The Carbon and Water Footprint of Cotton made in Africa

Assessment of Carbon and Water Footprint of Cotton made in Africa
as compared with average conventional cotton

Prepared by Dr. Moritz Nill and Kordula Wick:

systain

Aid by Trade Foundation

Version II, January 2013

Executive Summary

1 The “Cotton made in Africa” Initiative (CmiA), founded by the Aid by Trade Foundation (AbTF) in 2005, aims at advancing the cultivation of sustainable cotton and increasing its market share internationally. The CmiA’s main objectives are the protection of the environment and the improvement of the livelihoods of smallholder farmers in Africa.

2 Information about the environmental impact of CmiA (especially on climate change and water use) and prospective differences as compared with conventional cotton is of great importance to the AbTF as it clarifies the relative advantages of CmiA. The objective of this study is to evaluate the carbon and water footprint of CmiA compared with that of conventional cotton.

3 The carbon footprint (CF) and water footprint (WF) analysis was conducted following the Life Cycle Assessment (LCA) concept as defined in ISO 14040 and ISO 14044. An LCA addresses the environmental aspects and potential environmental impacts throughout the complete lifecycle of a product. This usually includes the extraction of raw materials as well as the processing, utilization and disposal of the product.

4 The CF evaluation was carried out based on requirements of the of Intergovernmental Panel on Climate Change (IPCC; 2006) for carbon accounting regarding origin emission sources of agriculture and quantification methodologies and was limited to greenhouse gases (GHGs).

5 The water footprint (WF) was based on the accounting approach provided by the Water Footprint Network (WFN). The WFN distinguishes both direct and indirect water consumption, where water consumption is differentiated into blue, green and grey water. In contrast to GHG emissions, the use of water has a regional impact on water resources, the ecosystem and the human environment. Surface and ground water (blue water) consumption is of particular environmental importance since its consumption contributes to water scarcity and water stress.

6 Impacts were calculated for a functional unit of 1.0 kg of lint cotton for the processes of cotton cultivation and cotton ginning as well as all upstream processes.

7 The carbon footprint of CmiA (1.92 kg CO_2-eq) is significantly better than average conventional cotton (4.64 kg CO_2-eq). Key drivers of CmiA’s carbon footprint are mineral fertiliser production (52%), N_2O fertiliser soil emissions (17%) and livestock emissions due to the use of draft animals (12%). In contrast, the GHG emission drivers of conventional cotton are mechanical energy (34%), fertiliser production (33%) and fertiliser soil emissions (10%). Different cultivation methods explain the differences here. Whereas CmiA smallholder production is

largely non-mechanised, conventional cotton is partly based and dependent on mechanical energy.

8 These results indicate potential starting points for the AbTF in working out a carbon footprint reduction plan. Optimal fertiliser management with respect to improved yields and a shift in land management systems to minimum or no-tillage systems might result in improvements in both productivity and environmental conservation.

9 The total water footprint of CmiA is slightly higher (14.2 m^3, 99% green water) than the water footprint of conventional cotton (13.1 m^3, 40% green water). However, due to the exclusion of irrigation, CmiA does not utilise surface or ground water (blue water). Consequently the production of CmiA has no environmental impact on blue water resources, the consumption of which is potentially harmful, while conventional cotton consumes about 5 m^3 of this water per kilogramme of lint cotton.

Content

I. List of figures

II. List of tables

III. List of abbreviations and acronyms

AbTF	Aid by Trade Foundation
BMU	Bundesministerium für Umwelt
CF	Carbon footprint
CH_4	Methane
CmiA	Cotton made in Africa
CO_2	Carbon dioxide
CO_2-eq	Carbon equivalents
Compaci	Competitive African Cotton Initiative
FAO	Food and Agricultural Organisation
GHG	Greenhouse gases
GPG	Good Practise Guidance
GWP	Global warming potential
ha	Hectare
ICAC	International Cotton Advisory Committee
IFA	International Fertiliser Agency
IPCC	Intergovernmental Panel on Climate Change
IWMI	International Water Management Institute
kg	Kilogram
LCA	Life cycle analysis
LULUCF	Land use, land use change and forestry
m^3	Cubic metres
N	Nitrogen
N_2O	Nitrous oxide/laughing gas
t	Ton
USDA	United States Department of Agriculture
WF	Water footprint
WFN	Water Footprint Network
WSI	Water stress indicator
WTA	Water-withdrawal-to-availability ratio

1. Background

10 Agriculture and cotton cultivation are an important source of carbon emissions and as such contributors to climate change. Worldwide cotton production and consumption generates around 220 Mio.t CO_2-eq that account for about 0.8% of global greenhouse gas (GHG) emissions (Carbon Trust 2011). At the same time cotton cultivation offers significant climate change mitigation potential.

11 Cotton is a major crop, making it an integral element in a substantial global industry. Its production is highly concentrated in relatively few countries around the world, some of which are developing countries. High fertiliser and pesticide inputs and the use of mechanical energy as well as significant water withdrawals have led to critical discussion about the sustainability of cotton production.

12 Along with greenhouse gas (GHG) emissions, the utilisation of water in cotton production is of crucial interest. Cotton is considered one of the "thirstiest" crops, and hence has a negative impact on our world's water resources. The current consumption of cotton products involves using 2.6% of the world's water resources (Chapagain, Hoeckstra, Savenije, Gautam 2005). The Aral Sea provides ample evidence of the environmental changes this brings. Due to irrigation and water withdrawal from tributary rivers, primarily for cotton cultivation in Kazakhstan, Turkmenistan and Uzbekistan, the Aral Sea's volume has shrunk by approximately 80% (1960-2000) and is still falling.

13 Hence analysing the environmental performance of cotton production in various countries with special attention to GHG emissions and water use represents an important starting point in reflecting on the possible advantages of sustainable cotton production.

14 The discussion about productivity and sustainable cultivation procedures is broad since productivity differs substantially depending on cultivation method, input and regional climatic conditions (see figure 1).

15 Highly mechanised cultivation methods with high mineral input may result in higher yields, but they do not automatically lead to improved environmental performance per unit of lint cotton. The discussion about the impact of cotton cultivation and the advantages of sustainable and/or organic cotton are far-reaching and concern specific industries, apparel producers in particular, and consumers.

16 The "Cotton made in Africa" Initiative (CmiA), founded by the Aid by Trade Foundation in 2005, aims at advancing and promoting the cultivation of sustainable cotton to increase market share and sales opportunities. CmiA's main

objectives are to protect the environment and improve the livelihoods of smallholder farmers in Africa.

17 Consequently, information about the environmental impacts (especially on climate change and water use) of CmiA and prospective differences from those of conventional cotton are very important to the AbTF.

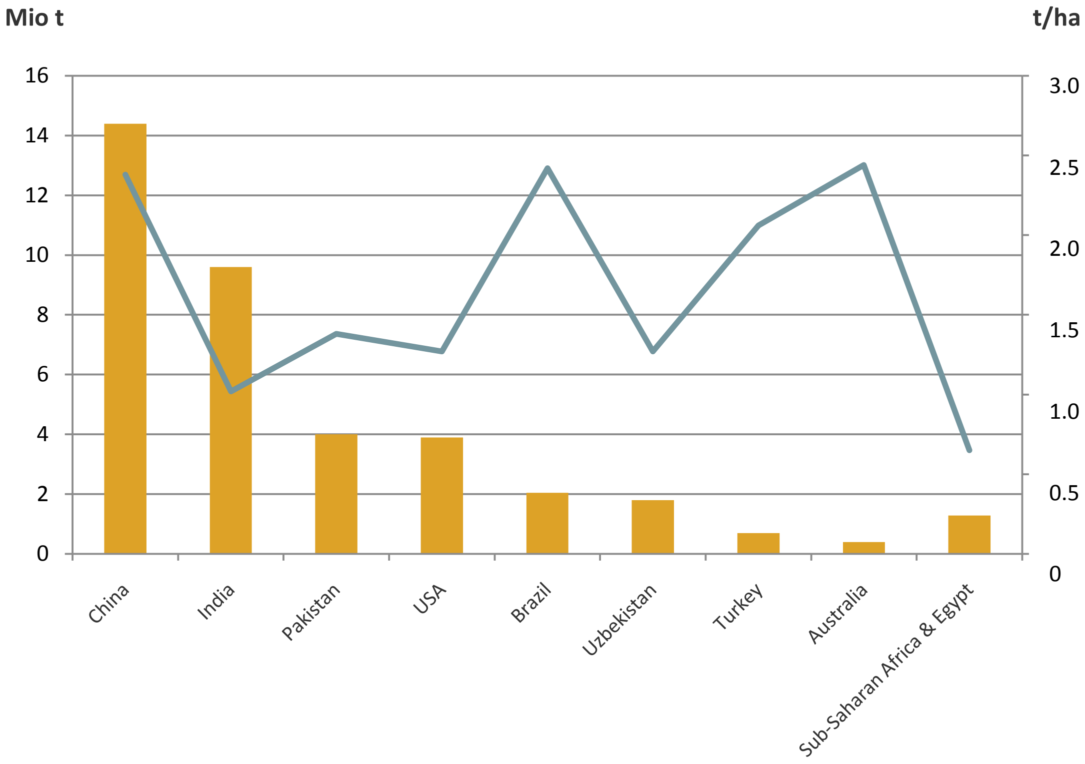


Figure 1: Total production (Mio. t) and yield (t/ha) of cottonseed per country 2009; Source: USDA 2010)

2. Objective of the study

18 The objective of this study was to evaluate the carbon and water footprint for CmiA with respect to that of conventional cotton.

19 The report provides answers to the following two questions:

- Does CmiA perform better or worse than conventional cotton?
- Where does CmiA production show potential for reducing its environmental impacts?

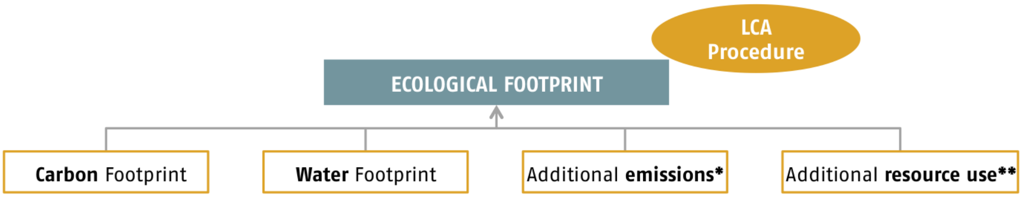
3 Methodology

20 The carbon footprint (CF) and water footprint (WF) have been calculated following the concept of the Life Cycle Assessment (LCA) as defined in ISO 14040 and ISO 14044. In a LCA the environmental aspects and potential environmental impacts are addressed throughout the complete lifecycle of a product. This includes the extraction of raw materials as well as the processing, use and disposal of the product.

21 A LCA is divided into four phases (ISO 14040 2006):

- Goal and scope definition, including unit, system boundaries, cut-off criteria, impact categories and limitations/assumptions
- Collection of all emission and resource use data throughout the lifecycle and within the system boundaries
- Assessment of impacts of emissions and resource use with regard to different impact categories (and possibly nomination of data)
- Interpretation and discussion of results, drawing of conclusions

22 Climate change and water use are two of the key impact categories in a LCA. Hence, CF and WF are important monothematic components in a LCA (see figure 2) and as such represent the essential starting point for an environmental impact assessment.



*: i.e. SO2, NOx, particulate matter (PM), NH3
**: i.e. energy carrier, metal

Figure 2: Components of an ecological footprint; Source: Authors' illustration

3.1 Carbon footprint

23 "The Product Carbon Footprint describes the amount of greenhouse gas emissions throughout the entire lifecycle of a product in a defined application and related to a defined unit" (BMU 2012). The CF evaluation was carried out on the basis of IPCC requirements for carbon accounting regarding origin emission sources of agriculture and quantification methodologies and was limited to GHGs.

24 IPCC (2006) provides guidance for the evaluation of the so-called global warming potential (GWP) of greenhouse gases (especially carbon dioxide (CO_2),

methane (CH_4), and nitrous oxide (N_2O)) over a 100-year time horizon (figure 3) The GWP describes the impact on climate change of CH_4 and N_2O compared with the impact of CO_2 and allows for the calculation of a weighted sum of GHG emissions measured in CO_2-equivalents (CO_2-eq).

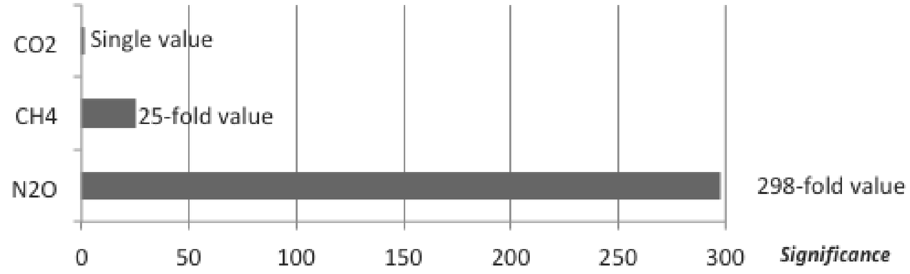


Figure 3: Global warming potential of greenhouse gases; Source: Authors' illustration in keeping with IPCC 2006

25 Data for carbon emissions do not need to reflect regional information, as GHG is a global problem in which the location of the emission source does not play a role.

3.2 Water footprint

26 The water footprint is based on the accounting approach provided by the Water Footprint Network (WFN). "The water footprint of a product (a commodity, good or service) is the total volume of freshwater used to produce the product, summed over the various steps of the production chain. "(Hoeckstra et al. 2011).

27 The WFN distinguishes both direct and indirect water consumption by source and polluted volumes by type of pollution. Consequently water consumption is differentiated into blue, green and grey water (figure 4).

- **Blue water** – "Fresh surface and groundwater, in other words, the water in freshwater lakes, rivers and aquifers"[2]
- **Green water** – "The precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation"[3]
- **Grey water** – indicator for water pollution in terms of a volume polluted

Figure 4: Differentiation of water according to WFN 2012; Source: Authors' illustration

28 Whereas the consumption of blue water is an essential component in the total evaluation of water use, green and grey water are optional elements depending on the object of investigation. Green water is of no relevance for the manufacture of metal products, for instance, while it is essential for agricultural processes. For the water footprint of cotton production, an agricultural product, green and blue water consumption is of interest. The crop-specific requirements for blue and green water are determined by crop evapotranspiration, which is dependent on climatic parameters (temperature, humidity, etc.), crop characteristics and soil water availability (Allen et al. 1998).

29 Accounting for grey water poses problems in practical application due to the complexity of its evaluation and a lack of data. It is more a pollution indicator and as such not included in this study (Ridoutt & Pfister 2010). Mekonnen and Hoeckstra conducted one initial study on grey water consumption in agriculture in 2010. As a starting point, they limited their investigation to the grey water used with the application of N-fertilisers (Mekonnen & Hoeckstra 2010).

30 Water that is consumed during upstream processes e.g. during the production of fertilisers, electricity etc. is defined as virtual water.

31 Furthermore, irrigation losses due to transport, unsatisfactory irrigation efficiencies and vaporisation are an issue in agriculture. Country-specific water requirement ratios have been collected by AQUASTAT (2000). These water requirement ratios relate the volume of irrigation water required to the volume of water extracted from rivers, lakes and aquifers for irrigation purposes.

32 In contrast to GHG emissions, the use of water has regional impacts on water resources, the ecosystem and the human environment. Hence, the components of a total water footprint are specified and assessed geographically and temporally with respect to different impacts on environmental, social and economic sustainability (WFN 2012).

33 Water scarcity and water stress following the Water Stress Index (WSI) by Pfister et al. (2009) provide the basis for the impact assessment of water use for cotton production on a national level. While green water consumption in all likelihood does not contribute to water scarcity (Ridoutt & Pfister 2010), blue water consumption is of particular importance. Blue water consumption contributes to water scarcity and affects water availability for human and environmental uses. The WSI can also be interpreted as a weighting factor for blue water to identify the amount of water consumption that is potentially harmful for the environment (Ridoutt & Pfister 2010).

34 The central unit of this indicator is the “water-withdrawal-to-availability ratio” (WTA) per watershed, which is also applied in other water stress indicators i.e. physical water scarcity (IWMI 2007). According to Pfister et al., water stress does not show a direct linear relationship to the WTA. Temporal variability of water availability due to seasonal precipitation conditions and water storage

potential is considered in the WSI. The WSI is calculated based on the following logarithmic function.

$$WSI = \frac{1}{1 + e^{-6.4 \times WTA} \times (\frac{1}{0.01} - 1)}$$

35 Values smaller than 0.1 indicate very low water stress, values between 0.1-0.5 indicate moderate stress, values between 0.5-0.9 high stress and values around 1 or above demonstrate extreme water stress to the region (Pfister et al. 2009).

3.3 Life cycle model of cotton production

3.3.1 Functional unit

36 Impacts were calculated for a functional unit of 1.0 kg of lint cotton.

3.3.2 Scope

37 The footprints were evaluated as production-weighted averages for both CmiA and conventional cotton. The following countries were included in this study:

Table 1: Overview of countries included; Source: Authors' illustration

CmiA:	Average conventional cotton
Benin	China
Burkina Faso	India
Côte d´Ivoire	USA
Malawi	Pakistan
Mozambique	Brazil
Zambia	Uzbekistan
Cameroon	Turkey
	Australia

38 Average conventional cotton represents around 85% of the total global lint cotton production in 2009 (USDA 2010) and as such serves as a representative benchmark for CmiA.

3.3.3 System boundaries

39 The footprint calculations contain direct and indirect GHG emissions and water consumption for the cultivation, ginning and inputs (intermediate products) needed. This covers the cycle from the production of the raw material to the ginnery factory gate (“from cradle to gate”).

40 Figure 5 illustrates the process along the lifecycle of one functional unit.

41 Sources of carbon-equivalent (CO_2-eq) emissions arise from energy consumption and production of intermediate products such as seeds, fertiliser and pesticides, mechanical energy, livestock, the application of fertilisers, land management and transport.

42 Carbon dioxide (CO_2) emissions occur mainly during the combustion of fossil energy carriers for heating (e.g. chemical processes) and electricity. Furthermore, land use and land use change have been investigated as the main drivers of carbon dioxide emissions in agricultural production (BMU 2012). On the one hand carbon dioxide can be stored in organic substances in the soil, which serves as an indirect carbon sink. On the other hand, agricultural processes such as ploughing, sowing, fertilisation etc. may lead to a release of stored carbon.

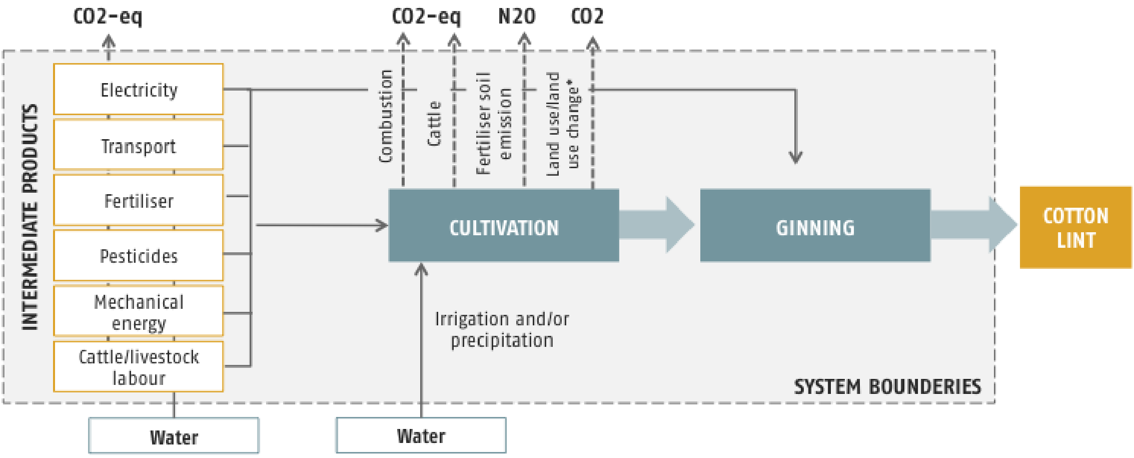


Figure 5: System boundaries of LCA of cotton production; Source: Authors’ illustration

43 According to IPCC Good Practise Guidance (GPG) (2006) land use, land use change and soil disturbance lead to considerably high carbon dioxide emissions. The methodology behind IPCC GPG involves the comparison of two reference states over a maximum of 20 years.

44 Official statistics (FAOSTAT 2012) on agricultural land occupation per country and per crop have not revealed the measurable conversion of land nor have

they provided an illustration of land use systems for conventional cotton cultivating countries. Hence, official evidence on land conversion was not available. This is an indication that GHG emissions due to land conversion have not been assigned to cotton cultivation and consequently have not had an impact on the footprints assessed. The lack information on land management systems made it impossible to account for these GHG emissions.

45 Thus, due to the lack of consistent statistics and information on the reference countries, emissions from land use and land use change have not been included in the carbon footprint to ensure the robustness and quality of the results. However, the potential of carbon sequestration in soil might be a key driver in reducing the carbon footprint of CmiA. Due to its high attention in public discourse and its potential importance, the carbon sequestration potential of changing land management systems has been evaluated and presented in this study.

46 Nitrous oxide (N_2O) originates from the production of fertiliser and pesticides as well as from the application of fertiliser and soil cultivation. Its contribution to greenhouse gas emissions from agricultural processes is substantial. Up to 80% of all nitrous oxide emissions are assigned to agriculture (BMU 2012) though accurate figures are difficult to evaluate. Nitrogen (N) in soil or provided in fertiliser or manure is microbiologically processed into nitrate compounds and bound in organic substances. Small amounts of N_2O are produced simultaneously as a by-product, a process favoured in the presence of low amounts of oxygen in soils and high temperatures.

47 N_2O emissions occur from the application of both mineral and organic fertilisers, though mineral fertiliser contains a significantly higher amount of nitrogen than organic fertiliser. According to the IPCC (GPG, LULUCF) (2006), 1% of applied nitrogen (either mineral or organic) is processed into nitrous oxide. Based on the results of several studies, the N-content of organic fertiliser is assumed to be about 2% (Jenkins, & van Zwieten, L. 2003) The N-content of manure from African cattle is 1.2% (FAO 2005).

48 Methane (CH_4) arises from enteric fermentation by ruminant animals (e.g. cattle, sheep) and from manure/organic fertiliser management. Methane emissions from manure management tend to be smaller than enteric emissions. In general it has been concluded that global livestock methane emissions account for up to 50% of all methane emissions. In addition to livestock, methane emissions might also be generated by the management of flooded fields (rice cultivation). This emission source does not apply to cotton cultivation.

49 Water consumption includes the amount used during the production of intermediate products, for cotton cultivation, and the amount associated with the ginning process. The following table shows a summary of inclusions and exclusions in the system boundaries:

Table 2: Inclusions and exclusions for the LCA; Source: Authors' illustration

Included	Excluded
+ Cotton growth, cultivation and ginning + Production of inputs[1] + Mechanical energy for field operations (tillage, sowing, application of fertiliser, pesticides, irrigation, harvest) + Transport of intermediate products and of harvested cotton to ginnery + Cattle/livestock labour + Electricity use (ginnery)	- Carbon storage in fibre - Construction of farm infrastructure - Human energy input - Packaging materials

3.3.4 Allocation

50 A system yields more than one output, the environmental burden needs to be allocated to the different products. LCA theory provides different approaches: system expansion, allocation by physical characteristics (i.e. mass) or allocation by monetary value. Cotton production is a multi-output process with two main products: lint cotton and seed cotton. Thus allocation criteria need to be applied.

51 An allocation based on mass is not suitable, since the by-product cotton seed accounts for up to 60% of the mass, but has a low monetary value for farmers compared to lint. Cotton is cultivated only once the market price for lint cotton is sufficiently high, an indication of the relatively low importance of seed cotton in terms of cultivation decisions. The allocation method for this investigation was therefore based on monetary values.

52 Since the monetary share of the value of seed and lint cotton differs greatly temporally and regionally (ICAC 2008) and the primary intention of growing cotton is to harvest and commercialize cotton fibres, 100% of the environmental burden is assigned to lint cotton to ensure a consistent comparative approach between CmiA and conventional cotton. In order to compare the carbon and water footprints of different regions, it is important to base the analysis on robust data. In Africa, for instance, the market price of cotton seed is extremely low. It only accounts for 4% of the monetary volume of the two products (ICAC 2008).

---

[1] The production of organic fertilizer is assigned with 0 emissions and water use, since its components are expected to be waste by-products/waste.

53 One third of livestock emissions are allocated to cotton cultivation based on expert assumptions and literature reviews. The other two thirds are assigned to milk and food production and other crops.

3.3.5 Data sources

54 For CmiA footprint modelling, it was considered very important to use primary input data as far as possible. This data was provided by the AbTF and Compaci (data can be found in the appendix). In cases where primary data was not available, official statistical data has been used to determine input data e.g. water consumption (Chapagain et. al 2005). All processes related to the production of inputs have been taken from LCA databases, such as Ecoinvent and PROBAS, and were included in the model. Soil and livestock emissions were calculated based on IPCC Good Practise Guidance, Volume 4 Agriculture.

55 For fertiliser use per country, official statistical data from the International Fertiliser Agency (IFA) were used, and statistics from U.S. Department for Agriculture (USDA) were used for yields.

56 Water consumption, irrigation efficiency rates (depending on region) were taken from Chapagain & Hoeckstra (2006).

57 Further input data for conventional cotton was taken from Ecoinvent. The two datasets (cotton cultivation in China and USA) have been adjusted for the cultivation techniques used in the respective countries. USA cotton cultivation represents conventional highly mechanised and industrialised farming system. The Chinese dataset is associated with a medium mechanised farming system.

58 Table 3 provides an overview of the data used.

59 Cattle/livestock labour and organic fertiliser was included in the LCA model for CmiA but not for average conventional cotton due to data availability reasons.

Table 3: Overview of data sources; Source: Authors' illustration

MODULE		CMIA	REFERENCE COUNTRIES
PARAMETER	Yield	AbTF, Compaci (2012)	USDA Foreign agricultural service (2010): "World Agricultural Production", data for 2009
	Conversion rate from seed cotton to lint cotton		Chapagain et al. (2005): "The water footprint of cotton consumption"
	N2O Fertiliser soil emission	The IPCC Guidelines for National Greenhouse Gas Inventories (2006), Volume 4, Chapter 11	
	N-content organic fertiliser	New South Wales Department of Primary Industries (2006)	
	N-content manure	FAO (2005): "Fertilizer use by crop in Ghana"	
	Share blue water	Chapagain et al. (2005): "The water footprint of cotton consumption"	
	Water requirement ratio	FAO, Aquastat (2000)	
INPUT	Consumptive water use	AbTF, Compaci (2012)	Chapagain et al. (2005): "The water footprint of cotton consumption"
	Mineral fertiliser use		Fertistat, IFA, Chapagain et al. (2005)
	Organic fertiliser use		-
	Numbers of draft animals (cattle, donkeys)		-
	Other input demand		Ecoinvent (data from 2006-2007))
INPUT PRODUCTION	Electricity production	ProBas (data from 2005, partly 2000)	
	Mechanical energy	ProBas – (data from 2005)	
	Transport	Ecoinvent (data from 2005)	
	Fertiliser Production	Ecoinvent (data from 2007)	
	Pesticide production	Ecoinvent (data from 2007)	
	Livestock emissions (CH4, N20)	The IPCC Guidelines for National Greenhouse Gas Inventories (2006), Volume 4, Chapter 10	
OTHERS	Carbon soil emissions land use	IPCC Guidelines for National Greenhouse Gas Inventories (2006), Volume 4, Chapter 5	-

4 Results

60 Compared with average conventional cotton, CmiA shows significant advantages regarding its carbon footprint and water footprint. The results of the study are presented in the following abstracts:

4.1 Carbon footprint

4.1.1 Comparison of average CmiA with average conventional cotton

61 The total carbon footprint for the production of 1 kg of CmiA lint cotton amounts to 1.9 kg CO_2-eq.

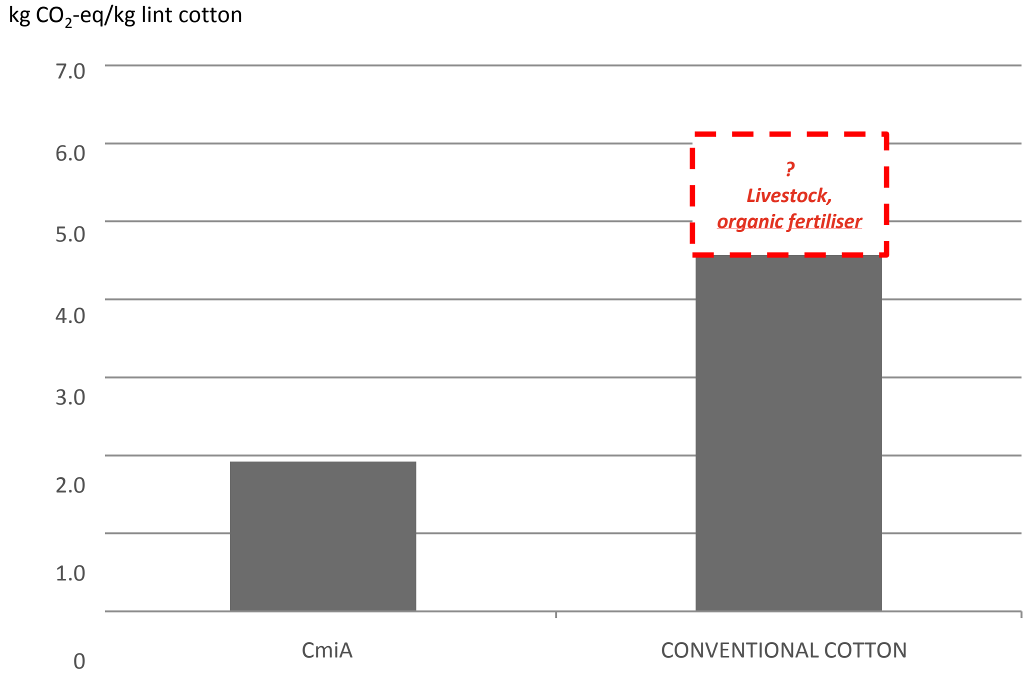


Figure 6: Comparison of the carbon footprints of average CmiA and average conventional cotton; Source: Authors' illustration

62 Cotton made in Africa has a significantly lower carbon footprint compared to average conventional cotton, which emits 4.6 kg CO_2-eq per kg lint cotton (see Figure 6). It is important to note that emissions from livestock and organic fertiliser were not included in the footprint of conventional cotton

what might result in even higher GHG emissions. This is illustrated by the red square.

4.2 Analysis of carbon emission drivers

4.2.1 CmiA – Key driver of carbon emissions

63 The carbon footprint and the respective emission drivers vary a great deal between CmiA and conventional cotton due to different cultivation methods.

Figure 8 shows the main drivers for the average CmiA carbon footprint. The following three aspects are responsible for more than 80% of the total GHG emission per kg lint cotton (CmiA):

- Mineral fertiliser production
- Fertiliser soil emissions
- Emissions from cattle/draft animals

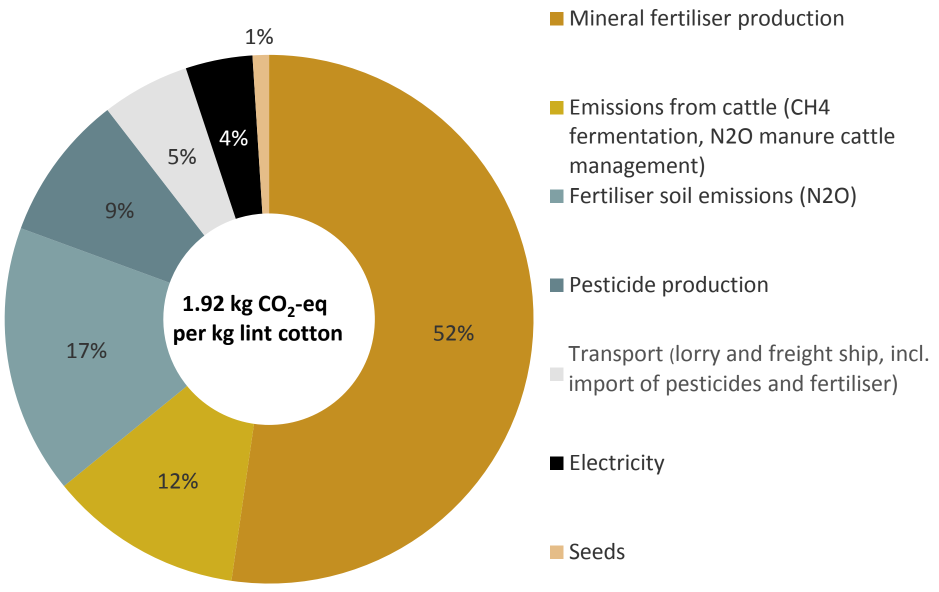


Figure 7: Distribution of emission drivers of average CmiA; Source: Authors' illustration

64 The emissions arising from mineral fertiliser production are mainly due to N-fertiliser production. The considerable amount of energy needed to produce ammonia and the nitrous oxide that is expended in the production process and storage are key contributors to the carbon emissions caused by fertiliser production.

65 Fertiliser soil emissions are, as mentioned above, emissions related to the application of N and organic fertiliser. These emissions account for almost one fifth of the total carbon footprint and thus have a significant impact.

66 Emissions from draft animals are related to fermentation and manure. For CmiA these can be roughly separated into 60% emissions from fermentation (CH_4) and 40% emissions from manure (N_20 and CH_4).

4.2.2 *Conventional cotton – Key driver of carbon emissions*

67 In comparison conventional cotton shows a different picture (figure 9). Here the main drivers are:

- Mechanical energy
- Mineral fertiliser production
- Fertiliser soil emissions

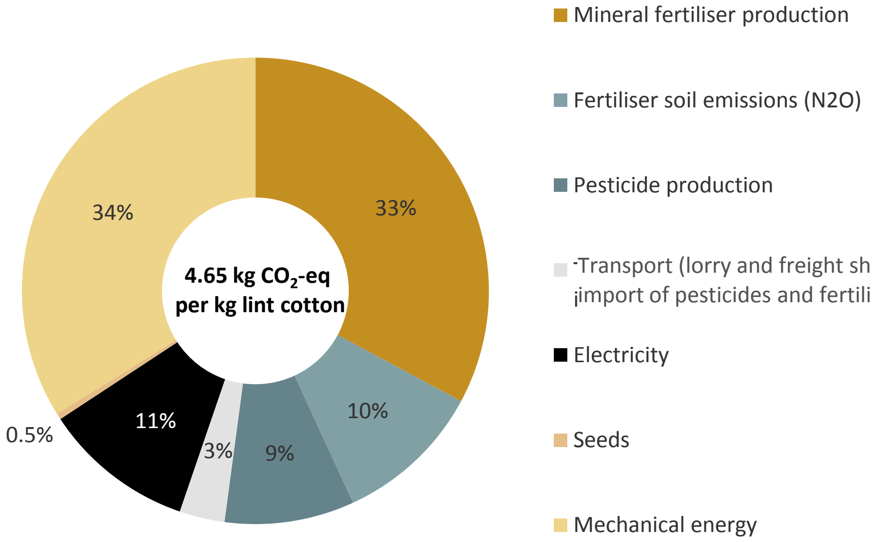


Figure 8: Distribution of emission drivers for average conventional cotton; Source: Authors' illustration

68 The main difference from CmiA is the use of mechanical energy. Based on primary data from CmiA no mechanical energy is used in the production of lint cotton. Conventional cotton emissions, in contrast, are mainly due to the combustion of fossil fuels (CO_2), the production of the tractor/vehicle and the infrastructure.

69 Since input data of conventional cotton has been taken from Ecoinvent database, high differences in consumption of electricity between CmiA and conventional cotton can be partly explained by the inclusion of electricity from processes other than ginning, such as electrical water pumps in Ecoinvent. In contrast to that, CmiA cotton production uses electricity mainly during the ginning process.

4.2.3 Share of greenhouse gases from cotton production

70 The share of the three greenhouse gases analysed, calculated based on their GWP, underlines the differences in cultivation methods. For CmiA nitrous oxide accounts for about 53%. Due to its non-mechanised cultivation method and the accounting of emissions of manure management, CmiA's share of N_2O is higher than that of carbon dioxide.

71 In contrast the carbon dioxide emissions from conventional cotton make up about 54% of all CO_2-eq emissions. This is due to the use of mechanical energy.

72 In general, CH_4 accounts for only a minor fraction of the total GHG emissions from both conventional cotton and CmiA. For conventional cotton it only accounts for 2% and for CmiA 11%. This is mainly due to the use of draft animals/livestock, which emit CH_4 through fermentation and manure.

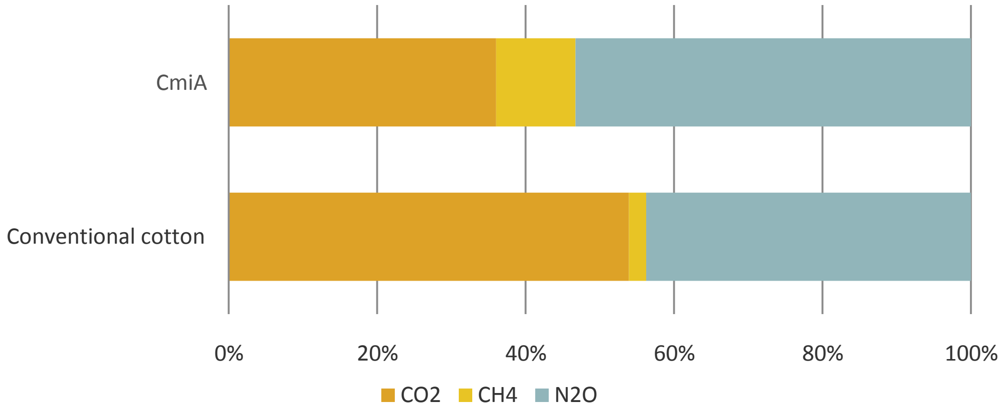


Figure 9: Share of greenhouse gases from cotton production; Source: Authors' illustration

4.2.4 *Comparison of CmiA with other cotton farming systems*

73 CmiA is based on a smallholder farming system, which makes it particularly important to compare the CmiA carbon footprint to other similar farming systems. Many regions in India and Pakistan also have smallholder farming systems.

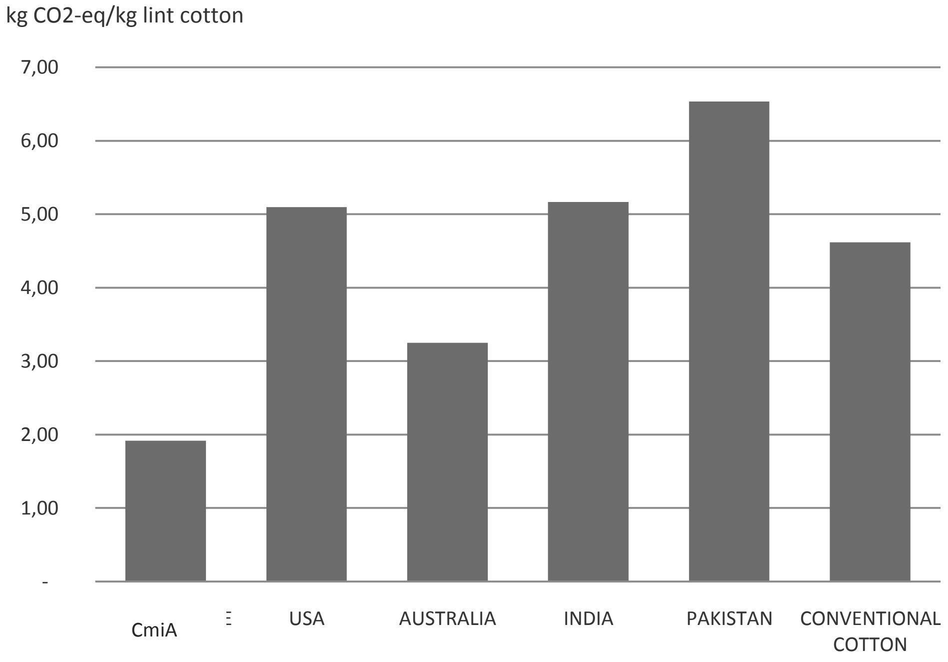


Figure 10: Comparison of carbon footprints of different farming systems; Source: Authors' illustration

74 Cotton production in India emits on average 5.2 kg CO_2-eq per kg lint cotton, which is 2.7 times higher than that emitted by CmiA. Even higher emissions have been calculated for Pakistan. With a carbon footprint of 6.5 kg CO_2-eq per kg lint cotton, Pakistan exceeds CmiA by 3.4 times. These findings are mainly due to high mineral N-fertiliser input in India (66 kg/ha) and even higher inputs in Pakistan (180 kg/ha) and partly to the use of mechanical energy. At the same time, seed cotton yields in India (1.02 t/ha) do not differ significantly from those in Africa (0.967 t/ha).

75 It is also important to compare CmiA to leading cotton producing countries, such as the USA and Australia. In both countries the cultivation of genetically modified cotton is allowed and increasing. All cultivation processes are highly mechanised and yields are relatively high (USA 1.38 t/ha; Australia 2.44 t/ha). However, CmiA also shows advantages regarding its carbon footprint compared to these two countries. This is based on the use of mechani-

cal energy for all fieldwork and the high input of mineral N-fertiliser (120 kg/ha; 121 kg/ha).

4.3 Carbon emission reduction potential

76 The key carbon emission drivers analysed and land cultivation techniques indicate potential approaches for reducing the CmiA carbon footprint.

77 The optimum use of mineral and organic fertilisers and general fertiliser management, which includes organic fertilisers (high organic inputs), represents GHG-emission reduction potential for CmiA.

78 Since fertiliser - both mineral fertiliser production and N_20 fertiliser soil emission - accounts for a large share of the carbon emissions, the effect the application and amount of fertiliser has on productivity (yield) and soil quality should be assessed. Having said that, the amount and type of fertiliser used must always be analysed and specified in connection to the fertiliser applied/emissions per kg lint cotton ratio and soil quality.

79 According to the IPCC GPG (2006), however, agriculture and hence land cultivation has a potentially high carbon sequestration potential in soil depending on inputs (as fertilisers) and land management systems[2].

80 At the moment CmiA cotton is cultivated using medium/full tillage systems that result in “substantial soil disturbance with frequent tillage operations” (IPCC 2006) with low organic inputs. Shifting to a “no-till” system (direct seeding without primary tillage and only minimal soil disturbance) and high organic input (e.g. crop residue input, organic fertilisers) would sequester carbon in the soil.

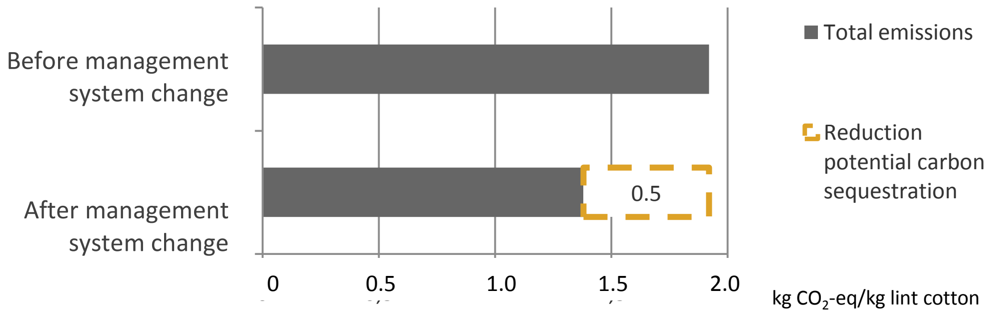


Figure 11: Carbon sequestration potential of CmiA, Source: Authors’ illustration

---

[2] In addition to soil, carbon, biomass, and dead organic matter as dead wood and litter are seen as relevant carbon pools for cropland according to the IPCC GPG (2006)

81 Figure 11 shows the roughly calculated CO_2-eq reduction potential for CmiA of 0.5 kg CO_2-eq by kg lint cotton by changing the land management system from full/medium tillage and low input to no tillage and high input according to the calculation methods provided by IPCC GPG (2006). This would allow the carbon footprint to be reduced by up to 25%.

82 Further analyses of the carbon sequestration potential of soil are recommended as the process and its effects differ by region and type of soil.

4.4 Water footprint

4.4.1 Comparison of average CmiA with average conventional cotton

83 As described above, water use in this study was classified as green, blue (separated into water loss and water consumption) and virtual water. The following figure illustrates the differences between CmiA and conventional cotton.

84 Firstly, it should be noted that irrigation is an exclusion criterion in CmiA's verification system, which means blue water is not utilised in CmiA cotton production. Water used e.g. for the dilution of pesticides or energy production is included in virtual water, as it is directly connected to intermediate products. Figure 12 shows that the virtual water content of cotton production is not relevant to the total amount of water used.

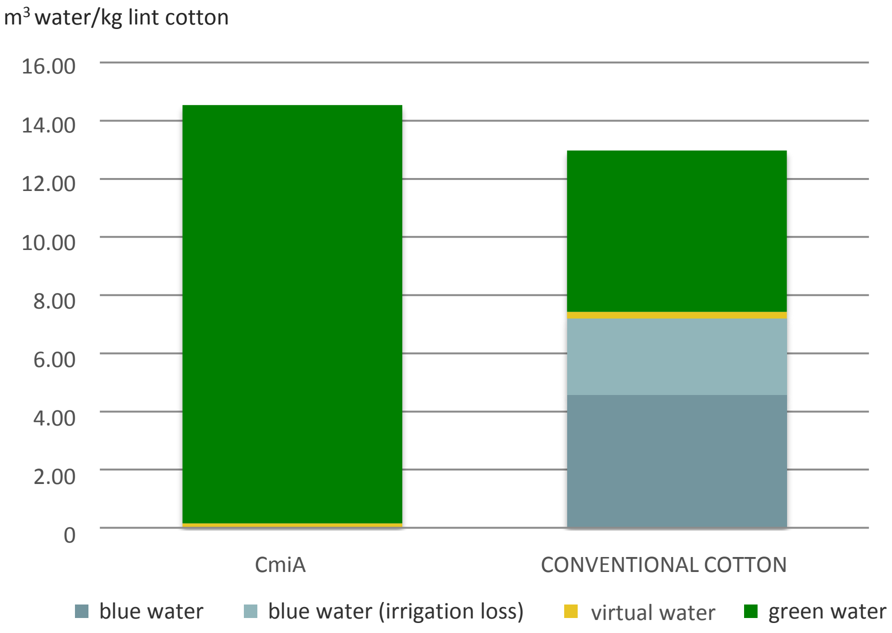


Figure 12: Comparison of total water footprints of average CmiA and average conventional cotton; Source: Authors' illustration

85 Overall CmiA consumes about 14.5 m^3 of water per kg lint cotton – 99% of which is green water (precipitation water and soil moisture). These amounts may differ according to climatic conditions, so these figures show a general tendency at this point.

4.4.2 Stress-weighted water consumption

86 As mentioned above, the impacts of blue water use and consumption on the environment spread geographically and temporarily. Consequently, withdrawals of water from rivers, groundwater etc. for irrigation have been weighted by regional water stress using WSI. The figure below shows the results and the comparison between the respective regions. Virtual water has not been included in the calculations, since its contribution is only minor (see figure 13) and water stress information is based on regional information, which is not available for the intermediate products (fertiliser, pesticides etc.)

87 Figure 13 highlights the stress-weighted water uses for average CmiA and average conventional cotton in India and Pakistan, two countries considered to have similar cultivation conditions to CmiA (smallholder farmers), and the USA and Australia.

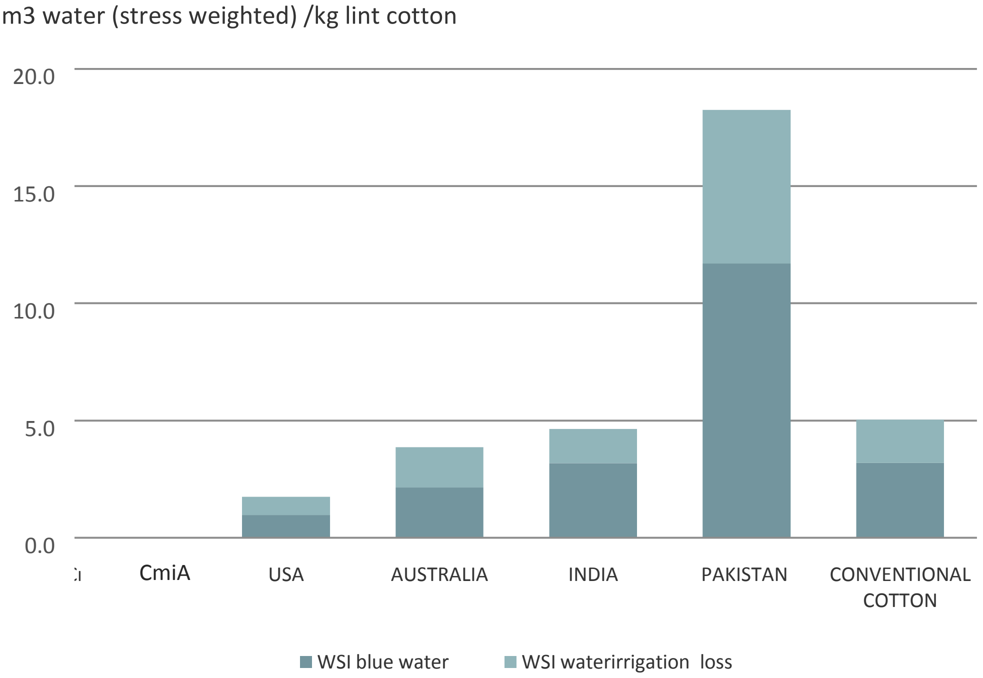


Figure 13: Comparison of stress-weighted blue water consumption; Source: Author's illustration

Please note: The figure shows stress-weighted water consumption following Pfister's methodology, not total blue water consumption.

88 To sum up, no irrigation means no potentially harmful water use. Consequently, with regard to direct blue water use to cultivate cotton, CmiA, unlike conventional cotton, does not have an environmental impact on natural water resources.[3]

89 Cotton cultivation can benefit from climate conditions. Countries as Pakistan, Uzbekistan, Turkey or Australia that face limited and particularly sporadic rainfalls and very high temperatures during the planting period depend on full irrigation systems. Furthermore, highly industrialised countries such as the US and Australia have only realised the advantages of higher yields thanks to complete irrigation systems.

90 Example: The share of blue and green water consumption without irrigation loss in Pakistan has been assessed at 79% blue and 21% green water. If the irrigation efficiency (water requirement ration) of 44% (Aquastat 2000) is included, the blue water share increases to 86%. Additionally, the water stress in Pakistan has reached a significant level with a factor of 0.967, an indication severe water stress according to Pfister. (Although Pakistan relies on full irrigation, the seed cotton yields in Pakistan (1.380 t/ha) are not significantly higher than yields in Cameroon (1.245 t/ha)).

5 Conclusion

91 Carbon and water footprint assessments cover essential issues and deliver important information about the relative advantages of CmiA.

92 At 1.92 kg CO_2-eq, the carbon footprint of one kg of CmiA lint cotton is better than that of average conventional cotton (4.64 kg CO_2-eq). Key drivers of the CmiA footprint are mineral fertiliser production (52%), N_2O fertiliser soil emissions (17%) and livestock emission due to draft animal holdings (12%). In contrast the GHG-emission drivers of conventional cotton are mechanical energy (34%), fertiliser production (33%) and fertiliser soil emissions (10%). These differences can be explained by different cultivation methods. While machines are not used to cultivate fields for CmiA, conventional cotton is partly based and dependent on mechanical energy.

93 These results indicate potential starting points where the AbTF could begin working on a carbon footprint improvement plan. Optimum fertiliser management aimed at improving yields and a shift in land management systems to a no-till system might result in improvements in both productivity and environmental conservation.

---

[3] WSI for CmiA countries varies between 0.011 (Cameroon) and 0.197 (Mozambique)

94 The total water footprint of CmiA is slightly higher (14.2 m^3, 99% green water) than the water footprint of conventional cotton (13.1 m^3, 40%). However, CmiA production is solely rain fed and as such potentially has no environmental impacts.

95 In contrast to conventional cotton (5 m^3 potentially harmful water use) CmiA does not utilise blue water since irrigation has been excluded. Consequently, CmiA leaves blue water resources, such as rivers, lakes and groundwater sources, untouched and has no environmental impact on them.

IV. Appendix

Table 4: Overview of parameters for CmiA countries

Parameter	Unit	Benin	Burkina Faso	Côte d'Ivoire	Malawi	Mozambique	Zambia	Cameroon	Average CmiA
Area	1000ha	75.84	21.42	103.40	18.52	82.86	200.00	148.89	650.91
Production of seed cotton	kt	67.113	22.845	108.074	24.000	33.000	90.000	185.420	530.452
Production cotton lint	kt	28.881	9.498	46.310	9.600	13.500	36.900	76.600	221.289
Yield (Seed cotton)	t/ha	0.885	1.067	1.045	1.296	0.398	0.450	1.245	0.967
Consumptive water use (water required in addition to water from precipitation (soil moisture))	m3/ha	5,510	5,380	5,510	5,510	5,380	5,380	5,510	5,475
water requirement ratio (irrigation efficiency as irrigation demand/agricultural withdrawal for irrigation)	rate	32%	32%	32%	32%	32%	32%	32%	32%
Share blue water	rate	2%	28%	2%	28%	28%	28%	2%	10%
N20 N-fertiliser soil emission rate (kg N2O/kg N)) (EF1)	rate	1%	1%	1%	1%	1%	1%	1%	1%
N-content organic fertiliser (average)	rate	2%	2%	2%	2%	2%	2%	2%	2%
Number of oxen and donkeys (cattle)	number	22,747	15,432	51,836	3,086	-	101,607	111,763	306,471
N-content cattle manure	rate	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
Allocation of oxen/ cattle	rate	33%	33%	33%	33%	33%	33%	33%	33%
Carbon stock in soil – shift in land management methods	t CO2/ha/ yr	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Lint/seed cotton mass	rate	43%	42%	43%	40%	41%	41%	41%	42%

Table 5: Overview of parameters for conventional cotton countries

Parameter	**Unit**	**USA**	**China**	**Uzbekistan**	**Turkey**	**Australia**	**India**	**Brazil**	**Pakistan**	**Average conventional cotton**
Area	1000ha	3,060	6,050	1,420	340	160	9,370	840	2,900	24,140
Production of seed cotton	kt	3,900	14,400	1,800.	700	400	9,600	2,040	4,000	36,840
Yield (seed cotton)	t/ha	1.380	2.380	1.270	2.060	2.440	1.020	2.420	1.380	1.754
Consumptive water use (water required in addition to water from precipitation (soil moisture))	m3/ha	4,190	6,380	9,990	9,630	8,430	5,380	5,510	8,500	6,330
water requirement ratio (irrigation efficiency as irrigation demand/agricultural withdrawal for irrigation)	rate	20%	36%	44%	40%	20%	54%	17%	44%	39%
Share blue water	rate	26%	38%	98%	91%	62%	25%	2%	79%	40%
N20 N-fertiliser soil emission rate (kg N2O/kg N)) (EF1)	rate	1%	1%	1%	1%	1%	1%	1%	1%	1%
N-content organic fertiliser (average)	rate	2%	2%	2%	2%	2%	2%	2%	2%	2%
Numbers of oxen and donkeys (cattle)	number									
N-content cattle manure	rate	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
Allocation of oxen/ cattle	rate	33%	33%	33%	33%	33%	33%	33%	33%	33%
Carbon stock in soil - emission through land conversion (from grassland)	t CO2/ha/yr	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Lint/seed cotton mass	rate	40%	40%	40%	40%	40%	40%	40%	40%	40%

Table 6: Overview of parameters for conventional cotton countries

	Input	Unit	Benin	Burkina Faso	CmiA Côte d'Ivoire	Malawi	Mozambique	Zambia	Cameroon	Average CmiA
CULTIVATION	Seeds	kg	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
	K-fertiliser	kg/ha	-	-	-	-	-	-	-	-
	N-fertiliser	kg/ha	37.0	37.5	37.5	-	-	-	37.5	27.33
	P-fertiliser	kg/ha	-	-	-	-	-	-	-	-
	PKN-fertiliser (composition 15-15-15) %share and addition to fertiliser	kg/ha	112.5	112.5	150.0	-	-	-	150.0	102.825
	Organic fertiliser (2% N content)	kg/ha	4,78	3,010.0	76.0	-	-	-	-	145.722
	Mechanical energy	MJ/kg	-							
	Pesticides	kg	0.003	0.003	0.003	0.003	0.003	0.003	0.003	-
	Transport lorry inter-mediate products	tkm	0,03554	0,59306	0,05098	0,00056	0,00056	0,00056	0,03067	0,003
	Transport boat inter-mediate products	tkm	0.35539	5.93055	0.50979	0.00560	0.00560	0.00560	0.30672	0.052
	Transport lorry (seed cotton)	tkm	0.100	0.150	0.090	0.078	0.050	0.060	0.100	0.515
	Electricity used in 2011	kWh	2,493,410	1,053,405	-	900,000	1,458,093	-	6,933,727	-
GINNING	Electricity	kWh/ kg lint	0.09	0.11	0.10	0.09	0.11	0.10	0.09	0.089
	General mix	share	0%	0%	0%	0%	0%	0%	0%	0.096
	Diesel power generator	share	100%	100%	0%	0%	50%	0%	0%	0%
	Gas	share	0%	0%	100%	0%	0%	0%	0%	20%
	Hydropower	share	0%	0%	0%	100%	50%	100%	100%	21%

Table 7: Input data from conventional cotton countries

	Input	Unit	USA	China	Uzbekistan	Turkey	Australia	India	Brazil	Pakistan	Average conventional cotton
CULTIVATION	Seeds	kg/kg lint cotton	0.016	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
	K-fertiliser	kg/ha	85	25	1.2	3	12	60	50	0.4	23.406
	N-fertiliser	kg/ha	120	120	210	127	121	66	40	180	112.554
	P-fertiliser	kg/ha	60	70	45	39	20	28	50	28	49.976
	Organic fertiliser (2% N content)	kg/ha	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Mechanical energy	MJ/kg seed cotton	6.796	7.425	1.391	4.553	3.844	8.663	3.876	6.403	6.985
	Pesticides	kg/kg seed cotton	0.004	0.006	0.008	0.004	0.004	0.008	0.005	0.008	0.007
	Transport lorry intermediate Products	tkm	0.07548	0.04029	0.08129	0.04157	0.03391	0.07020	0.01473	0.04688	0.053
	Transport boat intermediate Products	tkm	0.75478	0.40287	0.81292	0.41569	0.33906	0.70203	0.14729	0.46879	0.531
	Transport lorry (seed cotton)	tkm	0.033	0.243	0.243	0.033	0.243	0.243	0.243	0.243	0.217
GINNING	Electricity	kWh/ kg lint cotton	0.64	0.54	0.54	0.64	0.64	0.54	0.64	0.54	0.56
	General mix	share	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Diesel power generator	share	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Gas	share	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Hydropower	share	0%	0%	0%	0%	0%	0%	0%	0%	0%

V. References

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998) Crop evapotranspiration: guidelines for computing crop water requirements, FAO Drainage and Irrigation Paper 56, Food and Agriculture Organization, Rome.

Bundesministerium für Umwelt (BMU) 2012: http://www.umweltbundesamt.de/landwirtschaft/nahrungsmittelproduktion/ klimaschutz.htm; Access: August 2012

Chapagain, A.K.; Hoeckstra, A.Y.; Savenija, H.H.G.; Gautam, R. (2006): “The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries”, ecological Economies, 60 (1): 186-203

Ecoinvent (2010); Swiss data base for LCA data, Access August 2012

Food and Agricultural Organisation of the United Nations (FAO), (2005): http://www.fao.org/docrep/008/a0013e/a0013e08.htm, Access August 2012

Food and Agricultural Organisation of the United Nations (FAO), (2006): “Fertiliser use by crop”; Rome

Food and Agricultural Organisation of the United Nations (FAO), FAOSTAT; Statistics database; http://faostat.fao.org/default.aspx?lang=en; Access August 2012

Food and Agricultural Organisation of the United Nations (FAO); AQUASTAT; Access August 2012

Growing blue (2012): Growing blue Tool; http://growingblue.com/the-growing-blue-tool/; Accessed: August 2012

Hoeckstra, A.Y.; Chapagain, A.K.; Aldaya, M.M.; Mekonnen, M.M. (2011): The water footprint assessment manual: Setting the global standard. London: Earthscan; Water Footprint Network (WFN)

International Fertiliser Agency (IFA) et al. (2002): Statistical database “Fertilizer use by crop”; Access: July 2012

International Panel on Climate Change (IPCC) (2006): Good Practise Guidance (GPG); Chapter 4; Land use, land use change and Forestry (LULUCF)

Jenkins, A. and van Zwieten, L. (2003) How to compost on a farm. Agnote DPI-448. New South Wales Department of Primary Industries. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/166476/compost-on-farm.pdf. Accessed: August 2012

Mekonnen, M.M.; Hoeckstra, A.Y. (2010): “The green, blue and grey water footprint of crops and derived crop products“ Volume 1, Main Report; Value of Water Research Report Series No. 47

Pfister, S.; Koehler, A.; Hellweg, S. (2009): “Assessing the environmental impacts of freshwater consumption in LCA. Environmental Science and Technology, 43 (11): pp. 4098-4104

Ridoutt; B.G.; Pfister, S.(2010); "A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity"; Global Environmental Change 20 (2010), pp. 113-120

Umweltbundesamt (UBA): "PROBAS – prozessorientiere Basisdaten für Umweltmanagementsysteme", Access August 2012

United States Department of Agriculture (USDA) – Foreign agricultural service (2010): "World Agricultural Production"A