regenagri

Independent third-party review by GreenStory

Life Cycle Assessment

Greenhouse Gas Emissions of Regenagri-Certified Cotton (2024)

Published May 2026

Life Cycle Assessment

Greenhouse Gas Emissions of Regenagri-Certified Cotton (2024)

Assessment Year	2024 Data
System Boundary	Cradle-to-Gate (Crop Production and Ginning)
Functional Unit	1 tonne of ginned cotton lint at the gin gate
Geographic Scope	13 countries with Regenagri-certified cotton production
Methodology	Attributional Life Cycle Assessment
Standards	ISO 14067, ISO 14040, ISO 14044, Regenagri Carbon Standard

Document Control and Responsibility

Item	Description		Remarks
Document title	Greenhouse Gas Emissions of Regenagri-Certified Cotton		
Version	v1.0 (final, following four internal review cycles)	14 May 2026	Internal review and resolution of Green Story comments and feedback through four iterative review cycles, incorporated into the current final version dated 14 May 2026.
Version	v1.1 (minor revisions)	07 August 2026	Revisions addressing the Nike review points (scope, allocation, data year, background data and well-to-tank, ginning, and soil organic carbon). Methane characterisation factor aligned to the IPCC AR6 non-fossil value (27.0), with immaterial effect. The 2024 headline emission factors are unchanged. A major methodological revision, a full Higg and Cascale conformant run, is scheduled for the next LCA.
Assessment year	2024		
Prepared by	Regenagri team		
Reviewed by	**GreenStory - Independent technical reviewer (ISO 14040/44; ISO 14067)**		
Review status	Internal technical review completed		

INDEPENDENT CRITICAL REVIEW STATEMENT

In accordance with the requirements of ISO 14044:2006 (Clause 4.2.3.8) and ISO 14071:2024, an independent critical review of this LCA study has been conducted by Green Story (LCA Consulting). The reviewer, Prof. Dr. Kannan Muthu, CSO, Green Story, possesses recognised expertise in LCA methodology.
The review was conducted against ISO 14040:2006/Amd 1:2020 and ISO 14044:2006/Amd 1:2017/Amd 2:2020. The reviewer confirmed that the methods used to carry out the study are consistent with ISO 14040 and ISO 14044, that they are scientifically and technically valid, that the data used are appropriate and reasonable relative to the study's goal, that the interpretations reflect the limitations identified, and that the report is transparent and consistent.
The full critical review report, which includes all technical and general review items closed by the reviewer, is provided in Annex: Independent Review Report.

Table of Contents

List of Tables

Comprehensive overview of all tables included in the report, covering system boundaries, methodological assumptions, emission factors, country-level results, data quality, uncertainty analysis, and detailed breakdowns of greenhouse gas emissions across cotton production systems.

EXECUTIVE SUMMARY

This Life Cycle Assessment quantifies greenhouse gas emissions associated with the production of Regenagri-certified cotton lint for the 2024 production year. The assessment covers agricultural production and ginning across thirteen countries and uses verified farm-level activity data collected through the Regenagri certification system and independently audited by Control Union. This study quantifies greenhouse gas emissions following IPCC guidance and is consistent with a product carbon footprint approach (ISO 14067:2018). The assessment follows attributional LCA modelling principles and applies system boundaries and allocation logic consistent with ISO 14040 and ISO 14044.

The system boundary extends from crop production to the gin gate. It includes direct agricultural emissions, upstream input production, field energy use, transport to ginning facilities, and ginning operations. The functional unit is one tonne of ginned cotton lint at the gin gate. In 2024, Regenagri-certified cotton covered approximately 1.33 million hectares and produced 1.35 million tonnes of lint. Farm-level activities generated 1,719,396 tCO_2e. Ginning emissions were estimated using an absolute emission factor of 0.10 tCO_2e per tonne of lint, yielding 135,267 tCO_2e across all production countries. Total pre-allocation cradle-to-gate emissions were 1,854,663 tCO_2e. After applying the 84 percent economic allocation factor to lint, total cradle-to-gate lint emissions were 1,557,917 tCO_2e, corresponding to a weighted average emission intensity of 1.15 tCO_2e per tonne of lint (GHG emissions and removals).

The weighted global emission intensity of Regenagri-certified cotton lint is 1.15 tCO_2e per tonne lint when both emission reductions and soil carbon removals are included, while the corresponding country-level values range from −4.74 to 2.30 tCO_2e per tonne lint. When removals are excluded and only gross operational emissions are considered, the weighted global emission intensity is 1.83 tCO_2e per tonne lint, with country-level values ranging from 0.24 to 2.49 tCO_2e per tonne lint. These values represent the cradle-to-gate carbon footprint of Regenagri-certified cotton lint, including ginning and economic allocation to lint. Economic allocation (84 percent to lint, 16 percent to cottonseed) is the primary allocation method applied throughout this assessment, consistent with established cotton LCA practice and ISO 14044 hierarchy guidance. Mass allocation results are shown alongside as a transparency comparator only, to enable comparability with studies that adopt physical (mass-based) allocation. Under mass allocation (40.6 percent of co-product mass to lint, 59.4 percent to cottonseed, derived from typical lint and cottonseed yields per 100 kg of seed cotton), the corresponding weighted global intensities would be approximately 0.56 tCO_2e per tonne of lint (net, including removals) and 0.88 tCO_2e per tonne of

lint (gross, excluding removals). The mass allocation values are not used as primary results.

Emission intensity varies substantially between production regions. The main drivers are nitrogen fertiliser application, fertiliser manufacturing emissions, pesticide inputs, diesel use in field operations, irrigation electricity demand, yield levels, and soil organic carbon stock changes. Fertiliser-related soil emissions dominate the greenhouse gas footprint, while regenerative practices that increase soil carbon can substantially reduce net emissions.

Overall, the results show that regenerative cotton systems can reduce climate impacts through improved nitrogen management, soil carbon enhancement, and energy efficiency in field and processing operations. These factors remain the primary determinants of the greenhouse gas footprint of cotton production.

These results demonstrate that regenerative cotton production systems can achieve measurable improvements in greenhouse gas performance while maintaining agricultural productivity. Across the assessed systems, nitrogen management, soil carbon dynamics, and energy use in field and processing operations emerge as the most influential factors shaping the overall carbon footprint of cotton production. Continued optimisation of these management practices provides the most effective pathway for reducing the climate impact of cotton supply chains.

1 GOAL AND SCOPE DEFINITION

1.1 Study Goals

This LCA has been conducted to:

- Quantify greenhouse gas emissions for Regenagri-certified cotton production across verified farm networks.
- Support Regenagri certification and insetting claims under the Regenagri Carbon Standard.
- Enable tracking of regenerative outcomes at farm and supply-chain scale.
- Provide performance data for brands and supply-chain members with Regenagri certification.
- Establish baseline emission factors for certified cotton production.

1.2 Intended Use and Limitations

Intended Application:

Results are intended to support:

- Regenagri internal impact reporting and certified partner communication.
- Supply-chain members seeking verified GHG performance data.
- Certification audits and third-party verification processes.
- Regenerative outcome tracking within the Regenagri framework.

Critical Limitations:

- Results support Regenagri internal impact reporting and certified partner communication only.
- Public product-level comparisons require compliance with Regenagri Claim Requirements and relevant logo use rules.
- Results are not suitable for external comparative assertions without critical review by an independent expert.
- Results are not for ecolabel claims outside Regenagri frameworks.
- Assessment is limited to climate change impact category (GHG emissions only).
- No comparative assertions are made between countries, production systems,

or years.

- Results are based on 2024 verified data only and should not be extrapolated to other years.

- A full Life Cycle Inventory (LCI) in physical units (kWh, MJ, kg, L, ha) was not provided. However, using the GHG inventory presented, recalculation can be performed. The study cannot support impact categories beyond climate change.

  Public disclosure of farm-level start- and end-of-period SOC stocks remains restricted on commercial-confidentiality grounds, consistent with the parallel Regenagri carbon credit programme rules, hence could not be shared for verification to the external reviewer.

1.3 Standards and Framework

This LCA has been prepared in alignment with:

- ISO 14040:2006 – Life Cycle Assessment: Principles and Framework.
- ISO 14044:2006 – Life Cycle Assessment: Requirements and Guidelines.
- Regenagri Carbon Standard – Greenhouse Gas Quantification Methodology for Crops.
- IPCC Sixth Assessment Report (AR6, 2021), Working Group I, Chapter 7 – Global Warming Potential factors (GWP100, 100-year time horizon).
- ISO 14067:2018 – Greenhouse gases: Carbon footprint of products – Requirements and guidelines for quantification.

This study quantifies greenhouse gas emissions following IPCC guidance and is consistent with a product carbon footprint approach (ISO 14067:2018). The assessment follows attributional LCA modelling principles and applies system boundaries and allocation logic consistent with ISO 14040 and ISO 14044. Primary, verified farm activity data are used wherever available through the certification system, ensuring high data representativeness and traceability. Where primary data are not available, the assessment relies on recognised secondary emission factors derived from Intergovernmental Panel on Climate Change (IPCC) guidelines and established sectoral sources. The quantification of greenhouse gas emissions follows the calculation rules outlined in the Product Environmental Footprint Category Rules (PEFCR) for Apparel and Footwear for the climate change impact category; this should not be read as a claim of full PEF compliance, since the assessment covers only the climate change impact category and not the full 16-category PEF impact set.

Methodological choices have additionally been cross-referenced against the Cascale Industry-Aligned Cotton LCA Methodology (Cascale, 2024) and the Sphera/Textile Exchange Life Cycle Assessment for Cotton (Sphera, 2026), which together represent the most recent industry-aligned reference framework for cotton fibre LCA. This cross-reference confirms that the system boundary, functional unit, allocation principles, ginning treatment, and IPCC AR6 GWP100 characterisation factors applied in this assessment are broadly aligned in principle with current industry-aligned practice for cotton GHG quantification, without constituting strict item-by-item conformance with the Cascale Higg MSI cotton methodology.

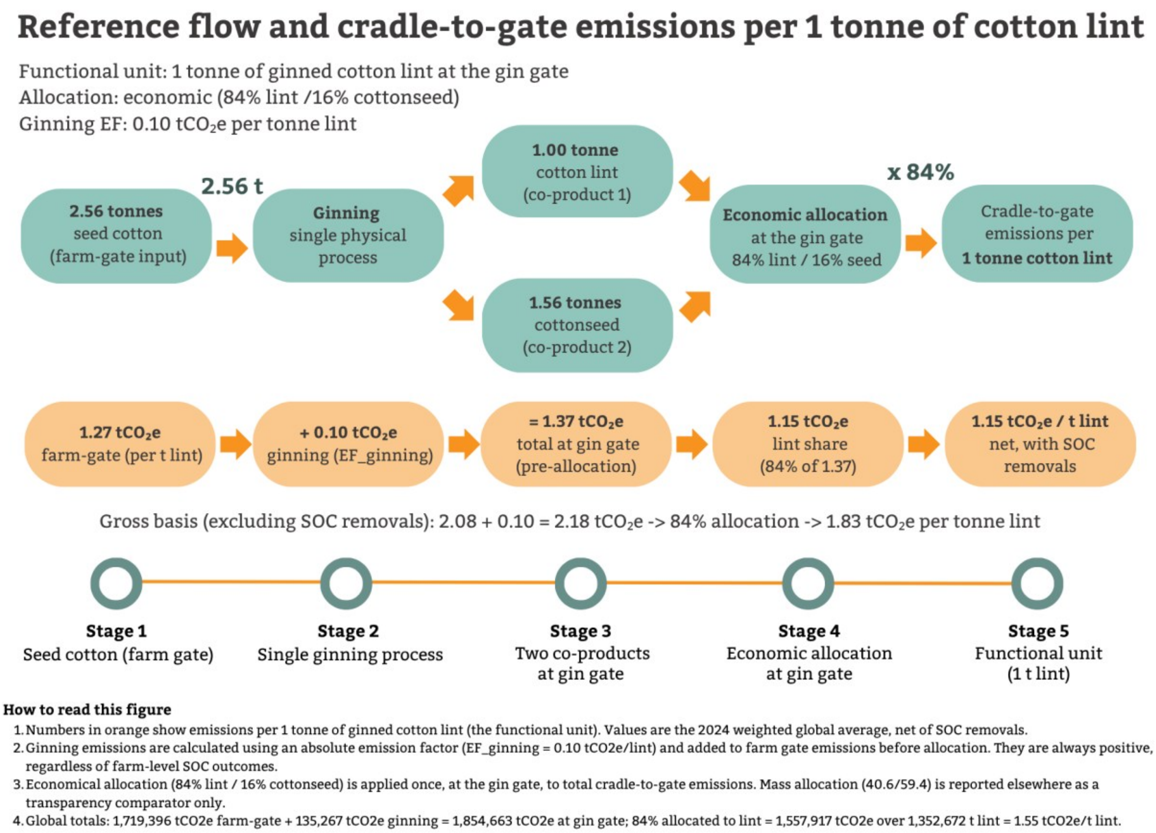
For clarity, this assessment was not developed specifically to the Cascale Higg Materials Sustainability Index (Higg MSI) cotton methodology; as stated in the goal and scope, its intended context is broader than the Higg MSI use case. The cross-reference above therefore indicates alignment in principle rather than strict conformance. The specific methodological differences identified on review (impact-category coverage, the economic allocation factor, the three-year data requirement, background-dataset documentation and the energy system boundary, the ginning default assumption, and the treatment of soil organic carbon) are addressed in the relevant sections of this report. Those that can be reconciled from figures already presented are identified as such, and the remainder are reserved for a Higg-conformant run in the next assessment cycle.

A critical review of the study was carried out by an external reviewer in accordance with ISO 14071:2024.

1.4 Functional Unit and Reference Flow

Functional Unit:

1 tonne of ginned cotton lint at the gin gate.



Reference Flow:

Figure 1: Reference flow and product system transformation from seed cotton to ginned cotton lint at the gin gate, including co-product generation and allocation.

The reference flow represents the quantity of seed cotton required to produce the functional unit of 1 tonne of ginned cotton lint. Based on a weighted average ginning outturn of 39 percent, 2.56 tonnes of seed cotton are required. The ginning process produces cotton lint and cottonseed as co-products. Following ISO 14044 principles, economic allocation is applied at the gin gate, assigning 84 percent of total cradle-to-gate emissions to lint and 16 percent to cottonseed.

Rationale:

The functional unit reflects the primary product delivered to textile processors and enables comparison of GHG intensity across production regions with different yields, agricultural practices, and soil carbon outcomes.

1.5 System Boundary

The system boundary of this assessment extends from cotton cultivation through ginning operations. The assessment includes upstream production of agricultural inputs such as fertilisers and pesticides, field operations including diesel use and irrigation electricity, transport of harvested cotton to the gin, and energy use during ginning operations.

Cradle-to-Gate System Boundary includes:

Table 1.5.1 – Cradle-to-Gate System Boundary: Included Life Cycle Stages and Processes

Life Cycle Stage	Included Processes
Agricultural Production	Land preparation, seed production, fertiliser application, pesticide/herbicide application, irrigation, field operations, direct field emissions (N_2O, CH_4, CO_2), soil carbon changes from management practices
Input Manufacture and Transport	Production and transport of seeds, fertilisers, pesticides, herbicides, fuel, and machinery
Field Operations	Fuel consumption for machinery, field energy use, irrigation energy
Transport to Gin	Transport of seed cotton from farm to ginning facility
Ginning Processes	Electricity and fuel use in ginning operations, allocation of emissions to lint and seed co-products

Processes Excluded from System Boundary:

- Textile processing (spinning, weaving, dyeing, finishing)
- Distribution beyond the gin gate
- Use phase (washing, wearing, maintenance)
- End-of-life (recycling, incineration, landfill)
- Capital goods and infrastructure (depreciated)
- Pesticide application machinery emissions (included in field energy)

Allocation Procedures:

Economic allocation is applied between cotton lint and cotton seed co-products at the gin gate in accordance with ISO 14044. Allocation is performed after aggregation of all cradle-to-gate emissions.

Allocation factors are based on the relative economic value of co-products:

- Cotton lint: 84 percent

- Cotton seed: 16 percent (allocation factors derived from international cotton commodity price ratios and from sector LCA benchmarks, including the Better Cotton Initiative cotton cultivation report by Anthesis Group, 2021)

This approach reflects the economic function of the system, where cotton lint represents the primary product and main value driver. Economic allocation is widely applied in cotton life cycle assessment studies and ensures comparability with existing literature.

Data Coverage – Primary and Secondary Data Sources

Primary farm-level activity data were collected through the Regenagri certification platform for all 13 participating countries included in this assessment. These primary data comprise:

- Crop area and lint yield
- Fertiliser application rates and fertiliser product types
- Pesticide and agrochemical use
- Fuel consumption for field operations
- Irrigation volumes or electricity consumption where available
- Crop residue management practices
- Soil organic carbon measurements or model input parameters

Primary activity data therefore cover 100 percent of farm-level production systems represented within the defined system boundary.
Secondary emission factors were applied where upstream industrial or energy system data were required. These include:

- Fertiliser production emission factors
- Pesticide and agrochemical production emission factors
- Country-specific electricity grid emission factors
- Transport emission factors
- Ginning process emission factor (EF_ginning = 0.10 tCO_2e per tonne of lint, absolute)

Facility-specific ginning energy data were not uniformly available across all countries for the 2024 reporting year. Ginning emissions were therefore estimated using an absolute emission factor approach (EF_ginning = 0.10 tCO_2e/t lint), as described in Section 3.6.

This clarification distinguishes between primary farm-level activity data and secondary emission factors used within the cradle-to-gate boundary, ensuring transparency regarding data precision and reproducibility.

Emission Source Disaggregation Coverage

Detailed emission source disaggregation (e.g., fertiliser soil emissions, residue emissions, irrigation energy, pesticide production, transport, machinery, processing energy) is available at full category level for the following countries: USA, Brazil, Australia, Turkey, India, Côte d'Ivoire, Egypt, Mexico, Mozambique, Pakistan, Peru, Tajikistan, and Tanzania.

1.6 Cut-off Criteria

No explicit numerical cut-off criteria were established for this assessment. Consistent with ISO 14044 (clause 4.2.3.3.3), the system boundary was defined based on the goal and scope of the study with the intention to capture all environmentally relevant flows for the climate change impact category. Secondary emission factors and proxy datasets were applied using conservative assumptions to avoid underestimation of greenhouse gas emissions, and these are documented explicitly in Section 2 and Appendix 13. Capital goods and infrastructure were excluded as depreciated; pesticide application machinery emissions were aggregated within field energy; and downstream stages beyond the gin gate were excluded from the system boundary, as set out in Section 1.5. These exclusions are not expected to materially affect the cradle-to-gate climate change results and are consistent with standard practice in cotton LCA studies.

1.7 Geographic and Temporal Boundaries

Geographic Scope:

The assessment covers Regenagri-certified cotton production in 2024 across 13 countries. The geographic scope includes Australia, Brazil, Côte d'Ivoire, Egypt, India, Mexico, Mozambique, Pakistan, Peru, Tajikistan, Tanzania, Turkey, and the United States.

Temporal Boundary:

Assessment year: 2024 only. Data represented production activities and verified outcomes during the 2024 growing season and harvest cycle.
This first assessment uses single-year 2024 data to establish a current-year baseline emission factor. Moving to a three-year rolling average with annual updates, consistent with the Cascale requirement, will be considered in the next assessment cycle as additional years of verified data accumulate within the certification

platform.

Technological Boundary:

Assessment includes organic and non-organic production systems certified under Regenagri standards. Regenerative practices (cover crops, reduced tillage, compost application, etc.) are captured through verified farm-level data and reflected in soil carbon outcomes.

2 METHODOLOGICAL BASIS AND MODELLING APPROACH

2.1 LCA Approach

This study quantifies greenhouse gas emissions following IPCC guidance and is consistent with a product carbon footprint approach (ISO 14067) and in accordance with Regenagri carbon accounting methods and the principles of ISO 14040 and ISO 14044. The quantification of greenhouse gas emissions follows the calculation rules outlined in the Product Environmental Footprint Category Rules (PEFCR) for Apparel and Footwear for the climate change impact category; this should not be read as a claim of full PEF compliance, since the assessment covers only the climate change impact category and not the full 16-category PEF impact set. Activity data are verified through the Regenagri certification system, and emission factors are consistent with IPCC guidance. The climate change impact category is expressed as kg CO_2 equivalent using the IPCC 100-year Global Warming Potential characterization factors. Greenhouse gas quantification and carbon intensity calculations are carried out using the Cool Farm Platform (CFP) methodology, which aligns with the Greenhouse Gas Protocol and Intergovernmental Panel on Climate Change (IPCC) criteria for agricultural emissions and removals.

Farm-level greenhouse gas emissions, soil organic carbon (SOC) stock changes and removals are quantified using the Cool Farm Platform (CFP), which is the third-party agricultural GHG quantification model adopted under the Regenagri Carbon Standard for annual crop systems. The Cool Farm Platform applies IPCC 2019 Refinement emission factors and process-based algorithms to verified farm activity data to calculate direct and indirect N_2O emissions, CO_2 emissions from fertiliser inputs, CH_4 emissions from residue management, energy-related emissions, and soil carbon stock changes.

This Life Cycle Assessment does not calculate or issue carbon credits. It quantifies cradle-to-gate greenhouse gas emissions and removals for product-level reporting. Any carbon credit generation under Regenagri operates under separate programme rules and is outside the scope of this LCA.

Attributional LCA is used to quantify greenhouse gas emissions directly associated with the production of cotton lint, without modelling consequential market effects or system-wide supply responses. For the climate change impact category, which is the only impact assessed in this study, the quantification follows the calculation rules outlined in the Product Environmental Footprint Category Rules (PEFCR) for Apparel and Footwear; this should not be read as a claim of full PEF compliance, since the assessment covers only the climate change impact category and not the full 16-category PEF impact set. This ensures consistent application of system boundaries, allocation rules, data hierarchy, and greenhouse gas characterization.

The emission factors results are expressed as emission factors including GHG and removals as well as emission factors including only GHG emissions.

For the 2024 reporting year, ginning emissions were estimated using an absolute emission factor approach. Facility-specific ginning energy consumption data was not consistently available across all production countries and were therefore not used in the calculation. Ginning emissions were calculated as: GHG_ginning = EF_ginning × Lint_production, using a fixed emission factor of 0.10 tCO_2e per tonne of lint, derived from published literature benchmarks. Total cradle-to-gate emissions were derived by additive aggregation: Total = Farm + GHG_ginning. This approach ensures ginning emissions are always positive and independent of farm-level SOC effects

Key Methodological Principles:

- Use of verified farm activity data collected through the Regenagri certification and third-party audit system.
- Primary activity data and emission factors are treated as distinct elements within the assessment. Activity data refer to quantified farm-level inputs and operations (e.g. fertiliser use, fuel consumption, irrigation), while emission factors represent coefficients used to convert these activities into emissions.
- Activity data are derived from verified farm-level records collected through the Regenagri certification system.
- Emission factors are sourced from the IPCC 2019 Refinement and are applied to quantify direct and indirect agricultural emissions in accordance with Tier 1 methodologies.
- Quantification of integrated farm emissions and soil organic carbon (SOC) changes using third-party GHG quantification models adopted under the Regenagri Carbon Standard (e.g., Cool Farm Platform), aligned with IPCC and GHG Protocol criteria.
- Use of recognised life cycle inventory (LCI) databases and sector benchmarks for upstream input production and energy emissions where primary data are unavailable.
- For the 2024 reporting year, facility-specific ginning energy consumption data were not uniformly available across all 13 production countries. Ginning emissions were therefore estimated using an absolute emission factor (EF_ginning = 0.10 tCO_2e per tonne of lint), derived from published ginning energy intensity benchmarks (Funk and Hardin, 2012 for US gins; Ismail et

al., 2011 for Australian gins) and a weighted average ginning outturn of 39 percent. Ginning emissions are calculated as GHG_ginning = EF_ginning × Lint_production, ensuring positive values in all countries regardless of farm-level SOC dynamics.

- Transparent documentation of data sources and tier hierarchy.
- Consistent application of allocation procedures across all production regions.
- Cool Farm Platform (CFT), the third-party GHG model adopted under the Regenagri Carbon Standard.

2.2 Emission Factor Selection and Data Hierarchy

Emission factors are selected according to the following hierarchy:

Table 2.2.1 – Emission Factor Selection Hierarchy and Data Sources

Level	Source	Application
Level 1	Regenagri verified farm data	Primary activity data for crop production, including fertiliser use, fuel consumption, irrigation, yield, and soil organic carbon (SOC) changes
Level 2	IPCC 2019 Refinement default factors	Direct and indirect N_2O emissions, CH_4 emissions, and other agricultural emission factors
Level 3	Regional/country-specific factors	Electricity grid emission factors, transport emission factors, and region-specific parameters
level 4	Industry-average and LCI databases	Upstream input production (fertilisers, pesticides, seeds) and ginning benchmark assumptions • Emission factors and secondary data sources are selected based on data availability and relevance, following the hierarchy defined above. • Fertiliser production emissions using product-specific emission factors derived from IPCC 2019 Refinement guidance and recognised life cycle inventory databases. • Pesticide and herbicide production emissions using emission factors from the World Food LCA Database and sector benchmarks. • Electricity grid emission factors applied on a country-specific basis for irrigation pumping and ginning energy use. • Ginning process emissions calculated using an

		absolute emission factor (EF_ginning = 0.10 tCO_2e per tonne of lint). This factor is not directly quoted from Anthesis (2021); it was derived by the authors of this report using benchmark inputs reported by Ismail (2009) among others, as follows: ginning energy intensity of approximately 100 kWh per tonne of seed cotton (midpoint of the 70–120 kWh/t seed cotton range derived from the Ismail (2009) Australian cotton gins benchmark); representative grid emission factor of approximately 0.40 kg CO_2e/kWh (midpoint of 0.35–0.45 kg CO_2e/kWh representative of national grid emission factors across the 13 production countries, based on the IEA Emissions Factors database (IEA, 2025)); and a weighted average ginning outturn of 39 percent. The derivation is: 100 kWh/t seed cotton × 0.40 kg CO_2e/kWh = 40 kg CO_2e/t seed cotton ÷ 0.39 = 103 kg CO_2e/t lint ≈ 0.10 tCO_2e/t lint, with a sensitivity range of 0.06–0.14 tCO_2e/t lint reflecting the energy and grid factor ranges. Applied as GHG_ginning = EF_ginning × Lint_production, independently of total cradle-to-gate emissions. Anthesis itself reports ginning as approximately 10 percent of total cradle-to-gate cotton emissions (Anthesis, 2021); the absolute factor 0.10 tCO_2e/t lint is a numerical equivalent derived by the authors and is not a verbatim Anthesis value.

Global Warming Potentials (GWP):

All greenhouse gases are converted to CO_2-equivalents using 100-year Global Warming Potential (GWP100) factors from the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (IPCC AR6), consistent with the methodology implemented in the Cool Farm Platform:

- CO_2: 1.0
- CH_4: 27.0
- N_2O: 273.0

Total GHG emissions (tCO_2e) = (CO_2_emissions × 1.0) + (CH_4_emissions × 27.0) + (N_2O_emissions × 273.0).

Certain secondary datasets applied in this assessment are drawn from the Cool Farm Platform and associated sectoral sources rather than from a single publicly published methodology document, which has implications for the documentation of the energy system boundary. For energy carriers in particular, some of these background factors represent direct combustion (tank-to-wheel) emissions and may not fully capture the upstream well-to-tank stages of fuel and electricity supply under a cut-off, by-classification system model. Excluding well-to-tank emissions understates energy-related impacts; for diesel and grid electricity the well-to-tank contribution is typically of the order of 15 to 25 percent of the combustion-only value. Because energy use (field operations, irrigation and ginning) is a minority of cradle-to-gate emissions in these systems, the indicative effect on the total cradle-to-gate climate result is estimated at approximately 2 to 5 percent, in the direction of under-reporting. This figure is disclosed as a bounded, indicative estimate rather than a recalculated result. To resolve it fully, the next assessment cycle will apply fully documented, well-to-tank-inclusive background datasets and will publish the applied energy factors so that the system boundary is transparent and independently reviewable. The 2024 headline emission factors are retained for the present cycle on the basis of this disclosure.

2.3 Data Quality Assessment

Data sources are assessed for:

- Temporal relevance: Data from 2024 production cycle (current).
- Geographic relevance: Country-specific and farm-specific data where available.
- Technological relevance: Data reflects Regenagri-certified production practices.
- Precision and completeness: Verified through Regenagri audit protocols.
- Uncertainty: Documented through sensitivity analysis.

Primary data from Regenagri-certified farms undergo annual third-party audit to verify data accuracy and supporting evidence. Audit scope includes assessment of compliance with Regenagri standards and validation of data required for GHG quantification.

3 INVENTORY ANALYSIS

3.1 Farm-Level Data Collection

Primary Data Sources:

Regenagri-certified farms provide verified activity data through the Regenagri digital platform and annual third-party audits:

Table 3.1.1 – Farm-Level Data Categories, Units, and Verification Methods

Data Category	Measurement Unit	Verification Method
Fuel consumption	Litres / hectare	Fuel purchase records, machinery logs
Fertiliser use	kg / hectare	Product invoices, application records
Pesticide/herbicide use	kg / hectare	Product invoices, application records
Irrigation water	m^3 / hectare	Pump records, water meter readings
Crop yield	tonnes / hectare	Harvest records, gin receipts
Soil carbon	tonnes C / hectare	Soil sampling, Regenagri measurement protocols
Regenerative practices	Yes/No, quantity	Farm records, audit verification

Regenerative Practice Data:

Farms provide documentation of management practices that influence GHG emissions:

- Cover crop adoption and biomass
- Reduced/no-till implementation
- Crop rotations
- Fertilisation
- Compost and organic amendment application
- Crop residue management (burning, incorporation, removal)
- Irrigation method and efficiency
- Integrated pest management adoption
- Land use and land use change

3.2 Agricultural Emissions Calculation

Sensitivity of fertiliser-related emissions:

Nitrogen fertiliser application represents a major contributor to total greenhouse gas emissions in the assessed cotton production systems, primarily through soil N_2O emissions. To evaluate the influence of uncertainty in fertiliser-related emissions, a sensitivity analysis was conducted by varying the direct and indirect N_2O emission factors by ±10 percent relative to the baseline IPCC Tier 1 values.

At the weighted global level, this results in a change in cradle-to-gate emission intensity from the revised baseline value of 1.15 tCO_2e per tonne lint to a range of approximately 1.10 to 1.20 tCO_2e per tonne lint. This demonstrates that uncertainty in fertiliser-induced soil emissions remains a key driver of overall result variability in the assessment.

Further details on sensitivity testing and uncertainty ranges are provided in Section 5 Sensitivity and Uncertainty Analysis.

Direct Field Emissions (Scope 1):

Direct N_2O emissions from nitrogen fertiliser application are calculated using IPCC Tier 1 methodology: L_N_2O direct = N_input × EF_direct

Where:

- N_input = Total nitrogen input (kg N/ha).
- EF_direct = Direct N_2O emission factor (kg N_2O-N/kg N applied).

The default IPCC direct emission factor (EF_direct) applied is 0.01 kg N_2O-N per kg N, with an uncertainty range of 0.003–0.03 kg N_2O-N per kg N, reflecting variability across soil, climate, and management conditions as reported in IPCC guidance.

Indirect N_2O Emissions:

Indirect N_2O emissions from nitrogen leaching and volatilization and leaching are calculated using separate IPCC Tier 1 emission factors for each pathway:

Volatilization and atmospheric deposition:

L_N_2O,vol = N_input × Frac_volatilization × EF_4

Where:

- N_input = total nitrogen input (kg N/ha)

- Frac_volatilization = fraction of applied nitrogen volatilized as NH_3 and NO_x
- EF_4 = emission factor for atmospheric deposition = 0.01 kg N_2O-N per kg N volatilized
- Uncertainty range: 0.002–0.05 kg N_2O-N per kg N

Leaching and runoff:

L_N_2O, leach = N_input × Frac_leaching × EF_5

Where:

- Frac_leaching = fraction of nitrogen lost through leaching and runoff
- EF_5 = emission factor for leaching and runoff = 0.0075 kg N_2O-N per kg N leached
- Uncertainty range: 0.0005–0.025 kg N_2O-N per kg N

Total indirect N_2O emissions are calculated as the sum of volatilization and leaching pathways.

Soil Organic Carbon (SOC) Changes:

Where measured or estimated through Regenagri protocols, soil carbon stock changes are included as: ΔC_SOC = (C_SOC_end - C_SOC_start) / assessment period

Positive values indicate carbon sequestration (negative emissions); negative values indicate carbon loss (positive emissions).

C_SOC_start represents the baseline soil organic carbon stock for each assessed farm. Where measured SOC data were available at the point of farm enrolment in the Regenagri system, these values were used as the baseline reference. Where historical measurements were not available, baseline SOC was initialised using soil type, climatic zone, and management history inputs within the Cool Farm Platform (CFT), consistent with IPCC 2019 guidance. Reported ΔSOC values (2024 data) reflect annual stock change relative to the defined baseline condition and are not amortised across multi-year periods. Baseline SOC values are not back-cast from modelled steady-state conditions but reflect either measured enrolment data or initialised model baseline consistent with CFT default parameters.

Soil organic carbon (SOC) stock changes are reported as annual stock changes for the 2024 assessment year and represent the net difference between baseline and end-of-year SOC conditions. SOC changes are not amortised over a multi-year period and therefore reflect a single-year snapshot rather than long-term equilibrium conditions.

This approach is consistent with annual greenhouse gas accounting frameworks such as IPCC methodologies; however, SOC dynamics are inherently multi-year processes and may vary over time depending on management practices and environmental conditions.

Calculation Steps – Soil Organic Carbon (SOC) Change

Box: Step 1 – Determine baseline SOC
stock C_SOC_start (t C/ha)
Measured at farm enrolment, or initialised using soil type, climate, and management inputs within CFT. Step 2 – Determine end-of-year SOC stock
C_SOC_end (t C/ha)
Quantified using Cool Farm Platform algorithms or measured soil sampling. Step 3 – Calculate annual SOC stock change
ΔSOC (t C/ha/year)
= C_SOC_end − C_SOC_start
Step 4 – Convert carbon to CO_2
equivalent SOC_CO_2e (t CO_2e/ha)
= ΔSOC × 44/12

Where 44/12 = molecular weight conversion factor from C to CO_2. Step 5 – Multiply by total area
Total_SOC_CO_2e (t CO_2e)
= SOC_CO_2e × Area (ha)
Step 6 – Aggregate at country level Net Farm Emissions
= Gross emissions − Total_SOC_CO_2e

Note: Soil carbon stock changes reflect annual net stock change during the 2024 reporting year and are not amortised across multi-year baselines.

SOC results are reported in alignment with attributional LCA principles and are not directly comparable to long-term carbon sequestration estimates used in consequential or project-based carbon accounting frameworks.

The reported SOC removals assume continuation of current management practices but do not constitute permanent carbon storage over a defined long-term period. Results should therefore be interpreted as annual net changes rather than long-term sequestration outcomes. The conservative annual stock-change framing applied here is consistent with the requirements set out in the GHG Protocol Land Sector and Removals Guidance (GHG Protocol, 2022) and with the Textile Exchange Biogenic Carbon Guidelines (Textile Exchange, 2024), which require ongoing storage monitoring, traceability of removals to the reporting organisation, primary data on land carbon pools, statistically significant uncertainty estimates, and explicit reversal accounting before SOC removals can be claimed in formal corporate GHG reporting. The SOC stock-change values reported in this assessment are therefore intended for product-level cradle-to-gate carbon footprinting in line with ISO 14040/44 and are not used to support corporate-level removals claims under the GHG Protocol Land Sector framework, which would require additional verification beyond the scope of this LCA.

The handling of soil organic carbon (SOC) sequestration in this assessment (single-year 2024 net stock change, not amortised) differs from the Cascale cotton methodology. The report already presents emission factors on two bases, one including SOC removals and one excluding them (gross greenhouse-gas emissions only); the SOC-excluded factors provide a directly comparable basis against Cascale and Higg MSI cotton datasets, which do not credit annual SOC removals on the same basis. Sufficient data are present in this report to reconcile the SOC treatment with the Cascale methodology without re-collecting primary data. The next assessment cycle will align the SOC accounting approach (baseline definition, amortisation period and removal-crediting rules) with the Cascale methodology so that a single, methodologically consistent lint emission factor can be reported.

Crop Residue Management Emissions:

Residue management practices are reported at farm level through the Regenagri certification platform and verified during third-party audit. The selected management pathway for each farm is recorded in the life cycle inventory (LCI) dataset and used to apply the corresponding CH_4 and N_2O emission factors. Country-level results reflect the aggregation of farm-specific residue practices rather than a uniform assumption. Where residues are incorporated into soil, emissions are accounted for within soil emission calculations and soil organic carbon (SOC) modelling in accordance with IPCC 2019 Refinement methodologies.

Emissions from crop residue management depend on the method employed:

Table 3.2.1 – Crop Residue Management Practices and Associated Emission Factors

Management Method	CH_4 Factor	N_2O Factor	Notes
Left on field (incorporated)	0	Accounted as soil emission	Preferred for carbon sequestration
Removed - forced-aeration compost	0.01	0.0006	Good management practice
Removed - non-aeration compost	0.0125	0.0009	Standard compost
Removed - untreated (heaps)	0.02	0.0009	Poor management

Burned	0.0027	0.00007	Conventional practice in some regions
Exported off-farm	0	0	No on-farm emissions

The primary residue management practice recorded for each production region is summarised below. The associated greenhouse gas sources reflect the emission pathway activated by each practice.

Table 3.2.2 – Country-Level Residue Management Practices and Associated GHG Sources

Country	**Primary Residue Management Practice**	**Associated GHG Source**
Australia	Incorporation into soil	Soil N_2O
Brazil	Incorporation into soil	Soil N_2O
Côte d'Ivoire	Incorporation / composting	Soil N_2O, CO_2
Egypt	Incorporation into soil	Soil N_2O
India	Mixed: incorporation and open-field burning	Soil N_2O, CH_4
Mexico	Incorporation into soil	Soil N_2O
Mozambique	Surface retention / incorporation	Soil N_2O
Pakistan	Incorporation into soil	Soil N_2O
Peru	Incorporation / composting	Soil N_2O, CO_2
Tajikistan	Incorporation into soil	Soil N_2O
Tanzania	Surface retention	Soil N_2O
Turkey	Incorporation into soil	Soil N_2O
USA	Incorporation into soil	Soil N_2O

Note: Country-level practices represent the dominant reported method across assessed farms. Where multiple practices are recorded within a country, the emission factors applied reflect the farm-specific method as reported in the LCI.

Soil organic carbon stock changes are included only where verified through Regenagri-approved protocols and are conservatively bounded to avoid over-crediting removals.

3.3 Input Production Emissions

Fertiliser Production:

Emissions from fertiliser production vary by product type and manufacturing technology. Product-specific emission factors are derived from the IPCC 2019 Refinement to the 2006 Guidelines for National Greenhouse Gas Inventories (Volume 3 – Industrial Processes and Product Use; Volume 4 – Agriculture), and supplemented where necessary with recognised life cycle inventory (LCI) databases and sector benchmarks commonly applied in agricultural LCA studies (e.g., World Food LCA Database; Anthesis 2021).

The following emission factors represent cradle-to-gate production of fertiliser products and exclude field application emissions, which are accounted for separately under soil emission calculations in accordance with IPCC Volume 4 (Agriculture, Forestry and Other Land Use).

Emissions from fertiliser production vary by product type and production technology. The table below presents European reference values, as implemented in the Cool Farm Platform. These values are incorporated within the on-farm GHG calculation tool, with region-specific factors planned for future inclusion (www.coolfarmtool.org).

Table 3.3.1 – Fertiliser Production Emission Factors Applied in the Assessment

Fertiliser Type	**Nutrient Content**	**Typical Emission Factor**	**Source**
Urea	46% N	0.89 kg CO_2e / kg product	https://www.researchgate.net/profile/Frank-Brentrup-2/publication/312553933_Carbon_footprint_analysis_of_mineral_fertilizer_production_in_Europe_and_other_world_regions/links/5881ec8d4585150dde4012fe/Carbon-footprint-analysis-of-mineral-fertilizer-production-in-Europe-and-other-world-regions.pdf https://app.coolfarmtool.org/documentation/technical-description/CFP-annual-crops/fertilisers.html Hillier, J. (2013). The Cool Farm Platform. FAO-EPIC consultation on soil carbon sequestration under CSA project. University of Aberdeen. https://www.fao.org/fileadmin/user_upload/epic/docs/workshops/Technical_consultation/Presentations/CFT_intro.pdf
Ammonium Nitrate	33.5% N	1.18 kg CO_2e / kg product	
DAP (Diammonium Phosphate)	18% N, 46% P_2O_5	0.64 kg CO_2e / kg product	
Muriate of potash	60% K_2O	0.23 kg CO_2e / kg product	

Where country-specific fertiliser production data were not available, these internationally recognised default factors were applied consistently across all production regions to ensure comparability and methodological transparency.

Pesticide and Herbicide Production:

Emissions from pesticide production are calculated using World Food LCA Database factors, varying by pesticide type:

$$L\_pesticide = Application\_rate \times Active\_ingredient\_fraction \times EF\_pesticide$$

Typical emission factors range from 5-15 kg CO_2e per kg active ingredient, depending on chemical class.

Seed Production:

Emissions from cotton seed production are included to account for certified seed used for planting in the subsequent growing season. A seed replacement rate of 100 percent of annual planted seed requirement is assumed, reflecting the common practice of purchasing certified seed each season in Regenagri-certified systems. Where farm-level data indicate partial on-farm seed saving, the reported replacement rate is adjusted accordingly. The average cotton seeding rate applied in this assessment ranges between 15–25 kg seed per hectare, depending on country and production system, based on verified farm data collected through the Regenagri platform).

Expressed per functional unit, the seed requirement is approximately 15 to 25 kg seed per tonne of lint. This is derived from a weighted global lint yield of approximately 1.02 tonnes of lint per hectare (1,352,672 tonnes lint divided by 1,331,359 hectares) and a verified average cotton seeding rate of 15 to 25 kg seed per hectare across participating farms. Total annual seed planted across the assessed portfolio is approximately 26,600 tonnes (range 20,000 to 33,300 tonnes, corresponding to the 15 to 25 kg/ha seeding rate range applied to the 1,331,359 ha total production area).

Applying typical cotton seed production emission factors of 1.5 to 2.5 kg CO_2e per kg seed (World Food LCA Database; Nemecek et al., 2019), seed production contributes approximately 0.02 to 0.06 tCO_2e per tonne of lint, equivalent to less than 2 to 3 percent of the cradle-to-gate intensity (1.15 tCO_2e per tonne lint net; 1.83 tCO_2e per tonne lint gross). On the basis of this immateriality, seed production emissions are reported as part of the aggregated country-level Cool Farm Platform output and are not separately disaggregated within the country emission source tables in Appendix 14. Their contribution is included implicitly within the overall farm-gate totals. Country-specific seeding rates and lint yields underlying this estimate are presented in Appendix 14 (Table 14.1).

Seed production emissions are calculated using cradle-to-gate emission factors derived from recognised agricultural LCI datasets and applied according to the country of seed production where known. Where country-specific seed production data are unavailable, regional average LCI factors are applied.

Seed production emissions are allocated to lint production proportionally based on the annual seed requirement per hectare and the total lint yield, ensuring consistency with the defined functional unit.

3.4 Energy and Fuel Use

Field Operations Energy:

Fuel consumption for field operations is documented through farm records: L_fuel = Fuel_volume × EF_fuel
Where:

- Fuel_volume = Litres of diesel/petrol consumed per hectare.
- EF_fuel = Emission factor for fuel combustion (2.68 kg CO_2e / litre diesel; 2.31 kg CO_2e / litre petrol), based on IPCC 2019 Refinement default combustion factors.

Irrigation Energy:

Irrigation energy requirements are calculated based on the physical energy required to lift water, adjusted for pump efficiency and converted to electricity-related emissions.

Electricity demand for pumping is calculated as:
Energy (kWh) = (Water_volume × Lift_Height x 9.81)/ (3.6 x106 x Pump_efficiency)
Where:

- Water_volume = m^3 of water pumped per hectare
- Lift_height = Total dynamic head in metres (vertical lift plus system losses)
- 9.81 = Gravitational acceleration constant (m/s^2)
- 3.6×10^6 = Conversion factor from Joules to kWh
- Pump_efficiency = Assumed pump and motor efficiency (typically 0.6–0.75 unless farm-specific data available)

Greenhouse gas emissions from irrigation electricity use are then calculated as:
L_irrigation = Energy (kWh) × EF_electricity
Where:

EF_electricity = Country-specific grid emission factor (kg CO_2e per kWh)

Where farm-level electricity consumption data are directly available, reported kWh values are used instead of theoretical pumping calculations.

A comparison between measured and calculated irrigation energy values indicates that differences are typically within the range of ±10–25 percent, depending on data quality and site-specific conditions. Variability arises from uncertainty in assumed parameters such as pump efficiency, total dynamic head, and system losses, as well as operational factors including pump performance, maintenance, and irrigation scheduling.

Measured farm-level electricity data are considered more representative and are therefore prioritised where available. The theoretical calculation approach is applied only where direct measurements are not available and is considered a reasonable approximation for estimating irrigation energy demand at scale.

Processing Energy (Ginning):

Ginning energy use is based on electricity and fuel consumption data from gin facility records where available, or sector benchmarks where facility-specific data are not accessible. Emissions are calculated using country-specific electricity grid emission factors and relevant fuel combustion factors.

Total ginning emissions are incorporated into the cradle-to-gate system boundary prior to economic allocation and are subsequently allocated between lint and seed according to the defined 84 percent / 16 percent economic allocation factors.

3.5 Transport Emissions

Farm to Gin Transport:

Transport emissions are calculated as:

$$L\_transport = Distance \times Load \times EF\_transport$$

Where:

- Distance = Average transport distance in kilometres.
- Load = Tonnes of seed cotton transported.
- EF_transport = Emission factor for transport mode (typically 0.05-0.10 kg CO_2e / tonne-km for truck transport).

Input Transport:

Transport of fertilisers, pesticides, seeds, and fuel to farms is included based on typical supply chain distances and transport modes.

3.6 Ginning Process Emissions

Ginning Outturn:

The average ginning outturn applied in this assessment is 39 percent, based on a weighted average across the main Regenagri production regions. This corresponds to a conversion factor of 2.56 tonnes of seed cotton required to produce 1 tonne of ginned cotton lint. A country-level breakdown of ginning outturn values used in the assessment is provided in Appendix 11: Ginning Outturn by Country. These values are derived from literature sources, national statistics, and industry benchmarks for each production region. The selected average of 39 percent falls within the typical

Inclusion of Ginning in the System Boundary

Farm-level greenhouse gas emissions are quantified using the Cool Farm Platform (CFP), which does not include post-farm processing stages. Ginning emissions are therefore incorporated to extend the system boundary from farm gate to gin gate, consistent with the defined cradle-to-gate system boundary and functional unit of 1 tonne of ginned cotton lint.

For the 2024 reporting year, facility-specific energy consumption data from all ginning operations were not uniformly available across the 13 production countries. To ensure methodological consistency and to maintain valid emission accounting under all farm-level conditions, ginning emissions are estimated using an absolute emission factor approach. Ginning emissions are calculated as a fixed emission factor of 0.10 tCO_2e per tonne of ginned cotton lint (EF_ginning), applied to total lint production in each country. This emission factor is derived from published literature values for ginning energy intensity (70–120 kWh per tonne of seed cotton; Ismail, 2009, among others), a weighted average ginning outturn of 39 percent, and a representative grid emission factor range of 0.35–0.45 kg CO_2e per kWh, yielding a central estimate of approximately 0.10 tCO_2e per tonne of lint (valid range: 0.06–0.14 tCO_2e per tonne of lint).The absolute emission factor approach ensures that ginning emissions are always positive and independent of farm-level outcomes in all countries. As an industrial processing stage, ginning consumes energy (electricity, fuel) and generates greenhouse gas emissions irrespective of soil carbon dynamics at the farm level. Industrial processing stages cannot generate negative greenhouse gas emissions; therefore, ginning emissions must not be derived by proportional scaling from net farm emissions, which may include soil organic carbon (SOC) removals. The fixed EF_ginning of 0.10 tCO_2e per tonne of lint represents an aggregated estimate of energy use and associated emissions from the ginning process within the defined system boundary, including electricity consumption, fuel use, and auxiliary operations. This approach is consistent with attributional LCA methodology and does not constitute system expansion under ISO 14044. Allocation between cotton lint and cottonseed is applied at the gin gate using economic allocation factors after aggregation of farm and ginning emissions. The use of a uniform secondary ginning emission factor across all production regions is consistent with the approach adopted in recent industry-aligned cotton LCAs (Cascale, 2024; Sphera, 2026), which apply common secondary ginning data across production systems on the basis that ginning energy use and ginning outturn are largely independent of the upstream cultivation system. This supports both methodological consistency and comparability of results across the 13 production regions assessed here.

The Cascale cotton methodology applies a default ginning assumption that is higher than the 0.10 tCO_2e per tonne of lint applied in this assessment. On the basis raised in review, the potential under-reporting of ginning impacts is greater than 0.15 tCO_2e per tonne of lint (0.15 kg CO_2e per kg of lint), depending on the ginning technology assumed. Part of this difference reflects the same well-to-tank component identified for background energy datasets above, because the grid factor underlying the current ginning estimate is generation-basis. This potential difference can exceed the sensitivity range reported for the current benchmark factor (0.06 to 0.14 tCO_2e per tonne of lint), which indicates that the absolute benchmark approach should be replaced with primary ginning energy data. For strict comparability with Higg MSI cotton datasets, the Cascale default ginning assumption can be applied directly in the interim. The next assessment cycle will collect primary, facility-level ginning energy data from supply-chain partners, or apply the Cascale default where primary data remain unavailable.

Ginning Energy Intensity and Emission Factor

Published cotton LCA studies indicate that ginning energy use depends on two key parameters:

1. Processing energy intensity
2. Electricity emission factor applied to that energy use

Processing energy intensity is typically expressed as kilowatt-hours (kWh) per tonne of seed cotton processed and reflects facility energy efficiency, equipment type, plant scale, drying requirements, and moisture content of incoming cotton. Reported values in the literature, including the Ismail (2009) Australian cotton gins benchmark (44–66 kWh per 227 kg bale; national average 52.3 kWh per bale, equivalent to approximately 75–115 kWh per tonne of seed cotton on an electricity-only basis), typically range between 70–120 kWh per tonne of seed cotton.

For the 2024 reporting year, facility-specific electricity consumption data were not uniformly available. Ginning emissions were therefore estimated using the absolute emission factor of 0.10 tCO_2e per tonne of lint described above, applied to lint production in each country. Where facility-specific energy data become available in future reporting cycles, ginning emissions should be calculated directly as:

GHG_ginning = (kWh per tonne seed cotton × tonnes seed cotton processed) × EF_electricity, where EF_electricity is the country-specific grid emission factor (kg CO_2e per kWh). Collection of primary ginning energy data from supply-chain partners is recommended as an improvement pathway for future reporting cycles. The direct calculation formula, to be applied when facility-level data are available, is: GHG_ginning
= (kWh per tonne seed cotton × tonnes seed cotton processed) × EF_electricity

Benchmark Validation Check

To validate the plausibility of the benchmark assumption applied for ginning emissions, an indicative electricity-based estimate was calculated using typical literature values. An average electricity intensity of 100 kWh per tonne of seed cotton was applied, together with a representative global grid emission factor of global grid emission factor of 0.40 kg CO_2e per kWh:

100 kWh × 0.40 kg CO_2e/kWh
= 40 kg CO_2e per tonne of seed cotton processed.

At an average ginning outturn of 39 percent, this is equivalent to approximately:
40 kg CO_2e / 0.39
≈ 103 kg CO_2e per tonne of lint

Compared to the 2024 weighted global gross emission intensity of approximately 1.83 tCO_2e per tonne of lint (GHG emissions only, Appendix 14 SOC basis), the absolute ginning emission factor of 0.10 tCO_2e per tonne of lint represents approximately 5–6 percent of gross cradle-to-gate emissions. This is consistent with the electricity-only estimate of 103 kg CO_2e per tonne of lint derived above. Electricity is the dominant driver within the ginning stage itself, accounting for the majority of the 0.10 tCO_2e per tonne of lint EF_ginning value, with the balance attributable to fuel use, drying, and auxiliary operations.

The EF_ginning value of 0.10 tCO_2e/t lint reflects a full cradle-to-gin gate representation of ginning-related processes, including electricity, fuel use, drying, auxiliary operations, and upstream energy-related emissions. This value is applied to farm-gate emissions excluding soil organic carbon (SOC) changes to ensure consistency with the treatment of gross emissions within the system boundary. The lower 5–6 percent estimate captures electricity consumption only and therefore represents a partial estimate rather than a complete system representation.

Calculation of Total Cradle-to-Gate Emissions

Total cradle-to-gate emissions are derived by adding absolute ginning emissions to farm-gate emissions, as follows:

[1] GHG_ginning = EF_ginning × Lint_production = 0.10 tCO_2e/t lint × Lint_production (tonnes); [2] Total_emissions_with_ginning = Crop_production_emissions + GHG_ginning

This formulation ensures that ginning emissions are always positive and are determined by lint production volumes, not by farm-level emission outcomes. Ginning emissions are calculated before allocation and added to farm-gate emissions (including any SOC effects). Allocation to lint (84 percent) and cottonseed (16 percent) is then applied to the aggregated total, consistent with ISO 14044 requirements for co-product allocation after full system aggregation. Accordingly, total cradle-to-gate emissions are obtained by scaling farm-level emissions to include the additional ginning component, rather than being independently calculated from primary ginning activity data.

3.7 Co-product Allocation

Cotton production generates two marketable co-products at the ginning stage: cotton lint and cottonseed. In accordance with ISO 14044 allocation principles, economic allocation is applied at the gin gate after all processes within the defined cradle-to-gate system boundary have been fully included.

3.7.1 Allocation Hierarchy and Justification

The allocation hierarchy applied in this assessment follows ISO 14044 Section 4.3.4:

1. Avoid allocation where possible: Allocation at the farm stage is avoided. Emissions are first aggregated at the system level up to the gin gate.
2. System boundary extension to a common boundary: The system boundary is extended from farm gate to gin gate by incorporating ginning operations. Ginning emissions are estimated using an absolute emission factor of 0.10 tCO_2e per tonne of lint, applied to lint production in each country, and are always positive regardless of farm-level SOC effects. This approach is consistent with attributional LCA and with published sector benchmark data (e.g., Ismail, 2009, among others). Ginning emissions represent a fixed per-tonne contribution to cradle-to-gate emissions, based on sector benchmark data (Anthesis, 2021).
3. Economic allocation at the co-product stage: After aggregation of total cradle-to-gate emissions, economic allocation is applied between lint and cottonseed based on their relative market value at the gin gate.

3.7.2 Allocation Factors

Economic allocation is calculated as:

Allocation to lint
= (Market value of lint) / (Market value of lint + market value of seed)

Based on international cotton price statistics and sector LCA benchmarks (e.g., Anthesis 2021), cotton lint represents approximately 80–85 percent of total co-product economic value. A midpoint value of 84 percent for lint and 16 percent for cottonseed is applied consistently across all production regions to ensure comparability. For comparison, the Cascale Industry-Aligned Cotton LCA Methodology applies a five-year economic allocation split of 82.7 percent to lint and 17.3 percent to cottonseed, derived from ICAC commodity price data (Cascale, 2024; ICAC, 2024). The 84/16 factor applied in this assessment lies within 1.3 percentage points of the Cascale/ICAC value and remains within the 80–85 percent range observed in published cotton LCA studies, supporting the comparability of the reported lint-level emission intensities with industry-aligned benchmarks.
The difference between the 84/16 factor applied here and the Cascale/ICAC five-year split of 82.7/17.3 is a deterministic, recalculable adjustment that does not require re-modelling of the underlying inventory. Substituting the Cascale 82.7/17.3 split for 84/16 reduces the emissions allocated to lint by approximately 1.5 percent, moving the weighted-average lint intensity from approximately 1.15 to approximately 1.13 tCO_2e per tonne of lint. Lint-level emission factors recalculated on the Cascale 82.7/17.3 basis can be provided on request, and the Cascale split will be adopted directly in the next assessment cycle.

The allocation factors are derived from published cotton LCA studies and global commodity price ratios during the reporting period. Where country-specific price differentials exist, a harmonised global allocation factor is applied to maintain methodological consistency.

3.7.3 Scope of Allocation

The 84/16 allocation is applied once, at the total cradle-to-gate emission level. Upstream emissions, including:

- Fertiliser production
- Soil emissions
- Fuel use
- Irrigation energy
- Transport
- Ginning energy

are first aggregated before allocation is applied. No allocation is performed at the individual input level.

3.7.4 Functional Unit Conversion

Following allocation, emissions assigned to lint are converted from seed cotton to ginned cotton lint using a verified average ginning outturn of 39 percent across participating production regions.

4 LIFE CYCLE IMPACT ASSESSMENT

4.1 Impact Category: Climate Change

This assessment focuses exclusively on the climate change impact category, quantified through greenhouse gas emissions expressed as CO_2-equivalents (tCO_2e).

This assessment is intentionally scoped as a single-issue (climate change) product carbon footprint prepared in accordance with ISO 14067:2018, rather than as a multi-category life cycle assessment, and this scope determines its comparability with the Higg MSI. The objective of this first assessment is to establish a verified cradle-to-gate greenhouse-gas emission factor for Regenagri-certified cotton. The full suite of impact categories specified by the Cascale Higg Materials Sustainability Index (Higg MSI) for cotton (namely eutrophication, abiotic resource depletion, water use, human toxicity and ecotoxicity) is therefore outside the scope of this reporting cycle, and no assessment of potential burden-shifting across those categories is made or implied. These additional impact categories, together with the full life cycle inventory in physical units required to characterise them, will be incorporated in the next assessment cycle. Until then, the climate results reported here should be treated as a single-category input rather than as a complete Higg MSI multi-category profile.

Scope of Assessment:

The assessment includes direct and indirect greenhouse gas emissions within a cradle-to-gate system boundary. Emission sources are categorised in alignment with GHG Protocol scope definitions and mapped to corresponding data sources and modelling approaches.

Table 4.1.1 – Mapping of Greenhouse Gas Emission Sources by Scope Category, System Boundary Stage, and Data Source

Scope Category	Emission Source	System Boundary Stage	Activity Data Source
Scope 1 – Direct emissions	Soil N_2O emissions from fertiliser application	On-farm	Verified farm records (fertiliser rates, crop data)
Scope 1 – Direct emissions	On-farm fuel combustion (tractors, machinery)	On-farm	Farm fuel logs (litres diesel/petrol per ha)
Scope 1 – Direct emissions	Residue management emissions	On-farm	Farm-reported residue practices
Scope 2 – Indirect emissions	Purchased electricity for irrigation	On-farm	Reported kWh or calculated pumping

			energy
Scope 2 – Indirect emissions	Electricity used in ginning	Processing stage (gin gate)	Sector benchmark or facility data where available
Scope 3 – Upstream emissions	Fertiliser production	Input production	Farm input purchase records
Scope 3 – Upstream emissions	Pesticide and agrochemical production	Input production	Farm input records
Scope 3 – Upstream emissions	Seed production	Input production	Seed rate per hectare; supplier information
Scope 3 – Upstream emissions	Transport of inputs	Supply chain	Distance and mode assumptions
Scope 3 – Processing emissions	Ginning energy (electricity and fuel)	Processing stage	Sector benchmark (EF_ginning = 0.10 tCO_2e/t lint) or energy intensity ranges (70–120 kWh/t seed cotton, as stated by Ismail, 2009, among others)

All primary farm-level activity data are collected through the Regenagri certification platform and verified via third-party audit. Secondary emission factors and life cycle inventory datasets are applied where primary data are not available, following a documented data hierarchy.

Excluded Impact Categories:

The following impact categories are not assessed in this report:

- Water use and eutrophication
- Acidification
- Photochemical ozone formation
- Toxicity and ecotoxicity
- Biodiversity impacts

These exclusions are consistent with Regenagri's focus on climate change quantification and do not imply these impacts are negligible.

4.2 Characterization: Global Warming Potential

All greenhouse gas emissions are characterised using IPCC AR6 100 year Global Warming Potentials (GWP100), applied consistently across all calculations.

Table 4.2.1 – Global Warming Potential (GWP100) Factors and Primary Emission Sources in Cotton Production

Greenhouse Gas	GWP (100-year)*	Primary Sources in Cotton Production
CO_2	1.0	Diesel and petrol combustion in field operations; electricity consumption for irrigation and ginning; upstream production of mineral fertilisers (ammonia, nitric acid, phosphate processing, potash mining); pesticide and agrochemical manufacturing; seed production; transport of inputs.
CH_4	27.0	Crop residue management (burning, composting, storage in heaps); minor contributions from organic amendment decomposition.
N_2O	273.0	Direct soil emissions from nitrogen fertiliser application; indirect emissions from volatilisation and leaching; residue nitrogen mineralisation.

*GWP100 factors are aligned with IPCC AR6 and applied consistently across all calculations. The CH_4 GWP100 value of 27.0 corresponds to the AR6 non-fossil "solely methane" value (IPCC AR6 WGI, Table 7.15), used here for biogenic methane from crop residue management and consistent with the Cool Farm Platform implementation. The fossil-CH_4 value (29.8) is not used because no fossil methane source is present in the cradle-to-gate system boundary. N_2O GWP100 = 273 is the AR6 value.

The methane characterisation factor applied in this assessment has been aligned to the IPCC AR6 non-fossil (biogenic) GWP100 value of 27.0, consistent with methane entering the cradle-to-gin-gate boundary only through crop-residue management, with no fossil methane source present. The effect of this alignment on the reported results is immaterial, and the 2024 results are not restated on this basis. Where the Higg MSI applies characterisation or flow-classification conventions that differ from these AR6 defaults, the difference will be reconciled in the next assessment cycle so that the reported climate results are directly comparable with Higg MSI cotton datasets.

In accordance with ISO 14044 clause 4.4.2.2, the Life Cycle Impact Assessment (LCIA) results presented in this study are relative expressions and do not predict actual impacts on category endpoints, the exceeding of thresholds, safety margins, or risks.

Upstream "input production" emissions refer specifically to cradle-to-gate manufacturing emissions associated with mineral fertilisers (including ammonia synthesis, nitric acid production, and phosphate and potash processing), pesticide and agrochemical formulation, certified seed production, and transport of inputs to farm. These upstream emissions are accounted for under Scope 3 and are calculated using recognised life cycle inventory datasets and IPCC industrial process guidance.

4.3 Results Presentation

The emission factors results are expressed as emission factors including GHG and removals as well as emission factors including only GHG emissions.

Total Emission Intensity:

Table 4.3.1 – Total Production and Emission Intensity Summary for 2024

Metric	2024 Value
Total Production Area	1,331,359 ha
Total Lint Production	1,352,672 MT
Total Cradle-to-Gate Lint Emissions (after 84% economic allocation)	1,557,917 tCO_2e
Weighted average (gross) emission intensity (GHG reductions only)	1.83 tCO_2e per tonne lint
Weighted average emission (net) intensity (reductions and removals)	1.15 tCO_2e per tonne lint

Country-Level Results – Farm-Gate GHG Emissions

In the following tables, emission intensity values are provided in two forms: emission intensity including both GHG reductions and removals, and emission intensity values including only GHG reductions. The latter is calculated by deducting the contribution of management changes and soil carbon stock changes from the total emissions, providing a view of the gross emissions from operations.

The greenhouse gas results presented below apply exclusively to seed cotton quantified at the farm-gate boundary. Emissions include all relevant on-farm sources up to the point of harvest and exclude ginning, processing, transport, and downstream activities. Yield values represent harvested seed cotton yield per hectare at farm gate. Note on Australia data basis: For the 2024 reporting year, the underlying Cool Farm Platform records for Australia were provided on a lint basis (432,070 tonnes of lint; 2.47 t lint/ha), reflecting the reporting convention of the Australian cotton industry. For consistency with the other twelve countries (for which Cool Farm Platform records are on a seed cotton basis) and with the farm-gate boundary applied in Table 4.3.2, Australia's reported lint has been converted to a seed cotton equivalent of 1,119,792 tonnes using Australia's ginning outturn (38.6 percent; Appendix 11). Australia's lint production (432,070 tonnes) appears directly in the cradle-to-gate results (Table 4.3.3) and Appendix 14, where the functional unit is 1 tonne of ginned cotton lint. The farm-gate emissions total (320,240 tCO_2e) and SOC stock change (−613,902 tCO_2e) are unaffected by this convention.

Table 4.3.2 – Farm-Gate Emissions and Emission Intensity by Country (Seed Cotton Basis)

		Farm level					
Country	Production Area (ha)	Seed Cotton Production (t)	Seed Cotton Yield (t/ha)	Total Farm-Gate Emissions (tCO_2e)	Emission Intensity, net (Reductions & Removals; tCO_2e / t seed cotton)	Emission Intensity (tCO_2e/ha)	Emission Intensity, gross (GHG Reductions; tCO_2e/t seed cotton)
Australia	174,688	1,119,791.8	6.40	320,240	0.29	1.83	0.83
Brazil	169,786	814,974.74	4.80	545,028	0.67	3.21	0.72
Côte d'Ivoire	84,925	100,667.66	1.19	−225,386	−2.24	−2.65	0.55
Egypt	665	1,596.65	2.40	1,640	1.03	2.47	1.03
India	501,341	726,102.32	1.45	705,605	0.97	1.41	1.12
Mexico	16,219	47,369.00	2.92	37,740	0.80	2.33	0.69
Mozambique	700	594.27	0.85	71	0.12	0.10	0.12
Pakistan	32,839	55,826.69	1.70	31,788	0.57	0.97	0.81
Peru	2,358	2,079.00	0.88	−2,894	−1.39	−1.23	0.28
Tajikistan	10,621	31,862.10	3.00	−17,497	−0.55	−1.65	0.61
Tanzania	91,914	61,629.54	0.67	4,549	0.07	0.05	0.07
Turkey	111,032	299,785.27	2.70	201,418	0.67	1.81	0.67
USA	134,271	218,031.39	1.62	117,093	0.54	0.87	0.54

This table summarises 2024 farm-level cotton production and associated greenhouse gas performance across 13 countries. It presents cultivated area, harvested production, yield, total farm-gate emissions, and emission intensity per tonne and per hectare. The results enable direct comparison of productivity and carbon efficiency across diverse production systems, including countries with net positive emissions

and others demonstrating net carbon sequestration at farm level. Negative values reflect net field-level removals driven by increases in soil organic carbon stocks.

Country-Level Results – Cradle-to-Gate GHG Emissions

(Including Ginning and Economic Allocation to Lint)
Lint production is calculated as harvested seed cotton multiplied by the ginning outturn ratio (GOT = 39 percent).

Table 4.3.3 – Cradle-to-Gate Emissions and Emission Intensity by Country (Lint Basis)

Country	Lint Production* (t) **2024**	Total Lint Emissions, net (Reductions & Removals) (tCO_2e)	EF, net (Reductions & Removals) tCO_2e / t Lint	Total Lint Emissions, Gross (Reductions) (tCO_2e)	EF, Gross (Reductions) tCO_2e / t Lint
Australia	432,070	305,296	0.71	820,973	1.90
Brazil	317,840	484,522	1.52	518,789	1.63
Côte d'Ivoire	39,260	−186,026	−4.74	49,688	1.27
Egypt	623	1,430	2.30	1,430	2.30
India	283,180	616,495	2.18	704,802	2.49
Mexico	18,474	33,254	1.80	29,040	1.57
Mozambique	232	79	0.34	79	0.34
Pakistan	21,772	28,531	1.31	39,711	1.82
Peru	811	−2,363	−2.91	562	0.69
Tajikistan	12,426	−13,653	−1.10	17,335	1.40
Tanzania	24,036	5,840	0.24	5,840	0.24
Turkey	116,916	179,012	1.53	179,012	1.53
USA	85,032	105,501	1.24	105,501	1.24

*Lint Production (t) = Harvested Seed Cotton (t) × GOT. Ginning outturn ratio (GOT). Ginning emissions are included as positive contributions in all countries, calculated as an absolute emission factor of 0.10 tCO_2e per tonne of lint (EF_ginning), independent of farm-level outcomes. Negative net values occur where soil organic carbon (SOC) removals at the farm level exceed the combined total of gross agricultural emissions and absolute ginning emissions.

Negative values indicate that net cradle-to-gate emissions are negative for the respective country, reflecting a net balance in which soil organic carbon (SOC) removals at the farm level exceed the sum of gross agricultural emissions and ginning emissions. Negative values do not indicate the absence of emissions within the production system; rather, they reflect the net effect of sequestration exceeding emissions. Ginning emissions are always positive and are accounted for in all countries. Reported intensities include farm-level emissions, absolute ginning emissions calculated using EF_ginning = 0.10 tCO_2e per tonne of lint, and economic allocation of 84 percent of total system emissions to lint.

Box: Calculation Basis for Cradle-to-Gate Lint Emissions

The following calculation framework is applied consistently across all reporting countries and is documented in Appendix 10.

Step 1 – Expansion to cradle-to-gate

Total emissions including ginning
= Crop production emissions + GHG_ginning; where GHG_ginning = 0.10 tCO_2e/t lint × Lint_production
This formulation ensures that ginning emissions are positive and independent of farm-level SOC effects. Ginning emissions are added to farm-gate emissions before allocation. Allocation to lint (84 percent) and cottonseed (16 percent) is applied to the aggregated total.

Step 2 – Economic allocation to lint

Emissions allocated to lint
= Total emissions including ginning × 0.84

This applies the 84 percent economic allocation factor to lint and 16 percent to cottonseed.

Worked example – Australia

Crop production emissions at farm gate
= 320,240.16 tCO_2e

Step 1 – Calculate ginning emissions:
GHG_ginning = EF_ginning ×
Lint_production = 0.10 tCO_2e/t lint ×
432,070 t lint = 43,207 tCO_2e; Step 2 –
Add ginning to farm emissions:
320,240.16 + 43,207
= 363,447.16 tCO_2e

Step 3 – Allocate to lint 363,447.16 ×
0.84
= 305,295.6 tCO_2e

Step 4 – Derive lint emission intensity 305,295.6 /
432,070 tonnes lint
= 0.71 tCO_2e per tonne lint (GHG emissions and removals), 1.90 tCO_2e per tonne lint (GHG emissions)
This explains the transition from farm-gate seed cotton emissions to cradle-to-gate lint

emissions and ensures consistency between total lint emissions and lint-level intensity values reported in the results tables.

Summary Statistics:
Lint cotton. Cradle to gate. Climate impact only.

- Highest GHG intensity: Egypt at 2.30 tCO_2e per tonne lint.
- Most negative net emission intensity: Côte d'Ivoire at −4.74 tCO_2e per tonne lint, reflecting net soil carbon stock gains exceeding gross emissions. Gross production emissions remain positive in Côte d'Ivoire (55,226 tCO_2e). The net value depends on a single-year SOC stock change of approximately 0.90 t C/ha/yr, which is at the upper end of published cotton SOC sequestration rates and should be interpreted as a transition-year rate rather than a steady-state sequestration value. See Section 6.2 sensitivity analysis and the SOC limitation note in Section 4.3.4.
- Median GHG intensity: 1.24 tCO_2e per tonne lint, representing the central value across reporting countries.
- Weighted average GHG intensity: 1.15 tCO_2e per tonne lint, calculated as total cradle-to-gate lint emissions (1,557,917 tCO_2e) divided by total lint production (1,352,672 tonnes lint). Ginning emissions of 135,267 tCO_2e (= 0.10 tCO_2e/t lint × 1,352,672 t lint) are included and are always positive. Under mass allocation (40.6 percent to lint), the equivalent weighted global intensity would be approximately 0.56 tCO_2e per tonne of lint (net).

Box: Weighted average emission intensity calculated as:

- Total cradle-to-gate lint emissions / Total lint production
  = 1,557,917 tCO_2e / 1,352,672 tonnes lint
  = 1.15 tCO_2e per tonne lint

Variation Drivers:

Variation in cradle-to-gate emission intensities across countries reflects differences in the relative contribution of specific emission sources as quantified in the emission breakdown tables.

The principal drivers of variation correspond directly to the emission categories reported in Section 4.4:

- Fertiliser soil emissions (N_2O from nitrogen application) — the single largest driver, representing approximately 40 percent of total cradle-to-gate emissions. Variation reflects differences in nitrogen input rates, fertiliser type, and soil conditions across regions.
- Field energy and machinery fuel use — approximately 10–15 percent of total emissions. Variation reflects diesel consumption intensity and mechanisation levels, with highest contributions in mechanised systems such as the USA, Brazil, Australia, and Turkey.
- Processing energy (ginning) calculated using an absolute emission factor (EF_ginning = 0.10 tCO_2e per tonne of lint) applied to lint production in each country. Absolute variation across countries arises directly from differences in lint production volumes.
- Residue management practices — approximately 5–10 percent of total emissions. Incorporation, composting, or open burning of crop residues materially influences CH_4 and N_2O emissions, particularly in low-input systems such as Tanzania and Mozambique.
- Fertiliser production (upstream manufacturing) — approximately 3–5 percent of total emissions. Variation reflects nitrogen input intensity and fertiliser product mix.
- Irrigation electricity use — 0.5–3 percent of total cradle-to-gate emissions globally. Relevant only in irrigated systems (Australia, Egypt, Pakistan, parts of India) and not a primary driver in rainfed systems such as the USA and West Africa.
- Yield performance (tonnes lint per hectare) — not an emission source, but a dilution factor. Higher yields reduce emission intensity per tonne of lint; lower yields increase it.

Soil organic carbon (SOC) stock changes represent a major source of variability in country-level emission intensity results. Differences in regenerative management practices, historical land use, soil type, and climatic conditions influence the magnitude and direction of SOC change. In certain countries, net SOC gains exceed gross agricultural emissions, resulting in negative net farm-gate values. These outcomes reflect verified carbon stock increases rather than absence of production-related emissions.

The pattern of emission source contributions described above is broadly consistent across all 13 production regions, with fertiliser soil N_2O dominating in all high-input systems. However, the relative ranking of secondary sources varies by system type. In residue-intensive or low-input systems (Côte d'Ivoire, Tanzania, Mozambique, Peru, Tajikistan), residue management and field energy contribute a higher share than fertiliser production. In irrigated systems (Australia, Egypt, Pakistan), irrigation electricity contributes more than in rainfed systems.

The emission source pattern is also linked to the depth of data available by country. Five production regions — USA, India, Brazil, Australia, and Turkey — provided fully disaggregated emission source data enabling source-level analysis. The remaining eight regions reported at aggregated country level, with secondary IPCC default emission factors applied where facility- or practice-specific data were not available. This means that source-level rankings for those eight regions are modelled estimates rather than directly measured values, which may affect the precision of country-level hotspot identification.

Soil Carbon Stock Change– Country-Level Contribution

The table below separates gross emissions from SOC changes for all countries where a material soil carbon component was recorded. Negative SOC values represent verified net carbon stock gains (sequestration). Positive SOC values represent net soil carbon loss. Gross production emissions remain positive in all countries.

Table 4.3.4 – Soil Organic Carbon Contribution to Farm-Gate Emissions by Country

Country	Gross Emissions (tCO_2e)	SOC Change (tCO_2e)	Net Farm-Gate Emissions (tCO_2e)
Côte d'Ivoire	55,226	−280,612	−225,386
Peru	588	−3,482	−2,894
Tajikistan	19,394	−36,891	−17,497
Pakistan	45,098	−13,310	31,788
Australia	934,142	−613,902	320,240
Brazil	585,823	−40,795	545,028
India	810,733	−105,128	705,605
Mexico	32,723	+5,017	37,740

Note: Country-level start- and end-of-period SOC stocks are not disclosed publicly in this report because they are commercial information related to land valuation and the parallel Regenagri carbon credit programme.

Countries not listed reported no SOC change within the 2024 assessment period.

Mexico's positive SOC value reflects a net soil carbon loss, increasing its net total above gross operational emissions. All other listed countries recorded net sequestration. Disclosure of aggregated start-of-period and end-of-period SOC stocks (C_SOC_start and C_SOC_end in t C/ha at country level) is constrained by the commercial confidentiality of the underlying farm-level Cool Farm Platform records. Many farms in this assessment treat baseline soil carbon condition as commercially sensitive information related to land valuation and to the carbon credit programmes operating in parallel under separate Regenagri rules. Country-level start and end SOC stocks have therefore been withheld from the public report. Supporting data for the reported SOC values are available within Regenagri internal datasets. Aggregated country-level start- and end-of-period SOC stocks for the eight countries with material SOC change (Australia, Brazil, Côte d'Ivoire, India, Mexico, Pakistan, Peru, Tajikistan); the underlying Cool Farm Platform model parameters used to initialise baseline SOC where measured enrolment values were not available; and a sample of measured enrolment SOC values for farms where soil sampling was conducted at certification onboarding. Public disclosure of farm-level start- and end-of-period SOC stocks remains restricted on commercial-confidentiality grounds, consistent with the parallel Regenagri carbon credit programme rules.

Ginning energy efficiency

Ginning emissions are incorporated using an absolute emission factor of 0.10 tCO_2e per tonne of lint (EF_ginning), consistent with the cradle-to-gin gate system boundary and derived from published sector benchmarks. Absolute ginning emissions vary directly with lint production volumes and are always positive, independent of farm-level outcomes. Because the same flat EF_ginning of 0.10 tCO_2e/t lint is applied to every country, country-specific electricity grid emission factors do not directly influence the per-tonne ginning emission value in this assessment. The factors that do produce country-level differences in absolute ginning contributions in this assessment are therefore:

- Lint production volumes (the only direct multiplier of the flat EF_ginning at country level)
- Lint yield per hectare
- Total production volume

Under the flat EF_ginning of 0.10 tCO_2e per tonne of lint, the ginning contribution per tonne of lint is identical across countries; absolute (country-total) ginning emissions therefore scale only with national lint production. Ginning remains a secondary driver relative to fertiliser soil emissions in all countries.

Box: Conversion and allocation rules

- Ginning outturn = 39 percent
- Allocation to lint = 84 percent (economic allocation)

Calculation steps

1. Total cradle to gate emissions

= Farm emissions + (0.10 × Lint_t)

2. Emissions allocated to lint

= Total cradle to gate emissions × 0.84

3. Lint production

= Seed cotton production × 0.39

4. Carbon intensity per tonne lint

= Lint emissions / Lint production

4.4 Emission Source Breakdown

Emission source breakdown tables are provided where detailed category-level disaggregation is available within the 2024 dataset. For countries where certain emission categories are not reported, this reflects the absence of the corresponding activity within the assessed farms rather than data omission. Zero values therefore indicate non-use of the emission source.

Country-level emission source breakdowns for all 13 production regions are provided in the Annex. In the main report, the USA is presented as a representative example due to the completeness and granularity of its disaggregated dataset.

Table 4.4.1 – Emission Source Breakdown (USA Example, Farm-Stage CFP Output)

Emission Source	Total (tCO_2e)	Percentage	Per hectare	Per tonne
Fertiliser soil	69,939	59.7%	0.521	0.321
Field energy	13,829	11.8%	0.103	0.063
Processing energy	10,879	9.3%	0.081	0.050
Residue	9,666	8.3%	0.072	0.044
Machinery	6,479	5.5%	0.048	0.030
Fertiliser production	4,211	3.6%	0.031	0.019
Pesticide	946	0.8%	0.007	0.004
Irrigation	641	0.5%	0.005	0.003
Transport	503	0.4%	0.004	0.002
Total	**117,093**	**100%**	**0.872**	**0.537**

Figures in this table reproduce the USA Cool Farm Platform (CFP) output at the farm-stage submission level. The CFP "processing energy" line represents on-farm processing (drying, cleaning, module building and other handling at the farm stage) and is not ginning (10,879 tCO_2e, 9.3 percent of USA totals, included within the farm-gate boundary). Ginning is added downstream and separately at the country level using the absolute ginning emission factor (EF_ginning = 0.10 tCO_2e/t lint), to ensure consistent treatment across all 13 countries; see Section 3.6. There is therefore no double counting of ginning energy between the farm-stage CFP output and the cradle-to-gate calculation. The country-level total reported elsewhere in this report applies the 84 percent economic allocation to lint, so the USA 117,093 tCO_2e shown here does not match the allocated cradle-to-gate value in Section 4.3.

Fertiliser soil emissions (N_2O from nitrogen fertiliser application) represent nearly 60 percent of total emissions, indicating this is the primary lever for emission reduction in cotton production.

Negative emission values represent net greenhouse gas removals resulting from verified increases in soil organic carbon stocks. These removals offset, and in some cases exceed, gross agricultural emissions and do not imply the absence of production-related emissions.

5 DATA QUALITY AND VERIFICATION

5.1 Data Sources

Primary Data:

- Regenagri-certified farms: Activity data from verified farm networks.
- Regenagri digital platform: Automated data collection and storage.
- Third-party audits: Annual verification of farm-level data and practices.
- Farm records: Fuel consumption, fertiliser application, harvest data.

Secondary Data:

- IPCC 2019 Refinement: Default emission factors for N_2O, CH_4, CO_2.
- National electricity grids: Country-specific grid emission factors.
- Transport databases: Emission factors for various transport modes.
- Industry sources: Ginning energy use, input production emissions.

5.2 Data Quality Assessment

Assessment Criteria:

Table 5.2.1 – Data Quality Assessment Criteria and Evaluation Results

Criterion	Evaluation
Temporal Relevance	Excellent – Data from 2024 production cycle
Geographic Relevance	Excellent – Country-specific and farm-specific data
Technological Relevance	Excellent – Data reflects Regenagri-certified practices
Precision	Good – Primary farm-level activity data collected for 100 percent of participating countries; secondary emission factors applied for upstream production, grid electricity, transport, and absolute ginning EF (0.10 tCO_2e/t lint).
Completeness	Good – 13 countries represented: minor data gaps in smaller regions addressed through conservative defaults
Consistency	High – Uniform system boundaries, allocation rules, emission factors, and modelling tools applied across all countries
Reproducibility	Medium – All calculations follow documented formulas (Appendix 10); emission factors, allocation factors, and conversion rules are explicitly disclosed. A full life cycle inventory in physical units (kWh, MJ, kg, L, ha) was not provided for all 13 production regions,

Uncertainty	Documented – Sensitivity analysis provided for key assumptions (nitrogen factors, absolute ginning EF = 0.10 tCO_2e/t lint, allocation factors)

Consistency is ensured through application of identical system boundaries, allocation procedures (absolute ginning EF = 0.10 tCO_2e/t lint; 84/16 economic allocation), 39 percent ginning outturn, and IPCC 2019 characterisation factors across all countries.

Reproducibility is supported by full disclosure of calculation formulas, emission factors, and allocation steps in Appendix 10, enabling independent recalculation of country-level and global emission intensities.

The assessment includes all Regenagri-certified cotton production for which complete and verified data were available in 2024, covering 13 countries.

Study Limitations

The following limitations apply to the 2024 cradle-to-gate assessment:

- Emission source disaggregation was not uniformly available across all participating countries. In certain cases, emissions were reported at aggregated country level rather than fully disaggregated by individual source category. Where category-level breakdown was not provided, this reflects the reporting structure of the 2024 dataset rather than omission of emissions within the defined system boundary.
- Facility-specific ginning energy consumption data (kWh per tonne of seed cotton processed) were not consistently available across all 13 production countries for the 2024 reporting year. Ginning emissions were therefore estimated using an absolute emission factor (EF_ginning = 0.10 tCO_2e per tonne of lint, aligned with published benchmarks from Anthesis 2021) rather than Tier 1 primary data. This constitutes a methodological limitation that may affect country-level precision; however, the absolute EF approach guarantees that ginning emissions are always positive and independent of farm-level SOC dynamics, ensuring full methodological validity across all reporting countries
- The assessment is limited to a single reporting year (2024). Multi-year baseline analysis and inter-annual variability were not evaluated within the scope of this study. Consequently, temporal fluctuations in emissions and carbon stock changes are not assessed beyond the reporting year.
- A full life cycle inventory in physical units (kWh, MJ, kg, L, ha) was not provided for all 13 production regions. However, using the GHG inventory

presented in Appendix 14, recalculation of country-level and global cradle-to-gate emission intensities can be performed using the formulas, emission factors, and allocation rules disclosed in Appendix 10. The study cannot support impact categories beyond climate change. The country-wise emission source breakdown tables presented in Appendix 14 should therefore be read as a GHG emissions inventory rather than as a full ISO 14040/14044 LCI.

- The Life Cycle Impact Assessment (LCIA) results presented in this study are relative expressions and do not predict actual impacts on category endpoints, the exceeding of thresholds, safety margins, or risks (per ISO 14044, clause 4.4.2.2).

5.3 Verification and Accreditation

Regenagri Verification Procedures:

All primary farm data is verified through:

- Annual third-party audits by ISO 14064/14065 accredited verifiers.
- Document review and on-farm verification.
- Compliance assessment against Regenagri standard criteria.
- Data validation through Regenagri digital platform.

Quality Assurance:

- Data entry validation through automated platform checks.
- Cross-verification of yield data against gin records.
- Consistency checks for fertiliser application rates.
- Outlier analysis for unusual emission intensities.

Uncertainty Analysis:

Key sources of uncertainty in this assessment:

Table 5.3.1 – Key Sources of Uncertainty and Mitigation Measures

Source	Impact	Mitigation
N_2O emission factors	High	IPCC 2019 default factors applied; sensitivity analysis conducted on emission factors and nitrogen rates
Soil carbon stock change	Medium to High	Use Regenagri-approved quantification protocols; model calibration; conservative accounting of removals

Economic allocation factors (84/16)	Medium	Fixed global allocation applied consistently; based on sector benchmarks and price ratios
Ginning energy allocation	Low to Medium	Absolute EF_ginning = 0.10 tCO_2e per tonne of lint derived from published benchmarks (Anthesis, 2021); cross-checked against typical energy consumption ranges (70–120 kWh per tonne seed cotton, as reported by Ismail 2009 and others) and grid emission factors (0.35–0.45 kg CO_2e/kWh; IEA, 2025); valid range 0.06–0.14 tCO_2e/t lint
Transport distances	Low	Use regional average distances; conservative assumptions applied; limited influence on total results

The uncertainty associated with ginning relates to variability in processing energy intensity across facilities and regions, rather than allocation methodology. Sensitivity testing indicates that reasonable variation in ginning energy assumptions does not materially alter overall emission intensity conclusions.

6 INTERPRETATION AND RESULTS

6.1 Results Summary

Global Cradle-to-Gate Emissions (2024):

Table 6.1.1 – Global Cradle-to-Gate Emissions Summary (2024)

Parameter	Value
Total Production Area	1,331,359 hectares
Total Lint Production	1,352,672 tonnes
Total cradle-to-gate lint emissions (including ginning and allocation)	1,557,917 tCO_2e
Weighted average emission intensity (GHG reductions only)	1.83 tCO_2e per tonne lint
Weighted average emission intensity (reductions and removals)	1.15 tCO_2e per tonne lint

This emission intensity represents the weighted average greenhouse gas footprint of Regenagri-certified cotton lint supplied to textile processors, covering all on-farm production activities and ginning operations within the cradle-to-gate boundary.

6.2 Sensitivity and Uncertainty Analysis

Key Assumptions Tested:

The following sensitivity tests evaluate the robustness of the 2024 weighted global emission intensity of 1.15 tCO_2e per tonne lint (when accounting for GHG emissions and removals), and 1.83 tCO_2e per tonne lint (when accounting for GHG emissions only) Under mass allocation, these baseline intensities correspond to approximately 0.56 tCO_2e per tonne of lint (net) and 0.88 tCO_2e per tonne of lint (gross).

1. **Ginning share of total emissions**

   Ginning emissions are estimated using a baseline EF_ginning of 0.10 tCO_2e per tonne of lint, with a valid sensitivity range of 0.06–0.14 tCO_2e per tonne of lint reflecting variability in ginning energy intensity (70–120 kWh per tonne of seed cotton; Ismail, 2009) and grid emission factors (0.35–0.45 kg CO_2e/kWh; IEA, 2025). At the lower bound (EF_ginning = 0.06 tCO_2e/t lint), pre-allocation ginning emissions decrease from 135,267 to 81,160 tCO_2e; after the 84 percent allocation to lint, total cradle-to-gate lint emissions fall by approximately 45,450 tCO_2e, reducing the weighted global intensity from 1.15 to approximately 1.12 tCO_2e per tonne of lint (about −3 percent). At the upper bound (EF_ginning = 0.14 tCO_2e/t lint), pre-allocation ginning emissions rise to 189,374 tCO_2e; allocated lint emissions increase by approximately 45,450 tCO_2e, raising the global intensity to approximately 1.19 tCO_2e per tonne of lint (about +3 percent). The direction of change is therefore: a higher EF_ginning increases total emissions, and a lower EF_ginning decreases them. Across the full range, the global intensity varies by approximately ±3 percent relative to the baseline.

2. **Economic allocation (84 percent lint / 16 percent seed)**

   An economic allocation factor of 84 percent to lint and 16 percent to cottonseed is applied at gin gate. The baseline assigns 84 percent of total cradle-to-gate emissions to lint. If the lint allocation factor decreases to 80 percent, lint receives a smaller share of total emissions. Using the 2024 totals, the weighted global emission intensity decreases from 1.15 to approximately 1.10 tCO_2e per tonne lint, a reduction of about 4–5 percent.

3. **N_2O emission factor (±10 percent)**

   If IPCC default N_2O emission factors vary by ±10 percent, the global emission intensity ranges from approximately 1.10 to 1.20 tCO_2e per tonne lint, corresponding to a variation of about ±4 percent.

Box: Calculation Steps – N_2O Emission Factor Sensitivity (±10%) Baseline 2024 totals Total cradle-to-gate emissions allocated to lint = 1,557,917 tCO_2e
Total lint production = 1,352,672 tonnes lint Baseline weighted global intensity = 1,557,917 / 1,352,672 = 1.15 tCO_2e per tonne lint Let the fraction of total emissions attributable to soil N_2O emissions be f_N2O. The sensitivity test applies ±10 percent only to this component. N_2O-related emissions = 1,557,917 × f_N2O Non-N_2O emissions = 1,557,917 × (1 − f_N2O)
Upper bound scenario (N_2O emission factor +10%) Total emissions = [1,557,917 × (1 − f_N2O)] + [1,557,917 × f_N2O × 1.10] Intensity = Total emissions / 1,352,672
Lower bound scenario (N_2O emission factor −10%) Total emissions = [1,557,917 × (1 − f_N2O)] + [1,557,917 × f_N2O × 0.90]

Intensity
= Total emissions / 1,352,672

Using the weighted 2024 dataset, soil N_2O emissions represent approximately 40 percent of total cradle-to-gate emissions. Applying f_N2O = 0.40 gives:
Upper bound intensity
= 1.15 × [1 + (0.40 × 0.10)]
= 1.20 tCO_2e
per tonne lint
Lower bound
intensity
= 1.15 × [1 − (0.40 × 0.10)]
= 1.10 tCO_2e per tonne lint
This corresponds to an overall variation of approximately ±4 percent relative to the baseline result.

4. **Soil carbon inclusion**

Verified soil carbon changes reduce the global average emission intensity. If soil carbon stock changes are excluded from the assessment (hence accounting only for GHG emissions), the global emission intensity increases to approximately 1.83 tCO_2e per tonne lint. Soil carbon sensitivity reflects removal inclusion only and does not alter gross emission sources.

Box: Soil Carbon Sensitivity – Calculation Method Baseline 2024 totals
Total cradle-to-gate lint emissions
= 1,557,917 tCO_2e
Total lint production
= 1,352,672 tonnes lint
Baseline weighted global intensity
= 1,557,917 / 1,352,672
= 1.15 tCO_2e per tonne lint

Step 1 – Identify total SOC removals
Sum of SOC changes in the reported countries
= −1,089,103 tCO_2e

Step 2 – Remove SOC component
Adjusted total emissions
= 1,557,917 + 914,846
= 2,472,763 tCO_2e

Step 3 – Recalculate global intensity
Adjusted intensity
= 2,472,763 / 1,352,672
= 1.83 tCO_2e per tonne lint

Clarification
This sensitivity removes soil carbon removals only. Gross agricultural emissions remain unchanged.

These results confirm that the overall conclusions are robust to reasonable variation in key methodological assumptions. Nitrogen management and soil carbon accounting remain the dominant drivers of global emission intensity across all sensitivity tests. However, the interpretation of results is subject to inherent study limitations. In several production locations, average emission factors, benchmark ginning assumptions, or aggregated country-level data were applied where facility-specific or fully disaggregated datasets were not available for 2024. These methodological constraints may influence the precision of country-level intensities but do not materially alter the global emission pattern or hotspot identification.

The analysis shows that the dominant sources of uncertainty are associated with nitrogen-related N_2O emissions and changes in soil carbon stocks. Both factors are addressed using IPCC-compliant methodologies and are controlled through the Regenagri data verification and audit framework, ensuring consistency, transparency, and robustness of the reported results.

In addition to the sensitivity tests presented above, several inherent sources of uncertainty influence the reported emission results. The most important source relates to nitrous oxide (N_2O) emission factors from agricultural soils, which are subject to natural variability due to soil type, climate conditions, and management practices. A second source of uncertainty relates to soil organic carbon stock change estimates, which depend on modelling approaches and assumptions regarding soil processes and management history. A third source relates to yield variability across production systems, which influences emission intensity expressed per tonne of cotton lint. While these factors introduce uncertainty at the country level, their influence on the aggregated global results is moderated by the large dataset and consistent methodological framework applied across all countries.

6.3 Hotspot Identification

Aggregated weighted-average emission source contributions across countries confirm fertiliser-related soil emissions as the dominant hotspot category, followed by field energy and processing energy.

Primary Emission Sources (Global):

Based on the consolidated country-level emission source data, the USA provides the most detailed and complete emission source breakdown and is therefore used as the primary reference for hotspot identification. The percentage ranges reported below are weighted-average figures across the portfolio and reflect the dominant pattern in nitrogen-intensive, mechanised systems (notably USA, Brazil, India). They should not be interpreted as country-specific values; the country-level emission source breakdown tables in Appendix 14 take precedence over these aggregate ranges, and the relative ranking of sources differs materially in several countries. In particular: in India fertiliser soil N_2O is 23 percent (with irrigation electricity at 29 percent the largest single source); in Turkey fertiliser production is 50 percent and the largest source, with fertiliser soil N_2O at 21 percent and ginning at 20 percent; in Tanzania fertiliser soil N_2O is 50 percent (the largest source despite a low-input system); in Australia the gross emission profile is dominated by fertiliser soil N_2O (180 percent of net total before SOC offset, 577,467 tCO_2e) with field energy at 63 percent of net total before SOC offset (201,639 tCO_2e); in Brazil field energy is 7 percent and ginning is 0.7 percent; in Mexico ginning reaches 34 percent; and in Pakistan fertiliser production accounts for 55 percent of net total, while fertiliser-related soil N_2O emission account for 78 percent of the net total before SOC offset. The aggregate ranges below should therefore be read as a portfolio-level summary, with country-specific contributions visible only in the Appendix 14 tables.

1. **Fertiliser soil emissions (N_2O)**

   Approximately 40 percent of total cradle-to-gate emissions at portfolio-weighted level, with substantial country-level variation. Primary driver is nitrogen fertiliser application and associated soil N_2O emissions, which dominate emission profiles in high-input systems including the USA (60 percent), Brazil (44 percent), Egypt (38 percent), Pakistan (78 percent of net total), Tanzania (50 percent), and Australia (where fertiliser soil N_2O is the dominant gross source at 577,467 tCO_2e, partially offset by SOC removals). The share is lower in India (23 percent, where irrigation electricity is the largest single source at 29 percent) and Turkey (21 percent, where fertiliser production at 50 percent is the largest source). Country-specific shares are reported in Appendix 14. Mitigation potential is high, through reduced nitrogen application rates, precision nutrient management, optimized timing, and the use of nitrification inhibitors where appropriate.

2. **Field energy (fuel consumption)**

   Approximately 10–15 percent of total emissions in the USA reference but with wide variation across other countries: 12 percent in the USA, 7 percent in Brazil, 13 percent in Mexico, 2 percent in India and Turkey, and 63 percent of net total before SOC offset in Australia (where diesel use is exceptionally high in absolute terms at 201,639 tCO_2e). Primary driver is diesel and fuel use for land preparation, cultivation, and harvesting operations, particularly in highly mechanised production systems. Mitigation potential is medium, through reduced tillage, conservation agriculture, and improved machinery efficiency.

3. **Processing energy**

Approximately 8–12 percent of total cradle-to-gate emissions at portfolio-weighted level under the absolute EF_ginning of 0.10 tCO_2e/t lint, with very wide country-level variation when farm-level activity-based contributions are reported. The country-level emission breakdown tables in Appendix 14 show large differences in the proportional share of ginning emissions: 0.7 percent in Brazil (where fertiliser dominates), 3.6 percent in India, 9.3 percent in the USA, 20 percent in Turkey, and 34 percent in Mexico. These country-level shares reflect the relative magnitude of other emission sources and farm-level SOC dynamics rather than differences in absolute ginning intensity per tonne of lint, which is uniform across countries under the flat EF approach applied in this assessment. Primary driver of ginning emissions is electricity and fuel consumption at ginning facilities. Mitigation potential is medium, through energy efficiency improvements and increased use of renewable electricity.

4. **Crop residue management**

   Approximately 5–10 percent of total emissions. Primary driver is N_2O and CH_4 emissions from residue decomposition or open-field burning. This source is particularly relevant in low-input systems such as Tanzania and Mozambique and in residue-intensive systems in larger mechanised producers. Mitigation potential is high, through residue incorporation, avoidance of burning, and improved compost and residue handling practices.

5. **Machinery fuel use**

   Approximately 4–6 percent of total cradle-to-gate emissions in mechanised production systems. Primary driver is diesel combustion for land preparation, cultivation, and harvesting operations. In Appendix 14 country tables, machinery is reported as a separate line item in India (6 %), Brazil (4 %), Turkey (4 %), Pakistan (4 %), Mexico (less than 1 %), and the USA (5.5 %). Australia does not report machinery as a separate category in the 2024 dataset; its mechanisation-related emissions are aggregated within field energy (fuel) at 201,639 tCO_2e. Mitigation potential is medium through reduced tillage and improved machinery efficiency.

6. **Fertiliser production (upstream manufacturing)**

   Approximately 3–5 percent of total cradle-to-gate emissions in the USA breakdown but substantially higher in several other countries, where fertiliser production becomes a major or dominant source. Country-level shares reported in Appendix 14 include Egypt (54 % the largest single source), Turkey (50 %, the largest source), Pakistan (55 % of net total, second largest), India (17 %), Brazil (18 %), Australia (43 % of net total before SOC offset), and Mexico (13 %). The 3–5 percent range reported here is therefore representative of the USA only and not of the portfolio. The category covers industrial emissions from nitrogen, phosphate, and potassium fertiliser manufacturing. Mitigation potential is medium through reduced fertiliser demand and lower-carbon production technologies.

7. **Irrigation electricity use**

   Typically 0.5–3 percent of total cradle-to-gate emissions at portfolio-weighted level. The country breakdown tables in Appendix 14 separately disaggregate irrigation electricity for India (29 %, the largest single source for India), the USA (0.5 %), and Turkey (less than 0.01 %). Australia, Egypt, and Pakistan do not disaggregate irrigation electricity as a separate line item in the 2024 dataset; their irrigation energy demand is included implicitly within field energy or unmeasured at the activity-data level, which limits direct verification of irrigation-specific contributions for those countries from the tables alone. India therefore provides the strongest direct evidence of irrigation as a major hotspot. Mitigation potential is medium through irrigation efficiency improvements and renewable electricity sourcing.

Regenagri Practice Linkages

The identified emission hotspots align directly with core Regenagri practice requirements:

- Soil health practices, including cover crops and organic amendments, reduce soil N_2O emissions and support soil carbon accumulation.
- Reduced and conservation tillage practices lower fuel consumption and field energy emissions.
- Precision nutrient management reduces excess nitrogen application and associated N_2O emissions.
- Improved crop residue management avoids combustion-related emissions and enhances soil carbon sequestration.
- Irrigation efficiency measures reduce energy demand associated with water abstraction and application.

Overall, the hotspot analysis confirms that nitrogen management and soil processes are the dominant drivers of the cotton GHG footprint, while energy-related emissions represent secondary but material mitigation opportunities across production regions.

6.4 Key Emission Drivers and Mitigation Opportunities

The hotspot analysis highlights the key emission drivers influencing the greenhouse gas footprint of Regenagri-certified cotton production systems and identifies the principal mitigation opportunities across production regions.

Across the assessed production systems, nitrogen fertiliser application represents the dominant driver of greenhouse gas emissions, primarily through nitrous oxide (N_2O) emissions from agricultural soils and upstream fertiliser production. Nitrogen-related soil emissions therefore constitute the largest contributor to total cradle-to-gate emissions across most countries.

Secondary emission sources include energy consumption associated with irrigation and diesel use in field operations. Electricity demand for irrigation pumping contributes to emissions in irrigated production systems such as Australia, Egypt, Pakistan, and parts of India, while diesel use for mechanised cultivation and harvesting operations contributes to emissions in highly mechanised systems including the USA, Brazil, Australia, and Turkey.

The analysis also highlights several key mitigation opportunities. Improved nitrogen management and fertiliser optimisation can substantially reduce soil N_2O emissions. Increased adoption of regenerative agricultural practices such as reduced tillage, cover cropping, and organic amendments can enhance soil health and increase soil organic carbon sequestration. In addition, improved irrigation efficiency and reduced diesel consumption through conservation agriculture practices can further reduce energy-related emissions.

Together, these measures represent the most effective pathways for reducing the greenhouse gas footprint of cotton production within the Regenagri system.

6.5 Geographic Variation Analysis

High Emission Intensity Regions (lint level – accounting for GHG emissions and removals)

- Egypt (2.30 tCO_2e per tonne lint): Driven by upstream fertiliser production emissions (54 percent of total farm-gate emissions) and fertiliser soil N_2O (38 percent), combined with very small farm area and limited soil carbon sequestration.
- India (2.18 tCO_2e per tonne lint): Driven by high irrigation electricity demand (29 percent of total farm-gate emissions), reflecting the predominantly irrigated cotton systems in key growing states, combined with fertiliser soil N_2O emissions (23 percent) and transport-related emissions (22 percent). Moderate to low yield levels further elevate emission intensity per tonne of lint.

Low Emission Intensity Regions (lint level – accounting for GHG emissions and removals)

- Côte d'Ivoire (−4.74 tCO_2e per tonne lint): Strong verified soil carbon sequestration from regenerative practices results in net negative cradle-to-gate emissions, where verified SOC removals exceed gross agricultural and ginning emissions.
- Peru (−2.91 tCO_2e per tonne lint): Net negative emissions driven by soil carbon gains exceeding gross production emissions.
- Tajikistan (−1.10 tCO_2e per tonne lint): Soil carbon sequestration offsets field-level emissions.
- Tanzania (0.24 tCO_2e per tonne lint): Low external input use and limited mechanisation result in very low emission intensity.
- Mozambique (0.34 tCO_2e per tonne lint): Low fertiliser application rates and minimal energy use contribute to low emissions.

Factors Driving Variation

Table 6.5.1 – Primary Drivers of Emission Intensity Variation Across Cotton Production Systems

Factor	Impact
Nitrogen fertiliser application rate	High – primary driver of soil N_2O emissions
Soil organic carbon sequestration	High – regenerative practices reduce (sequestration) net emissions
Crop yield	High – higher yields reduce emissions per tonne of product
Irrigation requirements	Medium – driven by climate and water demand
Fuel consumption	Medium – linked to mechanisation and field operations
Ginning emissions	Low – relatively consistent per tonne of lint

Qualitative ranking reflects relative contribution to total cradle-to-gate emissions based on 2024 weighted results.

Negative emission intensities indicate that verified SOC removals exceed gross agricultural and ginning emissions. They reflect a net accounting balance and do not constitute a climate benefit claim. Gross sequestration, not the absence of agricultural emissions. Gross production emissions remain positive in all countries. Net negative results in Côte d'Ivoire, Peru, and Tajikistan occur because verified SOC removals exceed gross agricultural emissions. Net negative results in Côte d'Ivoire, Peru, and Tajikistan occur because verified SOC removals exceed gross agricultural emissions.

6.6 Consistency Check

The study applied consistent system boundaries, allocation procedures (absolute ginning EF = 0.10 tCO_2e/t lint; 84/16 economic allocation), ginning outturn (39 percent), emission factors (IPCC 2019 GWP100), and modelling tools (Cool Farm Platform) across all countries. Soil organic carbon (SOC) stock changes were estimated using the Cool Farm Platform modelling framework, which applies IPCC-compliant methodologies for soil carbon dynamics. The model estimates changes in soil carbon stocks based on site-specific management practices, soil characteristics, and climatic conditions reported through the Regenagri farm dataset. Baseline soil carbon values reflect measured enrolment data or model initialisation parameters consistent with the Cool Farm Platform default baseline assumptions. No methodological deviations were applied between regions. Results are therefore methodologically comparable within the defined system boundary. No value choices were applied in interpreting country-level differences beyond the defined system boundary and methodological assumptions.

A final completeness and consistency check confirms that the dataset, methodological assumptions, and modelling parameters were applied uniformly across all assessed production systems. The large, aggregated dataset representing more than 1.3 million hectares of cotton production ensures that the reported global emission intensity reflects a representative weighted average of Regenagri-certified production systems for the 2024 reporting year. No inconsistencies were identified that would materially affect the interpretation of the global results.

7 CONCLUSIONS AND USE OF RESULTS

7.1 Key Findings

1. **Global Emission Intensity**

   Regenagri-certified cotton shows a weighted global cradle-to-gate greenhouse gas emission intensity of 1.15 tCO_2e per tonne of ginned cotton lint (GHG emissions and removals), based on verified 2024 production data aggregated across all countries included in this assessment, using the revised absolute ginning emission factor methodology (EF_ginning = 0.10 tCO_2e/t lint). The gross emission intensity (GHG emissions only, excluding SOC removals) is approximately 1.83 tCO_2e per tonne of ginned cotton lint. Under mass allocation (40.6/59.4 to lint/cottonseed), the corresponding net and gross intensities would be approximately 0.56 and 0.88 tCO_2e per tonne of lint, respectively.

2. **Significant Regional Variation**

   Emission intensities vary widely across production regions, ranging from −4.74 tCO_2e per tonne lint to 2.30 tCO_2e per tonne lint (accounting for both GHG emissions and removals). This variation reflects differences in nitrogen input rates, energy use, yield performance, irrigation demand, and changes in soil organic carbon stocks across production systems.

3. **Soil Carbon Impact**

   Regenerative practices implemented in several regions, notably Côte d'Ivoire, Peru, and Tajikistan, result in net negative emission intensities, where verified soil carbon sequestration exceeds gross production emissions. These results demonstrate the climate mitigation potential of Regenagri-certified systems beyond emission reduction alone.

4. **Primary Emission Hotspot**

   Nitrogen fertiliser application and associated soil N_2O emissions represent approximately 40 percent of total cradle-to-gate emissions in the 2024 dataset. This confirms nitrogen management as the most influential driver of emission intensity and the primary lever for further reductions in cotton production systems.

5. **Data Quality and Verification**

   All results are derived from verified farm-level data collected through the Regenagri certification system and are subject to annual third-party audit and validation by ISO 14064 and ISO 14065 accredited verifiers. This ensures high data integrity, traceability, and consistency with international GHG accounting standards. Country-wise emission source breakdown tables for all 13 production regions are provided in Annex 14 (LCI).

7.2 Recommendations for Emission Reduction

A data improvement pathway is recommended for ginning emissions in future reporting cycles: facility-specific ginning energy data (kWh per tonne of seed cotton processed, including electricity and fuel for drying and cleaning) should be collected from supply chain partners. This would constitute Tier 1 primary data and replace the current secondary emission factor approach (EF_ginning = 0.10 tCO_2e per tonne of lint), further improving precision across all 13 production regions.

Two further data improvement pathways are recommended for subsequent assessments. First, emission source disaggregation should be made uniformly available across all 13 participating countries, so that fertiliser soil emissions, fertiliser production, field energy, irrigation electricity, residue management, machinery, transport, and ginning are reported as separate line items in every country, in line with the breakdown already available for USA, Brazil, India, Australia, and Turkey. Second, the assessment should move beyond the single 2024 reporting year towards multi-year baseline analysis and explicit treatment of inter-annual variability in yield, nitrogen application, irrigation demand, and SOC stock change. Both improvements would strengthen the precision of country-level hotspot identification, support more robust trend analysis, and reduce the dependence on single-year SOC values.

Based on the quantified emission source breakdown and regional performance patterns, the following mitigation pathways target the largest contributing emission sources identified in the 2024 dataset and therefore represent the most material intervention areas within the current system boundary. These pathways are fully aligned with Regenagri practice requirements.

The percentage reduction ranges presented below are derived from scenario-based sensitivity modelling using the 2024 verified dataset. For each mitigation pathway, the relevant emission parameter (e.g. nitrogen application rate, diesel consumption, irrigation electricity demand, residue management factor) was adjusted within agronomically realistic ranges and recalculated using the existing country-level inventory structure. These values represent theoretical mitigation potential tested primarily in systems with detailed emission source disaggregation (USA, India, Brazil, Australia, Turkey). No production system was modified in reality; results reflect model-based sensitivity testing only.

1. **Precision Nutrient Management**

   Soil testing and nutrient planning to optimise nitrogen application rates. Variable-rate application and improved timing of fertiliser inputs. Use of nitrification inhibitors where agronomically and economically viable.
   Expected impact: Modelled sensitivity indicates potential reductions of approximately 10–20 percent in soil N_2O emissions.
   Tested change: Nitrogen application rates reduced by 10–20 percent in nitrogen-intensive systems (USA, India, Brazil), with proportional recalculation of direct and indirect N_2O emissions using IPCC Tier 1 emission factors.

2. **Soil Health and Cover Crops**

   Expanded adoption of cover crops to improve soil structure and nutrient cycling. Increased organic matter inputs through compost and residue incorporation.
   Reduced dependence on synthetic fertilisers through biological nitrogen fixation. Expected impact: 15–25 percent reduction in fertiliser requirements.
   Tested change: Synthetic nitrogen input reduced by 15–25 percent to simulate biological nitrogen fixation and improved nutrient retention; upstream fertiliser production emissions and soil N_2O emissions recalculated accordingly. Tested in USA, India, Brazil, Australia, and Turkey, the five production regions with fully disaggregated emission source data. The estimated reduction range is expected to apply equally in other nitrogen-intensive systems within the portfolio.

3. **Residue Management Optimisation**

   Transition from residue burning to incorporation or controlled composting. Implementation of well-managed compost systems where residues are removed. Expected impact: 5–10 percent reduction in CH_4 and N_2O emissions from residue handling.
   Tested change: Emission factors for residue burning replaced with incorporation or controlled composting factors under IPCC 2019 defaults. Tested in India, where open-field burning is a documented practice in the 2024 dataset. For other production regions, this pathway applies where burning is confirmed as the primary residue management method in verified farm records; country-specific testing is recommended once practice-level residue management data are available for all 13 regions.

4. **Field Energy Efficiency**

   Expansion of conservation agriculture and reduced-tillage systems. Optimisation of machinery use and fuel consumption.

Expected impact: 10–15 percent reduction in field energy emissions.
Tested change: Diesel consumption per hectare reduced by 10–15 percent in mechanised systems, with direct recalculation of fuel combustion emissions. Tested in Brazil, USA, Australia, and Turkey — the mechanised systems with the highest absolute field energy contributions in the 2024 dataset. Brazil in particular was added given its 6.98 percent field energy share, which is among the highest in the portfolio.)

5. **Irrigation Efficiency**

   Upgrade to efficient irrigation systems such as drip or micro-irrigation. Use of soil moisture monitoring to optimise water application.
   Expected impact: 20–30 percent reduction in irrigation-related energy use.
   Tested change: (Irrigation electricity demand reduced by 20–30 percent in irrigated systems, holding grid emission factors constant and recalculating associated Scope 2 emissions. Tested in India, Australia, Egypt, and Pakistan — the four production regions where irrigation electricity is a significant recorded emission source. India was prioritised given that irrigation represents 29 percent of its total farm-gate emissions, the highest irrigation contribution in the portfolio.

8 CRITICAL REVIEW

8.1 Critical Review Statement

In accordance with the requirements of ISO 14044 (4.2.3.8), a critical review of this LCA study has been conducted by Green Story Inc. The reviewer, Prof. Dr. Kannan Muthu/Ph.D./CSO/Green Story, possesses recognized expertise in LCA methodology. The review was conducted to ensure that this study quantifies greenhouse gas emissions following IPCC guidance and is consistent with a product carbon footprint approach (ISO 14067) and the allocation principles of ISO 14040 and ISO 14044. It was also checked that the data used, assumptions made and non-disclosures claimed are appropriate and reasonable, and that the interpretations reflect the limitations of the study. The review report can be found in Critical Review under Annex.

In accordance with ISO 14044, the critical review statement, the reviewer's report, and the practitioner's responses to the reviewer's comments are provided together in the Independent Critical Review Report annex to this report. This annex records the context for the methodological decisions taken in the study and is included so that reviewers can trace each decision to its documented justification.

9 REFERENCES AND SOURCES

Standards and Methodologies

1 European Commission, Joint Research Centre. (2019). Product Environmental Footprint Category Rules Guidance, version 6.3. https://eplca.jrc.ec.europa.eu/permalink/PEFCR_guidance_v6.3-2.pdf

2 European Commission (2013). Recommendation 2013/179/EU on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations. Official Journal of the European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32013H0179

3 ISO. (2006). ISO 14040:2006, Environmental management — Life cycle assessment — Principles and framework. International Organization for Standardization. https://www.iso.org/standard/37456.html

4 ISO. (2006). ISO 14044:2006, Environmental management — Life cycle assessment — Requirements and guidelines. International Organization for Standardization. https://www.iso.org/standard/38498.html

5 ISO. (2018). ISO 14064-1:2018, Greenhouse gases — Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals. International Organization for Standardization. https://www.iso.org/standard/66453.html

6 ISO. (2020). ISO 14065:2020, General principles and requirements for bodies validating and verifying environmental information. International Organization for Standardization. https://www.iso.org/standard/74257.html

7 ISO. (2018). ISO 14067:2018, Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification. International Organization for Standardization. https://www.iso.org/standard/71206.html

8 ISO. (2024). ISO 14071:2024, Environmental management — Life cycle assessment — Critical review processes and reviewer competencies. International Organization for Standardization. https://www.iso.org/standard/86264.html

9 IEA (2025). Emissions Factors 2025. International Energy Agency, Paris. https://www.iea.org/data-and-statistics/data-product/emissions-factors-2025

10 PEF Apparel and Footwear Technical Secretariat. (2025). Product Environmental Footprint Category Rules for Apparel and Footwear, version 3.1. https://pefapparelandfootwear.eu/

11 IPCC. (2019). 2019 Refinement to the 2006 IPCC Guidelines for National

Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

12 IPCC (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (AR6). Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, et al. (eds.). Cambridge University Press. Global Warming Potential values from Chapter 7, Table 7.15. https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-7/

13 Regenagri. (2024). regenagri Standard Criteria, version 3.1, and regenagri Content Standard, version 3.0. https://regenagri.org/standards-documents/

Reference Studies

14 Sphera Solutions. (2021). Life Cycle Assessment of Cotton made in Africa. Report prepared for Aid by Trade Foundation. https://cottonmadeinafrica.org/wp-content/uploads/CmiA_LCA-Study_2021.pdf

15 Ismail, S. A. (2009). Assessment of energy usage for cotton gins in Australia. Master of Engineering dissertation, University of Southern Queensland, Faculty of Engineering and Surveying. Cotton Research and Development Corporation. https://www.insidecotton.com/sites/default/files/article-files/UA17_Liu_Siti_thesis_%2528for_CRDC%2529.pdf

16 Ismail, S. A., Chen, G., Baillie, C., & Symes, T. (2011). Energy uses for cotton ginning in Australia. Biosystems Engineering, 109(2), 140–147. https://doi.org/10.1016/j.biosystemseng.2011.02.010

17 Funk, P. A. (2017). Energy utilization and conservation in cotton gins. Journal of Cotton Science, 21(2), 156–166. https://www.cotton.org/journal/2017-21/2/upload/JCS21-156.pdf

18 Better Cotton. (2021). Better Cotton releases first study on GHG emissions. Study conducted by Anthesis Group and commissioned by Better Cotton. https://bettercotton.org/better-cotton-releases-our-first-study-on-ghg-emissions/

19 BASF. (2022). Methodology for Product Carbon Footprint Calculation, version 1.1, 20 July 2022. https://www.basf.com/dam/jcr:66611f85-8ae8-3714-8a66-fdecde3ccee4/basf/www/global/documents/en/sustainability/we-drive-sustainable-solutions/quantifying-sustainability/product-carbon-footprint/BASF_Methodology_for_Product_Carbon_Footprint%20Calculation_August_2022.pdf

20 Nemecek, T., Bengoa, X., Lansche, J., Roesch, A., Faist-Emmenegger, M., Rossi, V., & Humbert, S. (2019). Methodological Guidelines for the Life Cycle Inventory of Agricultural Products, World Food LCA Database, version 3.5. Quantis and Agroscope. https://simapro.com/wp-content/uploads/2020/11/WFLDB_MethodologicalGuidelines_v3.5.pdf

21 Textile Exchange and Sphera Solutions. (2026). Life Cycle Assessment for Cotton. Textile Exchange. https://textileexchange.org/knowledge-center/reports/cotton-life-cycle-assessment/

22 Cascale (2024). Industry-Aligned Life Cycle Assessment Methodology and Requirements for creating Cotton Fiber Datasets for the Higg Product Tools. Cascale (formerly Sustainable Apparel Coalition). https://cascale.org/tools-programs/higg-product-tools-cotton-lca-methodology/

23 ICAC (2024). ICAC Cotton Production Data Portal, Data Book. International Cotton Advisory Committee. https://icacdatabook.de.r.appspot.com/DataPortal/

24 GHG Protocol. (2026). Land Sector and Removals Standard. World Resources Institute and World Business Council for Sustainable Development. https://ghgprotocol.org/land-sector-and-removals-standard

25 Textile Exchange. (2024). Biogenic Carbon: Guideline on the Consideration of Biogenic Carbon Emissions and Removals in Carbon Footprint Calculations. https://textileexchange.org/knowledge-center/reports/biogenic-carbon-guideline/

Additional Resources

26 IPCC. (2021). Climate Change 2021: The Physical Science Basis, Working Group I contribution to the Sixth Assessment Report, Chapter 7, Table 7.15, Global Warming Potential values. https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-7/

https://www.ipcc-nggip.iges.or.jp/public/2019rf/

27 Cool Farm Alliance. (2026). Cool Farm Platform and Cool Farm Tool. https://cfp.coolfarm.org/

10 APPENDIX: CALCULATION METHODOLOGY

10.1 Global Emission Intensity Calculation

- Step 1: Aggregate production data
  Total lint production equals the sum of lint production across all reporting countries.
  Total lint production
  = 1,352,672.00 tonnes

- Step 2: Aggregate emissions data
  Total cradle-to-gate emissions equal the sum of lint-allocated emissions across all countries, including ginning and economic allocation.
  Total cradle-to-gate emissions
  = 1,557,917 tCO_2e

- Step 3: Calculate global intensity
  Global emission intensity
  = Total emissions / Total lint production
  = 1,557,917 tCO_2e / 1,352,672.00 tonnes
  = 1.15 tCO_2e per tonne lint

This value represents a weighted global average derived from total emissions divided by total production. It is not a simple arithmetic average of country-level emission intensities.

10.2 Ginning Emissions Allocation

- Crop production emissions
  Farm-gate emissions are quantified using the Cool Farm Platform and include all agricultural emission sources within the cradle-to-gate boundary. They are derived from verified farm-level GHG data collected through Regenagri-certified operations and may include SOC removals where verified sequestration has been recorded.

- Ginning emissions
  GHG_ginning = EF_ginning × Lint_production = 0.10 tCO_2e/t lint × Lint_production (tonnes). Ginning emissions are always positive and independent of farm-level SOC effects.
  Total emissions including ginning
  = Crop production emissions + GHG_ginning;
  where

GHG_ginning = EF_ginning (0.10 tCO_2e/t lint) × Lint_production;

Ginning emissions
= Total emissions including ginning − Crop production emissions

- Allocation to co-products at gin gate
  Economic allocation is applied in line with ISO 14040 and ISO 14044 principles.
  Emissions allocated to lint
  = Total emissions including ginning × 0.84 Emissions allocated to cottonseed
  = Total emissions including ginning × 0.16

10.3 Economic Allocation Factors

An economic allocation of 84 percent to lint and 16 percent to cottonseed is applied at the gin gate. This reflects typical global value ratios between lint and cottonseed based on international cotton price statistics and sector benchmarks.

Economic allocation is calculated as:
Allocation to lint= Market value of lint / (Market value of lint + Market value of seed)

Based on representative global average price ratios, cotton lint accounts for approximately 80–85 percent of total co-product economic value. A midpoint value of 84 percent is applied in this assessment to ensure consistent treatment across all reporting regions.

The 84/16 allocation factor reflects a harmonised global allocation applied consistently across all countries to ensure methodological uniformity and does not represent country-specific price ratios.

Allocation is applied once at the total cradle-to-gate system level, after aggregation of all upstream agricultural and ginning emissions. Fertiliser production, soil emissions, fuel use, irrigation, transport, and ginning energy are first summed as total system emissions. The 84/16 allocation is then applied to the aggregated total. Upstream emission sources are not individually allocated.

This approach aligns with ISO 14044 allocation principles, avoids double allocation, and ensures methodological consistency and transparency across the dataset.

10.4 Functional Unit Conversion

- Reference flow calculation
  Average ginning outturn across verified production regions
  = 39 percent

- Seed cotton required to produce the functional unit Seed cotton required
  = Lint production / 0.39
  = 1,352,672 tonnes / 0.39
  = 3,479,183 tonnes of seed cotton

- Emission intensity per functional unit Functional unit
  = 1 tonne of ginned cotton lint at the gin gate Emission intensity
  = Total cradle-to-gate emissions / Total lint production
  = 1,557,917 tCO_2e / 1,352,672 tonnes
  = 1.15 tCO_2e per tonne lint

This calculation forms the basis for all reported lint-level emission intensities in the assessment.

10.5 SOC Cross-Reference

Soil organic carbon stock change calculation steps are detailed in Section 3.2 and aggregated in the Soil Carbon Impact table in Section 4.3.

11 APPENDIX: GINNING OUTTURN BY COUNTRY

Table 11.1 – Ginning Outturn by Country and Data Sources

Country	Ginning Outturn (%)	Source
Australia	38.6	Industry reports, Cotton Australia
Brazil	42	CONAB / Brazilian cotton statistics
Côte d'Ivoire	40	Regional West Africa cotton data
Egypt	36	Egyptian cotton authority reports
India	35	ICAR (Indian Council of Agricultural Research)
Mexico	39	FAO / regional benchmarks
Mozambique	38	Regional benchmarks (SSA cotton systems)
Pakistan	37	Pakistan Cotton Ginners Association
Peru	40	FAO / national reports
Tajikistan	39	Central Asia cotton statistics
Tanzania	38	Regional benchmarks (SSA cotton systems)
Turkey	41	Turkish Statistical Institute (TURKSTAT)
USA	40	USDA cotton statistics

12 APPENDIX: COUNTRY-LEVEL DETAILED RESULTS

12.1 Complete Country Data

Table 12.1.1 – Complete Country-Level GHG Emissions and Production Data (2024)

			Farm-Gate Emissions			Cradle-to-Gate Lint Emissions (Reductions and Removals)		Cradle-to-Gate Lint Emissions (GHG Only)	
Country	Production Area (ha, 2024)	Lint Production (t, 2024)	Total Farm-Gate Emissions (tCO_2e)	Emission Intensity (tCO_2e/t seed cotton)	Emission Intensity (tCO_2e/ha)	Total Lint Emissions (tCO_2e)	Lint Emission Intensity (tCO_2e/t lint)	Total Lint Emissions (tCO_2e)	Lint Emission Intensity (tCO_2e/t lint)
TOTALS GLOBAL	**1,331,359.4**	**1,352,672**	**1,719,396**	**0.49**	**1.29**	**1,557,917**	**1.15**	**2,472,763**	**1.83**
Australia	174,687.5	432,070	320,240.16	0.29	1.83	305,296	0.71	820,973	1.90
Brazil	169,786.4	317,840.1	545,027.85	0.67	3.21	484,522	1.52	518,789	1.63
Côte d'Ivoire	84,925.0	39,260.4	−225,385.90	−2.24	−2.65	−186,026	−4.74	49,688	1.27
Egypt	665.3	622.7	1,640.29	1.03	2.47	1,430	2.30	1,430	2.30
India	501,341.1	283,179.9	705,604.71	0.97	1.41	616,495	2.18	704,802	2.49
Mexico	16,219.0	18,473.9	37,740.38	0.80	2.33	33,254	1.80	29,040	1.57
Mozambique	700.1	231.8	71.10	0.12	0.10	79	0.34	79	0.34
Pakistan	32,839.2	21,772.4	31,787.72	0.57	0.97	28,531	1.31	39,711	1.82
Peru	2,358.1	810.8	−2,893.64	−1.39	−1.23	−2,363	−2.91	562	0.69
Tajikistan	10,621.0	12,426.2	−17,496.66	−0.55	−1.65	−13,653	−1.10	17,335	1.40
Tanzania	91,914.2	24,035.5	4,549.29	0.07	0.05	5,840	0.24	5,840	0.24
Turkey	111,031.6	116,916.3	201,417.95	0.67	1.81	179,012	1.53	179,012	1.53
USA	134,271.0	85,032.2	117,093.00	0.54	0.87	105,501	1.24	105,501	1.24

13 APPENDIX: EMISSION FACTOR REFERENCES

13.1 IPCC Default Emission Factors (2019 Refinement)

Table 13.1.1 – IPCC Default Emission Factors (2019 Refinement)

Emission Source	Emission Factor	Unit	Source
Direct N_2O from N fertiliser	0.01	kg N_2O-N/kg N	IPCC Vol 4, Ch 11
Indirect N_2O from N fertiliser	0.0075	kg N_2O-N/kg N	IPCC Vol 4, Ch 11
CO_2 from urea application	0.2	kg CO_2/kg urea	IPCC Vol 4, Ch 11
CO_2 from lime application	0.12	kg CO_2/kg $CaCO_3$	IPCC Vol 4, Ch 11
CH_4 from residue burning	0.0027	kg CH_4/kg residue	IPCC Vol 4, Ch 11
N_2O from residue burning	0.00007	kg N_2O/kg residue	IPCC Vol 4, Ch 11

13.2 Fuel and Energy Emission Factors

Table 13.2.1 – Fuel and Energy Emission Factors

Fuel/Energy Source	Emission Factor	Unit
Diesel combustion	2.68	kg CO_2e/litre
Petrol combustion	2.31	kg CO_2e/litre
Natural gas	2.04	kg CO_2e/m^3
Electricity (global average)	0.45	kg CO_2e/kWh
Electricity (USA grid)	0.38	kg CO_2e/kWh
Electricity (EU grid)	0.28	kg CO_2e/kWh

13.3 Input Production Emission Factors

Table 13.3.1 – Input Production Emission Factors

Input	Emission Factor	Unit
Urea fertiliser	1.48	kg CO_2e/kg N
Ammonium nitrate	1.27	kg CO_2e/kg N
DAP fertiliser	0.56	kg CO_2e/kg P_2O_5
Potassium chloride	0.15	kg CO_2e/kg K_2O
Pesticides	5-15	kg CO_2e/kg active ingredient

Note: Factors in Table 13.3.1 are IPCC 2019 Refinement cradle-to-gate defaults expressed per kg of nutrient (N, P_2O_5, K_2O). They are not directly comparable to the per-kg-product factors in Table 3.3.1, which are derived from Brentrup et al. as implemented in the Cool Farm Platform. For example, urea at 46 percent N: the Cool Farm Platform value of 0.89 kg CO_2e/kg product corresponds to approximately 1.93 kg CO_2e/kg N, while the IPCC default in Table 13.3.1 is 1.48 kg CO_2e/kg N. The difference reflects methodology, data sources, and reference year, not an error in either value.

14 APPENDIX: COUNTRY-LEVEL GREENHOUSE GAS EMISSION SOURCE TABLES

The tables below present verified farm-gate greenhouse gas emission source breakdowns for all 13 Regenagri-certified cotton production regions included in the 2024 assessment. Figures represent farm-level emissions before system boundary extension to include ginning and before economic allocation to lint. Emission sources are listed in descending order of contribution. Zero values and absent categories reflect non-use of the corresponding activity within the assessed farms, not data omission.

Note on negative totals: Three countries — Côte d'Ivoire, Peru, and Tajikistan — report negative net emission totals, reflecting verified soil organic carbon stock increases (SOC removals) that exceed gross agricultural emissions. Gross production emissions remain positive in all three cases.

Across the 13 Regenagri-certified cotton production systems assessed for 2024, total cultivated area amounts to 1,331,359 hectares, with a combined harvest of 2,792,589 tonnes of seed cotton and a weighted average yield of 2.10 tonnes per hectare. (Note: Australia's 2024 harvest of 432,070 tonnes reported in Table 14.1 represents lint production, reflecting the Australian cotton industry's standard reporting convention; the corresponding seed cotton equivalent is approximately 1,119,792 tonnes at Australia's 38.6 percent ginning outturn. The combined harvest total shown above treats Australia's lint tonnage at face value to align with the functional unit of 1 tonne of lint; see Section 4.3 for further detail.) Production is structurally concentrated: a small number of large-scale producers account for the majority of cultivated area and harvested volume, while several countries operate at considerably smaller scales. Yields span a wide range — from below 1 tonne per hectare in low-input, rain-fed systems to approximately 5 tonnes per hectare in highly mechanised and irrigated systems — reflecting the diversity of agronomic contexts represented in the portfolio. Total farm-level greenhouse gas emissions across all countries amount to 1,719,396 tCO_2e, with three countries recording net negative totals where verified soil carbon stock increases offset gross emissions. The combination of structural concentration, yield variability, and contrasting carbon outcomes explains the wide spread observed in emission intensities across regions, and underscores the importance of applying weighted, production-based aggregation when interpreting portfolio-level performance. Yield values represent harvested seed cotton per hectare.

Table 14.1 – Summary of Production Area, Yield, and Total Emissions by Country

Country	Project area ha	Harvest tonnes	Yield (MT/ha)	Total tCO_2e
Australia	174,687.52	1,119,792.28	6.41	320,240.16
Brazil	169,786.40	814,974.74	4.80	545,027.85
Côte d'Ivoire	84,925.00	100,667.66	1.19	-225,385.90
Egypt	665.27	1,596.65	2.40	1,640.29
India	501,341.07	726,102.32	1.45	705,604.71
Mexico	16,219.00	47,369.00	2.92	37,740.38
Mozambique	700.05	594.27	0.85	71.1
Pakistan	32,839.23	55,826.69	1.70	31,787.72
Peru	2,358.10	2,079.00	0.88	-2,893.64
Tajikistan	10,621.00	31,862.10	3.00	-17,496.66
Tanzania	91,914.16	61,629.54	0.67	4,549.29
Turkey	111,031.58	299,785.27	2.70	201,417.95
USA	134,271.00	218,031.39	1.62	117,093.00
Total / weighted	**1,331,359.38**	**3,480,310.91**	**2.61**	**1,719,396.25**

Australia's reported lint output of 432,070 tonnes has been converted to a seed cotton equivalent of 1,119,792 tonnes at its 38.6 percent ginning outturn (Appendix 11), so all 13 countries appear on a comparable seed cotton basis in this table; see Section 4.3 for further detail.

Yield Efficiency Analysis

Table 14.2 – Yield Efficiency Analysis Across Countries

Rank	Country	Yield (t/ha)	Per Tonne	Per ha	Status
1	Brazil	4.80	0.67	3.21	High Yield, Moderate Emissions
2	Tajikistan	3.00	-0.55	-1.65	Carbon Sink
3	Mexico	2.92	0.80	2.33	Good Yield, Moderate Emissions
4	Turkey	2.70	0.67	1.81	Good Yield, Moderate Emissions
5	Australia	2.47	0.74	1.83	Good Yield, Moderate Emissions
6	Egypt	2.40	1.03	2.47	Good Yield, High Emissions
7	Pakistan	1.70	0.57	0.97	Moderate Yield, Moderate Emissions
8	USA	1.62	0.54	0.87	Moderate Yield, Moderate Emissions
9	India	1.45	0.97	1.41	Moderate Yield, High Emissions
10	Côte d'Ivoire	1.19	-2.24	-2.65	Carbon Sink
11	Peru	0.88	-1.39	-2.46	Carbon Sink
12	Mozambique	0.85	0.12	0.10	Low Yield, Low Emissions

Rank	Country	Yield (t/ha)	Per Tonne	Per ha	Status
13	Tanzania	0.67	0.07	0.05	Lowest Yield, Lowest Emissions

Note: Australia values are on a lint basis (yield 2.47 t lint/ha; Per Tonne 0.74 tCO_2e/t lint). On a seed cotton basis, Australia's farm-gate intensity is 0.29 tCO_2e/t (as reported in Table 4.3.2; seed cotton equivalent 1,119,792 t at 38.6 percent ginning outturn, Appendix 11). The other 12 countries are reported on a seed cotton basis throughout. Australia's lint-basis reporting follows the convention used by Cotton Australia and the Australian Bureau of Agricultural and Resource Economics; see Section 4.3 and the note to Table 14.1.

Yield efficiency does not directly correlate with emission intensity. Brazil achieves the highest yield (4.80 t/ha) with moderate per-tonne emissions (0.67), demonstrating that intensive production systems can be managed for reasonable climate performance. Conversely, extensive systems (Tanzania, Mozambique) achieve very low per-tonne emissions but at the cost of very low yields (0.67-0.85 t/ha). These systems show low absolute emissions due to limited input intensity.

All Countries Emission Source Tables

Note: Per Hectare and Per Tonne values calculated from: Per Ha = Total / Area (ha), Per Tonne = Total / Harvest (tonnes).

Table 14.3 – Country-Level Emission Source Breakdown Tables (Detailed)

Australia | Area: 174,687.52 ha | Harvest: 1,119,792 t | Yield: 6.41 t/ha				
Emission Source	**tCO_2e**	**%**	**Per Hectare**	**Per Tonne Seed Cotton (tCO_2e/t)**
Fertiliser soil / N_2O	577,467.03	180.32%	3.31	0.52
Field energy (fuel)	201,639.31	62.97%	1.15	0.18
Fertiliser production	137,254.48	42.86%	0.79	0.12
Residue management	12,923.88	4.04%	0.07	0.01
Crop protection	4,185.01	1.31%	0.02	0.00
Off-farm transport	672.30	0.21%	0.00	0.00
Carbon stock changes	−613,901.86	−191.70%	−3.51	−0.55
Total	**320,240.16**	**100%**	**1.83**	0.29

Brazil | Area: 169,786.40 ha | Harvest: 814,974.74 t | Yield: 4.80 t/ha				
Emission Source	**tCO_2e**	**%**	**Per Hectare**	**Per Tonne (seed cotton)**
Fertiliser soil / N_2O	238,090.49	43.68%	1.40	0.29

Transportation	101,667.98	18.65%	0.60	0.12
Fertiliser production	98,890.84	18.14%	0.58	0.12
Pesticide	53,394.29	9.80%	0.31	0.07
Field energy (fuel)	38,066.33	6.98%	0.22	0.05
Crop residue	28,670.47	5.26%	0.17	0.04
Machinery	23,111.03	4.24%	0.14	0.03
Processing energy	3,931.08	0.72%	0.02	0.00
Management changes (SOC)	−40,794.67	−7.48%	−0.24	−0.05
Total	**545,027.85**	**100%**	**3.21**	**0.67**

Côte d'Ivoire | Area: 84,925.00 ha | Harvest: 100,667.66 t | Yield: 1.19 t/ha				
Emission Source	**tCO_2e**	**%**	**Per Hectare**	**Per Tonne (seed cotton)**
Fertiliser application	28,843.31	−12.8%*	0.3396	0.2865
Fertiliser production	13,898.36	−6.2%*	0.1637	0.1381
Crop residue	7,853.76	−3.5%*	0.0925	0.0780
Field energy (fuel)	2,410.87	−1.1%*	0.0284	0.0239
Transportation	1,678.60	−0.7%*	0.0198	0.0167
Pesticides	541.35	−0.2%*	0.0064	0.0054
Management changes (SOC)	−280,612.13	124.5%*	−3.3042	−2.7875
Total	**−225,385.90**	**100%**	**−2.6539**	**−2.2389**

* Note: * Percentages reflect share of net total; positive sources show as negative % when net total is negative.

Egypt | Area: 665.27 ha | Harvest: 1,596.65 t | Yield: 2.40 t/ha				
Emission Source	**tCO_2e**	**%**	**Per Hectare**	**Per Tonne (seed cotton)**
Fertiliser production	891.57	54.4%	1.3402	0.5584
Fertiliser soil / N_2O	630.33	38.4%	0.9475	0.3948
Pesticide	91.39	5.6%	0.1374	0.0572
Field energy (fuel)	27.00	1.6%	0.0406	0.0169
Total	**1,640.29**	**100%**	**2.4656**	**1.0273**

India | Area: 501,341.07 ha | Harvest: 726,102.32 t | Yield: 1.45 t/ha				
Emission Source	**tCO_2e**	**%**	**Per Hectare**	**Per Tonne (seed cotton)**
Irrigation electricity	204,792.59	29.02%	0.41	0.28
Fertiliser soil / N_2O	163,408.44	23.16%	0.33	0.23
Transportation	154,228.91	21.86%	0.31	0.21
Fertiliser production	119,099.52	16.88%	0.24	0.16
Crop residue	84,667.29	12.00%	0.17	0.12
Machinery	41,449.24	5.87%	0.08	0.06
Processing energy	25,518.99	3.62%	0.05	0.04
Field energy (fuel)	16,400.58	2.32%	0.03	0.02
Pesticide	1,167.01	0.17%	0.00	0.00
Management changes (SOC)	−105,127.88	−14.90%	−0.21	−0.14
Total	**705,604.71**	**100%**	**1.41**	**0.97**

Mexico | Area: 16,219.00 ha | Harvest: 47,369.00 t | Yield: 2.92 t/ha				
Emission Source	**tCO_2e**	**%**	**Per Hectare**	**Per Tonne (seed cotton)**
Processing energy	12,683.36	33.61%	0.78	0.27
Fertiliser soil / N_2O	5,632.44	14.92%	0.35	0.12
Management changes (SOC)	5,016.81	13.29%	0.31	0.11
Field energy (fuel)	4,979.91	13.20%	0.31	0.11
Fertiliser production	4,802.13	12.72%	0.30	0.10
Crop residue	2,777.59	7.36%	0.17	0.06
Pesticide	1,614.07	4.28%	0.10	0.03
Machinery	167.81	0.44%	0.01	0.00
Total	**37,740.38**	**100%**	**2.33**	**0.80**

Mozambique | Area: 700.05 ha | Harvest: 594.27 t | Yield: 0.85 t/ha				
Emission Source	**tCO_2e**	**%**	**Per Hectare**	**Per Tonne (seed cotton)**
Crop residue	69.82	98.2%	0.0997	0.1175
Pesticide	1.28	1.8%	0.0018	0.0021
Total	**71.10**	**100%**	**0.1016**	**0.1196**

* Note: Only categories with recorded activity data are reported. Absence of other categories reflects non-use within assessed farms.

Pakistan | Area: 32,839.23 ha | Harvest: 55,826.69 t | Yield: 1.70 t/ha				
Emission Source	**tCO_2e**	**%**	**Per Hectare**	**Per Tonne (seed cotton)**
Fertiliser soil / N_2O	24,890.82	78.3%	0.76	0.45
Fertiliser production	17,579.72	55.3%	0.54	0.31
Machinery	1,294.85	4.07%	0.04	0.02
Pesticide	699.96	2.20%	0.02	0.01
Processing energy	347.44	1.09%	0.01	0.01
Field energy (fuel)	285.07	0.90%	0.01	0.01
Management changes (SOC)	−13,310.14	−41.87%	−0.41	−0.24
Total	**31,787.72**	**100%**	**0.97**	**0.57**

Peru | Area: 2,358.10 ha | Harvest: 2,079.00 t | Yield: 0.88 t/ha				
Emission Source	**tCO_2e**	**%**	**Per Hectare**	**Per Tonne (seed cotton)**
Fertiliser production	170.76	n/a*	0.0724	0.0821
Transportation	160.80	n/a*	0.0682	0.0773
Fertiliser soil / N_2O	142.41	n/a*	0.0604	0.0685
Crop residue	114.07	n/a*	0.0484	0.0549
Management changes (SOC)	−3,481.67	n/a*	−1.4765	−1.6747
Total	**−2,893.64**	**100%**	**−1.23**	**−1.39**

* Note: * Percentage shares not reported when net total is negative. Net negative total results from SOC removals exceeding gross emissions.

Tajikistan | Area: 10,621.00 ha | Harvest: 31,862.10 t | Yield: 3.00 t/ha				
Emission Source	**tCO_2e**	**%**	**Per Hectare**	**Per Tonne (seed cotton)**
Field energy (fuel)	18,895.62	−108.0%*	1.7791	0.5930
Crop residue	418.17	−2.4%*	0.0394	0.0131
Fertiliser soil / N_2O	63.50	−0.4%*	0.0060	0.0020
Transportation	16.60	−0.1%*	0.0016	0.0005
Management changes (SOC)	−36,890.55	210.8%*	−3.4734	−1.1578
Total	**−17,496.66**	**100%**	**−1.6474**	**−0.5491**

* Note: * Percentages reflect share of net total; positive sources show as negative % when net total is negative.

Tanzania | Area: 91,914.16 ha | Harvest: 61,629.54 t | Yield: 0.67 t/ha				
Emission Source	**tCO_2e**	**%**	**Per Hectare**	**Per Tonne (seed cotton)**

Fertiliser soil / N_2O	2,293.91	50.42%	0.02	0.04
Crop residue	2,255.38	49.58%	0.02	0.04
Total	**4,549.29**	**100%**	**0.0495**	**0.0738**

* Note: Only categories with recorded activity data are reported. Absence of other categories reflects non-use within assessed farms.

Turkey | Area: 111,031.58 ha | Harvest: 299,785.27 t | Yield: 2.70 t/ha				
Emission Source	**tCO_2e**	**%**	**Per Hectare**	**Per Tonne (seed cotton)**
Fertiliser production	100,245.55	49.77%	0.90	0.33
Fertiliser soil / N_2O	42,214.27	20.96%	0.38	0.14
Processing energy	40,856.84	20.28%	0.37	0.14
Machinery	8,840.37	4.39%	0.08	0.03
Crop residue	5,354.78	2.66%	0.05	0.02
Field energy (fuel)	3,889.55	1.93%	0.04	0.01
Irrigation electricity	10.19	0.01%	0.00	0.00
Transportation	6.62	0.00%	0.00	0.00
Management changes (SOC)	−0.22	0.00%	0.00	0.00
Total	**201,417.95**	**100%**	**1.8141**	**0.6719**

USA | Area: 134,271.00 ha | Harvest: 218,031.39 t | Yield: 1.62 t/ha				
Emission Source	**tCO_2e**	**%**	**Per Hectare**	**Per Tonne (seed cotton)**
Fertiliser soil / N_2O	69,939	59.7%	0.521	0.321
Field energy (fuel)	13,829	11.8%	0.103	0.063
Processing energy	10,879	9.3%	0.081	0.050
Residue management	9,666	8.3%	0.072	0.044
Machinery	6,479	5.5%	0.048	0.030
Fertiliser production	4,211	3.6%	0.031	0.019
Pesticide	946	0.8%	0.007	0.004
Irrigation electricity	641	0.5%	0.005	0.003
Transportation	503	0.4%	0.004	0.002
Total	**117,093**	**100%**	**0.872**	**0.537**

The Regenagri-certified cotton portfolio demonstrates significant diversity in emission profiles, reflecting the range of production systems and regional contexts. The global emission intensity of 0.616 tCO_2e per tonne seed cotton (farm-level, preginning) reflects the 2024 farm-gate carbon intensity (seed-cotton basis), with three countries achieving net negative emissions through regenerative practices.

Key strategic opportunities exist for further emission reduction through:

1. Precision nutrient management
2. Processing energy efficiency (particularly in Mexico, Australia)
3. Irrigation efficiency (critical in India and water-stressed regions)
4. Expansion of regenerative practices (demonstrated success in Tajikistan, Côte d'Ivoire, Peru)

The portfolio's strength lies in its diversity—high-yield systems (Brazil) show that productivity and climate performance can be managed together, while systems with verified net SOC removals (Côte d'Ivoire) illustrate the potential contribution of regenerative practices within the 2024 reporting year. A balanced approach addressing regional priorities while scaling successful practices globally has the potential to reduce emissions over the medium term. The magnitude and timeframe of reductions will depend on regional baseline conditions, adoption rates, and management responses. Quantified reduction potentials should be confirmed through scenario modelling and sensitivity analysis.

15 APPENDIX: GLOSSARY OF TERMS

Attributional LCA: Life Cycle Assessment approach that quantifies the environmental impacts directly associated with the production of a product, without modeling consequential market effects.

Carbon Footprint of Product (CFP): Quantification of greenhouse gas emissions associated with a product across its life cycle, expressed as CO_2-equivalents.

Cradle-to-Gate: System boundary that includes all processes from raw material extraction (cradle) to the factory gate where the product leaves the production facility.

Economic Allocation: Method of dividing shared environmental impacts among co-products based on their relative economic value.

Emission Factor: Coefficient that quantifies the amount of greenhouse gas emitted per unit of activity (e.g., kg CO_2e per kg fertiliser applied).

Functional Unit: Quantified performance characteristic of a product system used as a reference unit for LCA calculations.

Global Warming Potential (GWP): Measure of how much a given mass of greenhouse gas contributes to global warming relative to CO_2 over a specified time period (typically 100 years).

Ginning Outturn: Percentage of lint recovered from seed cotton during the ginning process (typically 35-42%).

Hotspot: Life cycle stage or process that contributes significantly to the total environmental impact.

ISO 14040/44: International standards for conducting and reporting Life Cycle Assessments.

Life Cycle Assessment (LCA): Systematic evaluation of the environmental impacts of a product across its entire life cycle, from raw material extraction through end-of-life.

N_2O (Nitrous Oxide): Potent greenhouse gas produced primarily from nitrogen fertiliser application and soil processes.

Regenagri: Certification scheme focused on regenerative agriculture practices and carbon accounting for certified farms.

Scope 1 Emissions: Direct greenhouse gas emissions from sources owned or controlled by the organization (e.g., on-farm field operations).

Scope 2 Emissions: Indirect greenhouse gas emissions from purchased electricity, steam, and heat.

Scope 3 Emissions: Other indirect greenhouse gas emissions from the value chain (e.g., input production, transport, ginning).

Soil Organic Carbon (SOC): Carbon stored in soil organic matter; changes in SOC represent carbon sequestration (negative emissions) or loss (positive emissions).

Contact us

info@regenagri.org
www.regenagri.org