this difference is balanced by additional/reduced external fertilizer demand. The nitrogen balance is calculated as net nitrogen surplus or deficit after accounting for leaching and mineralization. Therefore, the amount of N being fixed in humus in the long run is assumed constant. This adjustment addresses the long-term effects of cultivation systems without fertilizer application which tend to reduce the nutrient pool in soil, thereby reducing the growth potential of the site. Compared to a pure N-balance model, this approach allows the consideration of nutrient deficits in case of low N-fertilization. In the case of high N-fertilization (e.g. intensive farming systems), the models correspond with the total N-balance approach.

A specific feature of the agricultural model is its consideration of temporal differences in the leaching potential of nutrients. The cultivation period is divided into two phases, defined by the point in time where the nutrient uptake by the main crop would significantly reduce the availability (and therefore leaching potential) of nutrients in the soil (typically when at least 10% of the biomass of the final plant is established). The leaching potential is assessed for both phases separately. The temporal differentiation also allows considering the impact of cover crops (temporal storage and prevention of leaching of nutrients before main crop is established).

Besides nitrogen-based emissions to water and air, phosphorus emissions are taken into consideration in the model. Phosphorous emissions are typically dominated by surface runoff of soil to surface water, causing eutrophication of water bodies, thus they are directly related to soil erosion. Please see section 3.4 below for a description of soil erosion modelling.

Cattle manure and compost are considered to be waste products from another production system (animal keeping) and enter the system burden free (see also COTTON INC. 2012). Their contributions to nutrient availability are considered.

3.3 Carbon Modelling

Carbon-based emissions such as CH_4, CO, CO_2 are considered in foreground and background datasets. Background datasets include emissions resulting from production of fertilizer, pesticides, electricity, and diesel while foreground datasets contain emissions such as CO_2 due to combustion of fossil fuels by the tractor or irrigation pumps and application and decomposition of urea fertilizer in the soil.

Soil carbon is another potential source or sink of carbon dioxide. Soil carbon balances were used to describe any increase or decrease in soil organic carbon (SOC) content caused by a change in land management, with the implication that increased/decreased soil carbon (C) storage mitigates or increases climate change. A recent study by GATTINGER ET AL. 2012 has reviewed 74 studies from pairwise comparisons of organic vs. nonorganic farming systems to identify differences in soil organic carbon (SOC) accumulation. GATTINGER ET AL. 2012 conclude that organic farming has the potential to accumulate soil carbon. However, the authors also clearly communicate the many uncertainties in quantifying the amount of carbon stored. As an example, the assessed positive difference in Soil organic carbon concentrations and C sequestration rates between organic and nonorganic systems does not reveal whether this change goes along with a net carbon gain due to conversion from conventional to organic farming or whether it rather reflects a reduced carbon loss if compared with the nonorganic treatment (GATTINGER ET AL. 2012). Furthermore, the meta-analysis confirms that carbon sequestration follows sink saturation dynamics, i.e. that C sequestration rates were not constant and could approach zero if assessed over a longer time period. Such uncertainties led to the approach commonly practiced in LCAs of agricultural products to not consider soil carbon sequestration, also followed by Cotton Inc. 2012 and the present study.

Natural soils could also act as greenhouse gas sinks, related predominantly to the methane depression function of natural soils due to their oxidizing and microbial transformation of methane (SCHMÄDEKE 1998). Differences between cultivated and natural soils in their methane depression function were considered. Data for methane oxidation in cultivation systems were taken from various sources e.g. (SCHMÄDEKE 1998, LE MER AND ROGER 2001, POWLSON ET AL. 2011).

The biogenic CO_2 sequestered in the cotton fibre was directly accounted for in the inventory as an input or uptake of carbon dioxide, which was treated as a negative emission of carbon dioxide to air. However, the carbon uptake in the cotton fibre was not considered in impact assessments as it was only temporarily stored in the product and would be released at the End of Life of the product.

3.4 Soil data and soil erosion

The agricultural model uses data on soil texture to estimate the leaching potential. Where soil types are not specified in primary data collection, they are specified using the World Soil Database v 1.2 (IIASA 2012). As mentioned above, soil erosion is an important potential contributor to eutrophication. However, it is very difficult to generalize erosion rates and deposition rates, as they are highly dependent on regional conditions such as climate, relief, soil type, crop cultivated and vegetation. The default soil erosion rates are estimated based on USDA data on vulnerability to soil erosion (USDA 2003) and soil erosion rates reported by Wurbs and Steiniger (WURBS & STEINIGER 2011). For India, more specific erosion rates are reported by Kothyari (KOTHYARI 1996). It is assumed that 10% of the eroded soil accesses the waters, based on evaluation of different literature sources (FUCHS AND SCHWARZ 2007, Hillenbrand et al. 2005, HELBIG ET AL. 2009, NEARING ET AL. 2005), while the rest accumulates to colluviums on other surfaces and is assumed irrelevant in the life cycle assessment. The nutrient content of the soil entering surface water with soil erosion is assumed to be 0.05% for phosphor, 0.6% for nitrogen (organic bound) and 0.4% for nitrate – representing values from literature independent from soil management practices. A 90% reduction of soil erosion was assumed for farming, i.e. only 10% of the estimated default erosion rates (described above) were considered in this study.

3.5 Surface preparation

It includes use of machinery for surface preparation such as clearing, amount of burned biomass including emission of nitrogen, carbon and Sulphur depending on their content in the biomass and also to the amount that passes over to combustion gases. It also accounts for uncontrolled emissions of flue gases. Thus, the emission profile, for example, a slash-and-burn or the burning of straw after the harvest, could be calculated and inventoried.

3.6 Reference system

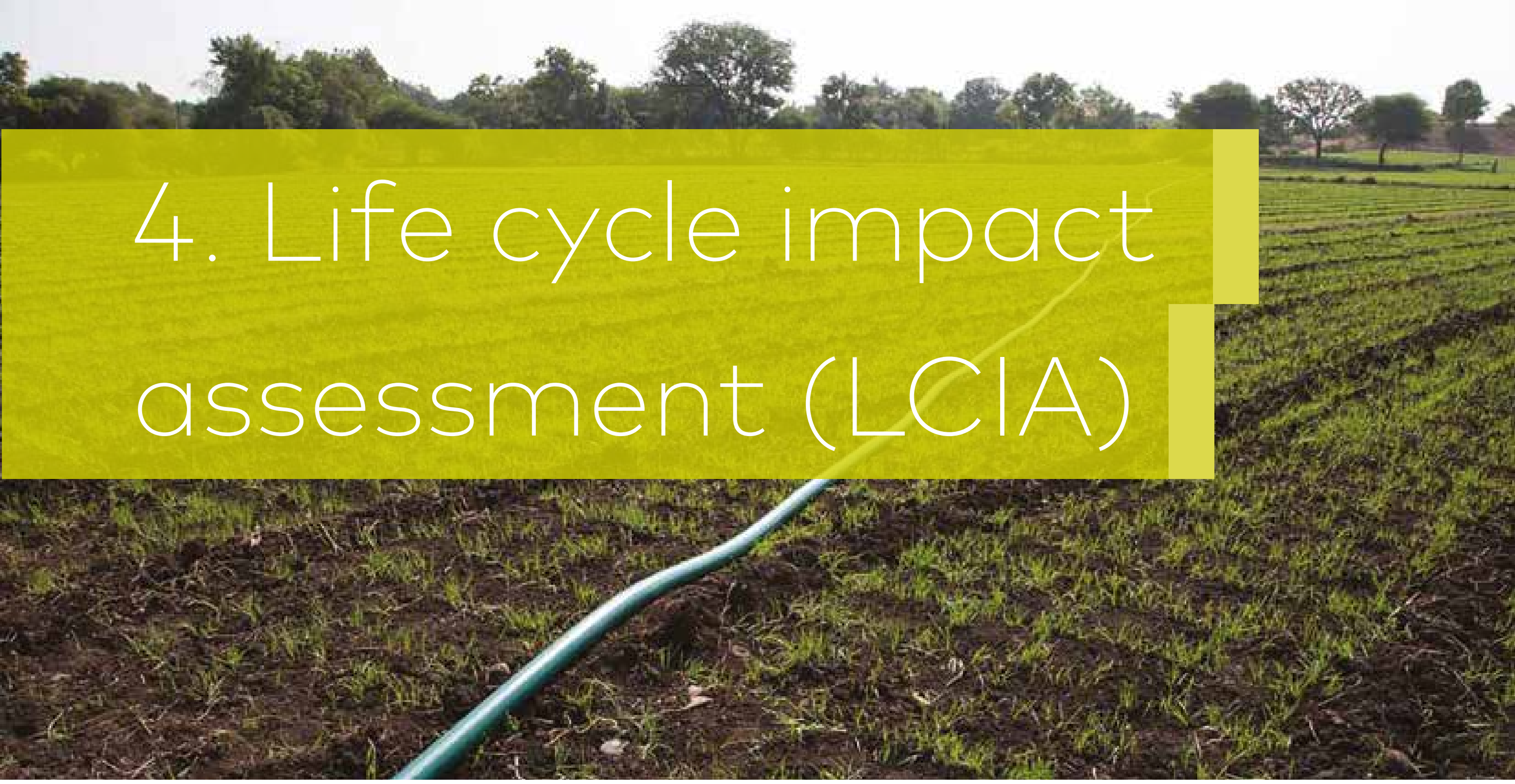
The reference system used in the model maps the surface behavior without use. It represents losses of nitrate to groundwater and gaseous nitrogen compounds from precipitation. These emissions occur independent of the land use and therefore cannot be assigned to the crop. Here it was assumed that the nitrogen balance was neutral for the reference system, as any entry of nitrogen with rainfall was re-emitted from the systems in various forms into ground water and air.

LCI data for energy and fuel production, auxiliaries and refinery products, transport and waste treatment were taken from GaBi software. These provided as secondary LCI data.

A data inventory which was used in for calculations in the software is given in section 8.4.

Assumptions made in the study are given in section in 8.2.

4. Life cycle impact assessment (LCIA)



4.1 Introduction to the impact assessment

The software model described above enables the calculation of various environmental impact categories. The impact categories describe potential effects of the production process on the environment. Environmental impact categories were calculated from material and energy flows. Elementary flows describe both the origin of resources from the environment as the basis for the manufacturing of the pre-products and generating energy, and emissions into the environment, which were caused by a product system.

As different resources and emissions were summed up per impact category the impacts were normalised to a specific emission and reported in "equivalents", e.g. greenhouse gas emissions were reported in kg CO_2 equivalent. This step requires the use of characterization factors, of which different were published and in use. In order to align with the Cotton Inc. study to the highest possible degree, it has been decided to follow the CML methodology published by the Institute of Environmental Sciences, University of Leiden. The CML characterization factors were widely used and respected within the LCA community. The most recently published list of characterization factors "CML 2001 – Jan. 2016" has been applied.[6]

A summary of the chosen impact categories and characterization models as well as reasons for selecting these impact categories is given below. Please refer to section 8.7 for detailed information.

Climate change was chosen as impact category as it is one of the most pressing environmental issues of our times led by a large public and institutional interest in the topic. The category indicator results were kg of CO_2 equivalent per functional unit. Please note that the carbon uptake in the cotton seed was not considered as it was only temporarily stored in the product and would be released at the End of Life of the product.

Acidification, causing e.g. acid rain, and eutrophication, also known as hypertrophication, were chosen because they were closely connected to air, soil, and water quality and were relevant and discussed environmental aspects of agricultural systems. The category indicator results were kg SO_2 (acidification) or phosphate (eutrophication) equivalent per functional unit.

Ozone could be created in the lower atmosphere in the presence of sunlight and nitrogen oxides (NO^x, a common pollutant) and volatile organic compounds (VOCs). Low-level ozone was associated with impacts as diverse as crop damage, damage to ecosystems, etc. The high atmospheric Ozone

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[6] The Product Environmental Footprint initiative of the European Commission - including its suggested methodologies, impact assessment methods and indicators - were drawing a lot of attention. The indicators which were recommended for a Product Environmental Footprint were under scientific discussion (FINKBEINER 2013) and were most likely due to changes within this initiative as the Product Environmental Footprint pilot phases were ongoing while this study was performed. The selection of LCIA methods of the Product Environmental Footprint were based on ILCD recommendations and took place in in 2010. Only methods in place in 2009 were considered. The calculation method for the indicator GWP is similar for CML and according to PEF recommendations. However, other impact assessments methods, other than CML could be applied with the existing models in a possible future update of the dataset.

was critical as it was a protective layer against the harmful UV light coming from the sun. To provide a wider perspective of environmental footprint of cotton cultivation systems, these two environmental indicators, i.e. photochemical ozone creation potential and ozone depletion potential, were analysed.

The importance of water use in agricultural systems was evident. This was why an environmental assessment of water use was specifically important in the assessment of agricultural products. In this study, methods and terminology as defined by the UNEP/SETAC working group on water and in the new ISO standard were used (Bayart et al. 2010, Pfister et al. 2009, ISO 14046). According to these publications, the following terms were used:

- **Water use**: use of water by human activity: Use includes, but was not limited to, any water withdrawal, water release or other human activities within the drainage basin impacting water flows and quality.
- **Water consumption**: water removed from, but not returned to the same drainage basin. Water consumption could be because of evaporation, transpiration, product integration or release into a different drainage basin or the sea. Evaporation from reservoirs was considered water consumption.
- **Surface water**: water in overland flow and storage, such as rivers and lakes, excluding seawater.
- **Groundwater**: water which was being held in, and could be recovered from, an underground formation.
- **Green water** refers to the precipitation on land that does not run off or recharges the groundwater but was stored in the soil or temporarily stays on top of the soil or vegetation. Eventually, this part of precipitation evaporates or transpires through plants. Green water could be made productive for crop growth.
- **Blue water** refers to water withdrawn from ground water or surface water bodies. The blue water inventory of a process includes all freshwater inputs but excludes rainwater.

Please refer to section 8.7 for details.

Total primary energy demand was chosen because of its relevance to energy and resource efficiency and its interconnection with climate change, which were all of public and institutional interest.

Two additional impact categories, eco-toxicity potential (ETP) and human toxicity potential (HTP) were included in the LCA. The UNEP SETAC USEtox® characterization model was used for both ETP and HTP assessment (Rosenbaum et al. 2008). Human effect factors relate to the quantity taken into the potential risk of cancerous and non-cancerous effects expressing cases per kg of chemical emitted. The final unit was comparative toxic units (CTUh). Effect factors for freshwater ecosystems were based on species-specific data of concentration at which 50% of a population displays an effect, expressed as an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of a chemical emitted (PAF m^3-day/ kg). The final unit was comparative toxic units (CTUe).

It should be noted that the precision of the current USEtox® characterization factors was less robust than for all other impact categories. For this reason, the USEtox® assessment conducted in this study should only be considered as a screening assessment. For the same reason, no values were given for the USEtox® impact category in the recent LCA of cotton fibre and fabric by Cotton Inc. (Cotton Inc. 2012).

In the following table the environmental impacts considered in the study are summarized:

Table 4 Environmental indicators for the assessment

	Indicators	Unit	Reference
Environmental Impact Categories	Climate Change	[kg CO_2 eq]	Guinée et al. 2001
	Acidification Potential (AP)	[kg SO_2 eq]	Guinée et al. 2001
	Eutrophication Potential (EP)	[kg Phosphate eq]	Guinée et al. 2001
	Ozone Depletion Potential (ODP)	[kg R11 eq]	Guinée et al. 2001
	Photochemical Ozone Creation Potential (POCP)	[kg ethene eq]	Guinée et al. 2002
Additional Environmental Indicators	Water consumption (with and without rainwater)	[m^3]	Bayart et al. 2010
	Total Primary Energy Demand	[MJ net calorific]	N/A - Inventory level indicator
Screening Assessment of toxicity potential (USEtox)	Human Toxicity Potential (HTP)	[CTUh]	Rosenbaum et al. 2008
	Eco-toxicity Potential (ETP)	[CTUe]	Rosenbaum et al. 2008

It should be noted that the term potential in the characterisation of environmental impacts indicated that the impacts could occur if the emitted molecules would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. LCIA results were therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

4.2 Categories of contribution

Field – Emissions released from metabolic processes taking place in the soil being released into air, water and soil, and emissions to water from soil erosion as well as the impact of (see sections 3.1-3.6).

Fertilizer production – Includes resource use and emissions associated with the production of fertilizer (as described in section 3.1, organic fertilizer was assumed to enter the system burden free; impacts associated with this category were mineral fertilizer such as rock phosphate that were used in organic farming systems).

Pesticide – Includes resource use and emissions associated with the production of pesticides.

Tractor operations – Includes the resource use and emissions associated with the running of tractors used for cultivation. This includes the production and combustion of fuels (diesel).

Energy used in Irrigation – This category refers to energy (diesel or electricity) used to run the irrigation pumps.

Transport – Includes the production emissions of fuels and tail pipe emissions of trucks used for raw material transportation.

Reference System – it included the emissions happening in the non-cultivated land area of the farm.

4.3 Results of Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA)

This section is divided into three sub-sections for each type of cotton cultivation systems.

4.3.1 Better Cotton

Consolidated average data for Better Cotton cultivation are given in Table 5.

Along with the chemicals inputs Better Cotton cultivators also use organic inputs described in Table 29.

Table 5 Consolidated data used for LCIA analysis of Better Cotton Cultivation

Parameter	Unit	Types of cotton farm Better cotton
Yield (Seed Cotton)	kg/ha	1888
Organic Fertilizer Input		
Farm yard manure (FYM)	kg/ha	0
Nitrogen content of FYM	% in fresh matter	0.4
Compost	kg/ha	134
Nitrogen content of compost	% in fresh matter	0.7
Cow dung	kg/ha	1656
Nitrogen content of cow dung	% in fresh matter	0.9
Chemical Fertilizer Input		
DAP	kg/ha	132
Urea	kg/ha	125
Potash	kg/ha	122
Pest and weed control		
Confidore (active ingredient Imidacloprid)	kg/ha	0.19*
Mono (active ingredient Monocrotophos)	kg/ha	0.01*
Acephate (active ingredient Acephate)	kg/ha	0.14*
Profeno (active ingredient Profenofos)	kg/ha	0.17*
Total pesticide		0.51
Machinery use		
Diesel demand (Tractor, not incl. irrigation)	l/ha	53.6
Irrigation		
Irrigation water use	m^3/ha	688

*active ingredient amount

The cropping calendar in Figure 5 highlights the activities along with the timelines in Better Cotton Cultivation.

Figure 5 Cropping calendar for Better Cotton

Cropping calendar												
Activities	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Ploughing				◨	◧							
Pre-sowing Irrigation					◧							
Plant protection Application					◨	◧						
Sowing					◨	◧						
Fertilization					◨	◧	▨	◨	◧			
Irrigation				◨	▨	▨	▨					
Hoeing/ Mechanical Weeding					◨	▨	▨	▨	◧			
Plant protection Application							▨	▨	▨	◧		
Picking										◨	▨	▨

Description of farming practices in Better Cotton Cultivation

Activity	Description
Soil preparation	Soil preparation was done after every 2 or 3 years. It mainly included ploughing (~80% famers) and tillage (~20% farmers).
Selection of cotton seeds	Bt cotton seeds which yield high density of cotton as well as control the growth period was used. Names of the seeds used by Better Cotton cultivators were Jaadoo-659, Raja, Bhakti, kalash, etc.
Fertilizer inputs	Di-ammonium Phosphate, Urea, Super phosphate and Super potash were commonly used sources of NPK in the Better Cotton Cultivation.
Pesticide inputs	Lancer Gold, Ulala, Confidore, Profano, Acefate, Polo, Mono, Panama and so on were the pesticides used by Better Cotton cultivators along with organic inputs. The amount of application of these pesticides varied as per the dosages. Application of the pesticide was in dosages of 250-500 ml @ pump of 16 litres.
Organic inputs	Cow dung and Compost were the major ingredients used by farmers as organic inputs. Other home-made organic inputs, as described in 8.5 , were applied in small quantities.
Type of Irrigation	Most of the farmers (~95%) used ground water for irrigation by the means of bore-well and well. The average depths of bore-well and well were 90-150 meters and 9-15 meters, respectively. Narmada river canals were available in some areas. Flood irrigation was adopted by majority of the farmers (~82%). Few farmers reported drip irrigation (~18%).
Intercropping	About ~65% of farmers planted gram along with cotton, but the yield of gram was less than 100 kg per hectare.
Crop rotation	Wheat was cultivated in rotation with cotton, but it was dependent on the availability of water.
Plant protection measures	Some farmers (~34%) reported making use of plant protection measures such as dams/ bunds against soil erosion, intercropping, agroforestry.

The LCIA results of Better Cotton for 1 ton of seed cotton are given below in Table 6.

Table 6 LCIA results of Better Cotton for 1 metric ton of seed cotton at farm gate

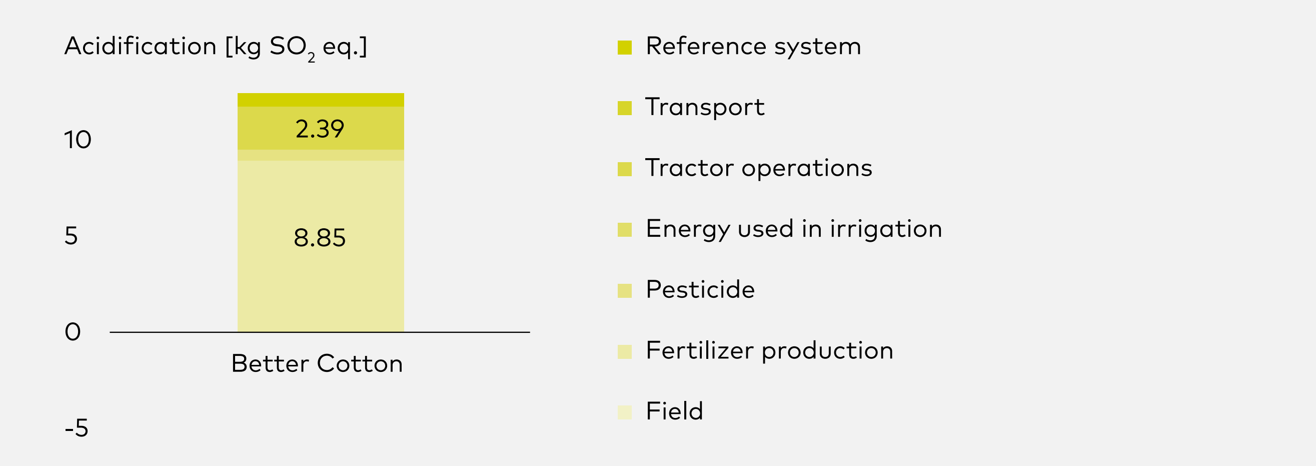
Impact indicator	Unit	Better cotton	Interpretation
Acidification	kg SO_2 eq.	12.41	71% impact was from field emissions of ammonia and nitrogen monoxide.
Eutrophication	kg phosphate eq.	1.66	Ammonia emissions occurring in field lead to maximum impact but there was credit from reference system which brought down the impact.
Climate Change	kg CO_2 eq.	688.00	The N_2O emissions occurring in the field were majorly contributing to climate change followed by CO_2 emissions in production of electricity consumed in irrigation.
Ozone Depletion	kg R11 eq.	7.18E-09	Refrigerants used in production of energy and raw materials were the major contributors to this impact.
Photochemical Ozone Creation	kg ethene eq.	0.17	Emissions of Sulphur dioxide and nitrogen oxides led to impact from energy used in irrigation. Reference system also added a net positive POCP impact, which came from emissions of NO and methane. There was a credit seen in Field due to NO emissions this was due to negative characterization factor of NO in CML.
Total Primary Energy Demand (net cal. value)	MJ	2.56E+04	77% was the solar energy consumed by the plant during the cultivation period. About 6% was consumed in fertilizer production, 6% in production of energy (grid electricity) used in irrigation.
Blue Water Consumption	kg	3.67E+05	Major source of water in field was mainly ground water. Water was drawn using electric pumps from bore wells. Rain water constituted 79% of the water wells and demand when total water demand was assessed.
Blue Water Consumption (including rain water)	kg	1.75E+06	
Eco-toxicity	CTUe	1.17E+04	Maximum impact was from pesticide emissions to freshwater.
Human Toxicity	CTUh	3.13E-07	Pesticide emissions to water had 99% contribution to the human toxicity impact.

Acidification Potential

Better Cotton cultivation resulted in an acidification potential (AP) of 12.41 kg SO_2 equivalent for 1 metric ton of seed cotton at farm gate. Emissions occurring in field contributed the most, followed by energy used in irrigation. While CO_2 emissions contribute to climate change, the parallel releases of SO_2 and nitrogen oxides increase AP. In addition to mentioned gases, ammonia was an important contributor to acidification with an AP 1.6 times higher than SO_2.

Figure 6 shows the contribution of various components to the acidification potential of Better Cotton cultivation.

Figure 6 Acidification Potential of Better Cotton for 1 metric ton of seed cotton at farm gate



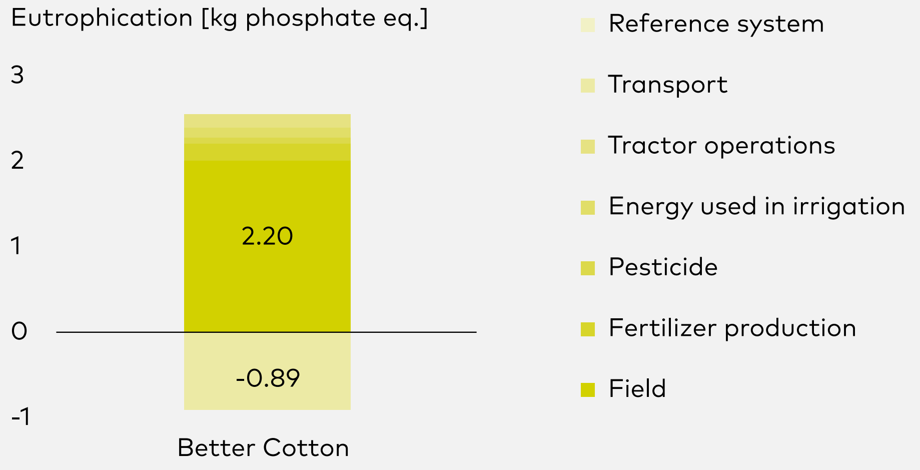
Emission of ammonia (depending on the amount of nitrogen applied) in the field dominated the acidification impact followed by nitrogen oxides and Sulphur dioxide emissions occurred during the production of energy and raw materials. Use of fossil based-fuels led to emissions of Sulphur dioxide.

Eutrophication Potential

Eutrophication in agriculture could be significantly influenced by soil erosion. Through soil erosion, nutrients get removed from the cultivated system via water and soil and lead to the fertilization of neighbouring water bodies and soil systems. EP was measured in phosphate equivalent and was influenced mainly by P- and N-containing compounds. Better Cotton cultivation resulted in an Eutrophication potential (EP) of 1.66 kg phosphate equivalent for 1 metric ton of seed cotton at farm gate. Figure 7 shows contribution of various components to Eutrophication potential of Better Cotton Cultivation.

Figure 7 depicts that EP was dominated by ammonia and Nitrous oxide emissions occurring in field, while all other processes of the production chain combined contribute less than 10%. The application of fertilizers led to excess ammonia emissions. The reference system, which maps the surface behavior without use, represented losses of nitrate to groundwater and gaseous nitrogen compounds from precipitation. These emissions occurred independent from the land use and therefore cannot be assigned to the crop. This was accounted as a credit to the impact and subtracted from the total EP.

Figure 7 Eutrophication potential of Better Cotton for 1 metric ton of seed cotton at farm gate



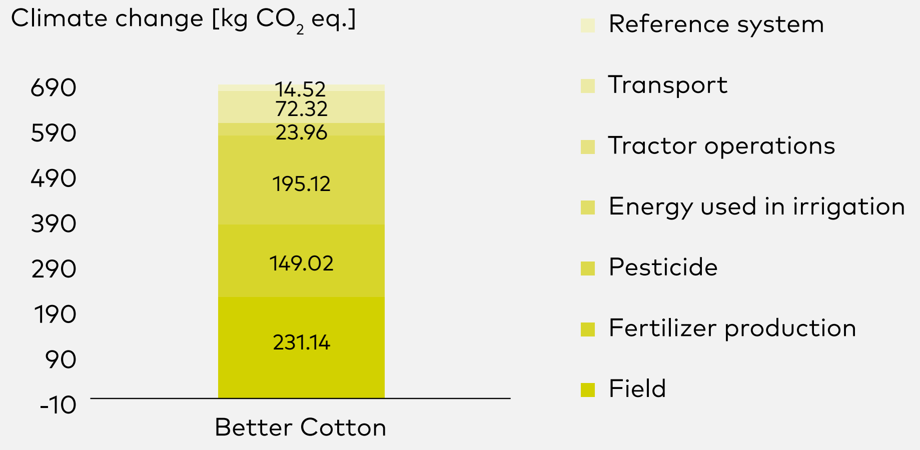
Climate change
Climate Change of Better Cotton cultivation for 1 metric ton of seed cotton at farm gate was 688.00 kg CO_2 equivalent. Figure 8 gives results of climate change impact of Better Cotton cultivation.

As shown in Figure 8, emissions occurring in the field dominated this impact category with over 33% share. Field emissions refer to gases emitted from soils due to agricultural activity. Essentially, these emissions derive from microbial nutrient transformation processes in the soil. As a result of such transformation processes, a fraction of the available total nitrogen becomes inorganic nitrous oxide, also known as laughing gas, with a global warming potential almost 300 times higher than carbon dioxide. This gas was responsible for the largest share of climate change (greenhouses gases) within field emissions.

The contributions in the other aspects of cotton cultivation largely depended on the fossil fuel combustion in each of the processes.

Please note that the results shown here do not account for the (temporal) uptake of CO_2 in the product. As cotton was considered as a short-lived consumer good, it was assumed this carbon dioxide would get released later at the end-of-life in the product, so that it was only temporarily stored. This was why the carbon uptake was not considered in the impact assessment in this study. If it was considered, the climate change impact for organic cotton would be negative. The climate change impact method used in this study refers to a time frame of 100 years (Guinée et al. 2001).

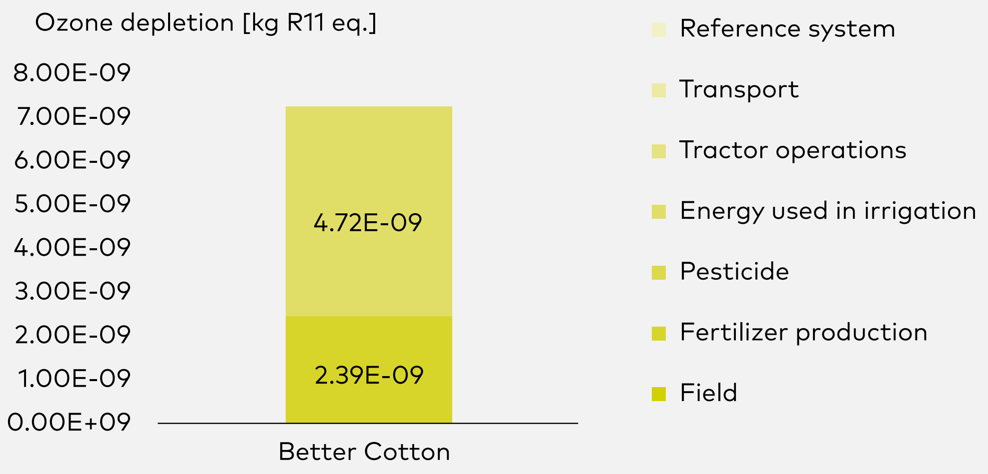
Figure 8 Climate Change of Better Cotton cultivation for 1 metric ton of seed cotton at farm gate



Ozone Depletion Potential
Better Cotton cultivation resulted in an Ozone Depletion potential (ODP) of 7.18E-09 kg R11 equivalent for 1 metric ton of seed cotton at farm gate. Figure 9 gives results of Ozone Depletion potential of Better Cotton cultivation.

Figure 9 shows that ODP impact was dominated by energy used in irrigation followed by fertilizer production while all other processes of the production chain combined contribute less than 1%. This was mainly due to use of refrigerants and coolants in the production process.

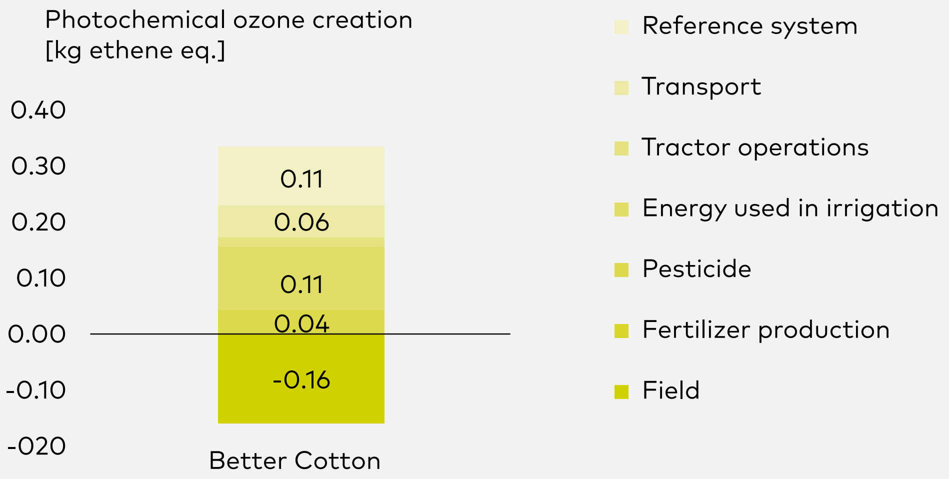
Figure 9 Ozone Depletion Potential of Better Cotton for 1 metric ton of seed cotton at farm gate



Photochemical Ozone Creation Potential
Better Cotton cultivation resulted in Photochemical Ozone Creation potential (POCP) of 0.17 kg ethene equivalent for 1 metric ton of seed cotton at farm gate. Figure 10 gives results of Photochemical Ozone Creation potential of Better Cotton cultivation.

Figure 10 shows that POCP was dominated by energy used in irrigation and reference system followed by fertilizer production while all other processes of the production chain combined contribute less than 1%. The emissions of nitrogen monoxide had a net positive impact in POCP due to negative characterization factor in CML. This was also why emission of nitrogen monoxide in field led to a credit. Whereas impact of carbon monoxide, nitrogen oxides, Sulphur dioxide and methane was observed in tractor operations, Irrigation, fertilizer production and transport of materials.

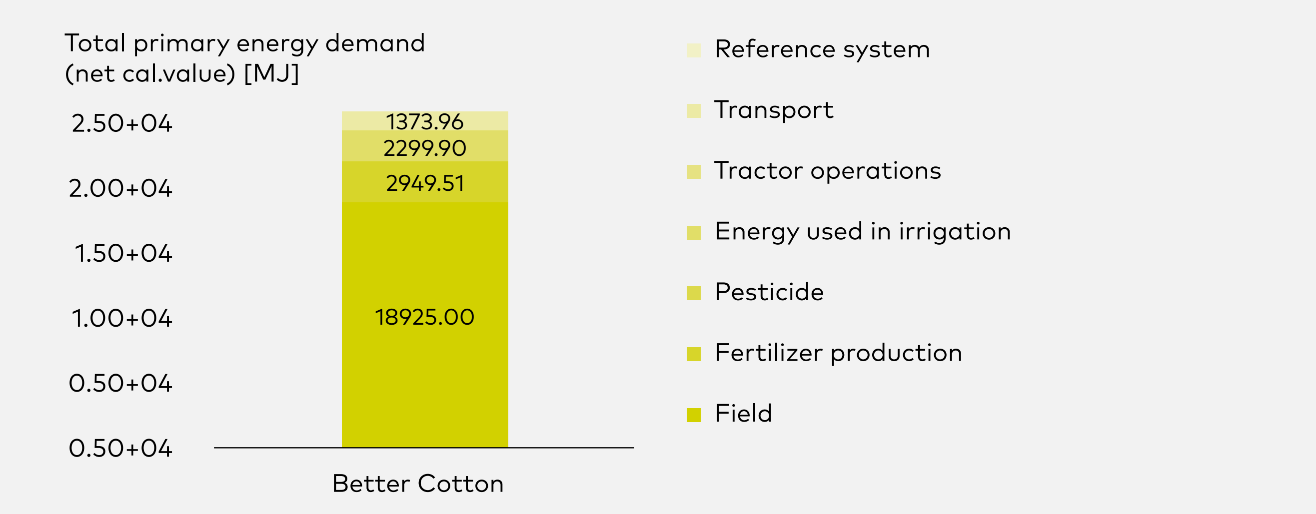
Figure 10 Photochemical Ozone Creation potential of Better Cotton for 1 metric ton of seed cotton at farm gate



Total Primary Energy Demand (including non-renewable and renewable PED)
Total Primary Energy Demand (PED) of Better Cotton cultivation for 1-ton seed cotton at farm gate was 2.56E+04 MJ. Total Primary Energy Demand (PED) was an indicator of the dependence on fossil resources as well as renewable resources such as solar energy. Figure 11 gives the contribution of various components to primary energy.

Electricity was used in running irrigation pumps, and diesel was the fuel used for tractors which had a higher energy-to-emission ratio than coal. The non-renewable energy demand was 22%, which was found in the production of energy used for irrigation, raw material production and diesel used in transport. The renewable energy demand in the field was covered by solar energy from the sun. The solar energy was calculated based on type of crop, plantation period, etc.

Figure 11 Total Primary energy demand (PED) of Better Cotton for 1 metric ton of seed cotton at farm gate

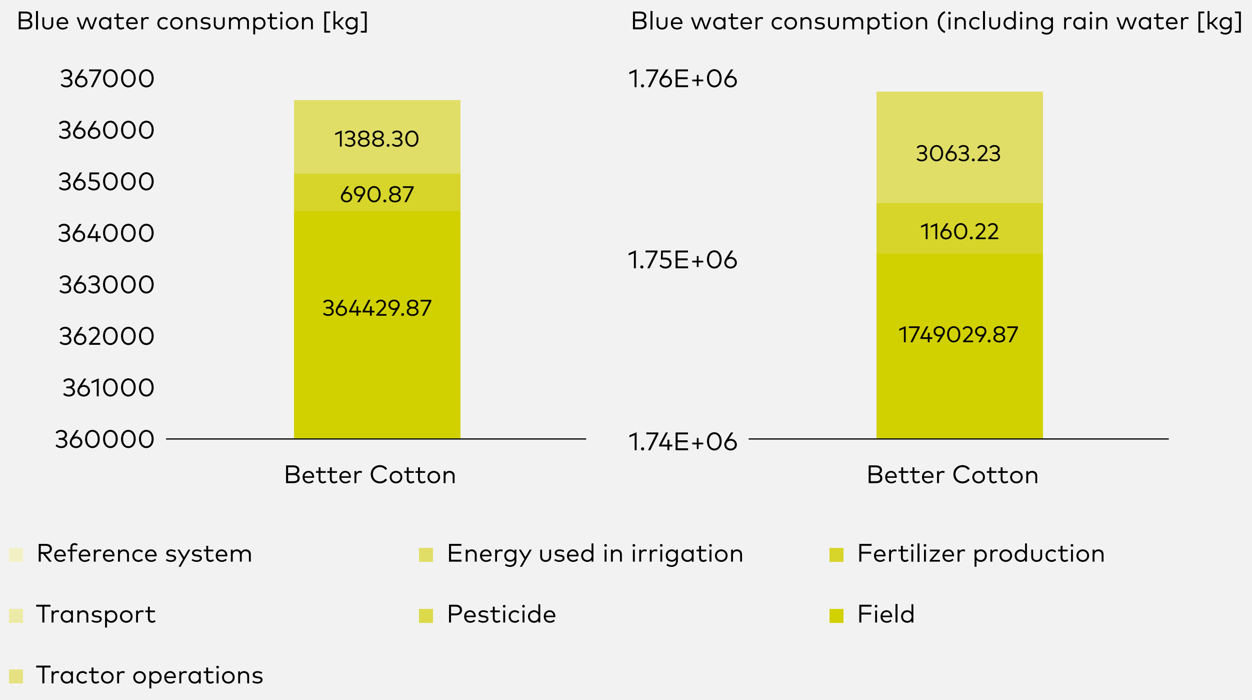


Water consumption

The total blue water consumption without rain water and including rain water of Better Cotton cultivation for 1 metric ton of seed cotton at farm gate was 3.67E+05 kg and 1.75E+06 kg, respectively. Figure 12 gives the contribution of various components to Blue Water consumption with and without rainwater of Better Cotton.

LCA accounts for water used in field by crops as well as the water consumption in production of energy and raw materials used in cultivation. Figure 12 shows that maximum water demand both with and without rainwater was majorly due the crop water requirement. If rain water was included, then it had a 79% share whereas in blue water consumption without rainwater ground water had a 70% share while river water had a 30% share.

Figure 12 Blue Water consumption with and without rainwater of Better Cotton for 1 metric ton of seed cotton at farm gate



Toxicity potential

Assessment of the toxicological effects of a chemical emitted into the environment implies a cause–effect chain that links emissions to impacts through three steps: environmental fate, exposure, and effects. In this LCA, environmental fate and exposure were considered by the application of the emission factors to soil, plant, water, and air, while the environmental effects were considered in the United Nations Environmental Program (UNEP) – Society of Environmental Toxicology and Chemistry (SETAC) toxicity model, USEtox™.

The focus in using the USEtox methodology in LCAs of agricultural systems laid on pesticide use, as pesticides were known to be the major contributor to toxicity in agricultural products (see also COTTON INC. 2012, BERTHOUD ET AL 2011).

The total Eco toxicity and Human toxicity of Better Cotton for 1 metric ton of seed cotton was 1.17E+04 CTUe and 3.13E-07 CTUh, respectively. Figure 13 gives the contribution of various components to USEtox results of Better Cotton.

Pesticide emissions occurring in field contribute nearly 99% of the toxicity impact. Eco-toxicity had 99% contribution from Profenofos emissions. In Human toxicity impact, nearly 99% was contributed by pesticide emissions out of which Acephate pesticide had a higher contribution of 82.28% followed by Profenofos pesticide contributing to 14.58%. The impact category "toxicity" was included to provide information for possible further studies or comparisons and should not be considered as the only basis to decide the precise pesticide amount and type for the cotton cultivation. Conclusions may be drawn on the basis of laboratory test results which should be included in future analysis.

Figure 13 USEtox results of Better Cotton for 1 metric ton of seed cotton at farm gate

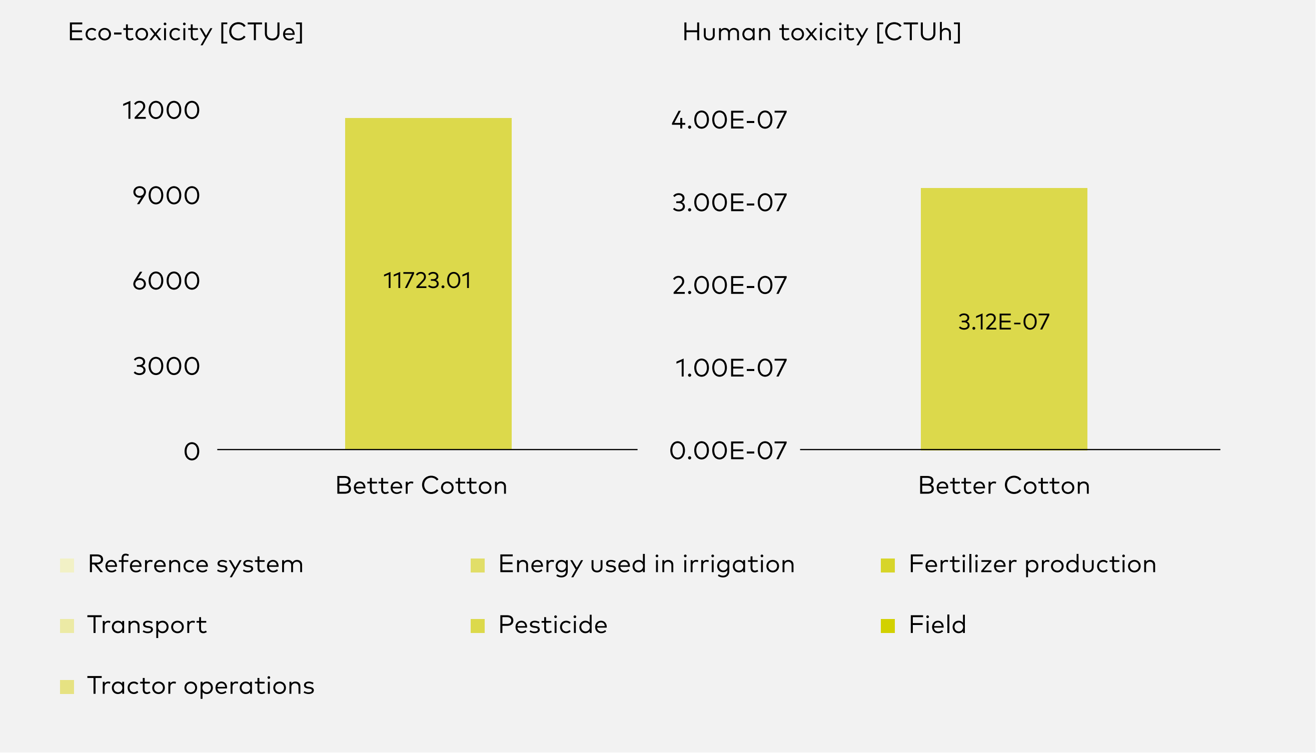


Table 7 Significant contributors to various impacts of Better Cotton for 1 metric ton of seed cotton at farm gate

Impact Category	Impact Value	Significant impact contributors			
		Activity wise		Activity wise	
Acidification [kg SO_2 eq.]	12.41	71.24%	Field	Ammonia	68.93%
				Nitrogen monoxide	2.30%
		4.49%	Fertilizer production	Ammonia	0.32%
				Nitrogen oxides	0.92%
				Sulphur dioxide	3.19%
		19.22%	Energy used in Irrigation	Hydrogen chloride	0.20%
				Hydrogen fluoride	0.07%
				Nitrogen oxides	2.97%
				Sulphur dioxide	15.95%
		5.82%	Tractor operations	Nitrogen oxides	5.13%
				Sulphur dioxide	0.68%
		-1.27%	Reference System	Nitrogen monoxide	-1.27%
Eutrophication [kg phosphate eq.]	1.66	134.81%	Field	Ammonia	119.82%
				Nitrogen monoxide	4.82%
				Nitrous oxide (laughing gas)	12.48%
				Nitrate	-17.24%
				Nitrogen organic bound	9.48%
				Phosphate	5.45%
		4.25%	Fertilizer production	Ammonia	1.34%
				Nitrogen oxides	1.91%
				Nitrate	0.09%
		6.60%	Energy used in Irrigation	Nitrogen oxides	6.13%
		10.63%	Tractor operations	Nitrogen oxides	10.59%
		-57.04%	Reference System	Nitrogen monoxide	-2.65%
				Nitrous oxide (laughing gas)	-4.37%
				Nitrate	-49.89%
				Phosphate	-0.12%
Climate Change [kg CO_2 eq.]	688.00	33.37%	Field	Carbon dioxide	7.06%
				Nitrous oxide (laughing gas)	27.82%
				Methane	-1.51%
		21.57%	Fertilizer production	Carbon dioxide	17.86%
				Nitrous oxide (laughing gas)	0.26%
				Methane	3.46%
		0.59%	Pesticide	Carbon dioxide	0.54%
				Nitrous oxide (laughing gas)	0.01%
				Methane	0.04%
		28.36%	Energy used in Irrigation	Carbon dioxide	27.20%
				Nitrous oxide (laughing gas)	0.13%
				Methane	1.04%
		1.53%	Transport	Carbon dioxide	1.53%
		12.46%	Tractor operations	Carbon dioxide	12.00%
		2.11%	Reference System	Nitrous oxide (laughing gas)	-9.75%
				Methane	11.86%

Impact Category	Impact Value	Significant impact contributors			
		Activity wise		Activity wise	
Ozone Depletion [kg R11 eq.]	7.18E-09	33.31%	Fertilizer production	Refrigerant	32.55%
		65.74%	Energy used in Irrigation	Refrigerant	65.36%
Photochemical Ozone Creation [kg ethene eq.]	0.17	-98.1%	Field	Nitrogen monoxide	-96.76%
		23.1%	Fertilizer production	Carbon monoxide	1.23%
				Nitrogen oxides	3.86%
				Sulphur dioxide	9.55%
				Group NMVOC to air	5.54%
				Methane	3.06%
		67.0%	Energy used in Irrigation	Nitrogen oxides	12.43%
				Sulphur dioxide	47.69%
		2.8%	Transport	Nitrogen oxides	1.40%
				Sulphur dioxide	0.26%
				Group NMVOC to air	0.78%
		40.7%	Tractor operations	Carbon monoxide	5.59%
				Nitrogen oxides	21.46%
				Sulphur dioxide	2.05%
				Group NMVOC to air	11.24%
		63.8%	Reference System	Nitrogen monoxide	53.24%
				Methane	10.53%
Total Primary Energy Demand [MJ]	2.56E+04	73.86%	Field	Primary energy from solar energy	73.86%
		11.47%	Fertilizer production	Crude oil (resource)	2.32%
				Natural gas (resource)	6.62%
		8.98%	Energy used in Irrigation	Hard coal (resource)	5.42%
				Lignite (resource)	1.34%
		4.78%	Tractor operations	Crude oil (resource)	4.43%
Blue Water Consumption [kg]	3.67E+05	99.40%	Field	Ground water	69.6%
				River water	29.8%
Blue Water Consumption (including rain water) [kg]	1.75E+06	99.75%	Field	Ground water	14.55%
				River water	6.24%
				Rain water	78.97%
Eco-toxicity [CTUe]	1.17E+04	99.99%	Field	Profenofos	99.90%
Human Toxicity [CTUh]	3.13E-07	99.99%	Field	Acephate	82.28%
				Profenofos	14.58%

4.3.2 Conventional Cotton

Consolidated average data for conventional cotton cultivation are given in Table 8.

Table 8 Consolidated data used for LCIA analysis of conventional cotton cultivation

Parameter	Unit	Types of cotton farm Conventional cotton
Yield (Seed Cotton)	kg/ha	1938
Organic Fertilizer Input		
Farm yard manure (FYM)	kg/ha	0
Nitrogen content of FYM	% in fresh matter	0.4
Compost	kg/ha	257
Nitrogen content of compost	% in fresh matter	0.7
Cow dung	kg/ha	2397
Nitrogen content of cow dung	% in fresh matter	0.9
Chemical Fertilizer Input		
DAP	kg/ha	136
Urea	kg/ha	137
Potash	kg/ha	117
Pest and weed control		
Confidore (active ingredient Imidacloprid)	kg/ha	0.210*
Mono (active ingredient Monocrotophos)	kg/ha	0.085*
Acephate (active ingredient Acephate)	kg/ha	0.995*
Profeno (active ingredient Profenofos)	kg/ha	0.144*
Total pesticide		1.43
Machinery use		
Diesel demand (Tractor, not incl. irrigation)	l/ha	51
Irrigation		
Irrigation water use	m^3/ha	663

*active ingredient amount

The cropping calendar in Figure 14 highlights the activities along with the timelines in conventional cotton cultivation.

Figure 14 Cropping calendar for conventional cotton

Cropping calendar

Activities	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Ploughing				◨	◧							
Pre-sowing Irrigation					◧							
Plant protection Application					◨	◧						
Sowing					◨	◧						
Fertilization					◨	◧	▨	◨	◧			
Irrigation				◨	▨	▨	▨					
Hoeing/ Mechanical Weeding					◨	▨	▨	▨	◧			
Plant protection Application							▨	▨	▨	◧		
Picking										▨	▨	▨

Description of farming practices in conventional cotton cultivation

Activity	Description
Soil preparation	Soil preparation was done after every 2-3 years. It mainly included ploughing (~85% famers) and tillage (~15% farmers).
Selection of cotton seeds	Only Bt cotton variety was cultivated in the region.
Fertilizer inputs	Di-ammonium Phosphate, Urea, Super phosphate and Super potash were commonly used sources of NPK in the conventional cotton cultivation.
Pesticide inputs	Lancer Gold, Ulala, Confidore, Profano, Acefate, Polo, Mono, Panama and so on were the pesticides used by conventional cotton cultivators along with some organic inputs.
Organic inputs	Cow dung and Compost were the major ingredients used by farmers. Other home-made organic inputs, as described in 8.6 , were applied in small quantities by some farmers.
Type of Irrigation	Most of the farmers (~95%) used ground water for irrigation by the means of bore-well and well. The average depths of bore-well and well were 90-150 meters and 9-15 meters, respectively. Narmada river canals were available in some areas. Flood irrigation was adopted by majority of the farmers (~90%). Few farmers reported drip irrigation (~10%).
Intercropping	No intercropping was reported by conventional cotton cultivators.
Crop rotation	Wheat and gram were cultivated in rotation with cotton, but it was dependent on the availability of water.
Plant protection measures	Many farmers reported planting of neem around the edges as crop protection measure.

The LCIA results of conventional cotton cultivation for 1 ton of seed cotton are given below in Table 9.

Table 9 LCIA results of conventional cotton for 1 metric ton of seed cotton at farm gate

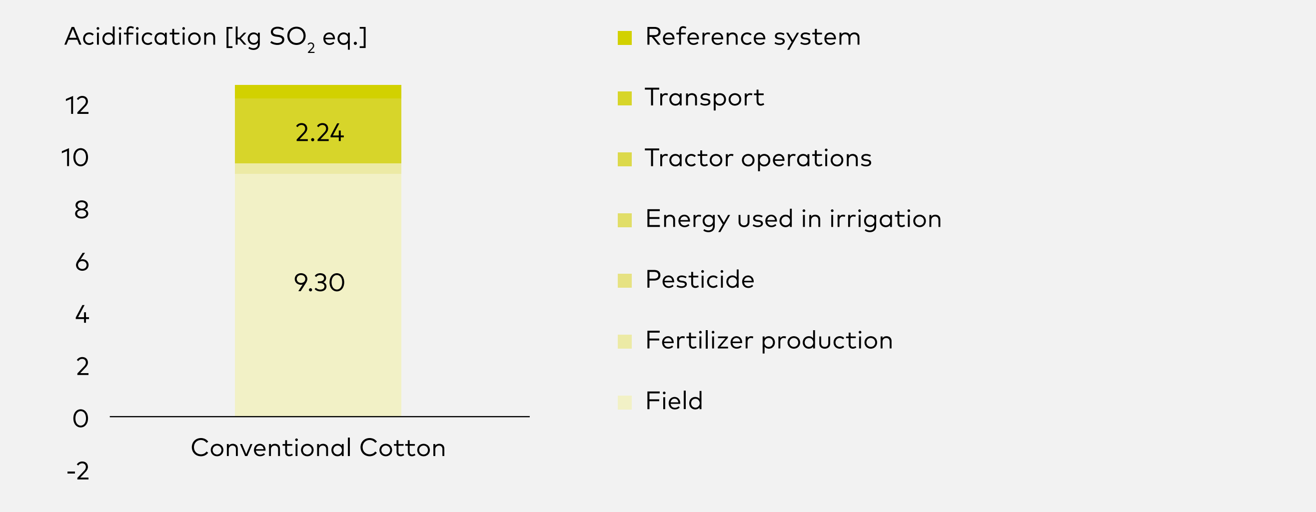
Impact indicator	Unit	Conventional cotton	Interpretation
Acidification	kg SO_2 eq.	12.68	73% of the impact was from the ammonia emissions happening in the field
Eutrophication	kg phosphate	1.92	Ammonia emissions occurring in field dominated the impact.
Climate Change	kg CO_2 eq.	680.20	The N_2O emissions occurring in the field were majorly contributing to climate change followed by CO_2 emissions in production of electricity consumed in irrigation.
Ozone Depletion	kg R11 eq.	6.90E-09	Refrigerants used in production of energy and raw materials were the major contributors to this impact.
Photochemical	kg ethene eq.	0.15	Emissions of Sulphur dioxide and nitrogen oxides led to impact from energy used in irrigation. Reference system also added a net positive POCP impact, which came from emissions of NO and methane. There was a credit seen in field due to NO emissions this was due to negative characterization factor of NO in CML.
Total Primary Energy Demand (net cal. value)	MJ	2.55E+04	74% was the solar energy consumed by the plant during the cultivation period. About 6% was consumed in fertilizer production, 6% in production of energy (grid electricity) used in irrigation.
Blue Water Consumption	kg	3.44E+05	Major source of water in field was mainly ground water. Other water demand was seen in the production of electricity used as energy in irrigation. 79% of the water requirement of the cultivation was achieved by rainwater consumption.
Blue Water Consumption (including rain water)	kg	1.71E+06	
Eco-toxicity	CTUe	9.00E+03	Maximum impact was from pesticide emissions to freshwater.
Human Toxicity	CTUh	1.82E-06	Pesticide emissions to water had 99% contribution to the human toxicity impact.

Acidification Potential

Conventional cotton cultivation resulted in an acidification potential (AP) of 12.68 kg SO_2 equivalent for 1 metric ton of seed cotton at farm gate. Figure 15 gives the contribution of various components to acidification potential of conventional cotton.

Emission of ammonia (depending on of the amount of nitrogen applied) in the field dominated the acidification impact. The nitrogen oxides and Sulphur dioxide emissions occurring during the production of energy and raw materials added to the acidification impact. Sulphur dioxide emissions depend on the type of fuel used, thus use of fossil-based fuels led to emissions of Sulphur.

Figure 15 Acidification potential of conventional cotton for 1 metric ton of seed cotton at farm gate



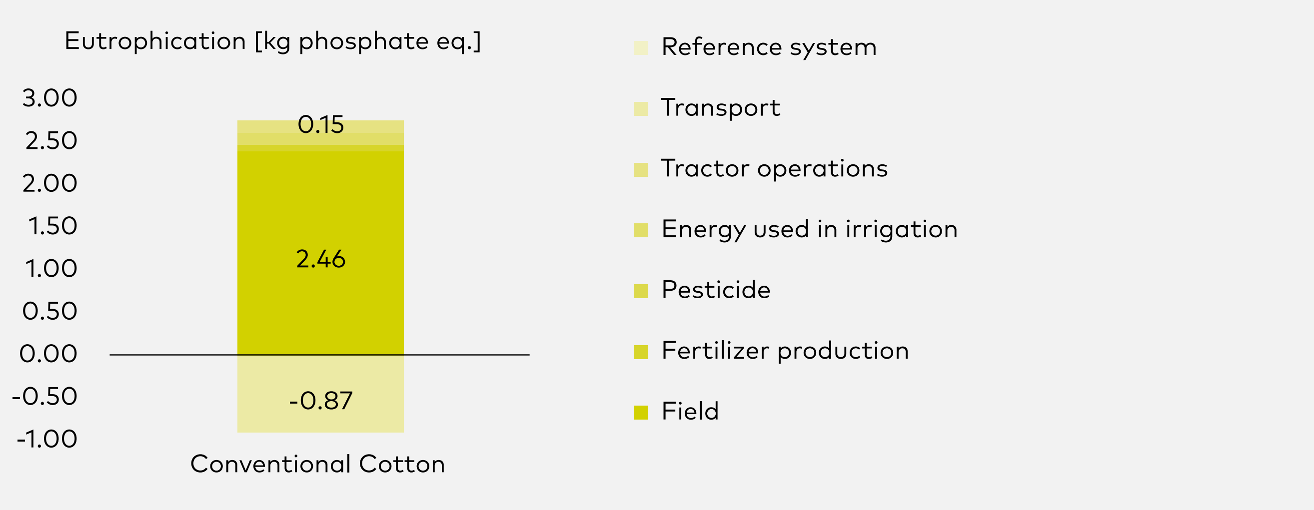
Eutrophication Potential

Conventional cotton cultivation resulted in an Eutrophication Potential (EP) of 1.92 kg phosphate equivalent for 1 metric ton of seed cotton at farm gate.

Figure 16 shows that EP was dominated by field emissions (88%), while all other processes of the production chain combined contributed less than 10%.

The main impact on total EP comes from field emissions of ammonia, resulting from the application of fertilizers. The reference system used to map the surface behavior without use, accounts for losses of nitrate to groundwater and gaseous nitrogen compounds from precipitation. These emissions occur independent from the land use and therefore cannot be assigned to the crop. Therefore, they were reported as a credit to the impact.

Figure 16 Eutrophication potential of conventional cotton for 1 metric ton of seed cotton at farm gate



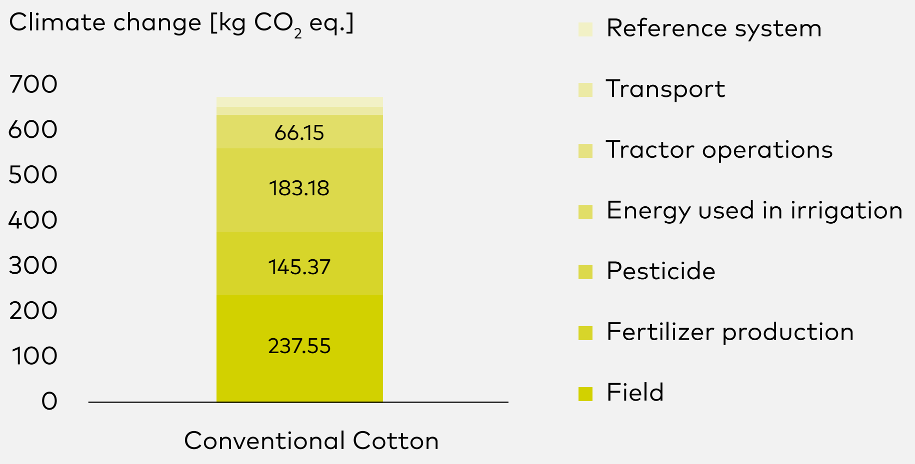
Global Warming Potential – Climate change
The climate change impact of conventional cotton for 1 metric ton of seed cotton was 680.20 kg CO_2 equivalent. Figure 17 gives results of climate change impact of conventional cotton.

As shown in Figure 17, field emissions dominated this impact category with over 35% share. Field emissions refer to gases emitted from soils due to agricultural activity. Essentially, these emissions derived from microbial nutrient transformation processes in the soil. As a result of such transformation processes, a fraction of the available total nitrogen becomes inorganic nitrous oxide, also known as laughing gas. The global warming potential of nitrous oxide was almost 300 times higher than carbon dioxide. This gas was responsible for the largest share of climate change within field emissions.

The contributions in the other aspects of cotton cultivation largely depend on the fossil fuel combustion in each of the processes.

Please note that the results shown here do not account for the (temporal) uptake of CO_2 in the product.

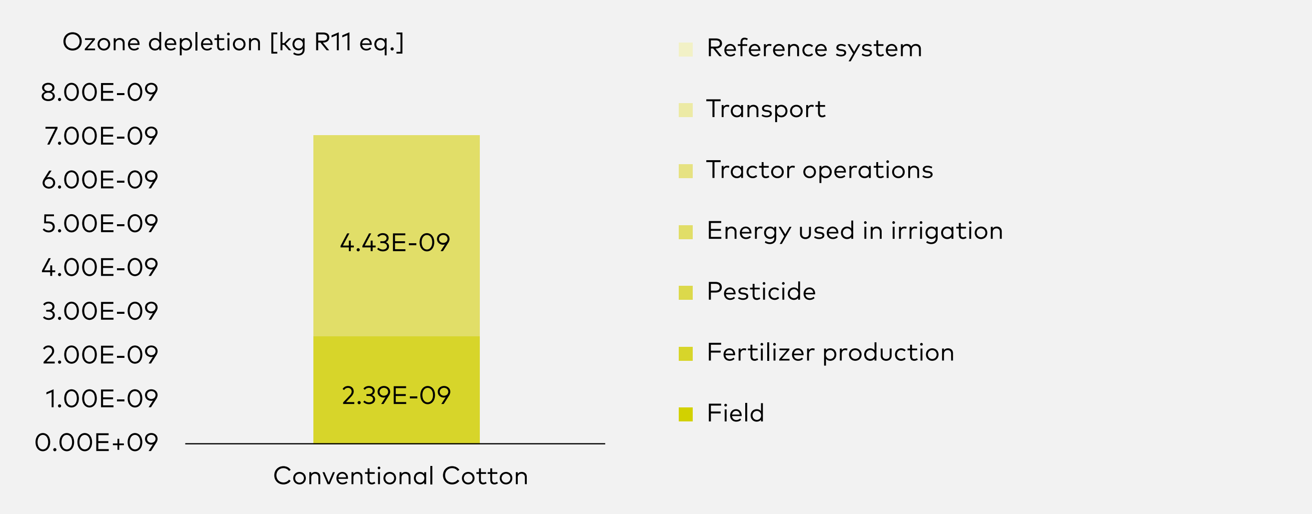
Figure 17 Climate Change of conventional cotton for 1 metric ton of seed cotton at farm gate



Ozone Depletion Potential
Conventional cotton cultivation resulted in an Ozone Depletion Potential (ODP) of 6.90E-09 kg R11 equivalent for 1 metric ton of seed cotton at farm gate. Figure 18 gives the contribution of various components to Ozone Depletion Potential of conventional cotton.

Figure 18 shows that ODP was dominated by energy used in irrigation followed by fertilizer production while all other processes of the production chain combined contribute less than 1%. The Ozone Depletion Potential was very less as CFC gases have been phased out and are no longer used in refrigerants or coolants which usually gave a higher ODP value.

Figure 18 Ozone Depletion potential of conventional cotton for 1 metric ton of seed cotton at farm gate

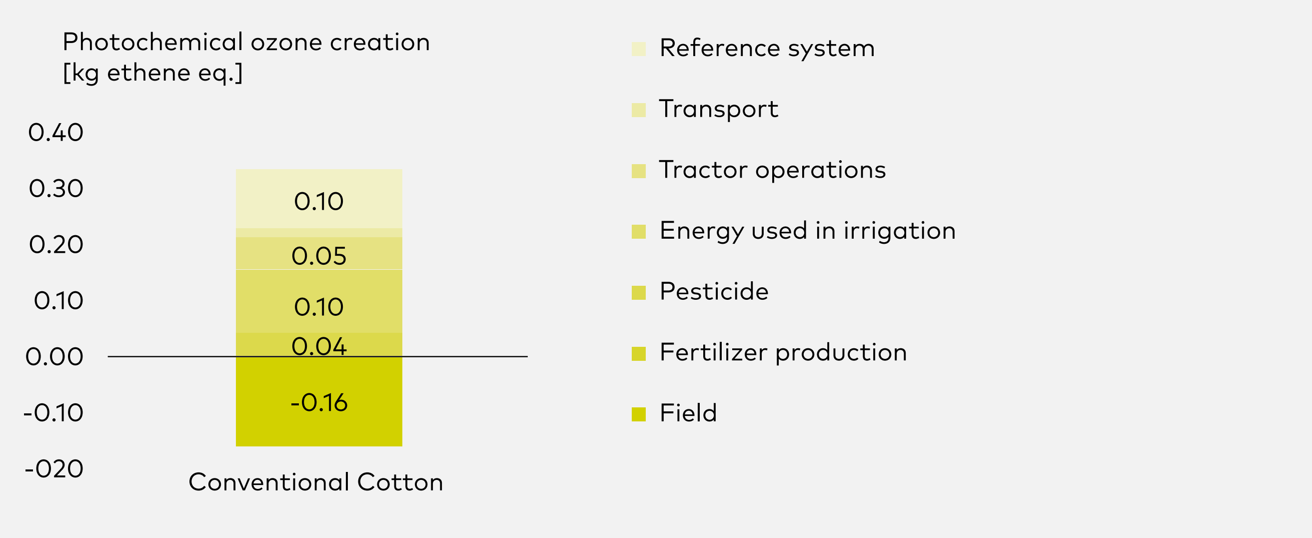


Photochemical Ozone Creation Potential
Conventional cotton cultivation has resulted in Photochemical Ozone Creation Potential (POCP) 0.15 kg ethene equivalent for 1 metric ton of seed cotton at farm gate. Figure 19 gives the contribution of various components to Photochemical Ozone Creation Potential of conventional cotton.

POCP was dominated by irrigation and reference system followed by fertilizer production, while all other processes of the production chain combined contribute less than 1%.

The release of nitrogen monoxide had a net positive impact in POCP in the reference system due to negative characterization factor of CML for Nitrogen monoxide. This also resulted in field emissions of NO giving a credit to the impact. Impact of carbon monoxide, nitrogen oxides, Sulphur dioxide and methane was observed in tractor operations, energy used in Irrigation, fertilizer production and transport of raw materials.

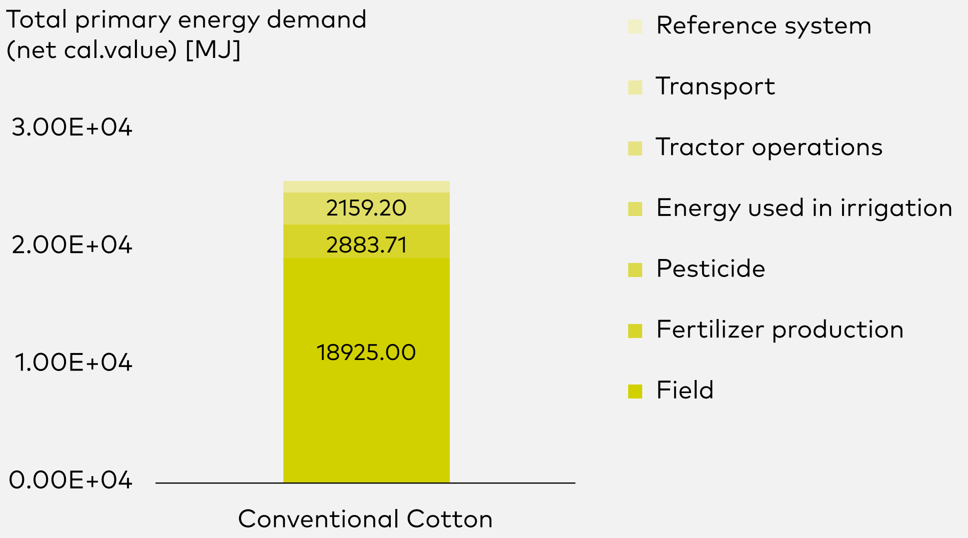
Figure 19 Photochemical Ozone Creation potential of conventional cotton for 1 metric ton of seed cotton at farm gate



Total Primary Energy Demand (including non-renewable and renewable PED)
The total primary energy demand (PED) of conventional cotton cultivation for 1 ton of seed cotton at farm gate was 2.56E+04 MJ. PED was an indicator of the dependence on fossil resources as well as renewable resources such as solar energy. Figure 20 gives the contribution of various components to Total Primary energy demand of conventional cotton.

Figure 20 shows that the field had maximum total primary energy demand (74.33%). The non-renewable energy demand of 22% was from the electricity used in irrigation, raw material production and fuel used in transport. The renewable energy demand was dominated by solar energy consumption in field. Solar energy consumption of the crop was calculated on the basis of type of crop, plantation period, etc.

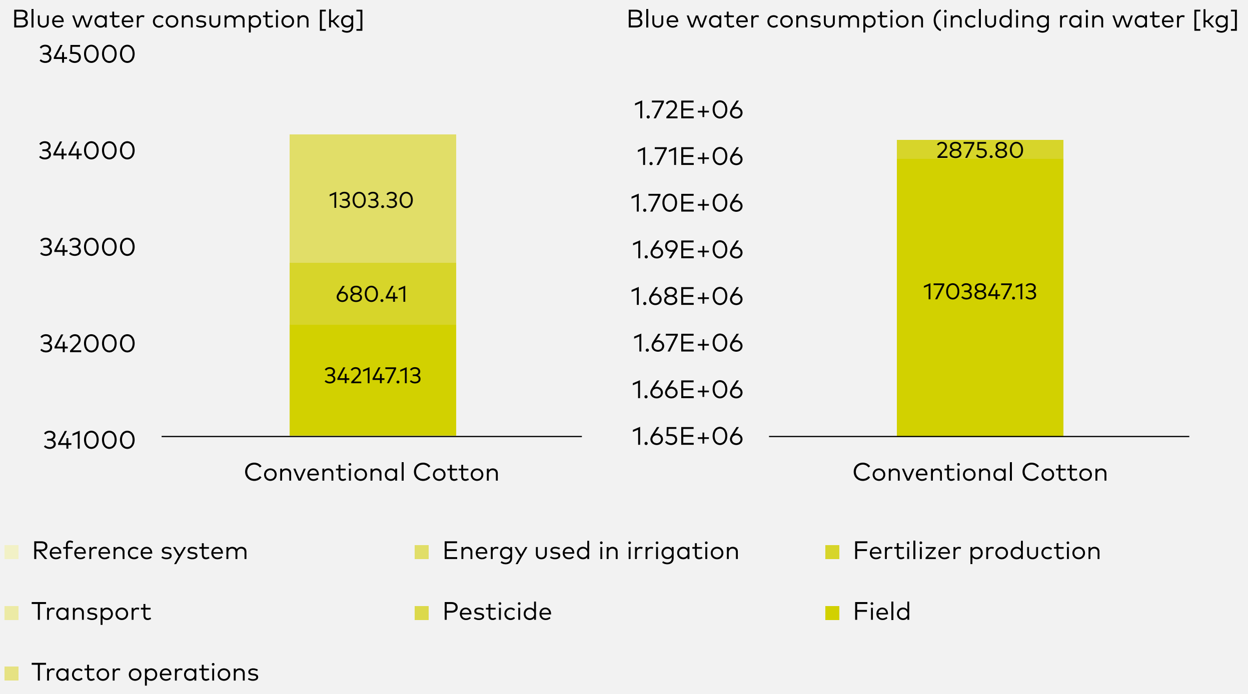
Figure 20 Total Primary energy demand of conventional cotton shown for 1 metric ton of seed cotton at farm gate



Water consumption
The blue water consumption without and including rain water of conventional cotton cultivation for 1 metric ton of seed cotton was 3.44E+05 kg and 1.71E+06 kg respectively. Figure 21 gives contribution of various components to the Blue Water consumption with and without rainwater of conventional cotton.

LCA accounts for water used in field by crops as well as the water consumption in production of energy and raw materials used in cultivation. Figure 21 suggested that maximum water demand both with and without rainwater was majorly due the crop water requirement. If rain water was included, then it had a 79% share, whereas in blue water consumption without rainwater ground water had a 70% share while river water had a 30% share.

Figure 21 Blue Water consumption with and without rainwater of conventional cotton for 1 metric ton of seed cotton at farm gate



Toxicity potential

Assessment of the toxicological effects of a chemical emitted into the environment implies a cause–effect chain that links emissions to impacts through three steps: environmental fate, exposure, and effects. In this LCA, environmental fate and exposure were taken into account by the application of the emission factors to soil, plant, water, and air, while the environmental effects were considered in the United Nations Environmental Program (UNEP) – Society of Environmental Toxicology and Chemistry (SETAC) toxicity model, USEtox™.

The focus in using the USEtox methodology in LCAs of agricultural systems was on pesticide use, as pesticides were known to be the major contributor to toxicity in agricultural products (see also COTTON INC. 2012, BERTHOUD ET AL 2011).

The Eco toxicity and Human toxicity of conventional cotton for 1 metric ton of seed cotton was 9.00E+03 CTUe and 1.82E-06 CTUh, respectively. Figure 22 gives the contribution of various components to USEtox results of conventional cotton.

Pesticide emissions occurring in field contributed to 99.99% of the toxicity impact. Eco-toxicity had maximum contribution from Profenofos emissions. In Human toxicity impact, nearly 99% was contributed by pesticide emissions out of which Acephate pesticide had a higher contribution of 94.90% followed by Profenofos pesticide contributing to 1.84%. The impact category "toxicity" was included to provide information for possible further studies or comparisons and should not be considered as the only basis to decide the precise pesticide amount and type for the cotton cultivation. Conclusions may be drawn on the basis of laboratory test results which were not in the scope of this study.

Figure 22 USEtox results of conventional cotton for 1 metric ton of seed cotton at farm gate

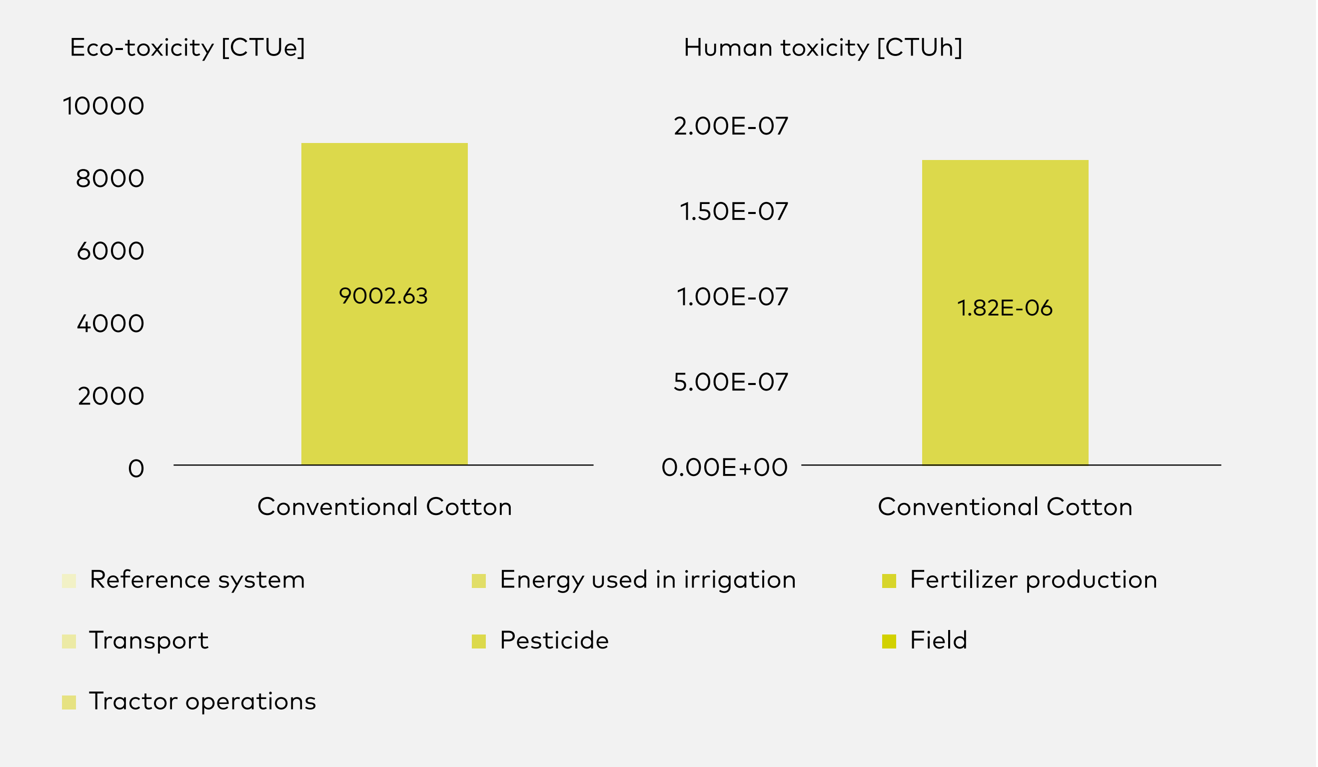


Table 10 Significant contributors to various impacts of conventional cotton for 1 metric ton of seed cotton at farm gate

Impact Category	Impact Value	Significant impact contributors			
		Activity wise		Component wise	
Acidification [kg SO_2 eq.]	12.68	73.32%	Field	Ammonia	71.07%
				Nitrogen monoxide	2.25%
		4.37%	Fertilizer production	Sulphur dioxide	3.13%
		17.68%	Energy used in Irrigation	Nitrogen oxides	2.73%
				Sulphur dioxide	15.95%
		5.21%	Tractor operations	Nitrogen oxides	4.60%
		-1.21%	Reference System	Nitrogen monoxide	-1.21%
Eutrophication [kg phosphate eq.]	1.92	129.58%	Field	Ammonia	107.70%
				Nitrogen monoxide	4.10%
				Nitrous oxide (laughing gas)	10.82%
				Nitrate	-5.48%
				Nitrogen organic bound	7.89%
				Phosphate	4.53%
		3.55%	Fertilizer production	Ammonia	1.10%
				Nitrogen oxides	1.60%
		5.29%	Energy used in Irrigation	Nitrogen oxides	4.92%
		8.30%	Tractor operations	Nitrogen oxides	8.28%
		-47.47%	Reference System	Nitrogen monoxide	-2.21%
				Nitrous oxide (laughing gas)	-3.64%
				Nitrate	-41.52%
Climate Change [kg CO_2 eq.]	680.20	34.80%	Field	Carbon dioxide	7.65%
				Nitrous oxide (laughing gas)	28.65%
				Methane	-1.49%
		21.35%	Fertilizer production	Carbon dioxide	17.69%
				Methane	3.40%
		1.62%	Pesticide	Carbon dioxide	1.47%
		27.02%	Energy used in Irrigation	Carbon dioxide	25.91%
		1.56%	Transport	Carbon dioxide	1.50%
		11.57%	Tractor operations	Carbon dioxide	11.14%
		2.09%	Reference System	Nitrous oxide (laughing gas)	-9.63%
				Methane	11.72%
Ozone Depletion [kg R11 eq.]	6.90E-09	34.68%	Fertilizer production	Refrigerant	33.92%
		63.79%	Energy used in Irrigation	Refrigerant	63.79%

Impact Category	Impact Value	Significant impact contributors			
		Activity wise		Component wise	
Photochemical Ozone Creation [kg ethene eq.]	0.15	-106.34%	Field	Nitrogen monoxide	-104.92%
				Methane	-1.42%
		24.84%	Fertilizer production	Carbon monoxide	1.31%
				Nitrogen oxides	4.14%
				Sulphur dioxide	10.38%
				Methane	3.24%
				NMVOC (unspecified)	1.54%
		68.47%	Energy used in Irrigation	Nitrogen oxides	12.69%
				Sulphur dioxide	48.71%
		3.04%	Transport	Carbon monoxide	0.30%
				Nitrogen oxides	1.53%
				Sulphur dioxide	0.28%
		40.54%	Tractor operations	Carbon monoxide	5.56%
				Nitrogen oxides	21.36%
				Sulphur dioxide	2.04%
				Group NMVOC to air	8.85%
		67.58%	Reference System	Nitrogen monoxide	56.42%
				Methane	11.16%
Total Primary Energy Demand [MJ]	2.55E+04	74.33%	Field	Primary energy from solar energy	74.33%
		11.28%	Fertilizer production	Crude oil (resource)	2.33%
				Natural gas (resource)	6.48%
		8.48%	Energy used in Irrigation	Hard coal (resource)	5.42%
				Lignite (resource)	1.34%
Blue Water Consumption [kg]	3.44E+05	99.40%	Field	Ground water	69.6%
				River water	29.8%
Blue Water Consumption (including rain water) [kg]	1.71E+06	99.75%	Field	Ground water	14.55%
				River water	6.24%
				Rain wate	78.97%
Eco-toxicity [CTUe]	9.00E+03	99.99%	Field	Profenofos	99.90%
Human Toxicity [CTUh]	1.82E-06	99.99%	Field	Acephate	94.9%
				Monocrotophos	2.21%
					1.84%

4.3.3 Organic cotton cultivation

Consolidated average data for organic cotton cultivation are given in Table 11.

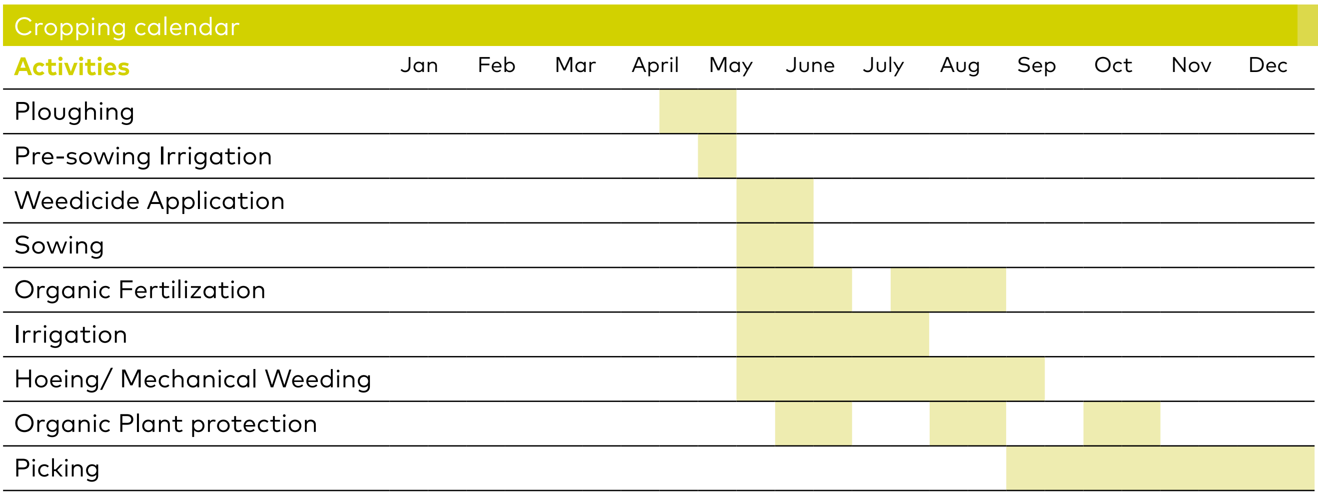
The organic inputs described in Table 29 were used as substitutes for chemicals in organic farming.

Table 11 Consolidated data used for LCIA analysis for organic cotton cultivation

Parameter	Unit	Types of cotton farm Organic cotton
Yield (Seed Cotton)	kg/ha	1755
Organic Fertilizer Input		
Farm yard manure (FYM)	kg/ha	535
Nitrogen content of FYM	% in fresh matter	0.4
Compost	kg/ha	4613
Nitrogen content of compost	% in fresh matter	0.7
Cow dung	kg/ha	10171
Nitrogen content of cow dung	% in fresh matter	0.9
Chemical Fertilizer Input		
DAP	kg/ha	-
Urea	kg/ha	-
Potash	kg/ha	-
Pest and weed control		
Confidore (active ingredient Imidacloprid)	kg/ha	-
Mono (active ingredient Monocrotophos)	kg/ha	-
Acephate (active ingredient Acephate)	kg/ha	-
Profeno (active ingredient Profenofos)	kg/ha	-
Total pesticide		-
Machinery use		
Diesel demand (Tractor, not incl. irrigation)	l/ha	46
Irrigation		
Irrigation water use	m^3/ha	244

The cropping calendar in Figure 23 highlights the activities along with the timelines in organic cotton cultivation.

Figure 23 Cropping calendar for organic cotton



Description of farming practices in organic cotton Cultivations

Activity	Description
Soil preparation	Soil preparation was done at intervals of 2-3 years. It included ploughing (~92% famers) and tillage (~8% farmers).
Selection of cotton seeds	Non-Bt cotton seeds (such as JK-4, JK-35, Suraj, NH 615, Vasudha P1- P2, etc.) were mainly used for cultivation. Some farmers reported use of some hybrid cotton seed varieties (such as Mallika, Banni-145, Nirmal 996, Nirmal 744, Ankur- 3028, etc.).
Fertilizer inputs	Di-Ammonium Phosphate (DAP), Urea, Super phosphate and Super potash were used as sources of NPK only by 5% of farmers in very small quantity. Most of them relied on organic inputs.
Pesticide inputs	No application of pesticides was reported by any farmers. They used organic inputs for crop protection.
Organic inputs	Along with cow dung and compost other home-made organic inputs, as described in 8.6, were applied to the crop as nutrients and protection measures.
Type of Irrigation	Most of the farmers used ground water (~88%) for irrigation by the means of bore-well and well. The average depths of bore-well and well were 90-150 meters and 9-15 meters, respectively. Wherever canals were available farmers made use of canal water.
Intercropping	About ~65% of farmers planted gram and maize along with cotton, but the yield of gram was less than 100 kg per hectare as reported by most of the farmers.
Crop rotation	Crop rotation was done by cultivating wheat and gram. Nearly 75% farmers reported crop rotation, but it was dependent on the availability of water.
Plant protection measures	Dams against soil erosion was adopted by majority of the farmers as a measure against soil erosion. Some reported growing hedges.

The LCIA results of organic cotton for 1 metric ton of seed cotton are given below in Table 12.

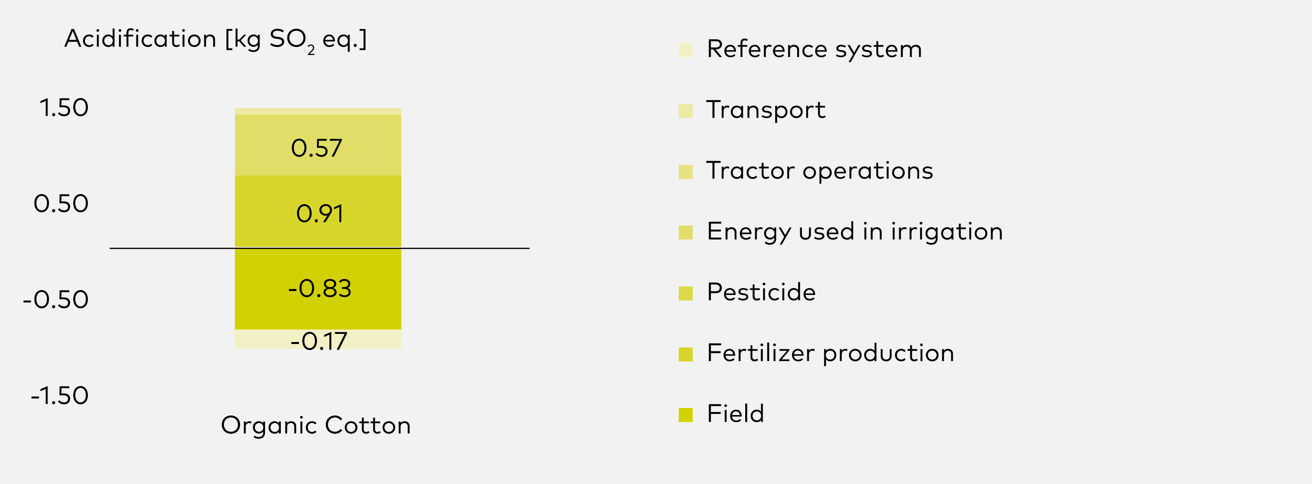
Table 12 LCIA results of organic cotton for 1 metric ton seed cotton at farm gate

Impact indicator	Unit	Organic cotton	Interpretation
Acidification	kg SO_2 eq.	0.57	Energy used in irrigation had the highest contribution to the impact mainly due to sulphur emissions.
Eutrophication	kg phosphate	-0.02	As there were no usage of fertilizers the net impact was negative.
Climate Change	kg CO_2 eq.	338.50	Carbon dioxide emissions in field dominated the impact followed by Carbon dioxide emissions in tractor operations and in electricity used as energy in irrigation.
Ozone Depletion	kg R11 eq.	1.85E-09	NMVOC emissions to air dominated the impact. These emissions mainly occurred in production of electricity used as energy in irrigation.
Photochemical	kg ethene eq.	0.05	N_2O emissions occurring in field had a net positive impact due to negative characterization factor of N_2O in CML. The net impact was also very low due to no usage of fertilizers
Total Primary Energy Demand (net cal. value)	MJ	2.09E+04	90% of the total primary energy demand was from solar energy consumed by the plant during the cultivation period.
Blue Water Consumption	kg	1.40E+05	Major source of water in field was mainly ground water. Other water demand was seen in the production of electricity used as energy in irrigation. 93% of the water requirement of the cultivation was achieved by rainwater consumption.
Blue Water Consumption (including rain water)	kg	1.88E+06	
Eco-toxicity	CTUe	1.41E-01	90% impact was contributed from diesel production emissions and 9.4% from production of electricity used as energy in irrigation.
Human Toxicity	CTUh	1.99E-10	77% impact was from production of electricity used as energy in irrigation.

Acidification Potential
Organic cotton cultivation resulted in an acidification potential (AP) of 0.57 kg SO_2 equivalent for 1 metric ton of seed cotton at farm gate. AP gets influenced by fossil fuel combustion processes. While CO_2 emissions contribute to climate change, the parallel releases of SO_2 and nitrogen oxides increases AP. Figure 24 shows the contribution of various components to acidification potential of organic cotton.

Acidification was dominated by nitrogen dioxide and Sulphur dioxide emissions in energy used for irrigation. Sulphur dioxide emissions were dependent on the type of fossil fuel used and nitrogen oxides depend on conditions of the combustion process, therefore the amount and type of fuels used determine the order of importance in the other categories (machinery, irrigation and transports). The emissions occurring in field show a net credit in ammonia emissions. This was due to absence of fertilizers supplying excess nutrient.

Figure 24 Acidification potential of organic cotton for 1 metric ton of seed cotton at farm gate



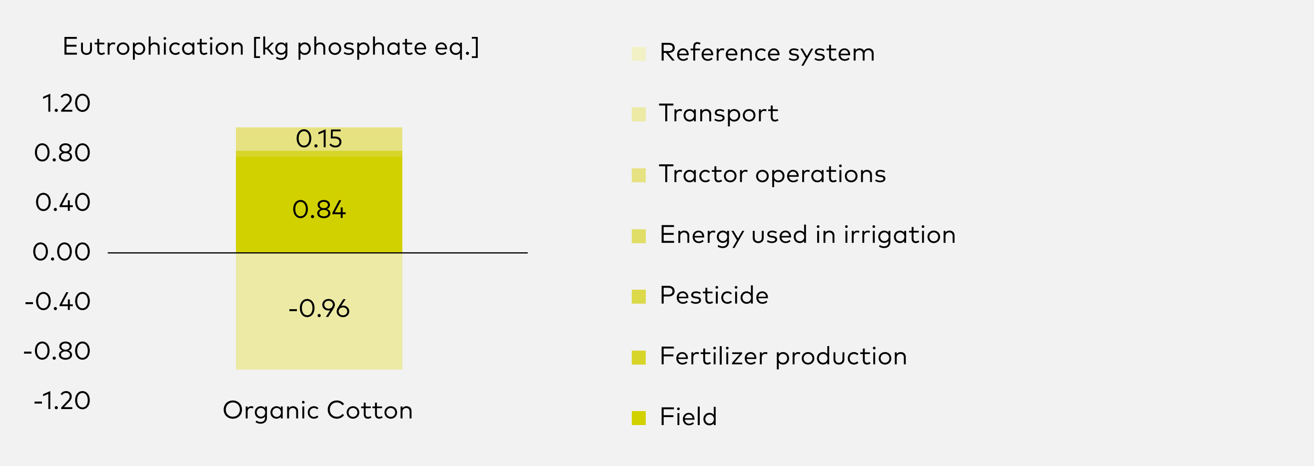
Eutrophication Potential
Eutrophication in agriculture can be significantly influenced by soil erosion. Through soil erosion, nutrients are removed from the cultivated system via water and soil and leads to the fertilization of neighbouring water bodies and soil systems. It is influenced mainly by P- and N- containing compounds.

Figure 25 shows contribution of various components to Eutrophication potential of organic cotton.

Organic cotton cultivation resulted in an Eutrophication potential (EP) of -0.02 kg phosphate equivalent for 1 metric ton of seed cotton at farm gate. It was observed that emissions of nitrates and phosphates to water, and nitrogen monoxide to air which occur in the field dominate the Eutrophication impact. Energy used in irrigation contributes only 4% of the impact, while tractor operations contribute 15% of the impact.

As described in section 3.4, soil erosion rates drastically reduced by soil protection measures that were widely used among organic cotton farmers. Based on data used in this study, low soil erosion rates can be assumed leading to relatively low EP.

Figure 25 Eutrophication potential of organic cotton for 1 metric ton of seed cotton at farm gate



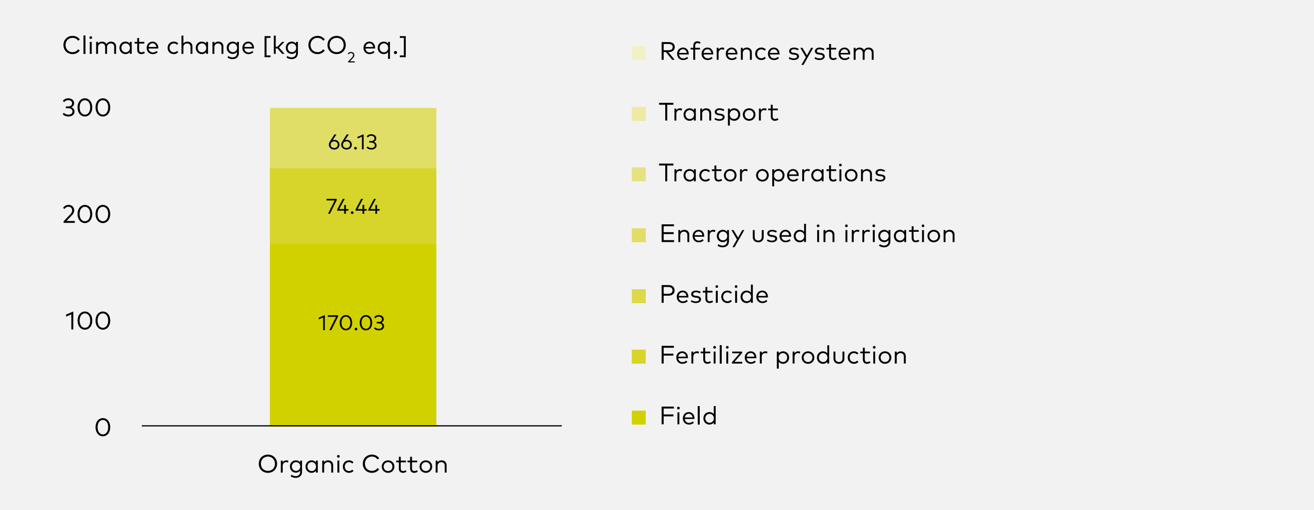
Climate change
Climate change impact for the production of 1 metric ton of organic cotton was about 338.50 kg CO_2 equivalent. Figure 26 shows contribution of various components to Climate change potential of organic cotton for 1 metric ton of seed cotton at farm gate.

As shown in Figure 26, Field dominated this impact category with over 50% share. Field emissions refer to gases emitted from soils due to agricultural activity. Essentially, these emissions derive from microbial nutrient transformation processes in the soil. As a result of such transformation processes, a fraction of the available total nitrogen becomes inorganic nitrous oxide, also known as laughing gas, with a global warming potential almost 300 times higher than carbon dioxide. It was observed that carbon dioxide emissions dominated the climate change impact.

The contributions in the other aspects of cotton cultivation largely depend on the fossil fuel combustion in each of the processes.

Please note that the results shown here do not account for the (temporal) uptake of CO_2 in the product.

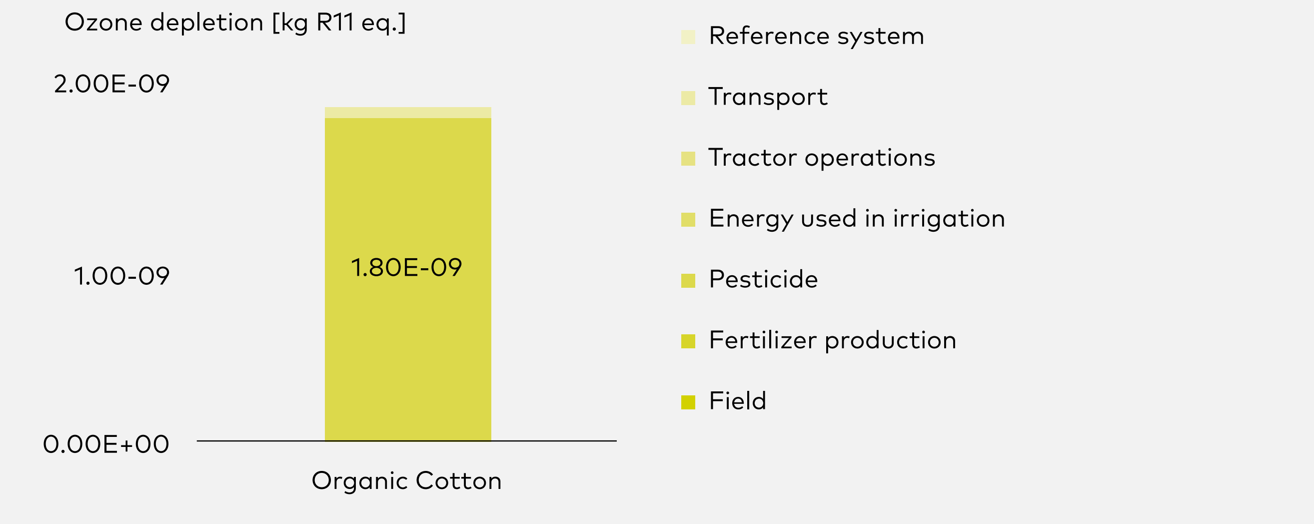
Figure 26 Climate Change of organic cotton for 1 metric ton of seed cotton at farm gate



Ozone Depletion Potential
Organic cotton cultivation resulted in an Ozone Depletion potential (ODP) of 1.85E-09 kg ethene equivalent for 1 metric ton of seed cotton at farm gate. Figure 27 gives contribution of various components to Ozone Depletion potential of organic cotton.

Figure 27 shows that ODP was dominated by production of energy used in irrigation, which was grid electricity. As there were no pesticides or fertilizers used the ODP impact was very low.

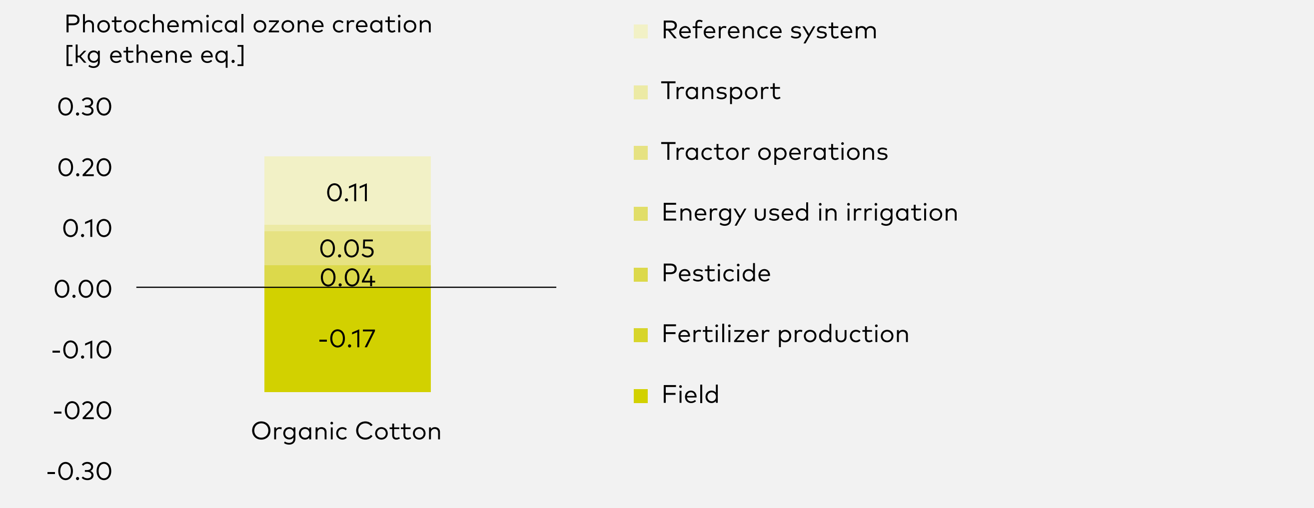
Figure 27 Ozone Depletion potential of organic cotton for 1 metric ton of seed cotton at farm gate



Photochemical Ozone Creation Potential
Organic cotton cultivation resulted in Photochemical Ozone Creation potential (POCP) of 0.05 kg ethene equivalent for 1 metric ton of seed cotton at farm gate Figure 28 gives contribution of various components to Photochemical Ozone Creation potential of organic cotton.

The release of nitrogen monoxide had a net positive impact in POCP due to negative characterization factor of NO in CML. This was why field emissions show a credit. Whereas impact of Carbon monoxide, Nitrogen oxides, Sulphur dioxide and methane occurring in tractor operations and Irrigation led to POCP impact.

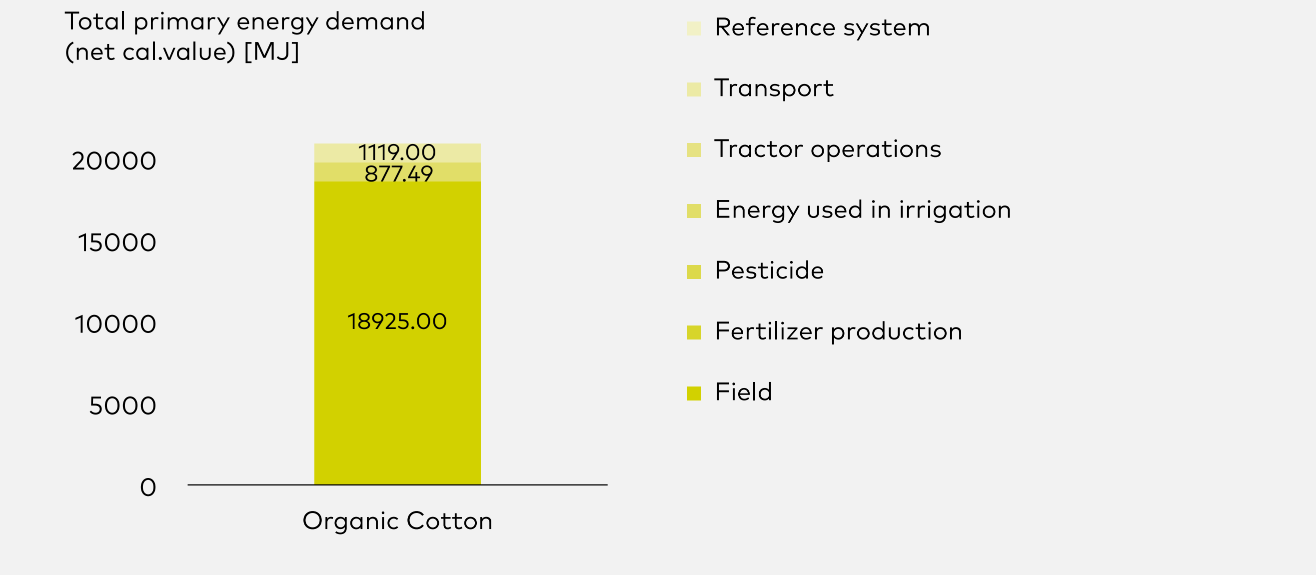
Figure 28 Photochemical Ozone Creation potential of organic cotton for 1 metric ton of seed cotton at farm gate



Total Primary Energy Demand (including non-renewable and renewable PED)
Total primary energy demand (PED) for 1-ton seed cotton at farm gate was 2.09E+04 MJ. TPED is an indicator of the dependence on fossil resources as well as renewable resources such as solar energy. Figure 29 shows the contribution of various components to total Primary energy demand (net calorific value) of organic cotton for 1 metric ton of seed cotton at farm gate.

Electricity used in running irrigation pumps and diesel used in tractors, which had a higher energy-to-emission ratio than coal was dominant in non-renewable energy consumption. Solar energy consumed by crop dominated the renewable energy consumption. The overall contribution of Field was 90% in the total primary energy demand which was due to solar energy consumed by the crop.

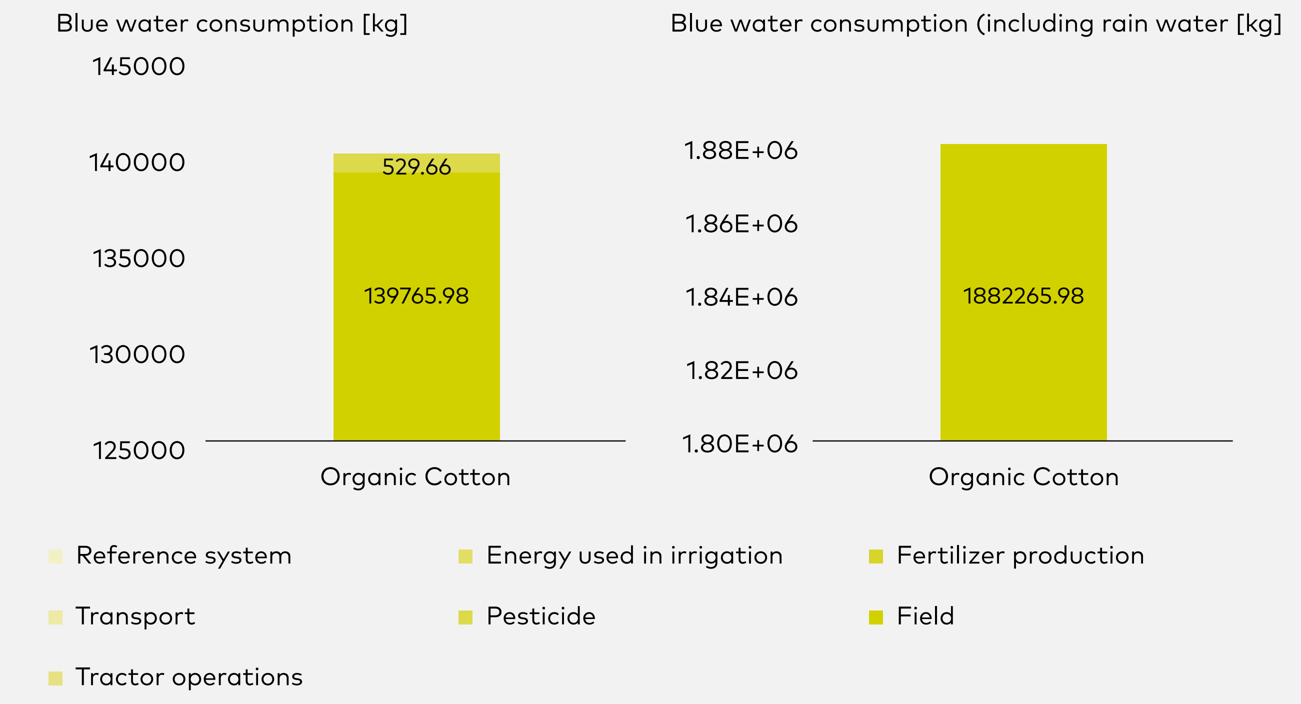
Figure 29 Primary energy demand (net calorific value) of organic cotton for 1 metric ton of seed cotton at farm gate



Water consumption
The total blue water consumption without and including rain water of organic cotton for 1 metric ton of seed cotton was 1.40E+05 kg and 1.88E+06 kg, respectively. Figure 30 shows the contribution of various components to blue water consumption with and without rainwater of organic cotton.

The ratio of ground water to river water typically 70:30 in the region. The major consumption was in the field whereas electricity used in irrigation lead to additional water demand at the electricity production site.

Figure 30 Blue Water consumption with and without rainwater of organic cotton for 1 metric ton of seed cotton at farm gate



Toxicity potential
Assessment of the toxicological effects of a chemical emitted into the environment implies a cause–effect chain that links emissions to impacts through three steps: environmental fate, exposure, and effects. In this LCA, environmental fate and exposure were taken into account by the application of the emission factors to soil, plant, water, and air, while the environmental effects were considered in the United Nations Environmental Program (UNEP) – Society of Environmental Toxicology and Chemistry (SETAC) toxicity model, USEtox™.

The focus in using the USEtox methodology in LCAs of agricultural systems was on pesticide use, as pesticides are known to be the major contributor to toxicity in agricultural products (see also COTTON INC. 2012, BERTHOUD ET AL 2011).

Total Eco toxicity and Human toxicity of organic cotton for 1 metric ton of seed cotton was 1.41E-01 CTUe and 1.99E-10 CTUh, respectively. Figure 31 gives the contribution of various components to USEtox results of organic cotton.

Production of diesel used in transport majorly contributed to eco-toxicity (90.5%). Whereas, electricity consumed in irrigation contributed 9.45%. In Human Toxicity, the electricity used as energy in irrigation dominated the impact. Toxicity values were low in organic cotton since there was no use of pesticides, which mainly lead to the impact.

It should be noted that, farming refuse of animal or botanical origin used in organic cotton cultivation as pesticides and seed treatment agents or for fertilization (e.g. neem cake, cow dung and urine, farmyard manure) were assumed to be burden-free for organic cotton cultivation.

Figure 31 USEtox results of organic cotton for 1 metric ton of seed cotton at farm gate

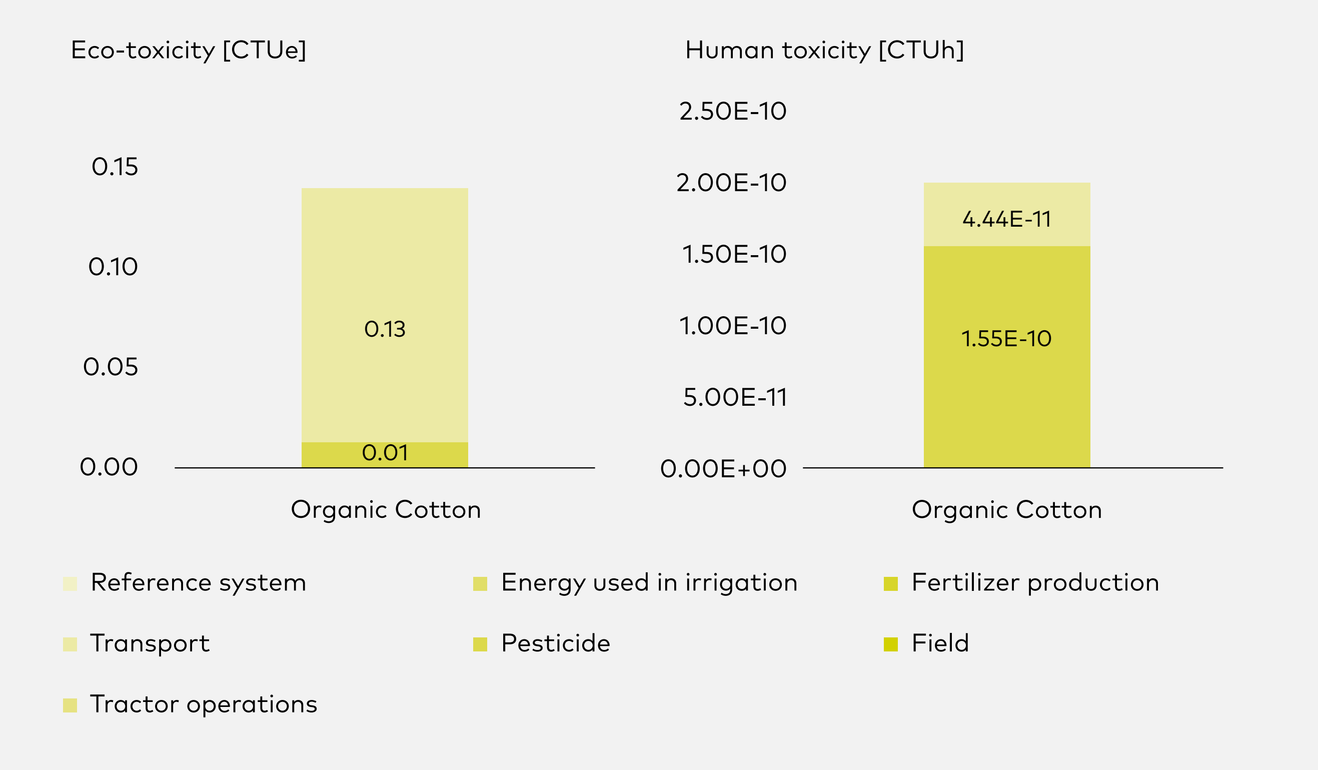
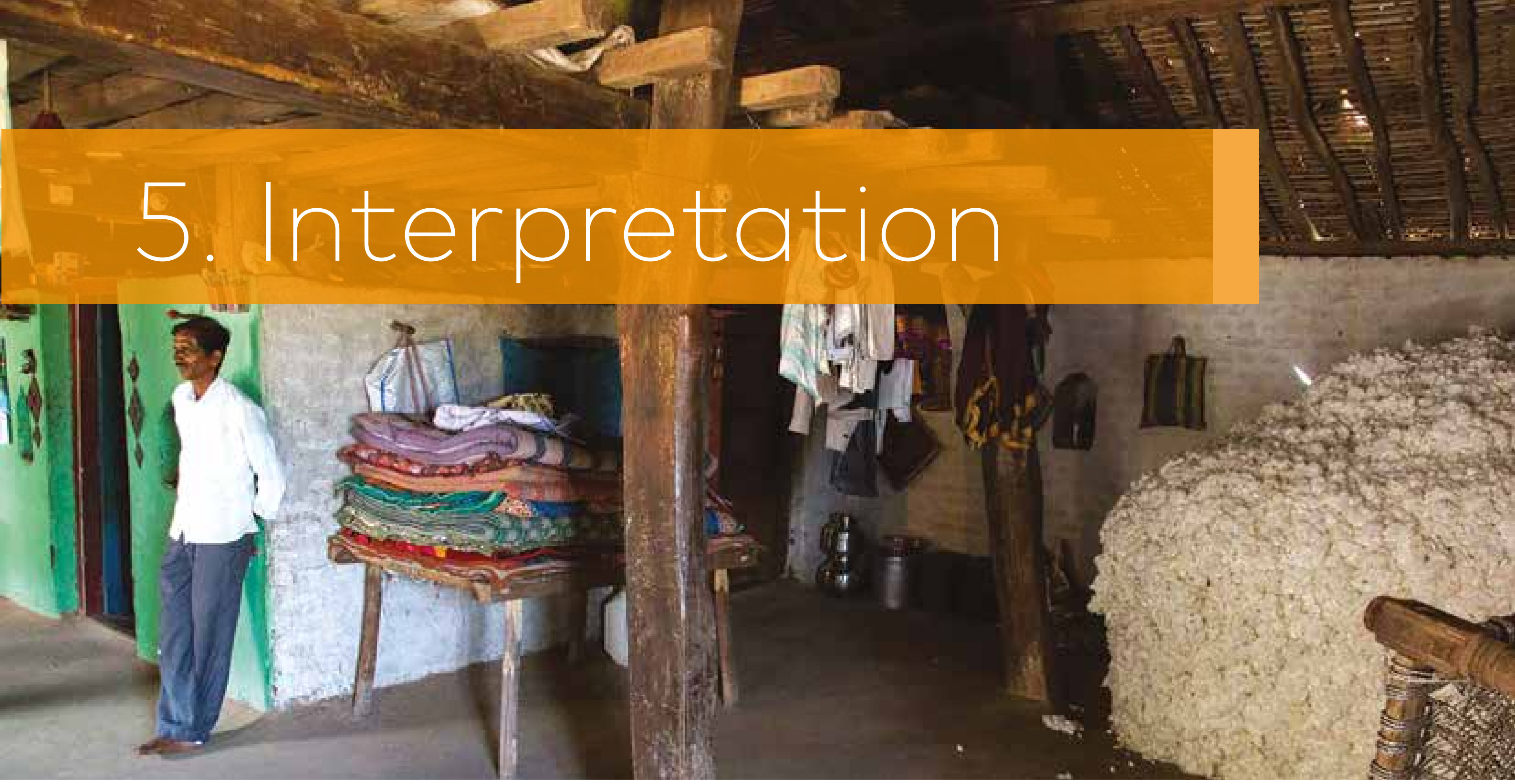


Table 13 Significant contributors to various impacts of organic cotton for 1 metric ton of seed cotton at farm gate

Impact Category	Impact Value	Significant impact contributors			
		Activity wise		Activity wise	
Acidification [kg SO_2 eq.]	0.57	-151.83%	Field	Ammonia	-205.59%
				Nitrogen monoxide	53.75%
		163.57%	Energy used in Irrigation	Nitrogen oxides	25.26%
				Sulphur dioxide	135.76%
		118.68%	Tractor operations	Nitrogen oxides	104.59%
				Sulphur dioxide	13.95%
		-30.42%	Reference System	Nitrogen monoxide	-30.42%
Eutrophication [kg phosphate eq.]	-0.02	75.23%	Field	Ammonia	-25.02%
				Nitrogen monoxide	7.87%
				Nitrous oxide (laughing gas)	18.30%
				Nitrate	49.00%
				Nitrogen organic bound	15.93%
				Phosphate	9.15%
		3.93%	Energy used in Irrigation	Nitrogen oxides	3.65%
		14.73%	Tractor operations	Nitrogen oxides	15.13%
		-95.85%	Reference System	Nitrogen monoxide	-4.45%
				Nitrous oxide (laughing gas)	-7.35%
				Nitrate	-83.84%
Climate Change [kg CO_2 eq.]	338.50	50.00%	Field emissions	Carbon dioxide	53.31%
				Methane	-3.31%
		22.09%	Power consumption in Irrigation	Carbon dioxide	21.19%
		23.27%	Tractor operations	Carbon dioxide	22.41%
		4.63%	Reference System	Nitrous oxide (laughing gas)	-21.41%
				Methane	26.04%
Ozone Depletion [kg R11 eq.]	1.85E-09	97.39%	Energy used in Irrigation	Group NMVOC to air	97.39%
		2.61%	Tractor operations	Group NMVOC to air	2.61%
Photochemical Ozone Creation [kg ethene eq.]	0.05	-356.56%	Field	Nitrogen monoxide	-351.56%
				Methane	-5.01%
		88.86%	Energy used in Irrigation	Carbon monoxide	3.13%
				Nitrogen oxides	16.47%
				Sulphur dioxide	63.21%
				Group NMVOC to air	4.90%
				Methane	1.21%
		129.41%	Tractor operations	Carbon monoxide	17.76%
				Nitrogen oxides	68.18%
				Sulphur dioxide	6.50%
				NMVOC (unspecified)	35.70%
		238.29%	Reference System	Nitrogen monoxide	198.95%
				Methane	39.34%

Impact Category	Impact Value	Significant impact contributors			
		Activity wise		Activity wise	
Total Primary Energy Demand [MJ]	2.09E+04	90.46%	Field	Solar energy	90.46%
		4.19%	Energy used in Irrigation	Hard coal (resource)	2.53%
				Lignite (resource)	0.63%
		5.35%	Tractor operations	Crude oil (resource)	4.96%
				Hard coal (resource)	0.07%
Blue Water Consumption [kg]	1.40E+05	99.09%	Field	Ground water	69.4%
				River water	29.7%
Blue Water Consumption (including rain water) [kg]	1.88E+6	99.90%	Field	Ground water	5.17%
				River water	2.21%
				Rain water	92.51%
Eco-toxicity [CTUe]	1.41E-01	9.45%	Energy used in Irrigation	Group NMVOC to air	2.3%
				Hydrocarbons to fresh water	4.48%
		90.54%	Tractor operations	Hydrocarbons to fresh water	90.30%
Human Toxicity [CTUh]	1.99E-10	77.08%	Energy used in Irrigation	Group NMVOC to air	77.08%
		22.31%	Tractor operations	Group NMVOC to air	11.96%
				Hydrocarbons to fresh water	10.23%



5. Interpretation

5.1 Scenarios

In the following, the influence of important assumptions regarding system boundaries and modelling approaches on the final results were investigated by means of scenario analysis.

5.2 The environmental footprint of cotton – Putting it into perspective

It should be noted here that given the limitations denoted in section 5.3 it was not the intention of the study to make comparative assertions as defined in the ISO 14044 standard. If the values provided in this study and the related dataset were to be used in further LCA studies – e.g. along the value chain of the apparel industry, or in comparison to other materials – attention should be paid to the definition of system boundaries and methodological assumptions. As demonstrated above, these had an influence on the outcomes, as often seen in the case of LCA studies. Absolute numbers from LCA studies should therefore always be interpreted with care and reference to the system under consideration. Stand-alone indicators for simplified statements or decision making are discouraged by the LCA community in general.

Table 14 Identified Flows and parameters for various inputs/processes

Sr.No	Input/Activity	Flow/parameter	Environmental indicator
1	Agricultural Machinery - Diesel	CO_2, CH_4, N_2O, SO_2, NOx	Global Warming Potential Acidification Potential Eutrophication Potential Total Primary energy demand
2	Agricultural Machinery - Tractor	CO_2, N_2O, NOx	Global Warming Potential Eutrophication Potential
3	Irrigation - Diesel	CO_2, CH_4, N_2O, SO_2, NOx	Global Warming Potential Acidification Potential Eutrophication Potential Total Primary energy demand
4	Irrigation - Electricity	CO_2, CH_4, N_2O, SO_2, NOx, Halogenated organic emissions to air	Global Warming Potential Acidification Potential Eutrophication Potential Total Primary energy demand
5	Field /Field Emission	CO_2, CH_4, N_2O, NO_x, N_2O, NH_3, PO_3, NO_3-, NH_4+	Global Warming Potential Acidification Potential Eutrophication Potential Total Primary energy demand
6	Soil Erosion	CO_2, CH_4, N_2O, SO_2, NO_x, N_2O, NH3, PO_3, NO_3-, NH_4+	Global Warming Potential Acidification Potential Eutrophication Potential Total Primary energy demand
7	Synthetic fertilizer Consumption	NO_x, N_2O, NH_3, PO_3, NO_3-, NH_4+, Halogenated organic emissions to air	Global Warming Potential Acidification Potential Eutrophication Potential Total Primary energy demand, Ozone Layer Depletion Potential
8	Organic Fertilizer Consumption - FYM	Burden Free -	-
9	Organic Fertilizer Consumption - Compost	Burden Free -	-
10	Pesticide Consumption	SO_2, NO_x, N_2O, NH_3, PO_3, NO_3-, NH_4+ , Pesticide emission to air and freshwater	Global Warming Potential Acidification Potential Eutrophication Potential Total Primary energy demand Eco-toxicity Potential Human toxicity Potential
11	Irrigation Water	Water used for irrigation purpose	Blue Water Consumption/Use Fresh Water Consumption/Use
12	Reference System	CH_4, NO_x, N_2O	Global Warming Potential Photochemical. Ozone Creation Potential

5.2.1 Better Cotton

5.2.1.1 Comparison of farms with highest and lowest yields of seed cotton

To understand the dynamics of the model a comparison between farms having the highest reported yield and lowest reported yield was conducted. Table 15 shows the results of this analysis.

It was observed that apart from human toxicity the values of all other impacts in farm having highest yield were lower than farm with lowest yield. Human toxicity was dominated by pesticides and the amount of pesticides used in farm with lowest yield was lesser which reduced the impact. It was concluded that yield played a dominant role in the impacts as per the functional unit of the study, but nutrient inputs and irrigation practices also had influence on the results.

Table 15 Comparison between farms with highest yield and lowest yield

Impact Category	Unit	Base Case (1888 kg/ha)*	Highest Yield (6000 kg/ha)	Lowest Yield (619 kg/ha)
		1 ton of seed cotton at farm gate (Better Cotton)		
Acidification	kg SO_2 eq.	12.41	4.08	54.93
Eutrophication	kg phosphate eq.	1.66	1.71	12.11
Climate Change	kg CO_2 eq.	688.0	385.97	1793
Ozone Depletion	kg R11 eq.	7.18E-09	2.86E-09	1.38E-08
Photochemical Ozone Creation	Kg ethene eq.	0.17	-4.97E-03	4.95E-01
Total Primary Energy Demand	MJ	2.56E+04	2.22E+04	3.39E+04
Blue Water Consumption	kg	3.67E+05	1.61E+05	1.03E+06
Blue Water Consumption (including rain water)	kg	1.75E+06	5.53E+05	5.35E+06
Eco-toxicity	CTUe	1.17E+04	0.21	0.83
Human Toxicity	CTUh	3.13E-07	6.53E-09	2.71E-09

* weighted average value

5.2.1.2 Effect of use of electricity-based pump vs diesel-based pump vs solar-based pump for irrigation

Better Cotton shows high consumption of energy for drawing irrigation water. Thus, the contribution to impacts from electricity-based pump were considered as a parameter and analysed against usage of diesel-based pump vs solar based pump. The results of this analysis are tabulated in Table 16.

In the base case electric pump was used for irrigation. With change in type of energy source it was observed that diesel-based pump could show a savings potential of 5.70% in the climate change impact. But it contributed 11% more in eutrophication. The solar based pump was found to be showcasing the highest possible savings in all impact categories. The primary energy demand needs to be verified with use of solar energy as the power source of electric pump. Other impact categories remain unchanged.

Table 16 Comparison between uses of electricity-based pump vs diesel-based pump vs solar-based pump for irrigation

Impact Categories	Base Case (electric pump)	Diesel-based pump		Solar based pump	
		Value	% change	Value	% Change
Acidification [kg SO_2 eq.]	12.41	11.67	5.94%	10.06	18.94%
Eutrophication [kg phosphate eq.]	1.66	1.85	-11.45%	1.46	12.05%
Climate Change [kg CO_2 eq.]	688.00	648.77	5.70%	502.46	26.97%
Ozone Depletion [kg R11 eq.]	7.18E-09	2.55E-09	64.48%	2.67E-09	62.81%
Photochemical Ozone Creation [kg ethene eq.]	0.17	0.19	-11.76%	0.06	64.71%

5.2.1.3 Effect of composting plant residues

In the base case, allocation was done between cotton seed and cotton residue as the cotton stalk was considered to be a by-product and could be utilised as compost in the field. The amount of nitrogen content in the cotton stalk was about 1% and the weight ratio of cotton seed to cotton stalk was 1:3.5.

To understand the effect of cotton stalk composting the amount of cotton stalk generated was considered for composting and application to land. The results of this analysis are given in Table 17.

Due to the large ammonia emissions (13% of total nitrogen input with the cotton stalks) the acidification potential increased significantly, as well as the eutrophication potential. Also, the total climate change impact was 38% higher than base case as in this the entire impact of the system was considered and not just pertaining to seed cotton. Other impact categories remained unchanged.

Again, it should be noted that the values given here in the scenarios should only be considered as a first screening with high uncertainty. To assume that the nitrogen organically bound in the stalks was as susceptible to volatilization during composting as the much more easily available nitrogen compounds in farm yard manure could be considered as a worst-case assumption.

Table 17 Results of composting of field residues

Impact Category	Unit	Base Case (allocation)	With Composting	% change
Acidification	kg SO_2 eq.	12.41	22.28	-79.56%
Eutrophication	kg phosphate eq.	1.66	5.34	-221.78%
Climate Change	kg CO_2 eq.	688.0	949.19	-37.96%
Ozone Depletion	kg R11 eq.	7.18E-09	5.82E-09	18.94%
Photochemical Ozone Creation	Kg ethene eq.	0.17	5.48E-02	67.76%
Total Primary Energy Demand	MJ	2.56E+04	2.68E+04	-4.75%

5.2.1.4 Effect of reduction in pesticide consumption

As toxicity was mainly due to use of pesticide, the effect of each pesticide was studied on the eco toxicity and human toxicity impact. The results of the same are shown in Table 18.

It was observed the pesticides having Profenofos as the active ingredient contributed highest to the Eco-toxicity. Thus, reduction in usage of Profenofos may lead to reduction in eco toxicity. Similarly, reduction in usage of pesticides having Acephate as the active ingredient may lead to reduction in the human toxicity potential. Other impact categories remained unchanged. It should be noted that the effect of pesticides on the toxicity of soil and water needs to be verified by performing lab tests. Decision of selection of pesticides should not depend solely on above analysis of toxicity.

Table 18 Effect of reduction in consumption of pesticides on eco toxicity and human toxicity

Impact Category	Base case	With no pesticide	With 10% less pesticide	With 50% less pesticide	With no Acephate	With no Monocrotophos	With no IMIDA	With no Profenofos
Eco-toxicity [CTUe]	1.17E+04	0.48	1.06E+04	5861.80	1.17E+04	1.17E+04	1.17E+04	0.62
% Change		100.00%	10.00%	50.00%	0.00%	0.00%	0.00%	99.99%
Human Toxicity [CTUh]	3.13E-07	8.09E-10	2.82E-07	1.57E-07	5.55E-08	3.07E-07	3.10E-07	2.68E-07
% change		99.74%	9.97%	49.87%	82.28%	1.86%	1.02%	14.58%

5.2.2 Conventional Cotton

5.2.2.1 Comparison of farms with Highest and lowest yields of seed cotton

To understand the dynamics of the model a comparison between farms having the highest reported yield and lowest reported yield was conducted. The results of this comparison are given in Table 19.

It was observed that apart from eco toxicity, the values of all other impacts in farm having highest yield were lower than farm having lowest yield. Eco-toxicity was dominated by pesticides emissions and the amount of pesticides used in farm with lowest yield was lower which lead to reduction of impact. Data tabulated in annexure 8.2.

Table 19 Comparison between farms with highest yield and lowest yield

Impact Category	Unit	Base Case (1938 kg/ha)*	Highest Yield (3438 kg/ha)	Lowest Yield (248 kg/ha)
		1 ton of seed cotton at farm gate (Conventional Cotton)		
Acidification	kg SO_2 eq.	12.68	5.41	65.44
Eutrophication	kg phosphate eq.	1.92	1.79	19.22
Climate Change	kg CO_2 eq.	680.20	426.71	2316.3
Ozone Depletion	kg R11 eq.	6.90E-09	2.27E-09	2.23E-08
Photochemical Ozone Creation	Kg ethene eq.	0.15	2.02E-02	6.77E-01
Total Primary Energy Demand	MJ	2.55E+04	2.27E+04	4.15E+04
Blue Water Consumption	kg	3.44E+05	1.05E+05	1.99E+05
Blue Water Consumption (including rain water)	kg	1.71E+06	9.62E+05	1.33E+07
Eco-toxicity	CTUe	9.00E+03	33703.00	17.20
Human Toxicity	CTUh	1.82E-06	1.84E-06	2.69E-05

* weighted average value

5.2.2.2 Effect of use of electricity-based pump vs diesel-based pump vs solar-based pump for irrigation

Conventional cotton shows high consumption of irrigation water. Thus, the contribution to impacts from electric pump was considered as a parameter and analysed against usage of diesel-based pump vs solar based pump. The results of this analysis are provided in Table 20.

In the base case irrigation was considered using an electric pump. With change in type of energy source it was observed that diesel-based pump could show a savings potential of 5.73% in the climate change impact. But it contributed 9.4% more in eutrophication. The solar based pump was found to be showcasing the highest possible savings in all impact categories. Although the primary energy demand needs to be verified with use of solar energy as the power source of electric pump. Other impact categories remain unchanged.

Table 20 Comparison between use of electricity-based pump vs diesel-based pump vs solar-based pump for irrigation

Impact Categories	Base Case (electric pump)	Diesel-based pump		Solar based pump	
		Value	% change	Value	% Change
Acidification [kg SO_2 eq.]	12.68	11.94	5.84%	10.46	17.51%
Eutrophication [kg phosphate eq.]	1.92	2.10	-9.38%	1.73	9.90%
Climate Change [kg CO_2 eq.]	680.20	641.21	5.73%	503.86	25.92%
Ozone Depletion [kg R11 eq.]	6.90E-09	2.56E-09	62.90%	2.67E-09	61.30%
Photochemical Ozone Creation [kg ethene eq.]	0.15	0.17	-13.33%	0.05	66.67%

5.2.2.3 Effect of composting plant residues

In the base case, allocation was done between cotton seed and cotton residue as the cotton stalk was considered to be a by-product and could be utilised as compost in the field. The amount of nitrogen content in the cotton stalk was about 1% and the weight ratio of cotton seed to cotton stalk was 1:3.5.

To understand the effect of cotton stalk composting the amount of cotton stalk generated was considered for composting and application to land. The results of this analysis are given in Table 21.

Due to the large ammonia emissions (13% of total nitrogen input with the cotton stalks) the acidification potential increased significantly, as well as the eutrophication potential. Also, the total climate change impact was 37% higher than base case as in this the entire impact of the system was considered and not just pertaining to seed cotton. Other impact categories remained unchanged.

Again, it should be noted that the values given here in the scenarios should only be considered as a first screening with high uncertainty. To assume that the nitrogen organically bound in the stalks was as susceptible to volatilization during composting as the much more easily available nitrogen compounds in FYM could be considered a worst-case assumption.

Table 21 Results of composting of field residues

Impact Category	Unit	Base Case (allocation)	With Composting	% change
Acidification	kg SO_2 eq.	12.68	22.45	-77.05%
Eutrophication	kg phosphate eq.	1.92	5.25	-173.44%
Climate Change	kg CO_2 eq.	680.20	930.04	-36.73%
Ozone Depletion	kg R11 eq.	6.90E-09	5.55E-09	19.57%
Photochemical	Kg ethene eq.	0.15	0.04	73.33%
Total Primary Energy Demand	MJ	2.55E+04	2.66E+04	-4.34%

5.2.2.4 Effect of reduction in pesticide consumption

As toxicity was mainly due to use of pesticide, the effect of each pesticide was studied on the eco toxicity and human toxicity impact. The results of the same is shown in Table 22.

It was observed the pesticides having Profenofos as the active ingredient had highest contribution to Eco-toxicity. Thus, reduction in usage of Profenofos may lead to reduction in eco toxicity. Similarly, reduction in usage of pesticides having Acephate as the active ingredient may lead to reduction in the human toxicity potential. It should be noted that dosage and type of pesticides used in the cultivation should be further assessed to draw conclusion as toxicity impacts reported in this analysis were used as a screening method. Other impact categories remained unchanged.

Table 22 Effect of reduction in consumption of pesticides on eco toxicity and human toxicity

Impact Category	Base case	With no pesticide	With 10% less pesticide	With 50% less pesticide	With no Acephate	With no Monocrotophos	With no IMIDA	With no Profenofos
Eco-toxicity [CTUe]	9.00E+03	0.46	8102.90	4501.80	9002.60	9002.70	9003.10	1.46
% Change		99.99%	10.00%	50.00%	0.01%	0.00%	0.00%	99.98%
Human Toxicity [CTUh]	1.82E-06	7.71E-10	1.64E-06	9.13E-07	9.23E-08	1.77E-06	1.82E-06	1.79E-06
% change		99.96%	9.99%	49.91%	94.93%	2.90%	0.19%	1.92%

5.2.3 Organic Cotton

5.2.3.1 Comparison of farms with Highest and lowest yields of seed cotton

To understand the dynamics of the model a comparison between farms having the highest reported yield and lowest reported yield was conducted. The results of this comparison are given in Table 23.

It was observed that impacts dominated by energy used in irrigation were higher in farm having lowest yield. This was due to higher water consumption by the farm. Eutrophication

Table 23 Comparison between farms with highest yield and lowest yield

Impact Category	Unit	Base Case (1755 kg/ha)*	Highest Yield (2722 kg/ha)	Lowest Yield (618 kg/ha)
		1 ton of seed cotton at farm gate (Organic Cotton)		
Acidification	kg SO_2 eq.	0.57	-0.13	3.63
Eutrophication	kg phosphate eq.	-0.02	0.26	-1.80
Climate Change	kg CO_2 eq.	338.50	244.09	844.05
Ozone Depletion	kg R11 eq.	1.85E-09	9.39E-10	1.35E-08
Photochemical Ozone Creation	Kg ethene eq.	0.05	-0.02	0.33
Total Primary Energy Demand	MJ	2.09E+04	19879	25543
Blue Water Consumption	kg	1.40E+05	7.17E+04	1.05E+06
Blue Water Consumption (including rain water)	kg	1.88E+06	1.21E+06	5.35E+06
Eco-toxicity	CTUe	0.14	0.06	0.10
Human Toxicity	CTUh	1.99E-10	9.90E-11	1.16E-09

* weighted average value

5.2.3.2 Effect of use of electric pump vs diesel-based pump vs solar based pump for irrigation

Organic cotton shows high consumption of energy for drawing irrigation water. Thus, the contribution to impacts from electric pump was considered as a parameter and analysed against usage of diesel-based pump vs solar based pump. The results of this analysis are tabulated in Table 24.

In the base case irrigation was done using an electric pump. With change in type of energy source it was observed that diesel-based pump could show a savings potential of 4.44% in the climate change impact. But it contributed ~100% more in eutrophication. The solar based pump was found to be showcasing the highest possible savings in all impact categories. Although the primary energy demand needs to be verified with use of solar energy as the power source of electric pump. Other impact categories remain unchanged.

Table 24 Comparison between uses of electric pump vs Diesel-based pump vs solar based pump for irrigation

Impact Categories	Base Case (electric pump)	Diesel-based pump		Solar based pump	
		Value	% change	Value	% Change
Acidification [kg SO_2 eq.]	0.56	0.28	50.54%	-0.34	~100%
Eutrophication [kg phosphate eq.]	-0.02	0.10	~-100	-0.05	~100%
Climate Change [kg CO_2 eq.]	336.94	321.97	4.44%	266.15	42.16%
Ozone Depletion [kg R11 eq.]	1.85E-09	8.30E-11	95.51%	1.28E-10	80.07%
Photochemical Ozone Creation [kg ethene eq.]	0.05	0.06	-18.42%	6.63E-03	~100%

5.2.3.3 Effect of composting plant residues

In the base case, allocation was done between cotton seed and cotton residue as the cotton stalk was considered to be a by-product and could be utilised as compost in the field. The amount of nitrogen content in the cotton stalk was about 1% and the weight ratio of cotton seed to cotton stalk was 1:3.5.

To understand the effect of cotton stalk, composting the amount of cotton stalk generated was considered for composting and application to land. The results of this analysis are given in Table 25.

Due to the large ammonia emissions (13% of total nitrogen input with the cotton stalks) the acidification potential increased significantly, as well as the eutrophication potential. Also, the total climate change impact was 42% higher than base case as in this the entire impact of the system was considered and not just pertaining to seed cotton. Other impact categories remain unchanged.

Again, it should be noted that the values given here should only be considered as a first screening with high uncertainty. To assume that the nitrogen organically bound in the stalks was as susceptible to volatilization during composting as the much more easily available nitrogen compounds in FYM could be considered as a worst-case assumption.

Table 25 Results of composting of field residues

Impact Category	Unit	Base Case (allocation)*	With Composting	% change
Acidification	kg SO_2 eq.	0.57	10.20	~100%
Eutrophication	kg phosphate eq.	-0.02	2.91	~100%
Climate Change	kg CO_2 eq.	338.50	479	-42%
Ozone Depletion	kg R11 eq.	1.85E-09	3.68E-10	80%
Photochemical Ozone Creation	Kg ethene eq.	0.05	-7.26E-02	252%
Total Primary Energy Demand	MJ	2.09E+04	2.02E+04	3%

* Allocation between seed cotton and cotton stalk

5.3 Limitations

This study provided LCA inventory data of good overall quality on seed cotton produced under the three conditions viz., Better Cotton Initiative, conventional cotton and organic cotton. These data were specific to cotton cultivation in the region of Madhya Pradesh, India. However, there are some limitations that are needed to be considered in interpretation of the results.

On inventory level, it has to be stated that time representativeness of inventory could be improved by a systematic collection of data to cover several cultivation periods and to cover the same time span. It should also be noted here, that this study was based on primary data that underwent plausibility checks but was not independently verified.

The agricultural model used in this study was constantly updated and improved, thus claiming to cover all relevant emissions and to allow a comprehensive LCI setup and LCIA of agricultural systems. However, for many relevant aspects (such as soil types, nutrient content of soils, soil erosion) primary data was very hard to obtain, so that default values were applied. These default values do not necessarily represent exact local conditions but were regional averages. To aggregate data into regional averages was additionally challenging and could potentially lead to distortions in a model trying to represent a realistic cultivation system.

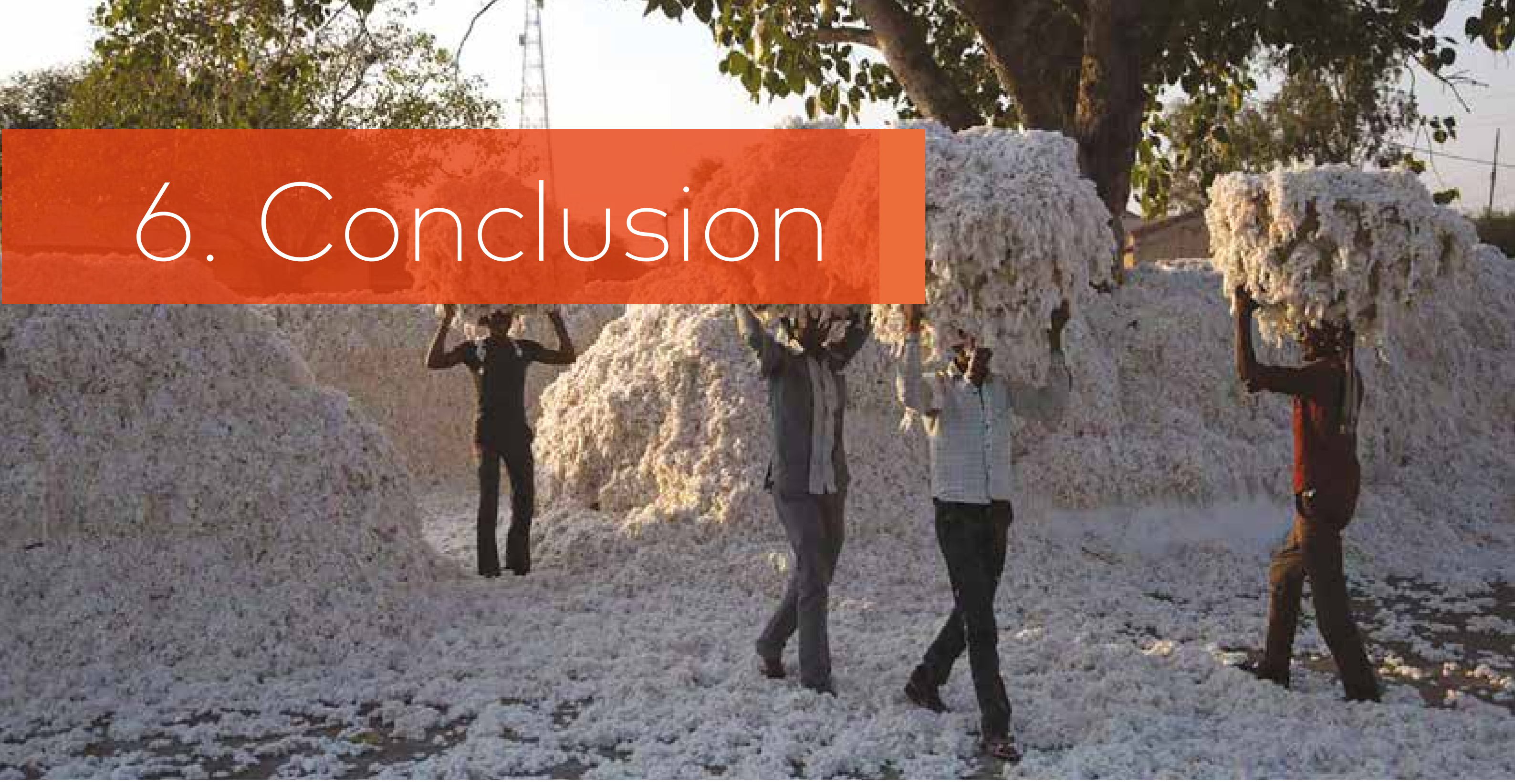
These variations do not necessarily mean that the data quality was compromised. To highlight the most obvious example, blue water consumption was expected to vary widely if irrigated and non-irrigated systems were included in the average. Still, it was observed that the results do not allow drawing conclusions on the environmental performance of individual sites.

Maybe even more important, agricultural systems were complex, and methodological decisions as well as the choice of modelling approaches and assumptions could influence the results significantly, very visibly illustrated by different scenarios shown in section 5.1. It should therefore be repeated here, that absolute numbers should be interpreted with care and not be used as stand-alone indicators for simplified statements or unfounded decision making.

It should also be noted that the impact categories represented potential impacts; in other words, they were approximations of environmental impacts that could occur, if the emitted molecules actually followed the underlying impact pathway and met certain conditions in the receiving environment while doing so. LCIA results were therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks. In addition, water consumption was reported as environmental indicators only and no further impact methodology was applied.

There were some additional limitations related to the LCA methodology that should be mentioned here. In this study, Life Cycle Assessment was used as a standardized tool for quantitative evaluation of potential environmental impacts on product basis. Thereby the methodology focuses on resource use efficiency rather than on overall impacts of entire production systems. It also does not allow drawing conclusions on the capacity of the concerned ecological systems to cope with these impacts. Additionally, some environmental aspects such as impact on biodiversity could not be accessed within the LCA methodology so far, despite being considered of high relevance. Hence, some of the environmental impacts that the cotton cultivation systems potentially had were omitted from the analysis.

All this said, and without even mentioning the social and socio-economic dimensions of sustainability, it becomes clear that further aspects than those investigated in this study need to be considered for a holistic assessment of sustainability of production systems or a comparison with another production system.



6. Conclusion

The key findings of this study can be summarized as follows:

- This study provides LCA inventory data of good overall quality on Better Cotton, conventional cotton and organic cotton cultivation systems for the region of Madhya Pradesh, India.

- The results of this study could be applied as a reference value for Better Cotton, conventional cotton and organic cotton cultivation systems in Indian state of Madhya Pradesh and should be used with confidence in any further LCA studies e.g. along the value chain of the apparel industry specific to this region.

- Better Cotton and conventional cultivation systems were impacted by emissions occurring in the field and activities like energy used in irrigation, tractor operations, pesticides and chemical/ organic fertilizers production, emissions from composts, etc.

- Organic systems were impacted by emissions occurring in field, energy consumption in irrigation, tractor operations, emissions from composts, other organic inputs for nutrition and plant protection, etc.

- Yield played a predominant role. Higher yield along with good agriculture practices would help optimize resource consumption and improve environmental impacts with respect to the functional unit, which was 1 metric ton of seed cotton.

- Decisions as well as the choice of modelling approaches and assumptions could influence the results significantly (specifically the assumption of burden free provision of organic fertilizers).

- Field emissions of ammonia and nitrogen monoxide dominate the impact on climate change and were an important contributor to acidification potential.

- Some of the potential environmental impacts of cotton cultivation such as the impact on biodiversity were not assessed in this study due to limitations in the LCA methodology with this regard.

- Decision should not be taken on toxicity parameters due to their uncertainty. The use of organic nutrients and protection measures had not only reduced the harmful effects on the toxicity, but also helped reduce other impacts. Increasing the awareness on the use of pesticides was recommended. Further, it was suggested that decisions on the type and quantity of pesticides, essentially be based on laboratory tests.

- Life Cycle Assessment is a powerful standardized tool for quantitative evaluation of potential environmental impacts on product basis; however, given the social and socio-economic dimensions of sustainability, further aspects than those investigated in this study need to be considered for a holistic assessment of sustainability of production systems or a comparison with another production system.

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8. Annexure

8.1 Critical Review Process

The proposed critical review process was conducted in three stages:

Stage 1: Goal and scope document submission to the panel to understand the project goal and scope- study purpose, boundaries, and data qualities

- **Step 1:** A brief teleconference was conducted for reviewers to make introductions and understand the goal and scope of the study.

Stage 2: LCA Draft Report was submitted to the panel to review LCA of all three cotton products

- **Step 2:** The panel reviewed the LCI modeling principles, primary data and background databases, adherence to the allocation procedures of ISO 14040/44 standard, selection of LCIA categories and conclusions.
- **Step 3:** The panel discussed potential revisions/ adjustments and communicated feedback.
- **Step 4:** Thinkstep team incorporated the feedback and submitted the revised LCA report
- **Stage 3:** The panel submitted final review statement for ISO 14044 compliance.

In parallel, the same three stage process was followed for review through advisory panel.

8.2 Assumptions

- Regional average data were considered for the parameters such as rainfall, soil erosion rate and evapotranspiration rate specific to Madhya Pradesh, India.
- The precipitation was assumed to follow the natural hydrologic cycle regardless of the land use type and therefore no environmental burden was associated with it from a LCA perspective in the blue water consumption impact and only quantification of amount was carried out.
- As manual farming was observed with an exception of Tractor being used for initial soil preparation. Only tractor operations emissions and production emissions of fuel consumed by tractor were considered.
- An average transportation distance of 300 km was considered for the transport of materials to the farm.
- The upstream impacts of organic inputs such as home-made nutrients as described in 8.6, cow dung, etc. were considered burden free.

8.3 Data Collection Questionnaire

The questionnaire provides an indication of the data collected by region within Madhya Pradesh, India for all three types of cotton cultivation systems. The weather and soils data specific to this region were input to the cultivation model to evaluate the nitrogen and carbon cycles. All information was collected for the period under investigation. The green circle signifies the applicability of the question whereas red signal signifies the non-applicability of the question.

Table 26 Questionnaire used for Data collection

Questionnaire for cultivation phase	Base Cotton	Conventional Cotton	Organic Cotton
Information on Field activity			
Typical crop rotation in the region (previous crop and following crop)	🟢	🟢	🟢
Did fire clearing take place prior to cultivation establishment?	🟢	🟢	🟢
Soil preparation (ploughing, tillage, minimum tillage, direct seeding)	🟢	🟢	🟢
Date of sowing / planting	🟢	🟢	🟢
Variety planted	🟢	🟢	🟢
Is the field irrigated [Yes / No]	🟢	🟢	🟢
If yes: amount of water irrigated (over the crop cycle)	🟢	🟢	🟢
Number of times the field gets irrigated in whole crop cycle	🟢	🟢	🟢
Number of Days the field gets irrigated for single irrigation	🟢	🟢	🟢
Number of Hours working of pump	🟢	🟢	🟢
If yes: Where does the water derive from (e.g. groundwater, surface water, rivers, tab water, rain water harvesting, other?)	🟢	🟢	🟢
Depth of Bore-well/ Well (in feet)	🟢	🟢	🟢
Power of irrigation pump in Horse Power	🟢	🟢	🟢
If yes: Kind of irrigation pump (diesel, electricity)	🟢	🟢	🟢
Harvesting Period	🟢	🟢	🟢
Amount of main product (seed cotton) harvested and taken off the field (fresh weight).	🟢	🟢	🟢
Are plant residues taken from the field [Yes / No]	🟢	🟢	🟢
Are there any other valuable products taken off from the field (intercropping)? [Yes / No]	🟢	🟢	🟢
If yes, kind of product harvested (e.g. beans) in kg	🟢	🟢	🟢
Total diesel demand for all mechanical operations taking place during cultivation, if any (soil preparation, fertilizing, harvest, etc.)	🟢	🟢	🟢
Diesel consumption (per hectare)	🟢	🟢	🟢
Information on mineral fertilizer application			
Fertilization 1 / Fertilization 2/..	🟢	🟢	🔴
Date of application	🟢	🟢	🔴
Type of Fertilizers (e.g. NPK, urea, ammonia)	🟢	🟢	🔴
Amount of fertilizer (per hectare)	🟢	🟢	🔴
Information on organic fertilizer application			
Fertilization 1 / Fertilization 2/..	🟢	🟢	🟢
Date of application	🟢	🟢	🟢
Kind (name) of fertilizer (Rock phosphate, Compost, FYM, etc.)	🟢	🟢	🟢
Amount of fertilizer (kg/ ha)	🟢	🟢	🟢
Source material of the fertilizer	🟢	🟢	🟢

Questionnaire for cultivation phase	Base Cotton	Conventional Cotton	Organic Cotton
Information on pesticides application			
Application 1 / Application 2/..	🟢	🟢	🔴
Date of application	🟢	🟢	🔴
Type of application/measure (e.g. herbicide, insecticide)	🟢	🟢	🔴
Name of active ingredient in the application	🟢	🟢	🔴
Amount of active ingredient applied to the field	🟢	🟢	🔴
Information on organic plant protection measures			
Measure 1/ Measure 2/..	🟢	🟢	🟢
Date of application	🟢	🟢	🟢
Kind (name) of application / measure (e.g. minerals, microbial products, botanical products, pheromone, other)	🟢	🟢	🟢
Name of active ingredient in the application (e.g. neem oil, neem cake, Bacillus thuringiensis, Sulphur, other)	🟢	🟢	🟢
Amount of application applied to the field	🟢	🟢	🟢
Information on measures taken for protection of biodiversity			
Any specific management practices in place to protect biodiversity (additional to the organic cultivation scheme) e.g. growing of hedgerows, dams against soil erosion, intercropping, agroforestry, etc.	🟢	🟢	🟢

8.4 Inventory input to GaBi Model (for review purpose only)

Inputs into the agrarian production system adapted in the GaBi model for all three types of cultivations are given below in Table 27.

Table 27 Inventory of the modelled systems

Better cotton			
	Unit	Value	Source
Biomass burning – Clearance			
Application	[%]	n. a.	questionnaire
Biomass on the field	[kg/ha]	n. a.	Estimate
Fertilizers			
Compost	[kg/ha]	134	questionnaire
N-Content	[% FM]	0.5	Literature
Cow dung	[kg/ha]	1656	questionnaire
N-Content	[% FM]	0.9	GaBi
Farm yard manure	[kg/ha]	0	questionnaire
N-Content	[% FM]	0.4	GaBi
Urea	[kg/ha]	125	questionnaire
N-Content	[% FM]	57	GaBi
Other Inputs			
Seed	[kg/ha]	1.5	questionnaire
DAP	[kg/ha]	132	questionnaire
Potash	[kg/ha]	122	questionnaire
Irrigation	[m3/ha]	688	questionnaire
Natural N Input			
N fixation soil	[kg/ha]	10	GaBi/Literature
N in precipitation	[kg/ha]	20	GaBi/Literature
Pesticide - Active Ingredient			
Imidacloprid	[kg/ha]	0.19	questionnaire
Monocrotophos	[kg/ha]	0.01	questionnaire
Acephate	[kg/ha]	0.14	questionnaire
Profenofos	[kg/ha]	0.17	questionnaire
Yield (seed cotton)			
Yield (seed cotton)	[kg/ha]	1888	questionnaire
N Content	[% FM]	2	GaBi/Literature/ Estimate

Conventional Cotton			
	Unit	Value	Source
Biomass burning – Clearance			
Application	[%]	n. a.	questionnaire
Biomass on the field	[kg/ha]	n. a.	Estimate
Fertilizers			
Compost	[kg/ha]	257	questionnaire
N-Content	[% FM]	0.5	Literature
Cow dung	[kg/ha]	2397	questionnaire
N-Content	[% FM]	0.9	GaBi
Farm yard manure	[kg/ha]	0	questionnaire
N-Content	[% FM]	0.4	GaBi
Urea	[kg/ha]	137	questionnaire
N-Content	[% FM]	57	GaBi
Other Inputs			
Seed	[kg/ha]	1.5	questionnaire
DAP	[kg/ha]	136	questionnaire
Potash	[kg/ha]	117	questionnaire
Irrigation	[m3/ha]	663	questionnaire
Natural N Input			
N fixation soil	[kg/ha]	10	GaBi/Literature
N in precipitation	[kg/ha]	20	GaBi/Literature
Pesticide - Active Ingredient			
Imidacloprid	[kg/ha]	0.21	questionnaire
Monocrotophos	[kg/ha]	0.09	questionnaire
Acephate	[kg/ha]	1.00	questionnaire
Profenofos	[kg/ha]	0.14	questionnaire
Yield (seed cotton)			
Yield (seed cotton)	[kg/ha]	1938	questionnaire
N Content	[% FM]	2	GaBi/Literature/ Estimate

Organic Cotton			
	Unit	Value	Source
Biomass burning – Clearance			
Application	[%]	n. a.	questionnaire
Biomass on the field	[kg/ha]	n. a.	Estimate
Fertilizers			
Compost	[kg/ha]	4613	questionnaire
N-Content	[% FM]	0.5	Literature
Cow dung	[kg/ha]	10171	questionnaire
N-Content	[% FM]	0.9	GaBi
Farm yard manure	[kg/ha]	535	questionnaire
N-Content	[% FM]	0.4	GaBi
Urea	[kg/ha]	N.A.	questionnaire
N-Content	[% FM]	57	GaBi
Other Inputs			
Seed	[kg/ha]	1.5	questionnaire
DAP	[kg/ha]	N.A.	questionnaire
Potash	[kg/ha]	N.A.	questionnaire
Irrigation	[m3/ha]	244	questionnaire
Natural N Input			
N fixation soil	[kg/ha]	10	GaBi/Literature
N in precipitation	[kg/ha]	20	GaBi/Literature
Pesticide - Active Ingredient			
Imidacloprid	[kg/ha]	n. a.	questionnaire
Monocrotophos	[kg/ha]	n. a.	questionnaire
Acephate	[kg/ha]	n. a.	questionnaire
Profenofos	[kg/ha]	n. a.	questionnaire
Yield (seed cotton)			
Yield (seed cotton)	[kg/ha]	1755	questionnaire
N Content Estimate	[% FM]	2	GaBi/Literature/

8.5 Data for Scenario

Table 28 Data of farms with Highest Yield and Lowest Yield in all three types of cotton cultivation

Better cotton			
Parameter	Unit	Highest Yield	Lowest Yield
		6000	619
Organic Fertilizer Input			
Farm yard manure	kg/ha	-	-
Nitrogen content of FYM	% in fresh matter	0.4	0.4
Compost	kg/ha	-	-
Nitrogen content of compost	% in fresh matter	0.7	0.7
Cow dung	kg/ha	1238	2000
Nitrogen content of cow dung	% in fresh matter	0.9	0.9
Chemical Fertilizer Input			
DAP	kg/hectare	124	0
Urea	kg/hectare	62	248
Potash	kg/hectare	0	248
Pest and weed control			
Confidore (active ingredient Imidacloprid)	kg/ha	1.89	0.03
Mono (active ingredient Monocrotophos)	kg/ha	0.00	0.00
Acephate (active ingredient Acephate)	kg/ha	0.00	0.00
Profeno (active ingredient Profenofos)	kg/ha	0.00	0.00
Total pesticide		1.89	0.03
Machinery use			
Diesel demand (Tractor, not incl. irrigation)	l/ha	48	32
Irrigation			
Irrigation water use	m^3/ha	963	636
Conventional Cotton			
Parameter	Unit	Highest Yield	Lowest Yield
		3438	248
Organic Fertilizer Input			
Farm yard manure	kg/ha	-	-
Nitrogen content of FYM	% in fresh matter	0.4	0.4
Compost	kg/ha	-	-
Nitrogen content of compost	% in fresh matter	0.7	0.7
Cow dung	kg/ha	743	1980
Nitrogen content of cow dung	% in fresh matter	0.9	0.9

Conventional Cotton			
Chemical Fertilizer Input			
DAP	kg/hectare	79	145
Urea	kg/hectare	79	124
Potash	kg/hectare	68	103
Pest and weed control			
Confidore (active ingredient Imidacloprid)	kg/ha	-	-
Mono (active ingredient Monocrotophos)	kg/ha	0.05	0.18
Acephate (active ingredient Acephate)	kg/ha	1.67	1.86
Profeno (active ingredient Profenofos)	kg/ha	0.89	0
Total pesticide		2.61	2.04
Machinery use			
Diesel demand (Tractor, not incl. irrigation)	l/ha	48	64
Irrigation			
Irrigation water use	m^3/ha	358	48
Organic Cotton			
Parameter	Unit	Highest Yield	Lowest Yield
		2722	618
Organic Fertilizer Input			
Farm yard manure	kg/ha	1198	495
Nitrogen content of FYM	% in fresh matter	0.4	0.4
Compost	kg/ha	4951	-
Nitrogen content of compost	% in fresh matter	0.7	0.7
Cow dung	kg/ha	18812	9406
Nitrogen content of cow dung	% in fresh matter	0.9	0.9
Chemical Fertilizer Input			
DAP	kg/hectare	-	-
Urea	kg/hectare	-	-
Potash	kg/hectare	-	-
Pest and weed control			
Confidore (active ingredient Imidacloprid)	kg/ha	-	-
Mono (active ingredient Monocrotophos)	kg/ha	-	-
Acephate (active ingredient Acephate)	kg/ha	-	-
Profeno (active ingredient Profenofos)	kg/ha	-	-
Total pesticide		-	-
Machinery use			
Diesel demand (Tractor, not incl. irrigation)	l/ha	0	32
Irrigation			
Irrigation water use	m^3/ha	193	648

8.6 Description of Organic input materials used by farmers

Table 29 Organic Inputs used by Better Cotton and Organic Farmers

Organic input material	Ingredients and preparation
Cow dung or Matka (Pot) khaad (Manure)	10 kg cow dung, 10 kg cow urine, 500 g of damp soil, 250 g of Jaggery, kept in a pot in a shaded area and mixed once a day for 7 days. On 8th day it was sprayed or applied using drip irrigation by diluting with water (200 l). It works as Urea.
Bistara Khaad Or Compost	A trolley of soil conditioner or DAP, 8 kg Maize dust, 10 kg ballast quarry husk or tubewell husk, Cow urine (10 litres in 100 litres of water).
Panch Patti Kadha (concentrate of Five leaves)	5 types of leaves including Custard apple, Neem, Indian Beech (Karanj), Devil's trumpets (Dhatura) and Ipomoea carnea. 0.5 kg of each were mixed with 7-8 litres cow urine and 10-12 litres water and then it was fermented for 6-7 days.
Garlic Onion Ginger Chilli paste	0.5 kg of garlic, 0.5 kg of shriller chilli, 0.5 kg of Onion, 0.5 kg of ginger (optional), was mixed with 4-6 litres of water, the paste was kept in water for 24 hours, and then filtered before application.
Fresh Butter milk	
Rotten Butter milk	10-15 days old butter milk
Soya Tonic	1 kg of soya bean was crushed and added with 0.5 kg of jaggery in 4 litres of water this mixture was kept for 24 h and then filtered before application.

8.7 Description of result parameters

Primary energy consumption
Primary energy demand is often difficult to determine due to the various types of energy source. Primary energy demand is the quantity of energy directly withdrawn from the hydrosphere, atmosphere or geosphere or energy source without any anthropogenic change. For fossil fuels and uranium, this would be the amount of resource withdrawn expressed in its energy equivalent (i.e. the energy content of the raw material). For renewable resources, the energy-characterized amount of biomass consumed would be described. For hydropower, it would be based on the amount of energy that is gained from the change in the potential energy of the water (i.e. from the height difference). As aggregated values, the following primary energies are designated:

The total "**Primary energy consumption non-renewable**", given in MJ, essentially characterizes the gain from the energy sources natural gas, crude oil, lignite, coal and uranium. Natural gas and crude oil will be used both for energy production and as material constituents e.g. in plastics. Coal will primarily be used for energy production. Uranium will only be used for electricity production in nuclear power stations.

The total "**Primary energy consumption renewable**", given in MJ, is generally accounted separately and comprises hydropower, wind power, solar energy and biomass.

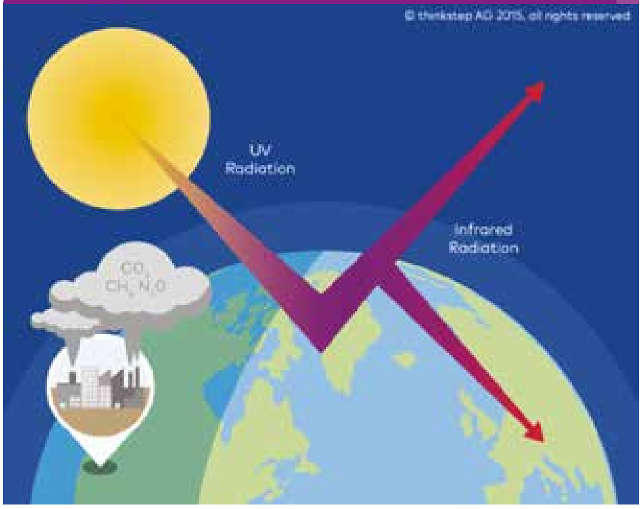
It is important that the end energy (e.g. 1 kWh of electricity) and the primary energy used are not miscalculated with each other; otherwise the efficiency for production or supply of the end energy will not be accounted for.

The energy content of the manufactured products will be considered as feedstock energy content. It will be characterized by the net calorific value of the product. It represents the still usable energy content.

Climate Change or Global Warming Potential (GWP)
The mechanism of the greenhouse effect can be observed on a small scale, as the name suggests, in a greenhouse. These effects are also occurring on a global scale. The occurring short-wave radiation from the sun comes into contact with the earth's surface and is partly absorbed (leading to direct warming) and partly reflected as infrared radiation. The reflected part is absorbed by so-called greenhouse gases in the troposphere and is re-radiated in all directions, including back to earth. This results in a warming effect at the earth's surface.

In addition to the natural mechanism, the greenhouse effect is enhanced by human activities. Greenhouse gases that are considered to be caused, or increased, anthropogenically are, for example, carbon dioxide, methane and CFCs. Figure 32 shows the main processes of the anthropogenic greenhouse effect. An analysis of the greenhouse effect should consider the possible long-term global effects. The global warming potential is calculated in carbon dioxide equivalent (CO2 equiv.). This means that the greenhouse potential of an emission is given in relation to CO2. Since the residence time of the gases in the atmosphere is incorporated into the calculation, a time range for the assessment must also be specified. A period of 100 years is customary.

Figure 32 Greenhouse effect (Kreissig and Kümmel 1999)



Acidification Potential (AP)

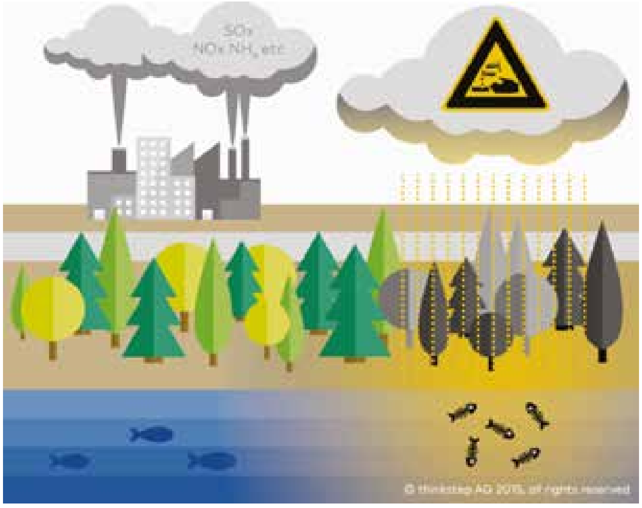
The acidification of soils and waters occurs predominantly through the transformation of air pollutants into acids. This leads to a decrease in the pH-value of rainwater and fog from 5.6 to 4 and below. Sulphur dioxide and nitrogen oxide and their respective acids (H_2SO_4 and HNO_3) produce relevant contributions. This damages ecosystems, whereby forest dieback is the most well-known impact.

Acidification has direct and indirect damaging effects (such as nutrients being washed out of soils or an increased solubility of metals into soils). But even buildings and building materials can be damaged. Examples include metals and natural stones which are corroded or disintegrated at an increased rate.

When analyzing acidification, it should be considered that although it is a global problem, the regional effects of acidification can vary. Figure 33 displays the primary impact pathways of acidification.

The acidification potential is given in Sulphur dioxide equivalent (SO_2 equiv.). The acidification potential is described as the ability of certain substances to build and release H+ - ions. Certain emissions can also be considered to have an acidification potential, if the given S-, N- and halogen atoms are set in proportion to the molecular mass of the emission. The reference substance is Sulphur dioxide.

Figure 33 Acidification Potential (Kreissig and Kümmel 1999)



Eutrophication Potential (EP)

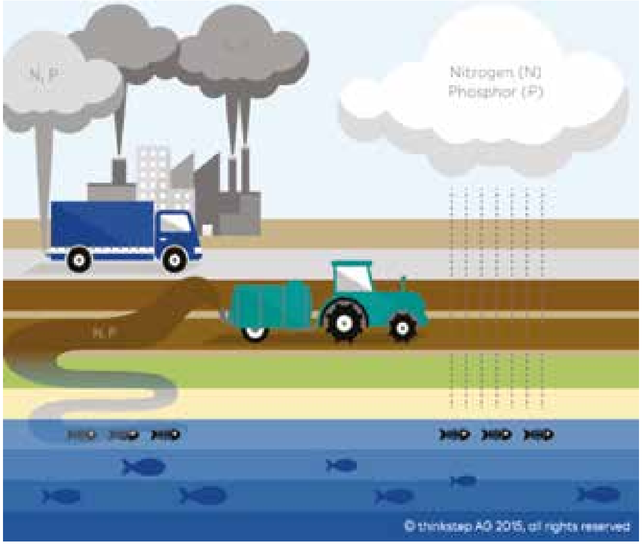
Eutrophication is the enrichment of nutrients in a certain place. Eutrophication can be aquatic or terrestrial. Air pollutants, waste water and fertilization in agriculture all contribute to eutrophication.

The result in water is an accelerated algae growth, which in turn, prevents sunlight from reaching the lower depths. This leads to a decrease in photosynthesis and less oxygen production. In addition, oxygen is needed for the decomposition of dead algae. Both effects cause a decreased oxygen concentration in the water, which can eventually lead to fish dying and to anaerobic decomposition (decomposition without the presence of oxygen). Hydrogen sulphide and methane are thereby produced. This can lead, among others, to the destruction of the eco-system.

On eutrophicated soils, an increased susceptibility of plants to diseases and pests is often observed, as is a degradation of plant stability. If the nutrification level exceeds the amounts of nitrogen necessary for a maximum harvest, it can lead to an enrichment of nitrate. This can cause, by means of leaching, increased nitrate content in groundwater. Nitrate also ends up in drinking water.

Nitrate at low levels is harmless from a toxicological point of view. However, nitrite, a reaction product of nitrate, is toxic to humans. The causes of eutrophication are displayed in Figure 34. The eutrophication potential is calculated in phosphate equivalent (PO4 equiv.). As with acidification potential, it's important to remember that the effects of eutrophication potential differ regionally.

Figure 34 Eutrofication Potential (Kreissig and Kümmel 1999)



Photochemical Ozone Creation Potential (POCP)
A measure of emissions of precursors that contribute to ground level smog formation (mainly ozone O3), produced by the reaction of VOC and carbon monoxide in the presence of nitrogen oxides under the influence of UV light. Ground level ozone may be injurious to human health and ecosystems and may also damage crops. Unit of POCP is kg C2H4 equivalent (Guinée, et al., 2002)

Ozone Depletion Potential (ODP)
A measure of air emissions that contribute to the depletion of the stratospheric ozone layer. Depletion of the ozone leads to higher levels of UVB ultraviolet rays reaching the earth's surface with detrimental effects on humans and plants. The unit for Ozone Depletion Potential is kg CFC-11 equivalent (Guinée, et al., 2002) or kg R-11 equivalent.

Water consumption
Water use is understood as an umbrella term for all types of anthropogenic water uses. On an inventory level, water use equals the measured water input into a product system or process. In most cases water use is determined by total water withdrawal (water abstraction).

Consumptive and degradative use
Freshwater use is generally differentiated into consumptive water use (= water consumption) and degradative water use, the latter denoting water pollution:

Freshwater consumption (consumptive freshwater use) describes all freshwater losses on a watershed level which are caused by evaporation, evapotranspiration harvest from plants[7], freshwater integration into products, and release of freshwater into sea (e.g. from wastewater treatment plants located on the coast line). Therefore, freshwater consumption is defined in a hydrological context and should not be interpreted from an economic perspective, so it does not equal the total water use (total water withdrawal), but rather the associated losses during water use. Note that only the consumptive use of freshwater, not sea water, is relevant from an impact assessment perspective because freshwater is a limited natural resource.

Degradative water use, in contrast, denotes the use of water with associated quality alterations and describes the pollution of water (e.g. if tap water is transformed to wastewater during use). These alterations in quality are not considered to be water consumption.

The watershed level is regarded as the appropriate geographical resolution to define freshwater consumption (hydrological perspective). If groundwater is withdrawn for drinking water supply and the treated wastewater is released back to a surface water body (river or lake), then this is not considered freshwater consumption if the release takes place within the same watershed; it is degradative water use.

The difference between freshwater use and freshwater consumption is highly crucial to correctly quantify freshwater consumption, in order to interpret the meaning of the resulting values and for calculating water footprints (ISO 14046).

The water footprint of a system is a set of different calculations and should be used as an umbrella term rather than to communicate a single number. According to ISO 14046 (in progress; (ISO 14046)) a water footprint consists of two parts: a water stress footprint caused by consumptive use and a water stress footprint caused by degradative water use.

Degradative use causes environmental impacts due to the pollutants released to nature. Yet, quality alterations during degradative use, e.g. release of chemicals, are normally covered in other impact categories of an LCA, such as eutrophication and eco-toxicity. Methods to assess additional stress to water resources caused by reduced availability of water (due to reduced quality) are under development, but not addressed in this study. So far, water foot printing focuses on the water lost to the watershed, i.e. water consumption. Water consumption is considered to have a direct impact on the environment (e.g. freshwater depletion and impacts to biodiversity).

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[7] Note: Typically, only water from irrigation is considered in the assessment of agricultural processes and the consumption of rain water is neglected. The rationale behind this approach is the assumption that there is no environmental impact of green water (i.e. rain water) consumption. Such an effect would only exist if crop cultivation results in alterations in water evapotranspiration, runoff and infiltration compared to natural vegetation. Additionally, it remains arguable whether or not such changes (if they occur) should be covered by assessment of land use changes rather than in water inventories. However, rain water use is sometimes assessed in different methodological approaches or can be used for specific analyses. The GaBi software allows assessment of both water use including rain water ("Total fresh water use", "total freshwater consumption") and without rainwater ("Blue water use" and "blue water consumption").

Human toxicity and Eco-toxicity
A measure of toxic emissions which are directly harmful to the health of humans and other species. Comparative toxic units (CTUh, CTUe) (Rosenbaum, et al., 2008)

The characterization factor for human toxicity impacts (human toxicity potential) is expressed in comparative toxic units (CTUh), the estimated increase in morbidity in the total human population, per unit mass of a chemical emitted, assuming equal weighting between cancer and non-cancer due to a lack of more precise insights into this issue. Unit: [CTUh per kg emitted] = [disease cases per kg emitted]

The characterization factor for aquatic ecotoxicity impacts (ecotoxicity potential) is expressed in comparative toxic units (CTUe), an estimate of the potentially affected fraction of species (PAF) integrated over time and volume, per unit mass of a chemical emitted.

Unit: [CTUe per kg emitted] = [PAF × m^3 × day per kg emitted]

8.8 Critical Review Statement

Fraunhofer Institute for Building Physics IBP

Directors
Prof. Dr. Philip Leistner
Prof. Dr. Klaus Peter Sedlbauer

Wankelstrasse 5
70563 Stuttgart
Germany

Dipl.-Ing. Matthias Fischer
Head of Department
Department Life Cycle Engineering Phone +49 711 970-3155 | Fax -970-3190 matthias.fischer@ibp.fraunhofer.de www.ibp.fraunhofer.de

Critical Review of the Study
Life Cycle Assessment of Cotton Cultivation Systems: Better Cotton, Conventional Cotton and Organic Cotton

Commissioner:
C&A Foundation

Practitioner:
Thinkstep Sustainability Solutions Pvt. Ltd., India
Dr. Rajesh Kumar Singh
Mr. Ritesh Agrawal
Ms. Hiranmayee Kanekar

Review Panel Chair:
Mr. Matthias Fischer (Fraunhofer IBP, Germany)

Review Panel Members:
Dr. Senthilkannan Muthu (SgT group & API, Hong Kong)

Mr. Simon Ferrigno (Cotton and Sustainability Expert)
Mr. Rajeev Verma (Cotton Connect, India)

Stuttgart, 25th May 2018

Content

1. Summary
According to the requirements of ISO 14040 and ISO 14044 a critical review of the study "Life Cycle Assessment of Cotton Cultivation Systems: Better Cotton, Conventional Cotton and Organic Cotton" was performed by a panel of independent external reviewers. Within the study "Life Cycle Assessment of Cotton Cultivation Systems: Better Cotton, Conventional Cotton and Organic Cotton" three different cultivation systems for cotton cultivation in Madhya Pradesh, India are analysed regarding their environmental performance following the methodology of Life Cycle Assessment. The functional unit used in the study is the production of 1 metric ton of seed cotton at farm gate.
The conformity regarding the requirements of the standards has been fulfilled, the used methodology is scientifically and technically valid, the approach is transparent and well documented. The data used is appropriate and reasonable, the results and interpretation correspond to the goals of the study and the study report is transparent and consistent. The study "Life Cycle Assessment of Cotton Cultivation Systems: Better Cotton, Conventional Cotton and Organic Cotton" thus complies with the ISO 14040 and ISO 14044 standards.

2. Critical Review Process

The subject of this Critical Review is the study "Life Cycle Assessment of Cotton Cultivation Systems: Better Cotton, Conventional Cotton and Organic Cotton", commissioned by C&A Foundation and carried out by Thinkstep Sustainability Solutions Pvt. Ltd. India. The Critical Review was performed in parallel to the study from June 2017 to May 2018 and the critical review statement is based on the final study report dated 17th May 2018. Several online meetings and phone conferences took place to discuss the study setup, the goal and scope, the modelling, the results and conclusions and specific topics regarding Life Cycle Assessment (LCA) methodology. The results of the meetings have been included in the study.

The critical review was carried out according to the requirements of ISO 14040 and ISO 14044. Particular focus of the review is the assessment of the conformity to the scientific and technical aspects and principles as well as the consistency of the derived statements and conclusions.

Subject of the study is the analysis of the environmental effects of three different cultivation systems for seed cotton, one system according to specifications of the Better Cotton Initiative, one system following conventional cotton cultivation and one system following organic cotton cultivation. The geographic reference of all systems is India, in particular Madhya Pradesh. The critical review is based on technical specifications, on Life Cycle Assessment models, on primary data from farmers for the cultivation systems as well as several used background data. The data and information were provided by Thinkstep Sustainability Solutions Pvt. Ltd., India.

Within the review process all open questions regarding methodology, modelling, report, data and assumptions have been discussed and resolved.

3. Critical Review Results

The study is performed in accordance with ISO 14040 and ISO 14044. The used methodology and the modelling of the system is of good quality and is suitable to fulfil the goals of the study. The study report is comprehensive and describes goal and scope, results and interpretation in a transparent way.

3.1 Conformity to ISO 14040 and ISO 14044

The study is performed in accordance with the requirements of ISO 14040 and ISO 14044.

3.2 General Aspects, Goal and Scope, Functional Unit and System Boundary

Study commissioner, practitioner, date of the report and a reference statement to the respective standards are given. The goal of the study, the scope of the study, the function and the system boundaries are well defined and described and are consistent to the objectives of the study. Significant assumptions and limitations are addressed transparently. The functional unit for all systems is 1 metric ton of seed cotton at farm gate.

3.3 Methodology, Data, Modelling, Assumptions, Results and Interpretation

The methodological basis of the study are the mentioned standards. The used methodology is in accordance with the state of technology and covers all relevant aspects of the systems. A high methodological quality of the study is ensured. The used data for the three cultivation systems are directly collected from farmers in Madhya Pradesh, India, background data for upstream processes and supply chains are taken from the GaBi software database. The data are detailed, consistent and based on an extensive data collection process. The data quality is of good quality level and the used data are appropriate and according to the goal of the study.

The assumptions used within the study are plausible and well documented. The interpretation of the results is carried out regarding the goals of the study. The interpretation is neutral, and the conclusions and recommendations are comprehensible derived.

With the analysed scenarios significant parameters of the cultivation systems have been evaluated regarding their sensitivity to the results. The scenario analysis is transparent and covers relevant parameters.

3.4 Study Report

The study report is in accordance with the requirements of the standards. It is clear structured, comprehensible and transparent. All relevant information is included, and the approach is comprehensible and consistent. The presentation of the results is factual, and the derived conclusions are coherent.

4. Critical Review Comments

The comments of the review panel have been included to the study and respective adaptations have been done. During the whole review process the relevant background information has been provided and detailed explanations have been given to the reviewers. All questions have been clarified in a competent and comprehensive way.

The Life Cycle Assessment study focuses on environmental aspects following the chosen impact assessment methodologies from CML (for Acidification Potential, Eutrophication Potential, Climate Change, Ozone Depletion Potential and Photochemical Ozone Creation Potential) and USEtox (for Eco-Toxicity

Potential and Human Toxicity Potential) as well as Primary Energy Demand and Fresh/Blue Water Consumption. All cultivation systems are modelled and analysed regarding primary data and boundary conditions from India. A regional differentiation therefore is not included. The results are representative for Khargone district of Madhya Pradesh region in India.

Relevant parameters are addressed to examine the reliability of the results. For all cultivation systems the same data collection methodology was used, and the data quality is assessed to be good. However, agrarian systems are subject to natural variation and uncertainty. Therefore, a long-term monitoring and examination of the significant parameters would be a suitable follow up of the study. Especially the consumption of water, energy, fertilizers and pesticides should be investigated in future over a longer period of time.

Furthermore, it is to be mentioned that toxicity assessment is subject to uncertainty and the systems show a clear dependency of toxicity aspects on specific pesticides. So, theses impact categories should be regarded with care and further investigation on the amount of pesticides but also on the type of pesticide are recommended. It is also recommended to use the study results for further investigation and for further improvement of the cultivation systems. A potential transferability of the results to other cotton cultivation regions has to be investigated separately.

5. Critical Review Confirmation

The members of the external critical review panel herewith confirm that the study "Life Cycle Assessment of Cotton Cultivation Systems: Better Cotton, Conventional Cotton and Organic Cotton" dated 17th May 2018, performed by Thinkstep Sustainability Solutions Pvt. Ltd., India, fulfils the requirements of ISO 14040 and ISO 14044 and was carried out according to the state of technology.

Chairperson of the Critical Review Panel
Mr. Matthias Fischer
Fraunhofer Institute for Building Physics IBP
Department Life Cycle Engineering
Wankelstrasse 5, 70563 Stuttgart, Germany

Independent Reviewer
Dr. Senthilkannan Muthu
Head of Sustainability, SgT group & API
Units 506-8, 5/F, Laford Centre, No. 838 Lai Chi
Kok Road Kowloon, Hong Kong

Independent Reviewer
Mr. Simon Ferrigno
Sustainable and Organic Farming Systems
3 Perth Street, Chaddesden, Derby DE21 4EL
United Kingdom

Independent Reviewer
Mr. Rajeev Verma
CottonConnect
615-616,6th Floor JMD Pacific Square, Sector 15
Part 2
Gurgaon, Haryana, India

Stuttgart, 25th May 2018

thinkstep

About Thinkstep

Established in 1991, thinkstep has become the global leader in sustainability performance management. It provides more than 8000 companies – including 45% of the Fortune 500 – with robust, proven software, data drawn from more than 10,000 datasets, and the combined expertise of more than 4,000 man years' experience and learnings from every major industry. Thinkstep has a wholly owned subsidiary in India, with an experience of 10 years and around 250 LCA studies across various sectors. Through its unique portfolio of software, data and consulting expertise, thinkstep leads organizations to sustainable success and help them contribute to a resilient and thriving planet.

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About C&A Foundation

C&A Foundation is a corporate foundation here to transform the fashion industry. We give our partners financial support, expertise and networks so they can make the fashion industry work better for every person it touches. We do this because we believe that despite the vast and complex challenges we face, we can work together to make fashion a force for good.

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