Life Cycle Assessment of Cotton made in Africa

REPORT

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TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

List of Acronyms

AP	Acidification Potential
AbTF	Aid by Trade Foundation
CmiA	Cotton made in Africa
CML	Centre of Environmental Science at Leiden
EP	Eutrophication Potential
GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
GHG	Greenhouse Gas
GWP	Global Warming Potential
ICAC	International Cotton Advisory Comittee
ILCD	International Cycle Data System
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment

Glossary

Life Cycle

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

Life Cycle Assessment (LCA)

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

Life Cycle Inventory (LCI)

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

Life Cycle Impact Assessment (LCIA)

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

Life Cycle Interpretation

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

Functional Unit

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

Allocation

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

Foreground System

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

Background System

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

Critical Review

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

Executive Summary

GOAL AND SCOPE

In 2014, Sphera (PE International) completed a project for the Aid by Trade Foundation to develop a life cycle Inventory (LCI) and carry out a life cycle assessment (LCA) for cradle-to-gate production of lint cotton (at gin gate) produced under the requirements of the Cotton made in Africa (CmiA) standard. The main purpose of this study is to carry out an update of the 2014 study:

- Update inventory data
- Use of several cultivation seasons to build multi-year averages
- Improve regional representativeness by including an additional cultivation region and more cotton companies
- Include comparison against global cotton production benchmark
- Include assessment of potential impacts of cultivation on biodiversity and soil carbon (at screening level)

The study is intended for external communication and is therefore conducted according to the requirements of the ISO 14044 standard and has been critically reviewed. The functional unit assessed in this study is 1t of cotton fibre at gin gate, the system boundaries can be summarized as "cradle-to-gin-gate". Economic allocation is applied to allocate burdens between cotton seed and fibre produced at the ginning stage. The following **impact categories** are **assessed** in this study:

- **Climate change**
- **Eutrophication**
- **Acidification**
- **Water consumption**

In addition, the following **impacts** are assessed on a **screening level**:

- **Biodiversity**
- **Changes in soil carbon stocks**

Toxicity and social indicators are assessed in separate studies.

INVENTORY DATA

The countries **Côte d'Ivoire**, **Cameroon** and **Zambia** assessed in this study, **together represent more than 50% of CmiA's production**. Primary data were provided by cotton companies partnering with the Aid by Trade Foundation from the last **three cultivation years** (2017 – 2019) at both the farm level and from the ginning stage. The life cycle inventory was assessed using the GaBi 10 software and database, and Sphera's LeanAgModel, which is based on the latest version of the IPCC Guidelines for National Greenhouse Gas Inventories.

The study **"LCA Update of Cotton Fiber and Fabric Life Cycle Inventory"** published by **Cotton Inc.** in **2017** was used as **benchmark to compare CmiA results against global cotton production**. System boundaries, modelling approach and data quality were compared to the present study, and no deviations were identified that would compromise a comparison of the two systems.

RESULTS (LIFE CYCLE IMPACT ASSESSMENT)

Updates on methodology and in the background datasets used in the assessment only had a minor impact on the results. Due to the altered data collection for this assessment (inclusion of another production country, more data providers) the **results from 2014 and 2020 are not directly comparable**. Impact on global warming was larger in the 2020 study compared to the 2014 study. As stated above, this is not related to a poorer standard of management practices, but only **related to the inclusion of a new production region and adjusted weighting** (production per country) to build the CmiA average. Eutrophication was lower in the 2020 study due an improved assessment of soil erosion but also due to the inclusion of an additional region.

For the impact potentials *climate change, eutrophication* and *acidification*, field emissions were the largest contributor. Field clearance had a visible impact on the results in all assessed impact categories. Other important contributing processes were the provision of fertilizers and energy use at the gin stage.

Comparing impacts on climate change between CmiA and global production, with updated results for both CmiA and the global production benchmark, the results laid in the same range for both production systems. CmiA cotton had smaller impact on climate change by 13%, mainly attributed to the additional energy required for irrigation in the global dataset. Eutrophication was reported to be lower in the global production systems compared to those of CmiA; this is likely due to climatic conditions that lead to lower emissions from leaching in the global production systems. Acidification potential was in a similar range when the two production systems were compared. Water use in CmiA was minimal compared to the global production as CmiA cotton does not include irrigation practices. This is a good indication that the **regions under study have suitable climatic conditions for growing cotton, an advantage of CmiA over arid cultivation regions** included in the global benchmark, where cotton cultivation relies heavily on irrigation.

Considering the results of a combined parameter uncertainty analysis, these results can be assumed to be comparatively stable, as results at the higher or lower end of the standard deviation calculated for CmiA would not lead to different conclusions. Conservative approaches taken in this study for both the uncertainty in the adoption rate of field clearance by combustion and the possibility of fertilizer shifting (application of fertilizers reported to be used in cotton to staple crops) could lead to results being reported higher than they actually are.

Impacts on biodiversity were influenced by the biodiversity value of the region under study and area use. With their classification as semi-intensive to extensive cultivation systems and the presence of crop rotations in all cultivation systems, the impact on biodiversity was lower than in more intensive cultivation systems. The extension of no-till practices can have a positive impact on biodiversity.

Including changes in soil carbon in the assessment, there was a significant impact on the climate change results. While the total calculated potential was large, there is large uncertainty around the exact extent, the speed of adoption of new management practices that lead to changes in soil carbon, and the timeframe over which such changes would occur and should be accounted for.

CONCLUSIONS AND RECOMMENDATIONS

The present study demonstrated a **clear improvement in terms of methodology and data quality** by comparison to the previous study from 2014. However, limitations in terms of data collection and data availability remained, especially for the adoption rates (for field clearance and no-till). Yearly systematic collection of LCA inventory data from the same data providers and internal evaluation of impact results will allow CmiA to measure continuous progress in environmental impact reduction.

CmiA cotton has advantages compared to the global benchmark in terms of impact on climate change and water consumption, predominantly due to the absence of irrigation practices at the farm. However, clear improvement potentials are identified. The (continued) adoption of no-till and cease of field clearance will help to reduce the impacts of CmiA cotton on the environment.

1. Goal of the Study

THE AID BY TRADE FOUNDATION

The Aid by Trade Foundation (AbTF) was founded in 2005 by Prof. Dr Michael Otto, an entrepreneur from Hamburg, Germany. The aim of the foundation, which operates independently of the Otto Group, is to help people to help themselves through trade, thereby preserving vital natural resources and securing the livelihoods of future generations. With the Cotton made in Africa (CmiA) initiative, AbTF is putting its principles into practice. The trade partners of the CmiA De-mand Alliance source African cotton produced according to the CmiA standard and pay the foun-dation a volume-based license fee that is reinvested in the cultivation areas. Consumers recog-nise products by the CmiA label and that they make a valuable contribution to protecting the environment and supporting smallholder farmers and their families in Africa.

GOAL

In 2014, Sphera (PE International) completed a project for the Aid by Trade Foundation to develop a life cycle Inventory (LCI) and carry out a life cycle assessment (LCA) for cradle-to-gate production of lint cotton (at gin gate) produced under the requirements of the Cotton made in Africa (CmiA) standard.

The main purpose of this study is to carry out an update to this study. Following improvement potentials identified in the 2014 study, this study focuses on improving the following:

- Update inventory data
- Use of several cultivation seasons to build mutli-year averages
- Improve regional representativeness by including an additional cultivation region and more cotton companies
- Include comparison against global cotton production benchmark
- Include assessment of potential impacts from cultivation on biodiversity and soil carbon (at screening level)

INTENDED APPLICATION

The study is intended to assess the environmental impact of cotton cultivation under the CmiA scheme. Strengths and weaknesses of the cultivation systems under study should be identified, supported by comparisons with global benchmark data. The results of this study can be used in life cycle assessments along the textile supply chain and in communication of the environmental impact of cotton cultivation under the CmiA standard.

This study does not intend to compare different regions under the CmiA standard, nor between cotton companies. Therefore, the published data represents an aggregated average of CmiA. Additionally, it's not intended to make claims about the differences between the environmental performance of the CmiA scheme and other cotton cultivation practices in Africa.

The updated study includes data from an additional country as well as different cotton companies and applies a weighting based on production shares. Therefore, the results of this study cannot be used to measure progress in management practices and environmental performance of CmiA farmers in comparison to the 2014 study.

COMPARATIVE ASSERTION

This study conducts a comparative assertion as defined in the ISO standard (14040 series) between CmiA and a global cotton production average. Data from the critically reviewed ISO compliant study from Cotton Inc. 2017 is used as a benchmark (global average based on large producing countries, i.e. USA, India, China, Australia). No additional data collection or assessments are conducted to create a global production benchmark, the data from Cotton Inc. 2017 is used without modification. As required by the ISO 14040 series, the present study is critically reviewed, including the comparative assertions.

INTENDED AUDIENCE

The intended audience comprises both internal and external stakeholders. The internal stakeholders at CmiA include those involved in marketing and communications, in business development and standard & outreach (with the goal of process improvement). The external stakeholders include brands and retailers, users of CmiA cotton, the LCA community, and other members of the textile supply chain as well as the general public.

ISO COMPLIANCE

This study is conducted according to the requirements of the ISO 14044 and critically reviewed (see section 2.11.)

2. Scope of the Study

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

2.1. PRODUCT SYSTEM

The present study refers to cotton cultivation in Africa, as per the requirements of the CmiA Initiative. The CmiA standard criteria encompass environmental, social, and economic aspects of cotton farming and ginning. The standard is based on a two-step verification process. Please refer to Cotton made in Africa (CmiA) Criteria Matrix (Version 3.1, 2015)[1] for a full description of the CmiA criteria.

CmiA works with local cotton companies which have an out-grower scheme. Farmers participating in the CmiA initiative are mostly small-scale farmers, growing cotton in rotation with other cash and food crops such as millet, sorghum, ground nuts, soybean, cow peas or maize. The farming systems can typically be described as semi-intensive/ extensive agriculture, as machinery use and fertilizer use is low, especially in Zambia (see section 3). In all CmiA countries, cotton is exclusively cultivated under rainfed conditions. In season 2018/2019 CmiA production amounted to 593.067 metric tons, equivalent to 2.3% of global cotton production (Global production according to ICAC 25.7 million metric tons).

The three countries, Zambia, Cameroon and Côte d'Ivoire, are selected to represent CmiA production, based on production shares and data availability (see section 3 for details on production shares). Côte d'Ivoire and Zambia were already assessed in the 2014 study and are therefore also included in the present study, while Cameroon is added to increase geographical representativeness of the study.

2.2. PRODUCT FUNCTION AND FUNCTIONAL UNIT

The cradle-to-gate LCA for CmiA lint cotton covers raw material production from field to ginning. The functional unit is:

1 metric tonne (t) of lint cotton at the gin gate.

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

1 https://cottonmadeinafrica.org/wp-content/uploads/2020/03/CmiA-Standard-Criteria-Matrix-Volume-3-1.pdf

2.3. SYSTEM BOUNDARY

The system boundaries of the LCA include the cotton cultivation according to the CmiA requirements and fibre production (ginning).

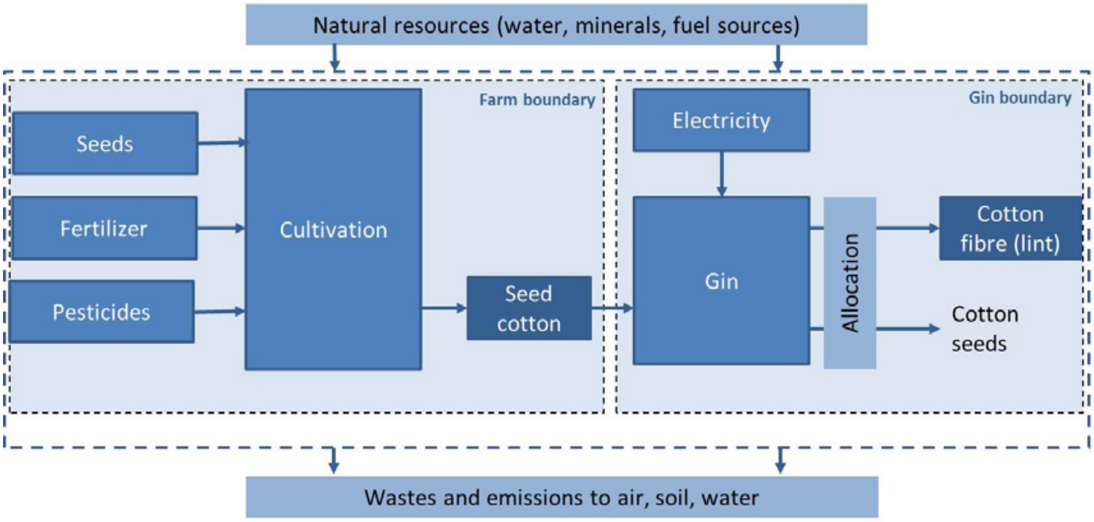


Figure 2-1: System boundaries

Included in the study are all material and energy flows required for the two phases of production (cultivation and ginning), as well as all associated wastes and emissions. This includes but is not limited to: fertilizer and pesticide production as well as field emissions (e.g. N2O), emissions related to fire clearing (i.e. the combustion of biomass remaining on the field from previous cultivation period) (e.g. CH4, SO2), electricity for ginning and all transports (fertilizer to the field, seed cotton to gin).

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

Furthermore, the End of Life of ginning waste was excluded, leaving the system burden free and without any benefits to the main product. Gin waste consists of broken seeds, fibres and plant remains (residues). In the worst case, it could be considered as waste that requires further treatment under specific consideration of pesticide remains. On the other hand, it is occasionally returned back to the land as organic fertilizer, sold to horticulture farms to improve physical soil conditions or used for composting. The potential negative impact due to toxicity is relatively minor since under the CmiA farming practises, pesticide application is reduced and the amount remaining as waste is even less. Therefore, attributing no burdens to the gin waste is a neutral approach, neglecting a small potential environmental impact along with a similarly small environmental benefit (fertilizer use). This approach is consistent with the approach followed in the 2014 study and in Cotton Inc. 2017.

As customary in LCA studies, construction of capital equipment and maintenance of support equipment are excluded due to their minimal contribution and extreme difficulty to measure.

This assumption is especially justified for CmiA production systems that only have minor machinery use. Social aspects are beyond the scope of this study scope and therefore, human labour was also excluded from the study. At the same time, it should be noted that fair and safe human labour conditions are some of the prerequisites of the CmiA label.

Also excluded from the study is an assessment of land use change (LUC), as clearing primary forests and encroachment into officially protected areas is prohibited by the CmiA scheme. In Zambia, farmers practice a system of shifting cultivation, and succession on the fallow plots could be considered as secondary forest that is cut when the area is brought under cultivation again. However, it could be argued that the whole system is at a steady state of equilibrium (land use change occurring in both directions – from secondary forest to arable land and vice versa). Deviations from this assumption would be difficult to detect and data to assess the potential impacts on climate change would be very uncertain. As this only applies to Zambia with a total share in production of 10%, this omission should not limit the validity of the results of this study.

2.3.1. Temporal coverage

The intended time reference for this study are the three most recent cultivation seasons (2016/17 – 2018/2019). The validity of the results is expected to be at least five years, as multiple year averages represent long term averages that only change slowly, as technological advances in agricultural systems such as improved varieties or changed management practices usually perforate slow.

2.3.2. Technological and geographical coverage

Cotton made in Africa, as the name suggests, is a label exclusively given to African-grown lint cotton. The data collection procedure and production shares of the regions under study are described in section 3.

2.4. ALLOCATION

When a system yields more than one valuable output, as is the case for cotton production, environmental burden is shared between the co-products. During cotton production, two valuable co-products are produced, lint cotton and cottonseed, thus the environmental burden is allocated to both the fibre and seed. If possible, allocation shall be avoided through e.g. product system expansion according to the ISO standard. If allocation cannot be avoided, the allocation method shall follow the physical relationships between the co-products (e.g. energy content, or weight). However, often these allocation methods will also not lead to meaningful results. In these cases, alternative allocation methods are used in LCA studies, such as economic allocation (splitting the burden based on monetary value of the different products). It was determined that economic allocation was the most suitable method to use for this study. Market value was chosen as the method of allocation as it describes best the demand that drives production of both products and this method was also utilized in the study assessing conventional cotton (Cotton Inc. 2017).

2.5. CUT-OFF CRITERIA

No cut-off criteria are defined for this study. As summarized in section 2.3., the system boundary was defined based on relevance to the goal of the study. For the processes within the system boundary, all available energy and material flow data have been included in the model. In cases where no matching life cycle inventories are available to represent a flow, proxy data have been applied based on conservative assumptions regarding environmental impacts (see Table 311).

2.6. SELECTION OF LCIA METHODOLOGY AND IMPACT CATEGORIES

The impact assessment categories and other metrics considered to be of high relevance to the goals of the project are shown in Table 2-1 and Table 2-2. Various impact assessment methodologies are applicable for use in the European context including e.g. Environmental Footprint v3.0 (EF 3.0), CML, ReCiPe, etc. This assessment predominantly reports on the CML impact assessment method. The CML method is used in both, the 2014 study and in the Cotton Inc 2017 study, so continuing to use this set of indicators ensures comparability of the results. For the selected impact categories, also EF 3.0 impact assessment results are provided in the annex of this study[2].

2 EF 3.0 consists of many more impact categories but their assessment is outside the scope of this study

Table 2-1: Impact category descriptions

Impact Category	Description	Unit	Reference
Climate change (global warming potential)	A measure of greenhouse gas emissions, such as CO_2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may in turn have adverse impacts on ecosystem health, human health and material welfare[3].	kg CO_2 equivalent	(IPCC, 2013)
Eutrophication (terrestrial, freshwater, marine)	Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition.	kg PO_4^{3-} equivalent	(CML 2001 – 2016)
Acidification Potential	A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H^+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline and the deterioration of building materials.	kg SO_2 equivalent	(CML 2001 – 2016)
Biodiversity	Biodiversity is defined as the variety of life on Earth at any level of organisation, ranging from molecules to ecosystems across all organisms and their populations. It includes the genetic variation among populations and their complex assemblages into communities and ecosystems. Biodiversity conservation is nowadays recognized as a global priority due to its essential contribution to human well-being and the functioning of ecosystems.	Biodiversity Impact (*BVI m²a*)	(Lindner, et al., 2019)

3 The results shown here do not account for the (temporal) uptake of CO_2 in the fibre. As cotton is a short-lived consumer good, this carbon dioxide is released later at the end-of-life in the product, so that it is only temporarily stored. Therefore the carbon uptake is not considered in the impact assessment in this study. This approach is consistent with the PEF method.

Table 2-2: Other environmental indicators

Indicator	Description	Unit	Reference
Water Consumption	A measure of the net intake and release of fresh water across the life of the product system. Only blue water (i.e. surface and ground water) is considered, not rain water[4]. In a strict sense, this is not an indicator of environmental impact without the assessment of regional water scarcity.	m^3 of water	(Sphera Solutions Inc., 2020)

Global warming potential is chosen because of its relevance to climate change and energy efficiency, both of which are strongly interlinked, of high public and institutional interest, and deemed to be one of the most pressing environmental issues of our time. The global warming potential impact category is assessed based on the current IPCC characterisation factors taken from the 5th Assessment Report (IPCC, 2013) for a 100 year timeframe (GWP_{100}) as this is currently the most commonly used metric.

Eutrophication and acidification potentials were chosen because they are covering emissions of typical concern from agriculture that are closely connected to air, soil, and water quality and capture the environmental burdens associated with commonly regulated emissions such as ammonia, nitrate, and others.

Water consumption, i.e., the anthropogenic removal of water from its watershed through shipment, evaporation, or evapotranspiration has also been selected due to its high political relevance, especially in global cotton cultivation. No Impact assessment based on local water availability (water scarcity footprint according to ISO 14046) was conducted in this study. Since CmiA is exclusively rainfed, water consumption is negligible, so an additional impact of water scarcity would not impact the assessment. Furthermore, water scarcity results were not included in the global benchmark hence, this would not allow for comparison.

Biodiversity was added to the assessment because together with climate change, it constitutes one of the most pressing environmental issues of our time (see (Rockström & et al., 2009)). Assessment methods of biodiversity in an LCA context are comparatively new, and a single consensus method is not yet available. A recent method developed by (Lindner, et al., 2019) is used in this study. While this method is less robust compared to the other impact assessment methods used in this study, the inclusion of the assessment shows a clear effort to include an important aspect of environmental impacts of agricultural systems into the study.

Assessment of toxicity and assessment of social impacts are outside the scope of this study but are considered in separate studies (see section 2.7). It shall be noted that the above impact categories represent impact *potentials*, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so.

4 Typically in LCA methodology, 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”).

In addition, the inventory only captures that fraction of the total environmental load that corresponds to the functional unit (relative approach). LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

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

2.7. LINK TO OTHER ASSESSMENTS OUTSIDE THIS STUDY

Assessment of toxicity and assessment of social impacts are outside the scope of this study. However, this does not mean that these impacts are not assessed in the CmiA program. The AbTF currently conducts a separate impact study for social and economic impacts and assesses toxicity via an independently developed methodology. The impact study is currently being carried out with the publication planned for September 2021. It will be available on the Cotton made in Africa website.

2.8. DATA QUALITY REQUIREMENTS

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

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

An evaluation of the data quality with regard to these requirements is provided in Chapter 5 of this report.

2.9. TYPE AND FORMAT OF THE REPORT

The report is written in accordance with the ISO 14044 requirements (ISO, 2006), which also specifies the structure and section headings used in this report. The document aims to report the results and conclusions of the LCA completely, accurately and without bias to the intended audience.

2.10. SOFTWARE AND DATABASE

The LCA model was created using the GaBi 10 Software system for life cycle engineering, developed by Sphera Solutions Inc. The GaBi 2020 LCI database provides the life cycle inventory data for several of the raw and process materials obtained from the background system (see section 3.4.).

2.11. CRITICAL REVIEW

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

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

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

- Dr. Ulrike Eberle, managing partner at corsus – corporate sustainability GmbH (Chair)
- Prof. Dr. Jan Paul Lindner, Chair of Sustainability in Engineering, Bochum University of Applied Sciences
- Wolfgang Bertenbreiter, Program Manager, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)

The Critical Review Statement can be found in Annex 1. The Critical Review Report containing the comments and recommendations by the independent experts as well as the practitioner's responses is available upon request from the study commissioner in accordance with ISO/TS 14071.

3. Life Cycle Inventory Analysis

Primary data collection for cotton cultivation under the CmiA scheme was facilitated by the Aid by Trade foundation. Case specific questionnaires were developed to collect inventory data for the agricultural systems. These questionnaires were completed by CmiA focal persons and other technical staff of the cotton companies, as specified in Table 3-1:

Table 3-1: Data providing cotton companies

Cameroon	Côte d'Ivoire	Zambia
Société de Développement du Coton du Cameroun (Sodecoton)	Compagnie Ivoirienne pour le Développement des Textiles (CIDT)[1)]	Alliance Ginneries Ltd Zambia
	Compagnie Ivoirienne de Coton (COIC-SA)	Continental Ginnery Ltd (CGL)
	Ivoire Coton	Highlands Cotton Trading (HCT)[2)]
		Louis Dreyfus Company Zambia (LDC)
		Grafax Cotton Zambia Ltd

[1)] Not CmiA partner before 2018/2019 [2)] Not CmiA Partner before 2017/2018

The questionnaires were used to assess data on yields, fuel use and management practices. In addition, data from the annual self-assessment of the cotton companies[5] was used to assess fertilizer and pesticide use. Quality checks and benchmarking against literature and previous cultivation data was conducted to ensure reliable results. Inventory data was also submitted to critical review. For the complete inventory data please refer to Table 3-4 and Table 3-5.

Electricity consumption at the gin has been modelled based on primary data from all locations. Ginning can be adequately described with the electricity consumption used for the process and the ratio of by-products (seed and fibre) and waste. Distances from farm to the gin were also derived from primary data collection.

In Côte d'Ivoire and Zambia, where more than one company provided data, the data was aggregated into a country average (weighting by production amount). Each country was assessed separately. The results were than aggregated into the CmiA average according to the production shares of each country (see Table 3-3).

5 AbTF requires cotton companies to report on various data points on a yearly basis, including but not limited to the farmer and ginnery worker data (separated by gender), area under cotton cultivation, purchased seed cotton, and ginned lint cotton. Furthermore, data on pesticides and fertilizers, including the product names, their active ingredients with the respective concentrations and total volumes of each product distributed to farmers, are provided by the cotton companies. This comes in addition to the self-assessment of each cotton company concerning the compliance with minimum criteria and the degree of progress achieved with regard to the development criteria outlined in the CmiA Standard.

Table 3-2: Production shares

		lint cotton production (mt)	lint cotton country share of CmiA total in %
2016/17	**CmiA total**	**495,839**	
	Cameroon	100,875	20.34
	Côte d'Ivoire	88,637	17.88
	Zambia	23,793	4.80
2017/18	**CmiA total**	**578,562**	
	Cameroon	106,880	18.47
	Côte d'Ivoire	140,879	24.35
	Zambia	34,370	5.94
2018/19	**CmiA total**	**593,067**	
	Cameroon	132,990	22.42
	Côte d'Ivoire	194,474	32.79
	Zambia	24,279	4.09

The three regions assessed in this study represent approximately 50% of total CmiA production. An average was taken over the three production seasons and scaled to 100%, resulting in the following weighting factors:

Table 3-3: Weighting factors for the regions

Region	Weighting Factor
Cameroon	41.0%
Côte d'Ivoire	48.9%
Zambia	10.1%
Total	100.0%

In comparison to the 2014 study, this study includes data provided by one cotton company operating in Cameroon and data from additional cotton companies in Côte d'Ivoire and Zambia. In addition to that, the 2014 study was built on the simple mean of the results from Côte d'Ivoire and Zambia. The inclusion of new regions and a new weighting scheme represents a major difference in the scope between the 2014 study and the present study. Hence, as stated in section 1, the results of this study cannot be used to measure progress in management practices and environmental performance of CmiA farmers.

3.1. FARM AND GIN INVENTORY DATA

3.1.1. Inventory data

The following table summarizes the main inventory data describing the farm production system.

Table 3-4: Inventory data at farm level

Region	Unit	Cameroon	Côte d'Ivoire	Zambia
Year	-	2017-2019	2017-2019[1]	2017-2019[1]
Precipitation[2]	mm	1042	1406	968
Adoption rate Field clearance	%	100%	78%	89%
Adoption rate ploughing	%	20%	96%	69%
Diesel	l/ha	33.5 [4]	4.4	0.0
Seed	kg/ha	15	45	15
Yield (seed cotton)	kg/ha	1423	1168	326
NPKSB 22-10-15	kg/ha	173.9		
NPKSB 21-08-12	kg/ha	5.7		
NPK 15-15-15	kg/ha		220.9	
NPKSB 19-19-19	kg/ha			1.1
Urea	kg/ha	41.2	59.0	
Lime	kg/ha		0.2	
Boron	kg/ha			0.2
Crop protection (unspecific. active ingredient)[3]	kg/ha	2.7	2.5	0.6

[1] With exception of companies that were not CmiA partners in all seasons, see Table 3-1
[2] Reported values from questionnaires
[3] No assessment of toxicity, therefore only impact of provision relevant.
[4] Mean value of a range reported by expert of data providing cotton company, i.e. expert judgment

Table 3-5: Inventory data gin

Region	Unit	Cameroon	Côte d'Ivoire	Zambia
Transport distance truck (average distance from farm to gin)	km	80	67.2	214
Output cotton fibre (ginning out turn, lints)	kg/1000 kg of seed cotton (input)	430	428	416
Output cotton seeds	kg/1000 kg of seed cotton (input)	540	501	547
Other (waste etc.)	kg/1000 kg of seed cotton (input)	30	71	38
Energy use (Electricity)	MJ/1000 kg of seed cotton (input)	210.7[5)]	210.7	161
Electricity source	-	Gridmix	Gridmix	Hydropower
Price ratio fibre to seeds	ratio	9.8:1[6)]	10.7:1	8.9:1

[5)] No data, reported data from Côte d'Ivoire used as proxy
[6)] No data, average price ratio of fibre to seed from other two countries used as proxy.

3.1.2. Comparison to inventory data from 2014

In the present study, data from several cotton companies and from multiple years were collected. In the 2014 study, only one producing company per region provided data, and only for one year. Therefore, changes in inventory data do not necessarily correspond to real changes on farms in the assessed regions, and the data is not directly comparable. However, some changes in the inventory data should be discussed here as they are important to understand and interpret the results.

In general, there is good consistency in the data from 2014 and 2020 for Zambia and Côte d'Ivoire. Reported yields went up in Côte d'Ivoire (from 1051 to 1201 kg/ha) but decreased in Zambia (from 442 to 311 kg/ha)[6]. Similar to the yield, also fertilizer application increased in Côte d'Ivoire (223 kg vs. 160 kg NPK/ha, 59.5 kg vs. 40 kg Urea/ha). The minimal fertilizer application rates of Zambia are confirmed in this study. Energy data at gin and price ratios reported in the present study are also close to those reported in 2014.

Changes occur regarding the adoption rate of field clearance. It is difficult to do a systematic assessment of how many farmers are applying the practice, and where data is available it is usually based on expert judgment from the data providers. A conservative approach is taken in this study: if field clearance is confirmed but no adoption rate is reported, it is assumed that all farmers apply this technique (adoption rate of 100%). In the 2014 study, with only two data providers, the assumed adoption rate was 25% for Côte d'Ivoire and 30% for Zambia.

3.2. MODEL

3.2.1. Method

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

- 2019 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 4, Agriculture, Forestry and Other Land Use)
- PEF method[7] (Suggestions for updating the Product Environmental Footprint PEF method, chapter 4.4.1.)

In combination with datasets from the GaBi 10 database, the model allows inclusion of all impacts from upstream processes, on the field and from downstream processing (in this case ginning). The contribution of each subprocess can be evaluated separately. The following table gives an overview of the different modules of the model and the emission modelling approach. Grey cells give the general description of the module, white cells provide the sub-modules and specific descriptions. The modules are also used to group the results in the contribution analysis (section 4) (Battye & Battye, 2002).

6 Precipitation between 2015 and 2018 was low and erratic in Zambia
7 https://publications.jrc.ec.europa.eu/repository/bitstream/JRC115959/jrc115959_pef_method-online.pdf

Table 3-6: Overview of model modules and approaches

Module	Description	Approach
Field Clearance	Emissions related to the combustion of biomass after cultivation to clear the field	(see below)
Emissions from combustion of biomass	Methane, ammonia, nitrous oxide and other emissions related to the combustion process	Modelled based on the amount of biomass burned, its carbon and nitrogen content, based on emission factors from (Battye & Battye, 2002).
Field emissions	Emissions from agricultural soil related to fertilizer application, crop residues and soil erosion	(see below)
Emissions from fertilizer application (direct and indirect field emissions)	Nitrous oxide emissions to air from microbial nutrient turnover (denitrification), ammonia emissions to air from mineral and organic fertilizer, nitrate emissions to water through leaching, carbon dioxide emissions from carbon contained in fertilizer (urea, lime)	Based on approach and emission factors provided in 2019 IPCC guidelines; fuel consumption considered under field work
Emissions from crop residues	Additional nitrogenous emissions due to nitrogen contained in crop residues	Based on approach provided in 2019 IPCC guidelines
Emissions from soil erosion	Nutrients contained in the soil reaching surface water bodies with soil erosion	Based on data from Global Soil Erosion Modelling platform (GloSEM) and default nutrient content in soil
Emissions from LUC	Carbon emissions related to the conversion of forest (or other land use type) to agricultural land.	Not applicable, see section 2.3.
Field work	Emissions from tractor use and provision of fuel	(see below)
Tractor use	Emissions from fuel combustion	Based on tractor and truck model in GaBi 10
Provision of Diesel	Upstream emissions in the fuel supply chain (e.g. refinery)	Based on energy provision datasets from GaBi 10 database (yearly updated)
Provision of fertilizer	Emissions related to fertilizer production	(see below)
Fertilizer production	Upstream emissions in the fertilizer supply chain (e.g. energy consumption of production)	Based on fertilizer production datasets from GaBi 10 database

Crop protection	Emissions related to production and application of crop protection agents	(see below)
Pesticide production	Upstream emissions in the pesticide supply chain (e.g. energy consumption of production)	Based on pesticide production datasets from GaBi 10 database
Pesticide application	Emission of pesticides into the environment	not applicable for this study (no assessment of toxicity); fuel consumption considered under field work;
Ginning	Additional modul added to the LeanAg model. All emissions related to ginning (separation of seed and lint)	Based on energy consumption, seed-to-lint ratios, typical transport distances and prices for allocation.
Provision of electricity	Upstream emissions in the fuel supply chain (e.g. refinery)	Based on energy provision datasets from GaBi 10 database (yearly updated)
Transports	Transports of agricultural inputs (fertilizer and pesticides to the field)	Based on transport distance, using the truck model in GaBi 10 and provision of diesel
Transports to gin	Transport of raw cotton	Based on truck model in GaBi 10 and provision of diesel

For all references to background data from GaBi 10 used, see section 3.4. on background data. The following sections provide additional information about assumptions made for model modules for which the specifications above are incomplete.

3.2.2. Field clearance

Combustion of biomass for field clearance was modelled based on the amount of biomass burned along with its carbon and nitrogen content. The amount of biomass burned was estimated based on values for crop residues from the IPCC 2019, which assumes a yield to above ground biomass ratio of 1:1. Nitrogen and carbon content of cotton stalks were based on the Phyllis database[8] and are assumed to be 38% for carbon and 1.1% for Nitrogen. All emission factors were modelled based on: (Battye & Battye, 2002) which have been prepared for the US EPA. This source was used instead of the IPCC 2019 emission factors because more emissions than greenhouse gases are covered. Not all CmiA farmers burn the fields before planting, the respective adoption rate of this practice is given in Table 3-4.

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

3.2.3. Emission from fertilizer application

The following emission factors were used according to IPCC 2006/2019 Guidelines for National Greenhouse Gas Inventories (Tier 1, aggregated).

Table 3-7: Emission factors for fertilizer application

Compartment	Emission Factor	Unit
N_2O	0.01	kg N_2O-N/kg N
NH_3 from urea	0.15	kg NH_3-N/kg N
NH_3 from other min. fertilizers	0.02	kg NH_3-N/kg N
NO_3^-	0.24	kg NO_3^--N/kg N
CO_2 direct from urea	0.2	kg CO_2-C/kg
P mineral	0.00048	kg P/kg P_2O_5

In order to assess the consistency of the reported fertilizer application data, yield and assumed losses (emission factors), a simplified nitrogen (N) balance was calculated, as shown in Figure 3-1.

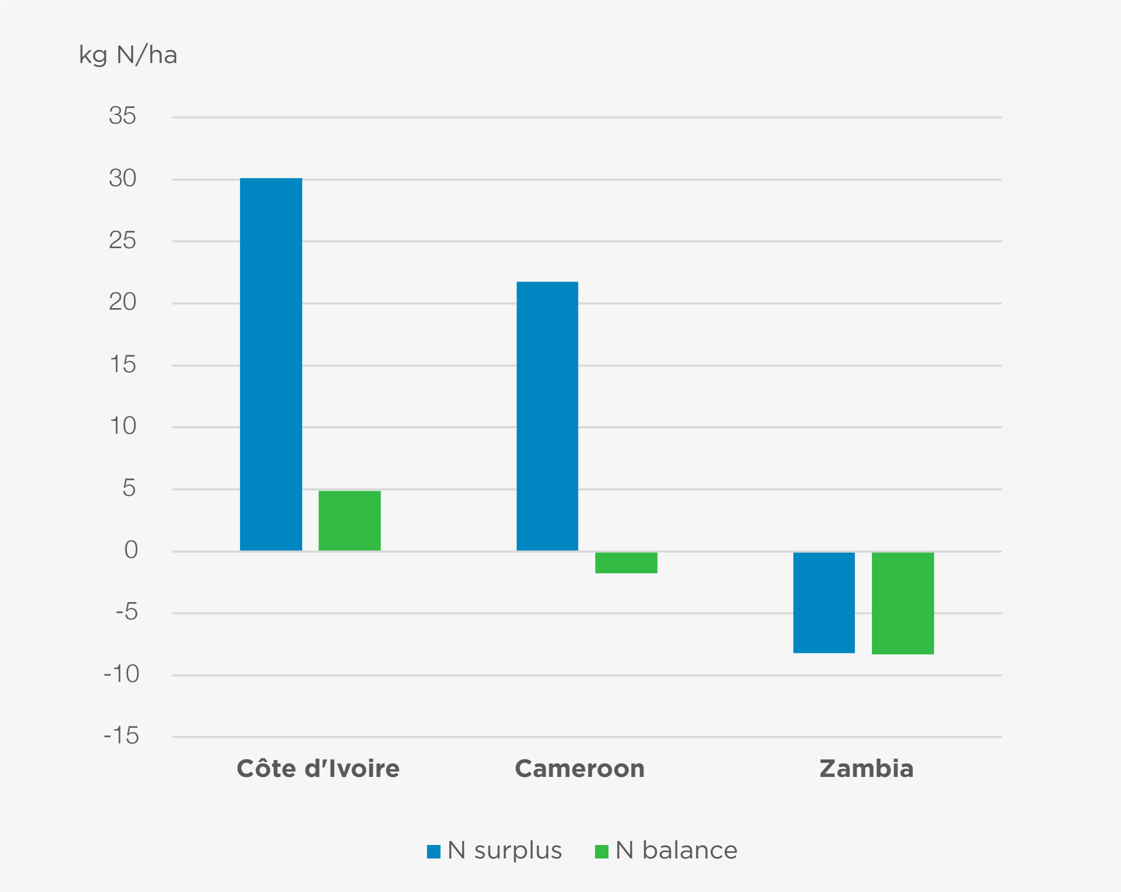


Figure 3-1: N Balance

N surplus was calculated as the Nitrogen supplied with fertilizer minus nitrogen crop uptake. The N balance was calculated as the N-surplus minus losses.

The N balance was close to zero in all cases, indicating good consistency between reported data and assumed losses. As there is close to no fertilization in Zambia, the N balance was negative. However, given the small amount, it is very realistic that the missing N is available from natural sources, such as from mineralization of organic material from previous crops, biological N fixation from free living symbionts, deposition or similar. This assumption is also supported by the fact that in some of the cotton growing areas of Zambia farmers still apply a type of shifting cultivation with fallow periods of 5-7 years.

It should be noted here that the model does not consider changes in the soil nitrogen stocks, i.e. it applies a steady state assumption. This means that both nitrogen available from previous crops and nitrogen left over from the current cultivation for the following crops was not considered. This simplification was applied due to the fact that previous and following crops can vary in the assessed farming systems, and changes in nitrogen stocks from one year to the other are difficult to assess and bring large uncertainty. The provided N balances justify this approach, as with the given closed balance, it is not likely that large changes in soil nitrogen stocks occur, and that a more detailed assessment would lead to different results.

3.2.4. Emission from crop residues

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

3.2.5. Emission from soil erosion

Soil erosion rates were assessed based on data from the Global Soil Erosion Modelling platform (GloSEM)[9], provided by the Joint Research Centre of the European Commission. Country averages from the provided 25 km raster data were calculated (see Table 3-8). It was assumed that 20% of total soil erosion eventually reaches surface water bodies (Prasuhn, 2006). The assumed P content of the soil was 500 mg/kg, a value on the lower end of the range reported in (Prasuhn, 2006), in accordance with the 2014 study and assuming a lower nutrient concentration in soils in the study area compared to intensive farming systems.

Management practices are known to reduce soil erosion significantly. Table 11 shows some reduction potentials of different management practices.

Table 3-8: Soil erosion reduction potential of different soil protection measures (own compilation based on (Blanco-Canqui, 2008))

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

All farmers under study apply crop rotation, which alone should reduce soil erosion by 30%. In Côte d'Ivoire and Zambia, there seems to be at least partial adoption of soil protection measures. On the other hand, due to high reported adoption rates for ploughing and field clearance, these potentials were not fully taken into consideration and the reduction rate was assumed to be 50%. In Cameroon, the adoption rate for no-till and direct seeding was reported to be 80%. Assuming a soil reduction potential of 90% for no-till, a reduction rate of 72% (80% multiplied by 90%) is assumed for Cameroon. Table 3-9 gives the resulting soil loss to water.

9 https://esdac.jrc.ec.europa.eu/content/global-soil-erosion

Table 3-9: Soil loss to water

	Soil erosion rate	20% going to water	Management reduction rate	Resulting soil loss to water
	t/ha	t/ha	%	kg/ha
Côte d'Ivoire	3.3	0.7	50%	331
Cameroon	5.4	1.1	72%	305
Zambia	1.9	0.4	50%	192

3.3. GLOBAL COTTON PRODUCTION

The study "LCA Update of Cotton Fiber and Fabric Life Cycle Inventory" published by Cotton Inc. (2017) was used as benchmark to compare CmiA results against global cotton production. The study was conducted according to the principles of ISO 14044 and was critically reviewed. The ISO compliant report is publicly available. No additional data collection or assessments were conducted to create a global production benchmark, the data from Cotton Inc. 2017 was used without modification.

While the report covers the full lifecycle from fibre to fabric, fibre production until gin-gate was assessed and described separately. Agricultural data were collected from the United States, India, China, and Australia to represent average production conditions from 2010 to 2014. These countries represented the top three cotton producing and cotton exporting countries during the study period. The countries were assessed on sub-regional level:

- United States (Far West, Southwest, Mid-south, & Southeast)
- China (Xinjiang or Northwest, Yellow River, & Yang Tse)
- India (North, Central, & South)
- Australia

However, no country specific results were provided, only the global average. With the ISO compliant report, all system boundaries, data quality and assumptions were clearly described and can therefore be compared with the present study, see following table (Table 3-10). In summary, no deviations were identified that would compromise a comparison of the two systems.

Table 3-10: Scope of global benchmark study and comparison to present study

Scope	Cotton Inc 2017	CmiA	Comment
Temporal representativeness	2010 to 2014	2017 to 2019	Whilst they are not exactly matching, it can be assumed that the time difference only has a low impact on the comparability of results, as changes in climate and agricultural practices only lead to different impacts over large time periods, especially when considering a global average. The Cotton Inc study states that the dataset is valid for at least five years.
Geographical representativeness	Global	CmiA	The Cotton Inc dataset can be assumed to represent global average production well. However, as only global average data is provided, no comparison of CmiA to specific countries, farming practices or farming systems can be made.
Technological representativeness	high	high	Data quality in the Cotton Inc. study is reported to be high. As average data is collected on sub-regional level, all technologies and farming practices can be assumed to be covered while maintaining a sufficient regional resolution to consider important regional differences.
System boundary	Cradle-to-gin gate	Cradle- to gin-gate	Similar system boundaries and all relevant inputs and outputs are considered.

Land use change	Not applicable	Not applicable	Cotton Inc 2017 assumes that all areas in the regions under study were under agricultural cultivation for more than 20 years; cutting of primary forest prohibited by CmiA scheme
Allocation at gin	Economic	Economic	Same approach, good comparability of results
Exclusions	Capital equipment, human labour, organic fertilizers	Capital equipment, human labour	Same approach, good comparability of results
Model and database	Thinkstep agricultural model in GaBi 2015	Sphera LeanAg-Model in GaBi 2020	Both models in general follow the IPCC guidelines. However, the model used in Cotton Inc 2017 is based on the 2006 version of the IPCC guidelines. In addition, it uses a more dynamic modelling of nitrogen emissions into water than the lean model used in this study, based on application time of the fertilizer, and soil and climate data. A similar model like the one used in Cotton Inc 2017 was used in the 2014 CmiA study. Changes in modelling approach and background data between the 2014 and 2020 CmiA studies are assessed in section 4 and are found to have minor influence on the results. It can therefore be concluded that differences in the modelling approach and update of the background data only has a minor impact on the results, with the exception of eutrophication where the differences in modelling between the global dataset and the CmiA study can be larger.

Similar to the present study, the benchmark data for global cotton production was updated from a previous version (2012) to improve data quality and geographical representativeness. The results for the global benchmark also changed significantly, especially the impact on climate change and water consumption values which both decreased. The 2014 study did not conduct a comparative assertion but used the 2012 version of the Cotton Inc global benchmark to put results into perspective. This should be kept in mind when comparing results from this study with its previous version or with other studies.

3.4. BACKGROUND DATA

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

Table 3-11: Background datasets

Material/ process	Location	Dataset	Data Provider	Reference Year	Comment
Urea fertilizer	United States	US: Urea (agrarian)	sphera	2019	No country specific datasets available. Average (simple mean) of available regions used as proxy for provision of fertilizer in the regions under study.
	EU-28	EU-28: Urea (46% N)	Fertilizers Europe	2011	
	India	IN: Urea (agrarian)	sphera	2019	
NPK fertilizer	United States	US: NPK 15-15-15	sphera	2019	See above. While specific nitrogen content of different NPK fertilizer was considered in emission modelling, NPK 15-15-15 fertilizer is used as proxy for the production of NPK fertilizers with different nutrient concentrations
	Europe	EU-28: NPK 15-15-15 (nitrophosphate route, 15N-15P2O5-15K2O)	Fertilizers Europe	2011	
Lime	United States	US: Limestone flour (50µm)	sphera	2019	Average (simple mean) used as proxy for provision of fertilizer in the regions under study
	Europe	EU-28: Limestone flour ($CaCO_3$; dried)	sphera	2019	
	India	Limestone flour ($CaCO_3$; dried) (estimation)	sphera	2019	
Tractor	Global	GLO: Universal Tractor	sphera	2019	
Truck	Global	GLO: Truck, Euro 0 - 6 mix, 14 - 20t gross weight / 11,4t payload capacity	sphera	2019	

Diesel	South Africa	ZA: Diesel at refinery	sphera	2019	No country specific datasets available for regions under study, dataset from South Africa used as proxy
Electricity	Region Africa[1)]	RAF: Electricity, medium voltage, consumption mix	sphera	2019	No country specific electricity datasets available. Gins use low voltage, therefore a grid loss of 3.5% was assumed for transformation from medium to low voltage (estimate).
	Region Africa	RAF: Electricity from hydropower, medium voltage, production mix	sphera	2019	

[1)] Countries included: Congo, Algeria, Egypt, Kenya, Morocco, Nigeria, South Africa

3.5. LIFE CYCLE INVENTORY ANALYSIS RESULTS

ISO 14044 defines the Life Cycle Inventory (LCI) analysis result as the "outcome of a life cycle inventory analysis that catalogues the flows crossing the system boundary and provides the starting point for life cycle impact assessment". The complete inventory comprises hundreds of flows and is only of limited informational value without the associated impact assessment. A summary of the inventory with the main flows contributing to impact assessment categories under study is given in Annex 2.

4. LCIA Results

This chapter contains the results for the impact categories and additional metrics defined in section 2.6. It shall be reiterated at this point that the reported impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach). LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

Please refer to Table 3-6 for a description of the different contribution compartments. As stated in section 2.6, the following results refer to the impact assessment methods of CML 2016. The results assessed with the EF 3.0 indicator set for the selected impacts are provided in Annex 4.

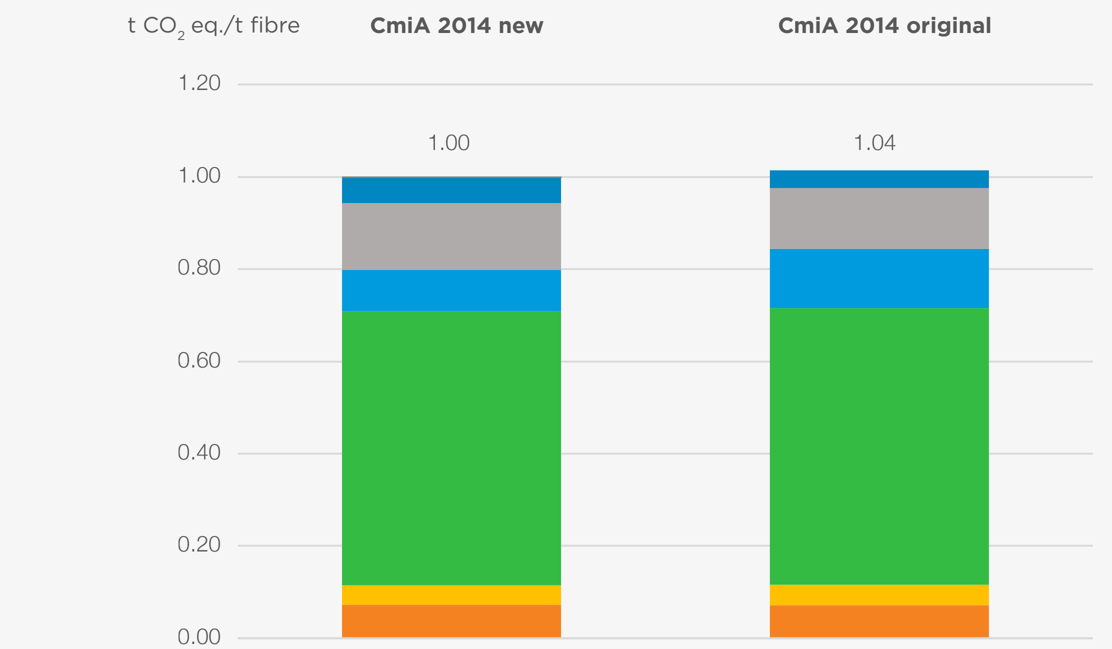
Due to the structure of data and models used in this study, no statistical testing was conducted in this study. This is common in most LCA studies. However, an assessment of standard deviation and uncertainty is provided in section 4.7. Calculated standard deviations laid in the range of 10% to 15%. Based on this assessment, the following wording is used in this study to describe differences in results:

Table 4-1: Differences in results and corresponding wording

Range of difference in results	Wording
<10%	small, slight, limited
10% – 20%	visible, clear
>20%	large, strong

4.1. IMPACT OF MODEL UPDATE

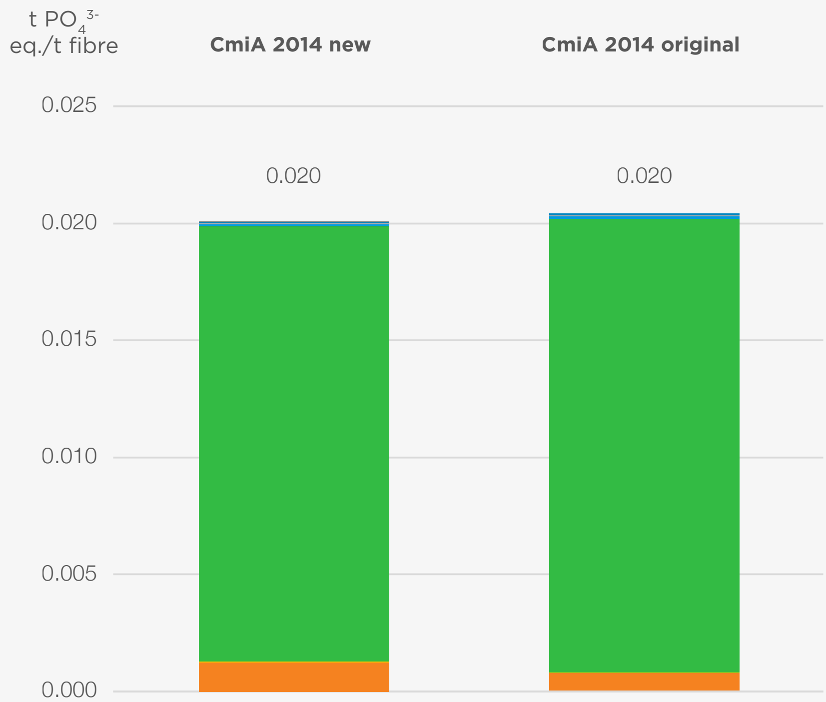
First, the impact of the model update was investigated. To do this, the inventory data from the 2014 study were entered to the updated/ modified model used in this study. The results for the assessed impact categories are shown in the following figures (Figure 4-1 to Figure 4-3).



	CmiA 2014 new	CmiA 2014 original
Transports	0.00	0.00
Transport to gin	0.05	0.04
Provision of fertilizer	0.14	0.13
Ginning	0.09	0.13
Field work	0.00	0.00
Field emissions	0.59	0.60
Crop protection	0.04	0.04
Field clearance	0.07	0.07

Figure 4-1: Impact of changes in the model on climate change results

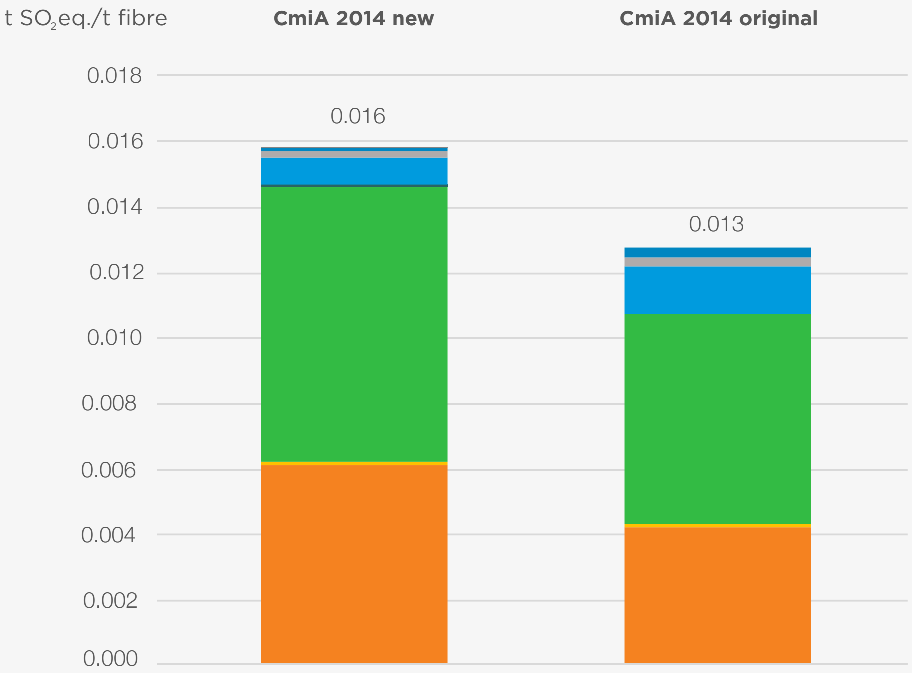
The update of the model had very limited impact on the climate change results (<5%, Figure 4-1). There were also close to no changes in eutrophication modelling caused by the model updates (<2%, Figure 4-2). The erosion rate was assumed to be part of the inventory data, so the same rate was used for the comparison and none of the updates reported above were applied. The assessment of nitrogen leaching used in the 2014 study was based on a more complex model compared to the 2020 study. The 2014 study considered application time, climate data and soil type, albeit on a weak data basis. The 2020 version used fixed emission rates for leaching in relation to fertilizer application. The assessment shows that this simplification did not have an influence on the results.



	CmiA 2014 new	CmiA 2014 original
Transports	0.000	0.000
Transport to gin	0.000	0.000
Provision of fertilizer	0.000	0.000
Ginning	0.000	0.000
Field work	0.000	0.000
Field emissions	0.019	0.019
Crop protection	0.000	0.000
Field clearance	0.001	0.001

Figure 4-2: Impact of changes in the model on eutrophication results

The update of the model lead to large changes in acidification potential (>20%, Figure 4-3). The increase in the contribution of field clearance was due to the assumption of nitrogen contained in the burned biomass is adjusted (based on the IPCC 2019 guidelines for crop residues), leading to higher ammonia emissions. Field emissions are an important contributor to acidification, mainly due to ammonia emissions from fertilizer application. The increase in acidification from field emissions can be attributed to different accounting methods for nitrogen coming from sources other than fertilizer (deposition, free living nitrogen fixing bacteria). In the old model, for “natural nitrogen inputs”, only the difference in emissions compared to a natural reference system were accounted for. For this comparison, these inputs were considered to be part of the inventory data and were therefore also considered as inputs into the new model, i.e. this nitrogen was added to the nitrogen inputs and the same emission factors as for fertilizer were used. But in the new model, no emissions from a reference system are subtracted, leading to higher impacts in the comparison. The above-mentioned nitrogen inputs were not considered in the updated 2020 inventory anymore (steady state assumption), therefore these changes in the model are not applicable for the present study.



	CmiA 2014 new	CmiA 2014 original
Transports	0.000	0.000
Transport to gin	0.000	0.000
Provision of fertilizer	0.000	0.000
Ginning	0.001	0.001
Field work	0.000	0.000
Field emissions	0.008	0.006
Crop protection	0.000	0.000
Field clearance	0.006	0.004

Figure 4-3: Impact of changes in the model on acidification results

4.2. 2020 RESULTS AND COMPARISON TO GLOBAL BENCHMARK

The following sections show the results for the 2020 inventory data and compares it with the global production benchmark.

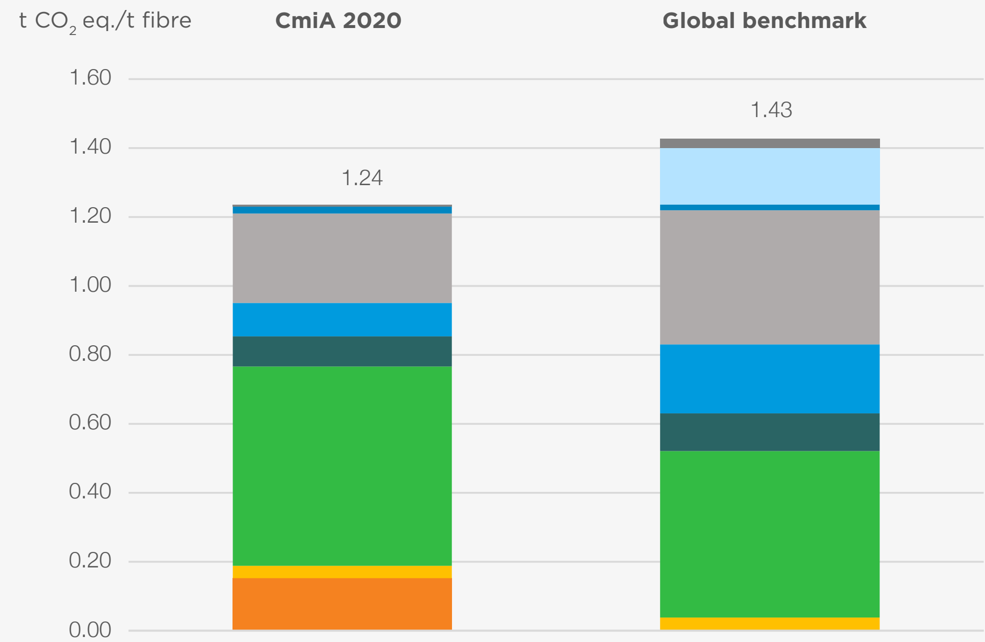
4.2.1. Climate change

Figure 4-4 shows the results for climate change. Field emissions and provision of fertilizer were the largest contributors to impacts on climate change. Field emissions are mainly related to fertilizer application (fertilizer induced N_2O emissions and CO_2 emissions from carbon contained in fertilizer in the case of urea), so these impacts are correlated. However, as the results were reported on a per kg product basis, the process was scaled by yield (emissions divided by yield). Therefore, as long as increased fertilizer use is accompanied by increased yields, the impact on a per kg basis can remain constant or even decrease.

These scaling effects might also be the reason why field emissions were lower for the global benchmark compared to CmiA. At the same time, impact from provision of fertilizer was higher for the global benchmark. This can also be related to different fertilizer types used and their related impact on production, as well as updates to the background data such as energy provision between 2014 (reference year of the global benchmark) and 2019 (reference year of energy datasets used in the present study).

A clear difference between the impact of CmiA and the global cotton benchmark is due to differences in irrigation practices. Irrigation does not only have an impact in terms of water consumption (see section 4.2.4) but also requires energy (for pumping), which in turn leads to an impact on climate change. Since CmiA is exclusively rainfed, these impacts do not occur and lead to visible savings in greenhouse gas emissions in comparison to the global benchmark (- 13%).

The results shown here do not account for the (temporal) uptake of CO_2 in the fibre. Assuming a carbon content of 42% in the fibre (Cotton Inc., 2017), 1540 kg CO_2 are stored in the product. As cotton is a short-lived consumer good, this carbon dioxide is released later at the end-of-life in the product, so that it is only temporarily stored. Therefore, the carbon uptake is not considered in the impact assessment in this study. This approach is consistent with previous studies and with the PEF method.

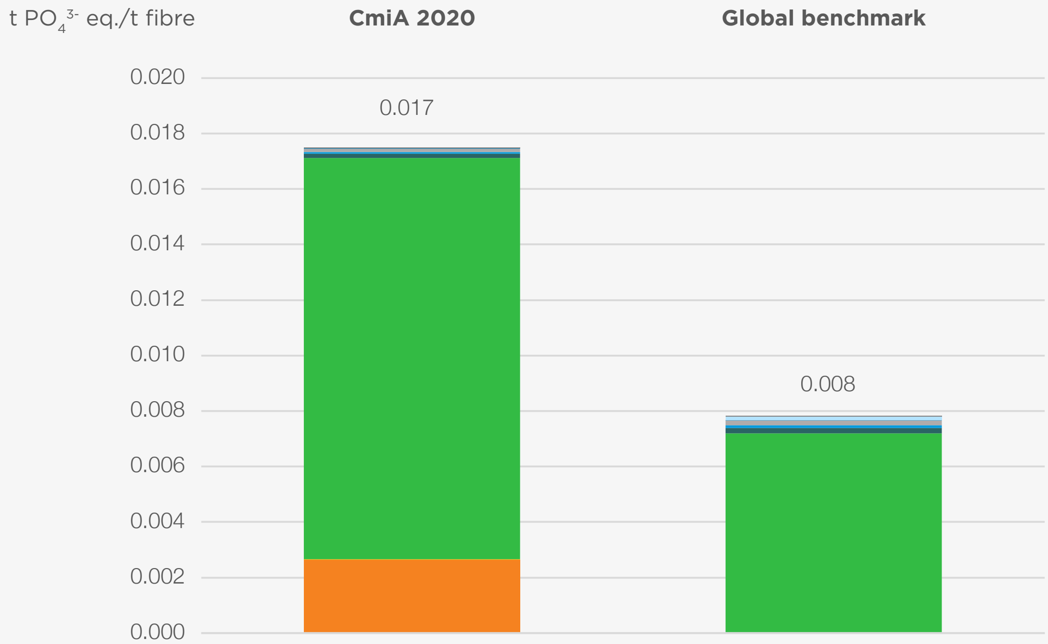


	CmiA 2020	Global benchmark
Packaging		0.03
Irrigation	0.00	0.16
Transports	0.00	0.00
Transport to gin	0.02	0.02
Provision of fertilizer	0.26	0.39
Ginning	0.10	0.20
Field work	0.09	0.11
Field emissions	0.58	0.48
Crop protection	0.04	0.04
Field clearance	0.15	0.00

Figure 4-4: Climate change results

4.2.2. Eutrophication

Figure 4-5 shows the results for eutrophication. The most relevant contribution pathways of agriculture to eutrophication are nitrate leaching from fertilizer application, and phosphorous emissions with soil erosion. Therefore, similar to climate change, field emissions are the largest contributor to this impact category. However, field clearance also had a significant contribution to the eutrophication potential due to ammonia emissions occurring during the combustion process. The contribution of the different eutrophication pathways to the eutrophication potential for the present study is provided in Table 4-2.



	CmiA 2020	Global benchmark
Packaging		0.000
Irrigation	0.000	0.000
Transports	0.000	0.000
Transport to gin	0.000	0.000
Provision of fertilizer	0.000	0.000
Ginning	0.000	0.000
Field work	0.000	0.000
Field emissions	0.014	0.007
Crop protection	0.000	0.000
Field clearance	0.003	0.000

Figure 4-5: Eutrophication results

Eutrophication results were lower for the global benchmark compared to CmiA. Leaching is likely to be lower on average in the global production systems, as it is assumed to be low to non-occurring in arid production regions (where many of the global production areas are located). In addition to that, nitrogen contained in the irrigation water was considered as a nitrogen input to the fields but also as an extraction from the environment (negative emission) in Cotton Inc. 2017, with the potential that the overall balance can be negative, thus reducing the eutrophication potential.

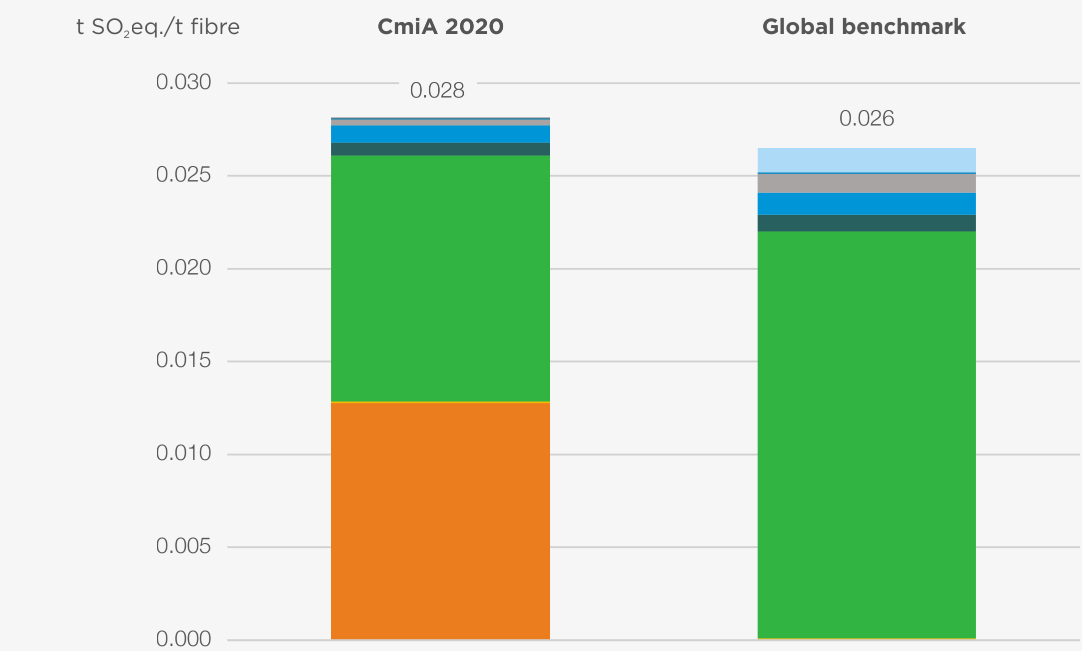
Table 4-2: Contribution of different eutrophication pathways to eutrophication (for CmiA 2020)

Eutrophication pathway	Contribution
Field emissions (fertilizer)	23%
Combustion	15%
Leaching	55%
Soil erosion	8%
Other	<0.25%

4.2.3. Acidification

Figure 4-6 shows the results for acidification. Field emissions are also an important contributor to acidification, mainly due to ammonia emissions from fertilizer application, especially from urea (see emission factors provided in Table 3-7). The contribution of field clearance was of particular relevance in this impact category as the combustion of biomass leads to the emission of multiple acidifying substances, i.e. ammonia, nitrogen monoxide and sulphur dioxide.

There was only a small difference in the acidification potential of CmiA and the global benchmark in absolute terms, but the contribution analysis showed clear differences. The acidification potential in the global benchmark was dominated by the field emissions. It is assumed that this is caused by the fertilizer profiles used: in India and China a large fraction of the applied nitrogen fertilizer is urea, which leads to larger ammonia emissions than other fertilizer (see Table 3-7). Field clearance was not assessed in the global benchmark study, so the comparison of acidification potential between the two systems may not be founded on an equal data basis.

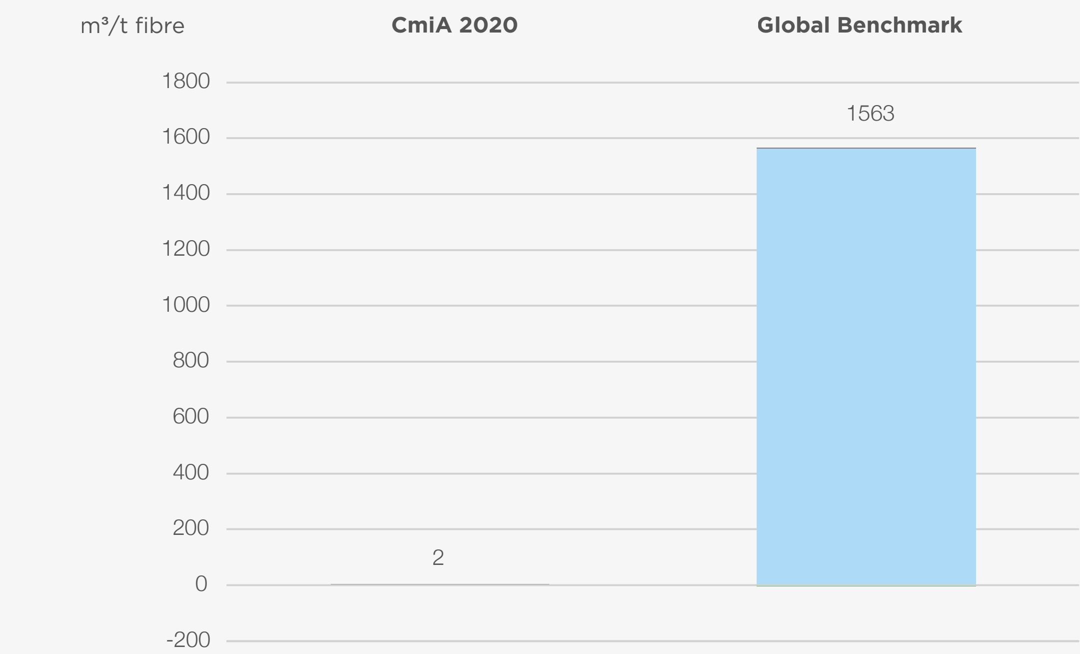


	CmiA 2020	Global benchmark
Packaging		0.000
Irrigation	0.000	0.001
Transports	0.000	0.000
Transport to gin	0.000	0.000
Soil Carbon	0.000	0.000
Provision of fertilizer	0.000	0.001
LUC	0.000	0.000
Ginning	0.001	0.001
Field work	0.001	0.001
Field emissions	0.013	0.022
Crop protection	0.000	0.000
Field clearance	0.013	0.000

Figure 4-6: Acidification results

4.2.4. Water

Figure 4-7 shows the results for water consumption. As described in section 2.6, the focus of the water assessment was the blue water consumption, i.e. water extracted from surface and ground water sources. As CmiA cotton does not rely on irrigation, there is only a very small amount of water consumed in the upstream processes (e.g. for the provision of energy for fertilizer production). Water consumption in the global benchmark is entirely (>99%) related to irrigation.



	CmiA 2020	Global Benchmark
Packaging		0
Irrigation	0	1560
Transports	0	0
Transport to gin	0	0
Provision of fertilizer	0	2
Ginning	1	1
Field work	0	0
Field emissions	0	0
Crop protection	0	0
Combustion	0	0

Figure 4-7: Blue water consumption results

4.3. COMPARISON WITH 2014 RESULTS

As stated above, the results for CmiA from 2014 and 2020 are not directly comparable. The main reason for that is that Cameroon was added as an additional cultivation region, and has a large share in the total production (>40%, see Table 3-2). This inclusion, in combination with an updated weighting scheme (see section 2), represents a major difference in the scope between the 2014 study and the present study. Hence the results of this study cannot be used to measure progress in management practices and environmental performance of CmiA farmers. Nevertheless, the changes in results compared to the 2014 study should be discussed here in relation to the underlying inventory data to provide an informed insight into why these changes occurred.

Table 4-3 shows a comparison of results from the 2014 study (original results, no updates applied) to the present study for the assessed impact of climate change, eutrophication and acidification. Blue water consumption is close to zero in CmiA, with no changes between 2014 and 2020 and is therefore not shown. Biodiversity was not assessed in 2014 and is therefore also not included.

Table 4-3: LCIA Comparison with 2014 study

	Climate change		Eutrophication		Acidification	
	kg CO^2 eq./t fibre		kg PO_4^{3-} -eq/t fibre		kg SO_2 eq./t fibre	
	CmiA 2020	CmiA 2014 original	CmiA 2020	CmiA 2014 original	CmiA 2020	CmiA 2014 original
Field clearance	153.1	71.8	2.7	0.8	12.8	4.2
Crop protection	35.1	43.7	0.0	0.0	0.1	0.1
Field emissions	578.4	600.3	14.5	19.4	13.2	6.4
Field work	87.1	0.0	0.2	0.0	0.7	0.0
Ginning	97.6	127.6	0.0	0.1	0.9	1.5
Provision of fertilizer	259.4	132.8	0.1	0.1	0.3	0.3
Transport to gin	20.2	38.3	0.0	0.1	0.0	0.3
Transports	4.6	0.0	0.0	0.0	0.0	0.0
Total	**1235.6**	**1036.5**	**17.5**	**20.4**	**28.1**	**12.7**

Climate change: Cameroon reported fertilizer rates comparable to Côte d'Ivoire and a higher use of machinery (while there was no reported machinery use in the 2014 study at all). Therefore, the provision of fertilizer and machinery use showed higher contribution in 2020 compared to 2014. Also, with higher assumed adoption rates for field clearance, this process also showed higher contribution to climate change. Field emissions are mainly related to fertilizer application, and increased fertilizer use will also lead to increased emissions. However, as the results were reported on a per kg product basis, the process was scaled by yield (emissions divided by yield). Therefore, as long as increased fertilizer use is accompanied by increased yields, the impact on a per kg basis can remain constant or even decrease.

Eutrophication: soil erosion was identified as an important contributor in the 2014 study. Hence, soil erosion was assessed in more detail in this study, using GIS data and considering management practices (see section 3.2.5). With these updates, soil erosion only contributed 8% to eutrophication (see Table 4-2), and eutrophication results are lower in 2020.

Acidification: Cameroon reported fertilizer rates comparable to Côte d'Ivoire, so the related emissions were visible in the results. In the 2014 study however, with the low fertilizer application and emission profile of Zambia accounting for 50% of the CmiA profile, the emissions were much lower. The contribution of field clearance was of particular relevance here as the combustion of biomass leads to the emission of multiple acidifying substances, i.e. ammonia, nitrogen monoxide and sulphur dioxide.

It should be stated here again, that similar to the present study, benchmark data for global cotton production was also updated from a previous version (2012) to improve data quality and geographical representativeness. The results for the global benchmark also changed significantly, whereby the impact on climate change and water consumption values decreased. The 2014 study did not conduct a comparative assertion but used the 2012 version of the Cotton Inc global benchmark to set results into perspective. This lead to additional changes in comparing CmiA results with a global benchmark compared to the 2014 study.

4.4. BIODIVERSITY

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

Whilst the results can be used as indicative to the relative improvements that could be achieved by the adjustment of management practices, the method is comparatively new and has not been broadly tested so there are no available benchmarks in literature. Hence, the results should not be taken as absolute but serve as a step towards including biodiversity assessments within LCA studies.

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

4.4.1. Estimated biodiversity

The hemeroby value for the less detailed calculation was estimated based on the land use type. The higher the hemeroby, the larger the distance the land is from a state of 'naturalness'. The method outlines four land use types (forestry, pasture, arable and mining) that all have a range of hemeroby based on the intensity of land use as detailed in Figure 4-8:

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

Figure 4-8: Hemeroby level for land use types forestry, pasture, arable and mining (Lindner & Knüpffer 2020, page 6)

The hemeroby value for this baseline scenario was determined based on the combination of land use types assumed to be occurring in the three production countries: extensive agriculture and semi-intensive agriculture. This resulted in the hemeroby of cotton cultivation areas defined for Zambia as 4 'semi-natural' and for Cameroon and Cote d'Ivoire as 5 'partially distant from nature' for arable land (Lindner & Knüpffer, 2020). The hemeroby value is then equated to a local biodiversity value $Bv_{local;}$; the lower the hemeroby value, the higher the local biodiversity value.

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

Eq.1:

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

As the collected data represents a multitude of farms within each country, an average ecoregion factor was determined based on the ecoregion contribution (% of area) for each country. For example, Côte d'Ivoire includes four ecoregions: West Sudanian savanna, Western Guinean lowland forests, Guinean forest-savanna mosaic and Eastern Guinean forests.

The method is tied in with the Land Use Framework by the Life Cycle Initiative which defines ΔQ as the quality difference of a land surface area that deviates from a reference condition and is maintained for a determined period of time which is interpreted to be the impact of the process[10]. ΔQ is calculated by determining the difference from the ecoregion factor and Q, the global biodiversity value (BV_{global}) as detailed in Eq.2.

Eq.2:

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

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

Table 4-4: Impact on Biodiversity, hemeroby approach, CmiA average

	Hemeroby	Local biodiversity value, BV_{local}	Ecoregion Factor, EF	BV_{global} =Q	ΔQ	Land Use per FU	Biodiversity Impact per FU = Land Use *Delta Q
Unit		*BVI*		*BVI*	*BVI*	*m2a/FU*	*BVIm2a*
Baseline scenario	4 (Zambia), 5 (Cameroon, Côte d'Ivoire)	0.767	0.352	0.285	0.082	10.198	0.737

4.4.2. Detailed biodiversity calculation

The calculation for the specific biodiversity value BV_{arable} was carried out using parameters based on (Fehrenbach, Grahl, Giegrich, & Busch, 2015) and the methodology defined by Lindner et al, (2019). The parameters considered were related to diversity of weeds, diversity of structures, soil conservation, material input and plant protection. The parameters are detailed in Table 4-5.

The baseline scenario parameters were determined based on the primary data gathered for each farming region to achieve the land use (arable) biodiversity value (BV_{arable}) as outlined by Lindner et al, (2019). While data availability was good for parameter group A3 to A5 (compare to table Table 3-4), more vague assumptions needed to be made for parameter A1.1, A1.2. and A2.1.

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

Table 4-5: Parameters considered in detailed biodiversity calculation (based on (Fehrenbach, Grahl, Giegrich, & Busch, 2015))

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

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

The individual BV_{local} for each region was aggregated into an overall value for all regions using the production volumes per region. As per the initial calculation, Eq.1, the BV_{global} (Quality) was determined by utilising the Ecoregion factors to determine the biodiversity impact per FU ($BV_{global} = BV_{local} * EF$). ΔQ was calculated using Eq.2.

Two scenarios were assessed using the detailed biodiversity calculation: no tillage and an increase in yield. In the case of no tillage, with no adjustment to the yield, the intensity of soil movement parameter was assumed to be 0 (L/ha) which is representative of the diesel utilised for machinery, and the ground cover assumed to be 100% of the time. For the increase in yield scenario, with no adjustment to management practices, the land use per FU was reduced by 15% for each region.

Table 4-6: Impact on Biodiversity, detailed approach

	Local biodiversity value, BV_{local}	Ecoregion Factor, EF	BV_{global} =Q	Delta Q	Land Use per FU	Biodiversity Impact per FU = Land Use * Delta Q
Unit	*BVI*		*BVI*	*BVI*	*m2a/FU*	*BVIm2a*
Baseline scenario	0.845	0.352	0.297	0.054	10.198	0.558
Scenario: No till	0.848	0.352	0.298	0.054	10.198	0.552
Scenario: 15% yield increase	0.845	0.352	0.297	0.054	8.669	0.474

The results show that by including no till, there is a small reduction on the overall biodiversity impact per FU. This is due to a combination of adjusting the parameter for intensity of soil movement (measure in L diesel/ha) and ground cover to 100%. With an increase in yield of 15% (adjusting the land use per FU), there is an estimated reduction in overall biodiversity impact of 15% (this follows from the Life Cycle Initiative land use framework where impact is related to land use over time and is thus not specific to the assessment method used here).

4.4.3. Results summary

The less detailed biodiversity calculation, utilising the hemeroby scale, resulted in a higher biodiversity impact per FU than all three scenarios assessed for the detailed biodiversity calculation. The baseline scenario for the detailed biodiversity calculation resulted in a biodiversity impact per FU of 0.558 $BVIm^2a$ which is 24 % lower than the calculation utilising the hemeroby scale which resulted in a biodiversity impact of 0.737 $BVIm^2a$. This is a good match despite the data uncertainty for some of the parameters used in the detailed assessment. However, comparisons are difficult to make as the assessment methods were developed recently and benchmark values do not exist.

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

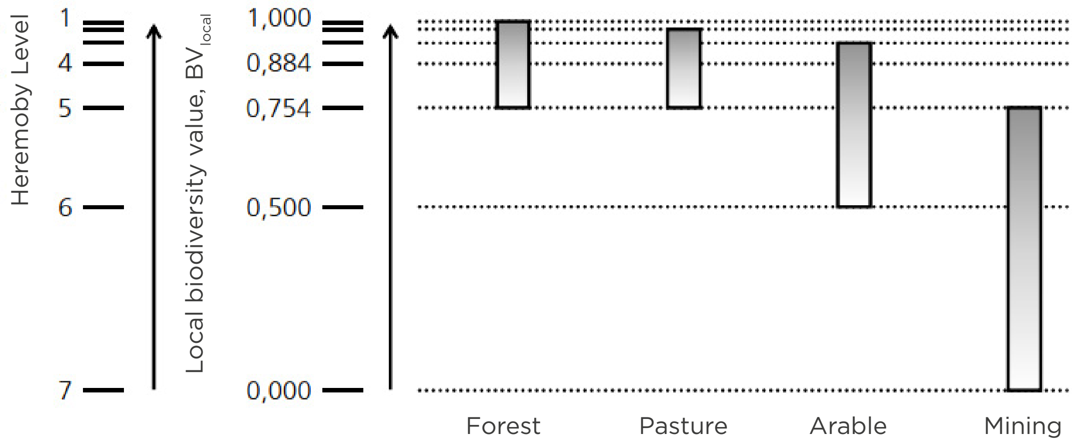


Figure 4-9: Value intervals of the land use types assessed by the biodiversity method (Lindner & Knüpffer 2020, page 7)

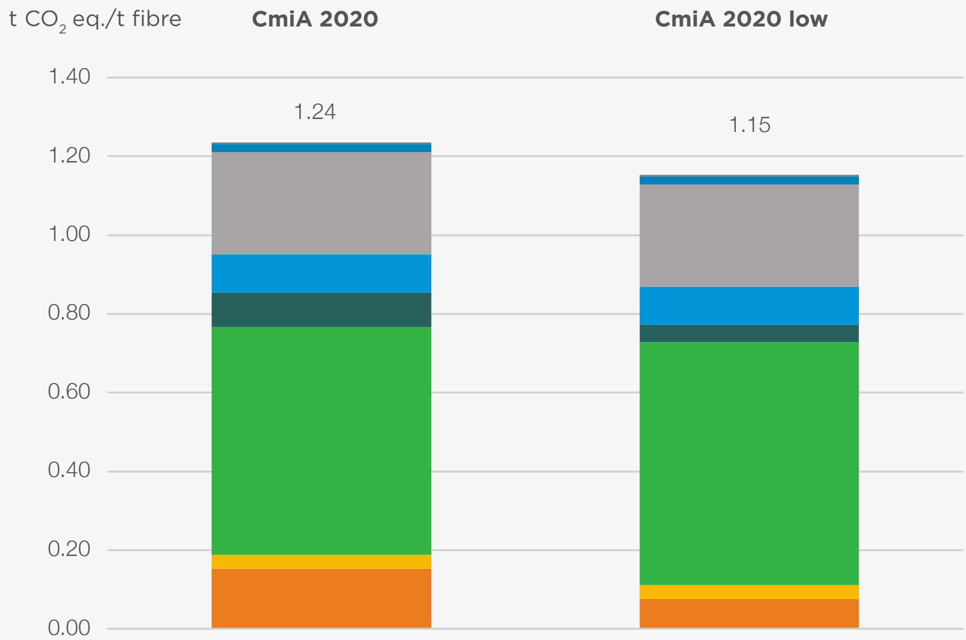
The local biodiversity value for the baseline and increased yield scenarios is 0.845 and is 0.848 for the no till scenario. This shows the local biodiversity value to lie within the range for arable land however is higher than that initially estimated. The values then lie between hemeroby level 4 (semi-natural) which represents an extensive agriculture system and 5 (semi intensive agriculture), confirming the chosen classification in the hemeroby approach. However, according to the detailed assessment, the systems under study would classify closer to "extensive agriculture" than to "semi-intensive agriculture". Again, these values should be interpreted with care as some of the input data and the validity of the model calibration for the biomes under study is related to uncertainty.

4.5. SENSITIVITY ANALYSIS

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

Therefore, not all of these parameters were assessed in the sensitivity analysis. The combined effect of parameter uncertainties on the results is assessed in section 4.7. Field clearance and diesel consumption are the two parameters from primary data collection with the largest uncertainty, in terms of data availability but also in terms of standard deviation (see also sections 3.1. and 4.7.). For both parameters, conservative approaches were taken to specify their values. Therefore, for a sensitivity analysis, both values were reduced by 50% (in each country) and the results were recalculated, see Figure 4-10 "CmiA 2020 low".

The impact on climate change was reduced by 7% assuming lower values for diesel consumption and lower adoption rates for field clearance. The reduction in acidification was larger (24%, no figure) due to the larger contribution of field clearance to this impact category. The reduction in eutrophication was only 3% (no figure).



	CmiA 2020	CmiA 2020 low
Packaging		
Irrigation	0.00	0.00
Transports	0.00	0.00
Transport to gin	0.02	0.02
Provision of fertilizer	0.26	0.26
Ginning	0.10	0.10
Field work	0.09	0.04
Field emissions	0.58	0.62
Crop protection	0.04	0.04
Field clearance	0.15	0.08

Figure 4-10: Sensitivity analysis, climate change results with 50% reduction in diesel use and field clearance ("CmiA 2020 low")

4.6. SCENARIO ANALYSIS

4.6.1. Soil carbon stock changes

Cropland management modifies soil carbon (C) stocks to varying degrees depending on how specific practices influence C input and output from the soil system. The main management practices that affect soil C stocks in croplands are the type of residue management, tillage management, fertilizer management (both mineral fertilizers and organic amendments), choice of crop, intensity of cropping management (e.g., continuous cropping versus cropping rotations with periods of bare fallow), irrigation management, and mixed systems with cropping and pasture or hay in rotating sequences (IPCC, 2019).

However, it is difficult to assess the precise amount of carbon potentially stored in or emitted from agricultural soils, as also soil type, climate and previous management practices are important aspects that influence the extend of soil carbon storage or emission. As for other emission modelling, the IPCC guidelines provide a tiered approach to assess changes in soil carbon stocks. For this study, as a first screening assessment, the Tier 1 approach from IPCC was used to assess the potential changes of soil carbon stocks with assumed future changes in management practices of CmiA farmers.

In the Tier 1 approach, changes of organic C stocks are assessed over a reference period of 20 years. First, an initial reference soil C stock is calculated for the beginning of the assessment period. This reference soil carbon stock can be increased or decreased over the assessment period with the adoption of different management practices. These changes are assessed in the Tier 1 approach with fixed change factors that specify the changes in soil carbon associated to the adoption of these management practices over 20 years.

The following scenarios were assessed to quantify the potential of future increases in soil carbon (see Table 4-7): One scenario assessed the potential of abandoning the practice of field clearance. According to the decision tree provided in IPCC 2019, this would change the system from low C input to medium C input. A second scenario assessed how an additional change to no-till and direct seeding would influence soil carbon. The full parameter setting for the IPCC Tier 1 calculation approach is given in Annex A2.

Table 4-7: Scenarios for changes in soil carbon stocks

Parameter	Baseline	Scenario “no field clearance”	Scenario “No field clearance + no till”
Land use (according to IPCC 2019 Figure 5.1)	Adoption rate field clearance = Low C input (CI=78%, CM=100%, ZM=89%), remainder = Medium C input	All regions 100% Medium C input	All regions 100% Medium C input
Tillage	Adoption rate full till (CI 96%, CM 20%, ZM 69%), remainder assumed to be no-till	No changes to baseline	All regions 100% no-till

The results of the assessment are provided in Table 4-8, both on a per kg and a per ha basis. The values are reported as sequestration (referring to the amount of carbon stored in the soil, i.e. negative emission) and reported as CO_2 equivalents (i.e. not as actual amount of carbon stored in the soil).

Table 4-8: Results of IPCC Tier 1 assessment of changes in soil carbon stocks in future management scenarios

	Scenario “no field clearance”	Scenario “No field clearance + no till”
Per ha	246 kg CO_2 eq./ha and year	677 kg CO_2 eq./ha and year
Per t fibre	0.49 t CO_2 eq./t fibre	1.41 t CO_2 eq./t fibre

The numbers provided above need to be interpreted with care. First, it should be kept in mind that the sequestration potential always refers to a time period of twenty years. They could be interpreted as “if all farmers switch to no field clearance next year, they will sequester 291 kg of CO2 eq. per ha and year for the following twenty years”. However, the changes will occur more gradually, so lower amounts of sequestered carbon over a longer time period is likely for CmiA production as a whole. The assessment assumed that farmers that already adopted no till and no field clearance are no longer sequestering any carbon as the changes happened in the past. Such changes could be addressed if the assessment was made backward looking into the last 20 years of cultivation. However, that also means that sequestering potential is lower in Cameroon, where already a large number of farmers practice no till and is higher in Côte d'Ivoire where the adoption rate for full-till is reported to be higher. The numbers provide the average future potential for CmiA for the given adoption rates.

As this is only a screening assessment, it should also be stated here again that soil carbon dynamics are complex and that a more detailed assessment under consideration of soil type and climate, and more refined assessment of the carbon inputs could lead to different results.

However, it also becomes clear from the values above that the abandonment of field clearance and the adoption of no till has significant carbon saving potentials. For the next twenty years, a farmer changing management practices in both aspects, could sequester more carbon than is emitted during the process from farm to gin[11], until the soil is assumed to reach a new equilibrium in C stocks.

4.6.2. Fertilizer shifting (reduced fertilizer application to cotton)

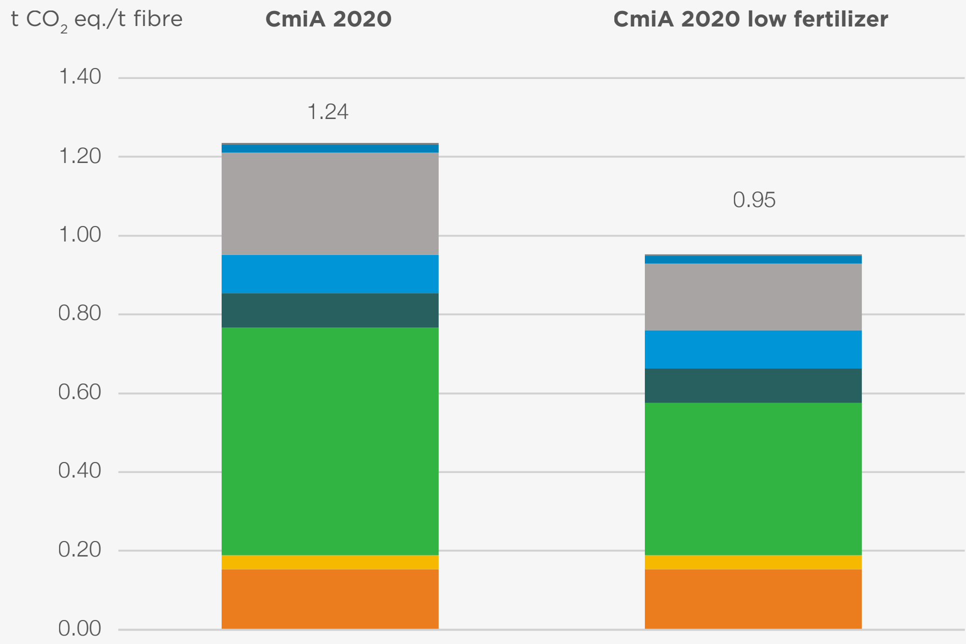
Cotton companies facilitate access to agricultural inputs such as fertilizer for their farmers, e.g. through credit programs. It is known that farmers often do not apply all fertilizer at the recommended and purchased rate but shift fertilizer from cotton to staple crops (e.g. maize, (Laris & Foltz, 2014)). In these cases, the impacts from fertilizer provision and application assessed in this study will be overestimated (since the fertilizer application rates used in the baseline calculations of this study were based on data of fertilizer purchased by the cotton companies and were not measured at field).

To assess the impact of possible fertilizer shifting from cotton to staple crops, the fertilizer application rates provided in Table 3-4 were reduced by 35%. It is very difficult to assess the actual extent of possible fertilizer shifting, but 35% was assumed to be a realistic possibility based on expert judgement. The results for this scenario for impacts on climate change are given in Figure 4-11.

Impacts on climate change are reduced by 23% in this scenario. Eutrophication results decreased by 26% and acidification results by 17% (not shown). This does not come as a surprise since provision of fertilizer and fertilizer induced field emissions were identified as important contributors to these impacts in the previous sections. Considering that the calculated nitrogen (N) balance was close to zero (Figure 3-1) in the baseline, a reduced fertilizer application would result in a N deficit. It is possible that additional N is available for cotton from the crop rotation (e.g. growing of legumes) and therefore allows to reduce fertilizer application in cotton and shift fertilizer to following staple crop cultivation.

The extend of fertilizer shifting and the plausibility of N availability for cotton from the crop rotation in nutrient scarce systems is difficult to assess. Following the "conservative approach" recommended for LCA studies for uncertain data, and given the closed N balance in the baseline, the exclusion of fertilizer shifting is justifiable for the baseline. However, this means that the environmental impact of CmiA could potentially be much lower than reported in the baseline.

11 By convention, emissions of CO2 usually refer to a timeframe of 100 years. That means that the radiative forcing of CO2 is integrated over a timeframe of 100 years . This also means that in order to fully account as carbon savings, these should be sequestered for a minimum of hundred years. However, as a change in management practices can quickly release the sequestered CO2 again, it is suggested to only account for 1/100 of the saving potential for each year the carbon is stored, meaning it would take 100 years until the full saving potential is realized. Certification schemes exist that allow for a faster accounting of carbon credits related to soil carbon sequestration, but these require close monitoring and long-term obli-gations. In consequence, saving potentials must be communicated with care



	CmiA 2020	CmiA 2020 low fertilizer
Transports	0.00	0.00
Transport to gin	0.02	0.02
Provision of fertilizer	0.26	0.17
Ginning	0.10	0.10
Field work	0.09	0.09
Field emissions	0.58	0.39
Crop protection	0.04	0.04
Field clearance	0.15	0.15

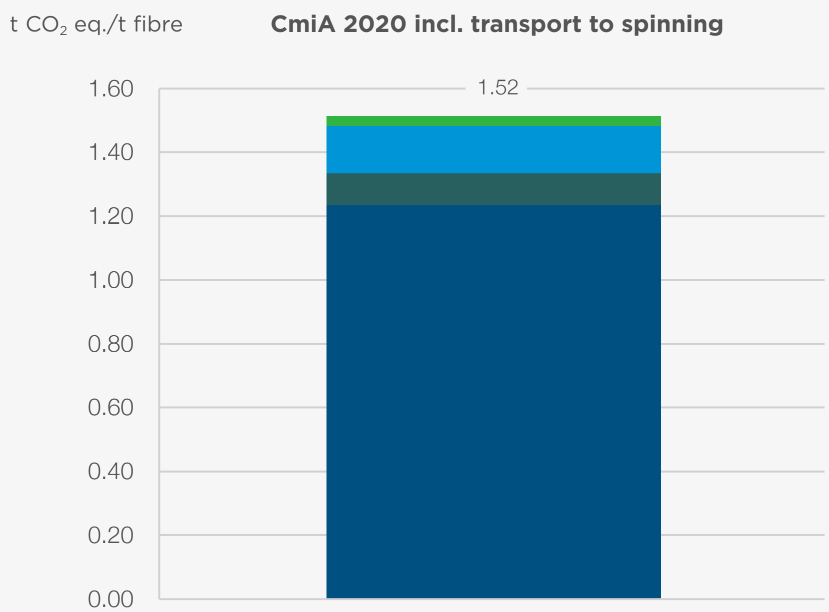
Figure 4-11: Scenario analysis, climate change results with 35% reduction in fertilizer application ("CmiA 2020 low fertilizer")

4.6.3. Inclusion of transports to processing

Transport from local gins in the regions under study to the destination of processing can span half the globe. In this scenario, the approximate impact of this transport stage is put into perspective of the results of cotton fibre from cradle to gin gate. No precise transport scenarios were used, but proximate distances to demonstrate the order of magnitude of the added impact:

- 750 km road transport (from gin to harbour)
- 10000 nautical miles (18520 km) per ship (from harbour to harbour)
- 250 km road transport (from harbour to spinning)

Figure 4-12 shows the results for global warming potential of CmiA fibre including transport to processing. The transport to processing added approximately 0.3kg of CO_2 eq./kg fibre, or approximately 25%, to the global warming potential of CmiA fibre, with the assumed transport distances.



Harbour to spinning	0.03
Harbour to harbour	0.15
Gin to harbour	0.10
Fibre at gin-gate	1.24

Figure 4-12: Climate change results of CmiA fibre including transport to spinning

4.7. UNCERTAINTY ANALYSIS

Uncertainty analyses test the combined effect of parameter uncertainties on the final results. The present analysis was performed using the Monte Carlo simulation in GaBi Analyst which draws random numbers from defined uncertainty intervals to calculate a multitude of possible results. The less these results vary, the lower the overall parameter uncertainty of the LCA model.

The use of a Monte Carlo Analysis requires the definition of the standard deviation for each parameter to be assessed. As most parameters used in this study are assessed based on multiple data points (multiple seasons, several cotton companies), for most parameters the standard deviation could be calculated. The calculated deviation should only be considered as an estimate because it is still based on a limited range of data points, and a normal distribution is assumed which might not always be the case in reality. However, it is considered that the estimates were sufficient for the purpose of this assessment. Where standard deviations could not be calculated, standard deviation from other regions were used as a proxy. As none of the regions had multiple data points for prices, a standard deviation of 20% was used as a proxy. Twice the standard deviation was used as minimum and maximum limit for parameter variation, accounting for the fact that more extreme values are highly unlikely to occur in the assessed production systems based on their physical and chemical relationships.

The uncertainty analysis was performed for the parameters that are based on collected data. Not included were the emission factors, as the uncertainty of emission factors is reported in the respective guidelines (IPCC 2019) and is not specific to this study. The following parameters were included in the uncertainty assessment:

- Yield
- Fertilizer use
- Fuel use
- Crop protection
- Adoption rate for field clearance
- Distance to gin
- Energy consumption at gin
- Prices (used for allocation)

Data for yield, fertilizer application, and distance to gin had a standard deviation of <20% in all regions. Higher standard deviation was calculated for diesel, crop protections and the adoption rate for field clearance.

The Monte Carlo Analysis was conducted for each country separately. 5000 runs were conducted per analysis. The calculated standard deviation for the LCIA results was then averaged into the CmiA average weighted by production (as reported above). Table 49 shows the result of the assessment.

Table 4-9: Results of uncertainty assessment via Monte Carlo analysis

LCIA	Unit	Baseline	Mean value	Standard deviation	10% percentile	90% percentile
Climate change	t CO_2 eq.	1.24	1.24	11.0%	1.01	1.38
Acidification	t SO_2 eq.	0.028	0.028	13.8%	0.021	0.032
Eutrophication	t PO_4^{3-} eq.	0.017	0.017	11.4%	0.015	0.021

The mean value of the analysis was equal to the baseline, meaning that the average of the 5000 runs with different parameter settings yielded the same results as the baseline settings of the parameter, confirming the validity of these settings. Combined standard deviation was 11% for climate change, 14% for acidification and 11% for eutrophication. The percentile values mean that 1 out of 10 runs, with parameter settings varied randomly according to their standard deviation, lead to results that are below or above these values, and 80% of all values are between the percentile values. Figure 4-13 serves as an example graph (impacts on climate change) with added confidence interval (80%).

In conclusion, the uncertainty of the results does not compromise any of the conclusions drawn in the results sections above. One interpretation that should be highlighted here, is that for climate change, the 90% percentile is below the results for the global production benchmark (1.38 vs 1.43 kg CO_2 eq./kg fibre), meaning that there is less than a 10% chance that the results for CmiA are larger than the global production benchmark.

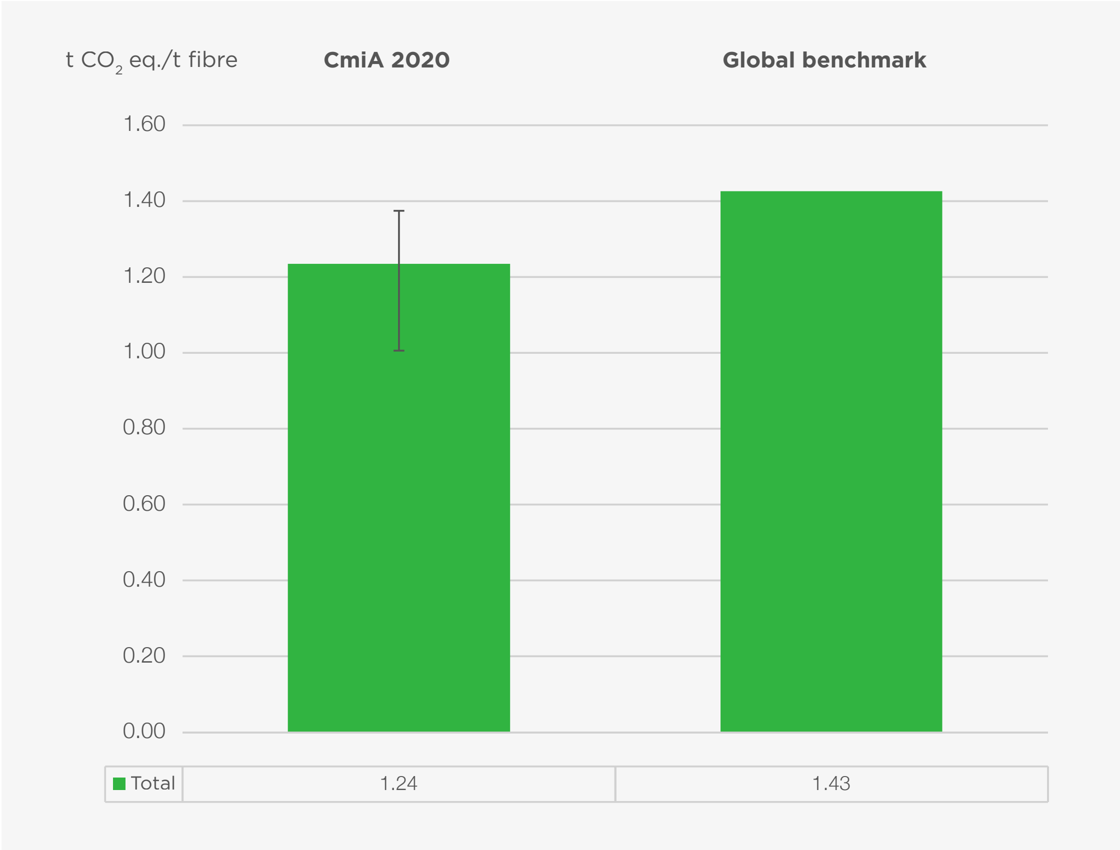


Figure 4-13: Climate change results of CmiA 2020 (baseline) including uncertainty (80% confidence interval, uncertainty data for global benchmark not available)

5. Interpretation

5.1. INTERPRETATION OF RESULTS UNDER CONSIDERATION OF LIMITATIONS AND UNCERTAINTY

For easy access, interpretations of the results that are necessary to understand differences and contributions are provided along with the results in the respective sections of the report. This section summarizes relevant findings on a larger scale, and reviews them in relation to assumptions, limitations, and the results of the uncertainty analysis.

The inclusion of a new region (Cameroon), more cotton companies and, in relation to that, the usage of a new weighting scheme represents a major difference in the scope between the 2014 study and the present study. Hence, the results of this study cannot be used to measure progress in management practices and environmental performance of CmiA farmers. With two large producing countries now included, which also represent the regional differences (more intensive cultivation systems in West- and Central Africa and extensive systems in Southern Africa (Zambia), it can be assumed that future updates will not change the results as dramatically as this update did. In addition, in the current weighting scheme, 90% of the production is represented by more intensive production systems compared to the 10% contribution of the low input low output system of Zambia. Other CmiA regions cannot be expected to be more input intensive than Cameroon and Côte d'Ivoire, therefore the inclusion of more regions is not likely to increase the results. Therefore, uncertainty related to geographic representativeness decreased clearly with this study compared to the 2014 study.

There is good consistency of the data both across reporting cotton companies and between the 2014 and 2020 study. However, limitations in terms of data collection and data availability remain. In particular, high uncertainty remains for the adoption rates, especially for field clearance. It is difficult to do a systematic assessment of how many farmers are applying the practice, and where data is available it is generally based on expert judgment from the data providers.[12] A conservative approach is taken in this study by assuming that if field clearance is confirmed but no adoption rate is reported, all farmers apply this technique (adoption rate of 100%). This might lead to an overestimation of the impacts of this practice. However, while the total extent of this practice is uncertain, reducing or eliminating this practice would have clear advantages in terms of environmental impact as assessed in this study. The possibility of fertilizer shifting from cotton to staple crops is another area of uncertainty related to the inventory data. Similar to field clearance, a conservative approach was taken and all fertilizer use was allocated to cotton cultivation, resulting in a potential overestimation of the assessed environmental impacts of CmiA.

The LCA study of Cotton Inc. from 2017 was compared to the present study as global production benchmark. System boundaries, modelling approach and data quality were compared to the present study, and no deviations were identified that would compromise a comparison of the two systems. The comparison against the global production benchmark lead to mixed results. There was a visible advantage in terms of climate change, mainly related to the additional energy use for irrigation in the global production systems. There was no difference in the acidification potential of the two systems and an increase in eutrophication potential for CmiA compared to global production. Water consumption in CmiA was found to be minimal compared to the global production systems. This is a good indication that the regions under study are well suited in terms of climatic conditions to grow cotton, an advantage of CmiA over arid cultivation regions included in the global benchmark, where cotton cultivation relies heavily on irrigation.

12 In Cameroon and Côte d'Ivoire it is sometimes still recommended to burn the cotton stalks to reduce cotton bollworm population and other pests. However, this is in contradiction to the CmiA criteria.

Considering the results of the combined uncertainty analysis, these results can be assumed to be comparatively stable, as results at the higher or lower end of the standard deviation calculated for CmiA would not lead to different conclusions. However, such a combined uncertainty assessment was not available for the global benchmark, so it cannot be concluded that a “best case against worst case comparison” of the two systems would not lead to different results. All this said, it should be highlighted again that the comparison of impacts was done based on multi-country averages. This means that impacts of single farms or even specific production regions as a whole could differ substantially from the reported average values, both for CmiA and for the global production system.

Additional uncertainty in the comparison is related to the possibility of fertilizer shifting in CmiA systems, which might lead to lower impacts than the baseline used for the comparison, providing additional advantages to the CmiA system. The exclusion of LUC in both product systems (CmiA and global benchmark) can be considered as another limitation. However, for CmiA the possible impact of this omission can be expected to be low (see section 2.1), while it is difficult to estimate the possible extent of this omission for the global production system.

Including changes in soil carbon into the assessment can have a visible impact on the climate change results. While the total calculated potential was large, there is large uncertainty around the precise extent, the speed of adoption of new management practices that lead to changes in soil carbon, and around the timeframe over which such changes would occur and should be accounted for. The results provided in this study should therefore only be seen as a first screening assessment that should be interpreted with care.

5.2. DATA QUALITY ASSESSMENT

The following section provides a more formal assessment of data quality as required for ISO compliance. Inventory data quality is judged by its precision (measured, calculated, or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied) and representativeness (geographical, temporal, and technological).

5.2.1. Precision and Completeness

✓ **Precision:** As the majority of the relevant foreground data are primary data (i.e. “measured”) covering multiple years and producing companies, precision is considered to be high. All background data are sourced from GaBi databases with the documented precision.

✓ **Completeness:** Each foreground process was checked for mass balance and completeness of the emission inventory. No data were knowingly omitted. Completeness of foreground unit process data is considered to be high. All background data are sourced from GaBi databases with the documented completeness.

5.2.2. Consistency and Reproducibility

✓ **Consistency:** To ensure data consistency, all primary data were collected with the same level of detail, while all background data were sourced from the GaBi databases.

✓ **Reproducibility:** Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modelling approaches in this report. Based on this information, any third party should be able to approximate the results of this study using the same data and modelling approaches.

5.2.3. Representativeness

- ✓ **Temporal:** All primary data were collected for the year 2017 to 2019. All secondary data come from the GaBi 2020 databases and are representative of the years 2010-2019. As the study intended to compare the product systems for the reference year 2019, temporal representativeness is considered to be high.
- ✓ **Geographical:** All primary and secondary inventory data were collected from cotton producing companies specific to the countries or regions under study. More than 50% of CmiA production is covered by the regions investigated. Where country-specific or region-specific data were unavailable, proxy data were used, e.g. for background datasets for energy and fertilizer supply. Geographical representativeness is considered to be good.
- ✓ **Technological:** All primary and secondary data were modelled to be specific to the technologies or technology mixes under study. Where technology-specific data were unavailable, proxy data were used. Technological representativeness is considered to be high.

6. Conclusions, Limitations, and Recommendations

The following section summarizes conclusions and limitations outlined in the previous sections and provides recommendations based on these results.

6.1. CONCLUSIONS

GENERAL

- The present study shows a clear improvement in terms of methodology and data quality compared to the previous study from 2014.
- Including Cameroon as an additional region and more cotton companies into the assessment improved the geographical representativeness of the results.
- The main recommendations from the previous study were considered in the present study:
    - several cultivation years were assessed,
    - assessment of eutrophication and soil erosion was improved,
    - the screening assessment of biodiversity and the inclusion of scenarios on soil carbon and transport to processing demonstrates clear progress towards a more holistic impact assessment.
- There is good consistency in the data both across reporting cotton companies and between the 2014 and 2020 study. However, limitations in terms of data collection and data availability remain (see next section).
- For the impact potentials *climate change, eutrophication* and a*cidification*, field emissions are the largest contributor. Field clearance has a visible impact on the results in these impact categories. Other important contributing processes were the provision of fertilizers and energy use at gin.
- While the total extent of field clearance among CmiA farmers is uncertain, reducing or eliminating this practice has clear advantages in terms of environmental impact.
- The (continued) adoption of no-till and elimination of field clearance also have a large potential to increase the soil carbon content in the soil, with clear improvement potential related to impact on climate change.
- Blue water consumption in CmiA cultivation systems is close to zero because they are exclusively rainfed.
- Impacts on biodiversity are influenced by the biodiversity value of the region under study and area use. Comparisons are difficult to make as the assessment methods were developed recently and benchmark values do not exist. With their classification as semi-intensive to extensive cultivation systems and the presence of crop rotations in all cultivation systems, the impact on biodiversity is lower than in more intensive cultivation systems. The extension of no-till practices can have a positive impact on biodiversity.

CMIA VS. GLOBAL PRODUCTION

- Similar to the present study, benchmark data for global cotton production was also updated to improve data quality and geographical representativeness. The results for the global benchmark also changed significantly and are now much closer to the results of CmiA cotton.
- In terms of impact on climate change, with the updated results for both CmiA and the global production benchmark, the results lay in the same range for both production systems. While fertilizer and pesticide use are higher in the global production systems, so are the yields. As results are reported on a per kg basis, these factors cancel each other out leading to results comparable to the CmiA production system. However, CmiA cotton has a smaller global warming potential of 13%, mainly attributed to the additional energy used for irrigation in the global dataset.
- Eutrophication is reported to be lower in the global production system compared to CmiA. Eutrophication is mainly caused by two processes: leaching and soil erosion. Leaching might be lower in the global production systems, as it is assumed to be low to non-occurring in arid production regions. Eutrophication related to soil erosion is already very small in the CmiA production system with the updated values. There is little surplus nitrogen applied in the CmiA systems under the given loss rates. Therefore, while losses could be minimized further, the improvement potential for impacts on eutrophication are not particularly large in CmiA systems.
- Acidification potential is in a similar range when the two production systems are compared. However, in CmiA systems there is a large impact of field clearance to acidification, indicating a clear improvement potential with a cease-out of this practice. Field clearance was not assessed in the global benchmark study, so the comparison of acidification potential between the two systems may not be reliable.
- Water use in CmiA is minimal compared to that of the global production as CmiA production does not include irrigation practices. This is a positive contribution to environmental sustainability in itself, given the scarcity of water resources in some of the alternative global cotton production areas. In addition, as mentioned above, the exclusion of irrigation also leads to reduced impacts on climate change.

2020 VS. 2014 STUDY

- Due to the updated data basis of the assessment (inclusion of another region, more producing companies), the results from 2014 and 2020 are not directly comparable.
- Updates on methodology and the background datasets used in the assessment have only a minor impact on the results.
- Impact on global warming is larger in the 2020 study compared to the 2014 study. As stated above, this is not related to a change to worse management practices, but only related to the inclusion of a new production region and adjusted weighting to build the CmiA average.
- Eutrophication is lower in the 2020 study due to an improved assessment of soil erosion but also due to inclusion of an additional region.

6.2. LIMITATIONS

- Primary data collection remains challenging. Conducting the study in 2020 under the restrictions of the COVID-19 pandemic added to the difficulties as no in-person meetings with the data providers could take place and on-site priorities may have shifted from data collection to more immediate matters.
- High uncertainty remains for the adoption rates, especially for field clearance. It is difficult to do a systematic assessment of how many farmers are applying the practice, and where data is available it is generally based on expert judgment from the data providers. A conservative approach was taken in this study by assuming that if field clearance is confirmed but no adoption rate is reported that all farmers apply this technique (adoption rate of 100%). This may lead to an overestimation of the impacts of this practice.
- The same is true for the possible extend of fertilizer shifting, where this study also took a conservative approach (assuming no fertilizer shifting) potentially overstating the environmental impact of CmiA.

6.3. RECOMMENDATIONS

- It is recommended that the Aid by Trade Foundation develops its LCA data collection scheme further: yearly collection of LCA inventory farm data from the same data providers and internal evaluation of impact results will allow AbTF to measure continuous progress in environmental impact reduction. Most of the relevant data is already collected on a yearly basis. However, possibilities to improve data availability for some of the aspects where data uncertainty still exists should be evaluated:
    - adoption rates of no-till and field clearance
    - possible fertilizer shifting
    - possible land use changes
    - diesel consumption
    - energy consumption at gin
    - prices at gin gate
    - biodiversity assessment.
- A network of sample farms could be established to verify collected data and to measure the impact of management practices from year to year on the same farms.
- The (continued) adoption of no-till and cease out of field clearance have clear potentials to reduce the impacts of CmiA cotton on the environment.
- Social impact assessment is outside the scope of this study but subject of a separate study. Conclusions about the sustainability of the present cultivation systems and decision on changes in practice should only be made with careful consideration of both studies.

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Annex:

ANNEX 1: CRITICAL REVIEW STATEMENT

corsus corporate sustainability

Critical Review Report

according to ISO 14040 & 14044

of

Life Cycle Assessment of Cotton made in Africa
conducted by Sphera Solutions Inc.
on behalf of the Aid by Trade Foundation, Hamburg

Reviewers:
Dr. Ulrike Eberle (Chair), corsus-corporate sustainability GmbH, Hamburg
Prof. Dr. Jan Paul Lindner, Bochum University of Applied Sciences, Bochum
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Hamburg, Bochum, Eschborn, 24 February 2021

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Content

1 Procedural Aspects

The Critical Review was commissioned by the Aid by Trade Foundation, Hamburg (thereafter referred to as AbTF) in autumn 2020 as an accompanying review. The reviewers have first been involved on a conference call on 17th September 2020 where the general setting of the study and the goal & scope have been discussed. Thereafter, on 13th January 2021 a second conference call took place, where the results have been presented.

The draft project report was received on 4th December 2020. The draft reports was commented in detail and has been submitted to the commissioner and the practitioner on 22nd December 2020. On 30th January 2021 the reviewers received the final version of the LCA study report, mentioning that there "might be some minor changes coming for the biodiversity calculations". This report including the changes for biodiversity received on 23rd February 2021 build the basis of the review. The inventory models themselves were not part of the review. However, the central assumptions for the inventory modelling were checked for plausibility.

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

The review panel is neutral with regard to and independent from particular commercial interests. The panel had to safeguard other interested parties issues, even if NGOs or other interested parties e.g. from competing materials manufactures or the consumer side have not been invited due to the time scale of the project and the limited budget. According to ISO 14044 [2], the chair of the panel is responsible for its composition, the inclusion of "interested parties" being optional.

The reviewers emphasise the open and constructive atmosphere of the project. All necessary data were presented to the reviewers and all issues could be discussed openly. This review report is part of the final study report. The resulting critical review report is consensual within the review panel.

2 General Comments

In the reviewed life cycle assessment (LCA) study, the 2014 study on LCA for cradle-to-gate production of lint cotton (at gin gate) produced under the requirements of the Cotton made in Africa (CmiA) standard was updated. The study does not compare the included CmiA-producing countries but gives an aggregated average of CmiA and compares this average to a global benchmark.

The report is well structured and conforms to the requirements of a third-party-report and comparative assertions intended to be disclosed to the public according to ISO 14044 clauses 5.2 and 5.3. The summary concentrates the results meaningfully. These are plausible according to the line of argument and all statements are substantiated in the report.

In the course of the review process, comments and issues raised by the review panel were comprehensively addressed.

3 Statements by the reviewers

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

"The critical review process shall ensure that:

- the methods used to carry out the LCA are consistent with the international Standard (section 3.1);
- the methods used to carry out the LCA are scientifically and technically valid (section 3.2);
- the data used are appropriate and reasonable in relation to the goal of the study (section 3.3);
- the interpretations reflect the limitations identified and the goal of the study (section 3.4);
- the study report is transparent and consistent (section 3.5)."

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

3.1 Consistency of the methods with ISO 14040 & 14044

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

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

The selection of the four included impact categories is explained sufficiently. The impact assessment methods chosen are in line with the ISO 14044 standards.

Concluding, it can be stated that the methods used are consistent with the international standard.

3.2 Scientific and technical validity of the methods

The methods used are scientifical and technical state of the art. Some specifics performed in the study are highlighted below:

- The influence of the updated LCIA model was addressed by recalculating the 2014 results with the updated model.
- For the first time also a biodiversity impact assessment of cotton cultivation with a newly developed method is included in a commercial, reviewed cotton LCA study.
- Land use change was addressed as part of the sensitivity analysis, even though the CmiA standard prescribes a continuous, non-degrading crop cycle.
- Water scarcity was addressed in a simplified manner because there is no irrigation under the CmiA standard.

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

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

As data base for generic data the GaBi database was chosen. The reviewers can follow the rationale of the authors, that these data are consistent, a quality management is in place, and data are updated periodically. If data were not available reasonable, proxies were calculated by the authors.

Specific data of CmiA were used for the cotton cultivation and the ginning. However, it was not part of this critical review to check the correctness of the primary data collected by AbTF.

For some datasets, it remains unclear how the proxy was modelled. This should be documented better, e.g. for the two datasets for the electricity mix for the Region Africa.

Overall, the data can be seen appropriate regarding the goal of the study.

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

3.4 Assessment of interpretation referring to limitations and goal

The interpretation in the final report is based on the analysis performed. The interpretation is sound and limitations and conclusions are derived comprehensively.

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

Thus, it can be stated that the interpretations reflect the limitations identified and the goal of the study.

3.5 Transparency and consistency of the report

The line of argument from inventory over impact assessment to interpretation is comprehensible.

The documentation could be improved somewhat to provide more clarity, for example in the abbreviations used (e.g. country codes) or the consistent indication of the temporal scope at different points in the report.

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

4 Conclusions and recommendations

It can be stated that this LCA study has been conducted according to the ISO standards 14040 and 14044. The study is foreseen for publication and this can be recommended by the reviewers. As is usual when communicating LCA results, great care must be taken in the wording and generalisations must be avoided.

5 References

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

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

ANNEX 2: INVENTORY FLOWS

The following table provides the most important inventory flows of CmiA. Only flows contributing more than 0.5% to any of the assessed impact categories are included. Water flows are excluded due to their large number and low relevance. The provided numbers refer to the inventory before impact assessment, i.e. to mass (t) per t fibre, no characterization factors are applied.

Table A-1: Inventory flows

	CmiA 2020 (t/t fibre)
Emissions to air	0.5434
Inorganic emissions to air	0.5367
Ammonia	0.0092
Carbon dioxide	0.5025
Nitrogen oxides	0.0203
Nitrous oxide (laughing gas)	0.0021
Sulphur dioxide	0.0026
Organic emissions to air (group VOC)	0.0067
Methane	0.0067
Emissions to fresh water	0.1005
Inorganic emissions to fresh water	0.1005
Nitrate	0.1002
Phosphorus	0.0003

ANNEX 3: PARAMETER USED IN CALCULATION OF CHANGES IN SOIL CARBON STOCKS

CI= CôteD'Ivoire, CM=Cameroon, ZM=Zambia; 1=no field clearance 2=no field clearance + no till

Parameter	CI1	CI2	CM1	CM2	ZM1	ZM2	Parameter description
Change factors							
SOC_ref	38	38	38	38	38	38	[t C/ha] Default reference condition soil organic carbon stock (IPCC 2019 Table 2.3)
FLU	0.48	0.48	0.48	0.48	0.48	0.48	change factor land use (IPCC 2019 Table 5.5)
FI_high	1.11	1.11	1.11	1.11	1.11	1.11	change factor high input (IPCC 2019 Table 5.5)
FI_high_org	1.44	1.44	1.44	1.44	1.44	1.44	change factor high input (IPCC 2019 Table 5.5)
FI_low	0.92	0.92	0.92	0.92	0.92	0.92	change factor low input level (IPCC 2019 Table 5.5)
FI_medium	1	1	1	1	1	1	change factor medium input level (IPCC 2019 Table 5.5)
FMG_full	1	1	1	1	1	1	change factor full tillage (IPCC 2019 Table 5.5)
FMG_no_till	1.22	1.22	1.22	1.22	1.22	1.22	change factor no tillage (IPCC 2019 Table 5.5)
FMG_reduced	1.15	1.15	1.15	1.15	1.15	1.15	change factor reduced (IPCC 2019 Table 5.5)
Initial							
Frac_low_in	0.78	0.78	1	1	0.89	0.89	[-] initial fraction of area with low inputs
Frac_medium_in	0.22	0.22	0	0	0.11	0.11	[-] initial fraction of area with medium inputs
Frac_high_in	0	0	0	0	0	0	[-] initial fraction of area with high inputs
Frac_high_org_i	0	0	0	0	0	0	[-] initial fraction of area with high inputs and org. fertilizer
Frac_full_in	0.96	0.96	0.2	0.2	0.69	0.69	[-] initial fraction of area where full tillage is applied
Frac_reduced_in	0	0	0	0	0	0	[-] initial fraction of area where reduced tillage is applied
Frac_no_till_in	0.04	0.04	0.8	0.8	0.31	0.31	[-] initial fraction of area where no tillage is applied

End							
Frac_low_end	0	0	0	0	0	0	[-] fraction of area with low inputs (end of assessment period)
Frac_medium_end	1	1	1	1	1	1	[-] fraction of area with medium inputs (end of assessment period)
Frac_high_end	0	0	0	0	0	0	[-] fraction of area with high inputs (end of assessment period)
Frac_high_org_e	0	0	0	0	0	0	[-] fraction of area with high inputs and org. fertilizer (end of assessment period)
Frac_full_end	0.96	0	0.2	0	0.69	0	[-] fraction of area where conventional tillage is applied (end of assessment period)
Frac_reduced_en	0	0	0	0	0	0	[-] fraction of area where conservation tillage is applied (end of assessment period)
Frac_no_till_en	0.04	1	0.8	1	0.31	1	[-] fraction of area where no tillage is applied (end of assessment period)

ANNEX 4: EF 3.0 LCIA

Table A-2 EF 3.0 LCIA for CmiA 202

Impact	Per kg fibre
Climate Change [kg CO_2 eq.]	1.5242
Eutrophication freshwater [kg P eq.]	0.0003
Eutrophication marine [kg N eq.]	0.0315
Eutrophication terrestrial [Mole of N eq.]	0.2108
Acidification terrestrial and freshwater [Mole of H+ eq.]	0.0463
Water scarcity [m^3 world equiv.]	0.0420

AID BY TRADE FOUNDATION

The Aid by Trade Foundation (AbTF) was founded in 2005 by Prof. Dr. Michael Otto, an entrepreneur from Hamburg, Germany. The aim of the foundation, which operates independently of the Otto Group, is to help people to help themselves through trade, thereby preserving vital natural resources and securing the livelihoods of future generations.

With the Cotton made in Africa (CmiA) initiative, AbTF is putting its principles into practice. The trade partners of the CmiA Demand Alliance source African cotton produced according to the CmiA standard and pay the foundation a volume-based license fee that is reinvested in the cultivation areas. Consumers recognise products by the CmiA label and make a valuable contribution to protecting the environment and supporting smallholder farmers and their families in Africa.

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