Sustainable Cotton Production Systems and their Nuances

Guiding information for retailers, brands and other buyers

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Sustainable Cotton Production Systems and their Nuances – the case of environmental sustainability

Guiding information for retailers, brands and other buyers

Study on behalf of the "Initiative for Sustainable Agricultural Supply Chains" (INA) as part of the GIZ programme "Sustainable Agricultural Supply Chains and Standards", financed by the German Federal Ministry for Economic Development and Cooperation (BMZ)

Partnership for Sustainable Textiles

HELVETAS

INA Initiative for Sustainable Agricultural Supply Chains

Jens Soth, HELVETAS Swiss Intercooperation
June 2022

Abbreviations

CmiA	Cotton made in Africa
FAO	Food and Agriculture Organization
GHG	greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
GMOs	genetically modified organisms
ICAC	International Cotton Advisory Council
IFOAM	International Federation of Organic Agriculture Movements
LCA	Life Cycle Assessment
OECD	Organisation for Economic Co-operation and Development
PEF	Product environmental footprint, Product Environmental Footprint

Contents

Executive summary

The Project *Initiative for Sustainable Agricultural Supply Chains (INA)* implemented by the *Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH* has taken up demands expressed in different expert committees of the *German Partnership for Sustainable Textiles* to elaborate a comprehensible comparison of the environmental impacts of different cotton production systems.

INA Initiative for Sustainable Agricultural Supply Chains

The desktop study was conducted between October and December 2021. It evaluates published studies dealing with environmental impacts of cotton production. The main target groups for the study at hand are decision makers and buyers in the textile sector. The innovative approach of the study is to integrate the actual impact data of different cotton cultivation methods rather than comparing the theory of sustainability standards and cotton production systems.

The **first part** structures the existing theory of the standards systems and introduces the tool of life cycle assessment (LCA).

First, an **overview of existing standards systems,** their labels, organisation and production volumes in 2018/19 is given.

Then, the standards systems with smallholder relevance are matched with the **existing agricultural practices** to ensure sustainability and mitigate Organisation for Economic Co-operation and Development (OECD) sector risks. The agricultural practices that are proposed by scientists and experts are also integrated into the various cotton farming and standard systems as key elements. These are:

- crop rotations,
- measures addressing soil health and fertility with nutrient cycling as an integral element,
- a suitable choice of the cotton variety to fit into local agro-ecological conditions,
- reasonable fertilizer management and crop protection,
- support of habitats to increase, or at least maintain, biodiversity.

The standards and cotton production systems are surprisingly in line with the emphasis and relevance of the mentioned practices. The main discrepancies between the standards systems pertain to their handling of genetically modified organisms (GMOs).

Finally, **life cycle assessments** as an **analytical tool** and their restrictions for applications in the agricultural context is introduced. Publications in this area have been proliferating in the last decade. As the tool stems originally from the chemical engineering sector, LCAs have certain limitations when applied to agricultural production systems. These are:

- Mixing of different data sources to complete data gaps,
- LCAs have no means (yet) to show the high dissipation of micro-fibres from synthetic textiles into the environment,
- Difficulties in defining comprehensible boundaries for the production system under assessment, especially when applying it to an open system such as agriculture,
- Cotton cultivation in particular has very broad variations of input and output figures,
- Seasonal and farm-to-farm differences are difficult to grasp,
- A lack of methodical approaches for environmental benefits of certain farming systems.

The **second part** entails the actual desk top study and LCA comparison. From a literature basis of more than 80 LCA related publications that deal with cotton and textiles, 40 were evaluated with regard to their utilization of original farming. Another 11 studies remained after filtering against the standards systems they are covering that were assessed in detail.

The **comparative analysis** of these studies came to the following **results:**

- Methodically properly conducted LCAs show that the sustainable cotton initiatives (*organic, Better Cotton* and *Cotton made in Africa (CmiA)*) keep their promise to lower the environmental impact of cotton production when benchmarked against conventional peers.
- The only existing comparative LCA that evaluates *organic*, *Better Cotton* and conventional cotton production can additionally prove that organic has the lowest environmental impact, at least for the regional context the study was referring to.
- The driving factor that catalyses the better environmental performance of sustainable cotton standards systems, when benchmarked against conventional cotton production, is the thoughtful and well managed utilization of agro-chemicals.
- For the impact category on greenhouse gas emissions, all studies that allow for a comparison show a lower emission of greenhouse gases for the sustainable cotton systems with organic having the lowest figure.
- Water consumption as an impact category is handled in very different ways. Thus, the discussion should focus more on the question of whether the farmers have a reasonable water stewardship in place that adheres to the locally available volumes and qualities.
- The LCA data regarding the impact category on toxicity are very incomplete and do not allow for a conclusive assessment. The driving factor that catalyses the better environmental performance of *CmiA* and *Better Cotton*, when benchmarked against conventional cotton production, is the thoughtful and well managed utilization of agro-chemicals, thereby reducing the environmental load created by excess inputs. Given the fact that organic practices avoid the application of agro-chemicals at all, one can conclude that a full inclusion of the impact category on toxicity would lead to an even better profile for the organic standard.

The results of the assessment allow the following **recommendations** for actors both in the textile and cotton sectors:

- **Engagement for the sustainable cotton sector:** Regardless of the differences between the standards systems that the study revealed, the engagement for sustainable cotton as a natural fibre overall is important. The leverage of the textile sector can be strong if a unified engaged demand pull can be realized. There is even a high relevance to take action in this direction as the EU is underway to set the Product environmental footprint (PEF) regulation into action despite manifold complaints that the underlying LCA based tools are applied incorrectly or are incomplete and thus give the false conclusion that synthetic fibres are preferable.
- **Embrace and support data collections and compilations** A pro-active partnership within the cotton and textile sector about the exchange and utilisation of supply-chain and especially field and farmer data could ease a lot of concerns that private sector actors have expressed in light of the upcoming supply-chain regulations. If the textile sector demands and also helps in implementing such a data and monitoring framework, all actors including the farmers could benefit.

Objectives and Methodological Approach of the Study

The *Initiative for Sustainable Agricultural Supply Chains* (*INA*) of the *Deutsche Gesellschaft für Internationale Zusammenarbeit* (*GIZ*) *GmbH* has taken up demands expressed in different expert committees of the *German Partnership for Sustainable Textiles* to elaborate a comprehensible and condensed comparison of the environmental impacts of different cotton production systems with a focus on smallholder cultivation conditions.

HELVETAS Swiss Intercooperation conducted the comparison study at hand on the basis of available and officially published literature between October and December 2021 under the lead of Jens Soth.

The list of studies to include in this comparison was cross-checked with the expert group members Natural Fibers of the *German Partnership for Sustainable Textiles* to strive for an extensive list that contains the majority of publications relevant for the topic at hand. The finally resulting list is the list of references of this study (see References).

2.1 Objectives and Target Group

The objectives of the study are to

- compile and analyse different cotton production systems based on existing reports, studies and other data AND
- classify them according to their ecological sustainability based on the OECD sector risks on environmental sustainability as well as on climate risks.

The overarching question for this analysis is:
Does the theory of sustainability standards systems translate into field level practice, and is there any proof that environmental improvements can be made by following the sustainable cotton production guidelines provided by the different standard systems?

The study is striving to find a reasonable and well-argued answer to this question.

The main target group for the study is not the cotton community and agricultural experts, but the decision makers and buyers in the textile sector. Therefore, the document tries to avoid scientific or agricultural jargon and expressions comprehensible to only a very confined circle of scientists. Nevertheless, the study is based on the assessment of scientific reports, studies and articles.

2.2 Methodological Approach

The innovative approach of the study is to integrate the actual data of different cotton cultivation methods and standards systems into the assessment. Many publications and tools exist that compare sustainability standards and production systems based "just" on the "theory" of the standards systems or guidance protocols. This study looks at the farming reality and what the actual environmental performance of the assessed standards and production systems might be.

To respond to the question outlined above and to adhere to the set objectives, the report conducts 4 working steps:

1

At **first** the multitude of existing standards and labels for the cotton sector are introduced. In an overviewing matrix key information about their logos, foundation, the production volumes in cotton season 2018/2019 (as this was the latest one where all data could be obtained) and its corresponding share in the global cotton production is depicted.

Aiming to keep the study at hand comprehensible, the matrix determines the smallholder relevance of the particular standards system and visualizes the availability of LCA related data. A global map, as quoted from the sustainable cotton challenge 2025, wraps up the chapter with the geographical relevance of sustainable cotton standards systems.

2

The **second** working step matches the standards systems with smallholder relevance with the existing agricultural practices to ensure sustainability and mitigate the OECD sector risks. Three renowned scientific sources are extracted to base the validity of these agricultural sustainability practices for cotton on. A comparative table allows to assess which of these practices are either mandatory, obligatory or even forbidden in the particular standards systems.

3

In a **third** step the identified studies, publications and scientific articles that contain information and data about the actual realization of the standard implementation are listed. The corresponding table applies two criteria to filter out the information that will form the assessment basis for the final question regarding the environmental performance of the standards in assessment:

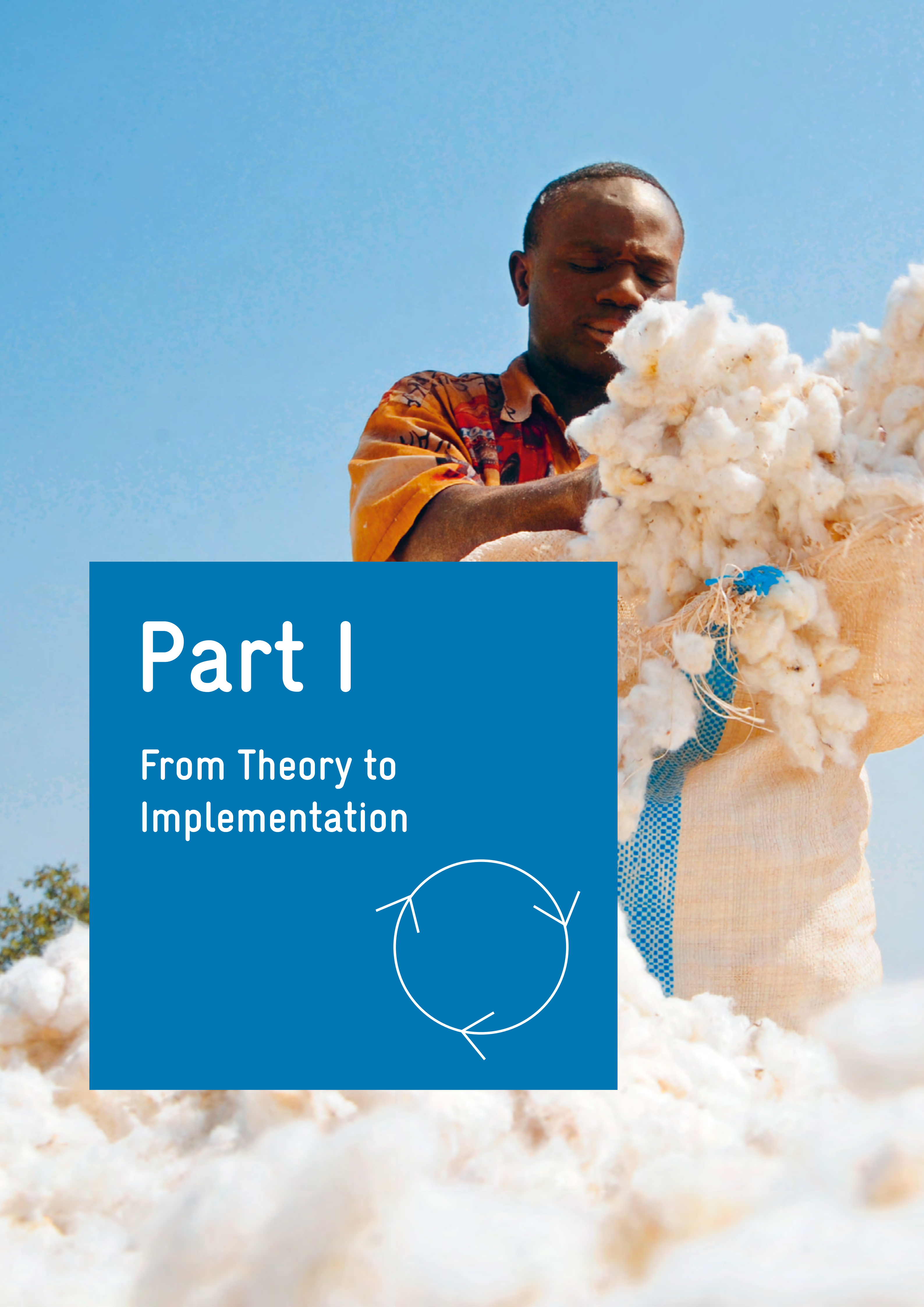
- » The use of original data from the field level
- » The actual comparison of at least one standards system with a conventional benchmark or even the comparison between several standards systems.

4

The **fourth** step is to compare the results and data from the studies passing the above-mentioned filter. Before this can be done in a comprehensible way, the key tool of these studies – the life cycle assessment – is introduced, and congruencies with the OECD sector risks are assessed (chapter 5). Since LCAs, despite being a highly scientific and elaborate tool, have severe restrictions particularly for a more holistic view on challenges and potentials of agricultural landscapes; these potential “pitfalls” of the tools are explained in 5.2.

The comparative tables that compile the results of the studies that passed the filtering process are the core element to answer the underlying question posed in the report. Major conclusions that can be drawn from the comparative table are consequently given.

Finally, these conclusions are further processed into recommendations for the textile sector as well as for the cotton sector.



Part I

From Theory to Implementation

Overview of existing cotton standards systems for sustainability

The discussion about the sustainability of agricultural commodities in general, and cotton in particular, dates back more than two decades. Organic cotton was introduced around the 1990s in India, Turkey and Egypt (Chaudhry 1993) by several organizations independently. The underlying standards were the existing organic farming standards and regulations, such as the EU Council Directive or the US National Organic Program. In the 2000s, three private voluntary sustainability standards for cotton production followed: Fairtrade Cotton (on market since 2005), Cotton made in Africa (2007), and Better Cotton (2010). Other standards followed, mainly on the grounds of national (e.g. US, Australia, Brazil) or local (e.g. California) organizations of the cotton sector, as private sector initiatives (e3 by Bayer, now owned by BASF), or by profit-oriented service providers (Cotton Connect).

Several initiatives work with cotton standards to reach sustainability goals. Among them are: the *German Partnership for Sustainable Textiles,* which recognizes cotton standards based on a set of criteria for credibility as well as environmental and social sustainability (so-called "systemic and content-related minimum requirements"); and also the *Sustainable Cotton Challenge 2025* by the International Sustainability Unit. Both initiatives have set goals for their members/signatories to source a threshold of more sustainable cotton by a fixed date. The key criteria for standards and initiatives to be accepted to this platform are (Textile Exchange 2021):

- a clearly defined standard or at least guideline
- a set of better (in comparison to conventional production) or best practices
- farmers are enrolled in the program
- monitoring of progress by second- or third-party verification processes.

This platform has set the aim to reach 50% of the global cotton production to be sustainable by 2025.
The goals of the *German Partnership for Sustainable Textiles* are shown in Figure 1

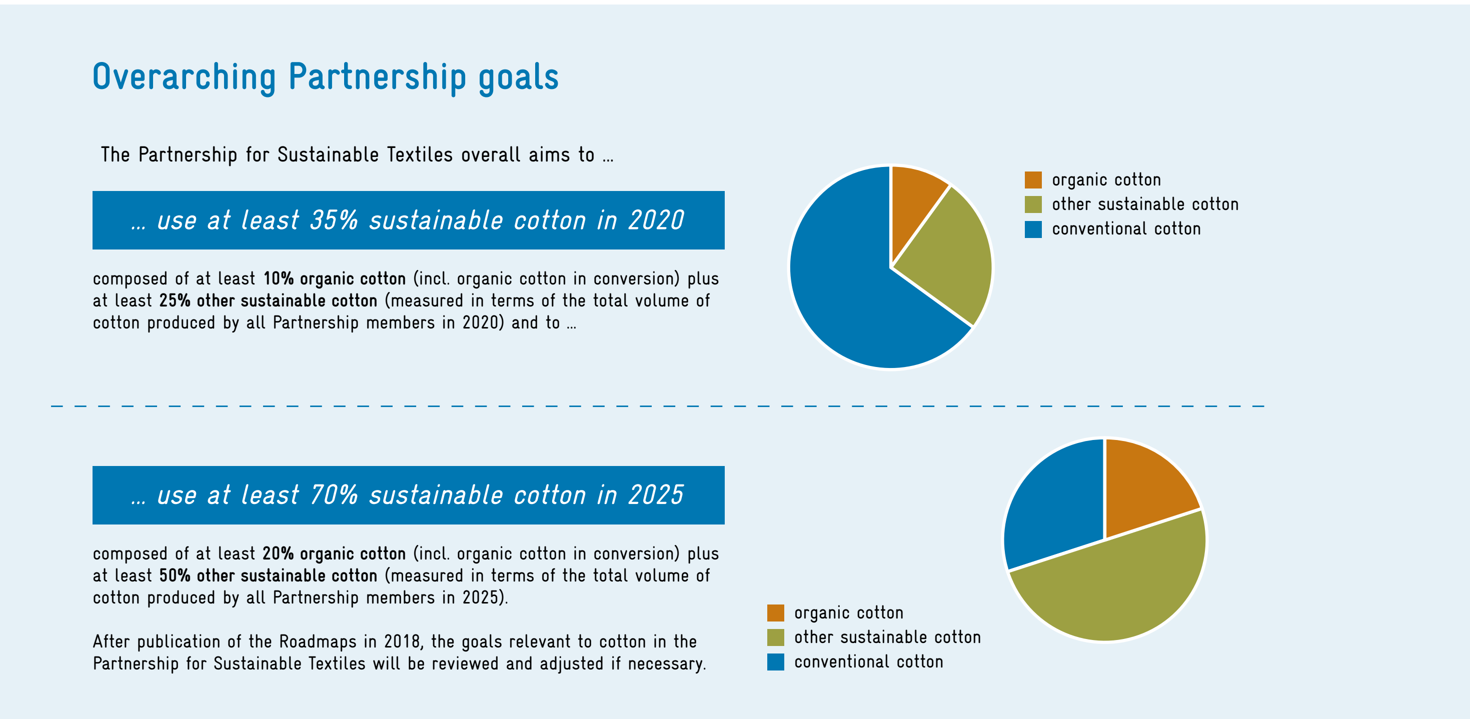


Figure 1: Targets of the German Partnership for Sustainable Textiles for procuring sustainable cotton by 2025.

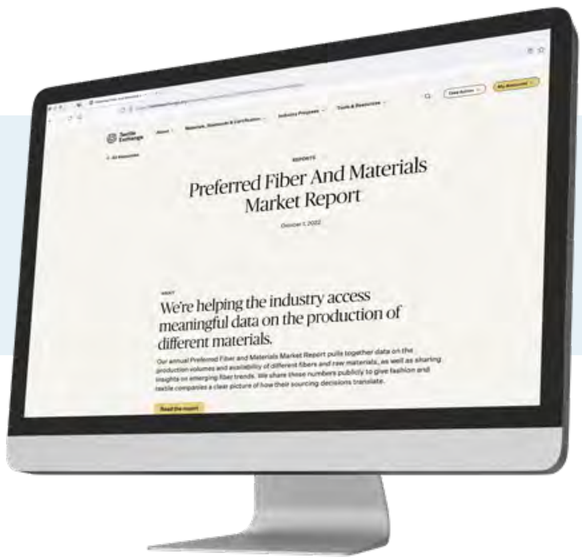
The criteria, or list of recognized standards, of those initiatives can serve as a baseline definition of what can be considered "sustainable" in the context of cotton production.

Lately, the global attention for climate change as well as the shrinking fertility of the world's soils catalysed the development of a type of agriculture that should address these topics particularly. The corresponding term is **regenerative agriculture,** with the underlying idea that organic farming should be amended by criteria that adhere to the topics of social fairness, animal welfare and soil health. The latter would entail measures that help to increase the soil organic matter thereby also addressing adaptation and mitigation to climate change.

Corresponding standards are Regenerative Organic Certified (established 2017), which builds upon the National Organic Programme – the organic certification of the US Department of Agriculture – and Reel Regenerative (2021).

The following Table 1 compiles key data to these standards and initiatives. The latest summarizing publication of the sustainable cotton challenge 2025 was compiled by Textile Exchange in 2021 and referenced the global cotton production of season 2018/2019. Though individual standards have published more recent volume figures, the data from the sustainable cotton challenge are quoted here as they are the most recent ones for which the authors undertook the challenge to sort out the volumes produced according to more than one standard. Thus, double counting is avoided. The table also indicates the relevance of the various standards for smallholders. Standards that are applied and implemented either in Africa, Asia or Latin America have been evaluated as highly relevant for smallholder cotton production. Furthermore, the table also indicates whether any of these standard systems has existing LCA studies or data available.

The cotton farming systems and standards compared in Table 1 are also being regularly mapped by Textile Exchange in the "Preferred Fiber and Materials Market Report" to give an idea of how sustainable cotton is distributed globally[1].



For a cotton standard comparison of a broad range of environmental criteria, but also social and economic criteria, there are several good online reference tools that allow to select the standards one wants to compare, for instance in a one-on-one matching[2].

It must be emphasised that these tools compare the standards themselves, but not their actual data stemming from implemented projects. This will be done in the next chapters, when looking at LCAs as a measure of actual impact.

1 Textile Exchange (2022): Preferred Fiber & Materials Market Report. Accessible at https://textileexchange.org/knowledge-center/reports/preferred-fiber-and-materials/(January 4, 2023)
2 Standardsmap initiated by BMZ, Germany and SECO, Switzerland: https://www.standardsmap.org
Siegelklarheit.de, a platform initiated by the German government and implemented by: https://www.siegelklarheit.de
Cottonup Guide initiated by Laudes Foundation: http://cottonupguide.org/wp-content/uploads/2021/07/sourcing-options_17_18-sustainability-considerations.pdf

Table 1: Overview of sustainable cotton initiatives and standards systems enrolled for the Sustainable Cotton Challenge 2025

Logo	Organization behind	Year in which cotton was on market	Verification	Production volume in season 2018/2019 [MT]	Percentage of sustainable cotton of world production [%]	Smallholder relevance	LCA data available [see also chapter 6]
COTTON MADE IN AFRICA	Aid by Trade Foundation, Hamburg, Germany	2005	3rd party	593'067 (97% Better Cotton benchmarked; 0.88% also organic)	2.29	High	Very recent externally conducted LCA
better cotton	Better Cotton, Geneva, Switzerland	2010	self-assessments, 2nd party checks, and 3rd party verification	5'628'000 (including equivalents ABR, myBMP, CmiA)	21.70	High	Available, Involved in comparisons
FAIRTRADE COTTON	Fairtrade International, Bonn, Germany	2005	3rd party	16'906; 10'265 thereof also organic	0.07	High	No
Organic (example logos)	No single responsible organization, though Textile Exchange acts as professional representation	From 1990 in Egypt and 1992 in Turkey, US and India	3rd party regulated by national laws e.g in US, EU or Japan	239'797	0.92	High	Most frequently used standard for LCA-based comparisons
COTTONCONNECT REEL COTTON	CottonConnect Ltd, London, UK	2010	3rd party (FloCert)	63'326	0.24	High	No
U.S. COTTON TRUST PROTOCOL	Cotton Council International and National Cotton Council of US, Washington, US	2020	2nd party and in cases of doubt also 3rd party verification	Not yet on market	0	No	No
myBMP	Voluntary farm and environmental management system of Australian cotton sector Benchmarked to Better Cotton	2010	self-assessment mechanisms plus auditing processes on request	102'721 (benchmarked to Better Cotton)	0.40	No	Some indicators are constantly monitored LCAs existing for Australian cotton
TOTAL (Better Cotton benchmarked/equivalents ABR, myBMP and CmiA and double certification of Fair trade/organic and CmiA/organic deducted)				6'401'000	25 %		

Agricultural practices mitigating risks of environmental impacts of cotton production

The discussion about the sustainability of cotton production has not only created manifold standards systems, but also stimulated a broad range of practices that attempt to reduce harmful impacts on the environment.

These practices are only to a small degree very particular to cotton production. The majority of the suggested practices are deriving from approaches to make agriculture in general more sustainable.

To visualize the congruency, but also the differences about the relevance of certain agricultural practices, three relevant publications were extracted with regard to their suggestions of field level practices for sustainability:

One of the first publications that claimed to summarize sustainable agricultural practices with a particular focus on cotton dates back to 2003 and thus was published before many standards systems were created after 2004. For the global cotton research conference 2003 in Cape Town the researchers Galanopoulou-Sendouca and Oosterhuis (2003) sorted out the global cotton production status and identified which measures they perceived as contributing to sustainable cotton production. They applied a lens of sustainability that entailed economic aspects and thus productivity, too.

With the onset of cotton standards system development after 2004, the global key organisation for the cotton sector, the International Cotton Advisory Council (ICAC) published a summary of practices (Chaudhry 2006) that adhere to the sustainability aiming to guide the member countries of the ICAC how they might react to the widening discussion and demand for sustainable cotton.

Aiming to match the above-mentioned cotton sector-based publications with a broader agricultural view, the sustainability practices suggested by a High-Level Panel of experts chaired by the Food and Agriculture Organization (FAO) are quoted.

Table 10 in the first annex allows a comparison of practices that have been suggested by these very heterogenous groups of actors. In a second step Table 10 shows how standards systems implement these practices. Aiming to keep that visualization comprehensible, only those standards systems that showed high relevance for smallholder production, as elaborated in Table 1, were analysed.

It must be noted that the practices are assessed against the "theory" of the standards system, not by actual surveys of the implementation practice. Since there is a range of regulations that could be applied for organic farming, the references utilised are the basic principles from the International Federation of Organic Agriculture Movements (IFOAM 2005) and the new EU Council Directive for organic farming 2018/848 that will enter into force only from 01.01.2022 onwards. This revision version of the older Directives 834/2007 and 889/2008 explicitly mention the contributions of organic farmers to mitigate and adapt to climate change.

4.1 Conclusions from the analysis of standards systems and their utilization of agricultural practices

The heated and controversial discussion around GMOs (not only in cotton) overshadows the fact that even very different actors and stakeholder groups have a very common understanding and endorsement of certain practices that should ensure a higher sustainability of cotton production.

The agricultural practices that are proposed by scientists and experts and also integrated into the various cotton farming and standard systems are:

- crop rotations,
- measures addressing soil health and fertility with nutrient cycling as an integral element,
- a suitable choice of the cotton variety to fit into local agro-ecological conditions,
- a reasonable fertilizer management and crop protection scheme,
- support of habitats to increase, or at least maintain, biodiversity.

The main discrepancies between the standards systems pertain to their handling of GMOs. The spectrum ranges from a ban (Organic, CmiA, Fairtrade) to a rather neutral approach. If the assessment would have included the entire range of standards systems, thus also the ones developed for the large farming systems in USA, Australia or Brazil (see Table 1), the number of standards permitting GMOs would have increased.

Differences are also visible for the aspect of water management. Nevertheless, there is a certain tendency in the standards systems that a holistic water stewardship approach is an appropriate way to handle the complex impact of cotton production on the water systems. Better Cotton, Fairtrade as well as CmiA adopt this perspective to the water challenges and refer to the guidance of the Alliance for Water Stewardship.

Agricultural practices mitigating risks of environmental impacts of cotton production

Life cycle assessment – methodological introduction

5.1 Life cycle assessments as tool for comparing environmental impacts

The assessments in the previous chapters have revealed that the various standards systems have a higher congruency than one could assume from the rather intensive and polarizing discussions. Ultimately, these congruencies may be the basis of why the different stakeholders agree to be unified under the roof of the sustainable cotton challenge 2025.

Nevertheless, the previous assessment steps looked "only" into the theory of the standards and initiatives. The next step is to face the farming reality resulting from the implementation of different guidelines and standards within cotton farming systems.

Obviously, farmers even in the same cotton production area have not only very different agro-ecological conditions, such as soil type or water availability, but also very different mind-sets, education backgrounds and ambitions. So even if farmers receive the same training and support, their achievements will still differ.

When looking for a science-based research method to conduct farm surveys and data collections in order to find out which cotton production system is the most favourable regarding environmental impacts, many actors and stakeholders would agree that a life cycle assessment would be the most appropriate tool.

A life cycle assessment is the systematic collection of actual input and output data from the production reality of a product along its entire life cycle. Since German scientists and organisations like the German *Umweltbundesamt* were pioneers in developing and utilizing the LCA method, the German term "Ökobilanz" is very common in the German speaking communities and more comprehensible than the direct translation of LCA as "Lebenszyklusanalyse".

As a scientific tool to compare different ways of producing any product, LCAs have become more and more popular in recent years. According to van der Werf (2020) the number of globally published scientific articles that utilised LCA as an essential element of research in the Food and Agribusiness sector increased from 1 publication per year in 1990 to more than 1000 publications annually in 2018.

The popularity of the tool even lead to a standard for conducting LCAs, developed and guarded by the International Standard Organisation as the ISO norms ISO 14040 and ISO 14044 (ISO 2006). Figure 2 quotes this norm to show both the working steps to perform a LCA as well as the range of applications. Product development and innovation as well as strategic planning are two essential areas LCA should be useful for. Thus, theoretically identifying the best cotton production system should be a manageable task if LCAs are applied to address this question.

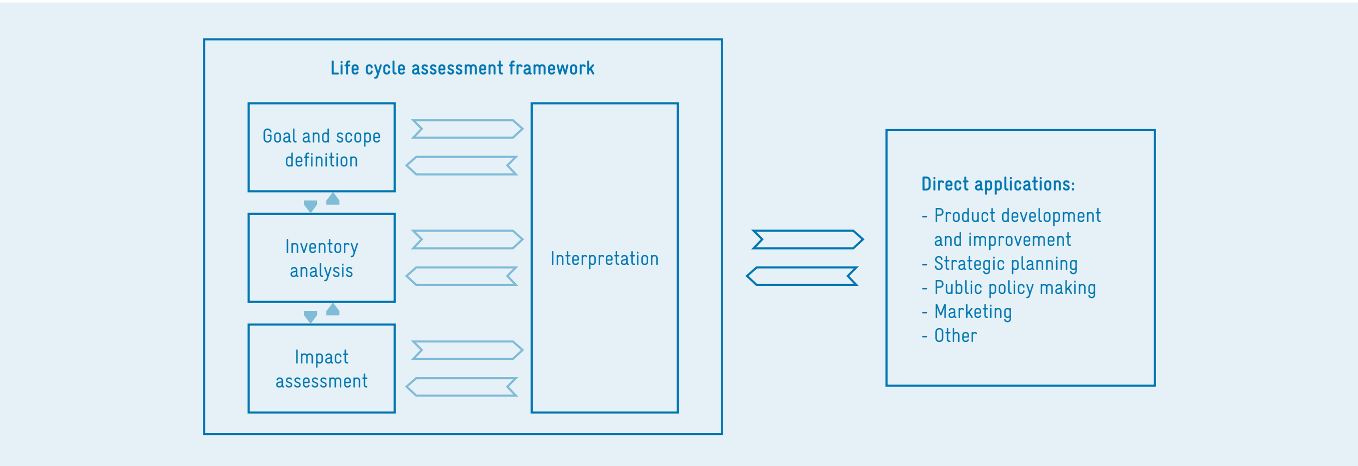


Figure 2: Stages and applications of a LCA according to the ISO 14040 (ISO 2006)

Unfortunately, the ISO 14040 does not give any guidance regarding which environmental criteria (impact categories in LCA terminology), areas or indicators a LCA step should analyse. Also, none of the manifold LCAs in the cotton or textile sector make active reference to relevant environmental risks, as for example compiled in the OECD Due Diligence guidance (OECD 2017).

As an example of which environmental risks are usually addressed in an LCA, Figure 3 matches the utilised impact categories of one of the most extensive LCA in the cotton sector mandated by Cotton Inc (2016) in 8 countries with the OECD sector risks for the garment and footwear sector (OECD 2017).

Abbreviation	Technical Term	Example	OECD sector risks
AP	Acidification Potential	Acid rain	
EP	Eutrophication Potential	Water pollution	Water pollution
GWP	Global Warming Potential	Greenhouse gas emitted	GHG Emissions
ODP	Ozone Depletion Potential	Ozone hole over polar ice caps	
POCP	Photochemical Ozone Creation Potential	Smog	
PED	Primary Energy Demand	Electricity & fuel needed	
WU	Water Used (Gross Volume)	Water used in washing machine	Water consumption
WC	Water Consumed (Net Volume)	Water evaporated in dryer	Water consumption
ETP	Ecotoxicity Potential	Animal health	Hazardous chemicals
HTP	Human Toxicity Potential	Human health	Hazardous chemicals

Figure 3: Environmental impact categories used in the cotton LCA of Cotton Inc in 2016 and the corresponding OECD sector risk (Cotton Inc 2016, OECD 2017)

The full overview of identified and published textile or cotton LCAs is given in Table 11 in the second annex. This listing also mentions whether the particular LCA study had a broad approach of impact categories and thus contained all 4 environmental OECD risks or whether the particular study focused on any specific impact category solely.

The main conclusion of Table 11 is that there is only a small range of LCA publications that focuses on smallholder related standards systems. Nevertheless, these data allow one to extract figures related to OECD sector risks for the garment and footwear sector based on the actual input and output data.

A more detailed analysis of these studies will be conducted in chapter 7.

5.2 Limitations and pitfalls of LCAs

The historical roots of the LCA method trace back to products with industrial origin rather than agricultural production. One of the pioneering studies in the early 70s by Coca-Cola compared the environmental impacts of glass and PET bottles.

The LCA method was further developed by the Society of Environmental Toxicology and Chemistry (SETAC) – an international association of chemical engineers and environmental experts. This is significant because it reveals that the method has been coined by engineering and industrial approaches – in this context the work is confined to closed reactors or systems with very little influence by outside conditions.

Pitfall 1: Mixing of data from various sources
The complexity and multitude of data required for a proper LCA is frequently underestimated. Thus, some studies mix data from different origins. In light of the described variation of cotton production, this may entail a propensity for inaccuracy or even misleading results.

The assessment matrix in the next chapter therefore makes a clear distinction between studies that operate on the basis of original data collected for the very publication or whether data have been pulled together from various sources.

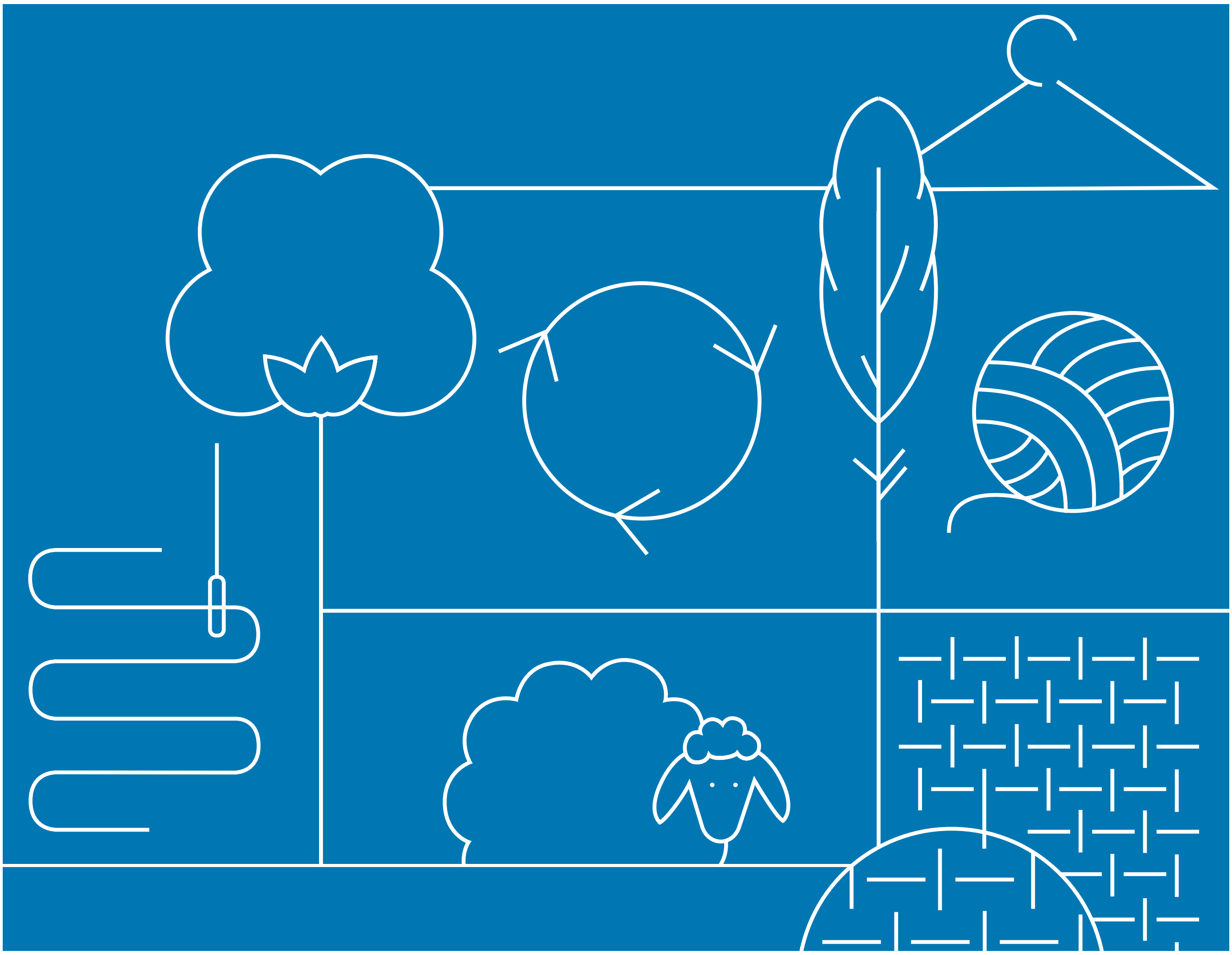
Pitfall 2: Relevant impacts not accounted for
The complexity of a LCA requires setting reasonable and comprehensible boundaries for the production system under assessment. Practically, that means certain aspects must be kept outside the assessment scope.

A very prominent and intensively debated example of an overlooked environmental impact is that of microfibers emitted during the life cycle of PET clothes, which can become a serious environmental burden (Law and Thompson 2014). Despite this imbalance, many LCA-based comparisons of clothes from natural fibers and PET do not even mention this aspect. This becomes even more problematic when the method is used in legislative processes such as the Product Environmental Footprint (PEF) of the EU (Pesnel and Payet 2019, Watson and Wiedemann 2018, EEB 2018).

Pitfall 3: Agricultural production is an open system influenced by manifold external factors
Contrary to industrial processes, agricultural production has to face the influence of environmental conditions of all kinds. Variations of weather conditions from season to season, changing soil structures and compositions from one farm to another, different neighbouring crops and varying pest patterns are illustrative examples of why the application of the LCA method needs a very attentive and experienced perspective when it comes to its utilisation in the agricultural context.

Pitfall 4: Variations in cotton production are particularly high
Moreover, the variations in the global cotton production are very extreme. Cotton is produced in more than 80 countries (ICAC 2021), with production methods ranging from smallholders with handheld implements to high-tech mechanized production systems. Thus, it is easy to comprehend that input and output figures can differ tremendously. To give an example: the lint yield ranged in season 2018/2019 from 117 kg/ha in Chad to 1794 kg/ha in China (ICAC 2019).

Pitfall 5: Beneficial aspects of certain production schemes not accounted for
The entire LCA method is based on the idea of identifying and quantifying negative impacts of a production process on the environment. Possibly beneficial aspects in agriculture are generally not taken into account. Cotton standards systems in particular also entail ideas of continuous improvement (e.g. Better Cotton), action plans for water stewardship (e.g. CmiA, Better Cotton, Fairtrade) or ecosystem services of soils (Dominati, Patterson and Mackay 2010). Van der Werf et al (2019) show clearly that particularly organic farming systems and their benefits are negatively misrepresented in LCAs due to their narrow focus on functions of agriculture and their product-based approach.



Part II

Desk Study

Compilation of LCA studies with relevance to the cotton standards systems

By keeping the aforementioned limitations of the LCA method in mind, the following assessment compiles LCAs that contain cotton and/or cotton of different farming systems.

The matrix in Table 11 (see annex) filters out the "solid" LCAs that worked
a) on the basis of original data,
b) have clear and transparent declarations of their data sources and
c) assess at least two cotton standards systems.

These studies are highlighted in green. They are benchmarked against two LCA studies that fully comply with relevant ISO norms, including critical peer review, and thus can be considered the "gold standard" for cotton-related LCAs: the *Life Cycle Assessment (LCA) of Organic Cotton – A global average by Textile Exchange* (Textile Exchange 2014) and the *LCA update of cotton fiber and fabric – life cycle inventory* by Cotton Incorporated (Cotton Inc. 2016). An assessment of the table shows that in the last 23 years around 40 studies were published that contained LCA related data for cotton production. Of those 40, only 24 contained original data. The other studies were either based on data pulled together from different origins or utilized data from other publications.

11 studies involved data from at least one standards system and benchmarked it against conventional cotton, but only three publications compared three different standard systems. If one would apply the working step of a classical external review, one requirement listed in the ISO norm for LCAs, the number of studies acceptable to be integrated into the next assessment steps, would have shrunk even further.

Comparative assessment of cotton related LCAs

The studies filtered out as "solid" LCAs are qualifying to be compared and visualised. Tables 5 to 11 show the corresponding results.

When quantitative comparable data could be extracted, they are mentioned specifically for the impact categories greenhouse gas (GHG) emissions and water consumption, because in most cases results require additional comments. In other impact categories the potential comparison data are given within the cell.

When the study itself operated with a global benchmark, it is indicated. In most cases this already gives a good indication for the situation of the particular sustainable cotton standard system. Therefore, no benchmarks were added on top. Note that not all studies utilised cotton lint as their functional unit. Some studies were using seed cotton, some textiles. This reduces the comparability even further.
The tables are following this structure:

- Studies between 2013 and 2014 are forming Part I of the tables
- Studies since 2015 are forming Part II of the tables

General results:	**Table 2 and Table 3**
Results for GHG:	**Table 4 and Table 5**
Results for Water Consumption and Toxicity:	**Table 6 and Table 7**
Results for Eutrophication and Acidification and further impact categories:	**Table 8 and Table 9**

7.1 Comparative assessment of cotton related LCAs – Descriptors of studies and overall results

Colour code for the cells:

Sustainable cotton better | No comparison possible | Sustainable cotton and conventional equal | Sustainable cotton worse | Not available

Table 2: Part 1 Comparative assessment of cotton related LCAs – Descriptors of studies and overall results

Publication year	2013	2013	2013	2014	2014
Author	Cardoso	Systain (commissioned by Aid by Trade Foundation)	WWF India and WWF UK	PE International (commissioned by Aid by Trade Foundation)	Textile Exchange
Products resp. functional unit	1 kg wool resp. Cotton yarn, but for cotton also 1 kg lint	cotton, 1 kg lint	kg CO_2e/ha; kg CO_2e/kg seed cotton	cotton, 1 MT lint	cotton, 1 MT lint
Country of cotton production	Tajikistan	Benin, Burkina Faso, Côte d'Ivoire, Malawi, Mozambique, Zambia, Cameroon	India (Warangal district)	Côte d'Ivoire, Zambia	India, Turkey, China, USA, Tanzania
Standards	Organic, conventional	CmiA, conventional	Better Cotton (a BmP predecessor), conventional	CmiA, conventional (Cotton Inc 2012 as benchmark)	Organic, conventional (Cotton Inc 2012 as benchmark)
Relevant results	Organic has lower impact throughout all impact categories, except human toxicity, where a high amount of heavy metals was calculated due to the use of chicken manure	Study focused on the impact categories water and GHG; carbon footprint of CmiA cotton significantly lower than conventional; total water footprint slightly higher, but due to exclusion of irrigation no impact on surface or ground water	Fertilizer management highly relevant for GHG reduction; thus Better Cotton Standard System very appropriate to lower carbon footprint of cotton	Erosion control scenario applied revealed high potential to further reduce eutrophication potential	Driving factors for eutrophication impact are erosion and nutrient leaching – thus organic system reported as advantageous

Table 3: Part 2 Comparative assessment of cotton related LCAs – Descriptors of studies and overall results

Publication year	2015	2016	2018	2021	2021
Author	Baydar, Ciliz and Mammadov	Cotton Incorporated	Shah, Bansal and Sing for Thinkstep	Aid by Trade Foundation (utilising Cotton Inc 2016 as benchmark)	Fidan, F., Aydogan, E. and Uzal, N.
Products resp. functional unit	T-Shirt, conventional and eco	cotton, MT fiber and 1,000 kg of finished garment	1 MT seed cotton at farm gate	1 t of fibre at gin gate	1 sqm denim fabric
Country of cotton production	Turkey	USA, China, India, Australia	India	Côte d'Ivoire, Cameroon, Zambia	Turkey
Standards	Organic, conventional	Conventional benchmarking basis	Organic, Better Cotton, conventional	CmiA, conventional (Cotton Inc 2016 as benchmark)	Organic, conventional
Relevant results	Organic T-shirt lower emissions in all impact categories	No comparison of different cotton standards; for entire life cycle of a textile, the highest GHG emissions occur in use phase followed by the industrial processes like dyeing and finishing	The only study that compares the systems organic, Better Cotton and conventional cotton in a defined region and thereby allowing direct comparisons; organic showing lowest impacts as compared to Better Cotton and conventional	Rather than benchmarking, the study focused on the identification of hotspots for improvements	The study compared organic and conventional textile for a broad range of impact categories; significantly lower impacts throughout all categories for the organic textile were proven

7.2 Comparative assessment of cotton related LCAs –GHG results

Colour code for the cells:

Sustainable cotton better | No comparison possible | Sustainable cotton and conventional equal | Sustainable cotton worse | Not available

Table 4: Part 1 Comparative assessment of cotton related LCAs –GHG results

Publication year	2013	2013	2013	2014	2014
Author	Cardoso	Systain (commissioned by Aid by Trade Foundation)	WWF India and WWF UK	PE International (commissioned by Aid by Trade Foundation)	Textile Exchange
Products resp. functional unit	1 kg wool resp. Cotton yarn, but for cotton also 1 kg lint	cotton, 1 kg lint	kg CO_2e/ha; kg CO_2e/kg seed cotton	cotton, 1 MT lint	cotton, 1 MT lint
Country of cotton production	Tajikistan	Benin, Burkina Faso, Côte d'Ivoire, Malawi, Mozam-bique, Zambia, Cameroon	India (Warangal district)	Côte d'Ivoire, Zambia	India, Turkey, China, USA, Tanzania
Standards	Organic, conventional	CmiA, conventional	Better Cotton (a BmP predecessor), conventional	CmiA, conventional (Cotton Inc 2012 as benchmark)	Organic, conventional (Cotton Inc 2012 as benchmark)
GHG	Lower impact due to avoidance of fertilizers and pesticides	CmiA GHG emissions significantly lower due to lower use of fertilizers and lower mechanization within CmiA farming systems	Emission resulting from fertilizers are main driver of GHG emissions	Lower carbon footprint due to lesser inputs and lesser mechanization	Lower carbon footprint (benchmarked against Cotton Inc 2012) of the organic system due to lesser inputs (no synthetic fertilizers or pesticides)
GHG (actual data)	organic: 0,597 kg Ce/kg lint conventional: 2.93 kg Ce/kg lint	CmiA: 1.92 Ce/kg lint conventional: 4.64 Ce/kg lint	better management: 0.45 Ce/kg seed cotton conventional: 1.5 kg Ce/kg seed cotton	CmiA: 1,037 kg Ce/kg cotton lint conventional: 1,808 Ce/kg	organic: 0.978 kg Ce/kg cotton lint conventional: 1,808 Ce/kg

Table 5: Part 2 Comparative assessment of cotton related LCAs –GHG results

Publication year	2015	2016	2018	2021	2021
Author	Baydar, Ciliz and Mammadov	Cotton Incorporated	Shah, Bansal and Sing for Thinkstep	Aid by Trade Foundation (utilising Cotton Inc 2016 as benchmark)	Fidan, F., Aydogan, E. and Uzal, N.
Products resp. functional unit	T-Shirt, conventional and eco	cotton, MT fiber and 1,000 kg of finished garment	1 MT seed cotton at farm gate	1 t of fibre at gin gate	1 sqm denim fabric
Country of cotton production	Turkey	USA, China, India, Australia	India	Côte d'Ivoire, Cameroon, Zambia	Turkey
Standards	Organic, conventional	Conventional benchmark-ing basis	Organic, Better Cotton, conventional	CmiA, conventional (Cotton Inc 2016 as benchmark)	Organic, conventional
GHG	Global warming potential highest relevance for conventional and organic T-Shirt in use phase as major factor followed by cotton production		Strong reduction of GHG emissions in organic due to lower inputs; lower emission of Better Cotton due to controlled inputs	Lower GHG emissions due to lesser and controlled inputs	Lower GHG emissions for organic fabric
GHG (actual data)	75% reduction of GHG for Eco T-Shirt		organic: 295 CO_2e kg per 1,000 kg seed cotton Better Cotton: 435 CO_2e kg per 1,000 kg seed cotton conventional: 731 CO_2e kg per 1,000 kg seed cotton	farm to gin gate: CmiA: 1.24 kg per 1,000 kg lint conventional: 1.43 kg per 1,000 kg lint	organic: 3.34 kg CO_2e per sqm fab-ric conventional: 4.2 kg CO_2e per sqm fab-ric

7.3 Comparative assessment of cotton related LCAs – Water consumption and toxicity results

Colour code for the cells:

Sustainable cotton better | No comparison possible | Sustainable cotton and conventional equal | Sustainable cotton worse | Not available

Table 6: Part 1 Comparative assessment of cotton related LCAs – Water consumption and toxicity results

Publication year	2013	2013	2013	2014	2014
Author	Cardoso	Systain (commissioned by Aid by Trade Foundation)	WWF India and WWF UK	PE International (commissioned by Aid by Trade Foundation)	Textile Exchange
Products resp. functional unit	1 kg wool resp. Cotton yarn, but for cotton also 1 kg lint	cotton, 1 kg lint	kg CO_2e/ha; kg CO_2e/kg seed cotton	cotton, 1 MT lint	cotton, 1 MT lint
Country of cotton production	Tajikistan	Benin, Burkina Faso, Côte d'Ivoire, Malawi, Mozambique, Zambia, Cameroon	India (Warangal district)	Côte d'Ivoire, Zambia	India, Turkey, China, USA, Tanzania
Standards	Organic, conventional	CmiA, conventional	Better Cotton (a BmP predecessor), conventional	CmiA, conventional (Cotton Inc 2012 as benchmark)	Organic, conventional (Cotton Inc 2012 as benchmark)
Water consumption	Blue water calculated (irrigation water)	Rainfed stated as advantageous as compared to the irrigated systems of the benchmarked study of Cotton Inc 2012			Rainfed stated as advantageous as compared to the irrigated systems of the benchmarked study of Cotton Inc 2012
Water consumption (actual data)	organic: 0.94 m^3/kg lint conventional: 1.29 m^3/kg lint	CmiA: 14 m^3 compared to 13.3 m^3 (green water)			
Toxicity (Ecotoxicity and/or Human toxicity)	organic: Higher amount of toxicity (cancer effect) due to heavy metal in chicken manure (not verified locally); lower amount of toxicity for non-cancer effects				Toxicity models explained and avoidance of pesticides emphasised, but no data given

Colour code for the cells:

Sustainable cotton better | No comparison possible | Sustainable cotton and conventional equal | Sustainable cotton worse | Not available

Table 7: Part 2 Comparative assessment of cotton related LCAs – Water consumption and toxicity results

Publication year	2015	2016	2018	2021	2021
Author	Baydar, Ciliz and Mammadov	Cotton Incorporated	Shah, Bansal and Sing for Thinkstep	Aid by Trade Foundation (utilising Cotton Inc 2016 as benchmark)	Fidan, F., Aydogan, E. and Uzal, N.
Products resp. functional unit	T-Shirt, conventional and eco	cotton, MT fiber and 1,000 kg of finished garment	1 MT seed cotton at farm gate	1 t of fibre at gin gate	1 sqm denim fabric
Country of cotton production	Turkey	USA, China, India, Australia	India	Côte d'Ivoire, Cameroon, Zambia	Turkey
Standards	Organic, conventional	Conventional benchmarking basis	Organic, Better Cotton, conventional	CmiA, conventional (Cotton Inc 2016 as benchmark)	Organic, conventional
Water consumption			Blue water consumption calculated (irrigation water)	Blue water calculated (irrigation water), thus rainfed in CmiA has "0"	
Water consumption (actual data)			organic: 391 m^3 per 1,000 kg seed cotton Better Cotton: 333 m^3 per 1,000 kg seed cotton conventional: 541 m^3 per 1,000 kg seed cotton	CmiA: 0 conventional: 1,563 m^3 per 1,000 kg lint	
Toxicity (Ecotoxicity and/ or Human toxicity)					Human toxicity, freshwater aquatic ecotoxicity, marine aquatic ecotoxicity and terrestrial ecotoxicity all showed lower values for the organic fabric

7.4 Comparative assessment of cotton related LCAs – Results for eutrophication, acidification and further impact categories

Colour code for the cells:

Sustainable cotton better | No comparison possible | Sustainable cotton and conventional equal | Sustainable cotton worse | Not available

Table 8: Part 1 Comparative assessment of cotton related LCAs – Results for eutrophication, acidification and further impact categories

Publication year	2013	2013	2013	2014	2014
Author	Cardoso	Systain (commissioned by Aid by Trade Foundation)	WWF India and WWF UK	PE International (commissioned by Aid by Trade Foundation)	Textile Exchange
Products resp. functional unit	1 kg wool resp. Cotton yarn, but for cotton also 1 kg lint	cotton, 1 kg lint	kg CO_2e/ha; kg CO_2e/kg seed cotton	cotton, 1 MT lint	cotton, 1 MT lint
Country of cotton production	Tajikistan	Benin, Burkina Faso, Côte d'Ivoire, Malawi, Mozambique, Zambia, Cameroon	India (Warangal district)	Côte d'Ivoire, Zambia	India, Turkey, China, USA, Tanzania
Standards	Organic, conventional	CmiA, conventional	Better Cotton (a BmP predecessor), conventional	CmiA, conventional (Cotton Inc 2012 as benchmark)	Organic, conventional (Cotton Inc 2012 as benchmark)
Eutrophication	organic: 0.00201 kg PO4e/kg lint conventional: 0.00219 kg PO4e/kg lint			CmiA: 2.04 kg PO4e/kg lint cotton, but corresponding data for soil erosion highly uncertain	organic: 2.8 kg PO4e per 1,000 kg lint conventional: 3.8 kg PO4e per 1,000 kg lint
Acidification	organic proved lower acidification impact, the study did not utilize internationally common unit for comparability, therefore the actual data are not quoted			for field to gin life cycle: field emissions most relevant factor for acidification as compared to gin and transport	organic: 5.07 kg SOe/1,000 kg lint conventional: 18.7 SOe/1,000 kg lint
Further impact categories assessed	Ozone depletion, marine eutrophication; transport phase as most intensive for that impact category, thus no comparison between cotton systems reasonable				Primary energy demand (use of fossil fuels) lower in organic due to avoidance of chemical fertilizers

Colour code for the cells:

Sustainable cotton better | No comparison possible | Sustainable cotton and conventional equal | Sustainable cotton worse | Not available

Table 9: Part 2 Comparative assessment of cotton related LCAs – Results for eutrophication, acidification and further impact categories studied

Publication year	2015	2016	2018, 2019	2021	2021
Author	Baydar, Ciliz and Mammadov	Cotton Incorporated	Shah, Bansal and Sing for Thinkstep	Aid by Trade Foundation (utilising Cotton Inc 2016 as benchmark)	Fidan, F., Aydogan, E. and Uzal, N.
Products resp. functional unit	T-Shirt, conventional and eco	cotton, MT fiber and 1,000 kg of finished garment	1 MT seed cotton at farm gate	1 t of fibre at gin gate	1 sqm denim fabric
Country of cotton production	Turkey	USA, China, India, Australia	India	Côte d'Ivoire, Cameroon, Zambia	Turkey
Standards	Organic, conventional	Conventional benchmarking basis	Organic, Better Cotton, conventional	CmiA, conventional (Cotton Inc 2016 as benchmark)	Organic, conventional
Eutrophication	97% reduction as compared to conventional due to avoidance of synthetic fertilizer		organic: 0.46 kg PO4e per 1,000 kg seed cotton Better Cotton: 2.49 kg PO4e per 1,000 kg seed cotton conventional: 7.31 kg PO4e per 1,000 kg seed cotton	CmiA: 0.017 kg PO4e conventional: 0.008 kg PO4e	organic: 0.0015 kg PO4e per sqm fabric conventional: 0.0028 kg PO4e per sqm fabric
Acidification			organic: 3.34 kg SO2e per 1,000 kg seed cotton Better Cotton: 12.14 kg SO2e per 1,000 kg seed cotton conventional: 14.06 kg SO2e per 1,000 kg seed cotton	CmiA: 0.028 kg SO2e conventional: 0.026 kg SO2e	organic: 0.0097 kg SO2e per sqm fabric conventional: 0.0128 kg SO2e per sqm fabric
Further impact categories assessed		photochemical ozone creation potential, ozone depletion potential, human health particulate air		new methods for biodiversity integration into LCA applied, though not yet standardized; values propose 15% lower impact for CmiA as compared to conventional scenarios	abiotic depletion, abiotic depletion fossil fuels, ozone layer depletion and photochemical oxidation show all lower figures for the organic fabric

Conclusions from the LCA comparison matrix

The previous Table 2 and Table 3 representing a summary of properly done methodical LCAs show that the sustainable cotton initiatives (organic, Better Cotton and CmiA) keep their promise that they can lower the environmental impact of cotton production when benchmarked to conventional peers.

8.1 Overarching conclusions

Green cells in all results tables in this study are clearly the majority, where the green colour indicates a superiority of the sustainable cotton system over the conventional peers. Those cases, where a direct quantifiable comparison could be made, came to 18 examples where the particular parameter for the sustainable cotton system is lower. Meanwhile, in 3 cases the figure for the sustainable production system was higher or equal, meaning that the sustainable cotton systems fared equally or worse than their conventional peers. These cases referred to water consumption and toxicity.

The driving factor for better environmental performance is the thoughtful and well managed utilization of agro-chemicals practiced when implementing these standards properly. This driving factor reduces the environmental impacts per unit of cotton produced twofold:
a) Fewer inputs translate into fewer impacts for the production of these inputs,
b) Fewer inputs mean as well fewer residues of these inputs released to the environment.

Faitrade is not included in the assessed LCAs, since no study meeting the criteria was found. Nevertheless, based on the strong focus of judicious use of fertilizers and pesticides, it can safely be assumed that the environmental performance of Fairtrade would also be better than conventional peers.

The only existing comparative LCA that evaluates organic, Better Cotton and conventional cotton production (Shah et al 2018) can additionally prove that organic has the lowest environmental impact, at least for the regional context of that study.

8.2 Conclusions for individual impact categories

Greenhouse gas emissions

All studies that allow for a comparison show a lower emission of greenhouse gases for the sustainable cotton systems, with organic having the lowest GHG figures. It must be emphasised that individual farmers could counteract this potential advantage by unwise measures on field level. Excess nitrogen, regardless of whether it stems from synthetic or organic fertilizers, will be converted by soil bacteria to nitrous oxide, which would weigh strongly in the greenhouse gas balance. Thus, the relevance of good farmer training and farmer awareness about such effects is a key success factor to realize the potential environmental benefits of the sustainable production systems.

Water consumption

Water consumption as an impact category is handled in very different ways, creating heterogenous results in the desk study. Some authors of the evaluated studies simply looked at the blue water footprint and concluded that rainfed farming is anyway preferable to irrigated cotton production. Although this might be a convenient conclusion for the public at first glimpse, it overlooks the fact that the sustainable use of irrigation water is a very local and/or regional issue. Thus, the discussion should focus more on the question of whether farmers have a reasonable water stewardship plan in place – one that adheres to the locally available volumes and qualities while protecting ecosystem functions and respecting indigenous rights. Pioneered by Better Cotton and recently adopted by CmiA and Fairtrade, water stewardship action plans have also been integrated into these standards and even certification/verification schemes.

Toxicity

The LCA data regarding toxicity are very incomplete and therefore do not allow for a conclusive assessment. The driving factor that catalyses the better environmental performance of CmiA and Better Cotton, when benchmarked against conventional cotton production, is the thoughtful and well managed utilization of agrochemicals, thereby reducing the environmental load created by excess inputs.

Given the fact that organic practices prohibit the application of synthetic agro-chemicals, one can safely presume that a full inclusion of the impact category toxicity would lead to an even better profile for the organic standard.

One study that looks at toxicity,compariing organic and conventional (Cardoso 2013), concludes that fertilization with chicken manure in organic farming may lead to a contamination with heavy metals. But the study draws this heavy metal content from general literature data and cannot prove it for the concrete study case. Therefore, heavy metal accumulation cannot be generalised as an inherent challenge for organic cotton production systems. Furthermore, such a contamination risk should be identified and counteracted through the organic certification process.

Eutrophication and acidification

These two impact categories show a slightly inconsistent image. The study that compares conventional, organic and Better Cotton (Shah et al 2018) in India indicates the lowest impacts for organic, followed by Better Cotton, and thus both sustainable systems having lower emissions for this impact category. This superiority of the organic system is also supported by the study of Fidan et al (2021) for Turkish conditions. The LCA study for CmiA (Aid by Trade Foundation 2021) gives nearly equal or even slightly higher impact for the sustainable system, indicating a high dependency on local context for these impact categories.

Part III

Recommendations

Recommendations for decision makers in the textile sector

9.1 Engage in sustainable cotton

Despite the comparatively clear and reasonable statements that can be extracted from the LCA overview in the last chapters, it must be emphasised that LCA as an analytical tool has its limitations when assessing sustainability aspects of cotton production.

Even if the very relevant social and economic aspects of sustainability are kept aside for the scope of this study, the LCA method – with its product and production focus – makes reflections about the landscape where the cotton is produced very difficult. It is often not clear if the studies describe a climate resilient, diverse and biodiversity-rich landscape or a monocultural "desert" with little economic and agro-ecological resilience. Nevertheless, standards systems themselves (Better Cotton, Fairtrade and CmiA) have been engaged in integrating landscape aspects into their criteria. Many organic cotton projects are also actively contributing to the resilience of the landscape, too, thereby going beyond of what is demanded for successful certification. This adds further complexity into comparing standards, since individual projects may be implementing sustainability measures that are not mandated by the standard to which they are certified.

An engagement or purchase policy of companies for sustainable cotton, as seen within the *German Partnership for Sustainable Textiles*, will find sufficient arguments in the previous chapters for setting priorities. Other tools such as *Standardsmap* or *Siegelklarheit* may help to work out these priorities on a broader "canvas" that includes other pillars of sustainability.

Overall, the engagement for sustainable cotton as a natural fiber is important. As the Sustainable Cotton Challenge 2025 shows, the leverage of the textile sector is strong when a unified, cross-standard and engaged demand pull can be realized.

Aside from the growing demand for sustainability by consumers, the various national and EU-wide regulations obligating corporate due diligence in supply chains makes taking action in this direction highly relevant. To comply with the new regulations, companies will have to assign resources and personnel to manage and gain knowledge about their suppliers. Companies which have already been engaged in sustainability activities or environmental health and safety (EHS) reporting will have much less problems complying than companies that have not engaged in this area before.

This becomes even more relevant since B2B decisions are increasingly made online, giving advantages to actors who can reveal details about their supply chain digitally.

9.2 Embrace and support data collections and compilations

The fact that LCAs have a limited focus does not render the tool useless. The value of the tool lies in two opportunities:

» Identification of hotspots of environmental impacts of a particular product or value chain AND
» Identification of improvement potentials and areas.

To unfold this potential, systematic data collection in partnership with other actors of the value chain would be very helpful, and it could lead to a dynamic lifecycle data inventory that allows manifold applications.

A pro-active partnership with suppliers about the exchange and utilisation of supply-chain information and especially field and farmer data could ease a lot of concerns that private sector actors have considering the upcoming supply-chain regulations.

The opportunity might be to go even further and actively report about more complex indicators like biodiversity or landscape parameters. A mid-term outlook for synergies of the supply-chain regulations with proactive reporting to consumers and at B2B levels might be that field data could be combined with regional sustainability data. The idea is to create verified sourcing areas where certain aspects of sustainability or OECD sector risks are handled (and even verified externally) by local stakeholders or authorities (e.g. child labour risks, deforestation). Such a scheme could allow sharing certification costs for certain aspects between various actors involved thereby greatly cutting costs for certification for individual actors and allow a higher confidence in the raw material purchased. Moreover, relevant actors in the textile sector are underway to set up data platforms that allow access to supply-chain relevant information. A lot of hype is made around blockchain technology, but other distributed ledger IT systems may be apt as well. It must be emphasised that these systems process but neither generate nor collect the data, particularly those from the field level and will have to be combined with data collection.

Recommendations for decision makers in the cotton sector

10.1 Engage and support data collection and sharing

There are cases of LCA studies in which an individual textile company or stakeholder organization commissions a LCA consultant, flies them into some cotton area to take random data from randomly sampled fields in a random year. Worse yet, the data gaps are filled with literature data that is difficult to interpret. Thus, conclusions will be prone to mistakes. Nevertheless, given the scientific approach, LCA may leverage internal decision making for a cotton sourcing or even find its way into textile related regulations (the most recent example being the EU PEF).

To overcome the challenges such individual approaches have, the call for a joint platform on data collection and exchange has been raised by different actors, standard organisations and conferences in the cotton sector.
The potential advantages are interesting:

- **Internally,** benchmarking with other projects would allow one to identify room for improvements of the sustainability performance or the productivity.
- **Externally,** a reasonable data set could make the sustainability progress visible, and one could create their own indicator sets without being subjected to indicators introduced by external parties that may not understand farm or project realities.

Most of the sustainable cotton projects and standards systems are collecting farmer and production data anyway. Either because it is a requirement for a successful certification/verification or because of the need to have updated monitoring reports for their stakeholders. Such data sets would also allow a much better handling of the limitations of LCAs in agriculture and counteract the methodical restriction of the LCA tool:

- Seasonal variations could be levelled out by creating 3- or 5-year average values.
- Farm-to-farm differences could be levelled out by establishing minimum, maximum and average values. As side effects the projects would also have a good basis to make target group specific extension, addressing the farmers in the groups differently. The potential for the collected data in this regard has not been utilized sufficiently in the past.

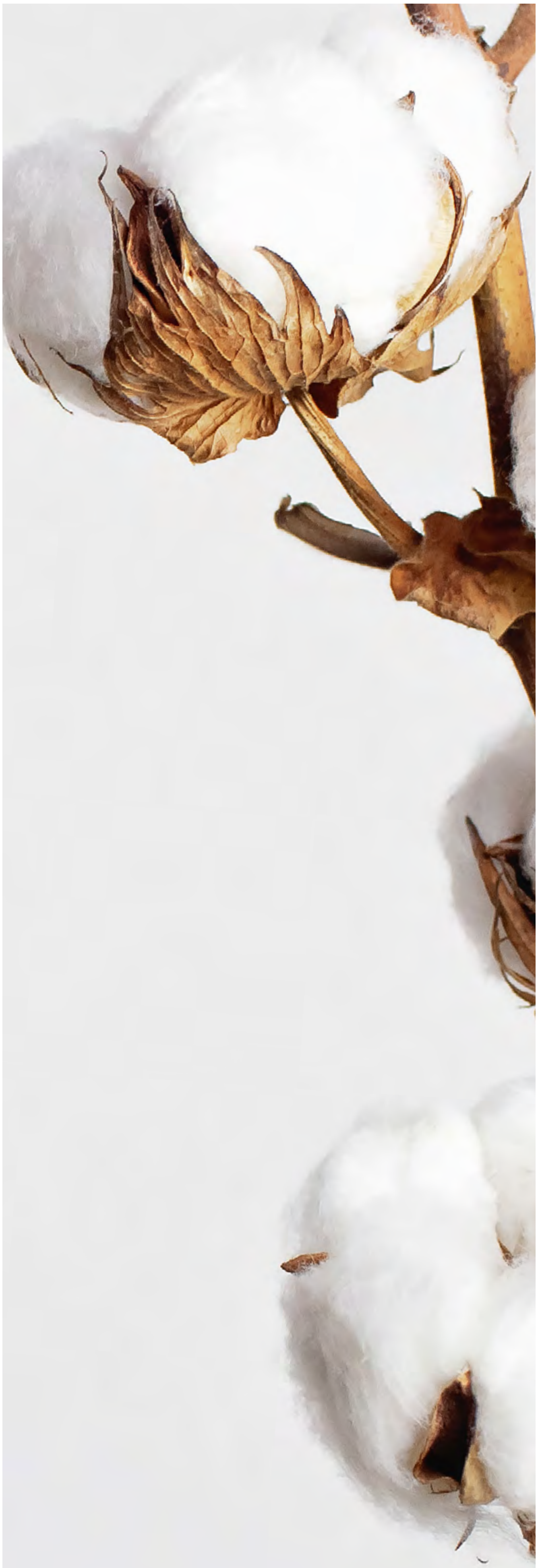
This data, which is collected anyway, could already form a reasonable basis for LCA-based further processing or to set – as frequently demanded – science-based targets. The wheel for further sustainability information of the cotton sector does not need to be reinvented. FAO and ICAC (2015) have created a very good basis for constant monitoring of all pillars of sustainability. Continuing the sector-wide discussion about this opportunity could be fruitful.

Two key challenges would need attention, but could certainly be resolved:

- Some indicators require training of the enumerators or data collectors to avoid bigger mistakes in the data recording and collection.
- The community needs to agree on the set of indicators and harmonize the methods for their measurement.

The data ownership and protection aspects need clarification in a way that the farmers' benefits are at the centre and not only the data interest of the collecting party. One interesting element in some of these concepts is that farmers could be rewarded for sharing and recording data. So-called tokens, that then could be used locally as currency, e.g. for mobile credit, could incentivize farmers to actively participate in such systems. Doubtless, the data protection aspects will need intensive discussions for creating mutually acceptable and beneficial ways of conduct. But the potential win-win for all actors will be rewarding.

Lastly, regarding the EU PEF regulatory framework, the process shows the already mentioned shortcomings in applying LCA to cotton as part of assessing textile products. These shortcomings have been addressed not only by the NGO community (EEB 2018), but have also been scientifically studied and published (Watson and Wiedemann 2019). The further rolling out of the regulation in the intended way will certainly prevent the cotton sector from participating and sharing data. Concerted efforts of the cotton sector may however still convince the EU to change their handling of the PEF regulation.



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Annexes

Agricultural practices and their utilization in cotton farming systems

Colour code for the cells:

- Mentioned as voluntary element
- Mandatory element of the standard implementation
- No particular mentioning
- Not allowed according to standard

Table 10: Comparison of agricultural practices for sustainability and their utilization in cotton farming systems

Category of practices	Concepts and approaches for sustainable cotton as of Galanopoulou-Sendouca and Oosterhuis 2003	Pillars of sustainable cotton as of Chaudhry 2006	Agroecology approaches as of High Level Panel of Experts (HPLE/FAO) 2019	Better Cotton	CmiA	Fairtrade	Organic	Reel
Standard source				Better Cotton 2018, Better Cotton 2021	CmiA 2020	Fairtrade 2011, Fairtrade 2019, FloCert 2018	EU 2018, IFOAM 2005	Cotton Connect no year
Cropping system	Crop rotation	Habitat management (Cotton to be regarded as farming system, with impacts of cotton to other crops and others to the cotton crop)	Diversification, mixed cultivation, intercropping, cultivar mixtures	Key element – Requested in several principles	Key element requested via criterion # 7.4 and corresponding indicator; even the minimum amount of rotation elements defined as 3	Potential element for pest management (#3.2.2 of generic small-holder standard) and soil fertility (# 3.2.13 and 3.2.23)	Key element of all organic regulations and standards	Encourage-ment for crop rotation (# 2.2.1.3)
Soil management	Counteract soil compaction		Improvement of soil structure and health	Key element expressed and requested via principle #3 "soil health"	Key element – Requested in several criteria	Mandatory element of management and training plans and corresponding reporting (#3.2.23)	Key element of all organic regulations and standards	Key element assigned for an entire criteria chapter (#3)
Climate and Carbon			Carbon sequestration	Climate change mitigation and adaptation requested via various principles	Key element requested via criterion # 7.5 and corresponding indicators (adaptation and mitigation as concern	Mandatory element for management and training plan (# 3.2.44) and defined in particular Fairtrade Climate Standard if application for Carbon Credits is intended	Indirect key element realized via mandatory measures to manage soil organic matter	Not in generic standard, but contained in specific standard "REEL regen-erative"
Fertilizer management	Judicious fertilization	Plant growth and input use (fertilizers, irrigation and physiology)	Manure, compost, waste management, reuse and recycling as inputs to the production process	Key element requested via various principles	Key element requested via criterion # 8.3 and corresponding indicator	Essential element of management and training plans and corresponding reporting (#3.2.22 and 23)	Key element of all organic regulations and standards	Key element assigned for as entire criteria sub-chapter (#3.3)

Colour code for the cells:

- Mentioned as voluntary element (yellow)
- Mandatory element of the standard implementation (olive)
- No particular mentioning (light blue)
- Not allowed according to standard (orange)

Category of practices	Concepts and approaches for sustainable cotton as of Galanopoulou-Sendouca and Oosterhuis 2003	Pillars of sustainable cotton as of Chaudhry 2006	Agroecology approaches as of High Level Panel of Experts (HPLE/FAO) 2019	Better Cotton	CmiA	Fairtrade	Organic	Reel
Standard source				**Better Cotton 2018, Better Cotton 2021**	**CmiA 2020**	**Fairtrade 2011, Fairtrade 2019, FloCert 2018**	**EU 2018, IFOAM 2005**	**Cotton Connect no year**
			Nutrient cycling	Key element requested via various principles	Key element requested via criterion # 7.1 and corresponding indicator	Essential element of management and training plans and corresponding reporting (#3.2.40)	Key element of all organic regulations and standards	Key element mandated by several measures in criteria chapter # 3
			Biological nitrogen fixation	Utilised in principle #3 (soil health)	Key element requested via criterion # 8.3 and corresponding indicator		Key element of all organic regulations and standards	Key element (# 3.1.1.4)
	Plant growth regulators			Regulated via principle # 1	No particular mentioning	No particular mentioning	Not permitted	No particular mentioning
Water management	Judicious irrigation	Plant growth and input use (fertilizers, irrigation and physiology)	Water conservation	Key element via own principle and even extended to holistic approach via water stewardship	Key element requested via criterion # 8.3 and corresponding indicator extended to holistic approach via water stewardship	Essential element of management and training plans and corresponding reporting oriented at water stewardship elements like mapping of water sources, etc.(#3.2.24)	Water conservation and wise use of water are general principles, but not underpinned with minimum criteria	Key element assigned for an entire criteria chapter (# 5)
Crop management	Early sowing	Crop attributes (varieties, seed, planting, etc.)			Included in implementation guidance		Via general remarks for recommended crop management	
	Narrow spacing	Crop attributes (varieties, seed, planting, etc.)			Included in implementation guidance		Via general remarks for recommended crop management	

Colour code for the cells:

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Category of practices	Concepts and approaches for sustainable cotton as of Galanopoulou-Sendouca and Oosterhuis 2003	Pillars of sustainable cotton as of Chaudhry 2006	Agroecology approaches as of High Level Panel of Experts (HPLE/FAO) 2019	Better Cotton	CmiA	Fairtrade	Organic	Reel
Standard source				Better Cotton 2018, Better Cotton 2021	CmiA 2020	Fairtrade 2011, Fairtrade 2019, FloCert 2018	EU 2018, IFOAM 2005	Cotton Connect no year
Crop management (continued)	Choice of variety (adapted to the location)	Crop attributes (varieties, seed, planting, etc.)		Key element mentioned in several principles	Included in implementation guidance and fibre quality criteria (# 11.1)		Inherent principle, but no criteria	Attached to advice of local experts (# 2.1.1.1)
Pest and disease management	Integrated pest control	Minimum use of pesticides	Biological pest control and natural regulation of diseases	Key element requested in principle # 1	Key element requested via criterion # 9	Essential element of management and training plans and corresponding reporting (#3.2.2)	All synthetic pesticides and agro-chemicals not permitted. Permitted substances regulated via listings in a positive list	Key element assigned for an entire criteria chapter (# 4)
	GMO			Technology neutral, but permitted	Not permitted	Not permitted	Not permitted	No particular mentioning
Biodiversity and Habitat management		Habitat management (see above)	Biodiversity conservation and habitat	Key element requested in principle # 4	Key element requested via criterion # 7.4 requesting a biodiversity management plan	Essential element of management and training plans and corresponding reporting (#3.2.2)	Mandatory with list of recommended practices	Key element assigned for an entire criteria chapter (#6)
			Management techniques for crop-associated biodiversity	Key element requested in principle # 4	Key element requested via criterion # 7.4 requesting biodiversity management plan	Optional element (# 3.2.33)	Mandatory with list of recommended practices	Key element (# 2.1.1.7 and 8)
Economic aspects		Economic pillar (quality, marketing and processing)		Key element requested in principle # 5 and 7; marketing supported via entire Better Cotton system	Key element requested via pillar # 4 "prosperity"	Creation of fair pricing is the basis of Fairtrade system	Social, economic and ethic considerations are part of the standards basic, but there are no defined criteria	Key element assigned for an entire criteria chapter (# 9)

Comparison list of cotton related LCA studies

Colour code for the cells:

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- Not allowed according to standard

Table 11: Comparison of identified cotton related LCA studies. The studies that qualify to be taken into the further assessment steps are highlighted in green. Yellow highlights mark the studies that are focusing only one standard, but have been used in other studies for benchmarking

Year	Author	impact category or LCA (if more than 3 impact categories)	Products resp. functional unit	Operating with original Data	Year of collection	Country of cotton production	Conventional cotton (= no specified farming system or standard)	Organic	BCI	CmiA
1999	Kalliala, E. and Nousiainen, P. University Tampere, Finland	LCA	Home textiles cotton, PE/cotton, PE	no	Mix	not specified	●	●		
2005	Stockholm Environment Institute (SEI) mandated by BioRegional Development Group, UK and World Wide Fund for Nature	LCA	5 Textiles: cotton, organic cotton, hemp, organic hemp, PE	no	Mix	India and not specified				
2005	Yilmaz, Aczaoz and Ozkan, Akdeniz University Antalya, Turkey	Energy input	Cotton	yes	2001	Turkey	●			
2006	Chapaign et al. UNESCO and University Twente, Netherlands	Water	Cotton	no	1997–2001	global, but country specific	●			
2010	Khabbaz, University of Queensland, Australia	Energy, GHG	Cotton	yes	2009–2010	Australia	●			
2010	Levi Strauss & Co Jeans	LCA	Jeans	no	2010	USA, Azerbaijan	●	●		
2010	Maraseni, Cockfield and Maroulis, University of Queensland, Australia	GHG, water	Cotton	no	2002, 2007	Australia	●			
2012	Cotton Incorporated	LCA	Cotton; 1 MT fiber	yes	2005–2009	USA, China, India	●			
2013	Cardoso, University of Porto, Portugal, supervised by Quantis, Switzerland, mandated by Hugo Boss	LCA	wool and cotton yarn	yes	2011		●	●		
2013	Nalley et al. University Arkansas, US	GHG	cotton, pound – GMO, non GMO	yes	1997, 2005, 2008	USA (Arkansas)	●			
2013	Systain (commissioned by Aid by Trade Foundation)	Carbon and water footprint	cotton, 1 kg lint	yes	??	Benin, Burkina Faso, Côte d'Ivoire, Malawi, Mozambique, Zambia, Cameroon	●			●
2013	WWF India and WWF UK	GHG	kg CO_2e/ha; kg CO_2e/kg seed cotton	yes	2010	India (Warangal district)	●		(●)	

Colour code for the cells:

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Year	Author	impact category or LCA (if more than 3 impact categories)	Products resp. functional unit	Operating with original Data	Year of collection	Country of cotton production	Conventional cotton (= no specified farming system or standard)	Organic	BCI	CmiA
2014	van der Velden, Patel and Vogtländer, Universities Delft and Utrecht within EU Research Programme FP7	LCA	textiles, PE cotton, nylon, elastane	yes	2011–2012		●			
2014	PE International (commissioned by Aid by Trade Foundation)	LCA	cotton, MT lint	yes	2010	Zambia, Côte d'Ivoire				●
2014	Textile Exchange	LCA	cotton, MT lint	yes		India, Turkey, China, USA, Tanzania		●		
2015	Baydar, Ciliz and Mammadov, Bogazici University, Turkey	LCA	T-Shirt, conventional and eco	yes	2004	Turkey	●	●		
2015	Levi Strauss	LCA	2 Jeans, 1 Dockers	yes	2013	US and others	●		(●)	
2015	Muthu et al. Compilation of various LCA related papers	div	div	div	Mix					
2015	Ullah et al. Asian Institute of Technology, Thailand, CIRAD, France	LCA	kg seed cotton	yes	2010	Pakistan, Punjab	●			
2016	Cotton Incorporated	LCA	cotton, MT fiber and 1,000 kg of 2 knit shirts, 1 woven pants	yes	2010–2014	USA, China, India, Australia	●			
2016	Wendin et al., Miljögiraff, Gothenburg, Sweden for H&M	LCA	recycled cotton, 1 kg fiber for spin	yes	2010	various				
2017	Turillas and de la Guardia, University Valencia, Spain for Hilaturas Ferre	LCA	1 kg coloured yarn; T-shirt (for comparison)	only for processing	2015–2016		●	●		

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Year	Author	impact category or LCA (if more than 3 impact categories)	Products resp. functional unit	Operating with original Data	Year of collection	Country of cotton production	Conventional cotton (= no specified farming system or standard)	Organic	BCI	CmiA
2017	Jungmichel, Schampel and Weiss, Sytain Consulting for adelphi	LCA data aggregated	sector comparison	no		global				
2018	Barnhardt Cotton Net, referring to Cotton Inc 2016	LCA	summarizing Cotton Inc 2016	yes	see Cotton Inc 2016	see Cotton Inc 2016	●			
2018	Khan et al., University of Fahsion and Technology, Bangladesh	LCA	T-Shirt	no		Pakistan, India	●	●		
2018	Laitala and Klepp, Oslo Metropolitan University, Norway, Queensland University, Australia	Use phase relevance	comparison of fiber type	no	2018					
2018	Lenzo et al. Universities of Messina and Rome , Italy and RWTH Aachen, Germany	LCA and social LCA	wool, knitted cape	yes	2016	Italy				
2018	Moazzem et al., Universities of Melbourne and Hawthorn, Australia	Climate change	textiles from wool, cotton and PE	yes	2015	Australia				
2018	Shah, Bansal and Sing, Thinkstep, see also C&A Foundation 2019	LCA	1 MT seed cotton at farm gate	yes	???	India	●	●	●	
2018	Zeller, Gioacchini and Traverso, Hugo Boss and RWTH Aachen, Germany	Climate change	Wool suit, silk ties, quote cotton textiles	yes	2017					
2019	C&A Foundation	LCA	1 MT seed cotton at farm gate	yes	2016/2016	India	●	●	●	
2019	GreenStory for Thred UP	Primary energy, GWP, Blue water	1 2nd hand item replacing new item	no	2018	Mix	●	●		
2019	La Rosa and Grammatikos, Norvegian University of Science and Technology	LCA	1 kg fiber; 1 kg textile (cotton, organic cotton , hemp, jute , kenaf)	no	2019	Mix	●	●		
2019	Pesnel and Payet Cycleco on behalf of the Technical Secretariat of the S-shirts PEFCR pilot, EU	LCA	wearing T-shirt 52 times	product rules	2019					

Colour code for the cells:

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Year	Author	impact category or LCA (if more than 3 impact categories)	Products resp. functional unit	Operating with original Data	Year of collection	Country of cotton production	Conventional cotton (= no specified farming system or standard)	Organic	BCI	CmiA
2020	Niinimäki et al. 6 different Universities	life cycle, textile sector	Global environmental impact of textile industry	no	Mix	Mix				
2020	McKinsey & Company	life cycle, textile sector, GHG	Global climate impact of textile industry	no	Mix					
2021	Fidan, Aydogan and Uzal, Abdul Gul University and Erciyes University, Turkey	LCA	1 m finished denim fabric, recycled cotton and processing scenarios	no	Mix	Turkey, global	●			
2021	Aid by Trade Foundation	LCA	1 t of fibre at gin gate	yes	2017–2019	Côte d'Ivoire, Zambia, Cameroon	●			●
2021	Fidan, F., Aydogan, E. and Uzal, N., Abdul Gul University and Erciyes University, Turkey	LCA	1 sqm denim	yes		Turkey	●	●		

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