Bayer Crop Science

Assessment of on-field GHG emission of crops

Report – Post 3rd review cycle

October 2023

Note to reviewers:

Through this critical review, Bayer aims to demonstrate a method for measuring specific on-farm GHG emissions in a reasonable approach and that the baselining and performance tracking methodology is adequate.

Disclaimer

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ANA Brazil	Agência Nacional de Águas e Saneamento Básico, Brasil National Water and Basic Sanitation Agency, Brazil
BCS	Bayer Crop Science
CCCs	Crop-country combinations
CDP	Carbon Disclosure Project
Cf.	compare
CFA	Cool Farm Alliance
CFT	Cool Farm Tool
CH_4	Methane
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
CPP	Crop protection product
EASAC	European Academies Science Advisory Council
FAO	Food and Agriculture Organization of the United Nations
FAQ	Frequently asked questions
FU	Functional unit
GHG	Greenhouse gas
Gt	Gigatons
ha	Hectare
ILCD	International Reference Life Cycle Data System
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogram
kWh	Kilowatt per hour
LCA	Life Cycle Assessment
mt	metric ton (1 mt equals 1,000 kg)
N	Nitrogen
N_2O	Nitrous oxide
NH_3	Ammonia
NO	Nitric oxide
pH	Potential of Hydrogen - Logarithmic expression of the hydrogen ions concentration in a solution
SBTi	Science Based Targets initiative
SDGs	Sustainable Development Goals
t	Ton
UK	United Kingdom
UN	United Nations
US	United States of America
USDA-NASS	U.S. Department of Agriculture - National Agricultural Statistics Service
WRI	World Resources Institute
WWF	World Wide Fund for Nature
yr	Year

1. Context and Objectives

1.1 Context

Bayer is a Life Science company with a more than 150-year history and core competencies in the areas of health care and nutrition. Contributing to sustainable development has become a core element of Bayer's corporate strategy. For Bayer Crop Science (BCS), a division of Bayer AG, sustainability focus areas and goals were developed to fulfill the commitment to shape the future of sustainable agriculture. BCS' sustainability focus areas were developed to address the end-to-end impacts of agriculture on the following: field GHG emissions, environmental impact reduction of crop protection, improving the livelihoods of smallholder farmers and driving positive change in water productivity in water scarce regional cropping systems.

According to the Intergovernmental Panel on Climate Change (IPCC), the GHG emissions from the global food system are estimated to be 21-37% of total net anthropogenic GHG emissions (IPCC, 2019). As one of the largest agricultural companies in the world, Bayer recognizes the impact of its products and aims to empower farmers to reduce the on-field GHG emissions of agriculture wherever the company operates. As part of its sustainability objectives, BCS has committed to **reduce on-field GHG emissions of its farming customers per mass unit of crop produced in its major markets by 30% by 2030 (i.e., the BCS on-field GHG commitment)**. The scope of BCS' efforts is focused on emissions of major GHGs (CO_2, CH_4, N_2O) from the field operations. To meet this objective, Bayer aims to foster and encourage the adoption of climate-smart practices and technologies amongst its farming customer base.

The main objective of this report is to document how BCS is quantifying GHG emissions and soil carbon sequestration. More specifically, this report documents how BCS compiles inventory data and conducts a GHG impact assessment based on the GHG Protocol and IPPC special report on Climate Change and Land and IPCC GHG emission factors for agriculture, as well as internationally recognized and empirically validated Cool Farm Tool (CFT) calculator. The CFT will further be used in the determination of improvement potentials towards the GHG reduction target. While being aware of the potential risk of burden shifting, BCS emphasizes that this assessment focuses on the GHG emissions and soil carbon sequestration resulting from field operations and does not cover other impact categories such as ecotoxicity and other BCS sustainability focus areas as they are assessed and documented in separate reports by different task forces.

In addition to setting targets on the GHG emissions resulting from farming, BCS has committed to reduce the environmental impact of Bayer's global crop protection portfolio per hectare by 30% by 2030. BCS also strives to improve the livelihoods of 100 million smallholder farmers through access to education and tailored solutions and has set a target for improving water use per kg of rice crop by 25% by 2030, by transforming rice-cropping systems for smallholder customers in the relevant regions where BCS operates, starting in India. In the context of this report, BCS does not conduct a full-fledged LCA according to ISO 14040/44 but intends to use the standard as a framework to document the project in the present report. With the critical review by external experts, BCS aims to demonstrate a method for measuring and accounting specific GHG emissions in a reasonable approach and that the baselining and performance tracking methodology is adequate. In case of external communication of the present report or any material based on it, BCS intends to publish the external expert panels feedback with transparency, and it intends to consult external expertise for validation of its sustainability commitment methodologies also in the future.

1.2 Review of GHG emissions related to agriculture, forestry, and land use activities with BCS' role in GHG reduction.

Food related emissions are those generated during production activities (crops and livestock), land use change and pre- and post-production processes. Production and land use change result in emissions generated on agricultural land, while pre- and post-production refer to emissions from supply chain processes including transportation, processing, and manufacturing of inputs. In 2019, the global anthropogenic emissions were estimated to be 54 billion tonnes of CO_2eq in which 17 billion tonnes CO_2eq (31%) comes from agricultural related activities. Breaking the share of agricultural related sources (31%) from the total anthropogenic emissions down to single gases, CO_2 accounts for 21%, methane (CH_4) accounts for 53% while nitrous oxide (N_2O) accounts for the highest which is 78 % (FAO., 2021). Aligning current production and consumption models in the agri-food sector with planetary boundaries[1] is vital for constructing a resilient food system and ensuring companies continue to thrive in a resource-constrained world.

According to the FAO (2021), farmgate emissions account for the largest share of the agricultural related emissions in 2019 with about 7 billion tonnes CO_2eq. While agriculture plays a role in GHG emission (Figure 1), climate change on the other hand also places significant pressures on agriculture in the form of reduced yields, land degradation, and increased threats from pathogens and disease. That means agriculture is confronted with tremendous challenges regarding climate change mitigation and adaptation.

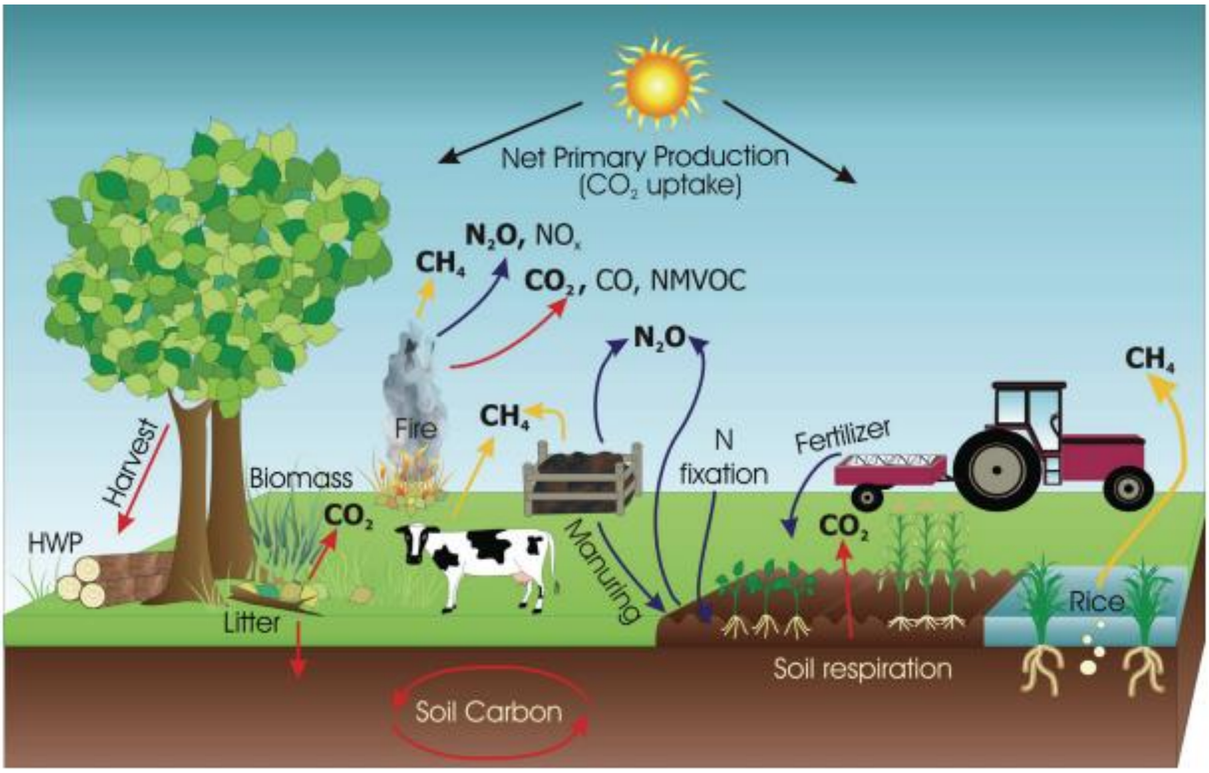

Figure 1 - Main sources and sinks of emissions from agricultural system. Figure taken from *(IPCC, 2006)*
CH_4: methane, CO_2: carbon dioxide, N_2O: nitrous dioxide, NOx: Nitrogen oxides, CO: Carbon monoxide, NMVOC: non-methane volatile organic compounds, HWP: harvested wood products.

BCS has a responsibility to advance a net zero future for agriculture. Great progress has already been made to reduce agriculture's overall carbon footprint, but BCS must work collectively with farmers and global partners to do even more. This will require innovation and new advancements in agricultural

[1] As defined by Steffen, 2015, "The planetary boundaries framework defines a safe operating space for humanity based on the intrinsic biophysical processes that regulate the stability of the Earth system – Steffen et al., by (2015) "

technologies. To accelerate this shift, Bayer has developed ambitious commitments to measure GHG reductions and sustainable intensification of key crops and regions Bayer operates.

1.3 Bayer GHG reduction target is consistent with its commitment to international frameworks and key initiatives.

Bayer AG (including the BCS division) is part of the world's leading Science Based Targets initiative (SBTi) that reviews Bayer's greenhouse gas (GHG) reduction targets. SBTi is a joint initiative of the Carbon Disclosure Project (CDP), the United Nations Global Compact, the World Resources Institute (WRI) and the World-Wide Fund for Nature (WWF). SBTi focuses on providing companies with a scientifically based framework for setting ambitious and effective climate targets towards the long-term goal of achieving net-zero emissions. It outlines criteria for effective reduction of companies` GHG emissions in line with the Paris Agreement goal of limiting global warming to 1.5 °C, compared to pre-industrial levels.

Bayer AG has the aim to continuously reduce GHG emissions within the company and along the entire value chain in accordance with the set criteria and validation of the SBTi. In line with this, and as stated in our 2022 Sustainability Report, Bayer has signed the Business Ambition for 1.5°C and committed to achieve net zero GHG emissions including its entire value chain by 2050 or sooner. By 2024 (interim target), Bayer plans to reduce its scope 1&2[2] emissions by 20% and its Scope 3 emissions by 6% with reference to the baseline year 2019. Until the end of 2029 (Mid-term target), it plans to reduce its scope 1 & 2 emissions by 42% and its scope 3 emission through cooperation with suppliers and customers by at least 12.3% compared to its 2019 baseline. To accomplish this, Bayer will combine measures, such as more efficient inward and outward ventilation systems, a move to climate-neutral technologies, such as geothermal energy for heating and cooling and a switch to 100% purchased electricity from renewable sources. These targets have been approved by the Science Based Target initiative as aligned with a 1.5°C pathway for Scope 1 and 2 and with a 2°C pathway for Scope 3 emissions. As such targets cannot be achieved by acting alone, Bayer has joined forces with other ambitious companies to drive progress as a part of the chemical industry's "Together for Sustainability" initiative. Bayer is also a member of the CDP Supply Chain Initiative and in direct contact with key suppliers**.**

Additionally, Bayer is on a path to become climate neutral by 2030 in its own operations. The remaining emissions after reduction will be offset by purchasing certificates from climate protection projects with recognized quality standards. The offset projects are related to our business. Based on our business purpose we focus on Natural Climate Solutions relating to forest and agriculture. Additionally, we invest in innovative projects and foster development of voluntary carbon markets.

The BCS division is also planning additional climate protection measures that go beyond the Bayer-AG-wide GHG reduction targets outlined above**.** With the BCS GHG commitment, BCS aims to enable its farming customers to reduce their GHG emissions per mass unit of crop produced by 30% by 2030. This applies to the highest GHG emitting crop systems and in the regions BCS serves with its products. While SBTi Forest, Land and Agriculture Guidance (FLAG) was launched in 2022, Bayer is not required to set a separate FLAG target.

Therefore, BCS will contribute to reduction of on-field GHG emissions and promote soil carbon sequestration in relevant crops and geographies. BCS will do so by leveraging their expertise and innovative seeds and crop protection portfolio, promoting the use of modern and efficient farming practices as well as capitalizing on its digital farming solutions. Together with its partners, BCS will strive to promote climate-smart solutions and combine different levers to profitable/customized tailored solutions that help farmers to increase their resilience to consequences of climate change (such as droughts, heavy rains, erosion). Consequently, BCS will bolster farmers with the right tools and technologies to sequester carbon in the soil, reduce and avoid emissions and grow crops in a

[2] Scope 1 emissions are direct GHG emissions that occur from company owned or controlled sources (e.g., emissions associated with fuel combustion in boilers, vehicles etc.), Scope 2 emissions are indirect GHG emissions associated with the purchase of electricity, steam, heat, or cooling while Scope 3 emissions are all indirect emissions (not included in scope 2) that occur in the value chain.

sustainable manner. Such levers include high yielding crop varieties, precision application of crop protection agents, water use efficiency, soil management through no-till and cover crops, crop rotation, root health, (nitrogen-) fertilization management, shortening the time of flooding in rice, digital tools to support decision processes and use of biological CPP (biologics).

Thus, the BCS on-field GHG reduction commitment will also contribute to several of the United Nations' Sustainable Development Goals (UN SDGs). The United Nations agreed on 17 SDGs to build a better world for people and our planet by 2030. The 2030 Sustainable Development Agenda emphasizes that development should be compatible with all three dimensions of sustainability: economic, social, and environmental. Implementing the 2030 Agenda presents an opportunity for collaborative action by many diverse actors, and at all levels, to minimize adverse climate change impacts of agriculture. Therefore, BCS' on-field GHG commitment is at the interface with several goals of the 2030 Agenda (UN, United Nations, 2021) to contribute to sustainable farming practices and food production:

- SDG 2 – End hunger, achieve food security and improved nutrition and promote sustainable agriculture. Considering that the on-field GHG commitment also builds on yield improvements, BCS will specifically contribute to the SDG targets 2.1 (end hunger), 2.3 (increase the agricultural productivity), and 2.4 (ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain eco-systems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality).
- SDG 13 – Take urgent action to combat climate change and its impacts.

1.4 Objectives

In 2019, Bayer publicly committed that Bayer aims to enable its farming customers to reduce their GHG emissions per mass unit of crop produced by 30% by 2030. This applies to the highest GHG emitting crop systems and in the regions Bayer serves with its products. To deliver on this goal, the first step is to establish a baseline against which to measure progress. BCS has set the foundations for its performance tracking method based on CFT to understand the current on-field GHG emissions. Establishing a baseline will help identify opportunities for reducing GHG emissions.

Therefore, this report is aimed at achieving the below objectives:

- Document a method to quantify specific GHG emissions (carbon intensity) using BCS farming customers' on-field GHG emissions and soil carbon sequestration to account for the climate change contributions from farming operations on the field.
- Determine improvement potentials of Bayer's product portfolio and Bayer farming customer' agronomic practices. in line with the Bayer on-field GHG reduction target.

To achieve this, we will be using the CFT GHG emission quantification tool and inventory data from Kynetec to account for the GHG emissions from BCS farming customers. Based on this method, BCS calculated a baseline to track performance and progress against the 30% on-field GHG reduction commitment.

1.5 Critical review

This report is structured using the Life Cycle Assessment (LCA) methodology (according to the ISO 14040 and ISO 14044) as a template for documentation of methodological choices, results, and interpretations as well as limitations. As such, BCS acknowledges that this report only focuses on the field gate-to-gate[3] life cycle stage for quantifying GHG emissions and soil carbon sequestration resulting from farming operations. As BCS intends to communicate to the public its sustainability commitments and achievements, a critical review has been performed, following a three-step iterative process. This

[3] Field gate-to-gate refers to the GHG emission resulting from crop production, starting from on-field soil preparation until the moment the crop leaves the farmers` field.

report provides the review panel composition, its conclusions and the details of the comments and final report adaptations.

Table 1 - Critical review panel composition

Members	Country	Area of expertise
Thomas Nemecek	Switzerland	Deputy Lead Life Cycle Assessment Research Group Agroscope. Worldwide known researcher on Life Cycle Assessment, specifically in its applications on agriculture.
Jeffrey Jenkins	U.S.A.	Expertise in environmental analytical chemistry, ecological risk assessment, and agronomically based ecohydrologic modeling to characterize watershed scale pesticide use and the potential impact on water quality.
Valery Forbes	U.S.A.	Dean and Professor at Florida Atlantic University. Broad expertise in mechanistic effect modeling and ecological risk assessment of pesticides and other chemicals.
Assumpció Anton	Spain	Researcher at Food and Agricultural Research Institute, IRTA. Expertise in the development and application of LCA methodology in agriculture.
Tiago Rocha	Brazil	Consultant/Partner at ACV Brasil and PhD in Environmental Technology. Extensive experience in life cycle assessment, specifically in the area of carbon footprint.
Lorie Hamelin	France	Researcher at the Federal University of Toulouse (France), studying the environmental impacts related to large-scale transitions towards low fossil carbon use.
Anne-Marie Boulay	Canada	Associate Professor in Chemical Engineering at Polytechnique Montreal and CIRAIG. Expertise on water footprint methodologies and impact assessment associated with plastic litter in LCA.
Jessica Hanafi	Indonesia	PhD in Life Cycle Engineering. Established the Indonesian Association of Life Cycle Assessment and Sustainability Professional. ISO Technical Committee on Life Cycle Assessment (TC 207/SC5), environmental labelling (SC3), Greenhouse Gas (SC7) and project leader for ISO/TS 14074 LCA normalization and weighting. Applied LCA based on ISO 14040/44 to various industrial sectors, including agriculture.
Laura Golsteijn (Chair of the panel)	Netherlands	Senior LCA Consultant at PRé. PhD in Toxic Impact Modelling. Supporting clients to understand, develop and embed environmental metrics to improve the sustainability of supply chains and products.

1.6 Organization of the study

The overall primary data collection and GHG impact calculation process can be summarized as follows: For the compilation of inventory data, BCS uses inventory data from Kynetec's FarmTrak™ which tracks global agriculture in 52 countries, by surveying and interviewing global grower panels annually and collecting details of the crops grown (Kynetec, 2021). These data are supplemented with FarmTrak Sustainability data which contain other field operation data like machinery and cultivation techniques. The combined data set compiles all relevant information related to seed, crop protection, fertilizer use, and yield. Based on these extensive crop input data sets, Kynetec calculates on-field GHG emissions following the calculation methodology of the Cool Farm Tool. Then, BCS interprets the results to set a global on-field GHG baseline value across Crop-Country Combinations (CCCs) and to determine improvement potentials. More details on the compilation of inventory data, impact assessment, and interpretation follow in later sections of this report.

Table 2 - Contact information for all parties

Organization	Task	Contact information (Role)
Bayer Crop Science	• Identification of key CCCs for methodology • Calculate global on-field specific GHG baseline and CI values across CCCs. • Apply global on-field GHG baseline internally at BCS to determine improvement potentials in line with the Bayer on-field GHG reduction commitment. • Assess how to integrate learnings into business models. Enable BCS organization to work with on-field GHG data.	Dr. Alexey Kuzmenkin Alexey.kuzmenkin@bayer.com (Global Ecosystems Lead) Dr. Miya Howell Miya.howell@bayer.com (Climate and Land Use Change Lead)
Kynetec	• Questionnaire development and data collection (based on FarmTrak™) • Data mapping to GHG models and data analysis for on-field GHG emission calculations per CCC	Christophe Labyt Christophe.labyt@kynetec.com (Director, Sustainability Products and Services at Kynetec) Stephen Hearn Stephen.hearn@kynetec.com (CEO, Kynetec)

1.7 Use of the study and target audience

The results of this report are intended to transparently and publicly describe the baseline, performance tracking and GHG calculation method. BCS aims to publish the expert panels feedback as well to ensure transparency and strive for credibility. Therefore, the main target audience are investors, press, academic partners, and the general public. Potentially, this report might also be used in the future for auditing processes.

This report is not BCS's main vehicle for informing external stakeholders. BCS is currently developing other internal and external training and communication materials and channels that will be specifically tailored to the information needs of the respective stakeholder group.

2 Scope

This section includes a description of the system boundaries, functional unit, and other relevant scenario and scope information.

2.1 Aggregated system studied: From individual farms to crop-country combinations (CCCs) and rationale for their selection

This report focuses on quantifying on-field GHG emissions and soil carbon sequestration to account for the most emitting crop systems in the regions where BCS operates. To achieve this, CCCs were identified and ranked using the total production volume of a particular crop in a particular market from the FAO database, BCS market share and greenhouse gas emissions estimated through public LCA databases. Data was then collected by Kynetec from farmers for each of the CCCs to allow for evaluation of specific baseline GHG emissions using CFT. BCS then aggregates the GHG emissions of each crop country with the production volume , and market share to estimate the carbon intensity for each CCC. The following 18 CCCs were selected for the assessment:

Table 3 - Selected crop-country combinations (CCC)

CCCs
Argentina-corn
Argentina-soybean
Australia-cotton
Australia-wheat
Brazil-corn
Brazil-soybean
Canada-rapeseed
Canada-wheat
France-wheat
India-rice, paddy
Italy-corn
Mexico-corn
Spain-corn
USA-corn
USA-cotton
USA-soybean
USA-wheat, spring*[5]
USA–wheat, winter*

Through this approach, BCS commitment will target crops with the largest potential for reduction to meet its sustainability-related objectives. The CCCs were selected based on the following criteria:

- Business relevance based on production volume of a particular crop in a particular market (FAO database) and Bayer market share in a particular market.
- Climate change mitigation through reduction of carbon footprint of the cropping systems and GHG emissions (Arunrat et al., 2021).
- Italy-Corn and Spain-Corn were not selected based on these factors but were additionally included because data were already available. In line with Bayer business

2.2 System Boundaries: Defining the scope of the estimated emissions

This section provides an overview of the emissions included (in-scope) in this assessment. The specific GHG emission is determined within the gate-to-gate GHG emission from the survey of BCS farming customers based on the CFT methodology v1.0. The assessment excludes some emission categories that occur beyond the farmers field and are considered out of scope. The assessment focuses on emissions that farmers can directly influence. Information on the emissions considered (in-scope) in this assessment are listed in Table below.

Table 4 - Overview of activities included in the system boundaries

In-scope emissions	Details
Fertilizer application	includes on-field emissions from fertilizer decomposition, encompassing CO_2, N_2O, NO and NH_3 emissions and the latter two gases are included due to their potential conversion to N_2O.
Energy sources consumed on the farm	includes farm machinery use during sowing, cultivation, application of fertilizer and crop protection products, harvesting, and irrigation.
Organic matter application	includes on-field emissions coming from decomposition of left-over residues, or from other ways of managing residue (incorporating it in the soil, taking it off field etc.).
Management changes	Includes changes in soil carbon stock due to soil management (tillage practices and cover crops), soil organic carbon accumulation (carbon sequestration) or decline.

Although the CFT calculates emissions related to the production of crop protection products and fertilizers, transportation, drying and land use change, these emissions are considered out of scope in this assessment. Transportation is excluded because it refers to activities outside the farmgate and land use change is considered out of scope due to lack of reliable data. Drying activity is carried out off field, therefore excluded as the analysis was done to calculate emissions from sources that are within the farm-gate to farm-gate boundaries. The production of crop protection products and fertilizers is out of scope because of BCS's strategic decision to focus on on-field GHG emissions that farmers can directly influence.

2.3 Functional unit

Since the function of the system is to produce crop biomass for food, feed, fuel, or renewable materials, in line with the CFT methodology, the functional unit (FU) is defined as follows:

FU = 1 kilogram of crop produced in a growing season within a crop-country combination

3 Method

The performance measurement approach needed to report on the carbon intensity to support Bayer's commitment to reduce on-field specific GHG emissions follows the processes highlighted below.

1. Inventory data compilation
2. Determination of on-field GHG emissions with the Cool Farm Tool v1.0
3. Calculation of BCS customer specific GHG emissions
4. Aggregation of all CCCs and weighting specific GHG emissions as a function of crop production and Bayer market share for baselining
5. Reporting and comparison to the calculated baseline every two years

3.1 Description of the GHG Assessment Inventory data

BCS uses primary inventory data from Kynetec's FarmTrak™ which tracks global agriculture in 52 countries, surveying and interviewing from amongst their 300,000 statistically representative grower community annually and collecting details of cropping systems used on over 43 million hectares of land each year. Kynetec, a global agricultural market research company, surveys customers to collect data needed to estimate GHG emissions using the science-based Cool Farm Tool calculator.

The inventory data used for this study as input for the CFT are sub divided into 2 categories/modules:

(a) Kynetec's FarmTrak primary panel data which focuses on all information related to crop protection, fertilizer, and seeds, but lacks data on other farm input domains. These data are collected on an annual basis by interviewing farmers in the relevant markets. FarmTrak provides essential information for calculating carbon footprints but lacks data on other input domains.

(b) Kynetec's FarmTrak supplementary sustainability data used for other necessary input information such as soil characteristics, machinery, cultivation techniques etc. This is required to fill the information gaps from the collected Kynetec primary data to enable sustainability-related analyses. Calculating GHG emissions at the field level using CFT v1.0, as shown in Figure 2, is an example of such an analysis.

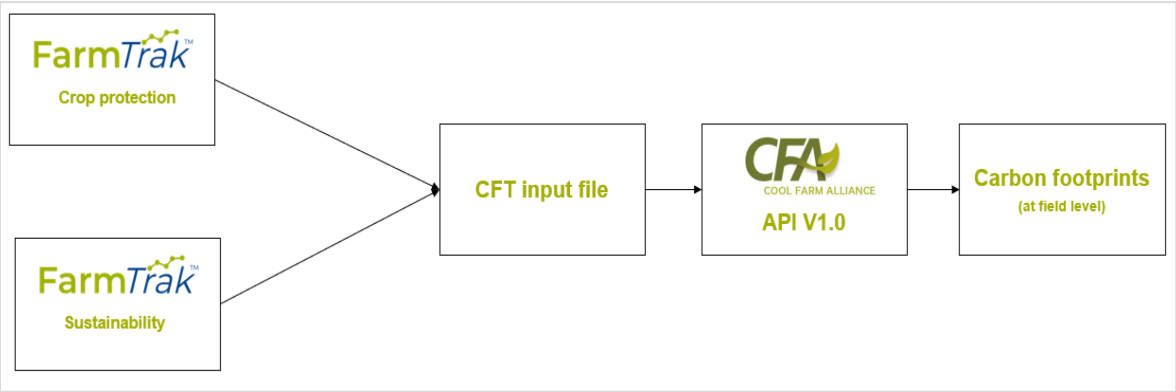

Figure 2 - Workflow for the calculation of farm level carbon footprints (supplied by Kynetec)

3.1.1 Sampling approach and processing

One of the aims of FarmTrak™ is to quantify input markets. A representative sampling design that accurately reflects the population is crucial. Kynetec sampling is based on official, statistical data for each crop across regions and is representative of all focus crops on the level of a particular region. The FarmTrak™ samples are built country-by-country while respecting local conditions.

A stratified sampling approach was used when selecting the FarmTrak™ panel respondents for initial baseline information and will be used for reporting methodology in the future. The three elements considered are (1) crop grown (2) location where the crop is grown and (3) size of the farm on which the crop is grown. Consequently, the entire population is split into subgroups considering these criteria. Size of each subgroup is determined by their relative importance in the market. Within each of those subgroups Kynetec applies a random sampling approach, i.e., each respondent belonging to one of these subgroups has the same a priori chance of being interviewed. Quota per subgroup is used and monitored to ensure a representative view of the market. An additional set of criteria are considered when selecting the respondents, to ensure Kynetec is interviewing the relevant person. For example, the surveyed respondent must be the farm manager or the person in charge of field level decisions (such as choice of fertilizer, seed, or CP product). (See Figure 3)

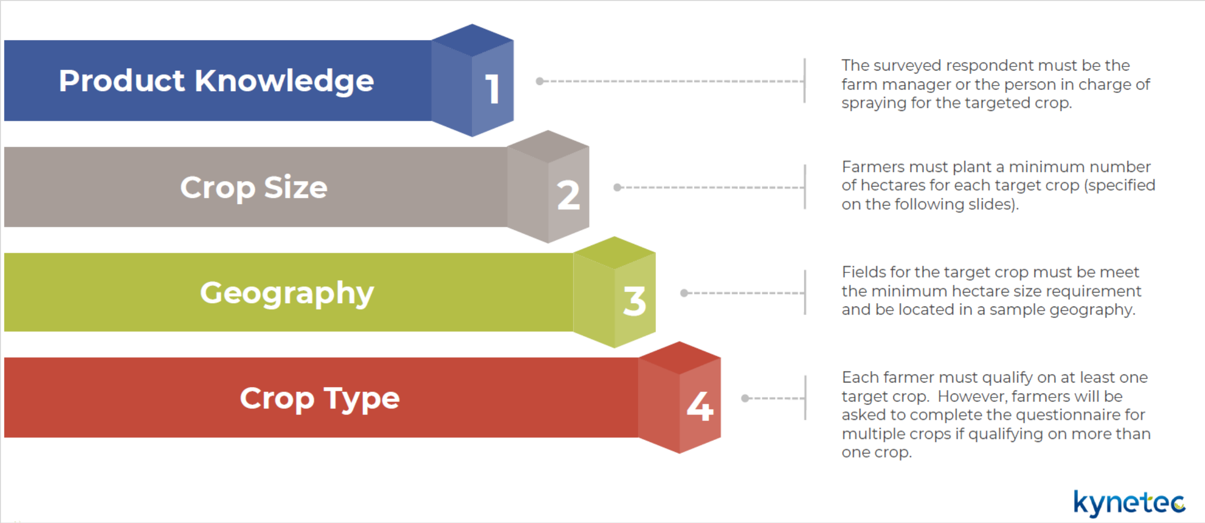

Figure 3 - Qualifying criteria to be met by farmers for selection as part of survey respondents.

FarmTrak™ and the sustainability data collection rely on the same sampling approach, with the only difference being the number of interviews conducted. Usually, no less than one third of the initial FarmTrak™ panel are re-interviewed. In collecting these data, multiple data collection methodologies are deployed such as face-to-face (F2F) interviews, telephone interviews and online surveys. Kynetec achieves a high rate of panel retention thereby ensuring a year-to-year data collection. The consistency of sample over the years will be between 60-90%. However, it is each time a statistically representative sample of randomly selected farmers by Kynetec, a third-party independent market research which BCS cannot influence.

Sampling Plan

Based on approximately 240K hectares

Minimum qualifying maize hectares = 3

<table>
<tr><th>Farm Size (ha) =</th><th>10-19.9</th><th>20-29.9</th><th>30-49.9</th><th>50-99.9</th><th>100+</th><th>Total</th></tr>
<tr><td>Flanders</td><td colspan="6">F2F | Telephone</td></tr>
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<tr><td>Flemish Brabant</td><td>5 | 5</td><td>3 | 4</td><td>6 | 6</td><td>8 | 10</td><td>7 | 9</td><td>29 | 34</td></tr>
<tr><td>Limburg</td><td>3 | 4</td><td>2 | 3</td><td>4 | 6</td><td>9 | 11</td><td>6 | 8</td><td>24 | 32</td></tr>
<tr><td>West Flanders</td><td>11 | 9</td><td>11 | 11</td><td>20 | 23</td><td>22 | 25</td><td>9 | 10</td><td>73 | 78</td></tr>
<tr><td>Wallonia</td><td colspan="6">F2F | Telephone</td></tr>
<tr><td>Hainaut</td><td>3 | 4</td><td>3 | 4</td><td>13 | 12</td><td>28 | 30</td><td>33 | 35</td><td>80 | 85</td></tr>
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<tr><td>Walloon Brabant</td><td>-</td><td>-</td><td>2 | 3</td><td>6 | 7</td><td>11 | 13</td><td>19 | 23</td></tr>
<tr><td>Total</td><td>34 | 38</td><td>34 | 38</td><td>79 | 88</td><td>146|163</td><td>157|173</td><td>450 | 500</td></tr>
</table>

Figure 4 - A stratified sampling plan for data collection on Maize (same as corn) cultivation in Belgium.

3.1.2 Data quality check by Kynetec

Several data quality control measures are implemented during and after data collection. First of all, the interviewers attend a professional training course related to research best practices and are given comprehensive instructions on the research procedures. All interviewers are initially accompanied and test-checked for their knowledge and competence.

The following methods are also adopted:

1. Collected data are checked for accuracy and consistency, including (telephone) back-checks.
2. Constant monitoring by fieldwork supervisors checking that all questions are asked correctly, proper responses are recorded, and that interviewers don't need further coaching/training.
3. Tablet and online questionnaires are equipped with proper logic so that farmers only answer questions relevant to them.
4. Based on knowledge and experience in data collection, Kynetec knows the acceptable ranges at product/application level with data collected therefore checks the data against extreme ranges to remove outliers.
5. Identified problem questionnaires are thoroughly reviewed by analysts and are subject to further telephone checks. This survey integrity stage is truly one of the most critical phases of producing this study.
6. Farmers are asked to report all behaviors and decisions. To achieve this, the respondent's anonymity is guaranteed. As a result, the panel data reflects the market realities of some off-label usage that would not otherwise be known.

3.1.3 Inventory data compilation for the GHG assessment of baseline

The inventory data compiled for this report are based on such a combination of FarmTrak™ base panel data and supplementary interviews undertaken with ~6,390 panelists in 10 countries for the calculation of carbon emissions. Table 5 below illustrates the different crop-country combination in which data collection at farm level was focused on for BCS' GHG emission assessment. As a result of the timelines in data collection by the data provider, Kynetec, the CCCs are divided into Tier 1 and Tier 2.

Table 5 - Kynetec data collection of each country-crop combination and indicated harvest year, tier based on timeline of data collection, sample size, and number of customers according to definition of BCS's customer base.

CCCs	Harvest year	Tier	Total sample size (No of farm surveyed)	No. of BCS customers
Argentina-corn	2021	1	278	124
Argentina-soybean	2022	2	367	172
Australia-cotton	2021	1	50	32
Australia-wheat	2021	2	622	217
Brazil-corn	2021	1	971	611
Brazil-soybean	2021	1	926	602
Canada-rapeseed	2021	2	324	236
Canada-wheat	2021	2	268	158
France-wheat	2021	2	760	298
India-rice, paddy	2020	1	1000	258
Italy-corn	2020	1	317	185
Mexico-corn	2021	2	319	232
Spain-corn	2020	1	254	168
USA-corn	2020	1	1006	600
USA-cotton	2020	1	264	129
USA-soybean	2020	1	919	507
USA-wheat, spring	2021	2	269	134
USA–wheat, winter	2021	2	491	195

BCS argues that such a large data set of farm-level primary data is sufficient for calculating and reporting of crop carbon footprints. For example, Clavreul et al (2017) stated that a minimum of 30 farms is needed for the region of concern for several years' worth of data, particularly as climate change effects become more prevalent and extreme events such as drought or torrential rain becomes norm rather than exception.

3.1.4 CCCs production quantity and BCS market share

The individual CCC production quantity was derived from the Food and Agriculture Organization of the United Nations Statistics (FAO Stats) (https://www.fao.org/faostat/en/#data/QCL, accessed on Sept. 27, 2021). This assessment uses the average crop production in the recent five years (2015-2019) for the 18 CCCs. The Table below summarizes the UNFAO reported average crop production in 2015-2019 for the 18 CCCs.

The BCS market share data for each of the 18 CCCs (Table 6) were extracted from OPTIMAS 2019 database. OPTIMAS is an internal BCS market planning tool that provides short- and long-term market forecast planning and market values to serve top management regarding strategic business planning and reporting. The OPTIMAS 2019 dataset represents the internal market view with market share assumptions that were based in 2019.

The production quantity and the BCS market share is used in deriving the weighting factor (further explanation in section 3.3.2).

Table 6 - Summary of UNFAO reported average crop production for 2015-2019 and BCS market share for the CCCs.

CCCs	Average crop production (mt)	BCS market share (2019), fraction
Argentina-corn	44,681,904.0	-.-*
Argentina-soybean	53,653,851.6	-.-*
Australia-cotton	674,335.5	-.-*
Australia-wheat	23,274,902.6	-.-*
Brazil-corn	86,177,438.8	-.-*
Brazil-soybean	108,154,739.8	-.-*
Canada-rapeseed	19,659,040.0	-.-*
Canada-wheat	30,942,707.0	-.-*
France-wheat	37,354,670.8	-.-*
India-rice, paddy	168,220,346.0	-.-*
Italy-corn	6,488,032.8	-.-*
Mexico-corn	27,021,010.2	-.-*
Spain-corn	4,087,309.8	-.-*
USA-corn	368,030,854.0	-.-*
USA-cotton	3,775,907.5	-.-*
USA-soybean	112,251,616.0	-.-*
USA-wheat, spring	10,849,670.5	-.-*
USA-wheat, winter	41,852,356.6	-.-*

* The BCS market share data extracted from our internal market planning tool were shared with the panel of experts under a non-disclosure agreement.

3.1.5 Definition of BCS customer base used for the on-field GHG assessment

For the on-field GHG assessment, BCS uses compiled inventory data for all 18 CCCs. The GHG emissions are measured and aggregated on the CCC level (for CCC-specific baseline values), and a consolidated global GHG performance across all CCCs selected (for a global aggregated baseline value) is calculated.

The BCS GHG target is measured as a 30% reduction of on-field GHG emissions per mass unit of crop produced by BCS's farming customers by 2030 for the highest GHG emitting crop systems and in the regions BCS serves with its products. Therefore, the focus of the BCS on-field GHG commitment is on the GHG emissions and carbon sequestration of BCS's farming customer base (i.e., specific field gate-to-gate emissions per mass unit of crop produced) for any BCS's farming customer in a particular CCC.

Because farmers in the FarmTrak™ panel data might use solutions from different competitors simultaneously, BCS's farming customers were identified and distinguished in FarmTrak™ following the below mentioned reasoning. The farms will be identified relying on "share of wallet" calculations, comparing it with BCS's market share in a CCC.

Farmers are BCS's customers based on the following principles:

1. BCS's share of wallet of a particular farm at least equals BCS's market share for the relevant country/crop combination (see equation 1 and 2 below) and / or
2. They use BCS's seed variety and / or
3. They use BCS's 'Climate Field View[4]' or any other digital platform from Bayer and / or
4. They are being incentivized by BCS for adoption of climate-smart practices by participating in Bayer's Carbon business

$$Market\ share\ (in\ a\ CCC, fraction) = \frac{Hectares\ treated\ with\ Bayer\ products\ in\ entire\ market}{Total\ hectares\ treated\ with\ crop\ protection\ in\ entire\ market} \quad (1)$$

Market share per country will be calculated considering hectares treated with Bayer's products relative to total hectares treated with crop protection in that market. Market share will be calculated considering all product lines. Hectares treated refers to "Super Developed Area" and takes multiple applications on same field into account. For example: if a field of 10 hectares is treated twice, BCS considers hectares treated/super developed area to be 20 hectares.

$$Share\ of\ wallet\ (on\ a\ farm) = \frac{Hectares\ treated\ with\ Bayer\ products\ on\ the\ farm}{Total\ hectares\ treated\ with\ crop\ protection\ on\ the\ farm} \quad (2)$$

In the current calculations, share of wallet states how much respondents spend/use on Bayer's products exclusively. Share of wallet can be calculated considering hectares treated with Bayer products relative to total hectares treated on the same farm.

Share of wallet allows to evaluate how Bayer is performing against competitors and allows to benchmark against Bayer's market share of a particular country-crop combination. All farms will be identified as Bayer customers if Bayer's share of wallet of a particular farm at least equals Bayer's market share for the relevant country-crop combination. Farms will be identified as non-customers, if Bayer's share of wallet of a particular farm is smaller than Bayer's market share for the relevant country-crop combination OR does not meet the other 3 criterial listed above.

3.2 Determination of on-field GHG emissions and carbon sequestration with the Cool Farm Tool v1.0

3.2.1 Cool Farm Tool model description

The Cool Farm Tool (CFT) was developed by the Cool Farm Alliance (CFA) and is used to measure GHG emissions from agricultural production. Bayer has been a member of Cool Farm Alliance since 2020. CFT is an online greenhouse gas (GHG) calculator that quantifies the carbon footprint of crops in kg CO2 equivalents (kg CO_2e) over a 100-year time horizon. The tool offers quantified, credible, and standardized metrics based on empirical research and a broad range of published data sets and IPCC methodologies. It has a specific farm-scale, decision-support focus making it possible to identify

[4] Climate Field View is BCS's digital farming software platform that helps farmer to monitor and make agronomic decisions on their fields for yield optimization and profit maximization.

emissions on the field. The model version used for this analysis was v1.0 or v1.11 (released in 2022). It further provides farmers with the opportunity to evaluate different management options that will lead to positive impact on the total emissions from the farm. Contrary to other farm GHG emission calculators, it includes a calculation of soil carbon sequestration which is an important aspect of agriculture GHG accounting in terms of adaptation and mitigation benefits. As a result of its use of readily available farm data, there is considerable scope for its use in global surveys to inform on current practices and potential for mitigation (Hillier, et al., 2011).

The CFT was originally developed by Unilever and researchers at the University of Aberdeen to help growers measure and understand on-farm GHG emissions. The use of the tool is designed to be simple, but scientifically robust in accounting for farm GHG emissions. It has been tested and adopted by many multinational companies which are using it to work with farmers to measure, manage and reduce GHG emissions arising from crop production towards contributing to the mitigation of climate change. More information about CFT can be found at http://www.coolfarmtool.org.

The CFT was selected for this assessment because of its ease of use, widespread adoption, global applicability, decision-support focus and its ready availability of farm data for the intended purpose which is to calculate GHG emissions. The CFT is being used by diverse array of stakeholders which includes food retailers, manufacturers, input suppliers, NGOs, universities, and consultancies. A list of CFT partner members can be found at https://coolfarmtool.org/cool-farm-alliance/members/.

The methodology used in the CFT, calculates GHG emissions and removals associated with the production of an agricultural product. A carbon footprint is reported for the three major sources of on-farm emissions associated with the production of agricultural products, namely, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). For crops, the CFT incorporates IPCC Tier 1 and Tier 2[5] when it comes to N_2O emissions and soil carbon sequestration. A simplified Tier 3 multi-factorial empirical model based on Bouwman et al. (2002), which is widely acknowledged, is used for N_2O emission. The Cool Farm Tool is moving towards Tier 3 when possible. Currently, the newest version release of CFT (v2.0) is based on the IPCC 2019 refined guidelines and uses the Global Warming Potentials from the IPCC Assessment Report 6 (Cool Farm Alliance, 2022). Detailed information on the data needed to calculate GHG emissions from crops is summarized in the CFT data input guide. Please refer to the CFT data input guide, the CFT FAQ, and Hillier et al., (2011) for a detailed technical description of the CFT methodology.

The CFT has several input sections which are listed below. Each section requires provision of information related to the crop being assessed. The carbon footprints are calculated for one selected growing area/parcel/field per farm, assuming similar soil characteristics and input/management practices on that same area/parcel/field. For each crop and growing area, a full annual production cycle is considered. The scope of the current project is to consider emissions before the crop leaves the farm (i.e., everything on-field before ‘farmgate’).

3.2.2 Cool Farm Tool input data

The CFT is structured according to the following sections:

(0) Farm settings
(1) Crop
(2) Soil
(3) Inputs
(4) Fuel & Energy
(5) Irrigation
(6) Carbon
(7) Transport (excluded)

[5] A tier represents a level of methodological complexity used in GHG calculation. There are three tiers namely Tier 1, Tier 2, Tier 3. Tier 1 is the basic method; Tier 2 represents the intermediate while Tier 3 is the most complex in terms of the methodology.

When using the CFT for emission calculation, some input parameters have been predefined in the model while some are to be defined by the user. In the next sub-chapters, we will go into the details of the input parameters used in the calculation of GHG emissions. The BCS inputs used in the next sections are based on Kynetec data (see section 3.1 for details).

0. Farm settings

This is the base section where details about the farm location and the climate condition are defined. The input parameters are described in Table 7 below.

Table 7 - Cool Farm Tool Input parameters on farm settings

Variable	Options / Unit	Description
Country	-	Country where the farm is located.
Annual average temperature	°C	This information is not collected during the interview with farmers, instead Kynetec relies on external sources (such as the National Oceanic and Atmospheric Administration - NOAA)
Climate	- Temperate - Tropical	Climate zones are defined following the logic of Bouwman et al. (2002) who categorize all Global Ecological Zones (FAO, 2010) as either temperate or tropical: - Tropical: tropical and subtropical - Temperate: temperate and boreal

1. Crop

This section is divided into three input sections which are crop details, crop residue management and co-products.

1.1 Crop details

Information here includes the type of crop, area for crop growing and the crop yield (see Table 8 below for details on the Input data required for crop details). The CFT has an additional emission calculation for rice when cultivated as paddy rice. This is because paddy rice plays a significant role in the overall emission from agriculture. The CFT accounts for the emission from paddy production using the IPCC approach based on Xiaoyuan Yan et al. (2005). The emission factor from this approach considers water regime during cultivation, water regime in the pre-season and organic amendments. The CFT v1.0 used in this study only covers seed emissions for potato, but not for other field crops. The model considers emissions from seeds to be quite low, compared to the other sources of emission.

Table 8 - Cool Farm Tool Input parameters on crop details

Variable	Options / Unit	Description
Crop name	-	Name of the crop.
Harvest year	-	Calendar year during which the crop was harvested.
Crop area	Hectare	Size of the parcel, including buffer zones.
Harvested amount	Metric ton	Total harvested crop from the crop area for the relevant harvest year before on-farm processing (e.g., drying, grading, sorting) of crops i.e., Fresh matter
Farm-gate ready amount	Metric ton	Total marketable yield from the crop area for the relevant harvest year after on-farm processing.
Assessment name	-	A reference name for the identification of the assessment.

1.2 Crop residue management

Crop residue refers to the plant matter from crop production that is not used as a sellable product. Often, harvest does not cover the full biomass of a crop and thus crop biomass remains as residue both above and below ground. Examples of residue from crop production typically include leaf lamina, leaf mid-rib, pseudostem sheath, fruit peelings etc.

For the calculation of emissions from residue in the CFT, the amount of residues generated per year and the way residues are managed are required as input data. The amount of plant residue is estimated by CFT based on IPCC method (V 4, Chapter 11, Table 11.2) and GHG emission of it is calculated based on IPCC report (V 4, Chapter 2.) . If residues are used to create compost, the tool will calculate the possible emissions associated with this compost production process. However, if compost is then used on crops, an emission factor of zero is associated with the compost since it is already accounted for in the residue section. When residues are used as compost, the emission increases depending on the technology (forced aeration or non-forced aeration) used during composting. Non-forced aeration accounts for more emission compared to forced aeration. Detailed description of the required input can be found in Table 9 below.

Table 9 - Cool Farm Tool Input parameters on crop residue management

Variable	Options / Unit	Description
Residue amount	Ton/ha	The default residue amount estimated by the CFT for various crops is used in this assessment.
Residue management	-	The CFT provides the following pre-defined options for selection. - Removed from field for use or for sale. - Used for composting: Forced aeration or non-forced aeration compost. - Left untreated in heaps. - Burnt on the field. - Distributed on the field, incorporated, or mulched. The above options are selected for the assessment based on the responses from the farmers on how they manage crop residues.

1.3 Co-products

This section of the CFT allows allocating the total crop emissions between main product (e.g., wheat) and co-product (e.g., straw). However, BCS excludes co-products because it does not allocate a proportion of emissions of the main crop to one or more co-products. The estimated GHG emissions from co-products are associated with main product. Therefore, this assessment uses the default by allocating all emissions to a single main product.

2. Soil

This section is where the soil characteristics of the field being assessed are specified. In defining the soil characteristics, the CFT considers input from the soil texture, soil organic matter, soil moisture, soil drainage and soil pH. The pre-defined chosen input range for soil organic matter is used in determining the soil organic carbon. Detailed description of the required input can be found in 10 below.

Table 10 - Cool Farm Tool Input parameters on soil characteristics

Variable	Options / Unit	Description
Soil texture	- Fine - Medium - Coarse	Soil texture is based on soil type, as stated by the grower, and grouped accordingly: - Fine: sandy clay, clay, silty clay - Medium: sandy clay loam, clay loam, silty clay loam - Coarse: sand, loamy sand, sandy loam, loam, silt loam, silt
Soil organic matter	- SOM <= 1.72% - 1.72% < SOM <= 5.16% - 5.16% < SOM <= 10.32% - SOM > 10.32%	The soil organic matter is expressed as percentage. As stated by the grower, selection is made based on the four categories.
Soil moisture	- Moist - Dry	As stated by the grower. Moist soils are those without any water constraints during the growing season.
Soil drainage	- Good - Poor	As stated by the grower. Soils which are often saturated or show surface water were classified by the grower as ‘Poor’, other soils are classified as ‘Good’.
Soil pH	- pH <= 5.5 - 5.5 < pH <= 7.3 - 7.3 < pH <= 8.5 - pH > 8.5	As stated by the grower, selection is made based on the four categories.

3. Inputs

This section is divided into two input sections which are fertilizer inputs and crop protection inputs. These inputs have influence on the GHG emission of the farm. The emissions resulting from the fuel used in applying of these inputs are entered in the 'Fuel & Energy' section. Detailed description of how emissions from fertilizer and crop protection inputs are calculated are described below:

3.1 Fertilizers

In the case of fertilizers, the CFT accounts for two types of emission pathways: emissions released during fertilizer manufacturing and emissions from the application of fertilizer on the field. Since emissions from fertilizer manufacturing are considered out of scope for the BCS on-field GHG commitment, only emissions from the application of fertilizer on the field are covered: These emissions are mainly triggered by bio-chemical process related to the addition of nitrogen fertilizers and limestone. Although emissions from soils may happen without the use of fertilizer, fertilizer application is one of the major sources of N_2O emissions. From the input of the type of fertilizer used on the field, the CFT tool defines the N:P: K ratio of the fertilizer. For nitrous oxide (N_2O) and nitric oxide (NO) emissions resulting from nitrification and denitrification process, the factor values from the multivariate empirical model of Bouwman et al. (2002) were used. NO and NH_3 emissions are converted to N_2O using recommended IPCC factor. Volatilization of NH_3 is also considered using the equation from FAO and IFA (IFA and FAO, 2001), and the recommended IPCC conversion factor is used for NH_3 to N_2O. In moist soils, some of the added nitrogen fertilizers are lost through leaching. Factors from IPCC are used to estimate the amount of nitrogen that are lost through this pathway and the resulting N_2O emissions. The emission effect from the presence of nitrification inhibitors in fertilizers are modelled using the methodology by Akiyama et al., (2010). The CFT methodology used in accounting for emissions associated with field application of fertilizers considers the different types of fertilizers, crop type, soil properties and fertilizer application methods (see Table 11).

Table 11 - Cool Farm Tool Input parameters on fertilizer management

Variable	Options / Unit	Description
Fertilizer type	Pre-defined list of applicable fertilizers	As stated by the grower, the fertilizer used during crop production is selected here from the CFT predefined list.
Application rate	Kg or L per Hectare	The amount of fertilizer used per hectare, as stated by the growers
Fertilizer weights or units	Product or Units of active element	Units of product (kg or liter) is used as default option.
Application method	- Broadcast - Incorporate - Apply in solution - Fertigation	As stated by the grower, a selection is made on how the fertilizer is applied on the field.
Emission inhibitors	- None - Nitrification inhibitor	For each fertilizer applied, the growers mention if the fertilizer contains an emission inhibitor or not. None is chosen when the applied fertilizer contains no inhibitor.

3.2 Crop protection inputs

The CFT assumes that a part of the emissions from use of CPPs occur during their production. Since this type of embodied emissions take place off-field, they are out-of-scope and not considered in this report. Emissions related to the energy use from applying the crop protection products on the field are accounted for in the direct energy section.

4. Fuel & Energy

This section deals with the estimation of emission resulting from energy consumption in the growing area. Possible energy sources that are considered are electricity and fuels. This includes on site energy use for machinery and irrigation. The consumption of fuel and the use of energy for farm operation adds to the overall emissions from agricultural production. The emission calculation includes both electricity and liquid fuel use. For energy sources which consist of diesel, petrol, bioethanol, biodiesel, electricity (grid, hydroelectricity, and wind), the CFT uses emission factors derived from the GHG protocol (2003). The CFT does not assume a zero emissions factor for renewable energy. Emissions for electricity from renewable energy are significantly lower than for electricity from the grid but not accounted as zero due to emissions released during the development of renewable energy technology and construction of plants. In situations when the data of annual amounts of energy sources consumed for certain activities are not available, indirect figures such as number of applications, machinery/vehicle type, fuel type, and size of area treated are used to compute emissions.

In the CFT, this section is divided into three parts: Direct energy use, field operations energy use and wastewater.

4.1 Direct Energy

Energy consumption related to irrigation is accounted for in direct energy use. See Table 12 below for details on the input paraments for this section

Irrigation

Two steps are undertaken to estimate energy consumption from irrigation pumps:

- Desk research[6] is done to estimate irrigation volumes at relevant subnational level (i.e., state, province etc.), focusing on the most recent statistics available. Different methods of irrigation (i.e., flooding, rain gun, pivot, or drip irrigation) are considered. (For example, EASAC, USDA-NASS, ANA Brazil etc.)
- The CFT calculates the energy requirements in kWh for irrigating 1 mm/ha depending on irrigation method and fuel used. These reference values are used to estimate energy consumption.

Table 12 - Cool Farm Tool Input parameters on direct energy use

Variable	Options / Unit	Description
Energy source	Predefined list of different sources of energy	Electricity or diesel is assumed to be the relevant energy sources.
Energy used	- Kwh - liter	Volume of energy used (liter of diesel or KWH electricity)
Category	- Field - Facility	Energy consumption from irrigation is categorized as 'field'.

4.2 Field Operations Energy Use

Energy consumption related to on-field machinery operations is considered in the section 'field operations energy use.' The CFT supports estimating fuel use for common agricultural machinery from tillage, sowing, spraying crop protection, fertilizer applications and harvesting. The focus of this section is to determine energy used based on machinery operation on the field. Required inputs are the type of machine (obtainable from a pre-defined list), fuel used and number of field operations. Type and number of field operations are entered following the below mentioned logic.

- Sowing and cultivation practices: As part of the 'sustainability' data collection, growers are asked to mention which one of three cultivation practices they adhere to (1) conventional tillage (2) reduced tillage (3) zero tillage. Building on the logic as described in Khaledian et al. (2014) these cultivation practices result in the below mentioned machinery operations. These are mapped accordingly on the CFT machinery typology.

Table 13 - Cool Farm Tool Input parameters on cultivation practices and field operations

Cultivation practice	Machinery operations
Conventional tillage	Plowing, Harrow, Disc Harrow, Seed Drill
Reduced tillage	Harrow, Disc Harrow, Seed Drill
Zero tillage	No-till Seed Drill

- CPP spraying and fertilizer applications: Number of times the field was visited for applying crop protection products and fertilizers is derived from the FarmTrak™ crop protection data and sustainability data. Both databases provide information on the timing of the different

[6] Alternatively, water irrigation volumes can be estimated using the 'water footprint calculator' from CFT. At the time the data was processed this was not available yet but can be considered for future data processing.

applications. All applications that happen on the same date are aggregated and are assumed to happen during one single pass for fertilizers and crop protection (Cf. concept of tank mix for crop protection data).

- Harvesting and residue management: Kynetec assumes that harvesting is mainly done with a combine (e.g., cereals, soybean, corn), or could be done manually in some smallholder markets (e.g., India rice). A special 'Corn combine' is selected for harvesting corn. In case the grower mentioned that the crop residue is taken off field, a pass with a baler for collecting the residue is added.

Table 14 - Cool Farm Tool Input parameters on field operations energy use

Variable	Options / Unit	Description
Machine category	Pre-defined list of different farm operation	Selection is made based on different farm operations. E.g. Harvesting, tillage, spraying, sowing, fertilization.
Machine	Pre-defined list of different machines based on the selected farm operation	Selection is made based on different machines used in farm operations. For example, when spraying was selected as machine category, herbicide sprayer was selected here.
Fuel use	- Diesel - Petrol	Diesel is used as a default fuel type for machinery.
Number of operations	-	Number of completed field operations related to the farm operation being assessed during the growing cycle for the crop. Filled based on response from the growers.

4.3 Wastewater Emissions

Most crops do not have wastewater emissions and are thus not accounted for in GHG emission calculation. Methane emissions from wastewater arises from the decomposition process of organic material. This is common in coffee where a wet milling process is used to separate the pulp from the bean. The Bayer CCC list has no coffee as part of the selected crops, therefore wastewater emission is not relevant for this report.

5. Irrigation

In the irrigation section, a repeated computation of irrigation energy was not carried out as energy for operating irrigation pumps is already captured in the 'Direct energy' section.

6. Carbon

This section describes the emission resulting from changes in management practices that alters the carbon stocks i.e., carbon stored by or released from the soil and above ground biomass of the growing area. Changes in carbon stocks can occur from alterations in land use, soil management, and biomass. They can affect net carbon capture or release, thereby impacting emissions. Land use change (e.g., deforestation) is not considered in this report (see section 5 on limitation for more information). Soil management practices considered are tillage and cover crops. Management changes can either increase or decrease the carbon in the soil and will continue doing so until a new equilibrium is reached. The CFT (v1.11) only considers changes in farm management practices that have occurred within the last 20 years because this time frame is assumed by IPCC and other GHG accounting standards as the period that soil carbon stocks need to reach a new equilibrium. Any management change that has happened before is assumed to be no longer relevant.

In the CFT, determination of the carbon stocks in the top 30 cm of the soil are based on the user soil characteristics input and are determined mathematically using bulk density and carbon density. The carbon density describes the carbon available in the top 30 cm of 1 ha of soil based on an assumed bulk density of 1 g/cm3 and 1% soil organic matter equals 1.72% of soil organic carbon. The IPCC Tier 1 method is used for the estimation of soil carbon stock changes using coefficients from (Ogle S.M., 2005) for carbon stock changes related to change in management practice for a period of 20 years. The resultant amount of a change in soil carbon is dependent on climate (Hillier, et al., 2011). The changes in carbon were converted to an annualized CO2 emission (can either be positive or negative) when land management changes in relation to carbon input practice and tillage practice. The carbon input practice is classified into low, medium, and high. Low refers to minimal residue return as a result of residue removal, medium category accounts for annual cropping with cereals where residues are returned to the field while high is in addition to medium with higher inputs due to production of high residue yielding crops, cover crops, improved vegetated fallows and frequent use of perennial grasses in annual crop rotations. The tillage classes (conventional, reduced, or no till) are defined following IPCC classification. The changes in soil carbon stock as a result of manure and compost addition are derived from Smith et al. (1997).

Table 15 - Cool Farm Tool Input parameters on tillage and cover crops management

Variable	Options / Unit	Description
Changed from …		Based on the information Kynetec gets from the growers, these types of management change are considered: - Tillage: Comparison of how the field was tilled (conventionally, reduced or not) - Cover crops: Checking if a cover crop is grown
Number of years ago	-	Number of years ago the situation changed.
Percentage of field	%	For changes related to tillage and cover crops, it is assumed the change occurred on the entire field.

3.3 Calculation of BCS Customers GHG emission

In the following section, we describe in detail the methodology in the calculation of BCS Customer GHG emission for the baseline year (baseline year = harvest year 2020-2022 depending on CCC dataset). This section further includes the formulae that will be used for future tracking of the performance.

3.3.1 Calculation of specific GHG baseline for CCC´s

The specific GHG emission (kg CO2e per kg crop) is the **normalized gate-to-gate GHG emissions calculated for an individual CCC.** For a baseline and a specific base year, the specific GHG emission is calculated as shown in equation 3 below:

$$GHG_{BL,spec}^{CCC} = \frac{\sum_{i=1}^{k} GHG_{i,BL}^{CCC}}{\sum_{i=1}^{k} W_{i,BL}^{CCC}} \qquad (KgCO2/KgCrop) \qquad 3$$

For *k* farmers assessed in a base year for a particular CCC:

- $GHG_{BL,spec}^{CCC}$ = Specific GHG emissions for a particular CCC in the base year
- $GHG_{i,BL}^{CCC}$ = Absolute GHG emissions of a farmer i for a particular CCC in the base year
- $W_{i,BL}^{CCC}$ = Crop weight (Kg) of a farmer i for a particular CCC in the base year

To track GHG reductions over time until 2030, the **baseline GHG performance in a particular CCC will be compared with the GHG performance in a future target year (t)** (e.g., next performance tracking year 2024) based on the following formula:

$$GHG_{t,spec}^{CCC} = \frac{\sum_{i=1}^{n} GHG_{i,t}^{CCC}}{\sum_{i=1}^{n} W_{i,t}^{CCC}} \qquad (KgCO2e/kgCrop) \qquad 4$$

For *n* farmers assessed in a target year t for a particular CCC:

- $GHG_{t,spec}^{CCC}$ = Specific GHG emissions for a particular CCC in a year t
- $GHG_{i,t}^{CCC}$ = Absolute GHG emissions of a farmer i for a particular CCC in a year t
- $W_{i,t}^{CCC}$ = crop weight (kg) of a farmer i for a particular CCC in a year t

As the absolute emissions and crop weight values are separately summed up, specific BCS emissions are weighted according to different crop weights and, indirectly, field sizes.

Finally, a specific GHG emission reduction is calculated as:

$$R_t^{CCC} = \left[1 - \frac{GHG_{t,spec}^{CCC}}{GHG_{BL,spec}^{CCC}}\right] x\ 100 \qquad (\%)$$

5

- R_t^{CCC} = Specific GHG emission reduction for a particular CCC in a year t as compared with the base year

Additionally, target achievement for this CCC can be calculated as:

$$TA_t^{CCC} = \left[\frac{R_t^{CCC}}{T^{CCC}}\right] x\ 100\% \qquad (\%)$$

6

- TA_t^{CCC} = Target achievement for a particular CCC in a year t
- T^{CCC} = Target set for a particular CCC

3.3.2 Setting an aggregated baseline for GHG emission reduction across CCCs

To calculate GHG emissions across CCCs for a baseline and a particular year (for an aggregated global baseline value), the individual baseline results which are specific for each CCC (as described above) need to be aggregated. For this aggregation, the specific baseline GHG emissions for a particular CCC in the base year ($GHG_{BL,spec}^{CCC}$) are weighted with a weighting factor (Wf_{CCC}) which is also specific for each CCC.

$$GHG_{BL,agg} = \sum_{CCC} GHG_{BL,spec}^{CCC}\ x\ Wf_{CCC} \qquad (KgCO2e/kgcrop)$$

7

- $GHG_{BL,agg}$ = Aggregate GHG baseline emissions across CCCs (weighted to represent BCS market)
- $GHG_{BL,spec}^{CCC}$ = Specific GHG emissions for a particular CCC in the base year
- Wf_{CCC} = Weighting factor for a particular CCC in the base year

The weighting factors (Wf_{CCC}) are determined by the total production volume of a particular crop in a particular market multiplied by BCS market share and by the specific GHG footprint of BCS customers in this CCC (baseline). The combination of the production volume, the BCS market share and the specific GHG emissions is referred to as the Total GHG emission (kg CO_2e). To avoid complexity, these weights are determined once during baselining and then kept fixed[7] (for the future).

$$Wf_{CCC} = \frac{P_{CCC}\ x\ M_{CCC}\ x\ GHG_{BL,spec}^{CCC}}{\sum_{CCC} P_{CCC}\ x\ M_{CCC}\ x\ GHG_{BL,spec}^{CCC}} = \frac{Total\ GHG}{sum\ of\ Total\ GHG\ across\ CCC's} \quad (unitless)$$

8

[7] Note: Base year is CCC-specific.

- Wf_{CCC} = Weight of a particular CCC in the portfolio (determined during baselining and fixed) (dimensionless)
- P_{CCC} = Production volume of a particular crop in a particular market (FAO database) (mt)
- M_{CCC} = BCS' market share in a particular market (fraction)
- $GHG^{CCC}_{BL,spec}$ = Specific GHG emissions for a particular CCC in the base year (kgCO2e / kg Crop)

Also, for future target years, the specific GHG emissions for a particular CCC in a year t ($GHG^{CCC}_{t,spec}$) will be weighted with the fixed weighting factor (Wf_{CCC}).

$$GHG_{t,agg} = \sum_{CCC} GHG^{CCC}_{t,spec} \, x \, Wf_{CCC} \qquad (kgCO2e/kgcrop)$$

9

- $GHG_{t,agg}$ = Aggregate GHG emissions across CCCs in a year t (weighted to represent BCS market)
- Wf_{CCC} = Weight of a particular CCC in the portfolio (determined during baselining and fixed)
- $GHG^{CCC}_{t,spec}$ = Specific GHG emissions for a particular CCC in a year *t*

Finally, a specific (i.e., relative) GHG emission reduction is calculated across CCCs as:

$$R_t = \left[1 - \frac{GHG_{t,agg}}{GHG_{BL,agg}}\right] x \, 100 \qquad (\%)$$

10

- R_t = Specific (i.e., relative) GHG emission reduction across CCCs in a year *t* as compared with the baseline

Additionally, target achievement across CCCs can be calculated as:

$$TA_t = \left[\frac{R_t}{30\%}\right] x \, 100 \qquad (\%)$$

11

- TA_t = Target achievement across CCCs in a year *t* at the overall target of 30%

The performance will be tracked by frequently collecting data, calculating the GHG performance in future years based on the same methodology as described in the above sections, and then comparing the future performance with the baseline performance.

Following guidance from the Greenhous Gas Protocol Corporate Accounting and Reporting Standard (WRI, World Resources Institute, 2004), for consistent tracking of emissions over time, the base year emissions may need to be retroactively recalculated/restated as BCS undergo significant structural changes such as:

- Inclusion or exclusion of crop-country combinations.
- Investments or divestments.
- Change of boundaries.
- Changes in calculation methodology or improvements in the accuracy of emission factors or activity data that result in a significant impact on the base year emissions data.
- Discovery of significant errors, or several cumulative errors, which are collectively significant.

Consequently, BCS shall develop a base year emissions recalculation policy, and clearly articulate the basis and context for any recalculations. If applicable, the policy shall state any 'significance threshold' for deciding on historic emissions recalculation. A significance threshold is a quantitative criterion used to define any significant change to the data, inventory boundary, methods, or any other relevant factors (WRI, World Resources Institute, 2004).

It is the responsibility of BCS to determine the 'significance threshold' that triggers base year emissions recalculation and to disclose it. Based on recommendations of the California Climate Action Registry, the change threshold is set to 10 percent of the overall specific base year emissions, determined across CCCs from the time the base year is established.

In sum, if BCS realizes in the future that significant structural changes as described above happen, BCS will re-check the baseline performance value. If the re-checked baseline performance value differs by 10% from the currently calculated baseline value, BCS will restate the baseline and re-evaluate the further implications for the progress tracking towards the 30% reduction commitment.

4 Interpretation

4.1 Results and setting of GHG emission tracking baseline.

Towards achieving the 30% reduction in the on-field GHG emissions per mass unit of crop produced in our customer base, first will be to determine the baseline upon which our progress will be tracked. We calculated the specific GHG emission based on the gate-to-gate GHG emissions using the CFT and the crop weight from the surveyed customer farms in the 18 CCC´s. The specific GHG emission is the same as GHG footprint, with a mass unit of CO_2e per mass unit crop produced. We then calculated the total GHG emissions based on the specific GHG emissions, United Nations Food and Agriculture Organization (UN FAO) reported 5-year average crop production in 2015-2019 (UNFAO 2021) and BCS market share for each of the 18 key markets. The baseline calculation of the GHG emissions was carried out by Kynetec using the CFT version 1.0 with results described in the following sections.

4.1.1 Specific GHG emissions for the baseline

The baseline specific GHG emissions varied across the 18 CCC´s ranging from 0.07 mt CO2e per mt crop in Italy-Corn to 0.97 mt CO2e per mt crop in India-Rice (Table 16, Figure 5 below). Corn (0.07-0.13 mt CO2e per mt crop in Italy, USA, Spain, Argentina) had smallest specific emissions compared to other crops, except for Brazil-corn (0.18 mt CO2e per mt crop) and Mexico-corn (0.42 mt CO2e per mt crop). USA-soybean had the specific emission of 0.14 mt CO2e per mt crop and France-wheat had the specific emission of 0.19 mt CO2e per mt crop), then USA-wheat winter had the specific emission of (0.25 mt CO2e per mt crop). Brazil and Argentina soybean (0.26, 0.38 mt CO2e per mt crop respectively), US-spring and Canada wheat (0.29, 0.32 mt CO2e per mt crop respectively) and Canada rapeseed (0.45 mt CO2e per mt crop) had moderate specific emissions. While cotton had higher specific emissions (0.56 mt CO2e per mt crop in USA and Australia) followed by Australia-wheat with a specific emission of 0.61 mt CO2e per mt crop mainly contributed by the smallest total crop weight. Rice in India had the largest specific emission (0.97 mt CO2e per mt crop) of all the 18 CCCs.

Table 16- Specific GHG emission (mt CO2e per mt crop-dry weight) from surveyed BCS customer farms in the baseline

CCCs	CFT-modeled GHG emission (mt CO2e)	Crop weight of surveyed customer (mt)	Specific GHG emission (mt CO2e per mt crop)
Argentina-corn	148,839.20	1,109,361.90	0.1342
Argentina-soybean	130,193.46	344,495.70	0.3779
Australia-cotton	5,236.42	9,408.22	0.5566
Australia-wheat	4,775.62	7,877.66	0.6062
Brazil-corn	135,548.63	774,304.77	0.1751
Brazil-soybean	150,393.04	584,936.18	0.2571
Canada-rapeseed	33,124.89	75,533.29	0.4385
Canada-wheat	19,814.09	61,022.70	0.3247
France-wheat	6,221.66	32,100.50	0.1938
India-rice	3,526.32	3,634.71	0.9702
Italy-corn	4,612.71	64,558.41	0.0715
Mexico-corn	26,203.83	62,709.07	0.4179
Spain-corn	10,641.95	95,512.85	0.1114
USA-corn	272,990.30	2,909,794.63	0.0938
USA-cotton	49,354.34	88,910.75	0.5551
USA-soybean	94,663.96	683,436.80	0.1385
USA-wheat, Spring	13,184.91	45,565.18	0.2894
USA-wheat, Winter	13,481.57	54,669.41	0.2466

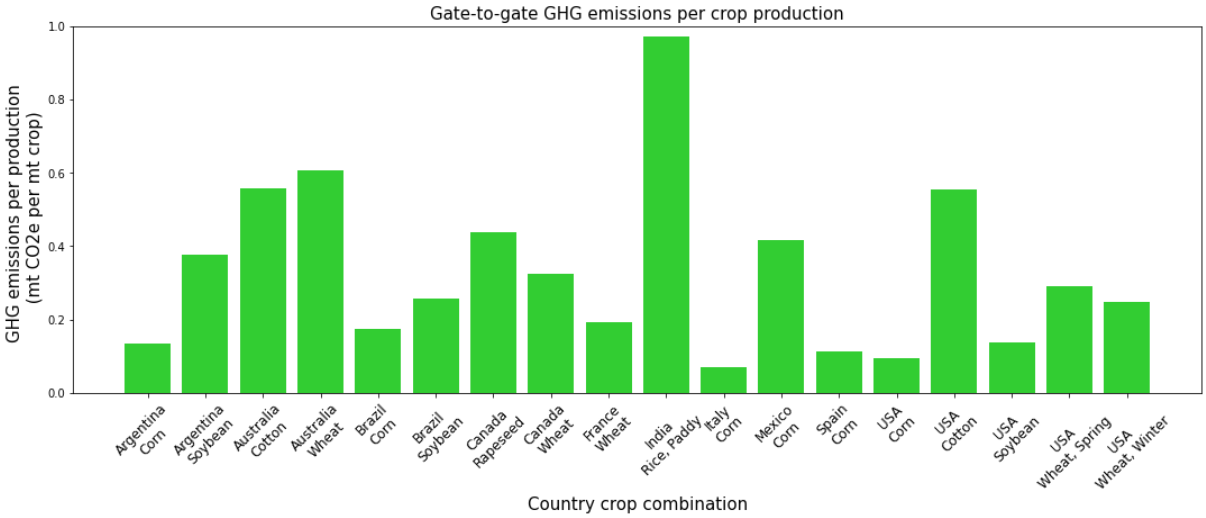


Figure 5 - Specific GHG emission in the baseline based on BCS'S customer farms

The Emission sources contributing to GHG emissions varied greatly. Fertilizer decomposition was a major contributor to GHG emissions across the 18 CCC´s, except for India rice. In the India rice market, methane emissions from the paddy play a major role in GHG emissions (see Table 20 in the appendix for the numbers and see below Figure 6 for the graph on the different emission sources).

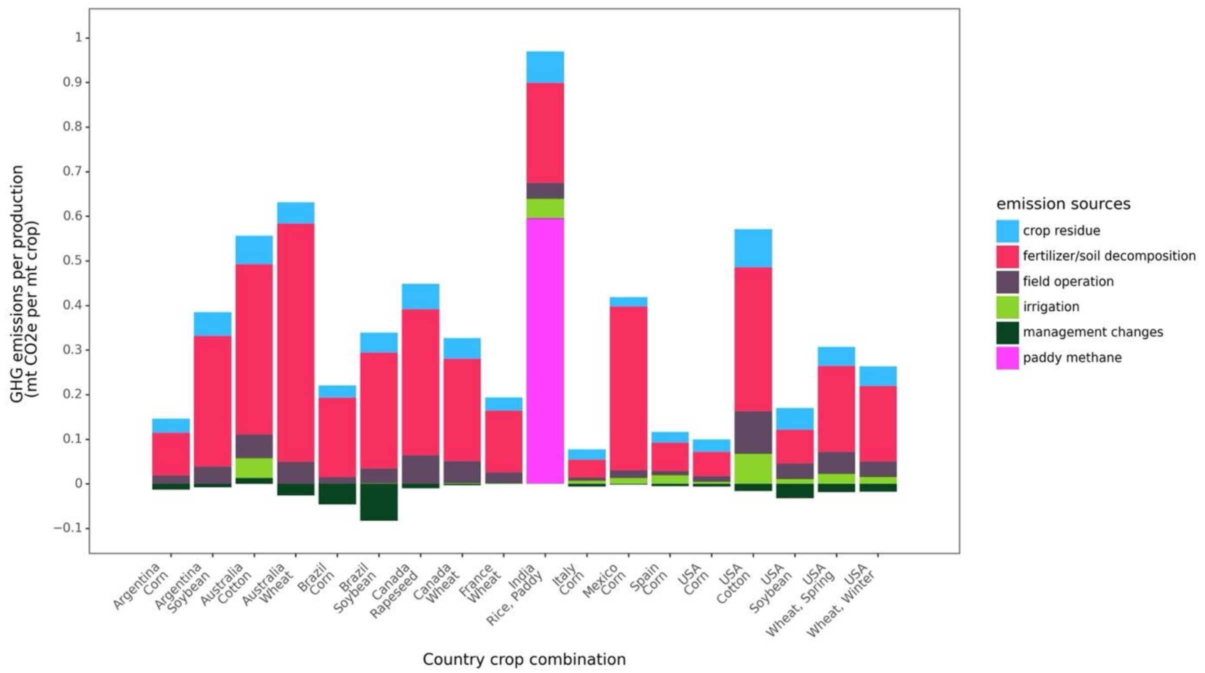


Figure 6 - Specific GHG emission in the baseline based on BCS'S customer farms grouped by emission sources

4.1.2 Total GHG emissions across the CCC for the baseline

The total GHG emissions in the baseline varies across the 18 markets (Table 17, Figure 7). This is due to market share, specific GHG emission and the production amount. Spain-corn had the smallest total emission followed by Italy-corn and India-rice had the largest total emission, mainly contributed by the highest specific GHG emission. USA-corn has the second largest total emission, mainly contributed by the largest crop production.

Table 17 - Total GHG emissions (mt CO2e) in the baseline year and different factors used in calculating Bayer's total GHG emissions in the 18 CCCs.

CCCs	Average Crop Production (mt)	Bayer's Market Share (fraction)	Specific GHG Emission (mt CO2e per mt crop)	Total GHG Emission (mt CO2e)
Argentina-corn	44,681,904.0	-.-*	0.1342	-.-*
Argentina-soybean	53,653,851.6	-.-*	0.3779	-.-*
Australia-cotton	674,335.5	-.-*	0.5566	-.-*
Australia-wheat	23,274,902.6	-.-*	0.6062	-.-*
Brazil-corn	86,177,438.8	-.-*	0.1751	-.-*
Brazil-soybean	108,154,739.8	-.-*	0.2571	-.-*
Canada-rapeseed	19,659,040.0	-.-*	0.4385	-.-*
Canada-wheat	30,942,707.0	-.-*	0.3247	-.-*
France-wheat	37,354,670.8	-.-*	0.1938	-.-*
India-rice	168,220,346.0	-.-*	0.9702	-.-*
Italy-corn	6,488,032.8	-.-*	0.0715	-.-*
Mexico-corn	27,021,010.2	-.-*	0.4179	-.-*
Spain-corn	4,087,309.8	-.-*	0.1114	-.-*
USA-corn	368,030,854.0	-.-*	0.0938	-.-*
USA-cotton	3,775,907.5	-.-*	0.5551	-.-*
USA-soybean	112,251,616.0	-.-*	0.1385	-.-*
USA-wheat, Spring	10,849,670.5	-.-*	0.2894	-.-*
USA-wheat, Winter	41,852356.6	-.-*	0.2466	-.-*

* The BCS market share data extracted from our internal market planning tool were shared with the panel of experts under a non-disclosure agreement.

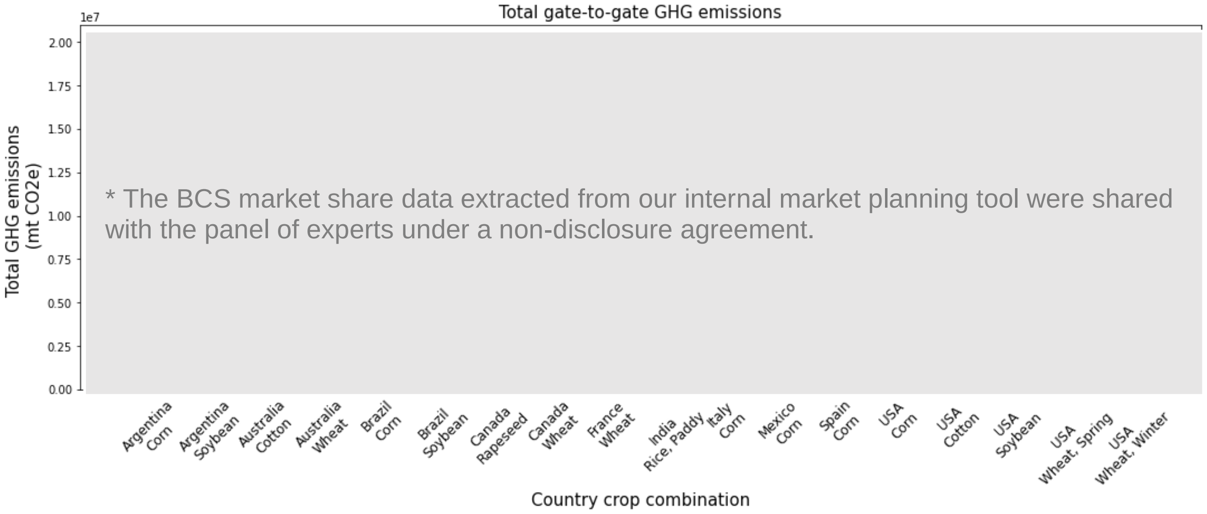


Figure 7 - Total GHG emission based on BCS's customer farms for the 18 CCC´s

4.1.3 Aggregated GHG emission for the baseline year

To determine the overall baseline, the individual CCC baselines are weighted. The weighting factors for each CCC is the ratio of total emissions in each market to total emissions across all the markets. They vary greatly across key market (Table 18, Figure 8). Based on weighting factors, the weighted specific GHG emission across 18 key markets in the baseline is **0.443 mt CO2e per mt crop produced**.

Table 18 - The specific GHG emission, total GHG emission weighting factors and weighted specific GHG emission for the 18 CCCs

CCCs	Specific GHG Emission (mt CO2e per mt crop)	Total GHG Emission (mt CO2e)	Weighting Factor	Weighted Specific GHG Emission (mt CO2e per mt crop)
Argentina-corn	0.1342	-.-*	-.-*	-.-*
Argentina-soybean	0.3779	-.-*	-.-*	-.-*
Australia-cotton	0.5566	-.-*	-.-*	-.-*
Australia-wheat	0.6062	-.-*	-.-*	-.-*
Brazil-corn	0.1751	-.-*	-.-*	-.-*
Brazil-soybean	0.2571	-.-*	-.-*	-.-*
Canada-rapeseed	0.4385	-.-*	-.-*	-.-*
Canada-wheat	0.3247	-.-*	-.-*	-.-*
France-wheat	0.1938	-.-*	-.-*	-.-*
India-rice	0.9702	-.-*	-.-*	-.-*
Italy-corn	0.0715	-.-*	-.-*	-.-*
Mexico-corn	0.4179	-.-*	-.-*	-.-*
Spain-corn	0.1114	-.-*	-.-*	-.-*
USA-corn	0.0938	-.-*	-.-*	-.-*
USA-cotton	0.5551	-.-*	-.-*	-.-*
USA-soybean	0.1385	-.-*	-.-*	-.-*
USA-wheat, Spring	0.2894	-.-*	-.-*	-.-*
USA-wheat, Winter	0.2466	-.-*	-.-*	-.-*
Total				**0.443**

* The BCS market share data extracted from our internal market planning tool were shared with the panel of experts under a non-disclosure agreement.

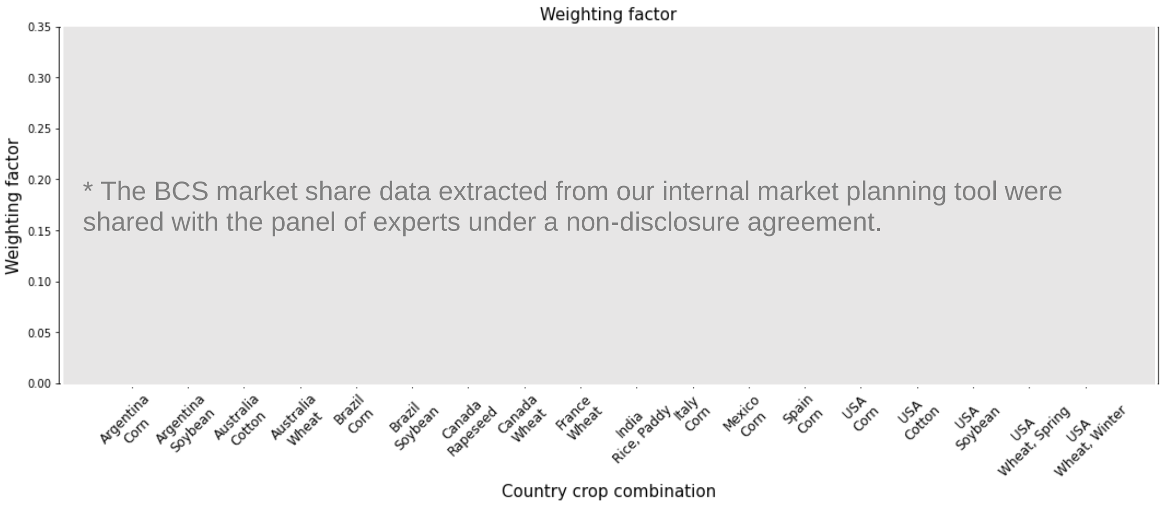
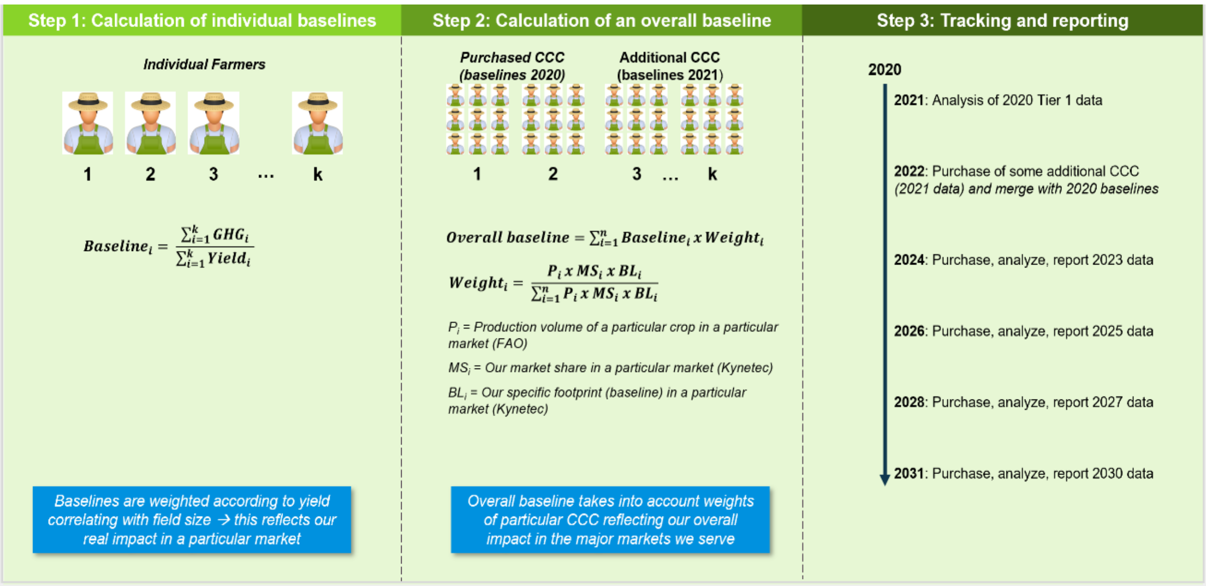


Figure 8 - Individual weighting factors for the 18 CCCs

4.1.4 Performance tracking

Having established the baseline GHG emissions, future GHG emission modeling for Bayer's customers will be compared to the baseline. The next steps are to estimate the specific GHG emissions based on the data to be collected by Kynetec biennially (every two years) up to 2030. BCS plans to continuously purchase data from Kynetec to determine our progress for the achievement of our set target (see Figure 9 below for more details).

Figure 9 - Baseline establishment and performance tracking



4.2 Discussion

In this section, we describe the key findings in our assessment. The number of surveyed customers ranged from 32 (Australia cotton market) to 611 (Brazil corn market), with most markets consisting of 120-300 surveyed customers (Argentina corn, USA cotton, USA spring wheat, Canada spring wheat, Spain corn, Argentina soy, Italy corn, US winter wheat, Australia winter wheat, Mexico corn, Canada spring rape, India rice, and France winter wheat) or 500-611 surveyed customers (Brazil soybean and corn, and USA soybean and corn). The Baseline specific GHG emission varied across the 18 CCCs. Corn (0.07-0.18 mt CO_2e per mt crop in Argentina, Brazil, Italy, Spain and US) had smallest specific emissions compared to other crops, expect Mexico corn (0.42 mt CO_2e per mt crop). While cotton had higher specific emissions (0.56 mt CO_2e per mt crop in Australia and USA). Rice in India had the largest specific emission (0.97 mt CO_2e per mt crop).

The emission sources contributing to the GHG emissions varied greatly. Fertilizer decomposition was a major contributor to GHG emissions across the key markets, except for India rice. In the India rice market, methane emissions from the paddy play a major role in GHG emissions. Switching from conventional to conservation land management practices can be a GHG sink. The variance of total GHG emissions in the baseline across the 18 markets was dependent on the market share assessed, specific GHG emissions, and the production amount. The weighted specific GHG emission across 18 key markets for the baseline is **0.443** mt **CO_2e per** mt **crop produced**.

Following the definition of a baseline upon which our improvement and progress will be tracked, future GHG emission modeling for Bayer's customers will be compared to the baseline specific GHG emission. We will estimate the specific GHG emissions for the 18 CCCs based on the data to be collected in the next every two or three years by Kynetec up to 2030. We will assess our 30% reduction commitment against these data estimated for baseline. Data sources in the future can be derived from internal data through Bayer field trials and Bayer Carbon business programs, or external data from similar surveys conducted in baseline.

4.3 Uncertainty analysis discussion in extant literature

In the assessment of GHG emissions, uncertainty evolves from three sources: Uncertainties on activity data (inventory), uncertainty resulting from year-to-year variability (i.e., changes in climate and management practice), and uncertainty resulting emission factors (i.e., characterization; Gibbons et al (2006).

- Uncertainty arising from inventory data can be controlled by avoiding under-representation. At the farm scale, only a little uncertainty relates to the inventory data, as data are provided directly by farmers. At landscape or regional scale, data are often based on statistical averages or expert knowledge, thus, the degree of uncertainties are typically higher compared to farm scale (Colomb, et al., 2012). Therefore, BCS has decided to partner with Kynetec to collect primary data based on interviews with farmers to ensure high accuracy of all reported activities especially those with strong influence on results, such as amount of N fertilizers reported.
- Uncertainty resulting from year-to-year variation can be reduced by using average climatic data and management practices on a several years period. For example, the same quantity of Nitrogen will result in different nitrification-denitrification rates due to variation in climatic condition (Colomb, et al., 2012). BCS has initiated data collection for harvest years 2020-2022 and therefore, multi-year data for a crop and country are not yet available but planned to be included in future to avoid such uncertainty.
- Uncertainty resulting from emission factors are associated with the chosen GHG emission calculators. Specifically, for the CFT, Clavreul et al (2017) found that the influence of model uncertainties on the GHG results are low.

4.4 Sensitivity analysis discussion in extant literature

This report only provides sensitivity analysis insights on the CFT GHG calculations using v1.0 and 1.11 based on existing literature. In a CFT case study example on the carbon footprint of open-field tomato production from 198 farms, Clavreul et al. (2017) found that several factors contribute to the variability in the carbon footprint results from CFT GHG calculation. Using a one-factor-at-a-time technique and Monte Carlo simulations, they conducted a sensitivity analysis to understand the impact of the different input parameters (farmer's inputs and model parameters) on the CFT GHG emissions results.

The results showed that the variability of total GHG emissions per mt of tomato produced was highly sensitive to variations in the production yield. Clavreul et al (2017) stated that a 70% reduction in yield resulted in a threefold increase in the GHG emission per mt of tomato. Furthermore, GHG emissions results were discovered to be sensitive towards variability in farm practices (underlined in Figure 10 below); in particular, to the ones related to fertilizer and diesel uses (e.g., for irrigation pumping).

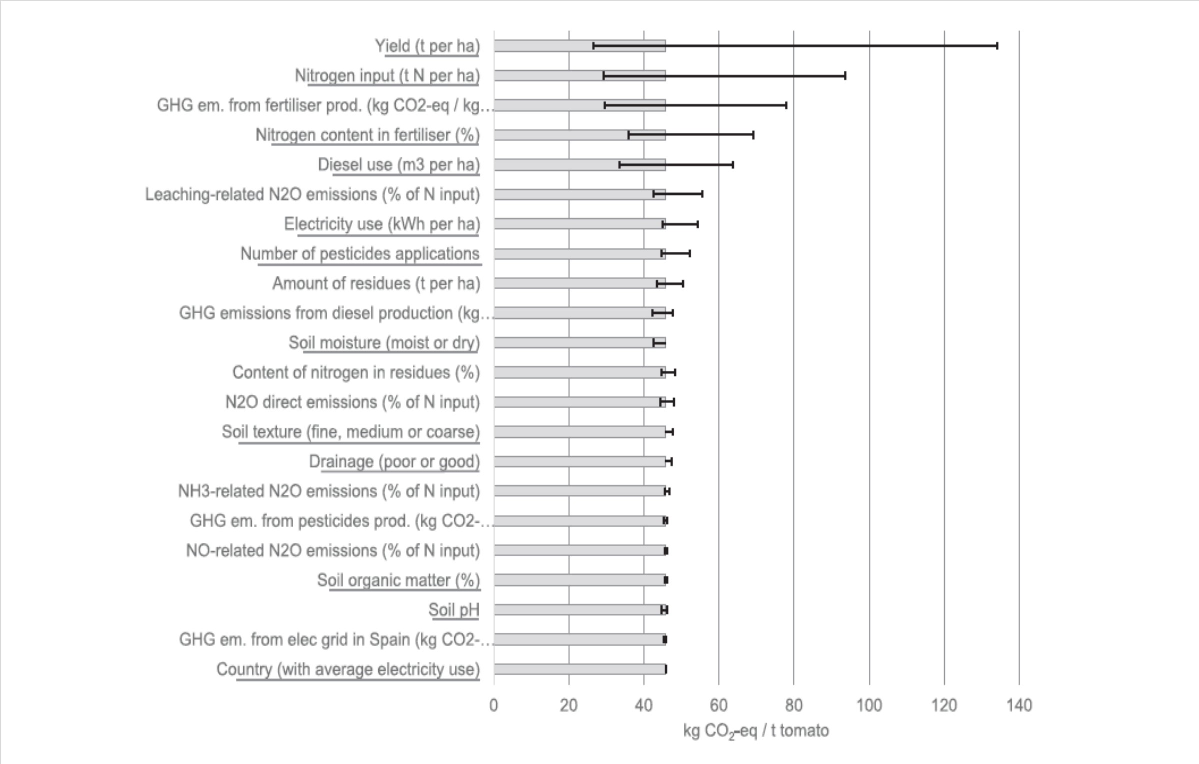


Figure 10 - Factors that contribute to the variability in the carbon footprint results from CFT GHG calculation (Figure from Clavreul et al. (2017))

The Figure 10 shows the total GHG emissions obtained (tomato production case) with error bars portraying the minimal and maximal GHG emissions obtained when testing minimal and maximal values for each parameter one at a time. Underlined are farmer related input data. The others are model parameters.

In a very recent study, Lam et al (2021) used the CFT to evaluate possible sources of variability in GHG footprint (in terms of kg CO2-eq/kg crop produced) of 26 crops using data from 4565 farms in 36 countries from 2013 through 2016. Across all crops and countries, they found that fertilizer use was the most important source of GHG emissions. Furthermore, they found negative relationships between GHG footprints and yields for the vast majority of the crops, suggesting that an increase in yield e.g., by growing more productive crop varieties) typically results in lower GHG footprints. According to the researchers, the reduction of GHG footprints with yield reflects that yield increase measures do not typically lead to a proportional increase in emissions. The researchers state that increases in yield are typically obtained through an increased farming efficiency which in turn does not increase GHG emission. An example is by synchronizing fertilizer application with crop nutrient requirements or by adopting more efficient crop varieties.

However, Lam et al (2021) also found several non-linear negative relationships between GHG footprints and yields for certain crops in their dataset, suggesting that optimum yield values may exist in terms of GHG footprints. For example, the GHG footprints of parsley and strawberry decreased with increasing yield, up to a certain yield value and then increased again. Therefore, several GHG improvement levers (along with yield increase) should be implemented in an orchestrated and coordinated way (Lam, et al., 2021).

- For example, with precision farming that seeks to optimize amounts, types, methods and timing of fertilizer application, yields can be increased while limiting or reducing GHG emissions from the production and application of synthetic nitrogen fertilizers.
- Other opportunities to reduce GHG emissions without reducing yields are efficiency improvements of electricity and fossil fuel (e.g., by replacing inefficient machinery or substituting fossil energy).

- GHG emissions caused by electricity use for irrigation can be reduced by optimizing the efficiency of the irrigation technologies and strategies or transitioning to alternative electricity sources such as solar power.

5 Main limitations of the assessment

Relating to the limitation of the emission calculation using the CFT, the tool only considers seed emissions from potatoes and not for other crops. These could lead to an underestimation of emissions. However, these emissions are reported to be quite low, compared to the other sources of emissions. The CFT plans to include this emission category in future.

In relation to Land use change (LUC), BCS acknowledges that LUC is one of the biggest contributors of GHG emissions in the global food systems. However, LUC emissions are not covered in this report due to the lack of reliable data and estimation difficulties. Therefore, BCS only included emissions which can be reliably measured in the scope of its GHG commitment. Regarding the exclusion of the production of crop protection products and fertilizers, and transportation, this is considered out of scope because the assessment focusses on emissions resulting from operations on the field.

6 Further developments of this report

In addition, the following sections will be further developed for the purpose of the further review cycles:

- Sensitivity analyses
- Uncertainty analysis
- Recommendations for further developments
- Review comments and practitioner responses
- Updates based on CFT versioning and relevance to methodology and reporting
- Biennial reports for achieving GHG reduction commitment based on the methodology listed here.

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8. Appendix

Table 19 - Specific GHG emission (mt CO2e per mt crop-dry weight) from surveyed BCS customer farms in the baseline

CCCs	CFT-modeled GHG emission (mt CO2e)	Crop weight of surveyed customer (mt)	Specific GHG emission (mt CO2e per mt crop)	Applied fertilizer (Mineral N, kg/ha)	Applied fertilizer (Organic N, kg/ha)
Argentina-corn	148839.20	1109361.9	0.1342	63.1	0.0
Argentina-soybean	130193.46	344495.7	0.3779	7.5	1.4
Australia-cotton	5236.42	9408.22	0.5566	95.4	58.5
Australia-wheat	4775.62	7877.66	0.6062	50.7	0.0
Brazil-corn	135548.63	774304.77	0.1751	106.3	37.2
Brazil-soybean	150393.04	584936.18	0.2571	102.3	30.8
Canada-rapeseed	33124.89	75533.29	0.4385	87.9	24.3
Canada-wheat	19814.09	61022.7	0.3247	81.5	16.2
France-wheat	6221.66	32100.5	0.1938	99.1	5.6
India-rice	3526.32	3634.71	0.9702	203.9	111.9
Italy-corn	4612.71	64558.71	0.0715	102.8	87.1
Mexico-corn	26203.83	62709.07	0.4179	193.4	1.8
Spain-corn	10641.95	95512.85	0.1114	148.6	67.5
USA-corn	272990.30	2909794.63	0.0938	136.8	108.2
USA-cotton	49354.34	88910.75	0.5551	88.2	27.1
USA-soybean	94663.96	683436.8	0.1385	58.0	27.5
USA-wheat, Spring	13184.91	45565.18	0.2894	102.5	26.0
USA-wheat, Winter	13481.57	54669.41	0.2466	68.9	27.3

Table 20 - Summary of specific GHG emission (kg CO2e per kg crop) from surveyed BCS customer farms by gate-to-gate emission source in the baseline year for the 18 CCC`s.

CCC	**CFT modeled GHG Emission (kg CO2e)**	**Total Crop Weight of Surveyed Customer (mt)**	**Specific GHG Emission (kg CO2e per kg crop)**	**Distribution of Specific GHG Emission per Emission sources (kg CO2e per kg crop)**					
				Fertilizer/ Soil decomposition	Irrigation	Machinery	Managemen t changes	Crop Residue	Paddy methane
Argentina-corn	148839197	1109361.9	0.1342	0.0956	0	0.0191	-0.0123	0.0318	-
Australia-cotton	5236418.46	9408.22	0.5566	0.382	0.0441	0.0528	0.0134	0.0642	-
Brazil-corn	135548634.1	774304.77	0.1751	0.178	0.0002	0.0149	-0.0458	0.0278	-
Brazil-soybean	150393044.6	584936.18	0.2571	0.2606	0.0011	0.0328	-0.0826	0.0453	-
India-rice, paddy	3526317.05	3634.71	0.9702	0.2249	0.0435	0.0352	0.0008	0.071	0.5948
Italy-corn	4612713.74	64558.41	0.0715	0.0397	0.0075	0.0068	-0.0059	0.0233	-
Spain-corn	10641954.47	95512.85	0.1114	0.0635	0.0196	0.0091	-0.0053	0.0246	-
USA-corn	272990301.3	2909794.63	0.0938	0.055	0.0053	0.0116	-0.0058	0.0278	-
USA-cotton	49354335.23	88910.75	0.5551	0.3228	0.0673	0.0954	-0.0158	0.0854	-
USA-soybean	94663958.61	683436.8	0.1385	0.0755	0.0107	0.0349	-0.0318	0.0493	-
Argentina-soybean	130193457.4	344495.7	0.3779	0.293	0	0.039	-0.0071	0.0531	-
Australia-wheat	4775618.29	7877.66	0.6062	0.5335	0	0.0497	-0.0255	0.0485	-
Canada-rapeseed	33124891.18	75533.29	0.4385	0.3281	0	0.0637	-0.0099	0.0567	-
Canada-wheat	19814089.57	61022.7	0.3247	0.23	0.0017	0.0488	-0.0026	0.0468	-
France-wheat	6221656.53	32100.5	0.1938	0.1385	0.0008	0.0234	0.0013	0.0298	-
Mexico-corn	26203826.23	62709.07	0.4179	0.3671	0.0131	0.0171	-0.0013	0.0219	-
USA-wheat, Spring	13184910.7	45565.18	0.2894	0.1926	0.0226	0.0492	-0.018	0.043	-
USA-wheat, Winter	13481567.08	54669.41	0.2466	0.1687	0.0155	0.0348	-0.0173	0.0449	-