COTTON MADE IN AFRICA

Life Cycle Assessment (LCA) of Cotton made in Africa (CmiA)

Carried out by: PE INTERNATIONAL AG

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Acronyms

AbTF	Aid by Trade Foundation
ADP	Abiotic Depletion Potential
ADPE	Abiotic Depletion Potential (elementary)
ADPF	Abiotic Depletion Potential (fossil)
AP	Acidification Potential
CmiA	Cotton made in Africa
CML	Centre of Environmental Science at Leiden
CTUe	Comparative Toxic Unit for Ecosystems
CTUh	Comparative Toxic Unit for Humans
ELCD	European Life Cycle Database
EoL	End of Life
EP	Eutrophication Potential
eq	equivalent
GaBi	Ganzheitliche Bilanzierung (German for Life Cycle Engineering)
GHG	Greenhouse Gas
GWP	Global Warming Potential
ILCD	International Life Cycle Data System
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NMVOC	Non-methane Volatile Organic Compound
ODP	Ozone Depletion Potential
PE	PE INTERNATIONAL
POCP	Photochemical Ozone Creation Potential
USGS	United States Geological Survey
VOC	Volatile Organic Compound
WIP	Waste Incineration Plant

Foreword

The Aid by Trade Foundation (AbTF) is interested to assess the environmental impact of lint cotton produced under the requirements of the Cotton made in Africa (CmiA) verification scheme. AbTF commissioned PE INTERNATIONAL AG to analyze CmiA field and gin production according to the principles of the ISO 14040 series and to document the results in an ISO-compliant report (present document).

This study is the second of two independent studies on the CmiA environmental footprint and independent from an earlier study carried out by Systain Consulting. While both studies strictly follow the ISO 14040 principles, system boundaries and inventory data vary and the modelling approach of the two studies differ.

The aim of this study is to use similar models, methods and assumptions as the established LCI for the global average of conventional cotton as in a similar study commissioned by Cotton Incorporate in 2012 (COTTON INC. 2012).

The study is based on primary data from Ivory Coast and Zambia as representative of the main two climatic regions where CmiA cotton is cultivated: West Africa and Eastern / Southern Africa.

In order to ensure a high level of quality and credibility, a critical review was conducted by experts from the Fraunhofer Institut and the Seminar für ländliche Entwicklung (SLE) of the Humboldt University. Recommendations were incorporated into this report.

Aid by Trade Foundation, Hamburg

November 2014

Executive summary

1. The main purpose of this study is the development of a Life Cycle Inventory (LCI) for cradle-to-gate production of lint cotton, accounting for cotton farming and ginning and including the production of inputs (e.g. pesticides, fertilizers) in keeping with the Cotton made in Africa (CmiA) verification scheme requirements.

2. The farmers who participate in the CmiA initiative are small-scale farmers. Utilization of agricultural inputs such as fertilizers or pesticides is low or – depending on the country, and cost and availability of such inputs - very low. Harvest is exclusively done by hand. In all CmiA countries, cotton is cultivated under rain fed conditions and in crop rotation with other cash or subsistence crops such as maize, sorghum, millet and groundnuts. The CmiA cotton production system can be described as an extensive cultivation system that is adapted to available resources and ecological as well as socio-economic conditions.

3. The necessary life cycle inventories for upstream processes (e.g. fertilizer production, provision of energy) were retrieved from the GaBi 6.3 program database. The model was used to set up a cradle-to-gate LCI where the functional unit is 1,000 kilograms (kg) of lint cotton at the gin gate. In order to carry out an LCIA, the following impact categories were investigated (using the CML impact assessment methodology framework): climate change, eutrophication, and acidification. Additionally, water use and water consumption were investigated.

4. The potential impact on climate change of CmiA cotton is quantified as 1,037 kg CO_2-equivalent (eq). for 1,000 kg of lint cotton. As mentioned above, the study on CmiA cotton follows similar system boundaries and the same agricultural modelling approach as a recently published LCA study on cotton grown in various locations around the globe (COTTON INC. 2012). The result given for the global average impact of this cotton on climate change is 1,808 kg of CO_2-eq per 1,000 kg of lint cotton produced[1]. Given the 1,037 kg of CO_2-eq per 1,000 kg of lint cotton calculated in this study, the extensive CmiA cultivation system potentially emits fewer greenhouse gases per kg fiber produced.

5. The total freshwater used to produce 1,000 kg of CmiA lint cotton is around 3,400m³. Since cultivation is done under rain fed conditions, water use in African countries is dominated by natural precipitation (green water). Upstream processes (e.g. provision of energy, fertilizer production), where surface and ground water (blue water) is used, contribute only little to water use (7%). Only a minor fraction of the above-mentioned upstream blue water use is consumptive use. Thus, the contribution of 1,000 kg of CmiA lint cotton to blue water consumption is extremely small. In contrast, all the regions under investigation in COTTON INC. 2012 were at least partially irrigated. It therefore comes as no surprise that blue water con-

[1] The values given in COTTON INC. 2012 are considering the carbon uptake in the product (1540 kg CO_2 per 1000kg, resulting in a value of 268 kg CO_2-equiv. per 1000 kg of lint cotton). 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. This is why the carbon uptake should normally not be considered in LCA studies and is not declared in this study. If it was considered, the GWP for CmiA would be negative, i.e. -503 kg CO_2-equiv. per 1000 kg of lint cotton.

sumption, which is of environmental relevance here, was orders of magnitude smaller for CmiA ($1 m^3$/1,000 kg lint cotton) compared to the global average (2,120 m^3/1,000 kg lint cotton).

6. When assessed using default values, soil erosion contributed significantly (>60%) to eutrophication and caused comparatively large values per kg of final product (20.4 kg PO_4-eq. per 1,000 kg of lint cotton), as an assumed average erosion rate per ha is distributed over a relatively low yield. However, values for soil erosion and nutrient content of the soil were found to be based on large uncertainties, though they are highly sensitive parameters with regard to the eutrophication results. The degree of soil erosion highly depends on applied soil management methods (i.e. when minimum tillage is practiced – such as with conservation agriculture – erosion can be almost completely eliminated), which were not assessed in this study.

7. The acidification impact category presents a pattern similar to that of climate change impact: 86% of impacts derive from agrarian processes, 11% from ginning and 2% from transport from farm to gin. Of the agrarian processes, field emissions still dominate the impact category with 58%, while clearance contributes a significant share of 38%.

8. A life cycle assessment is used as a standardized tool for the quantitative evaluation of potential environmental impacts on product basis. Thereby the methodology focuses on resource use efficiency (impact per kg final product) rather than on the overall impacts of production systems. Additionally, some environmental impact routes (e.g. biodiversity, carbon sequestration in soils) are difficult to assess in an LCA framework at the moment and were not investigated in this study. CmiA could potentially also show advantages over intensive production systems with regard to these aspects due to its extensive cultivation practices. Based on all these factors, it is apparent that additional aspects to those investigated in this study need to be considered for a holistic assessment of the sustainability of different production systems.

1 Introduction

9. The main purpose of this study is the development of a Life Cycle Inventory (LCI) for cradle-to-gate production of lint cotton (at gin gate) produced in keeping with the Cotton made in Africa (CmiA) certification scheme requirements. Additionally, a Life Cycle Impact Assessment (LCIA) was performed to evaluate the environmental impact of this LCI. The Aid by Trade Foundation (AbTF) commissioned PE INTERNATIONAL to perform these analyses according to the principles of the ISO 14040 series and to document the study results in an ISO-compliant report (present document).

10. LCA has been proven to be a reliable method for objectively and scientifically evaluating the resource requirements of a product and its potential impact on the environment during every phase of its production, use, and disposal. The LCA approach was utilized in a previous large-scale study undertaken by the cotton industry to evaluate the environmental impact of conventional cotton farming practices and textile production systems (Cotton Inc. 2012). This study provided a solid baseline with up-to-date LCI data for evaluating cotton products and has sparked interest among stakeholders along the entire textile supply chain in investigating the environmental performance of their supply chains.

11. As stated on the AbTF website, the CmiA Initiative follows an innovative approach to development cooperation. "The Cotton made in Africa Initiative follows the principles of 'social business' – as the name of the foundation says, this is aid by trade, helping people to help themselves by means of commercial activities." (http://www.cottonmadeinafrica.org/en/the-initiative.html)

12. CmiA is a label with strict exclusion criteria for labor practices such as slavery, human trafficking or exploitative child labor. CmiA promotes integrated pest management and controls compliance with internationally recognized lists of banned pesticides[2]. Smallholder farmers are not subsidized, for instance, through the payment of higher prices. Instead in exchange for license fees for the CmiA label, the farming communities receive training enabling them to apply farming practices that result in higher yields, including some non-financial or social/communal benefits such as school buildings, classrooms, school uniforms etc. The small-scale farms producing under the CmiA label are regularly verified according to criteria that include social, environmental and economic aspects, thus promoting the three pillars of sustainability.

13. In response to interest from the apparel industry, a preliminary Life Cycle Assessment was commissioned (SYSTAIN 2013) with promising results for the carbon and water footprints. In order to deepen and broaden the understanding of environmental impacts, PE INTERNATIONAL was subsequently hired to run a full LCA study including further impact

[2] Use of pesticides banned under the Stockholm Convention on Persistent Organic Pollutants (POPs), the WHO list of highly hazardous and hazardous pesticides, and pesticides listed in the Rotterdam Convention on Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade (PIC).

categories known to be highly relevant for agricultural products and document the findings in an adjoining ISO-compliant report.

2 Goal and scope

2.1 Goal of the study

2.1.1 Intended application

14. The goals of this study were to:

1. Create an up-to-date, representative, and well-documented Life Cycle Inventory (LCI) for lint cotton (ginned) from cotton cultivation certified through Cotton Made in Africa (CmiA). The environmental profile is to be presented for 1,000 kg of lint cotton (ginned) in ILCD format (ILCD 2011).
2. Provide a full Life Cycle Impact Assessment (LCIA) of the same product (comprising cultivation and ginning operations).

2.1.2 The reasons for carrying out the study

15. The study was meant to establish a holistic picture of CmiA's environmental profile. Additionally the outcomes are thought to fill a knowledge gap regarding the environmental impact of the various forms of cotton farming. Recently, an in-depth and peer-reviewed study was published on the environmental profile of conventional cotton farming globally (COTTON INC. 2012). Since cotton farming in Africa in general, and under the CmiA Initiative in particular, has very specific and distinctive characteristics, it was suspected that the robust global average of conventional cotton farming did not very accurately describe the environmental profile of CmiA cotton. Therefore a study with credentials and system boundaries similar to those of the Cotton Incorporate study was launched.

2.1.3 Intended audience

16. The intended audience comprises both internal and external stakeholders. The internal stakeholders include those involved in marketing and communications, in operations (with the goal of process improvement). The external stakeholders include customers, the LCA community, and other members of the textile supply chain as well as the general public.

2.1.4 Use of the outcomes

17. The objective of this LCA is to understand the environmental profile of CmiA fiber while also considering existing LCA studies on cotton cultivation. Accordingly, the resulting LCI should use models and methods similar to the established LCI for the global average of conventional cotton (COTTON INC. 2012). Therefore, and in order to ensure the highest level of quality and credibility, a critical review of the study was conducted per Section 7 of the ISO standard (14040 series). This standard details the requirements and guidelines for carrying out an ISO compliant Life Cycle Assessment. The results of the study are intended for publication on the homepage (website) of the AbTF or the CmiA Initiative.

18. This study was not designed to compare different regions under CmiA certification. The published data are intended to represent an aggregated average for CmiA. Additionally, it also makes no claims about differences between the environmental performance of the CmiA scheme and other cotton cultivation practices in Africa. This study does not include a comparative assertion as defined in the ISO standard (14040 series). Available published data were used to put the results of the presented study into perspective, and for discussion and interpretation.

2.2 Scope of the study

2.2.1 Product system to be studied

19. The present study refers to cotton cultivation in Africa, as per the requirements of the CmiA Initiative. The farmers who participate in the CmiA initiative are mostly small-scale farmers who grow cotton in rotation with other cash and food crops such as millet, sorghum, groundnuts, and maize. Two regions, Zambia and Ivory Coast, were selected to represent Western and Southern / Eastern Africa, respectively (see section 2.2.4.2).

20. Fertilizer use is evidently minimal (close to zero) in Zambia, where the system can be considered at equilibrium, i.e. there is no fertilizer applied, natural nitrogen deposition and fixation equals nitrogen leaving the field with the harvest. In Ivory Coast, fertilizer is applied (an order of magnitude greater than in Zambia, ca. 40 kg N per ha) but remains at a relatively low level when compared to global conventional cotton (Cotton Inc. 2012). Economic considerations are the main reason for the limited use of fertilizer in the systems under study. Fertilizer is an expensive and imported input, and in Zambia it is not profitable to use it under the conditions given.

21. In all CmiA countries, cotton is exclusively cultivated under rain fed conditions. Pesticide use under the CmiA scheme is restricted. First of all, the ban on hazardous pesticides is taken very seriously and compliance is controlled as part of the regular verification process. As for the use of pesticides, the concept of integrated pest management, i.e. spraying according to defined thresholds of pests and diseases, is being introduced, whereby pesticides are only used when pathogens have already appeared and economic losses can be expected unless pesticides are applied. This practice is still not fully operational, however.

22. Harvest residues are often left as mulch or soil cover on the fields, but some farmers (25-30%) leave the plants standing and burn the fields before re-cultivation, so-called “clearing”. This method releases emissions including methane, a powerful greenhouse gas. It is the intention of the CmiA Initiative to gradually phase out this practice via training in combination with conservation agriculture, thereby leaving the cut biomass on the fields as soil cover.

23. Harvesting is done exclusively by hand in contrast to the main growing regions for conventional cotton where machines are used. The benefit is that only the cotton bolls are collected, making the cotton cleaner than machine-harvested cotton that can contain twigs, leaves etc. An additional potential benefit is that varieties with a higher fiber length can be

cultivated when manually harvested. However, these potential differences in quality were not considered in this study.

2.2.2 System boundaries

24. The system boundaries of the LCA encompass cotton cultivation under the requirements of the CmiA Initiative and fiber production (ginning) as shown in (Figure 2-1).

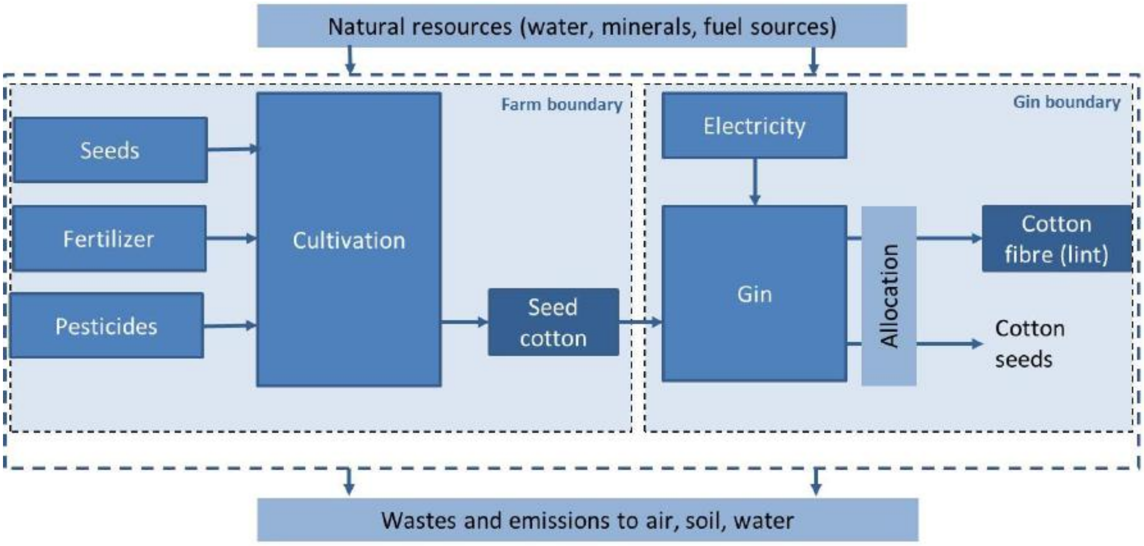


Figure 2-1: System boundaries considered in this study. Transports are included.

Inclusion and exclusion

25. 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. These include but are not limited to: fertilizer and pesticide production as well as field emissions (e.g. N_2O), emissions related to fire clearing (i.e. the combustion of biomass remaining on the field from previous cultivation period) (e.g. CH_4, SO_2), electricity for ginning and all transports (fertilizer to the field, seed cotton to gin).

26. 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 for many different crops being cultivated and used for other work, such as transport to the market. Additionally, soil preparation is generally done by service providers (the animal is only used for a few hours on a single cotton field, i.e. its use in the cotton fields makes up only a very small fraction of their useful life). This multipurpose use makes it difficult to allocate the impact of the animal solely for cotton and justifies the assumption that its contribution to the environmental impact of cotton cultivation is marginal and can be ignored.

27. Furthermore, end of life of gin waste was excluded, as it leaves the system burden free and without any benefits to the main product. Gin waste consists of broken seeds, fibers and plant remains (residues). In the worst case, it could be considered toxic waste because of pesticide remains (residues) (see Buser 2001). On the other hand, it is occasionally returned back to the land as organic fertilizer. The potential negative impact due to toxicity is rather minor since under the CmiA farming practices, pesticide application is considerably reduced and the amount remaining on the waste is even lower. As such, attributing no burden to the gin waste is a neutral approach, disregarding a small potential environmental impact and also annulling a similarly small environmental benefit (fertilizer use). This approach was also followed in Cotton Inc. 2012.

28. As is customary in LCA studies, the construction of capital equipment and maintenance of support equipment were excluded due to their minimal contribution and the extreme difficulty of measuring them. Social aspects are beyond the scope of this study and human labor was therefore also excluded from the study. At the same time it should be noted that fair and safe human labor conditions are included in the prerequisites for the CmiA label.

29. Considering the above-mentioned exclusions, it can safely be said that the sum of the excluded material flows does not exceed 5% of mass, energy or environmental relevance.

2.2.3 Function and functional unit

30. The cradle-to-gate LCI for CmiA lint cotton covers raw material production from field to ginning. The functional unit is 1,000 kilograms (kg) 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.

2.2.4 Data collection and data quality

2.2.4.1 Data collection

31. Primary data for cotton cultivation under the CmiA scheme were provided by the Aid by Trade foundation. Specifically adapted questionnaires to collect inventory data for agricultural systems were used. These questionnaires were filled out by advisors from two cotton associations (SECO and Alliance Zambia). Both associations provided aggregated average data for their associations. No farmer interviews were conducted. After being submitted to PE, these data were subjected to quality checks and benchmarking against literature and other primary cultivation data to ensure reliable results. Inventory data were also submitted to critical review. For the complete inventory data, please refer to Table A-1, supplement. Technological, geographical and time references as well as an assessment of data quality are described in the following.

32. Electricity consumption at the gin was modelled based on primary data from both locations. Distance to the gin also derived from primary data collection, whereas waste was derived from secondary data. Ginning can be adequately described by the electricity con-

sumption used for the process and the ratio of by-products (seed and fiber) and waste (the data points are summarized in Table A-2, Annex).

2.2.4.2 Technological and geographical reference

33. Cotton made in Africa, as the name suggests, is a label exclusively given to African-grown lint cotton. Currently 8% of the world's cotton is produced in Africa, almost exclusively by small-scale farmers (source: CmiA website). Within Africa, the CmiA initiative involves farmers from Benin, Burkina Faso, Ivory Coast, Malawi, Mozambique and Zambia. In 2011, the CmiA initiative had around 270 thousand smallholder farmers under its license. The numbers of farmers in the various African cotton-growing regions are shown in Table 2-1.

Table 2-1: Number of cotton farmers in Africa's various countries and regions (Source: CmiA website)

Number of cotton farmers under CmiA	Number of all cotton farmers in country	Country/region
72,472	145,000	Zambia
75,000	235,000	Mozambique
26,432	130,000	Malawi
173,904		S-Africa
29,212	90,000	Ivory Coast
15,732	240,000	Burkina Faso
20,016	237,500	Benin
64,960		W-Africa
238,864	**1,077,500**	**Africa Total**

34. This study is based on data from Ivory Coast and Zambia a representative of the two main climatic regions where CmiA cotton is cultivated: West Africa and Southern Africa. In Zambia about 72,472 farmers grow CmiA cotton (2010 data, source: CmiA), which amounts to almost half the total number of cotton farmers in the country (145,000 in 2010, source: CmiA). To put it from another perspective, about 42% of all Southern African CmiA farmers are Zambian, making data collection in this country representative for conditions in Southern Africa. Ivory Coast had 29,212 farmers growing CmiA cotton in 2010, out of the total of 90,000 cotton farmers. This constitutes about 45% of CmiA cotton grown in West Africa, again offering a very good basis for data collection in this country. Future updates of the LCI presented in this study will cover more CmiA regions and cotton associations.

2.2.4.3 Time reference

35. Data were collected for the 2012-2013 growing season. The latest available data (last growing season) were used in order to represent current cultivation practices, but also to limit the data collection effort. It is, however, well known that collecting data over a range of years can average out seasonal and annual variations such as droughts and floods (unfavorably heavy rainfalls were reported for both regions in the season under study). Future updates of the LCI presented in this study will cover cultivation data from different years.

2.2.4.4 Background data

36. The necessary life cycle inventories for upstream processes (e.g. fertilizer production, provision of energy) are available from the GaBi 6.3 database (GaBi 6.3). The database was last updated in 2013.

2.2.4.5 Assessment of data quality

Representativeness

37. Technological: All primary and secondary data were modelled to be specific to the technologies or technology mixes under study. Technological representativeness with regard to the goal and scope of this study is considered good.

38. Geographical: All primary and secondary data were collected specific to the countries / regions under study. Where country specific data for background processes were unavailable, proxy data were used. Geographical representativeness with regard to the goal and scope of this study is considered good. Future updates of the LCI will cover additional cultivation regions, which will increase geographical representativeness.

39. Temporal: All primary data were collected for the growing season 2012/2013. All secondary data came from the GaBi 2013 databases and were representative of the years 2009-2013 (GaBi 6.3). Temporal representativeness with regard to the goal and scope of this study is considered good. Future updates of the LCI will cover cultivation data from different years, which will increase temporal representativeness.

Completeness

40. All relevant process steps are considered and modelled to represent each specific situation, i.e. cultivation in Ivory Coast and Zambia were modelled separately. The process chain is considered sufficiently complete with regard to the goal and scope of this study. Disregarded material and energy flows were described above in chapter 2.2.2

Reliability

41. Primary data were collected using a specifically adapted spreadsheet for agrarian systems. Crosschecks concerning the plausibility of mass and energy flows were carried out on the data received. Similar checks were made of the software model developed during the study. Inventory data and their implementation into the agricultural model were critically reviewed (see 2.3). The agricultural model itself is part of the GaBi 2013 database, which was

recently reviewed by an external auditing company (DEKRA). Overall the data quality with regard to the goal and scope of this study can be described as good.

Consistency

42. To ensure consistency, all primary data were collected with the same level of detail, while all background data were sourced from the GaBi databases (GaBi 6.3). Allocation and other methodological choices were made consistently throughout the model.

2.2.5 Allocation

Allocation in the foreground data:

43. 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 was allocated to both the fiber and seed. If possible, allocation should be avoided through e.g. product system expansion according to the ISO standard. If allocation cannot be avoided, the allocation method follows the physical relationships between the co-products (e.g. energy content or weight).

44. However, allocation methods often do not yield meaningful results. In such cases, alternative allocation methods are used in LCA studies, such as economic allocation (splitting the burden based on the 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 best describes the demand that drives production of both products and was also the method used in the study assessing conventional cotton (Cotton Inc. 2012).

45. This study calculated a global average allocation factor of 84:16 for fiber and seed respectively. As shown in Table 2-2, the two African regions investigated in the present study have a higher allocation factor for lint cotton (87% and 93% in Ivory Coast and Zambia respectively). No burden was assigned to the stalks or gin waste (see 2.2.2)

Table 2-2: Market value and derived allocation of seed and lint cotton in the two locations considered

	Ivory Coast	Zambia
Price seed [$/kg]	0.12	0.2
Price lint [$/kg]	1.7	1.5
Seed to lint ratio (mass) [-]	1.3	1.38
Allocation of environmental burden to lint [%]	87%	93%

Allocation of upstream data:

46. Allocation was also applied to the background data used, including, for example, energy content allocation, price allocation etc. Allocation procedures were carefully chosen and documented in the GaBi 6.3 datasets documentation (documentation.gabi-software.com).

Recycling

47. Recycling does not take place in the system under investigation.

2.2.6 Cut-off criteria

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

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

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

51. Environmental relevance – If a flow meets the above criteria for exclusion, yet was thought to potentially have a significant environmental impact, it was included. Material flows that leave the system (by emissions) and whose environmental impact is greater than 1% of the whole impact of an impact category considered in the assessment must be covered. This judgment was made based on experience and documented as necessary.

52. In the assessment, all available data from production processes were considered, i.e. all raw materials used, and thermal energy and electric power consumption using best available LCI datasets. In these cases, even material and energy flows contributing less than 1% of mass or energy were considered.

53. A list of exclusions can be found in section 2.2.2.

2.2.7 LCIA methodology and types of impacts

54. A detailed description of the selected LCIA methodology and types of impacts assessed is given below in chapter 4.1.

2.2.8 Software and database

55. The LCA model was created using the GaBi 6.3 Software system for life cycle engineering developed by PE INTERNATIONAL AG. The GaBi LCI database (GABI 6.3) provides life cycle inventory data for several of the raw and process materials obtained from the background system. The most recent update of the database was in 2013.

2.3 Critical review

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

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

57. The critical review was conducted by two independent experts, namely Ulrike Bos (Fraunhofer Institute for Building Physics, Department Life Cycle Engineering), an expert in agricultural science and Life Cycle Assessment and Dr Susanne Neubert (Centre for Rural Development, SLE, Humboldt University of Berlin), an expert in agricultural science and specifically cotton cultivation in the African socio-economic and environmental context. Both reviewers had access to inventory level data (data collection sheets) and were involved in methodological discussions from an early stage.

58. The review was performed according to ISO 14040 and ISO 14044 and a posteriori after delivery of the draft of the final report. The review report and statement can be found in Supplement B.

3 Life cycle inventory (LCI) analysis

59. The specific data collection of material and energy flows refers to the foreground system, i.e. the cultivation of CmiA cotton in Zambia and Ivory Coast.

60. The reference unit is 1,000 kg lint cotton. The results reflect average cultivation in the two countries. The life cycle impact assessment resulting from the life cycle inventory is displayed in chapter 4 of this report. The software model is described in the following chapters.

3.1 The GaBi model of CmiA cotton

61. The overview of the GaBi model set up in order to calculate the environmental profile of CmiA lint cotton is shown in Figure 3-1. It includes the cultivation model (agrarian model), transport to the gin, and the ginning process itself. The agrarian model is described in detail in section 3.2. Transport to the gin comprises truck transport over a distance of 200-250km and includes diesel consumption and all emissions.

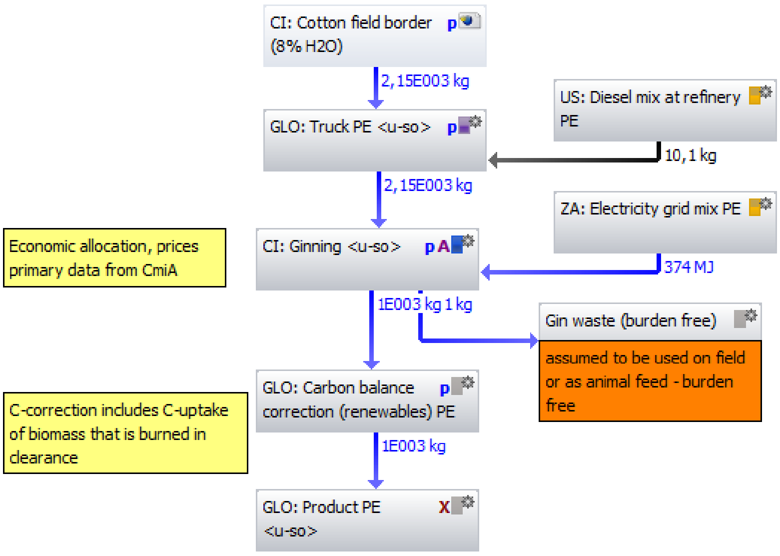


Figure 3-1: The GaBi model of CmiA cotton (Zambian boundary conditions). Cotton from the field is transported to the gin, where electricity is applied to separate the by-products, lint (fiber) and seed from the waste.

62. Two models were set up, one for Zambian boundary conditions (shown in figure above) and one for Ivory Coast. The two model systems were averaged to represent CmiA. No weighting was applied (both cultivation regions contribute equally to the CmiA average).

3.2 Agricultural model

63. Agrarian systems number among the most complex production systems for a LCA due to their dependence on environmental conditions that are variable over time (e.g. inside one year, from year to year) and in space (e.g. variation by country, region, site conditions). The following factors contribute to the complexity of agricultural modelling:

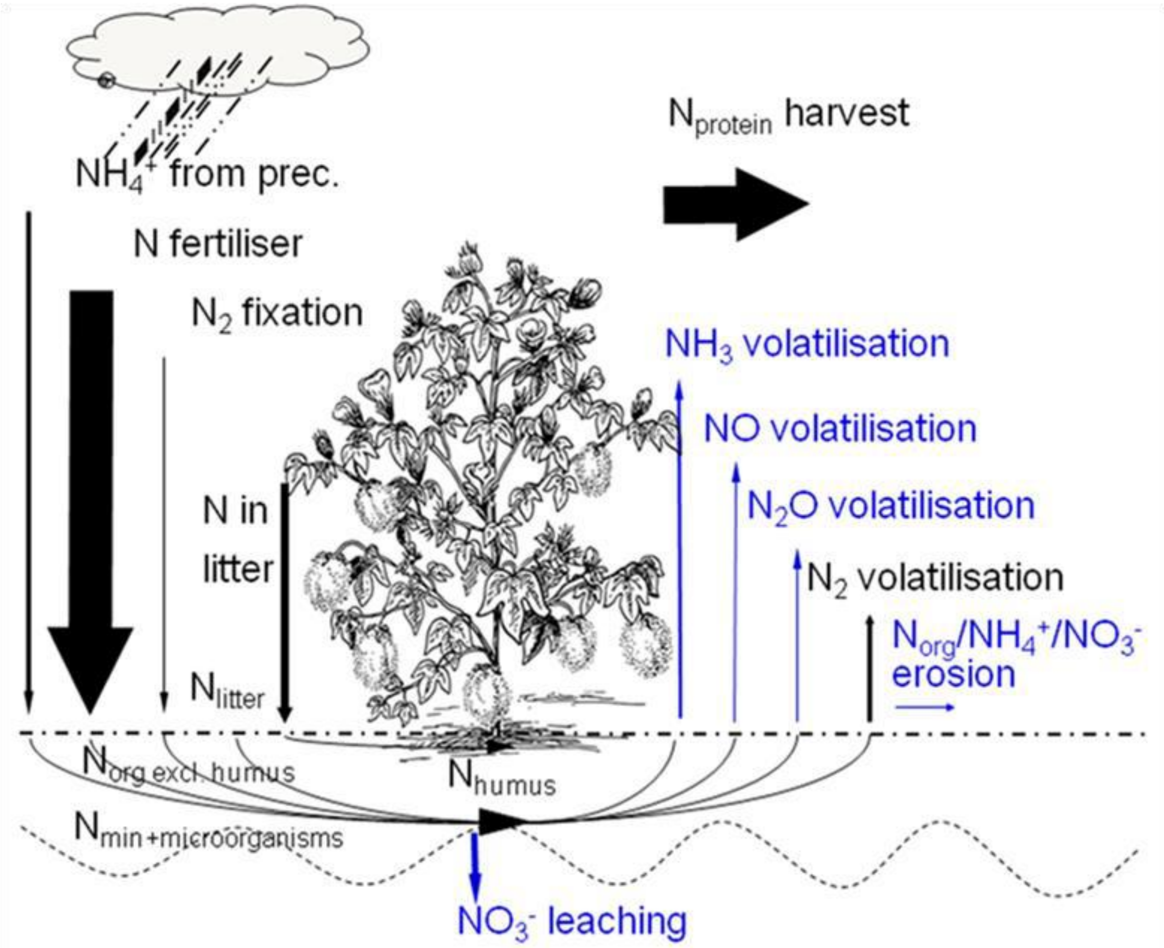
- Variety of different locations.
- High variability of soil characteristics over a small scale.
- Large number and diversity of farms.
- Variety of agricultural management practices applied.
- Technically no defined border with the environment.
- Complex and indirect dependence of the output (harvest, emissions) on the input (fertilizers, location conditions etc.).
- Variable weather conditions over one and between different years.
- Variable pest populations (insects, weeds, disease pathogens, etc.).
- Different crop rotations.

64. Due to the complications inherent in characterizing an agricultural system, a nonlinear complex agrarian model was used for plant production (developed by the LBP of the University of Stuttgart and PE INTERNATIONAL). This model covered a multitude of input data, emission factors and parameters. This part of the GaBi model was used for cradle-to-gate (seed-to-bale) environmental impact assessments associated with the planting, growing, harvesting, processing, handling, and distribution of cotton. For annual crops, a cultivation period starts immediately after the harvest of the preceding crop and ends with the harvest of the respective crop.

65. The entire production of lint cotton (and its by-products) including harvesting processes up to the field edge were included in the agrarian plant model. The model included possible cradle-to-gate burdens for all relevant input materials for the cultivation process itself (commercial fertilizer including lime, organic fertilizer, pesticides, seeds including their production and transport). The model included irrigation (excluding equipment production) and excluded agricultural infrastructure and farm buildings. All the relevant processes that take place in the area under cultivation including emissions into the air and groundwater (lower limit of rooted soil zone) were integrated. Erosive loss of N_{org} (organic nitrogen) and C_{org} (organic carbon) as well as of nutrients (e.g. phosphorus) in water was considered.

3.2.1 Nutrient modelling

66. Nitrogen plays a fundamental role in agricultural productivity and is also a major driver of the environmental performance of an agricultural production system. For these reasons it is essential to evaluate all relevant nitrogen flows within, to and from the agricultural system.



The agriculture model used accounted for the nitrogen cycle that occurs in agricultural systems. The model ensured that nitrogen emissions were consistent for all cultivated species. Specifically the model included emissions of nitrate (NO_3-) into water and nitrous oxide

Figure 3-2: Nitrogen system flows. The figure shows sinks (black arrows) and sources (blue arrows) in the nitrogen cycle. Source: PE INTERNATIONAL AG, 2011.

67. The different N-based emissions were calculated as follows:

- **NH_3 emissions into air** from organic fertilizers were adapted from the (BRENTRUP ET AL. 2000) model and modelled specifically for the cropping system dependent on the fertilizer-NH_4 content, soil pH, rainfall and temperature. NH_3 emissions into air from mineral fertilizers were also adapted from (BRENTRUP ET AL. 2000) and modelled specifically for the cropping system dependent on the kind of fertilizer and the soil pH.
- **N_2 emissions into air** result from complete denitrification. N_2 emissions were assumed to be 9% of the N-fertilizer input based on a literature review by Van Cleemput (Van Cleemput O 1998). N_2 emissons were also considered to determine the nitrate leaching potential.

- **NO emissions into air** were derived from partial denitrification. NO emissions were calculated using the reference system after N-input from air plus 0.43% of the N-fertilizer input specific to the cultivation system as NO.
- **N_2O emissions into air** were derived from partial denitrification. According to various sources and the IPCC, N_2O emissions were calculated using the reference system after N-input from air plus 1% of the N being used as fertilizer specific to the cultivation system (minus NH_3 losses) as N_2O-N.
- **N_{org}, NO_3^- and NH_4 emissions into water** occurred due to erosive surface runoff. Specifically for the cultivation system, they were calculated based on the emission of eroded soil multiplied by the respective N_{org}-, NO_3- and NH_4+ contents of the eroded fraction and also multiplied by a fraction of the eroded materials transferred into the drainage system and not deposited beforehand
- **NO_3^- emission into groundwater** was calculated based on the remainder of the outgoing N not occurring as gaseous losses or in harvests, litter, unused extractions from the site, storage in soil, etc. Based on the quantity of leakage water during the time period evaluated, an large part of this remaining N was calculated as leached nitrate.
- (N_2O), nitrogen oxide (NO) and ammonia (NH_3) into air. The model ensured that emissions from erosion, the reference system (comparable non-cultivated land area) and nutrient transfers within crop rotations were consistently modelled.

68. Compared to a pure N-balance model, this approach allows for N-losses to be illustrated in cases of very low N-fertilization (e.g. N-deficit in rubber-tree plantations). In the case of high N-fertilization (e.g. intensive farming systems), the models correspond with the total N-balance approach.

69. In addition to nitrogen-based emissions into water and air, phosphorus emissions were also considered in the model. However, phosphorus is a stable compound that is not significantly leached into groundwater. Phosphorous can be washed out with surface runoff of soil into surface water, causing the eutrophication of water bodies. It is very difficult to generalize erosion rates and deposition rates, as they are highly dependent on regional conditions such as climate, relief, soil type, crop cultivated and vegetation. Soil erosion rates were estimated based on (WURBS & STEINIGER 2011). In this study it was assumed that 10% of the eroded soil accesses the waters, based on an evaluation of different literature sources (Fuchs and Schwarz 2007, Hillenbrand et al. 2005, Helbig et al. 2009, Nearing et al. 2005), while the rest accumulates as colluviums on other surfaces and was assumed to be irrelevant for the life cycle assessment.

70. The nitrogen balance in the model was closed: Ninput = Noutput for the cultivation crop examined. If any cultivation processes yields a net nitrogen reduction or accumulation in the soil, this difference is balanced through increased/reduced external fertilizer demand. The nitrogen balance was calculated as a net nitrogen surplus or deficit after accounting for leaching and mineralization. Therefore, the amount of N fixed in humus was assumed constant over the long run. This adjustment addressed the long-term effects of cultivation sys-

tems that do not apply fertilizer and as such tend to reduce the nutrient pool in soil, thereby reducing the growth potential of the site.

71. Leaching is an aspect that was also taken into consideration by the agrarian model. Leaching was estimated as

Leaching = Precipitation + Irrigation – Evapotranspiration – Runoff

where evapotranspiration was estimated using the formula described in Thornthwaite 1948.

72. Cattle manure and compost (applied in small quantities in Ivory Coast) were considered waste products from another production system (animal husbandry) and entered the system burden free. Their contribution to nutrient availability was considered.

3.2.2 Carbon modelling

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

74. Soil carbon is another potential source or sink of carbon dioxide. Soil carbon balances are used to describe any increase or decrease in soil organic carbon (SOC) content caused by a change in land management, with the implication that increased/decreased soil carbon (C) storage mitigates or intensifies climate change. The net effect of cotton cultivation is highly variable and depends on various factors such as fertilization or soil cultivation practices (see e. g. Powlson et al. 2011, Causarano et al. 2006). Due to these variations and related uncertainties, carbon sequestration might be significant, particularly since the CmiA scheme promotes conservation agriculture, but was not considered within the scope of this study.

75. In addition to emissions, positive effects (sinks) due to the natural conversion of gases in the soil were considered. Gaseous sinks are predominantly related to the methane depression function of natural soils due to their oxidizing and microbial transformation of methane. Data for methane oxidation in cultivation systems were taken from various sources e.g. (Schmädeke 1998, Le Mer and Roger 2001, Powlson et al. 2011).

76. The biogenic CO_2 sequestered in the cotton plant and its fiber was directly accounted for in the inventory as an input or uptake of carbon dioxide, which is treated as a negative emission of carbon dioxide into air. The carbon uptake in the lint cotton was not considered in the impact assessment, however, since it is only temporally stored in the product and is released at the product's end of life.

3.2.3 Modelling pesticides

77. LCI data on pesticide production were modelled using the PE GaBi 6.3 software and based on generic pesticide production data from multiple sources (Birkved and Hauschild

2006, Green 1987, Hauschild 2000, Williams et al. 2006, Williams et al. 2009). For each pesticide group (herbicides, fungicides, insecticides, and plant growth regulators) a manufacturing model was built to represent the average production of all pesticides in that category. Lacking comprehensive data on the manufacture of all pesticides (many of which have proprietary chemical formulas), five pesticide models were used as proxies for the entire list of pesticides used to estimate the embedded energy and other environmental burdens of the manufacturing process.

4 Life cycle impact assessment (LCIA)

4.1 Introduction to the impact assessment

78. The software model described above enables the calculation of various environmental impact categories. The impact categories describe potential effects of the production process on the environment. Environmental impact categories are calculated from “elementary” material and energy flows. Elementary flows describe both the origin of resources from the environment as the basis for the manufacturing of the pre-products and generating energy, and emissions into the environment, which are caused by a product system. As different resources and emissions are summed up per impact category, the impacts are normalized to a specific emission and reported in “equivalents”, e.g. greenhouse gas emissions are reported in kg CO2 equivalents. This step requires the use of characterization models, of which different ones have been published and are in use. The CML (Center voor Milieukunde at Leiden, NL) impact assessment methodology framework was selected for this assessment. The CML characterization factors are widely used and respected within the LCA community. The most recently published list of characterization factors “CML 2001 – Apr. 2013” was applied.

79. The following is a brief summary of the impact categories and characterization models chosen as well as reasons for selecting these impact categories. Please refer to Supplement A for detailed information.

80. Climate change was chosen as an impact category, since climate change is deemed to be one of the most pressing environmental issues of our time and there is great public and institutional interest in the subject. The category indicator results were given in kg of CO_2 equivalents per functional unit. Please note that carbon uptake in the lint cotton was not considered as it is only temporally stored in the product and is released at the product’s end of life.

81. Acidification, causing e.g. acid rain and eutrophication, also known as over fertilization, was chosen because it is closely related to air, soil, and water quality and a relevant and discussed environmental aspect of agricultural systems. The category indicator results were given in kg SO_2 (acidification) or PO_4 (eutrophication) equivalents per functional unit.

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

- Water use: use of water by human activity: Use includes, but is not limited to, any water withdrawal, water release or other human activities within the drainage basin impacting water flows and quality.

- Water consumption: water removed from but not returned to the same drainage basin. Water consumption can be because of evaporation, transpiration, product integration or release into a different drainage basin or the sea. Evaporation from reservoirs is considered water consumption.
- Surface water: water in overland flow and storage, such as rivers and lakes, excluding seawater.
- Groundwater: water that is held in and can be recovered from, an underground formation.
- Green water refers to the precipitation on land that does not run off or recharge the groundwater, but instead is stored in the soil or temporarily stays on top of the soil or vegetation. This part of precipitation eventually evaporates or transpires through plants. Green water can be made productive for crop growth.
- Blue water refers to water withdrawn from ground water or surface water bodies. The blue water inventory of a process includes all freshwater inputs but excludes rainwater.

Please refer to Supplement A for details.

Table 4-1: Environmental impact assessment – category description/indicators

Impact category	Characterization factor	Description	Abbreviation	Unit
Climate change	Global warming potential	Greenhouse gases causing the climate change excluding biogenic carbon	GWP 100	kg CO_2-equiv.
Acidification	Acidification potential	Emissions causing acidifying effects (acid rain, forest decline)	AP	kg SO_2-equiv.
Eutrophication	Eutrophication potential	Emissions causing over-fertilization of soil or water	EP	kg PO_4^{3-}-equiv.
Water	Water use	All types of anthropogenic water uses, including consumptive and degradative	N/A	m^3
Water	Water consumption	Consumptive water use, i.e. water loss at watershed level	N/A	m^3

83. It should be noted that the term *potential* in the characterization of environmental impacts indicates that the impacts could occur if the emitted molecules (a) actually followed the underlying impact pathway and (b) met certain conditions in the receiving environment while doing so. LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

4.2 Impact assessment results

4.2.1 Climate change

84. The impact on climate change of the lint cotton was quantified as 1037 kg CO_2-eq for 1,000 kg of lint cotton (Figure 4-1). As noted before, this number excludes the biogenic uptake of carbon dioxide during plant growth, since the same carbon dioxide will again be released within 100 years into the atmosphere upon degradation of the product. Agriculture dominated the impacts, contributing ca. 84%, while ginning (12%) and transport to the gin (4%) added to the overall picture to a smaller degree. For ginning, electricity consumption was entirely responsible for impact, while transports were largely determined by road emissions and to a smaller extent by diesel production (not shown). Absolute values are shown in Table 4-2.

Table 4-2: Global warming potential (kg CO_2-equiv.) of producing 1000 kg lint CmiA, broken down as agricultural processes (agriculture), ginning and transport to the gin (transport)

Total (kg CO_2-equiv.)	Agriculture (kg CO_2-equiv.)	Ginning (kg CO_2-equiv.)	Transport (kg CO_2-equiv.)
1037	871	128	38
100%	84%	12%	4%

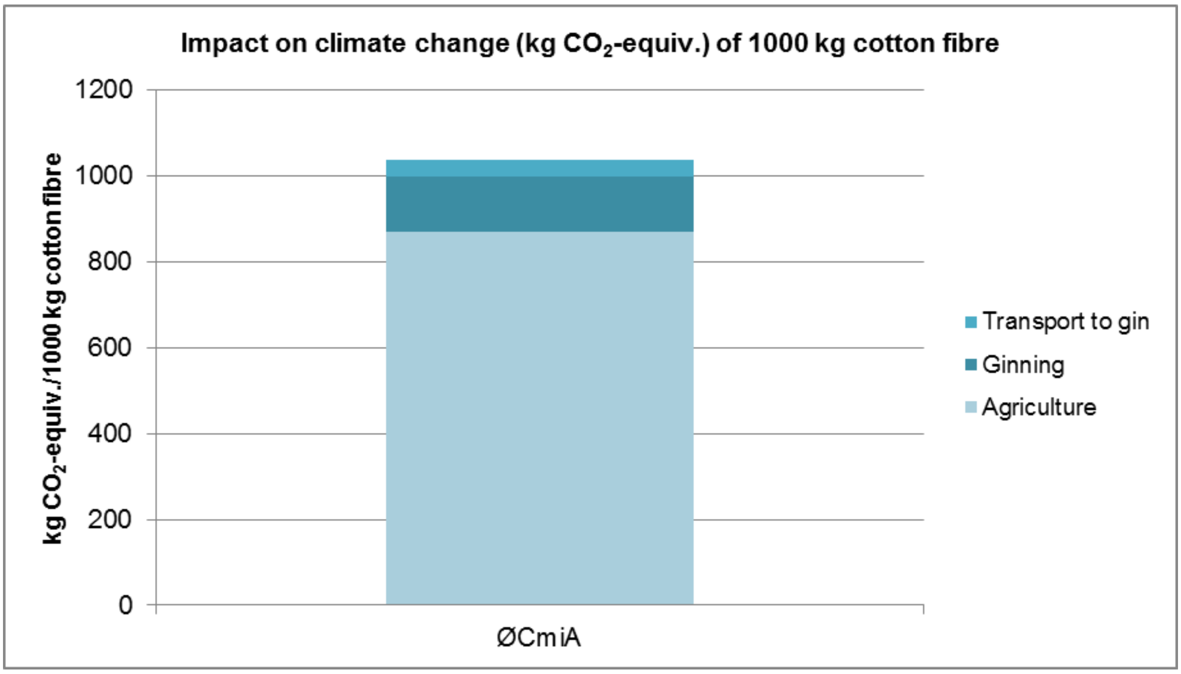


Figure 4-1: Impact on climate change of 1,000 kg lint cotton at gin gate

85. By contrast, agriculture is a system in itself that requires a more detailed look in order to tease apart the influencing factors. This detailed view is offered in Figure 4.2, which shows that field emissions were responsible for about two thirds (70%) of agriculture's GWP. Field emissions refer to gases emitted from soils due to agricultural activity. Microbial nutrient transformation processes in the soil were another key aspect. As a result of such transformation processes, a fraction of the available total nitrogen becomes inorganic nitrous oxide, also known as laughing gas, with a global warming potential almost 300 times higher than carbon dioxide. Laughing gas is one of the main contributors to field emissions. Please refer to section 3.2 for details on field emission modelling.

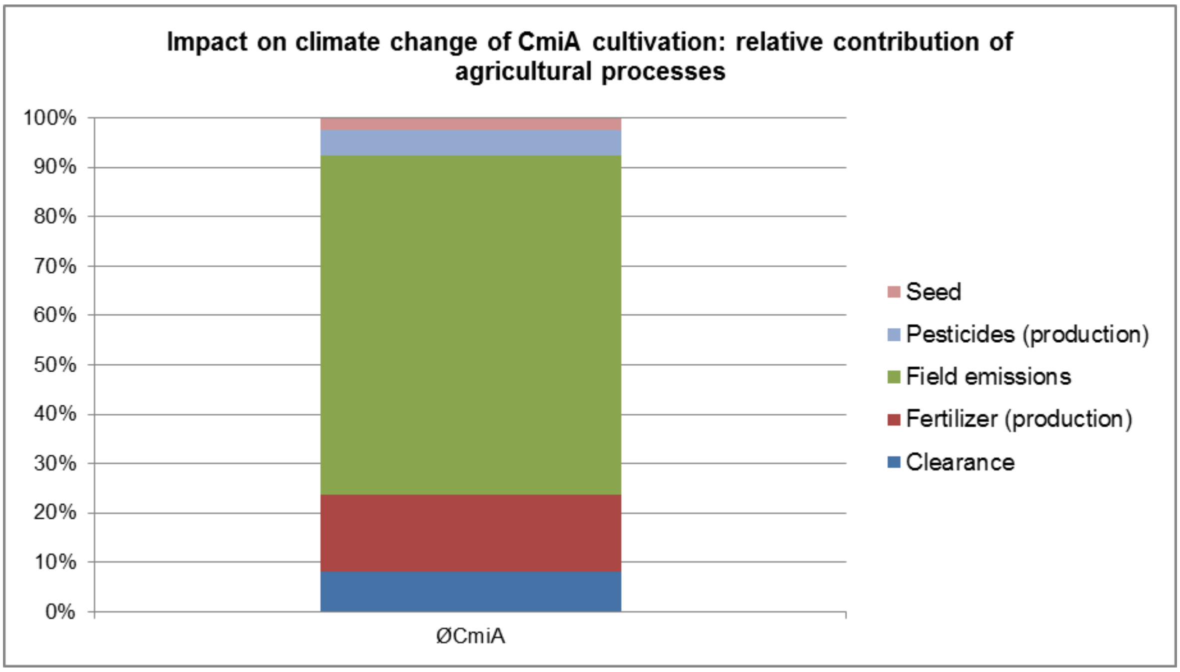


Figure 4.2: **Impact on climate change of CmiA cultivation: relative contribution of agricultural processes**

86. Although relatively little mineral fertilizer was applied, the amount was still a significant contributor (16%) to the greenhouse gas emissions from agriculture, since it is a product from the petro-chemical industry and energy intensive in production. Pesticide production contributed another 5%, while the practice of clearance, i.e. burning of plant residues on the fields before planting, contributed another small but significant 8%. Finally, the seed production added a non-negligible 3%.

4.2.2 Eutrophication

87. Eutrophication potential (EP) was calculated at 20.4 kg PO_4-eq per 1,000 kg of lint cotton produced and displayed an even more dominant share of agrarian processes than was shown for GWP. In this impact category, agricultural processes contributed over 99% of impacts, while ginning and transport to the gin contributed 0.3% each (Figure 4-3). Although electricity production and transports also had eutrophication-relevant emissions, these were dwarfed by the emissions from agrarian systems where nutrients leak into nearby waters by surface run-off, leaching or soil erosion. Table 4-3 shows the contribution of different eutrophication routes to the total eutrophication potential.

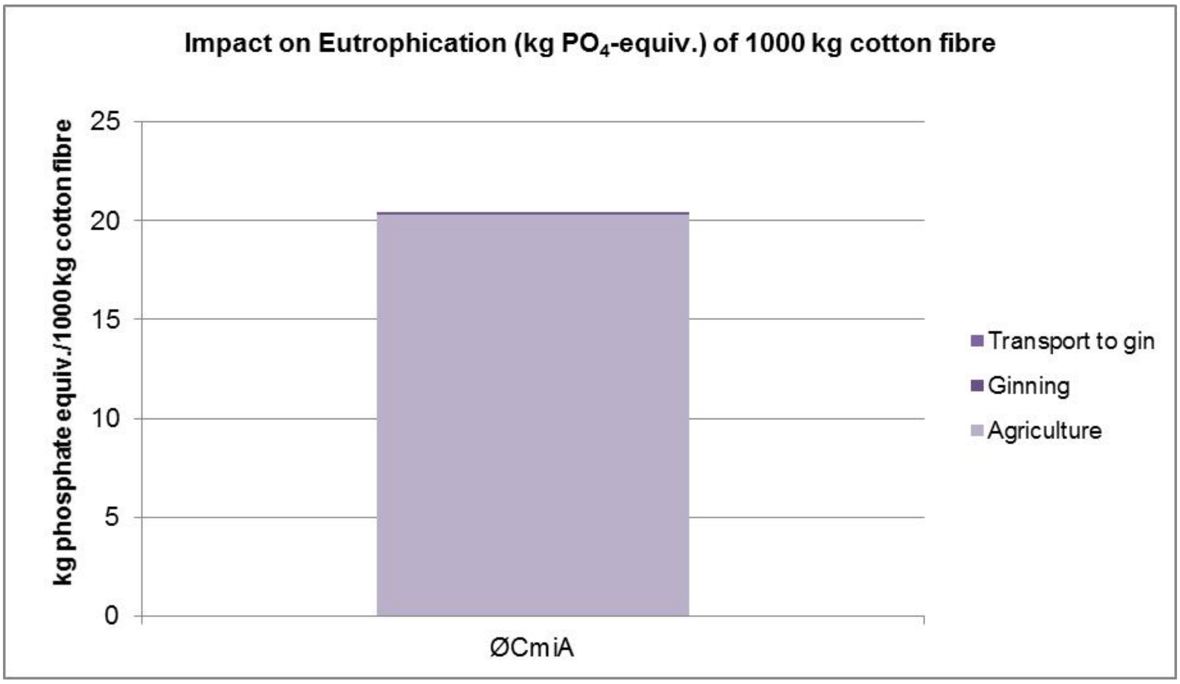


Figure 4-3: Eutrophication potential of 1,000 kg lint cotton at gin gate

Table 4-3: Contribution of different eutrophication routes to total eutrophication potential

Eutrophication route	Contribution to overall eutrophication potential (CmiA)
Emissions to air (ammonia, nitrogen oxides)	17%
Leaching (nitrate)	19%
Soil erosion (org. nitrogen, phosphate)	64%

88. The above table shows how eutrophication was dominated by soil erosion, where soil erosion data refer to area and were not influenced by yield. This means that the lower the yield per ha, the higher the soil erosion per kg of final product. Given a lack of specific data, default values were assumed for erosion rates and nutrient content of the soils. These values had a large degree of uncertainty, and did not necessarily accurately represent conditions in the CmiA systems. Soil erosion is highly dependent on soil management practices, which were not assessed in this study. To illustrate the sensitivity of the final results to the assumptions of soil erosion and soil nutrient content, a scenario with a lower soil erosion rate (25% of the original value) and lower nutrient content in the soils (50% of the original value) was investigated in the following ("Reduced soil erosion", Table 4-4). Please note that the scenario assumptions were only chosen to demonstrate sensitivity. They were backed up by the

assumption that CmiA promotes conservation agriculture, which potentially decreases soil erosion significantly, and the assumption that nutrient contents in soils in the regions under investigation are known to be low. Due to the lack of specific data, however, the scenario was not validated by literature data or models and should only be considered a screening assessment.

Table 4-4: Impact of assumptions of soil erosion on results of eutrophication potential: baseline scenario and reduced soil erosion scenario

Base line scenario per 1,000 kg	Reduced soil erosion scenario per 1,000 kg	Base line scenario per ha	Reduced soil erosion scenario per ha
(kg PO_4-eq/1,000 kg lint)	(kg PO_4-eq/ 1,000 kg lint)	(kg PO_4-eq/ha)	(kg PO_4-eq/ha)
20.4	7.0	6.7	2.7

4.2.3 Acidification

89. The acidification impact category presented a pattern similar to that of impact on climate change: 86% of impacts derived from agrarian processes, 11% from ginning, and 2% from transport to the gin. Here the most relevant emissions were sulphur dioxide, a direct effect of the sulphur contained in coal (power generation in African grid mixes relies heavily on coal) and diesel (transports). As for the agricultural processes, Figure 4-5 provides a detailed view revealing that while field emissions still dominated the impact category (58%), clearance contributed a significant share of 38%. Fertilizer production added another 2% to the total impacts, while pesticides added 1%. As for the high relevance of field emissions, ammonia and nitrogen monoxide were acidification-causing gases emitted from the breakdown processes in the soil. With clearance, sulphur dioxide and nitrogen oxides were emissions from burning processes that were relevant for this impact category.

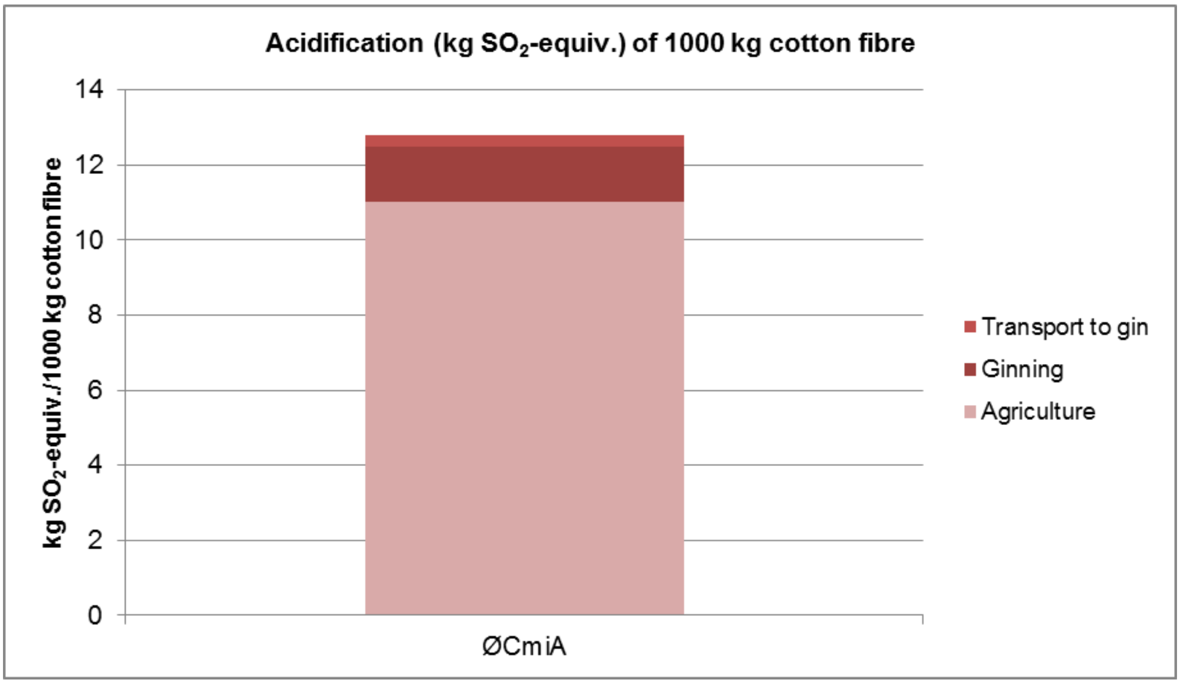


Figure 4-4: Acidification potential of 1,000 kg lint cotton at gin gate

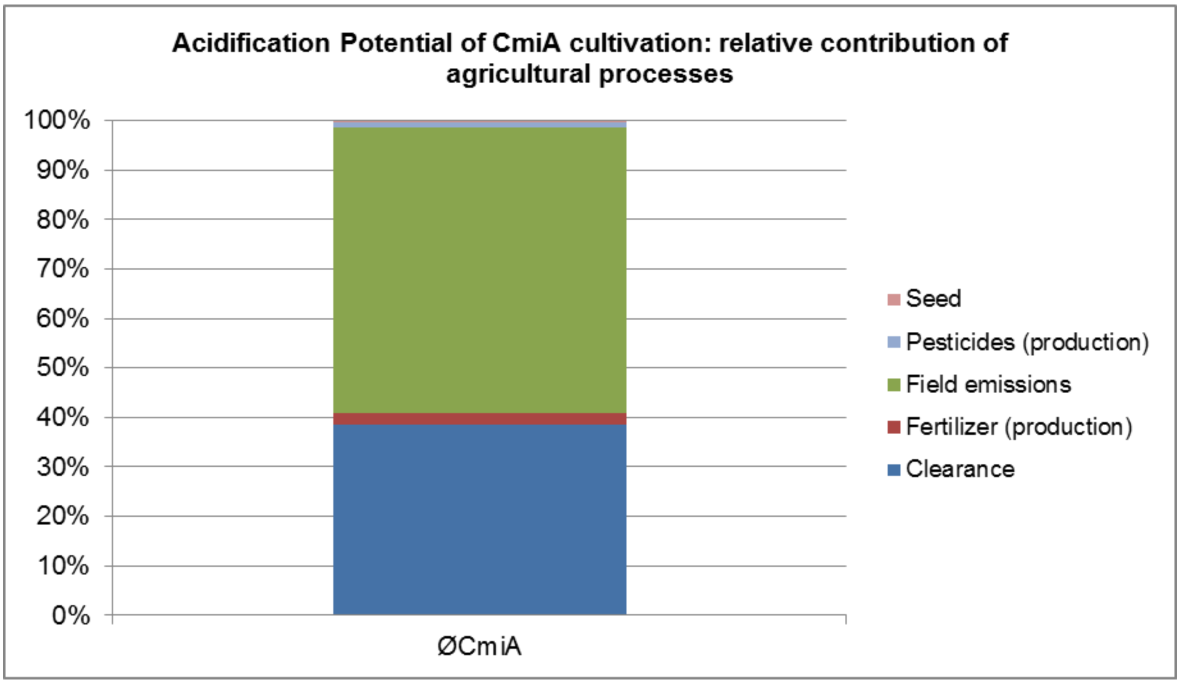


Figure 4-5: Acidification potential of CmiA cultivation: relative contributions of agricultural processes

4.3 Water use and water consumption

90. Figure 4-6 shows the contribution of different phases to total fresh water use. Fresh water use included surface water, groundwater and rainwater (green water) and as such was related to water withdrawal, thus no statement about the impact of water withdrawal was made (see also Supplement A). Water use also included water used for the provision of energy, where water used for cooling and the provision of hydro energy played an important role.

91. The total freshwater used to produce 1,000 kg of CmiA lint cotton was around 3,400m^3. Water use was dominated here by the usage of natural precipitation (green water). Upstream processes (provision of energy, fertilizer production), where blue water is used, contributed only little to water use (7%).

92. Water use values are only of limited informative value with regard to the environmental relevance of water withdrawal. The water lost to the watershed, i.e. water consumed, is of much more interest. Here too only the values for blue water consumption (surface and ground water) are of particular relevance, as it is assumed that precipitation would follow the natural hydrologic cycle regardless of the type of land use and therefore has no environmental burden from a LCA perspective. Hence the values given in Figure 4-7exclude precipitation (green water).

93. Since CmiA cotton is not irrigated, blue water was only used in upstream processes of lint cotton production and only a minor fraction of that water use was consumptive use. Thus, the contribution of 1,000 kg of CmiA lint cotton to blue water consumption was very small (1m^3 per 1,000 kg of CmiA lint cotton).

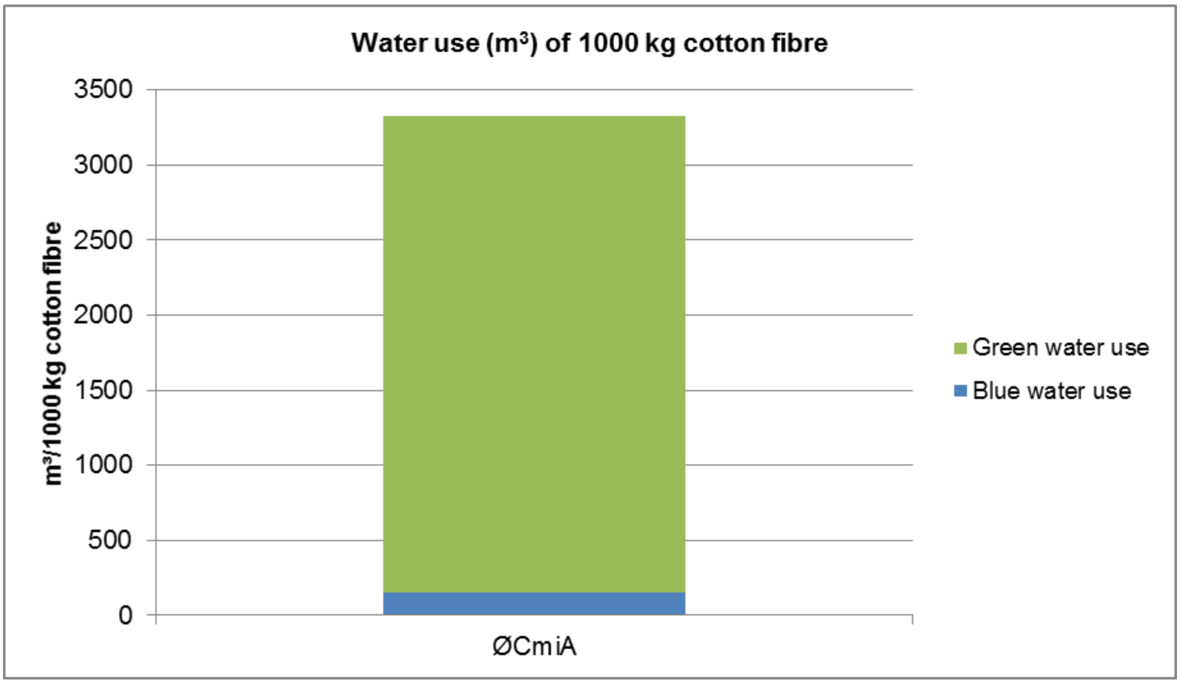


Figure 4-6: Water use of 1,000 kg lint cotton at gin gate

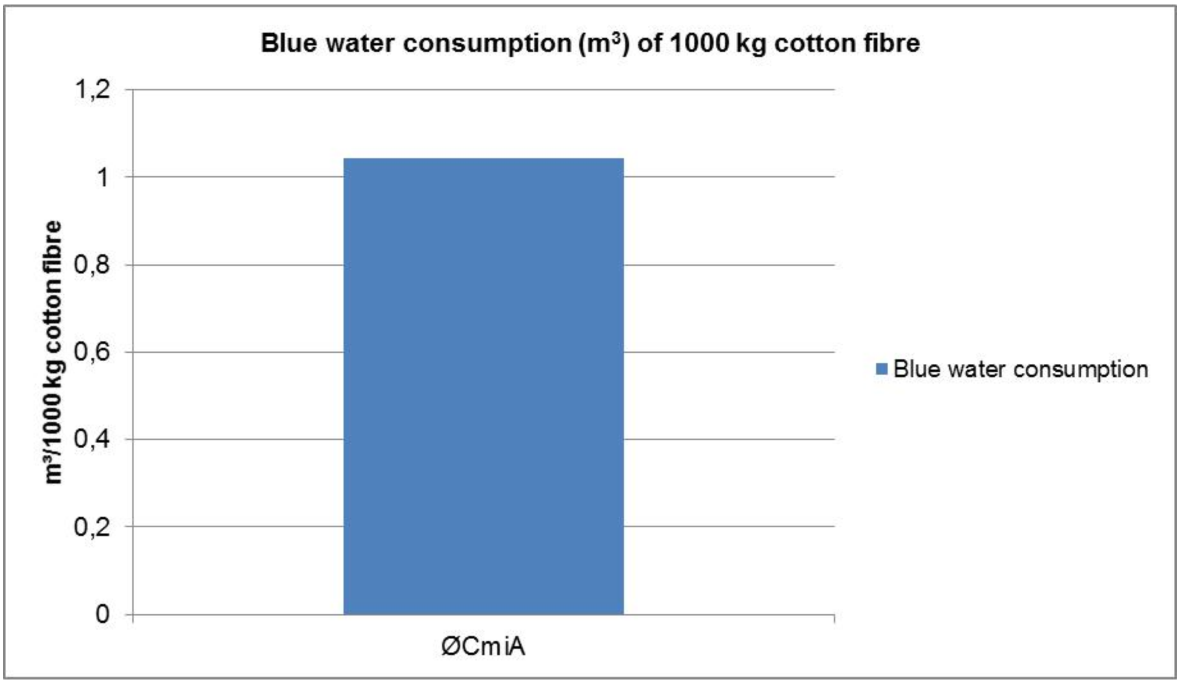


Figure 4-7: Blue water consumption of 1,000 kg lint cotton at gin gate

5 Interpretation

5.1 The environmental footprint of CmiA – Putting it into perspective

94. The LCIA results are difficult to interpret as standalone indicators. Only when it has been put in perspective in relation to published data and scientific literature can conclusions on the environmental performance of CmiA be drawn. That is the subject of this section. It should be noted here that given the limitations denoted in chapter 5.2, this is not intended as a comparative assertion as defined in the ISO 14044 standard.

Climate change

95. First, the impact on climate change should be assessed. As mentioned above, a detailed LCA study on conventionally grown cotton was recently published (COTTON INC. 2012). This study used similar system boundaries and the same agricultural modelling approach as this study. The results given for the global average impact on conventionally grown cotton on climate change are 1,808 kg of CO_2-eq per 1,000 kg of lint cotton produced[3]. Given the 1,037 kg of CO_2-eq per 1,000 kg of lint cotton calculated in this study, this means that the extensive CmiA cultivation system potentially emits fewer greenhouse gases per kg fiber produced. The difference between the results is mainly due to the difference in the contributions of agricultural inputs, i.e. fertilizer production, provision of pesticides, tractor operation and energy use for irrigation in the conventional system. Field emissions per kg fiber (not per ha) do not differ significantly between the two systems, since every system has an optimum point where the additional application of fertilizer will lead to an increase in emissions, but also to an even larger increase in yield, so that emissions per kg final product actually decreases.

96. A previous study (SYSTAIN 2013) also investigated CmiA's impact on climate change. Like this study, it found that conventional cotton cultivation had a higher (4,600 kg CO_2-eq per 1,000 kg product) impact on climate change than CmiA (1,900 kg CO_2-eq per 1,000 kg product). The results for impact on climate change from SYSTAIN 2013 for CmiA were also significantly higher than the results presented in this study. These differences were largely due to (1) the omission of allocation in the SYSTAIN 2013 study, (2) the inclusion of drought animals tin the environmental impacts in the SYSTAIN 2013 study (3) different data (more regions, but older data, less primary data used, different agricultural model used in the SYSTAIN 2013 study). The lack of allocation means that all environmental impacts were assigned to the cotton fiber, whereas the valuable by-product, the seed, left the system burden-free – a worst-case scenario. As discussed before, the evaluation of draught animals was excluded from the main study results here for reasons of uncertainty and low relevance. When the current study was "corrected for" these two differences in methodology, the total impact of

[3] The values given in COTTON INC. 2012 are considering the carbon uptake in the product (1540 kg CO_2 per 1000kg, resulting in a value of 268 kg CO_2-equiv. per 1000 kg of lint cotton). 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. This is why the carbon uptake should normally not be considered in LCA studies and is not declared in this study. If it was considered, the GWP for CmiA would be negative, i.e. -503 kg CO_2-equiv. per 1000 kg of lint cotton.

1,037 CO_2-eq per 1,000 kg lint cotton rose to approx. 1,500 kg CO_2-eq per 1,000 kg fiber. This discrepancy can be explained by differences in agricultural modelling. This said, this also means that even based on two worst-case assumptions (allocation and draught animals), the CmiA climate change impact results do not exceed those given for the conventional global average[4].

97. Another recent study (Babu and Selvadass 2013) investigated the environmental impact of cultivating conventional and organic seed lint cotton fibers in India. The article lacks a clear description of the system boundaries and modelling approaches used. The results given for “the LCA analysis for the cultivation of 1 kg ‘conventional seed cotton cultivation’ and 'organic seed cotton cultivation'” are given as 1.32 kg CO_2-eq/kg and 1.08 CO_2-eq/kg respectively. It seems these values refer to seed cotton (fibers and seed) at field edge. Although these results need to be interpreted with care, they provide a promising indication that CmiA also performs better in this comparison (0.44 CO_2-eq/kg seed cotton at field edge found in this study).

Eutrophication

98. When compared with the eutrophication of conventional lint cotton (Cotton Inc. 2012), CmiA fiber scores higher (20 kg PO_4-eq per 1,000 kg fiber compared with less than 4 kg PO_4-eq per 1,000 kg fiber). As outlaid in chapter 4.2.2, this can be explained by the fact that eutrophication in the CmiA system is dominated by soil erosion, and soil erosion data refer to area and are not influenced by yield. That means that the lower the yield per ha, the higher the soil erosion per kg final product. Per ha eutrophication values are not available for conventional lint cotton (Cotton Inc. 2012). They can only be estimated based on the average fiber yield per ha given in Cotton Inc. 2012 and are slightly higher as the values for CmiA in the base line scenario (ca. 7 kg PO_4-eq per ha). Please note that also no specific data on soil erosion rates assumed in Cotton Inc. 2012 is given. Thus the comparison with regard to eutrophication of the two systems remains vague. CmiA experts indicated that nutrient values in African soils tend to be lower than in other soils, and the uncertainty of the erosion rate is large, specifically if considering that conservation agriculture, i.e. minimum tillage practices and mulching are being applied by some CmiA farmers. Additionally, the ground water level in the regions under investigation is mostly low to very low, so that leaching into groundwater is not likely to occur. But specific values that would allow a justified deviation from available default values were not available. All together that gives reason to assume that the eutrophication rate reported in the base line scenario is an overestimation. This is further illustrated by the reduced soil erosion scenario that could serve as a best case assumption and illustrates that assumptions on soil erosion and nutrient content of the soil are sensitive parameters with regard to eutrophication.

[4] If the current study was “corrected” for these two differences in methodology, the total impact of 1037 CO2-equiv. per 1000 kg lint cotton could be raised to ca. 1500 kg CO2-equiv. per 1000 kg lint cotton, the remaining difference to the results given in the Systain study to be explained by differences in the agricultural model. This said, that also means that even with two worst case assumptions (allocation and animal draught), the CmiA results for impact on climate change do not exceed those given for the conventional global average.

99. In addition, it can be stated that the environmental relevance of potential eutrophication differs among different regions (other than global warming potential where the impact on the environment is the same all over the globe). This fact is not yet considered in the impact assessment methods in use. Eutrophication could be considered of less environmental concern in the CmiA regions compared to regions of conventional cotton cultivation (see Figure 5-1). All this said, the results shown for eutrophication could also be interpreted as an appeal for further investigation and data collection, but also to take the issue of soil erosion serious and to consider prevention measures.

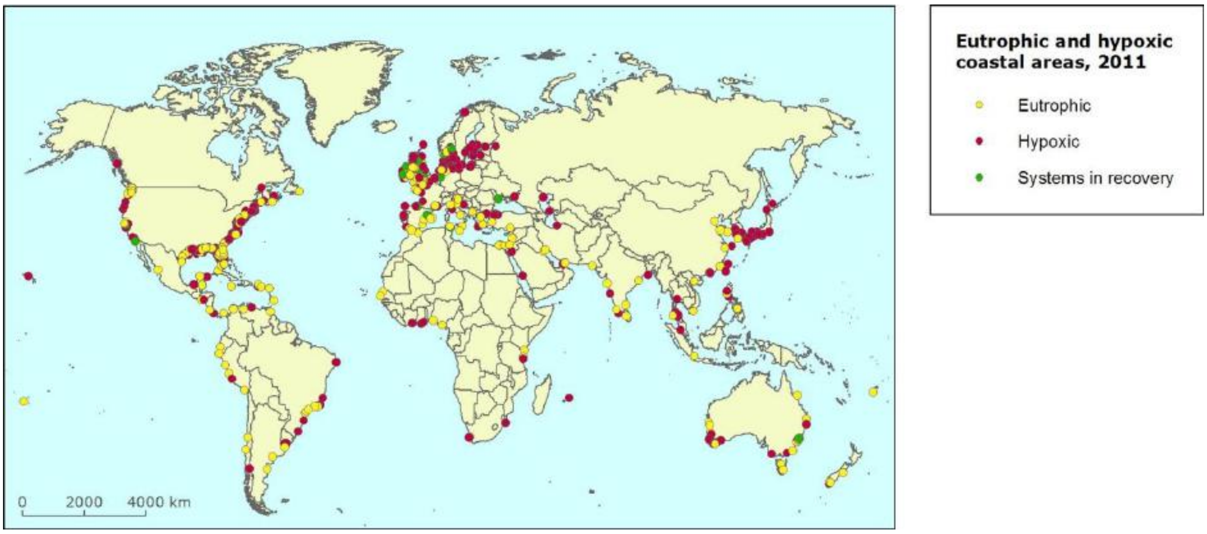


Figure 5-1: Eutrophic and hypoxic hotspot areas, 2011 (Source: **WRI 2013**) Eutrophic areas are those with excessive nutrients (yellow dots), putting them at risk of adverse effects. Hypoxic areas are those where oxygen levels in the water are already depleted and adverse effects expected due to nutrient and or organic pollution (red dots). Green dots are systems that were hypoxic at one time but are recovering.

Acidification

100. CmiA also shows some advantages compared to conventional cotton (COTTON INC. 2012) in this impact category (12.7 vs. 18.7 kg SO_2-eq/1,000 kg lint cotton). Again, the difference is driven by agricultural inputs which are used to a lesser extend (or not used at all) in the CmiA systems, i.e. fertilizer and pesticide production, irrigation pumps and tractor operations. Here, the most relevant emissions (sulphur dioxide and nitrous oxides) are caused by power generation and in diesel combustion (transports and machinery use).

Water use

101. CmiA is rain fed, i.e. no water is used for irrigation. In contrast, all the regions under investigation in COTTON INC. 2012 were at least partially irrigated. It therefore comes as no surprise that blue water consumption, which is of environmental relevance here, was orders of magnitude smaller for CmiA (1m^3/1,000 kg lint cotton) compared to the global average (2,120 m^3/1,000 kg lint cotton).

102. Methods for additional impact assessments of water use exist (see Pfister et al. 2009, Bayart et al. 2010 and the "water use in LCA" - UNEP/Setac working group). When assessing water consumption, it is crucial to consider where the water consumption takes place. In water-abundant areas, the impacts of water consumption are generally low, while in dry areas the impact is much higher. This distinction can be addressed by applying the water stress index (WSI) developed by Pfister et al. 2009. The water stress index is used to weight water consumption according to regional availability. The resulting figure is called the "water scarcity footprint". Both this study and Cotton Inc. 2012 did not conducted this additional impact assessment of blue water consumption. Given the very low amount of blue water consumed by CmiA, however, and given that this amount is consumed solely in upstream processes, it is not at all likely that such an extended assessment would change the overall picture.

5.2 Limitations

103. This study provides LCA inventory data of good overall quality on lint cotton produced under the CmiA scheme. However, there are some limitations that need to be considered in interpreting the results.

104. On an inventory level, it should be noted that data from additional CmiA regions and data from different years would improve the representativeness of the results. The agricultural model used in this study is constantly updated and improved, and thus can be said to cover all the relevant emissions and allow for a comprehensive LCI setup and LCIA of agricultural systems. However, for many relevant aspects (such as soil type, nutrient content of soil, soil erosion) primary data is very hard to obtain, so that default values must be applied. These default values do not necessarily reflect local conditions. To aggregate data into regional averages is additionally challenging and could potentially lead to distortions in a model intended to represent a realistic cultivation system.

105. When compared to the published data on other cotton cultivation systems, CmiA cotton shows considerable advantages in several impact categories. It should, however, be noted that the data presented in this study refers to a specific dataset representing a relatively small segment of cotton producers unified by cultivation practices and location. By contrast, other cotton datasets mask local, climatic and other differences as single production-weighted averages. No conclusions can be drawn regarding the environmental performance of individual sites of (conventional) cotton cultivation. It should also be noted that an ISO consistent comparison of two product systems would require additional effort in assessing the precision, completeness and representativeness of the data used, a description of the equivalence of the systems being compared, uncertainty and sensitivity analyses, and an evaluation of the significance of the differences found. This said, it should also be noted that this study did not assess the global average for conventional cotton (on a possibly insufficient data basis), and instead used a published and reviewed LCA study that employed the same methodology as this study (Cotton Inc. 2012) as a basis for comparison. Given that this study also underwent critical review, a discursive comparison of the data seems justified.

106. Further, there are some limitations related to the LCA methodology that should be discussed here. In this study, Life Cycle Assessment is used as a standardized tool for the quantitative evaluation of potential environmental impacts on a <u>product basis</u>. As such, the methodology focuses on resource use efficiency (functional unit 1,000 kg output) rather than on the <u>overall impacts of entire production systems</u>. It also does not allow conclusions to be drawn regarding the capacity of the ecological systems concerned to cope with these impacts.

107. It should also be noted that the impact categories represent <u>potential impacts</u>. In other words, they are approximations of environmental impacts that would occur if the emitted molecules actually followed the underlying impact pathway, then met up with certain conditions in the receiving environment. LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks. Additionally water use and water consumption are reported as environmental indicators only and <u>no further impact methodology</u> was applied.

108. Four environmental impact categories were investigated in this study. Many more have been established in LCA methodology and could broaden the picture on the environmental performance of CmiA (e.g. ozone depletion, smog creation). Other aspects, e.g. <u>toxicity</u>, are still difficult to assess so far, although methods are being developed (e.g. the UNEP and SETAC USEtox model). Some environmental aspects such as impact on <u>biodiversity</u> cannot yet be accessed using the LCA methodology, although they are considered highly relevant. Hence, CmiA could potentially show clear advantages over conventional production systems for some environmental impact routes <u>omitted</u> from this assessment.

109. Based on the above, and noting that the social and socio-economic dimensions of sustainability have not even been mentioned yet, it is apparent that other aspects in addition to those investigated in this study need to be considered for a holistic assessment of the sustainability of different production systems.

6 Conclusion

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

- This study provides LCA inventory data of good overall quality on lint cotton produced under the CmiA scheme.
- The CmiA cotton production system is an extensive cultivation system that is well adapted to available resources and natural as well as social and socio-economic conditions.
- CmiA appears to have very good environmental performance compared to published data.
- Comparison to published data has shown that the advantages of CmiA regarding its impact on climate change stem from extensive cultivation, i.e. the limited use of agricultural inputs (fertilizer, pesticides, and machinery).
- In contrast to many conventional cotton cultivation systems, cotton is grown under rain fed conditions in rotation with other crops. CmiA does not use irrigation and therefore conserves blue water (surface and groundwater) resources.
- When assessed using default values, soil erosion contributed significantly to eutrophication and caused comparatively large values per kg of final product (assumed average erosion rate per ha distributed over a low yield). However, values for soil erosion do not consider different soil management practices and varying nutrient contents of the soil as well as groundwater tables, therefore the results were found to be based on relatively large uncertainties.
- Representativeness of data could be improved by including more cultivation regions and several cultivation periods.
- Life Cycle Assessment is used as a standardized tool for the quantitative evaluation of potential environmental impacts on a product basis. Thereby the methodology focuses on resource use efficiency (impact per kg final product) rather than on the overall impacts of production systems.
- Some environmental impact routes (biodiversity, carbon sequestration in soils) are difficult to assess in a LCA framework and were not investigated in this study. CmiA could potentially also show clear advantages over conventional production systems with regard to these aspects.
- Other aspects in addition to those investigated in this study need to be considered for a holistic assessment of the sustainability of different production systems.

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A. (Supplement): Foreground data

Table A-1: Inventory of the modelled system. Inputs into the agrarian production system and at the gin

		Zambia		Ivory Coast		
	Unit	**Calcula-tion**	**Value**	**Calculation**	**Value**	**Source**
Biomass burning – clearance						
Application	[%]		30		25	Questionnaire
Biomass on the field	[kg/ha]		1000		1000	Estimate
Fertilizers						
Compost	[kg/ha]	350*0.005	1.75	350*0.05	17.5	Questionnaire
N-Content	[% FM]		0.5		0.5	Literature
Cattle dung	[kg/ha]		n.a.	350*0.91	318.5	Questionnaire
N-Content	[% FM]				0.4	GaBi
NPK	[kg/ha]	1*0.19/0.15	1.3		160	Questionnaire
N-Content	[% FM]		15		15	GaBi
Urea	[kg/ha]		n.a.		40	Questionnaire
N-Content	[% FM]				46	GaBi
Other inputs						
Seed	[kg/ha]	15	15	37.5	37.5	Questionnaire

		Zambia		Ivory Coast		
	Unit	**Calcula-tion**	**Value**	**Calculation**	**Value**	**Source**
Irrigation	[l/ha]		0		0	Questionnaire
Natural N input						
N fixation soil	[kg/ha]		10		10	GaBi/Literature
N in precipi-tation	[kg/ha]		7.2		7.2	GaBi/Literature
Pesticides: active ingredient						
Glyphosate	[kg/ha]	2*0.36	0.72	3*0.36	1.08	Questionnaire
Prometryn	[kg/ha]			3*0.25	0.75	Questionnaire
Profenofos	[kg/ha]			2*0.3	0.6	Questionnaire
Metolachlor	[kg/ha]			3*0.1625	0.4875	Questionnaire
Cyperme-thrin	[kg/ha]			2*0.036+0.5*0.072	0.108	Questionnaire
Avermectin (Abamectin)	[kg/ha]			2*0.5*0.0192	0.0192	Questionnaire
Acetamiprid	[kg/ha]		0.1	0.5*0.016	0.008	Questionnaire
Lambda-Cyhalothrin	[kg/ha]	1*0.05	0.05			Questionnaire
Yield (seed cotton)						
Yield (seed cotton)	[kg/ha]	442	442	457+594	1051	Questionnaire
N Content	[% FM]		2		3	GaBi / Literature / Esti-mate

Table A-2: Parameters used to model transport to the gin and ginning

		Zambia		Ivory Coast		
Parameter	**Unit**	**Calculation**	**Value**	**Calculation**	**Value**	**Source**
Distance to the gin	[km]		248		225	Questionnaire
Energy use	[kWh/kg lint]		0.111		0.111	Questionnaire
Seed to lint ratio	[-]	(1-0.42)/0.42	1.381	594/457	1.30	Calculated
Gin waste	[kg/kg lint]		0.3		0.3	GaBi/Literature

B. (Supplement): Review Report

Report concerning the Critical Review of the study
"Life Cycle Assessment (LCA) of Cotton made in Africa (CmiA)"

Critical Review of the study "Life Cycle Assessment (LCA) of Cotton made in Africa (CmiA)"

2014-05-28

For:
Aid by Trade Foundation
Cotton made in Africa
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Summary

In this study prepared by PE INTERNATIONAL AG, Leinfelden-Echterdingen, a Life Cycle Inventory (LCI) for cradle-to-gate production of cotton fibre (at gin gate) produced under the requirements of the Cotton made in Africa (CmiA) certification scheme was developed. Additionally, a Life Cycle Impact Assessment (LCIA) was performed to evaluate the environmental impact of this LCI.

A critical review was conducted to confirm the specific results of the study according to the ISO standards.

As a result the reviewers concluded that the chosen methods are consistent with the international standards ISO 14040 and ISO 14044, meet the state of scientific and technical knowledge and are explained in a transparent and sufficiently critical manner. The used data, both for the foreground and background systems, are consistent and appropriate for the goal and scope of the study. Furthermore, the analysis and interpretation of the results are consistent with the goal and scope of the study. The interpretation reflects the identified limitations and the goal of the study.

Review - Scope

The scope of this Critical Review comprises the study "Life Cycle Assessment (LCA) of Cotton made in Africa (CmiA)" prepared by PE INTERNATIONAL AG on behalf of the Aid by Trade Foundation.

A Critical Review according to ISO 14040:2006 and ISO 14044:2006 by external experts was conducted. The objectives of this Critical Review are to ensure the compliance of the study with ISO 14040:2009 and ISO 14044:2006 in terms of formal procedures and methods and whether the LCA report is written in accordance with the formal requirements of the ISO standards. The evaluation of the content of the study comprises applied data sources, life cycle models, assumptions and calculations and their transparency and applicability for the goal and scope of the study.

The reviewers had the task to assess whether:

- The methods used to carry out the LCA are consistent/compliant 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.

Review - Process

The critical review was conducted by two independent experts, namely Ulrike Bos (Fraunhofer Institute for Building Physics, Department Life Cycle Engineering), expert in agricultural science and Life Cycle Assessment and Dr. Susanne Neubert (Centre for Rural Development, SLE, Humboldt University of Berlin), expert in agricultural science and specifically cotton cultivation in the African socio-economic and environmental context. Both reviewers have had access to inventory level data (data collection sheets) as well as the LCA models and have been involved in methodological discussions from an early stage.

Review - Results

The results of the Critical Review process are presented according to the requirements and recommendations of the ISO standards. The issues discussed with the author during the review process were completely clarified; the requested modifications were implemented and integrated in the report. Ideas for improvement are enclosed at the end of this report.

Compliance with the international standards ISO 14040:2009 and ISO 14044:2006

The study, i.e. the developed model, was generated in accordance with the specifications of the ISO standards ISO 14040:2009 and ISO 14044:2006 in regards to the stated goal and scope.

Evaluation of the applied methods from a scientific and technical point of view

The techniques chosen meet the state of scientific and technical knowledge and are explained in a transparent and sufficiently critical manner.

Evaluation of the used data

The data used for the foreground and background systems are consistent and appropriate for the goal and scope of the study. Data gaps are closed by conservative estimates based on well-founded justifications. The data quality is sufficient and explicitly documented in terms of source, completeness, consistency and validation.

Evaluation of the interpretation

The analysis and interpretation of the results are consistent with the goal and scope of the study and are in accordance with the state of the scientific and technical knowledge. The interpretation reflects the identified limitations and the goal of the study.

Evaluation of the report

The submitted study is in accordance with the specifications of ISO 14040:2009 and ISO 14044:2006. The report covers the specific fields of the conducted study. Used data, methods, assumptions and restrictions are presented appropriately. Overall the report is transparent and coherent.

Remarks and Recommendations for further improvements

Methods used

The method chosen is the Life Cycle Assessment (LCA), which is a widely used and accepted approach, giving information about the efficiency of chemical use or the use of natural resources such as soil and water in relation to the emissions released per kg final product. Hence, with this approach only some aspects of sustainability can be analysed, but not the whole concept. The whole concept would include - among others - the assessment of the affected water bodies or the (fertile) land surfaces as well as their state, possible changes and the risk of pollution accompanied by the applied agricultural practises. In order to show the differences in results on per kg product or on per ha basis, it would have been very interesting to have both: Calculations and graphs with regard to kg product and calculations with regard to ha surface.

However, since LCA was given as method in the Terms of Reference in order to ensure consistency with other published studies and since the authors highlighted the limits of the method used, no critical comments are added by the reviewer concerning the method here, except of the following remark:

The limits of the methods used in this study appear most clearly in the calculation of Eutrophication. In the formula used the erosion potential, which is a major factor of Eutrophication, is solely regarded as a function of area under cultivation. Though it is widely known that the degree of erosion of agricultural lands heavily depends on how the land is managed, this fact is neglected here. Among others, this means differences in tillage are not reflected by the results. Since Conservation Agriculture as a technique is promoted by CmiA, which - as a matter of fact - can lead to zero erosion through minimum tillage, soil cover and crop rotation, these effects are not shown in the calculation. Obviously the authors didn't get data about the percentage of farmers really applying CA in Zambia and Ivory Coast. Hence, this potentially very positive impact of CA on the Eutrophication cannot be highlighted here as benefit of CmiA.

Fertilizer application in Southern African countries

In the study it stays quite unclear, why farmers do not apply fertilizers or at least why they apply such low quantities. The reason is purely economic at least in Zambia, as mentioned one time also in this study. Since fertilizers are not produced in the African countries concerned, all kinds of fertilizers and pesticides have to be imported from Europe or may be SA. Especially fertilizers are so expensive that their application is not profitable at all under the fluctuating rainfall conditions and the world market prices given (law of diminishing marginal returns). Lacking profitability is also the reason why fertilizers are not included in the chemical packs distributed by the cotton companies to the farmers as credit. But since the situation is slightly different in West Africa the use of fertilizers can be profitable to a certain extend at least there. However, the reader does not get any insights here, though the data is certainly available. It would have been interesting to get more information about these backgrounds in the study.

Economic sustainability

Having in mind that the sustainability of the production system in African countries is underestimated because of the mentioned methodological limits, the study still reveals that the African system is far more environmentally sustainable than the usual conventional intensive cotton production systems elsewhere.

Though this result is encouraging it should be made clear here that this applies only for the environmental side of sustainability, but not necessarily for the economic profitability or concerning the production risks. These largely depend on the political and economic frameworks, which are both beyond the scope of this study and also beyond of the CmiA initiative. To make this more clear the reviewer would like to mention that in countries as Zambia the effects of price fluctuations on the cotton world market fully affect the small scale farmers until now, because there are still no insurances nor any buffer mechanism on the national or international levels. Since there is no alternative cotton market (domestic textile industry is down) nor is there any smooth fund, which could buffer price shocks, the farmers are at the mercy of these price fluctuations until now. Since the cotton companies cannot guarantee them a pre-planting price (the risks would be also too high for them) cotton production is still at farmers risk only up to today. However, though the study doesn't say it differently the authors do also not address this, and so the reviewer at least would like to highlight that these economic dilemmas shouldn't be forgotten, when cotton growing systems in Africa are assessed. Though CmiA might certainly be not powerful enough to decide on these dimensions, it would be still possible for this initiative to think of and discuss mechanisms, which could smooth these risks for farmers for a better future.

Allocation

As the choice of the allocation method has a great effect on the result, a scenario analysis using different allocation methods (e.g. mass, heating value, different prices) would improve the significance of the study.

Review - Annotations (implemented)

There is a separate document listing the reviewer's comments and the respective answers and corrections by the authors.

Report concerning the Critical Review of the study
"Life Cycle Assessment (LCA) of Cotton made in Africa (CmiA)"

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C. (Supplement): Description of result parameters

Climate Change

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

In addition to the natural mechanism, the greenhouse effect is enhanced by human activities. Greenhouse gases considered to be caused or increased anthropogenically include carbon dioxide, methane and CFCs. Figure B-1 shows the main processes of the anthropogenic greenhouse effect. An analysis of the greenhouse effect should consider the possible long-term global effects.

Global warming potential is calculated in carbon dioxide equivalents (CO_2-eq). This means that the greenhouse potential of an emission is given in relation to CO_2. Since the residence time of the gases in the atmosphere is incorporated into the calculation, a time range for the assessment must also be specified. A period of 100 years is customary.

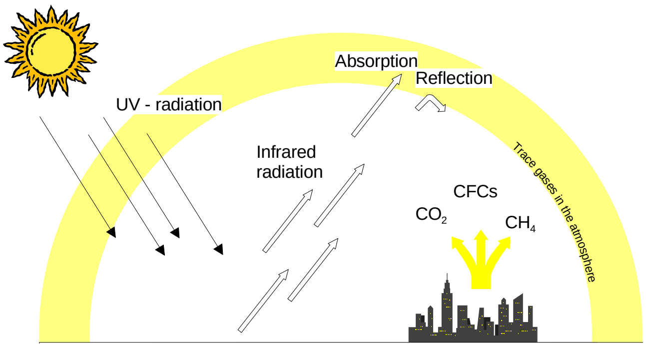

Figure B-1: Greenhouse effect (KREISSIG AND KÜMMEL 1999)

Acidification (AP)

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

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

When analysing acidification, it should be noted that awhile it is a global problem, the regional effects of acidification can vary. Figure B-2 displays the primary impact pathways of acidification.

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

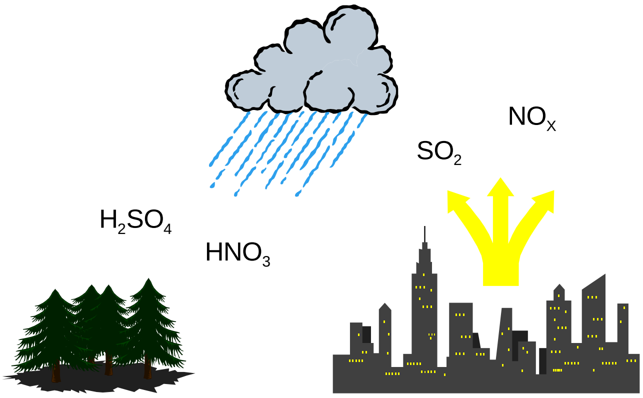

Figure B-2: Acidification Potential (KREISSIG AND KÜMMEL 1999)

Eutrophication (EP)

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

The result in water is accelerated algae growth, which, in turn, prevents sunlight from reaching the lower depths. This leads to a decrease in photosynthesis and less oxygen production. Additionally oxygen is needed for the decomposition of dead algae. Both effects cause oxygen concentration in the water to decrease, which can eventually lead to fish kills and anaerobic decomposition (decomposition without the presence of oxygen), producing hydrogen sulphide and methane. This can lead to the destruction of the eco-system.

On eutrophicated soils, an increased susceptibility of plants to diseases and pests is often observed, as is a degradation of plant stability. If the nitrification level exceeds the amount of nitrogen necessary for a maximum harvest, this can lead to enrichment in nitrate. Leaching of these nitrates can lead to increased nitrate content in groundwater. Nitrate also ends up in drinking water.

At low levels, nitrate is harmless from a toxicological point of view. However, the nitrate reaction product nitrite is toxic to humans. The causes of eutrophication are displayed in Figure B-3. Eutrophication potential is calculated in phosphate equivalents (PO_4-equiv.). As with acidification potential, it is important to remember that the effects of eutrophication potential

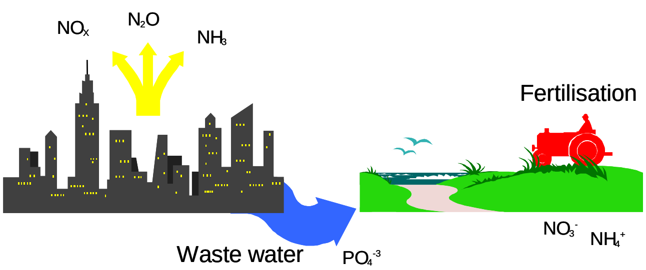

Figure B-3: Eutrophication Potential (KREISSIG AND KÜMMEL 1999) differ regionally.

Water use and water consumption

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

Consumptive and degradative use

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

Freshwater consumption (consumptive freshwater use) describes all freshwater losses on a watershed level that are caused by evaporation, evapotranspiration from plants[5], freshwater integration into products, and release of freshwater into a sea (e.g. from wastewater treatment plants located along the coastline). Therefore, freshwater consumption is defined in a hydrological context and should not be interpreted from an economic perspective. It does not equal total water use (total water withdrawal), but rather water losses associated with water use. Note that only the consumptive use of freshwater, not seawater, is relevant from an impact assessment perspective because freshwater is a limited natural resource.

Degradative water use, in contrast, denotes the use of water with associated quality alterations and describes the pollution of water (e.g. if tap water is transformed into wastewater by use). These alterations in quality are not defined as water consumption.

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

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

The water footprint of a system is a set of different calculations and should be used as an umbrella term rather for communicating a single number. According to ISO 14046 (in pro-

[5] Note: Typically, only water from irrigation is considered in the assessment of agricultural processes and the consumption of rainwater 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 is debatable whether or not such changes (if they occur) should be covered by an assessment of land use changes rather than by water inventories. However, rainwater use is sometimes assessed in different methodological approaches or can be used for specific analyses. The GaBi software allows for an 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").

gress) a water footprint consists of two parts: a water stress footprint caused by consumptive use and a water stress footprint caused by degradative water use.

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

D. (Supplement): Comparison of the environmental impact assessment results for Cotton made in Africa (CmiA) by Systain and PE International

Dr. Moritz Nill (Systain), Daniel Thylmann (PE International)

The Aid by Trade Foundation (AbTF) is interested to assess the environmental impact of lint cotton (at gin gate) produced under the requirements of the Cotton made in Africa (CmiA) certification scheme. Therefore it commissioned two studies (independent from each other) with different goal and scope: one in 2013 (SYSTAIN 2013) and one in 2014 (PE 2014).

Both studies follow the ISO 14040 principles. The ISO 14040 defines necessary steps and documentation to conduct an ISO compliant LCA. However, it does not specify modelling approaches, data to be used or impact categories to be assessed. Data, inventory set up and impact assessment should be made in a way to meet the requirements defined in the goal and scope (for each LCA independently).

The main goal of the SYSTAIN 2013 study is to assess the carbon- and water footprint for both, CmiA and global average conventional cotton. The intention is to be as transparent as possible in terms of inventory data used (e.g. using public available statistical data in cases where secondary data was needed) and modeling approaches chosen (e.g. using the IPCC method for greenhouse gas accounting in agricultural systems). The study covered for CmiA all CmiA countries and for global average cotton world's eight biggest cotton producing countries.

The main purpose of the 2014 study from PE is to develop a complete Life Cycle Inventory (LCI) for CmiA. Different impact categories are assessed; therefore, the use of a complex agricultural model is necessary. The intention was to use similar models, methods and assumptions as the established LCI for the global average of conventional cotton (COTTON INC. 2012). The study was restricted to two African countries.

Given the different approaches and intentions of the two studies, different results are to be expected. This does not compromise the quality, liability or ISO compliance of neither of the two studies, but only reflects the differences in goal and scope.

If the differences in goal and scope are taken into account, there is no contradiction in the results of the two studies. As stated above, assumptions and modelling approaches were made in accordance to the goal and scope of the respective studies; please refer to the study reports for detailed documentation and justification of these assumptions.

The differences can be attributed to three different LCA areas:

- System boundaries and background data.
- Inventory data (data collection).
- Modelling approach (agricultural emissions).

System boundaries and background data

The Systain 2013 study does not use allocation (distribution of environmental impact on main product (lint) and co product (seed), while the PE 2014 study allocates 10% of the environmental burden of cotton cultivation to the seeds (based on economic value).

The PE 2014 study did not consider animal draught in the impact assessment, while Systain 2013 allocated a share of the environmental impact of livestock keeping to the cotton cultivation.

Different background data from widely recognized sources with regard to the provision of fertilizer are used in the two studies, with different impact profiles per kg fertilizer used.

Inventory data

The Systain 2013 study collected primary data from seven African countries in order to calculate the CmiA average for agricultural activity (timeframe 2012), while the PE 2014 study is based on primary data from two regions only (timeframe 2013), resulting in a different average.

Modelling approaches (agricultural emissions)

The Systain 2013 study followed the IPCC approach of modeling greenhouse gas emissions related to crop cultivation. The PE 2014 study uses an extended emission model and considers:

- indirect emissions (nitrogen volatilization, deposition, and emission as nitrous oxide), and
- methane sink function of agricultural soils (reduced compared no natural vegetation).

These factors explain the larger share of field emissions in the PE 2014 study compared to the Systain 2013 study.

Conventional cotton as a reference value

The PE 2014 study does not assess the environmental impact of conventional cotton, but refers to a published study (COTTON INC. 2012), and is based on the same modeling approach and system boundaries as the COTTON INC. 2012 study. The SYSTAIN 2013 study provides an assessment of the conventional cotton, based on the best available public data. All the differences mentioned above in system boundaries, background data, inventory data (data collection) and modelling approach (agricultural emissions) also apply for the results for conventional cotton and explain the differences between COTTON INC. 2012 and the SYSTAIN 2013 study. The difference assessed between the impact on climate change of conventional cotton and CmiA lays in the same order of magnitude in the SYSTAIN 2013 and the PE 2014 study (i.e. CmiA performing approximately 50% better with regard to climate change)[6].

Water data

As CmiA is exclusively rain fed, both the PE 2014 study and the SYSTAIN 2013 study straightforwardly arrive at the same results for blue water consumption. Differences between the COTTON INC. 2012 and the SYSTAIN 2013 study for water use can be explained by different inventory data (geographic reference, primary vs. secondary data collection) and system boundaries (e.g. evaporation of in irrigation channels considered in the SYSTAIN 2013 study).

Conclusion

The two studies commissioned by the Aid by trade Foundation with regard to Cotton made in Africa differ in their goal and scope, resulting in differences with regard to the absolute numbers of impact assessment results on climate change. These differences do not compromise the quality, liability or ISO compliance of neither of the two studies. It can be seen that the results of the two studies closely match to each other once differences in goal and scope are taken into account. Even more important, despite these differences in goal and scope the two studies arrive at the same main conclusion, namely they confirm the positive environmental performance of CmiA with regard to climate change and water use when compared to published data.

[6] It should also be noted that both studies do not conduct a comparative assertion as defined in the ISO standard (14040 series). Available published data is used to set the results of the presented study into perspective, for discussion and interpretation. An ISO consistent comparison of two product systems would require additional effort in assessment of the precision, completeness and representativeness of data used; description of the equivalence of the systems being compared, uncertainty and sensitivity analyses and evaluation of the significance of the differences found, all confirmed by critical review.