Better Cotton Initiative

Study of Greenhouse Gas Emissions of Better Cotton

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Executive summary

Better Cotton Initiative (BCI) were seeking to quantify greenhouse gas emissions of Better Cotton and comparable production to help inform their 2030 strategy. This study has calculated that, based on the data provided, on average Better Cotton production across China, India, Pakistan, Tajikistan, and Turkey has a lower emissions intensity per tonne lint than comparison production by 19%. Over half of the difference in emissions performance between Better Cotton and comparison production was due to difference in emissions from fertiliser production. A further 28% of the difference was because of emissions from irrigation.

A separate piece of analysis was undertaken to assess emissions from Better Cotton (or recognised equivalent) production across Brazil, China, India, Pakistan, and USA. Together production in these countries constitute over 80% of licensed Better Cotton global production and have average annual GHG emissions of 8.74 million tonnes carbon dioxide equivalents to produce 2.98 million tonnes lint – equating to 2.93 tonnes carbon dioxide equivalents per tonne lint produced. The largest emissions hotspot was found to be fertiliser production which accounted for 47% of total emissions from Better Cotton production. Irrigation and fertiliser application were found to be significant drivers of emissions.

Reductions in GHG emissions are possible through efficiency improvements through reduced use of inputs (primarily synthetic fertilisers and water), the adoption of land management practices to sequester carbon in soils, and the use of renewable energy sources. The collection of additional information from Better Cotton farmers will help improve the accuracy of future emissions quantification projects.

Key findings

The key findings of this study are as follows:

- GHG emissions from Better Cotton production across China, India, Pakistan, Tajikistan, and Turkey are on average 19% lower than comparison production. Over half the difference in emissions performance between Better Cotton and comparison production was due to difference in emissions from fertiliser production. A further 28% of the difference was because of emissions from irrigation.
- Programmes that constitute over 80% of licensed Better Cotton global production had average annual greenhouse gas emissions of 8.74 million tonnes carbon dioxide equivalents, equating to 2.93 tonnes carbon dioxide equivalents per tonne lint produced.
- Total emissions were highest in Brazil and China reflecting their significant contribution to total Better Cotton production.
- USA produced lint at the lowest carbon intensity of 1.92 tonnes carbon dioxide equivalents per tonne lint whilst India had the highest intensity at 4.08 tonnes carbon dioxide equivalents per tonne lint.
- The primary source of emissions was fertiliser production – contributing 47% of Better Cotton's average total annual emissions. Irrigation and fertiliser application were also found to be significant sources of emissions. Between them, these three sources accounted for over three quarters of total emissions.
- Given their sizable contribution to total emissions, reductions in the use of synthetic fertilisers and irrigation[1] can unlock significant reductions in emissions.
- The adoption of management practices such as cover cropping, no/reduced tillage and application of organic manures offer significant opportunities to reduce emissions through carbon sequestration.
- The collection of additional data from Better Cotton farmers will permit refinement of the emissions quantification process in subsequent years.

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[1] Due to the energy required to move the water from source to crop

Table of contents

Table of figures

1 Introduction

The agriculture sector's role in greenhouse gas (GHG) emissions is widely known, contributing approximately 20% of the world's GHG emissions. Assuming current levels of production efficiency and the continuation of current deforestation rates, the business-as-usual outlook will see emissions increase by 15% to 20% by 2050 [2].

Climate change poses a material risk to the world's farmers, many of whom cultivate their crops in countries that are particularly vulnerable to climate risks. Production, particularly in the tropical regions of the world, looks set to suffer under predicted rising temperatures, decreased soil moisture and more extreme weather events and flooding. Cotton is no exception.

Cotton is the world's most widespread and valuable non-food crop. Grown in more than 100 countries, cotton is a heavily traded agricultural commodity, with over 150 countries involved in exports or imports of cotton. Its production employs circa 7% of all labour in developing countries and provides income for more than 250 million people worldwide. Managed properly, cotton is a flexible natural resource used for food, packaging, medical supplies, and the textile industry, but current production methods are unsustainable and ultimately undermining the industry's ability to maintain future production.

The sector accounts for a large, growing, and impactful share of global greenhouse gas (GHG) emissions, with most of the emissions resulting from fertiliser production, fertiliser application, irrigation and land use change (where it occurs). Leadership and innovation from the sector are therefore vital in making progress in reducing these emissions and in abating the worst effects of climate change on cotton production. Action in this arena also makes good business sense. By addressing GHG emissions, companies and producers can identify opportunities to bolster their bottom line, reduce risk, and discover competitive advantages.

For BCI, an important area of focus going forwards will be to quantify the emissions resulting from Better Cotton production, where the emissions hotspots are and how Better Cotton can affect positive change in reducing emissions and credibly quantify these reductions in subsequent years. The outputs of this will be used to inform BCI's development of its 2030 strategy, in which climate change mitigation and the reduction of emissions from Better Cotton production will feature.

Additionally, BCI has several stakeholders, notably brands and retailers who need to include emissions from Better Cotton production in their Scope 3 emissions reporting against Science-Based Targets and other climate commitments.

2 Goal and scope

2.1 Goal of the study

The purpose of this project was to quantify the greenhouse gas (GHG) emissions for cradle to post-gin lint production in Better Cotton Initiative (BCI) and recognised equivalent programmes that constitute over 80% of licensed Better Cotton globally. Better Cotton Initiative commissioned Anthesis Group to perform this quantification.

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[2] https://www.mckinsey.com/~/media/mckinsey/industries/agriculture/our%20insights/reducing%20agriculture%20emissions%20through%20improved%20farming%20practices/agriculture-and-climate-change.pdf

A carbon footprint is the result of an analysis which measures the GHG emissions associated with an organisation, product, or process. The shorthand term “carbon footprint” originates from the fact that carbon dioxide (CO2), released primarily from fossil fuel burning (oil, diesel, petrol, coal, natural gas, etc.) makes up the bulk of most GHG and is the main contributor to global climate change.

Carbon footprint studies also include the impact of other GHGs, such as methane (CH4) and nitrous oxide (N2O), which have higher global warming potentials (GWP) than CO2 and therefore can contribute substantially to climate change, even if emitted in small quantities. This study includes the impacts of GHGs beyond CO2, as such GHGs are expressed as carbon dioxide equivalents (CO2e) units - which normalises the impact of non-CO2 GHGs to CO2 levels based on global warming potential.

Understanding the GHG emissions that arise from the agricultural phase of cotton production is a highly relevant indicator for a variety of BCI stakeholders. This includes Retailer and Brand members who need to include cotton production in their Scope 3 reporting against Science-Based Targets and other climate initiative commitments; Better Cotton licensed farmers and Implementing Partners who need better data to improve hotspot analyses and targeting of interventions to contribute to climate change mitigation and adaptation; and civil society actors concerned with the potential and achieved effects of BCI programming on climate change mitigation.

The goals of this study were to:

1. Calculate the comparative GHG emissions for Better Cotton Production and comparable production across five countries (India, Pakistan, China, Tajikistan, Turkey), averaging the results across three growing seasons – 2015/16, 2016/17 and 2017/18.
2. Calculate the average GHG emissions for countries contributing over 80% of Better Cotton’s total production (India, Pakistan, China, Brazil and USA) across the 2015/16, 2016/17 and 2017/18 growing seasons as above.

The results of this study were to be reported using the following emissions categories:

- Crop residue management – emissions resulting from crop residues
- Fertiliser application – emissions from soils resulting from the application of nitrogen fertilisers
- Fertiliser production – emissions from fertiliser production
- Field operations – emissions arising from field preparation, sowing, crop fertilisation, crop protection and harvesting
- Ginning – emissions from the ginning process
- Irrigation – emissions from energy used to power irrigation systems
- Pesticides – emissions from pesticide production
- Transport to gin – emissions from transportation of seed cotton from farm to gin

In addition, where emissions from land use change (LUC) were identified, they were reported as emissions per year. To correctly allocate emissions from LUC to cotton lint, additional information such as other crops grown in the annual rotation and value of the harvested crops would be required (detailed in section 6). However, this information was not available at the time this project was undertaken. Values for emissions resulting from LUC (on an annual basis) have been included where relevant in section 4.

2.2 Scope of the study

The product under study in this GHG emissions quantification project was cotton lint, post ginning. Table 1 details the countries and states which were studied in this project.

Table 1: Countries and states/provinces under study

Country	State / Province	Comparison emissions calculation	Total BCI emissions calculation
India	Andhra Pradesh, Gujarat, Madhya Pradesh, Maharashtra, Telangana, Karnataka, Punjab, Rajasthan, Haryana	Included	Included
China	Gansu, Hubei, Hebei, Shandong, Shanxi, Xinjiang	Included	Included
Pakistan	Punjab, Sindh	Included	Included
Turkey	Adana, Antalya, Aydin, Hatay, Izmir, Kahramanmaras, Sanliurfa, Diyarbakir, Denizli	Included	Not included
Tajikistan	Khatlon, Sughd	Included	Not included
Brazil	Bahia, Goias, Maranhao, Minas Gerais, Mato Grosso Do Sul, Mato Grosso, Piaui	Not included	Included
USA	Alabama, Arizona, Arkansas, California, Florida, Georgia, Louisiana, Mississippi, Missouri, New Mexico, North Carolina, South Carolina, Tennessee, Texas, Virginia	Not included	Included

This project consisted of two parts:

1. Calculate the comparative GHG emissions for Better Cotton Production and comparable production (using comparison data) for India, Pakistan, China, Tajikistan, Turkey – averaged across three growing seasons: 2015-16, 2016-17, 2017-18.
2. Calculate the average GHG emissions of Better Cotton production averaged across three growing seasons (2015-16, 2016-17, 2017-18) for Better Cotton production in Brazil, Pakistan, China, India, USA. Identify key emissions drivers to inform BCI's 2030 strategy development.

The number of assessments, the harvested area and the amount lint production which were used in the GHG quantification exercise across the three growing seasons (2015-16, 2016-17, 2017-18) are detailed in Table *2*.

Table 2: Number of assessments, harvested area and lint production used in GHG quantification process

Country	Better Cotton / Comparison production	No. assessments	Harvested area (hectares)	Lint production (tonnes)
India	Better Cotton	89,773	148,547	105,884
India	Comparison	24,900	37,544	24,234
Pakistan	Better Cotton	49,190	453,177	376,162
Pakistan	Comparison	13,238	43,889	30,696
China	Better Cotton	26,791	542,989	1,234,793
China	Comparison	8,336	84,171	183,567
Tajikistan	Better Cotton	1,755	31,268	30,675
Tajikistan	Comparison	663	5,887	4,918
Turkey	Better Cotton	1,536	47,782	90,756
Turkey	Comparison	164	3,687	6,598
Brazil	Better Cotton	647	2,077,355	3,417,267
USA	Better Cotton	506	306,140	369,531

2.2.1 System boundaries

The boundaries for this project encompassed five elements: synthetic inputs production (pesticides & NPK fertilisers), cotton cultivation, transportation, and ginning. Cotton cultivation comprises six main tasks: field preparation, sowing, fertilisation, crop protection, irrigation, and harvesting.

Components excluded from this GHG quantification were human and livestock labour, construction of capital equipment, maintenance of farm machinery, transportation of inputs to farm, production and transportation of any packaging materials used, carbon released or sequestered by soil relating to tillage practices or cover cropping.

Primary data used in this study was self-reported by Better Cotton and Comparison farmers and collected by field staff employed by Better Cotton's implementation partners for each of the three growing seasons in question. This was done as part of the Better Cotton Standard System (BCSS) which covers environmental, social, and economic sustainability of cotton production at farm level.

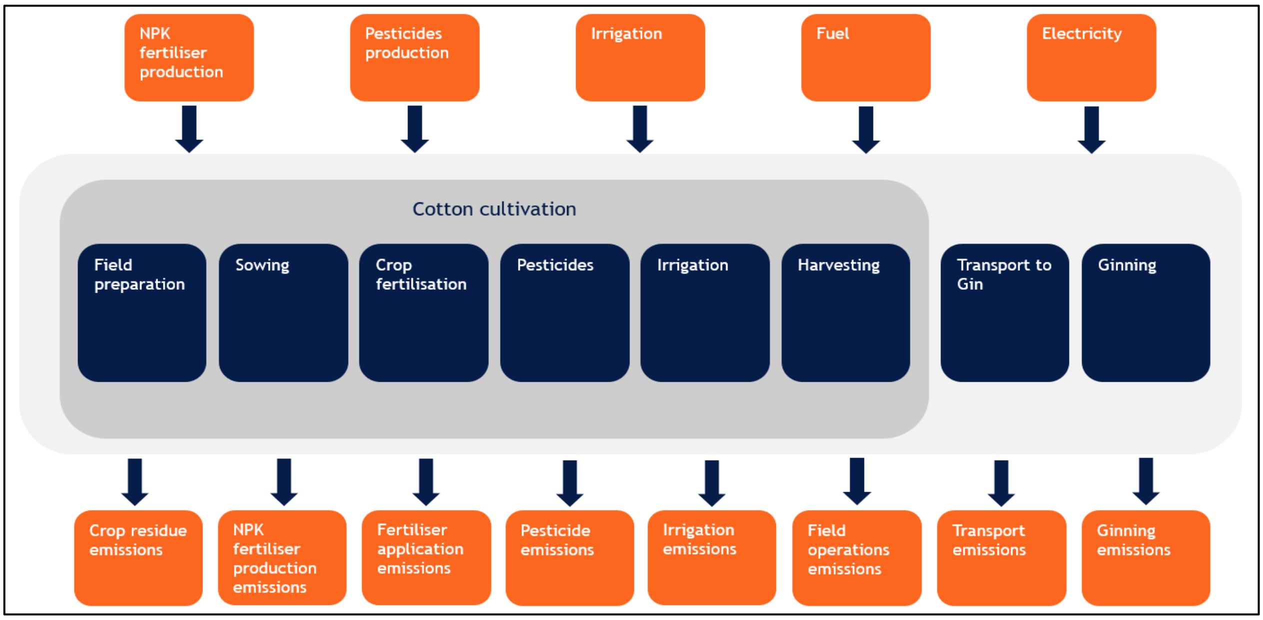

Figure 1: System boundary of study

2.2.2 Functional unit

The cradle to post-gin GHG assessment covers raw material production from field up to and including ginning. Use of a functional unit(s) allows for quantification of the GHG emissions relating to cotton cultivation, transportation to gin and ginning. The GHG emissions in this project have been calculated using two functional units:

- Kilograms carbon dioxide equivalents per tonne cotton lint produced (kgCO2e / t lint) was used to assess the comparative GHG emissions for Better Cotton production and comparable production.
- Tonnes carbon dioxide equivalents (tCO2e) was used when assessing the average GHG emissions for countries contributing 80% of Better Cotton's total production.

2.2.3 GHG emissions allocation

Cotton production yields more than one valuable output – cotton lint and cotton seed. As such, the environmental burden needs to be allocated, i.e. split between them. Most life cycle assessment studies have allocated impacts based on economic values - splitting the burden based on monetary value. As such, it has been deemed the most suitable method for this project. This project used economic allocation values as per Life Cycle Assessment of Cotton Cultivation Systems[3], with 84% of GHG emissions allocated to cotton lint and 16% to cotton seed. As such this project allocated emissions accordingly. This project quantifies emissions allocated to lint production only.

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[3] https://www.laudesfoundation.org/en/resources/4332environmentallcareportjune19.pdf

3 Methodology

The methodology for undertaking this GHG emissions quantification utilised primary data collected by Better Cotton's implementation partners, supplemented with desk research undertaken by Anthesis. The data was combined to enable calculation of the GHG emissions using the Cool Farm Tool (CFT). Full details relating to the methodology used by the tool to calculate GHG emissions can be found online at the Cool Farm Alliance website[4].

3.1 Data

3.1.1 Primary data

All primary data used in this project were collected by Better Cotton's implementation partners as part of their Monitoring, Evaluation, and Learning (MEL) programme. Data from this programme which was utilised in this project were:

- Growing season
- Country
- Province
- Farm category
    - Smallholder – less than 20 hectares
    - Medium – between 20 and 200 hectares
    - Large – greater than 200 hectares
- Location of producer (either large farm or Producer Unit)
- Status of farmer – Better Cotton or comparison farmer
- Total area harvested (hectares)
- Total seed cotton harvested (kilograms)
- Total lint obtained from gin (tonnes)
- Total water applied (cubic meters)
- Total irrigated area (hectares)
- Total nitrate (kilograms)
- Total phosphate (kilograms)
- Total potassium (kilograms)
- Total farmyard manure (kilograms)
- Total pesticides (kilograms)

3.1.2 Desk research

Desk research was undertaken to ascertain additional information in relation to soil characteristics, irrigation, and land use change (LUC) which are required to obtain results from the CFT in line with BCI's specified emissions categorisation. Details of the research undertaken is presented in the Table 3.

Information relating to soil characteristics and LUC were obtained from online tools using Producer Unit geolocation data provided by BCI. Where this was not available the Producer Unit address details were used. Given that the location and addresses often related to an urban area,

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[4] https://coolfarmtool.org/coolfarmtool/greenhouse-gases/

the prevailing soil characteristics, and LUC (if present) in the surrounding area was recorded and used when calculating results in the CFT.

When researching LUC, a timeframe of 20 years prior to the three growing seasons in scope for this study were assessed. This assessment of LUC over a 20-year timeframe is in line with agricultural GHG accounting methodologies which amortise GHG emissions and sequestration from LUC over this period. After 20 years, agricultural GHG accounting methodologies consider that any emissions or sequestration associated with LUC will have ceased as the soil will have reached a new soil carbon equilibrium.

The CFT calculates emissions from LUC on an annual basis. In a given year, farmers growing cotton may grow different crops e.g. soyabeans in their fields either before the cotton is sown or after it is harvested. Therefore, to allocate the appropriate proportion of emissions from LUC to cotton based on an economic basis (as used to assign emissions between cotton seed and cotton lint in this study), information relating to the value of the crops grown per year would have been required. This information was not available at the time this study was undertaken, as such emissions from LUC are not included in the results however commentary on annual emissions from LUC are included in the results and analysis where appropriate.

Table 3: Desk based research undertaken and data sources

Category	Data researched	Source
Soil	Soil texture, percentage soil organic matter, soil moisture, soil drainage, soil pH	Soilgrids[5] - online tool developed by ISRIC (World Soil Information)
Irrigation	irrigation source, application method, power source, depth of water table (where applicable)	Various
Land use change	Nature of change in last 20 years (forest to arable, grassland to arable), year of land use change, age of forest (where applicable)	Open Land Map[6] – Land cover images for 1992 to 2018 layer
Transportation	Average distance seed cotton is transported from farm to gin	Cotton Incorporated LCA study*
Ginning	Energy required to gin a tonne of seed cotton	Cotton Incorporated LCA study*

*where no specific values were able to be obtained for individual countries, an average based on the available data was used.

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[5] Soilgrids: https://soilgrids.org/

[6] Open Land Map: https://openlandmap.org/

3.1.3 Data aggregation

To assess GHG emissions at a country and state/province level, the farm assessment data provided by BCI was aggregated at a state/province level for each season in scope. The assessments for each province/state were then grouped together based on variables which have:

1. An impact on efficiency of cotton production (farm category and status of farmer – where applicable)
2. A direct influence on the GHG emissions results were captured and represented in the emissions calculation and assessments from each state/province were divided into groups.

Each group represented a combination of the variables present in the dataset for a given state/province and season. The variables which have an impact on the GHG emissions are:

- Soil characteristics (soil texture, percentage soil organic matter, soil moisture, soil drainage
- Irrigation applied (yes, no)
- Land use change (forest to arable, grassland to arable)

An assessment for each of the group combinations that were present in each state/province per season was processed through the CFT. The results were aggregated to produce values for total emissions and emissions per tonne lint at a state/provincial and country level, averaged across the three seasons with the emissions expressed as carbon dioxide equivalents. GHG emissions were broken down by source category as detailed in section 3.2.

3.2 GHG emissions source categorisation

GHG emissions for each country and their respective states/provinces were reported per tonne lint when comparing Better Cotton with comparison production, both expressed as CO2e. To identify emissions drivers and hotspots, the GHG emissions were broken down across the following source categories:

- Crop residue
- Fertiliser production
- Soil fertiliser induced emissions
- Pesticides
- Field operations
- Irrigation
- Transport to gin
- Ginning

Emissions from LUC are detailed on a per year basis, where relevant.

3.3 Assumptions

When conducting this project, the following assumptions were made:

- After harvesting, all crop residues are either left in the field, incorporated into the field, or mulched.

- Soil characteristics for farms in each location are the same (soil texture, percentage soil organic matter, soil moisture, soil drainage and soil pH).
- All fertilisers used were manufactured in the geographical region*.
- All field operations were conducted using diesel powered machinery.
- The irrigation water source, method, power source and depth of water table (where appropriate) were uniform across all farms in each state/province.
- Diesel fuel was used to power irrigation systems aside from countries where it was known electricity was used.
- The addition of organic amendments to soil are not new practices in the last 20 years.
- The amount of seed cotton ginned was the same as the seed cotton harvested.
- All cotton is transported to the gin (where applicable) using heavy goods vehicles.
- Where cotton is transported to a gin, the distance transported is uniform for all farms in each country.
- Grid electricity is used to power the gins.

*exceptions were India and Pakistan where a world average was used.

Where LUC was identified as having occurred, this was assumed to be uniform across all farms in each Producer Unit.

4 Results and analysis

4.1 Comparative GHG emissions for Better Cotton versus comparable production

To compare GHG emissions of Better Cotton with Comparison production, a functional unit of kilograms carbon dioxide equivalents per tonne cotton lint (kgCO2e/t lint) was used.

With reference to Figure 2, at a global level, Better Cotton production had average GHG emissions of 3,589 kgCO2e/t lint compared with 4,443 kgCO2e/t lint for comparison production, a difference of 854 kgCO2e/t lint. Therefore, on a per tonne basis, Better Cotton production has 19% lower GHG emissions than comparison production.

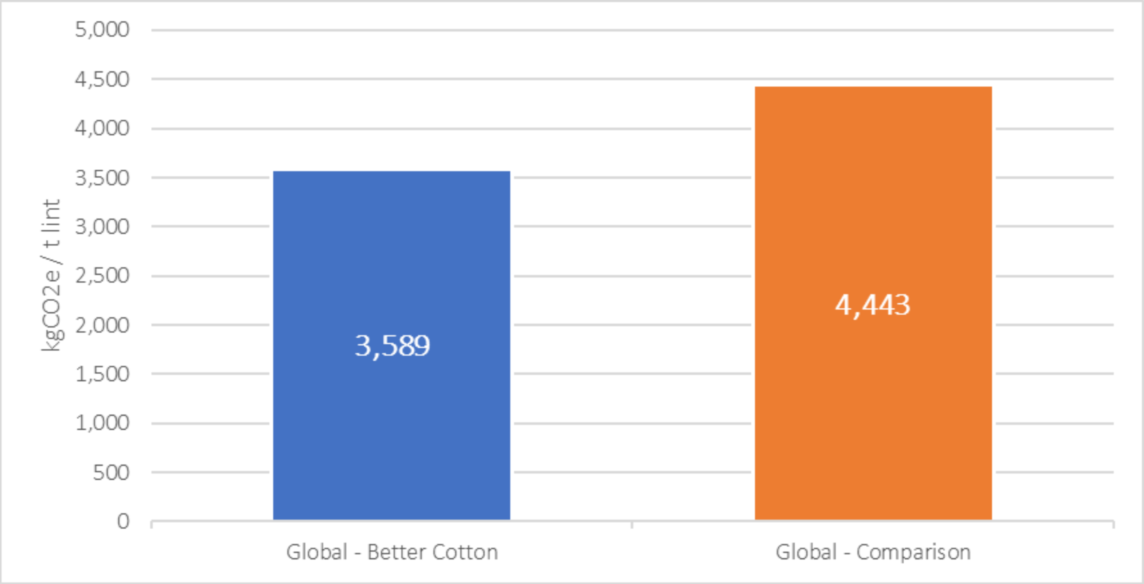

Figure 2: Global comparison of GHG emissions from Better Cotton with comparison production per tonne cotton lint

A comparison of the GHG emissions of lint production for each of the five countries in scope (China, India, Pakistan, Tajikistan, and Turkey) averaged across the three growing seasons in scope are detailed in Table 4.

Table 4: GHG emissions per tonne cotton lint by country

Country	Better Cotton GHG emissions (kgCO2e / t lint)	Comparison GHG emissions (kgCO2e / t lint)	Difference between Better Cotton and comparison production (kgCO2e / t lint)	Percent difference between Better Cotton and comparison
China	3,277	3,976	699	18%
India	4,076	5,158	1,082	21%
Pakistan	3,887	4,876	989	20%
Tajikistan	2,620	3,171	551	17%
Turkey	1,475	1,586	112	7%

In all five countries assessed, comparison production had a higher emissions intensity than Better Cotton production. The largest difference absolute terms were identified in India (1,082 kgCO2e/t lint) where Better Cotton emissions were 21% lower than comparison production. The smallest difference between Better Cotton and comparison production in absolute and relative terms was recorded in Turkey at 112 kgCO2e/t lint, or 7%.

A comparison of GHG emissions from Better Cotton and comparison production by emissions intensity source is illustrated in Figure 3. At a global level, emissions from fertiliser production were found to be the largest source for both Better Cotton and comparison production representing 48% and 49% of total emissions per tonne lint, respectively. The relative contribution of fertiliser production to total emissions to the overall country totals varied from 29% in Turkey (Better Cotton & comparison production) to 69% and 68% for Better Cotton and comparison production respectively in Tajikistan. Difference in emissions from fertiliser production were identified as being the largest source of difference in emissions between Better Cotton and comparison production at a global level – responsible for 55% of the observed difference. Differences in emissions from fertiliser production between Better Cotton and comparison production were found to be responsible for at least 40% of the total difference and the largest single source of difference in all countries except China, where it was emissions from irrigation.

Globally, the second biggest contributor to emissions was irrigation comprising 23% of emissions from Better Cotton production and 24% for comparison production. At a national level, the relative contribution of emissions from irrigation to total emissions varied; from 9% and 11% of Better Cotton and comparison production in Tajikistan, to 29% and 33% for Better Cotton and comparison production in China. Emissions from irrigation were found to account for 28% of the differences in emissions between Better Cotton and comparison production globally. This varied between countries, responsible for 9% of the reported difference between Better Cotton and comparison production emissions in India to 50% of the reported difference in China.

At a global level, emissions from fertiliser application were found to be the third largest source of emissions, responsible for 11% of total emissions for both Better Cotton and comparison production. The relative contribution of emissions from fertiliser application to total emissions differed between countries; from 4% and 5% of total emissions in China (Better Cotton and comparison production respectively), to 23% and 22% of total emissions in India for Better Cotton and comparison production reciprocally.

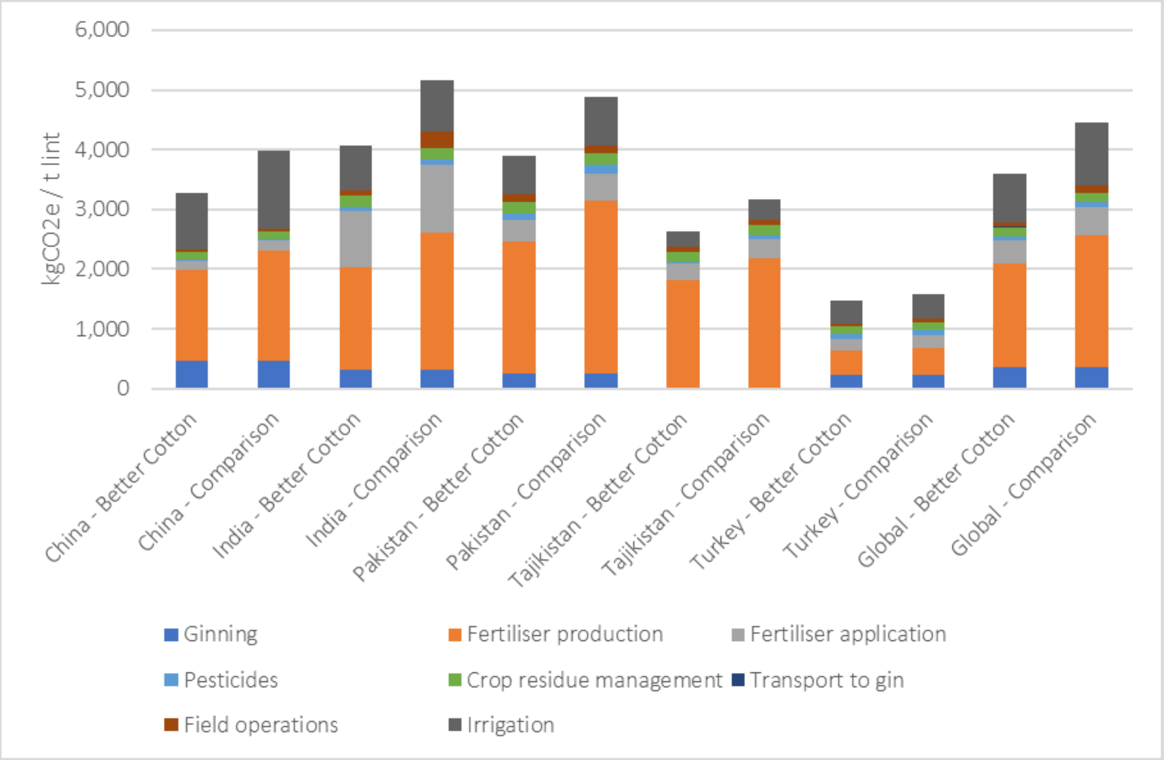

Figure 3: Proportion of GHG emissions by source per tonne cotton lint, per country, per farm category

Emissions from fertiliser production, application and irrigation accounted for over 80% of emissions from both Better Cotton and comparison production and 93% of the reported differences in emissions between Better Cotton and comparison production at a global level. Emissions from ginning, pesticides, crop residues, field operations and transport of seed cotton to gin account for the remainder of the emissions with the last source accounting for less than 1% of total emissions. Emissions from ginning in Tajikistan represented 1% of total emissions due to the low emissions intensity of grid electricity in the country.

4.1.1 Comparison of emissions - China

A comparison of Better Cotton versus comparison production GHG emissions of cotton lint production by emissions source for each of the Chinese provinces in scope for this project are displayed in Figure 4.

At both a national and provincial level Better Cotton had a lower emissions intensity than comparison production. For China overall, Better Cotton production emissions per tonne lint were 699 kgCO2e (or 18%) lower than emissions from comparison production. The largest difference between Better Cotton and comparison production was identified in Shanxi where Better Cotton emissions were 972 kgCO2e / t lint, or 49% lower than comparison production. However, given the very small sample size, and the negligible recorded use of synthetic fertilisers by Better Cotton farmers in Shanxi, this figure may not have been a true reflection of the differences in emissions performance. The next largest absolute and relative difference was found in Xinjiang where Better Cotton production emissions were 663 kgCO2e / t lint (or 17%) lower than comparison production. The smallest differences in both relative and absolute emissions performance between Better Cotton and comparison production were identified in Hubei and Gansu where

Better Cotton production was 5% lower - or 156 kgCO2e / t lint and 191 kgCO2e / t lint lower than comparison production respectively.

At a national level, the main drivers of emissions were fertiliser production and irrigation. Fertiliser production accounted for 46% of total emissions from both Better Cotton and comparison production and irrigation was responsible for 29% of total emissions for Better Cotton and 33% for comparison production.

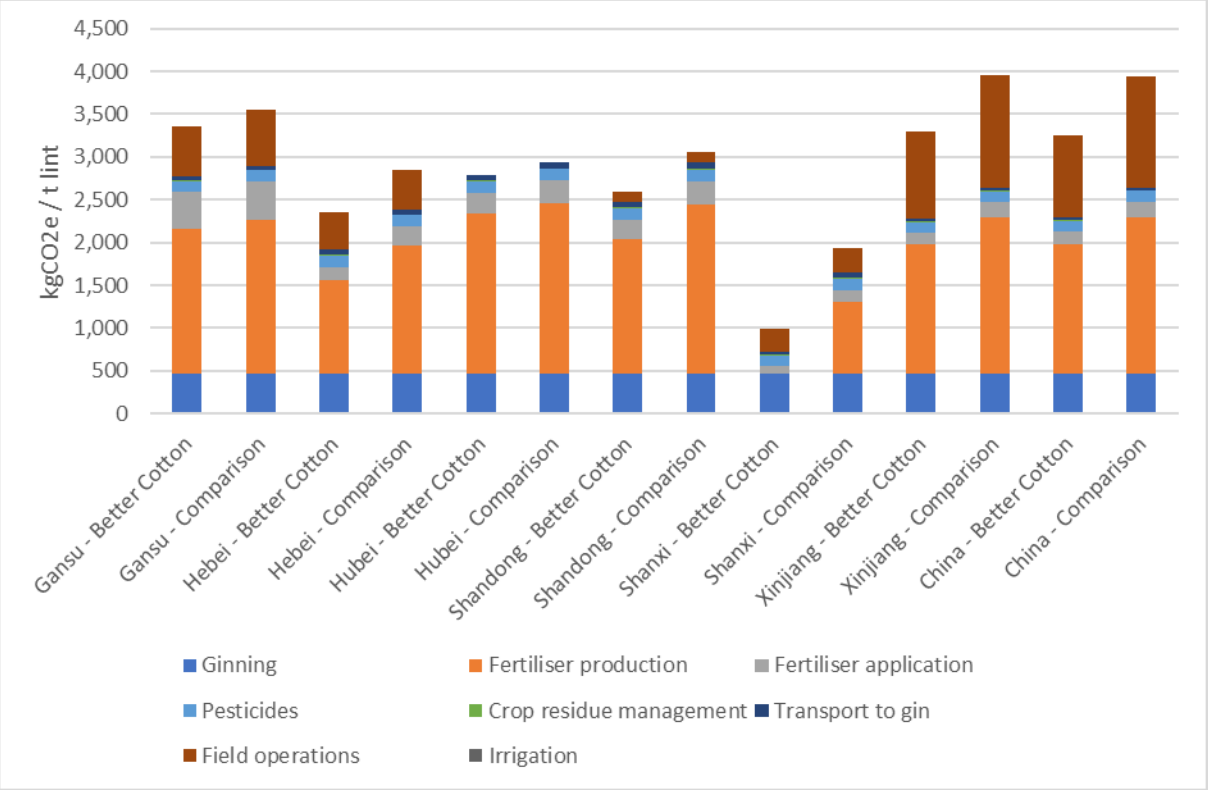

Figure 4: GHG emissions for Better Cotton and comparison production in China by source per tonne cotton lint

Differences in emissions from both irrigation and fertiliser production accounted for over 95% of the reported difference in emissions between Better cotton and comparison production in China. Irrigation accounted for 50% of the observed difference at a national level however this was highly variable between provinces, accounting for less than 6% of the observed difference in emissions between Better Cotton and comparison production in Hebei, Hubei, Shandong, and Shanxi but accounted for 34% in Gansu and 45% in Xinjiang. Emissions from fertiliser production accounted for 44% of the reported differences in emissions between Better Cotton and comparison production at a national level. This varied between provinces accounting for 51% and 48% of the observed differences in emissions between Better Cotton and comparison production in Gansu and Xinjiang respectively and over 80% in Hebei, Hubei, Shandong, and Shanxi. All other emissions sources made minor contributions to the differences in emissions between Better Cotton and comparison production at a national and provincial level. The exception to this was fertiliser application which was found to account for 14% and 12% of the difference between Better Cotton and comparison emissions in Gansu and Hebei respectively.

Emissions resulting from LUC were found to have occurred in Gansu province at an amount of 1.6 tonnes per hectare, per year. If it was assumed that no other crops were grown in the cotton fields and the emissions from LUC were fully allocated to lint production; the carbon footprint of lint would have increased from 3,393 kgCO2e/ t lint to 4,165 kgCO2e/ t lint for Better Cotton, and from 3,584 kgCO2e/ t lint to 4,385 kgCO2e/ t lint for Comparison production. Under such a scenario, emissions from LUC would be a significant driver of emissions in Gansu – representing 19% of total emissions from Better Cotton production and 18% from Comparison production. However, it is important to state that this scenario is unlikely given that it is highly probable that other crops were grown, meaning the true value of emissions from lint production, including those from LUC would lie somewhere between the values stated in this paragraph. At a national level, emissions from LUC were not material even if all were allocated to lint due to the relatively small contribution cotton grown in Gansu makes to total Better Cotton production in China.

4.1.2 Comparison of emissions – India

A comparison of Better Cotton versus comparison production GHG emissions of cotton lint production by emissions source for each of the Indian states in scope for this project are illustrated in Figure *5*.

At both national and state levels, Better Cotton had a lower emissions intensity than comparison production, except for Haryana where Better Cotton production had a marginally higher emissions intensity value (10 kgCO2e / t lint). Nationally, Better Cotton production emitted 1082 kgCO2e (21%) less than comparison production per tonne lint. The largest difference between Better Cotton and comparison production was identified in Karnataka where Better Cotton produced 3,452 kgCO2e (52%) fewer emissions per tonne lint than comparison production. Other significant performance differences were identified in Andhra Pradesh – 1,751 kgCO2e (34%) lower - and Telangana – 1,556 kgCO2e (27%) lower.

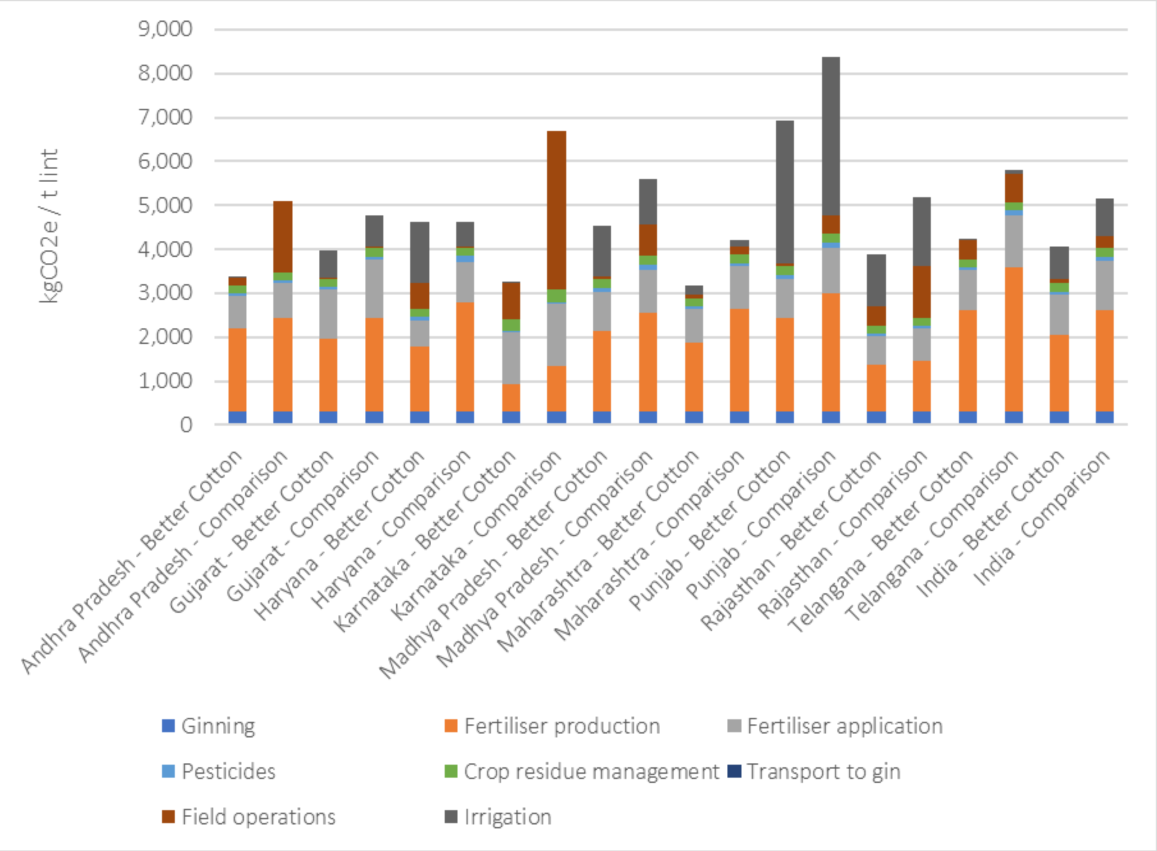

Figure 5: GHG emissions for Better Cotton and comparison production in India by source per tonne cotton lint

Nationally, the main drivers of emissions in descending order of contribution were fertiliser production, fertiliser application and irrigation. Fertiliser production accounted for 42% of total emissions from both Better Cotton production and 44% for comparison production. Fertiliser application was responsible for 23% and 22% of Better Cotton and comparison emissions respectively. Irrigation was responsible for 19% of Better Cotton's total emissions, and 17% of those for comparison production.

At a national level, fertiliser production was found to be the largest driver for differences in emissions between Better Cotton and comparison production, accounting for 53% of the difference. Emissions from fertiliser application was found to be the second largest source responsible for 19% of the difference, followed by irrigation which accounted for 9%.

At a provincial level, fertiliser production was the largest source of difference in emissions between Better Cotton and comparison production in all states aside from Rajasthan where irrigation was the source responsible for the largest difference. The degree to which fertiliser production was responsible for the observed differences in emissions between Better Cotton and comparison ranged from 12% in Karnataka through to 75% in Maharashtra. In Rajasthan, it accounted for 7% of the difference reported. Fertiliser application varied in contribution from as little as 2% in Andhra Pradesh and 5% in Rajasthan, up to 23% in Gujarat. Differences in emissions from irrigation made a significant contribution to the differences observed between Better Cotton and comparison production in the states of Punjab and Rajasthan where it accounted for 24% and 30% respectively.

High emissions intensities from field operations were observed for comparison production in both Karnataka and Andhra Pradesh. This was a function of relatively low cotton yields recorded for several comparison farmers.

4.1.3 Comparison of emissions - Pakistan

A contrast of Better Cotton and comparison production emissions by source for each of the Pakistan provinces in scope for this project are illustrated in Figure *6*.

At a national level, Better Cotton production had 20% lower emissions per tonne of lint than comparison production – a difference of 989 kgCO2e / t lint. Both provinces, Punjab and Sindh recorded lower emissions intensity for Better Cotton production versus comparison production. Punjab's GHG emissions intensity was lower by 1174 kgCO2e / t lint (23%) whist Sindh's was 867 kgCO2e / t lint (19%) lower.

At both a national and state level, the main drivers of emissions in descending order of contribution were fertiliser production, irrigation and fertiliser application. Nationally, fertiliser production accounted for 57% of total emissions from Better Cotton production and 60% for comparison production. Irrigation was responsible for 16% of both Better Cotton and comparison production emissions. And fertiliser application was responsible for 9% of Better Cotton and comparison production emissions.

The biggest contributor to the differences in emissions intensities found between Better Cotton and comparison production was fertiliser production – responsible for 69% of the difference at a national level, 60% in Punjab and 79% in Sindh. Nationally, irrigation accounted for 17% of the difference in emissions between Better Cotton and comparison production, 25% in Punjab and 5% in Sindh. Fertiliser application accounted for 11% of the difference for Pakistan as a whole, 8% in Punjab and 11% in Sindh. The remaining sources accounted for the remaining differences.

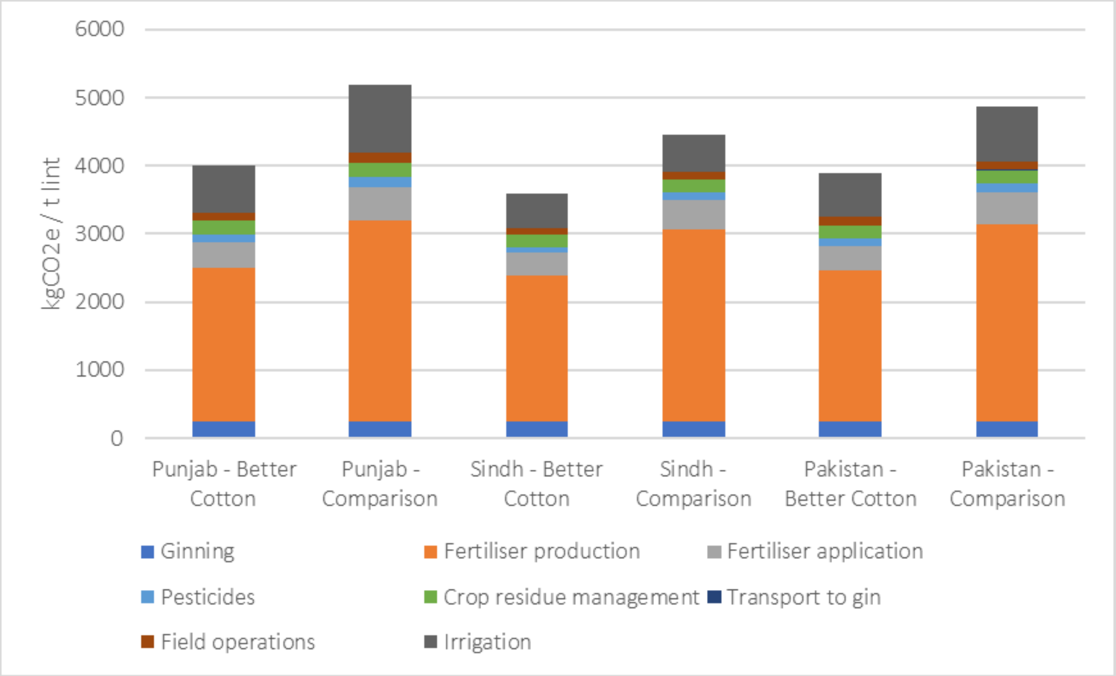

Figure 6: GHG emissions for Better Cotton and comparison production in Pakistan by source per tonne cotton lint

Pakistan is one of BCI's priority countries due to its high share of Better Cotton that has both a large smallholder producer base but also many large farms producing cotton. Emission from Better Cotton and comparison farms for smallholders, medium and large farms by source for each of the two provinces and the country as a whole are displayed in Figure7.

At both a provincial and national level Better Cotton production has a lower emissions intensity per tonne cotton lint produced for both smallholder and medium sized farms. For smallholder production, Better Cotton had 22% lower emissions in Punjab, 30% lower in Sindh, and 24% lower for Pakistan overall. For medium farms, Better Cotton had 24% lower emissions in Punjab, 14% lower in Sindh, and 19% lower for Pakistan overall. A contrast between large farms was not possible as there was no data available for large farms in the comparison cohort.

At both a national and provincial level, the main drivers of emissions for medium and smallholder farms in descending order of contribution were fertiliser production, irrigation and fertiliser application. For smallholders, fertiliser production accounted for 58% of total emissions from Better Cotton production and comparison production. Irrigation was responsible for 15% of both Better Cotton and comparison production emissions. And fertiliser application was responsible for 10% of Better Cotton and comparison production emissions. For medium sized farms, fertiliser production accounted for 56% of total emissions from Better Cotton production and 59% for comparison production. Irrigation was responsible for 18% of total emissions from Better Cotton production and 17% for comparison production. And fertiliser application was responsible for 9% of Better Cotton and comparison production emissions. For Better Cotton producing large farms, emissions from irrigation accounted for 55% of total emissions, fertiliser production was responsible for 31%, and fertiliser application for 5%.

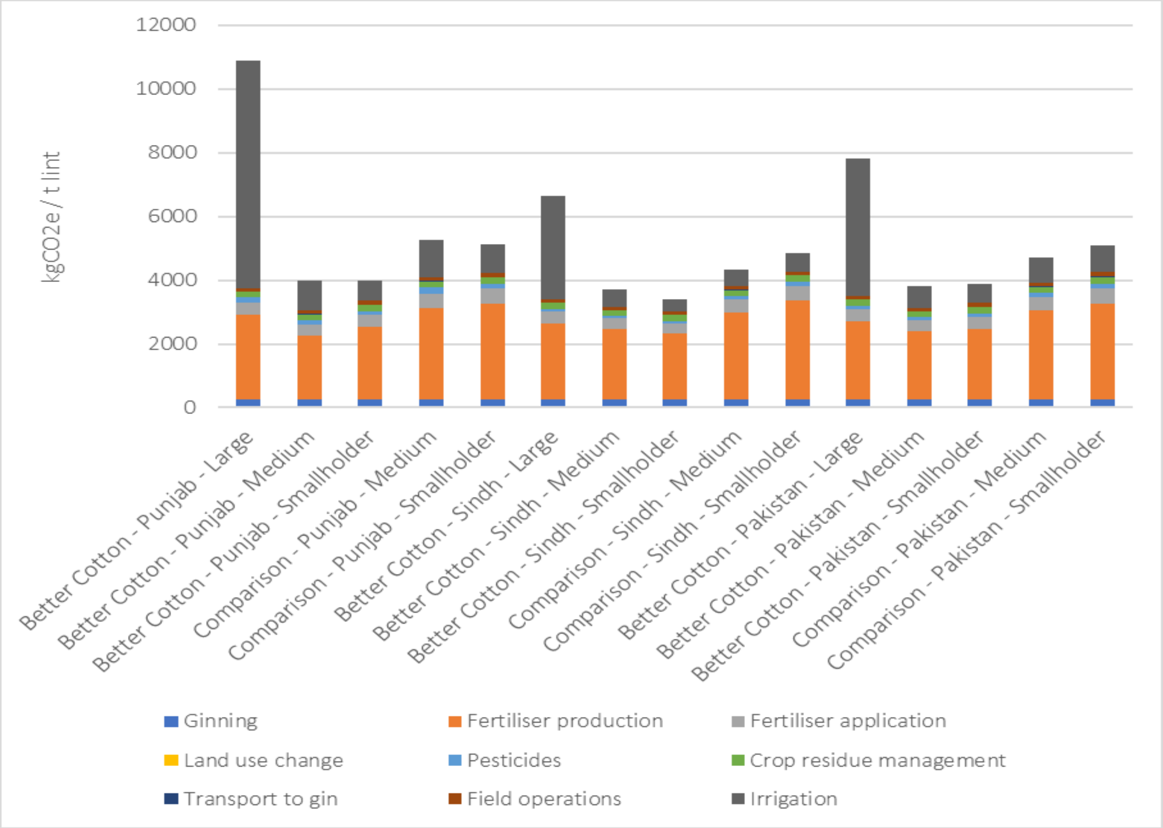

Figure7: GHG emissions for Better Cotton and comparison production in Pakistan by farm size, by source per tonne cotton lint

The biggest contributor to the differences in emissions intensities found between Better Cotton and comparison production for both medium and smallholder farms was fertiliser production – responsible for 74% of the difference between medium farms at a national level, 66% in Punjab and 85% in Sindh. Amongst smallholder farms fertiliser production was responsible for 66% of the observed difference in emissions between Better Cotton and comparison production at a national level. This figure varied from 64% in Punjab to 72% in Sindh.

Nationally, irrigation accounted for 9% of the difference in emissions between Better Cotton and comparison production amongst medium farms and 19% amongst smallholders. At a provincial level this varied from 18% and 21% for medium and smallholder farms in Punjab respectively, to 12% for smallholders in Sindh. Medium sized Better Cotton Farms in Sindh had 2% higher emissions from irrigation than comparison farms.

Fertiliser application accounted for 10% of the difference between medium farms for Pakistan as a whole and 9% for smallholders. At a provincial level, fertiliser application accounted for 9% of the observed difference in Punjab between Better Cotton and comparison production for both medium farms and smallholders. In Sindh, fertiliser application was responsible for 10% of the difference in emissions between medium sized Better Cotton and comparison farms, and 9% amongst smallholders.

4.1.4 Comparison of emissions – Tajikistan

A comparison of emissions from lint production for Better Cotton and comparison production for both the Tajikistan and the provinces of Khatlon and Sughd are illustrated in Figure 8.

When viewed at a national level, Better Cotton production had 17% lower emissions per tonne of lint than comparison production (551 kgCO2e / t lint). Both Khatlon and Sughd recorded lower GHG emissions intensity for Better Cotton production when compared with comparison production. Khatlon's GHG emissions intensity was lower by 800 kgCO2e / t lint (25%) whist Sughd's was 313 kgCO2e / t lint (10%) lower. Emissions from ginning in Tajikistan represented 1% of total emissions due to the low emissions intensity of grid electricity in the country.

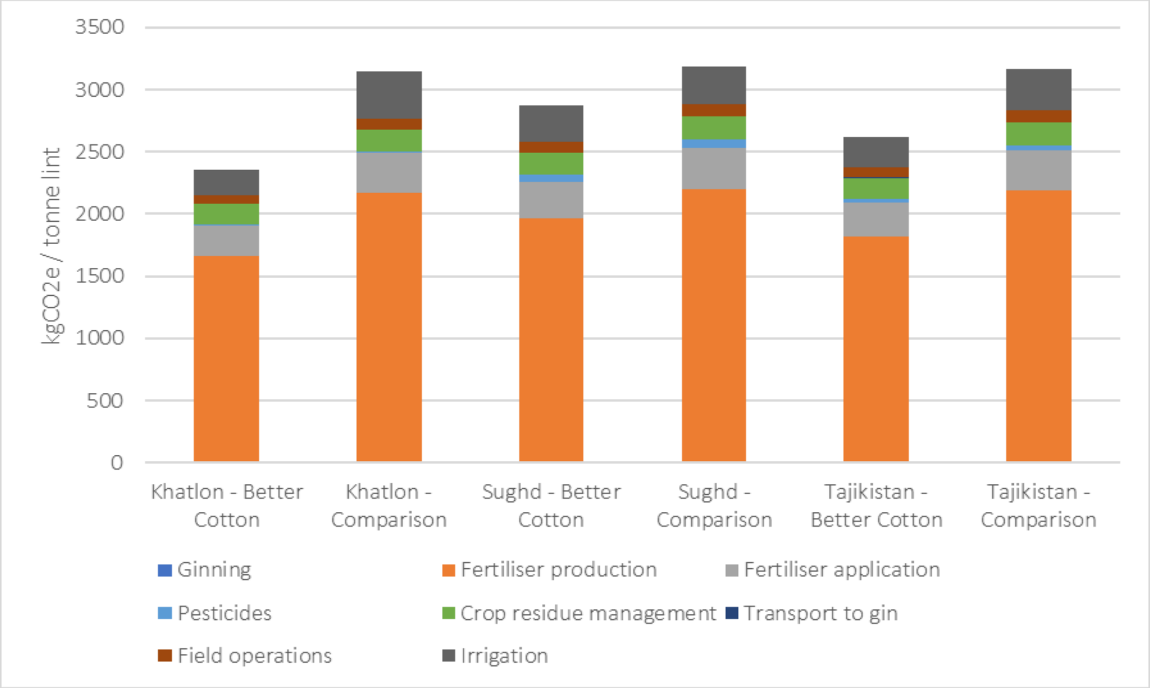

Figure 8: GHG emissions for Better Cotton and comparison production in Tajikistan by source per tonne cotton lint

At a national and regional level, the main drivers of emissions in descending order of contribution were fertiliser production, fertiliser application, and irrigation. Nationally, fertiliser production accounted for 69% of total emissions from Better Cotton production and 68% for comparison production. Fertiliser application was responsible for 10% of Better Cotton and comparison production emissions. And irrigation was responsible for 9% of Better Cotton emissions and 11% of comparison production emissions.

The biggest driver of difference in emissions intensities between Better Cotton and comparison production was fertiliser production – responsible for 67% of the difference at a national level, 63% in Khatlon and 76% in Sughd. Irrigation was the second largest contributor to the differences observed, responsible for 17% for Tajikistan as a whole, 23% in Khatlon and 4% in Sughd. Fertiliser application accounted for 10% of the difference at a national level, 9% in Khatlon and 11% in Sughd. Between them, these three emissions drivers accounted for over 90% of the recorded differences in emissions between Better Cotton and comparison production at both a regional and national level. As such, differences from the remaining emissions sources were not found to be material.

4.1.5 Comparative GHG emissions - Turkey

A comparison of Better Cotton versus comparison GHG emissions of cotton lint production by emissions source for the regions of Turkey in scope for this project are illustrated in Figure 9.

At a country level, Better Cotton production had 7% lower emissions per tonne of cotton lint than comparison production (112 kgCO2e / t lint). Better Cotton recorded lower emissions per tonne lint in all regions aside from Denizli which reported 16 kgCO2e / t lint (1%) higher emissions from Better Cotton production. Among the regions where Better Cotton reported lower emissions than comparison production, the difference ranged from 6 kgCO2e / t lint (<1%) lower in Aydin up to 565 kgCO2e / t lint (25% lower) in Adana.

Across the country as a whole, the main drivers of emissions in descending order of contribution were fertiliser production, irrigation and ginning. Nationally, fertiliser production accounted for 29% of total emissions from both Better Cotton and comparison production. And ginning was responsible for 15% of Better Cotton emissions and 14% of comparison production emissions.

Fertiliser production was identified as being the largest contributor to differences in emissions intensities between Better Cotton and comparison production at an average of 41% for Turkey as a whole. This level of contribution fertiliser production made a large difference in emissions between Better Cotton and comparison production varied between regions, accounting for 24% of the observed difference in Diyarbakir through to 63% in Izmir. Additionally, in the regions of Aydin, Denizli and Hatay emissions from fertiliser production were higher in Better Cotton production than comparison production.

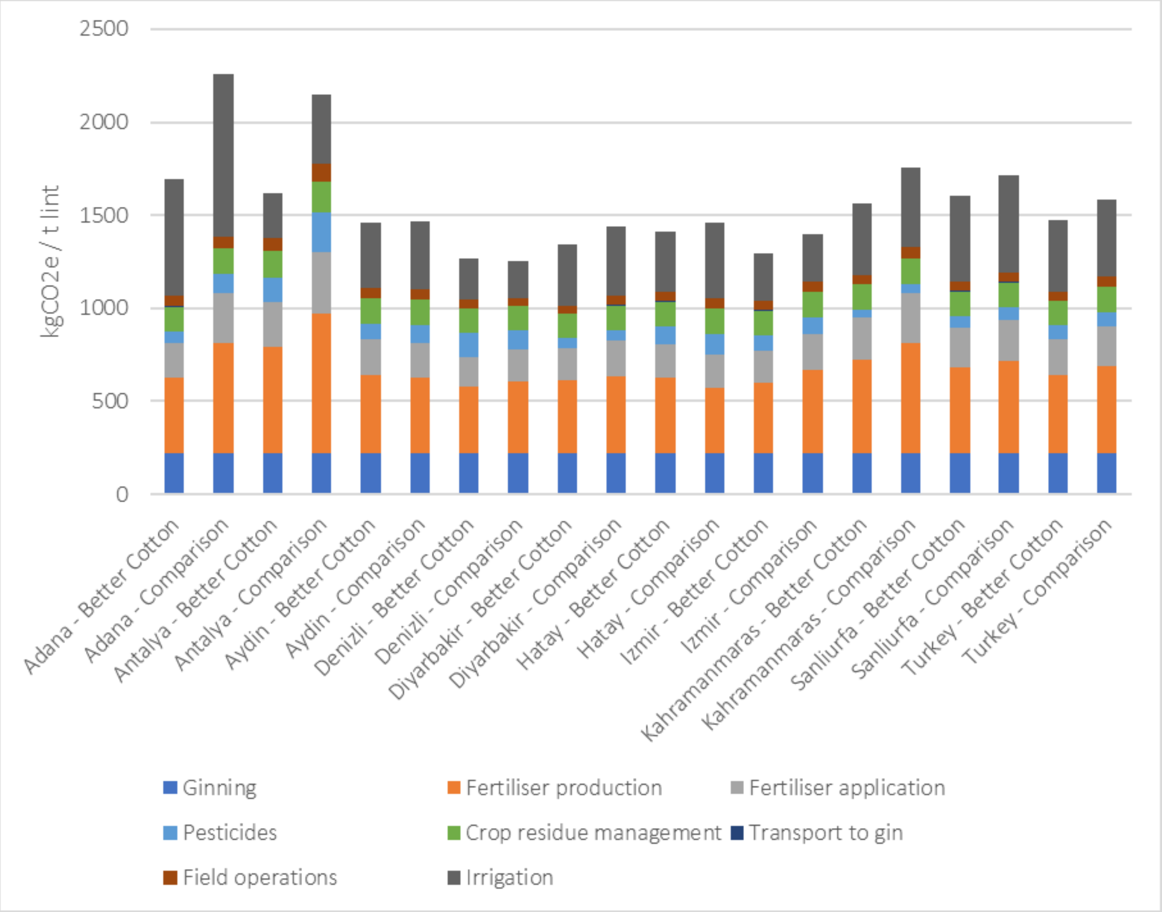

Figure 9: GHG emissions for Better Cotton and comparison production in Turkey by source per tonne cotton lint

The second largest contributor to the difference in emissions between Better Cotton and comparison production was irrigation, accounting for 30% of the reported difference at a national level. The relative contribution to the overall differences observed attributable to irrigation ranged from 5% of the difference in Izmir, through to 56% in Sanliurfa. In the region of Denizli, Better Cotton had higher emissions from irrigation than comparison production.

Differences in emissions from fertiliser application was the third substantial source of difference in emissions between Better Cotton and comparison production, totalling 18% of the total difference at a national level. The relative contribution of fertiliser application emissions to the differences in emissions observed between Better Cotton and comparison production varied between 11% in Diyarbakir up to 23% in Izmir. In the region of Aydin, Better Cotton reported slightly higher emissions from fertiliser application than from comparison production (4.5 kgCO2e / t lint).

4.2 Average GHG emissions for countries contributing over 80% of Better Cotton's total production

The global and national averages across seasons 2015/16, 2016/17 and 2017/18 of GHG emissions from lint production across the countries in scope (Brazil, China, India, Pakistan, and USA) are displayed in Table 5.

Brazil represented the largest producer of lint in scope of this project at 31% of total annual BCI lint production and USA the smallest at 3%. USA and Brazil had the lowest emissions per tonne lint of the countries assessed at 1.93 and 1.99 tCO2e/t respectively. India and Pakistan had the highest emissions intensities at 4.08 and 3.89 tCO2e/t lint in that order.

When examining the proportion of GHG emissions by source at a national level and the study as a whole (Table 6), emissions from fertiliser production represented 47% of total emissions and is the primary emissions driver in each country under study – ranging from 40% in USA to 57% in Pakistan. Irrigation was the second largest emissions hotspot accounting for 17% of total emissions however, there is a degree of variability in its relative contribution across the different countries. Ranging from as little as 2% in Brazil a reflection of the fact that the crop is predominantly rainfed, through to 29% in China where the crop is heavily irrigated.

Table 5: Breakdown of average annual GHG emissions of lint production by country (2015/16 to 2017/18)

Country	Lint production (tonnes)	Percentage of BCI total lint production	Total GHG emissions (tonnes)	GHG emissions / t lint (tCO2e/t)
Brazil	1,139,089	31%	2,268,631	1.99
China	845,604	23%	2,771,702	3.28
India	418,713	11%	1,706,591	4.08
Pakistan	451,572	12%	1,755,196	3.89
USA	123,177	3%	237,174	1.93
Total	**2,978,155**		**8,738,566**	**2.93**

Fertiliser application contributed to 12% of total emissions, varying from 23% of India's emissions through to 4% of China's total emissions, reflecting differences in the soil characteristics and climate between countries. Ginning accounted for 11% of emissions – varying from 6% in Pakistan to 14% in China.

Emissions from crop residue management, field operations and transport to gin - account for the remaining emissions.

Table 6: Breakdown of GHG emissions by source, by country

Emissions source	Brazil	China	India	Pakistan	USA	Average
Crop residue management	7%	4%	5%	5%	8%	5%
Fertiliser application	15%	4%	23%	9%	10%	12%
Fertiliser production	43%	46%	42%	57%	40%	47%
Field operations	3%	1%	2%	3%	3%	2%
Ginning	14%	14%	8%	6%	11%	11%
Irrigation	2%	29%	19%	16%	23%	17%
Pesticides	17%	0%	1%	3%	4%	5%
Transport to gin	0%	0%	0%	0%	0%	0%

Emissions resulting from LUC were found to have occurred in both Brazil and China at an amount of 1.3 tonnes per hectare, per year and 0.002 tonnes per hectare, per year respectively. Assuming no other crops were grown in the cotton fields and the emissions from LUC were fully allocated to lint production; the carbon footprint of lint would have increased from 1.99 tCO2e/ t lint to 2.51 tCO2e/ t lint in Brazil. For China emissions would remain unchanged at 3.28 tCO2e/ t lint for due to the province where emissions from LUC were identified as having occurred represented less than 1% of Better Cotton's production in the country. Under such a scenario, emissions from LUC would be a significant driver of emissions in Brazil – representing 28% of total emissions. Given that Brazil represents 31% of total Better Cotton production in scope for this study, emissions from LUC would represent 9% of total emissions from Better Cotton production and increase the average global carbon footprint from 2.93 tCO2e/ t lint to 3.14 tCO2e/ t lint. However, it is important to note that such a scenario is unlikely given that it is highly probable other crops were grown in addition to cotton, meaning the true value of emissions from lint production including those from LUC would lie somewhere between the values stated in this paragraph.

4.2.1 Average GHG emissions – Brazil

At a national level, across the three seasons covered by this study, Brazil produced on average almost 1.14 million tonnes lint at an average emissions intensity of 1.99 tCO2e / t lint (see Table 7). The states of Bahia and Mato Grosso accounted for 89% of total lint production and 88% of total emissions. The remaining states account for 11% of total production and 12% of emissions.

Table 7: Breakdown of average GHG emissions of lint production by state

State	Lint production (tonnes)	Percentage total lint production	Total GHG emissions (tonnes)	Percentage total GHG emissions	GHG emissions / t lint (tCO2e/t)
Bahia	264,270	23%	478,470	21%	1.81
Goias	37,455	3%	71,577	3%	1.91
Maranhao	25,883	2%	54,278	2%	2.10
Mato Grosso	744,451	65%	1,516,142	67%	2.04
Mato Grosso Do Sul	39,064	3%	78,398	3%	2.01
Minas Gerais	23,147	2%	60,249	3%	2.60
Piaui	4,819	0%	9,518	0%	1.98
Brazil	**1,139,089**		**2,268,631**		**1.99**

When examining the proportion of GHG emissions by source at a state and national level (Table 8), fertiliser production is the largest driver of emissions representing 43% of total emissions. Within this there was a degree of variability between states with emissions from fertiliser production representing 32% of total emissions in Minas Gerais, through to 46% in Mato Grosso.

Table 8: Breakdown of GHG emissions by source, by state

Emissions source	Bahia	Goias	Maranhao	Mato Grosso	Mato Grosso Do Sul	Minas Gerais	Piaui	Brazil average
Crop residue management	7%	7%	7%	6%	7%	5%	7%	**7%**
Fertiliser application	15%	14%	15%	15%	14%	11%	16%	**15%**
Fertiliser production	37%	37%	37%	46%	37%	32%	45%	**43%**
Field operations	3%	3%	3%	3%	3%	2%	3%	**3%**
Ginning	16%	15%	13%	14%	14%	11%	14%	**14%**
Irrigation	3%	4%	0%	1%	0%	28%	0%	**2%**
Pesticides	19%	21%	24%	15%	25%	11%	14%	**17%**
Transport to gin	0%	0%	0%	0%	0%	0%	0%	**0%**

Pesticides contributed to 17% of total emissions, ranging from 11% in Minas Gerais through to 24% and 25% in Maranhao and Mato Grosso Do Sul respectively. Fertiliser application contributed to 15% of total emissions, varying from 11% in Minas Gerais up to 16% in Piaui. Ginning accounted for 14% of emissions, ranging from 11% in Minas Gerais and Mato Grosso up to 16% in Bahia. Emissions from crop residue management, field operations, transport to gin, and irrigation accounted for 11% of total emissions. However, whilst irrigation accounted for 2% of total emissions at a national level, it accounted for 28% of emissions in Minas Gerais where significant irrigation took place. Transport to gin was responsible for less than 0.1% of total emissions at both a state and national level as 90% of the seed cotton harvested was ginned on farm.

Emissions resulting from LUC were found to have occurred in the states of Bahia and Mato Grosso at an amount of 1.5 tonnes per hectare, per year and 1.4 tonnes per hectare, per year respectively. If an assumption were to be made that no other crops were grown in the cotton fields and the emissions from LUC were fully allocated to lint production; the carbon footprint of lint would have increased from 1.81 tCO2e/ t lint to 2.71 tCO2e/ t lint in Bahia and from 2.04 tCO2e/ t lint to 2.09 tCO2e/ t lint in Mato Grosso. Under such a scenario, emissions from LUC would be a significant driver of emissions in both states – representing 33% and 30% of total emissions respectively. Given that Bahia and Mato Grosso represent 88% of Better Cotton production in Brazil, emissions from LUC would represent 28% of total Better Cotton emissions at a national level and the carbon footprint would have increased from 1.99 tCO2e/ t lint to 2.51 tCO2e/ t. However, it is essential to recognise that this scenario is unlikely given that it is highly probable other crops were grown in addition to cotton and that the true value of emissions from lint production, including those from LUC would lie somewhere between the values stated in this paragraph.

4.2.2 Average GHG emissions – China

Typically, across the three seasons covered by this study, China produced on average just over 845 thousand tonnes lint at an average emissions intensity of 3.28 tCO2e / t lint (Table 9). Over 92% of production and just over 94% of emissions were concentrated in Xinjiang. Aside from Gansu, the remaining provinces produced lint at a lower emissions intensity than Xinjiang.

When assessing the relative contribution of emissions sources at a province and national level (Table 10) fertiliser production is the largest driver of emissions representing 46% of total emissions. This varied from 45% in Hebei and Xinjiang to 66% Hubei. Emissions from fertiliser production in Shanxi was zero on account of the farms not recording any nitrogen, phosphorous or potassium fertiliser use. At a national level, irrigation was identified as the second largest emissions driver representing 29% of emissions. However, the significance of irrigation's contribution to total emissions was primarily driven by substantial emissions from irrigation having been identified in Xinjiang which represented over 92% of total production. Amongst the other provinces the relative contribution of emissions from irrigation is a more varied with emissions ranging from zero percent in Hubei, to 31% in Xinjiang.

Table 9: Breakdown of average GHG emissions of lint production by province

Province	Lint (tonnes)	Percentage total lint production	Total GHG emissions (tonnes)	Percentage total emissions	GHG emissions / t lint (tCO2e/t)
Gansu	2,824	0.3%	9,585,263	0.3%	3.39
Hebei	3,106	0.4%	7,457,046	0.3%	2.40
Hubei	9,312	1%	26,558,793	1.0%	2.85
Shandong	49,722	6%	131,514,401	4.7%	2.64
Shanxi	463	0.1%	474,768	0.02%	1.03
Xinjiang	780,178	92%	2,595,383,259	93.7%	3.33
China	**845,604**		**2,770,973,530**		**3.28**

Ginning represented 14% of total emissions at a national level and the relative contribution at a provincial level fluctuated between 14% in Gansu and Xinjiang up to 19% in Hebei. Emissions from ginning accounted for 45% of total emissions in Shanxi because of the absence of emissions from synthetic fertiliser production. The relative significance of emissions from ginning was a function of the high emissions intensity of grid electricity in China.

Emissions from crop residue management, fertiliser application, field operations, pesticides and transport to gin accounted for the remaining 10% of emissions.

Emissions resulting from LUC were found to have occurred in Gansu province at an amount of 1.6 tonnes per hectare, per year. If an assumption were made that no other crops were grown in the cotton fields and the emissions from LUC were fully allocated to lint production; the carbon footprint of lint would have increased from 3.39 tCO2e/ t lint to 4.17 tCO2e/ t lint. Under such a scenario, emissions from LUC would be a significant driver of emissions in Gansu – representing 19% of total emissions. However, it is important to state that this scenario is improbable as it is highly likely that other crops would have been grown in addition to cotton, meaning the true value of emissions from lint production, including those from LUC would lie somewhere between the values stated in this paragraph. At a national level, emissions from LUC were negligible due to the province's representing less than 1% of national production - even if all emissions from LUC we allocated to lint.

Table 10: Breakdown of GHG emissions by source, by province

Emissions source	Gansu	Hebei	Hubei	Shandong	Shanxi	Xinjiang	China
Crop residue management	4%	6%	5%	5%	13%	4%	**4%**
Fertiliser application	13%	7%	9%	8%	8%	4%	**4%**
Fertiliser production	50%	45%	66%	59%	0%	45%	**46%**
Field operations	1%	2%	2%	3%	4%	1%	**1%**
Ginning	14%	19%	16%	18%	45%	14%	**14%**
Irrigation	17%	18%	0%	5%	25%	31%	**29%**
Pesticides	1%	2%	2%	2%	4%	1%	**1%**
Transport to gin	0%	0%	0%	0%	0%	0%	**0%**

4.2.3 Average GHG emissions – India

At a national level, across the three seasons covered in this study, India produced on average almost 419 thousand tonnes lint at an average emissions intensity of 4.08 tCO2e / t lint (Table 11).

Table 11: Breakdown of average GHG emissions of lint production by state

State	Lint production (tonnes)	Percentage total lint production	Total GHG emissions (tonnes)	Percentage total GHG emissions	GHG emissions / t lint (tCO2e/t)
Andhra Pradesh	7,318	1.7%	24,440	1.4%	3.35
Gujarat	152,827	36.5%	606,732	35.6%	3.98
Haryana	14,375	3.4%	66,407	3.9%	4.63
Karnataka	1,637	0.4%	5,277	0.3%	3.23
Madhya Pradesh	37,366	8.9%	169,361	9.9%	4.55
Maharashtra	123,261	29.4%	389,207	22.8%	3.17
Punjab	38,043	9.1%	262,722	15.4%	6.93
Rajasthan	9,650	2.3%	37,297	2.2%	3.88
Telangana	34,236	8.2%	145,147	8.5%	4.25
India	**418,713**		**1,706,591**		**4.08**

The states of Gujarat and Maharashtra accounted for almost two thirds of BCI India total lint production and 58% of total emissions, indicating that the lint production in these states had lower emissions intensities than the states which accounted for the remaining third of lint production. The state of Punjab was identified as having the highest emissions intensity at 6.93 tCO2e / t lint.

When examining the relative significance of GHG emissions by source at a state and national level (Table 12), fertiliser production is the largest driver of emissions representing 42% of total emissions. Within this, there was a significant amount of variability between states with emissions from fertiliser production, from 19% of total emissions in Karnataka through to over 50% in Andhra Pradesh and Telangana. Emissions from fertiliser application was an additional significant driver of emissions at 23% of total emissions at a national level. This varied at a state level, from 12% of total emissions in Punjab to 37% in Karnataka. It is worthy of note that in Karnataka emissions from fertiliser application were almost double that from fertiliser production - a function of the state's prevailing soil characteristics and climate. Irrigation contributed on average 19% of total emissions however this fluctuated between states based on the amount of irrigation which took place. Haryana, Punjab and Rajasthan all recorded 30% or more of their total emissions coming from irrigation. In Punjab, emissions from irrigation comprised almost half of total emissions. Ginning accounted for 8% of national emissions and varied from 5% to 10% between states. Crop residue management, field operations, pesticides, and transport to gin accounted for the remaining 8% of total emissions. Transport to gin accounted for less than 0.1% of total emissions at both a state and national level on account of the short distance seed cotton is transported from farm to gin.

Table 12: Breakdown of GHG emissions by source, by state

Emissions source	Andhra Pradesh	Gujarat	Haryana	Karnataka	Madhya Pradesh	Maharashtra	Punjab	Rajasthan	Telangana	India
Crop residue management	6%	5%	4%	9%	5%	6%	3%	4%	5%	**5%**
Fertiliser application	22%	28%	13%	37%	19%	24%	12%	17%	21%	**23%**
Fertiliser production	56%	41%	32%	19%	40%	49%	31%	27%	54%	**42%**
Field operations	5%	0%	13%	25%	1%	3%	1%	11%	10%	**2%**
Ginning	10%	8%	6%	10%	7%	10%	5%	8%	8%	**8%**
Irrigation	0%	16%	30%	0%	26%	6%	47%	31%	1%	**19%**
Pesticides	2%	2%	2%	0%	2%	1%	2%	2%	1%	**1%**
Transport to gin	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**

4.2.4 Average GHG emissions – Pakistan

Across the three seasons covered in this study, Pakistan produced on average just over 451 thousand tonnes of lint with an average emissions intensity of 3.89 tCO2e / t lint (Table 13).

Table 13: Breakdown of average GHG emissions of lint production by province

Province	Lint production (tonnes)	Percentage total lint production	Total GHG emissions (tonnes)	Percentage total GHG emissions	GHG emissions / t lint (tCO2e/t)
Punjab	314,613	69.7%	1,262,893	72.0%	4.01
Sindh	136,959	30.3%	492,303	28.0%	3.59
Total	**451,572**		**1,755,196**		**3.89**

The province of Punjab accounted for almost 70% of production and 72% of emissions whilst Sindh was responsible for just over 30% of production and 28% of emissions.

When the relative significance of GHG emissions by source at a province level were assessed (Table 14), fertiliser production was found to be the main driver of emissions accounting for 57% of total emissions at a country level and 56% for Punjab and 60% for Sindh. Irrigation was identified as the second largest source of emissions accounting for 16% at a national level - 17% for Punjab and 14% for Sindh. Fertiliser application was found to be responsible for 9% of total emissions at a national level and Punjab accounted for 10% of Sind's total emissions.

The remaining emissions sources, crop residue management, field operations, ginning, pesticides, and transport to gin each represented between 0.1% and 6% of emissions with no significant differences between the provinces for each of these sources. No emissions from LUC were reported.

Table 14: Breakdown of GHG emissions by source, by province

Emissions source	Punjab	Sindh	Pakistan
Crop residue management	5%	5%	**5%**
Fertiliser application	9%	10%	**9%**
Fertiliser production	56%	60%	**57%**
Field operations	3%	3%	**3%**
Ginning	6%	7%	**6%**
Irrigation	17%	14%	**16%**
Pesticides	3%	2%	**3%**
Transport to gin	0%	0%	**0%**

Pakistan is a priority country for BCI due to its high share of Better Cotton that has both a large, medium and smallholder producer base. A breakdown of the percentage of cotton production by farm size and their respective emissions intensities are detailed in Table 15. Based on this data, large farms have over double the emissions intensity of either medium or smallholder farms. This was due to significantly higher emissions from irrigation and moderately higher emissions from fertiliser production, fertiliser application, and pesticides.

Table 15: Breakdown of average GHG emissions of lint production by farm size

Farm category	Percentage total lint production	Percentage total GHG emissions	GHG emissions / t lint (tCO2e/t)
Large	1.5%	3.1%	7.83
Medium	21.7%	21.1%	3.83
Smallholder	76.8%	75.8%	3.88

When the relative significance of GHG emissions by farm size, by source was examined (Table 16), fertiliser production was found to be the main driver of emissions for both smallholder and medium farms accounting for 58% and 56% of total emissions respectively. However, for large farms, irrigation was found to be the primary emissions driver accounting for 55% of total emissions. Irrigation was identified as the second largest source of emissions for medium farms and smallholders, representing 18% and 15% of total emissions respectively. For large farms the second largest source of emissions was fertiliser production, accounting for 31% of total emission. Fertiliser application was the third largest source of emissions accounting for 5% of total emissions for large farms, 9% for medium farms, and 10% for smallholders.

Table 16: Breakdown of GHG emissions by source, by farm size

Emissions source	Large	Medium	Smallholder
Crop residue management	2%	5%	5%
Fertiliser application	5%	9%	10%
Fertiliser production	31%	56%	58%
Field operations	1%	3%	3%
Ginning	3%	6%	6%
Irrigation	55%	18%	15%
Pesticides	1%	2%	3%
Transport to gin	0%	0%	0%

The remaining emissions sources, crop residue management, field operations, ginning, pesticides, and transport to gin each represented between 1% and 6% of emissions with no significant differences between farm sizes. No emissions from LUC were reported.

4.2.5 Average GHG emissions – USA

At a national level, across the three seasons covered by this study, USA produced on average just over 123 thousand tonnes lint with an average emissions intensity of 1.93 tCO2e / t lint (Table 17). The states of Arkansas, California and Texas amounted to 57% of total BCI USA production and emissions. From an emissions intensity perspective, the states with the lowest emissions were Virginia at 0.64 tCO2e/t lint and Arizona at 0.88 tCO2e/t lint. However, Virginia's sample size was the smallest in USA and between them the two state's production represented less than 3% of total production and 1% of total emissions. The states with the highest emissions intensity per tCO2e/t lint were Georgia (2.53 tCO2e/t lint), Florida and Tennessee – both at 2.33 tCO2e/t lint. However, both Florida and Tennessee made modest contributions to total USA production and emissions.

Table 17: Breakdown of average GHG emissions of lint production by state

State	Lint production (tonnes)	Percentage total lint production	Total GHG emissions (tonnes)	Percentage total GHG emissions	GHG emissions / t lint (tCO2e/t)
Alabama	5,978	5%	9,230	4%	1.55
Arizona	1,907	2%	1,673	1%	0.88
Arkansas	26,908	22%	39,691	17%	1.49
California	22,301	18%	47,873	20%	2.16
Florida	2,545	2%	5,893	2%	2.33
Georgia	11,258	9%	28,328	12%	2.53
Louisiana	1,590	1%	2,418	1%	1.53
Mississippi	10,343	8%	21,633	9%	2.11
Missouri	3,733	3%	5,274	2%	1.42
New Mexico	630	1%	1,181	0%	1.89
North Carolina	7,753	6%	11,490	5%	1.49
South Carolina	737	1%	1,461	1%	2.00
Tennessee	5,444	4%	12,614	5%	2.33
Texas	21,219	17%	47,885	20%	2.27
Virginia	831	1%	529	0%	0.64
USA	**123,177**		**237,174**		**1.93**

When examining the proportion of GHG emissions by source at a state and national level (Table 18), fertiliser production is the largest driver of emissions representing 40% of total emissions. In all states aside from California, New Mexico, Texas and Virginia fertiliser production was the largest source of emissions.

Table 18: Breakdown of GHG emissions by source, by state

State	Crop residue management	Fertiliser application	Fertiliser production	Field operations	Ginning	Irrigation	Pesticides	Transport to gin
Alabama	11%	18%	38%	6%	14%	3%	9%	0%
Arizona	15%	11%	37%	4%	25%	1%	6%	1%
Arkansas	10%	10%	43%	4%	15%	13%	5%	0%
California	6%	7%	34%	2%	10%	38%	2%	0%
Florida	7%	11%	55%	4%	9%	8%	4%	0%
Georgia	7%	14%	53%	4%	9%	10%	3%	0%
Louisiana	10%	11%	42%	5%	15%	8%	9%	0%
Mississippi	7%	9%	50%	3%	10%	13%	7%	0%
Missouri	10%	10%	49%	4%	16%	7%	3%	1%
New Mexico	8%	9%	29%	3%	12%	35%	4%	0%
North Carolina	11%	18%	41%	5%	15%	3%	6%	0%
South Carolina	8%	15%	48%	4%	11%	4%	9%	0%
Tennessee	7%	14%	59%	3%	9%	2%	5%	0%
Texas	7%	8%	29%	3%	10%	39%	3%	0%
Virginia	23%	23%	0%	8%	35%	6%	3%	1%
USA	**8%**	**10%**	**40%**	**3%**	**11%**	**23%**	**4%**	**0%**

In California, New Mexico, and Texas irrigation was identified as the main source of emissions representing over 35% of total emissions on account of the volume of water being applied and the amount of energy required to pump the water from below ground sources. In Virginia, the main source of emissions was identified as ginning, this was due to low levels of emissions from fertiliser production and irrigation being reported. Overall, irrigation was the second largest source of emissions at a national level representing 23% if total emissions. This was driven by the high level of emissions from irrigation in two of the largest lint producing states in this study – California and Texas. Outside of these two states, irrigation accounted for between 1% and 13% of the state's total emissions.

Ginning represented 11% of USA's total emissions due to the relatively high intensity of the country's grid electricity. The relative contribution of ginning to the individual state's total emissions typically varied from 9% in Florida, Georgia, and Tennessee to 16% Missouri. Ginning accounted for 35% of total emissions in Virginia however this was due to no emissions from fertiliser production and small amounts from irrigation. The final significant source of emissions was fertiliser application which represented 10% of total emissions at a national level; this varied from 7% in California through to 18% in Alabama and North Carolina. Virginia fertiliser application represented 23% of emissions as did emissions from crop residue management. These disproportionately high percentage values can be attributed to the non-use of synthetic fertilisers skewing the results.

The remaining emissions sources (crop residue management, field operations, pesticides, and transport to gin) accounted for 15% of total emissions. No emissions from LUC were reported.

5 GHG reduction opportunities

In conducting this study, potential opportunities were identified to help reduce GHG emissions from Better Cotton production. These can be grouped into two categories which are:

1. Reduced the use of inputs, for example fertilisers, irrigation.
2. Adoption of land management practices that sequester carbon.

5.1 Reduced use of inputs

Emissions from fertiliser production and irrigation were identified as material contributors to total emissions both at a global level and for each of the individual countries covered by this study; accounting for an average of 42% and 14% of total emissions, respectively.

Whilst farmers have little control over the energy intensity of fertiliser production, once the fertiliser arrives on to farm, it is up to the farmer to ensure it is used appropriately. By more accurately matching fertiliser additions to crop requirements, soil properties and timing less fertiliser is required to achieve the same results. Based on Cool Farm Tool modelling, if nitrate fertiliser use were reduced by 10 kilograms per hectare, emissions from fertiliser production could be reduced by 4% in Turkey, 10% in USA, 9% in India, 6% in Pakistan, 7% in Brazil, 6% in Tajikistan and 4% in China. By ensuring factors such as product selection, timing, rate, weather conditions, crop demand, soil properties are considered when fertilisers are applied, emissions reductions of between 10% to 30% from fertiliser application[7] may be possible through minimising of losses through leaching and nitrogen volatilisation.

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[7] https://www.yara.co.uk/crop-nutrition/agronomy-advice/reducing-fertiliser-carbon-footprint/

Moving water from source to crop can be an energy intensive process, especially when the water source is either some distance from the crop or comes from a source deep beneath the ground. Whilst there is little growers can do about where water is sourced, there are a number of actions that can be taken to reduce the GHG emissions associated with irrigation. Firstly, growers can look to adopt precision irrigation technologies such as drip irrigation systems. Based on modelling undertaken in the CFT, moving from a rain gun or pivot irrigation system and using the same volume of water can reduce irrigation emissions by 34% and 26% respectively. In addition, drip irrigation allows for the water to be delivered more closely to a plant's roots, it is highly likely that the volume of irrigation can be reduced. A 10% reduction in water would translate into a 10% reduction in emissions from irrigation. Where adoption of more precise irrigation is not possible, opportunities still exist to reduce emissions from irrigation through improvements in more closely matching irrigation applications with the crop's water requirements. Additionally, reductions in emissions are possible by powering irrigation systems through either through renewable electricity generated on-site or purchased from certified sources.

Additionally, gins could potentially be powered by renewables. Given that ginning represented 10% of Better Cotton's average total emissions, if 50% of cotton harvested was processed through gins powered by zero carbon renewables this would reduce Better Cotton's total footprint by 5%. The savings could be even greater if efforts were focussed in regions such as China, USA and India where grid electricity has a higher emissions intensity. It is noted that making such a change is outside of BCI's scope however it is something BCI could advocate for amongst stakeholders and mobilise them to act.

5.2 Adoption of land management practices that sequester carbon

Opportunities to further reduce GHG emissions exist through working with Better Cotton growers to adopt land management practices such as moving to reduced till/no till production systems, planting of cover crops and the addition of farmyard manures, slurries and digestates to the soil which sequester carbon in the soil.

Minimum tillage practices have been reported to reduce GHG emissions through decreased use of fossil fuels in field operations and by increasing carbon sequestration in soil. However, this would need to be balanced with the potential for carbon to be lost to the atmosphere through decomposition of plant material left on the soil surface. Based on CFT calculations, adoption of reduced tillage or no tillage practices could sequester between 400 kgCO2 and 1,400 kgCO2 per hectare, per year - depending upon the practice adopted, the percentage of the fields the practices are applied, soil texture, current levels of soil organic matter and climate. In terms of carbon reductions, adoption of these practices could equate to a reduction in emissions of between 12% and 42% in Turkey, 15% to 51% in USA, 12% to 43% in India, 11% to 40% in Pakistan, 8% to 28% in Brazil, 13% to 46% in Tajikistan, and 5% to 16% in China.

Cover crops help to add organic matter to soil, helping to build fertility thereby reducing the need for synthetic fertilisers. In addition, cover crops help to improve moisture availability during periods of erratic weather. This in turn can help lessen the need for irrigation. Based on CFT calculations, adoption of cover cropping could sequester more than 1,200 kgCO2 per hectare, per year - depending upon soil texture, current levels of soil organic matter and climate. In terms of carbon reductions adoption of cover cropping could result in a reduction in emissions of 36% in Turkey, 43% in USA, 37% in India, 34% in Pakistan, 24% in Brazil, 39% in Tajikistan, and 14% in China.

Both cover cropping and reduced/no till has been shown to have additional benefits which would indirectly feed into a reduction in emissions. For example, both practices are widely recommended to help protect soils from erosion and degradation of structure and improve soil health. Healthy soils require fewer synthetic inputs to support proper crop development.

6 Data collection recommendations for future studies

To help refine the accuracy of subsequent GHG quantification exercises using the CFT, the following additions/changes to farm level data collected by BCI are proposed. Doing so would help to reduce the number of assumptions made in the GHG emissions calculation – thereby refining their accuracy.

- Crop residues: collect information from the farms as to how crop residues are managed post-harvest as the treatment of residues from crops (such as straw or leaf litter) can result in emissions of CH4 and N2O. If residues are left on the field, incorporated, or mulched, the nitrogen contained in the residues contributes to the nitrogen input, which contributes to N2O emissions. Capturing this information and its use in future calculations could have a modest impact on the results.
- Soil characteristics: gather information from farmers about their soil texture, soil organic matter percentages, average soil moisture, soil drainage and soil pH. Soil characteristics play an important role in the calculation of the amount of N2O emissions from fertiliser applications. Capturing this information and its use in future calculations could have a moderate impact on the results.
- Farmyard manure (or slurry/digestate) applications: ask farmers who apply organic fertilisers if this is a new practice adopted in the last 20 years. If it is a new practice in the last 20 years, carbon accounting methodologies recognise that the soil carbon stock is increasing as carbon sequestration is occurring – resulting in negative emissions. Capturing this information and its use in future calculations could have a moderate impact on the results – depending upon how much manure is added.
- Field operations: obtain information from farmers as to which field operations (field preparation, sowing, fertilisation, crop protection, harvesting) are undertaken using machinery and the nature and number of occurrences of these. Mechanised field operations will require the use of diesel fuel which contributes to the crop's GHG emissions. Capturing this information and its use in future calculations could have a moderate impact on the results.
- Irrigation: collect details from farms on their method of irrigation, water source, whether the irrigation system is powered by pumps (diesel or electricity) and if so the depth from which water is pumped and the distance which the water is pumped from source to field. Given that irrigation can be an energy intensive operation and has been identified as a significant source of GHG emissions in all geographies assessed in this project. Capturing this information and its use in future calculations could have a significant impact on the results.
- Land management practices: gathering information from farmers relating to any alterations in land management practices (tillage practices and use of cover crops) and tree planting/removal on farm in the last 20 years would allow for more accurate calculation of any carbon emissions or sequestration which has taken place due to

changing carbon stocks. Capturing this information and its use in future calculations could have a significant impact on the results.

- Land use change: obtain information from farmers or other first-hand sources on whether the land used to grow cotton has been converted from either forest or grassland in the last 20 years, and if so what proportion of their cotton growing land was converted. Capturing this information and its use in future calculations could have a significant impact on the results. To ensure the emissions from LUC can be correctly allocated to lint, collection of information relating to other crops cultivated on the land in the annual rotation and the value of the crops harvested would be required. Should values of the crops not be available, this could be ascertained through desk-based research.
- Transportation of cotton from farm to gin: gathering information from farmers on the distance the seed cotton is transported from farm to gin and the mode of transport would help to refine the accuracy of GHG emissions calculated resulting from this activity. Capturing this information could have a modest impact on the results.

If the above recommendations would be deemed too onerous to collect from farmers, BCI could potentially engage their implementation partners to provide commentary on the above recommendations at a Producer Unit level.