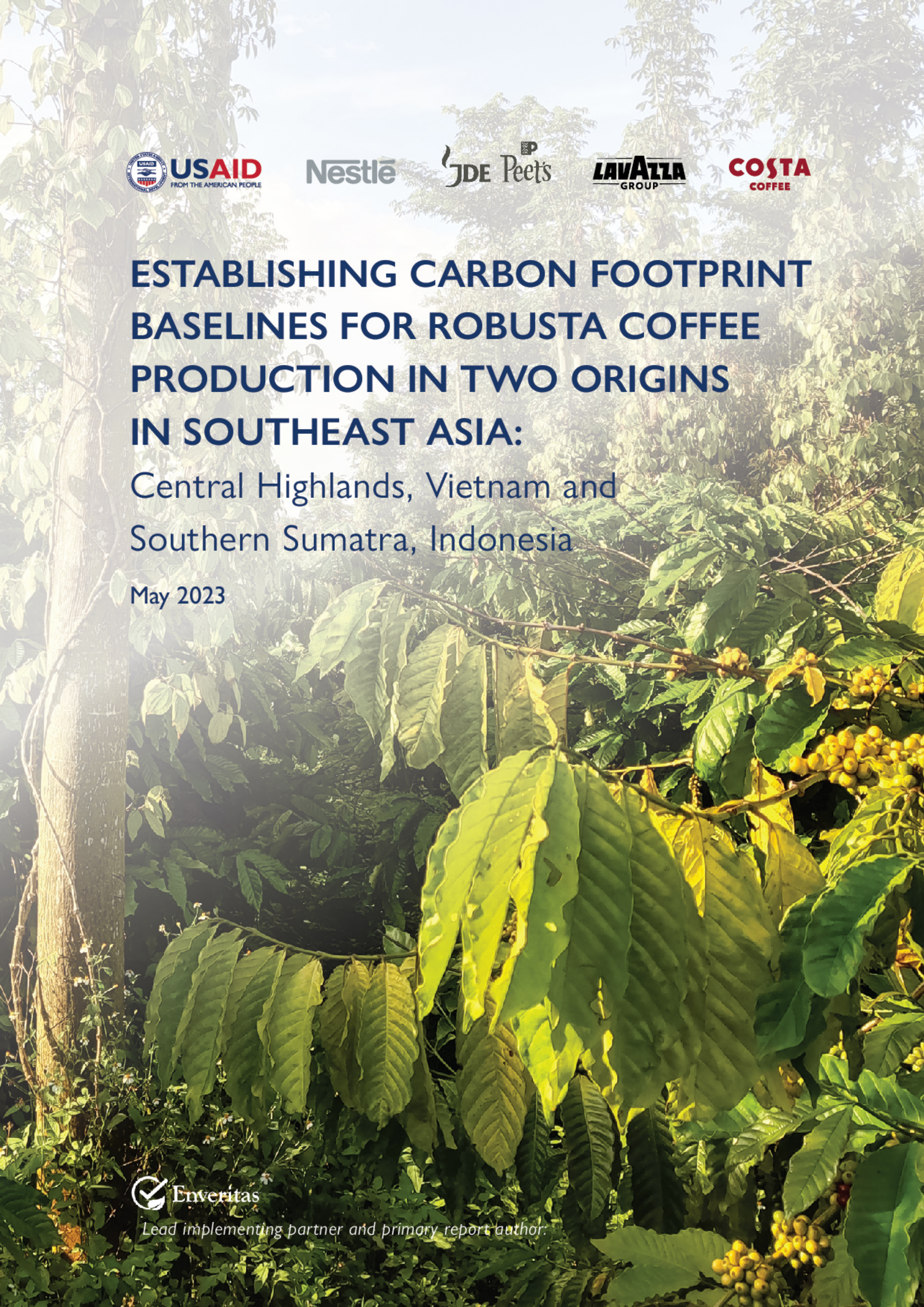

ESTABLISHING CARBON FOOTPRINT BASELINES FOR ROBUSTA COFFEE PRODUCTION IN TWO ORIGINS IN SOUTHEAST ASIA:

Central Highlands, Vietnam and Southern Sumatra, Indonesia

May 2023

Lead implementing partner and primary report author:

Enveritas

FUNDING PARTNERS

USAID FROM THE AMERICAN PEOPLE · Nestlé · JDE Peet's · LAVAZZA GROUP · COSTA COFFEE

LEAD IMPLEMENTING PARTNER

Enveritas

PARTICIPATING SUPPLIER-PARTNERS

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TECHNICAL PARTNERS

cirad · geotree ENVIRONMENTAL MONITORING · sphera · 4C · YARA

DIALOGUE PARTNERS

GLOBAL COFFEE PLATFORM · idh the sustainable trade initiative · RAINFOREST ALLIANCE

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1. Abbreviations and Acronyms

CFA	Cool Farm Alliance
CFT	Cool Farm Tool
CH_4	methane
CO_2e	carbon dioxide equivalent, using conversion factors from the Intergovernmental Panel on Climate Change
EF	emission factor
GAPs	Good Agricultural Practices
GBE	green bean equivalent
GHG	greenhouse gas
ha	hectare
IPCC	Intergovernmental Panel on Climate Change
km	kilometer
LCA	life cycle assessment
LUC	land use change
MoE	margin of error (always calculated at a 95-percent confidence level)
MT	metric ton
N_2O	nitrous oxide
QC	quality control
WASI	Western Highlands Agriculture & Forestry Science Institute
WFLDB	World Food LCA Database

2. Executive Summary

One quarter of global coffee production originates from Vietnam and Indonesia.[1] While both countries produce Arabica and Robusta coffee, Robusta is the predominant type, accounting for 88 percent and 97 percent of the coffee produced in Vietnam and Indonesia during the 2021/22 harvest period, respectively.[2] The major Robusta-producing hubs are the Central Highlands in Vietnam, accounting for 94 percent of national Robusta production,[3] and Southern Sumatra in Indonesia, accounting for approximately 60 percent of the country's total Robusta output.[4]

Coffee farming and post-harvest processing activities emit greenhouse gases (GHGs). Yet, large-scale, pre-competitive initiatives at a sectoral level to establish a carbon footprint are rare. To fill this need, in 2022, a consortium of 25 private sector and technical partners ("the Consortium") have collaborated on an industry-led initiative ("the Initiative") to develop carbon footprint baselines for Robusta coffee production in these two key producing regions. Together, these two globally important origins represent about 20 percent of worldwide coffee production (nearly 2 million tons per year), with an annual trade value of over $4 billion, grown on over 1 million hectares (ha) by as many smallholder farmers. Establishing such baselines is a critical first step in the journey toward Net Zero and an important guidepost to inform collaborative climate action.

With co-investment from USAID Green Invest Asia (implemented by Pact), Nestlé, JDE-Peet's, Lavazza Group, and Costa Coffee, the Initiative included a core group of 11 participating supplier partners: ECOM, Hanns R. Neumann Stiftung, (HRNS) Intimex, Louis Dreyfus Company (LDC), Neumann Kaffee Gruppe (NKG), Olam Food Ingredients (ofi), Sari Makmur, Simexco, Sucafina, Sucden, and Volcafé. Formally launched in March 2022 with lead technical partner Enveritas, a data-driven sustainability non-profit specializing in verification services for the coffee sector, the Initiative's objectives included:

- Establish industry-accepted, statistically sound **carbon footprint baselines** for Robusta coffee production for the two sourcing regions.
- Create a **standardized framework** and mechanism for regular data collection, sharing, and analysis to facilitate annual impact measurement, reporting, and verification for the sector.
- **Increase the capacity** of supplier partners to understand, document, and report on carbon emissions and sequestration in coffee systems.

Enveritas developed a farmer survey plan for the two landscapes, designing a standardized questionnaire tailored to collect inputs required for the Cool Farm Tool, which served as the primary framework for the carbon footprint estimations.

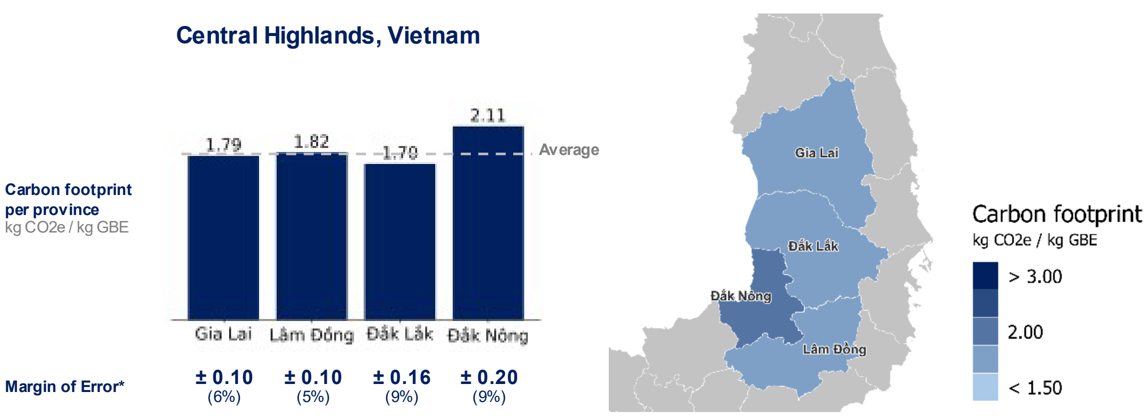
Enveritas trained more than 100 agronomists and field staff, made available to the Initiative as an in-kind contribution from participating supplier partners to survey 4,920 farmers (2,703 in Vietnam and 2,217 in Indonesia). Sample numbers were determined with the objective of obtaining results that are representative at the origin and province levels, weighted by coffee production volumes. The sampling strategy was designed to ensure a confidence interval of max +/– 10 percent margin of error (MoE) at a 95-percent confidence level,

[1] Vietnam is the world's second-largest producer and Indonesia is the fourth-largest producer. See USDA Foreign Agricultural Service (2022) p6.
[2] Ibid.
[3] General Statistics Office (2021)
[4] Ibid. About 75% of Robusta produced in Indonesia comes from Southern Sumatra and Java, with the bulk of production concentrated in Southern Sumatra.

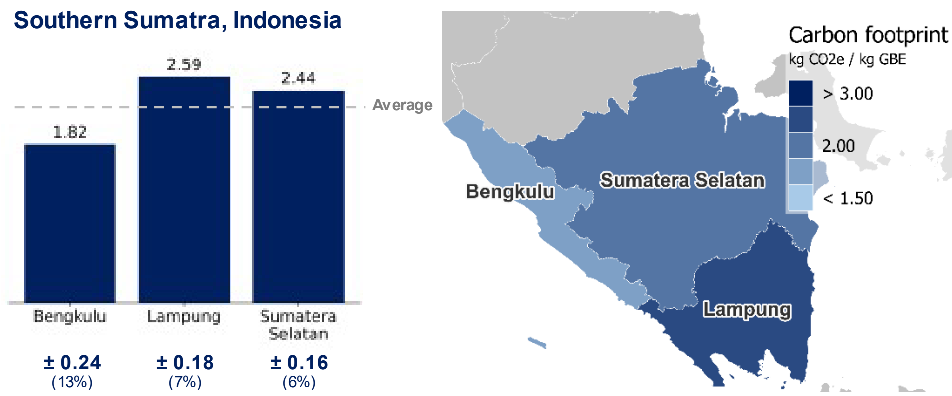
and to maintain a buffer of 5 percent samples to allow for invalid surveys. Enveritas then collated, cleaned, and analyzed the gathered data with the Cool Farm Tool to generate the following carbon footprint estimates.

	Central Highlands, Vietnam	Southern Sumatra, Indonesia
	1.83 kg CO2e / kg GBE	**2.38** kg CO2e / kg GBE
Margin of Error*:	**± 0.07** (4%)	**± 0.11** (4%)
Number of observations:	**2,526** (target of 2,600)	**2,023** (target of 1,950)

The results indicated average farm-level emissions of 1.83 kg CO_2e per kg green bean equivalent (GBE) produced in the Central Highlands of Vietnam. At the province level, emissions were estimated at 1.70 kg CO_2e/kg GBE in Dak Lak, 1.79 CO_2e/kg GBE in Gia Lai, 1.82 kg CO_2e/kg GBE in Lam Dong, and 2.11 kg CO_2e/kg GBE in Dak Nong. Only Dak Nong has a level of emissions that is statistically different from the country average. The variation is mostly explained by differences in productivity between provinces, as coffee farming practices and processing methods are quite similar across all four provinces. Coffee farmers in Dak Nong experience yields on average 20 percent lower than farmers in other provinces, even though they use similar amounts of inputs. This results in higher emission intensity per kg GBE produced. **Fertilizer production and use, energy use for irrigation, and residue management are the three major sources of emissions in this origin**, contributing about 94 percent of the total. Fertilizer production and use alone is responsible for 74 percent of total emissions.



Average farm-level emissions are somewhat higher in Southern Sumatra, at 2.38 kg CO_2e/kg GBE. Again, there is variation among the three provinces, with emission estimates ranging from 1.82 kg CO_2e/kg GBE in Bengkulu to 2.44 kg CO_2e/kg GBE in Sumatra Selatan and 2.59 kg CO_2e/kg GBE in Lampung. In Indonesia, this variability is mostly driven by emissions arising from transportation and fertilizer usage. Coffee farmers in Bengkulu transport their produce and/or get their inputs from relatively shorter distances than farmers in Lampung and Sumatra Selatan and use over 40 percent less fertilizer than the national average, without a corresponding drop in productivity. Fertilizer production and use, transportation, and residue management are the three largest sources of emissions, contributing about 93 percent of the total footprint. Fertilizer production and use is responsible for the greatest share of the overall carbon footprint, at 66 percent. Mechanical irrigation is not a common practice among coffee farmers in Southern Sumatra, so energy use for irrigation is not a major contributor to emissions in this origin.



While fertilizer production and its use are the primary source of emissions in both origins, farmers in the Central Highlands apply fertilizers in significantly larger quantities (an average of 1,678 kg/ha) compared to farmers in Southern Sumatra (an average of 179 kg/ha). Significantly higher yields in the Central Highlands (2,947 kg GBE/ha vs. 705 kg GBE/ha in Southern Sumatra) counterbalance the emissions from fertilizer use, leading to lower per kg GBE emissions in the Central Highlands.

In addition to the statistical sampling error expressed as the margin of error above, there are limitations in the underlying models used by the Cool Farm Tool that result in uncertainty about the results. These include:

1. **Difficulty properly classifying the residue management methods observed on the farms.** The CFT does not provide an option to select multiple management methods. There are substantial differences between each method’s emission factors, resulting in large uncertainty in the residue management emissions figures.
2. **Difficulty identifying where fertilizers were produced**. The CFT provides emission factors for fertilizer production based on where the fertilizer was manufactured, but farmers were often unable to accurately identify the manufacturing region. Assumptions made in such situations may distort the reported fertilizer-related emissions figures in either direction, depending on the actual producing country.
3. **Incomplete transportation options**. The CFT does not include motorbikes as an option for transportation, so the emission factor of light goods vehicles was used as a proxy. This resulted in increased transportation emissions values, particularly in Southern Sumatra where a majority of farmers use motorbikes for transporting inputs and coffee.
4. **Potential underestimation of land use change (LUC) emissions derived from farmer survey data**. The variability of LUC emissions over complex landscapes was quantified from farmer survey data and pointed

toward a low overall impact, except in Bengkulu, Southern Sumatra, where it accounted for one-third of the province-level variability. However, farmers might have underreported deforestation events, leading to a bias toward lower emissions. This bias could be partly corrected with the use of remote-sensing techniques to assess deforestation from a more objective perspective.

A conservative approach was followed to tackle the uncertainty related to residue management and transportation, which inflated overall results. On the other hand, a possible underreporting of deforestation events by surveyed farmers may have led to an underestimate of the related footprint. The impact of uncertainty regarding fertilizer origins was limited to the Central Highlands, where it is estimated that this issue may have led to total emissions being underestimated by up to 4 percent.

In addition to the uncertainties associated with the CFT, there were potential issues with regard to data collection. Enveritas' pilot assessments indicated that the average survey length should be approximately 45 minutes. About 6–7 percent of the farmer interviews conducted in each origin were completed in less than 15 minutes, which is concerningly low and may indicate a rushed, incomplete, or poorly completed survey. Thus, all surveys completed in under 15 minutes were removed from the dataset. There was also some bias observed toward larger and certified farms, probably due to these farms being more accessible.

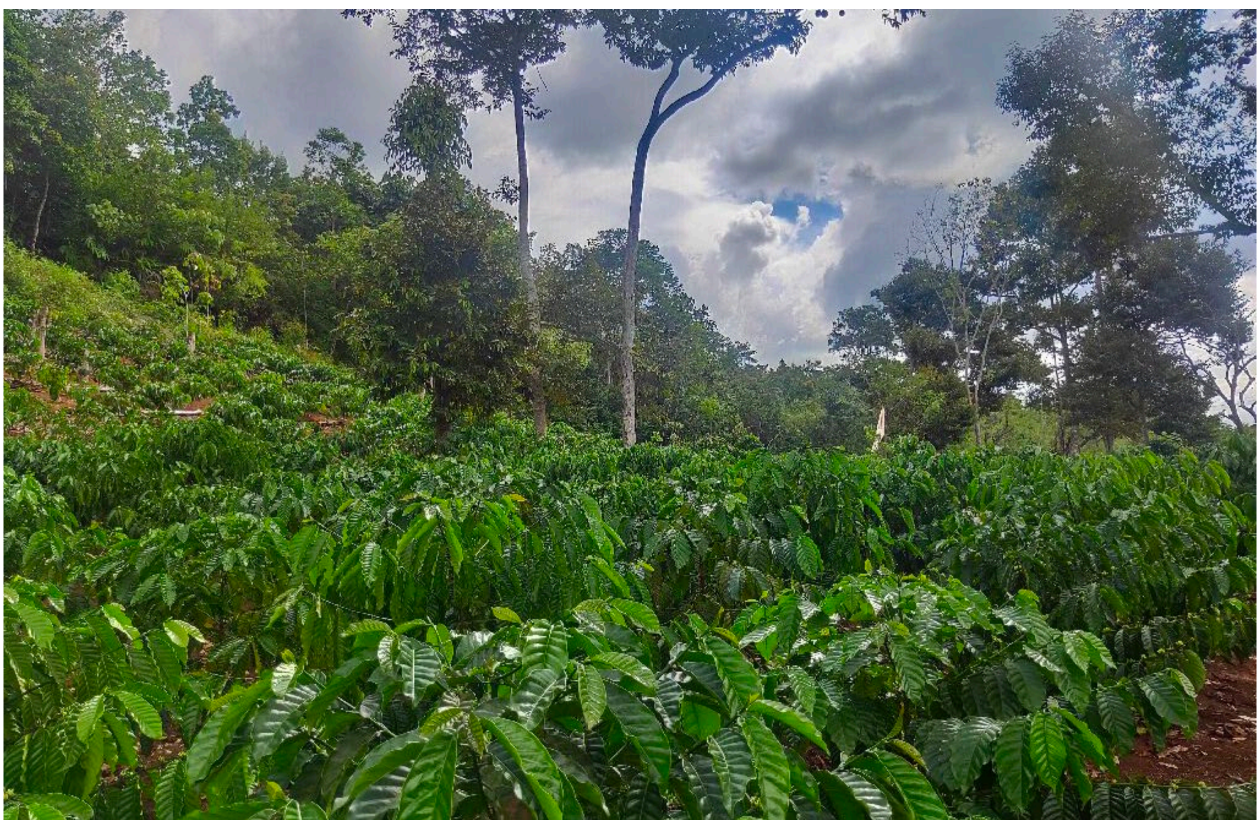
The representativeness of the emission estimates based on a one-year baseline may also be debated, for reasons such as climate variability, geopolitics, and the lingering effects of the Covid-19 pandemic. Best practice recommends collecting data for a few or several seasons to establish a comprehensive baseline that accounts for seasonal variability in weather patterns, yield, and other variables that might affect the carbon footprint. Estimating footprints over a period of multiple years is recommended to establish a solid baseline that accounts for inter-year variability in key factors such as climate, yields, fertilizer usage, revenue from co-products, and coffee prices. The present analysis also indicates that a solid baseline can be established without including all of the Cool Farm Tool's components: data on fertilizer production and use, co-products, residue management, irrigation, and transportation is sufficient to cover more than 90 percent pf farm-level CO_2e emissions in both origins. Scaling back the survey to include only these indicators would streamline and speed up the process of collecting, cleaning, and analyzing the data.

To help benchmark and triangulate results, additional technical partners analyzed the same datasets using other carbon footprinting models and tools, including Sphera with their LeanAg model, 4C and Meo Carbon Solutions with their 4C Carbon Footprint Add-On, and Lavazza Group using the SimaPro life cycle assessment (LCA) model. CIRAD, the French Agricultural Research Centre for International Development, provided technical inputs on the design and results. Geotree worked with the datasets to enhance estimates of carbon sequestration in coffee farms and soils, and Yara International contributed technical inputs on fertilizer emissions and management. IDH (The Sustainable Trade Initiative), the Global Coffee Platform (GCP), and Rainforest Alliance participated as dialogue partners. In addition, GCP and USAID Green Invest Asia hosted six Sustainable Coffee Dialogues to engage a wider audience on these topics, reaching a total of over 900 participants representing 300 organizations in the coffee sector.

Estimating the carbon footprint of agricultural commodities is highly technical and new to most industries, with multiple tools, calculators, and approaches available. As many companies and organizations are just beginning to mitigate their climate impacts, GIA (Green Invest Asia) needed to increase their capacity to report and document their climate-smart interventions, while aligning the sector around standardized approaches in this area. Establishing a robust carbon footprint baseline is a critical first step to honoring climate commitments, as it provides an important starting point and reference for monitoring improvements. This is key for agricultural supply chains where 70–90 percent of emissions typically come from the commodity's production at the farm level (Scope 3).

Identifying and quantifying the main emission sources associated with Robusta coffee production (fertilizer production and use, energy for irrigation, residue management, land use change, etc.) provides a benchmark for comparison across origins and within specific supply chains, helping to inform low-emission strategies for land use management. Improved metrics enable targeted investments and interventions to address the main emissions sources and monitor change over time. The Initiative aims to help move the sector toward a low-carbon future, while continually improving farmer livelihoods, productivity, and nature conservation.

While informing and guiding a Net Zero vision for the Robusta coffee sector in Vietnam and Indonesia, the Consortium hopes this model of corporate pre-competitive collaboration and co-investment can accelerate climate action to transform this and other coffee origins, along with other agricultural supply chains.



3. Background

Vietnam and Indonesia are among the top coffee-producing countries in the world. Coffee is an important crop in both countries, contributing to the livelihoods of about 1.3 million smallholder farmers in Indonesia and 600,000 in Vietnam,[5] as well as hundreds of thousands more workers, traders, and processors. Given the significance of coffee farming in these countries and the role they play in the global coffee trade, it is important to future-proof the sector for impending sustainability challenges. Climate change poses a significant threat to coffee farming in Southeast Asia. Establishing a robust carbon footprint baseline estimate for farm-level emissions is a good place to start, as reliable estimates are currently not available.

The present initiative was divided into five phases (planning, design, data collection, analysis, and reporting) and seven activities with clear timelines, requiring different levels of effort from participating supplier partners (see Figure 1).

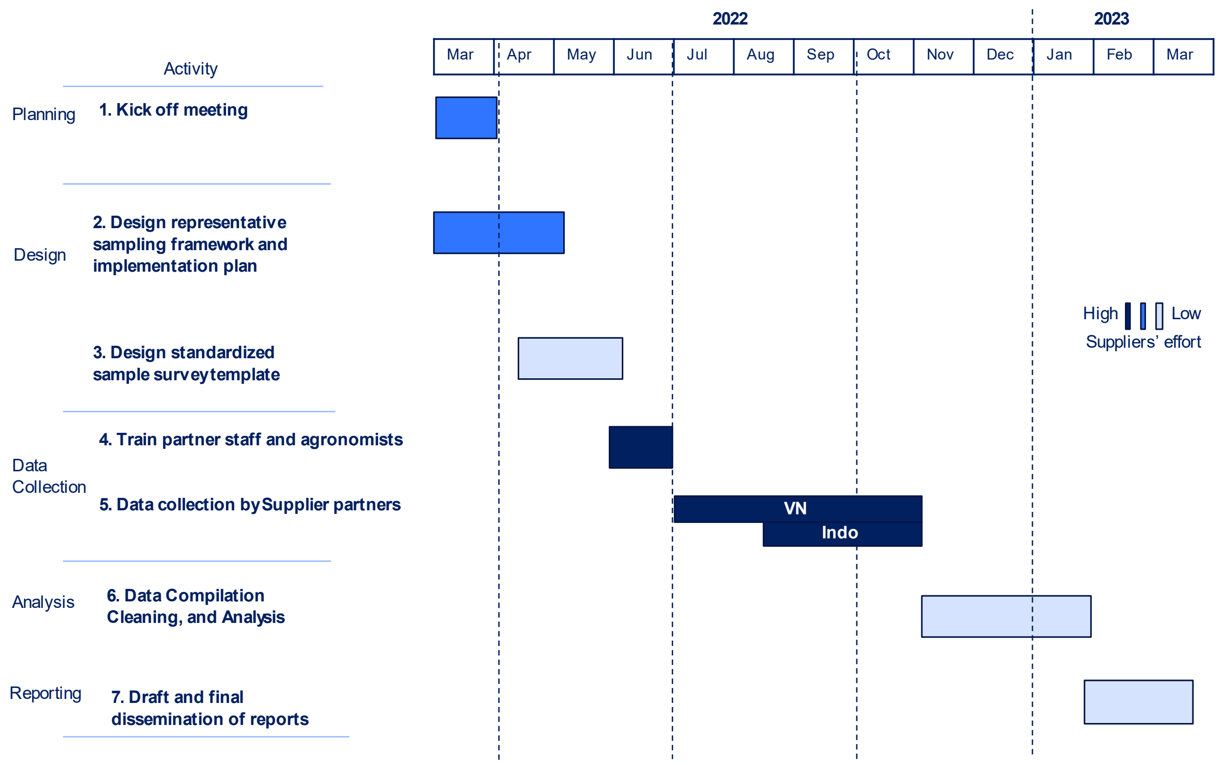


Figure 1: Overall timeline of the initiative

[5] Enveritas (2020)

A brief description of each of the activities is provided below:

1. **Kick-off meeting:** Initial meeting with lead technical partner Enveritas and participating partners to introduce and discuss the initiative, including the strategic approach and methodology, details of activities and processes, timelines, roles and expectations, and confirmation of geographic boundaries.
2. **Design representative sampling framework and implementation plan:** Enveritas developed a sampling approach to guarantee representative and statistically significant results at the country level. Statistical significance was defined as a maximum 10 percent margi of error (MoE) at a 95-percent confidence level.
3. **Design standardized sample survey template:** Enveritas drafted a survey questionnaire that covered all the typical inputs required for the Cool Farm Tool, as well as other data points of interest identified by partners in initial meetings. The survey questions were drafted in English and translated into Vietnamese and Bahasa Indonesia. The survey was deployed on ODK Collect without requiring an internet connection or mobile carrier service at the time of data collection.
4. **Train partner staff and agronomists:** Enveritas developed training materials in both English and local languages to prepare enumerators for conducting the surveys. Training was offered in a self-service format through a platform called Genial.ly. Enveritas staff were available during weekly virtual office hours throughout the data collection period to assist with queries and any challenges encountered by enumerators.
5. **Data collection by supplier partners:** A total of 11 participating supplier partners dispatched enumerators (over 100 in all) to collect data through farmer interviews and farm visits at randomized locations.
6. **Data compilation, cleaning, and analysis:** Enveritas cleaned the survey data and passed it through a quality control process. The cleaned data was compiled and shared for the use of participating partners and input into the CFT to establish carbon footprint baselines for the two origins.
7. **Draft and final dissemination of reports:** Enveritas prepared reports that summarized the overall project activities, sampling and analysis methodologies, and results for each of the two coffee origins.

4. Methodology (Summary)

4.1 Scope

4.1.1 Geographical boundaries

Robusta coffee is grown in different areas of Vietnam and Indonesia. The geographic scope of this project focused on the following two origins that produce the majority of the two countries' Robusta output:

1. The Central Highlands in Vietnam, including approximately 609,227 ha[6] across the four provinces of Dak Lak, Dak Nong, Gia Lai, and Lam Dong.
2. Southern Sumatra in Indonesia, including approximately 350,000 ha[7] across the three provinces of Bengkulu, Lampung, and Sumatra Selatan.

4.1.2 Operational boundaries

The life cycle emissions from coffee includes emissions from inputs, coffee farming, processing, transportation, storage, sale, use, and disposal. Defining the operational scope for emission estimations is important. The operational boundary of this carbon footprint estimate is at a farm level, and excluded emissions related to coffee farming activities outside farmers' control . Elements taken into consideration were selected in alignment with the Cool Farm Tool components listed below.

Farm characteristics	• Country • Climate • Temperatures	**Direct energy**	• Category • Source • Usage (quantity)
Crop characteristics	• Production volume • Area • Soil organic matter • Residue	**Land management**	• Type of land changed • Years ago • Area of expansion • Forest: ecological zone • Forest: age • Cover crops: years change • Cover crops: area of expansion / clearing
Pesticides & herbicides	• Type • % active ingredient • Application rate		
Irrigation	• Method • Allocation • Water volume • Power source	**Transport**	• Mode • Weight carried • Distance
Fertilizers	• Type • Origin • Application rate • Application method • Inhibitor	**Tree biomass**	• Intercropped tree type • Shade tree type • Density last year • Size last year • Size this year • Change in number of trees
Wastewater	• Production (quantity) • Oxygen demand • Treatment type	**Co-products**	• For intercropped trees, food crops, coffee husks: % of green coffee value

[6] General Statistics Office (2021)
[7] Statistics Indonesia (2022)

4.1.3 Collected indicators

Indicators collected were primarily based on two sets of criteria: those required to establish carbon footprint baselines using the Cool Farm Tool, and additional topics of importance identified by the Core Committee, comprised of representatives of the co-funding partners USAID Green Invest Asia, Nestle, JDE-Peet's, Lavazza Group, and Costa Coffee. A complete list of collected indicators with detailed descriptions is provided in Appendix 9.5. A summary of the main groupings and selected indicators follows:

- **Chemicals:** Indicators related to chemical application, such as names of chemicals applied, rounds of chemical application, and volumes of chemicals applied.
- **Intercrops:** Indicators related to both food trees and non-food trees intercropped with coffee trees, such as species, count, age, and circumference of the trees; any new planting, cutting, or pruning; as well as income from the sale of products derived from the intercropped species.
- **Inbound and outbound vehicles:** Indicators related to vehicles used by farmers to transport things such as inputs or equipment to the farm or to move goods such as farm produce or byproducts from the farm to destinations such as nearby markets. These include indicators such as types of vehicles used, fuel used, and distance traveled.
- **Fertilizers:** Indicators related to both organic and inorganic fertilizers, including the volumes applied and number of rounds of application, type and composition of fertilizers, and manufacturing country or region.
- **Irrigation (Vietnam only[8]):** Indicators related to irrigation, such as number of rounds, quantity of water used, type of irrigation equipment and system, and power source.
- **Others:** Other indicators required to segment geographies and define archetypes, such as GPS locations of the farms, certification status, farmers' challenges, climate adaptation, and age of the farmers.

4.2 Sampling Framework

4.2.1 Sampling approach

The overall objective of the sampling strategy was to establish carbon footprint estimations that were representative at the origin and province levels. As a first step, coffee production volumes at the provincial level (or at district level, where available) were taken from government statistics. Using the coffee production numbers as sampling weights, minimum sample sizes were then determined based on the following assumptions:

- Confidence interval: max +/– 10 percent with a 95 percent confidence level
- Level of uncertainty (*p*): 50 percent (max to guarantee representativeness even for highly variable indicators)
- Buffer (to account for non-valid surveys): 5 percent

For more details, see Appendix 9.1 ("Defining number of samples – technical document" and "Sample calculation workbook final).

4.2.2 Sample allocation

A bottom-up approach was used for allocating samples across the 11 supplier partners. Supplier partners were provided with the target number of samples for each province and asked to propose which areas they wanted to cover and the number of samples in each area they could collect. Through an iterative process, collectively the suppliers agreed to meet 87.5 percent and 93 percent of the sample requirements in the Central Highlands and Southern Sumatra, respectively. The remaining samples were collected by two external vendors selected through a competitive tender process (TMT Consulting in Vietnam and AKVO in Indonesia).

[8] Although irrigation-related indicators were captured in both origins, Southern Sumatra had a negligible share of farmers who reported irrigating their coffee, mostly because rainwater is more abundant in this origin; therefore, the indicators were only reported for the Central Highlands.

4.2.3 Randomization strategy

The main goal of the farm randomization strategy was to ensure sampled coffee farms were randomly selected within each district. Samples were weighted at the district level, but not at the province level (each province had the same number of samples).

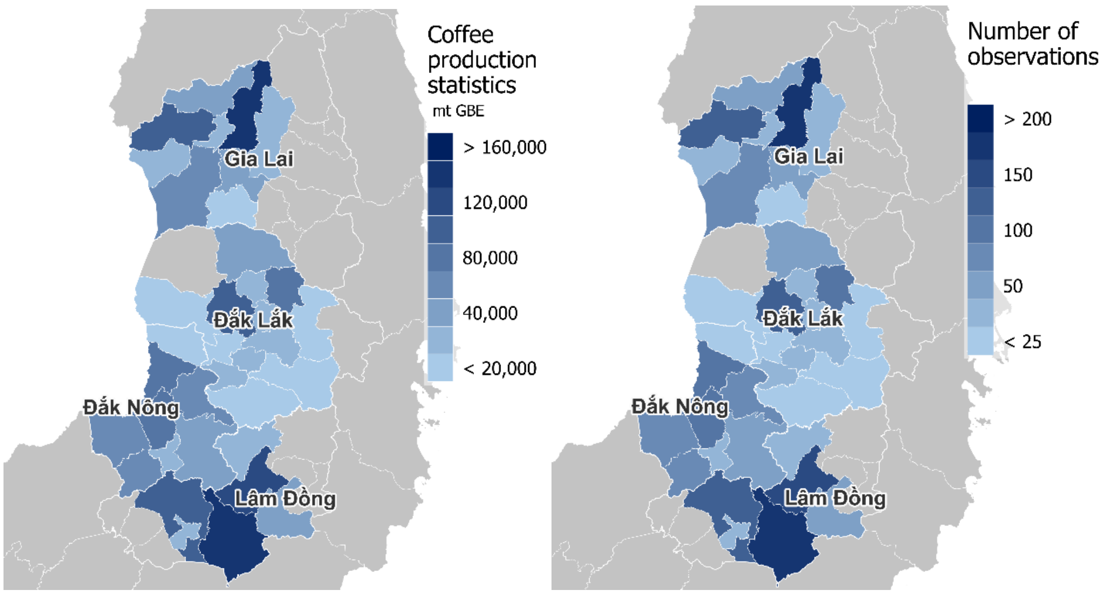


Figure 2: Coffee production statistics and number of observations per district, Central Highlands

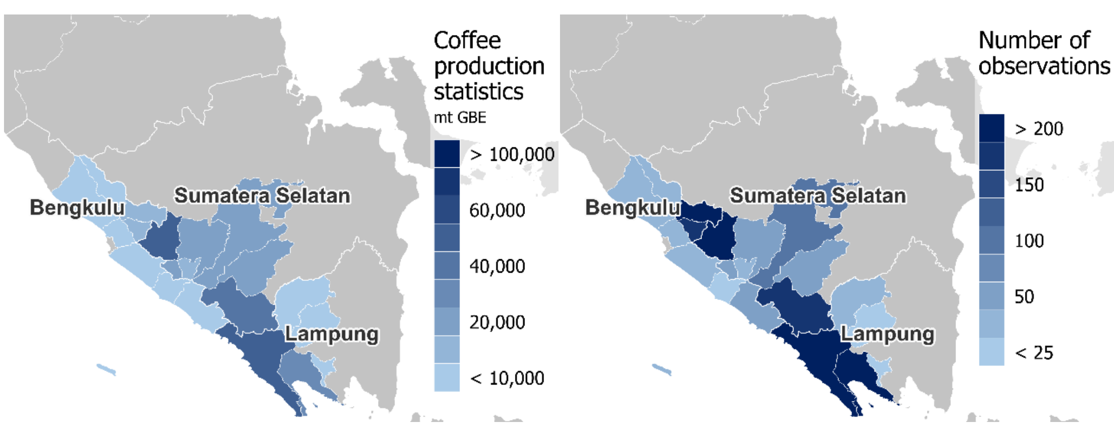


Figure 3: Coffee production statistics and number of observations per district, Southern Sumatra

The randomization process started with identifying the most granular administrative data available regarding coffee production. From publicly available government statistics,[9] Enveritas retrieved district-level coffee production data for the Central Highlands and subdistrict-level (*kecamatan*) data for Southern Sumatra. Within each identified administrative boundary, the number of samples required were converted into pins (geo-randomized locations where an enumerator could conduct up to three surveys within a 10 km radius).

The pins were then dropped on coffee farming areas using QGIS software. Each pin underwent two rounds of manual reviews to ensure it was situated in a coffee farming area, to avoid enumerators traveling to locations where they would not be able to conduct surveys. Extra pins were generated to cover deficits that might arise due to non-respondents or accessibility issues. Enumerators visited each of the assigned pin locations and conducted up to three surveys, following randomization protocols (see Appendix 9.1 – "Randomization strategy – technical document").

4.3 Farmer Survey Questionnaire

4.3.1 Survey design process

The main objective of the survey design process was to build a questionnaire that was focused, simple, and short, yet comprehensive enough to generate inputs required by the CFT. Partners recommended a maximum survey duration of one hour. With this goal in mind, Everitas designed an initial version of the survey questionnaire focusing solely on incorporating inputs required for the CFT. After receiving participating partners' input, some questions on other topics of interest were added. The draft questionnaire was then circulated to partners and technical experts for feedback. About two hundred comments were received and evaluated, and updates were made where applicable.

The survey questions and answer choices were designed using simple, easily understandable language, as enumerators with varying levels of experience from multiple supplier partners were involved in data collection. The surveys were initially written in English and then translated into local languages (Vietnamese and Bahasa Indonesia), with enumerators given clear guidance on the different types of questions and answers (see Table 1).

[9] Provincial Statistical Yearbook 2021 data for Dak Lak, Gia Lai, Lam Dong, and Dak Nong and Kabupaten in Figures 2020 data for Bengkulu, Lampung, and Sumatra Selatan. District-level data for Southern Sumatra was available from Ministry of Agriculture (2021).

Question Answer

Type	Description	Example
Ask Farmer	Enum reads the question as it was written to the farmer	**ASK FARMER:** Do you grow Arabica or Robusta coffee?
Tell Farmer	Enum must say this out loud to the farmer	**TELL FARMER:** The questions I am going to ask you refer to the last harvest year, spanning from [VN: January 2021 to December 2021 / ID: September 2021 to August 2022].
Report	There are some questions in the survey that will ask enum to elaborate on what the farmer said. This requires enum to type in the answer from the farmer	***Please work with the farmer to estimate how many coffee trees they have in total.*** **REPORT:** What is the estimated total number of coffee trees?
Observe	Enum needs to walk around many parts of the farm to observe certain features. Enum does their best to observe as many as possible.	**OBSERVE:** What does the canopy of shade trees on the plot look like?
Single Choice	Enum can select only one answer choice.	**Observe** Is the flat or sloped? A) Sloped B) B)Flat
Multiple Choice	Enum can select more than one answer – Enum selects all answers that apply.	**Ask farmer** In the last harvest year, in what forms have you sold your coffee on this plot? A) Cherry B) Dry Cherry C) Wet parchment D) Dry Parchment E) Green coffee
Text	Enum should answer in a string (alphabetical)	**Ask farmer** What is your name?_____
Decimal Number	Enum should answer in a decimal number format	**REPORT:** Randomly select 3 trees of [tree_species_1] and measure and report (in centimeters) the average diameter of the tree at breast height.
Whole Number	Enum should answer in a whole number format	**ASK FARMER:** What is the most common coffee tree age on your farms?
GPS Recording	Enum should record the GPS location of the farm	**CAPTURE** GPS coordinates

Table 1: Guidance on questionnaire provided to enumerators

4.3.2 Survey implementation

The survey questionnaire was finalized after multiple iterations based on partners' feedback, after which implementation details were discussed. Most suppliers preferred paperless surveys to avoid manual data entry and quality checking. Based on practicality and their experience using these tools, participating partners nominated survey applications including Google Forms, ODK Collect, Qualtrics, and SurveyMonkey.

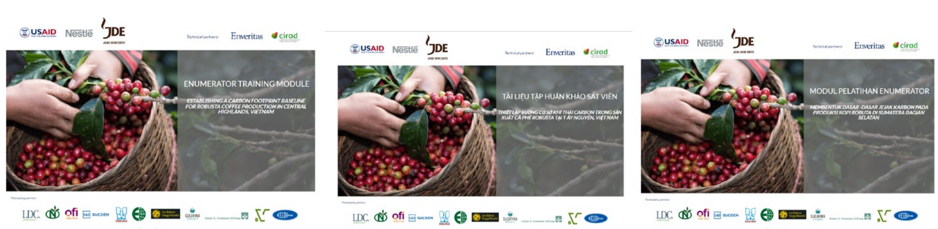
All proposed tools were evaluated, and the choice was made to use ODK Collect. The questionnaire was converted from a spreadsheet to XML format and hosted on a KoboToolbox server. The server was linked to ODK Collect, which enumerators were able to download to their phones from any Android app store; collected data were warehoused on the server. A username and password were generated for each enumerator, providing access to pin locations and training modules.

4.4 Training

Training materials were offered in English, Vietnamese and Bahasa Indonesian. Materials were designed to help suppliers and enumerators understand some of the basics of carbon footprint calculation, and to equip them with the knowledge required to perform the survey. Before beginning data collection, enumerators were required to complete an interactive training session on a platform called Genial.ly, comprising the following modules:

- Module 1: Understanding greenhouse gases
- Module 2: Navigating to GPS locations, randomization, and criteria for interviewing respondents
- Module 3: What is ODK Collect and how do I use it?
- Module 4: How to introduce yourself to a farmer and behavioral expectations
- Module 5: Understanding common elements of the questionnaire
- Module 6: Farm characteristics & land use change
- Module 7: Production and sales
- Module 8: Farm management
- Module 9: Processing
- Module 10: Transportation
- Module 11: Household characteristics
- Test Survey
- Quiz

On average, completing the self-service training session (including the quiz and test survey) took around five hours. The coordinator responsible for managing the enumerators ensured only the enumerators who had successfully completed the training proceeded to data collection.



In addition to the online training, virtual office hours were provided with in-country experts from Enveritas three hours every week during the training and data collection phases. During these office hours, members from partner organizations could log in and ask clarifying queries about any challenges they faced with the training modules and the survey process.

Training materials in all languages are provided in Appendix 9.1 – "Build a training module for enumerators".

4.5 Data Collection

4.5.1 Schedule

The data collection phase ran from July 2022 through October 2022 in Vietnam, and from August 2022 through November 2022 in Indonesia. Based on partners' inputs, a single harvest season/year was selected for assessment: the 2021 harvest season for Vietnam (peak harvest Dec. 2021) and the 2021/22 season for Indonesia (peak harvest Aug. 2022).

Country	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Total**
Vietnam	72	1,609	592	430	0	**2,703**
Indonesia	1	987	1,125	100	4	**2,217**
Total	73	2,596	1,717	530	4	**4,920**

Table 2: Number of surveys conducted per month in both origins

4.5.2 Fieldwork teams and management

Data collection was performed by 113 enumerators who visited farms and conducted in-person surveys: 48 in Indonesia from eight partners and 65 in Vietnam from ten partners. Each partner organization assigned a Field Coordinator and/or Project Manager to manage the enumerator teams, and act as a conduit between enumerators and Enveritas.

4.5.2.1 QC process and communication

All surveys submitted by enumerators went through a quality control (QC) process conducted by Enveritas and were checked against qualitative and quantitative thresholds. The main objectives of QC were as follows:

- Verify the progress of the partners on a weekly basis.
- Align the teams on the content of the survey and the methodology of operations (toward the beginning of verification).
- Review quantitative data.
- Develop qualitative context behind the quantitative data.

Surveys flagged for quality checks were compiled on a weekly basis in a QC document and shared with the Field Coordinators for discussion with their respective enumerator teams.

Field Coordinators collected feedback from the enumerators and included this in the QC document, enabling further evaluation and, where necessary, updated surveys flagged during the data cleaning process. Frequent reasons for flagging a survey for a quality check included short survey lengths, distance between pins and the farmers' houses, and typos in responses to questions requiring a decimal or whole number as a reply. Urgent questions from field teams were addressed via phone or email, and partners and enumerators could log in during weekly office hours and ask clarifying questions on survey questionnaires or processes.

4.5.2.2 Obstacles and challenges in data collection

Frequent problems during data collection included challenging weather conditions (particularly in Vietnam, where heavy rains were experienced during the data collection period) and enumerator attrition or change. Enumerators also experienced some technical challenges, such as difficulty pinning locations and locating nearby farms, and accessing the KoboToolbox server.

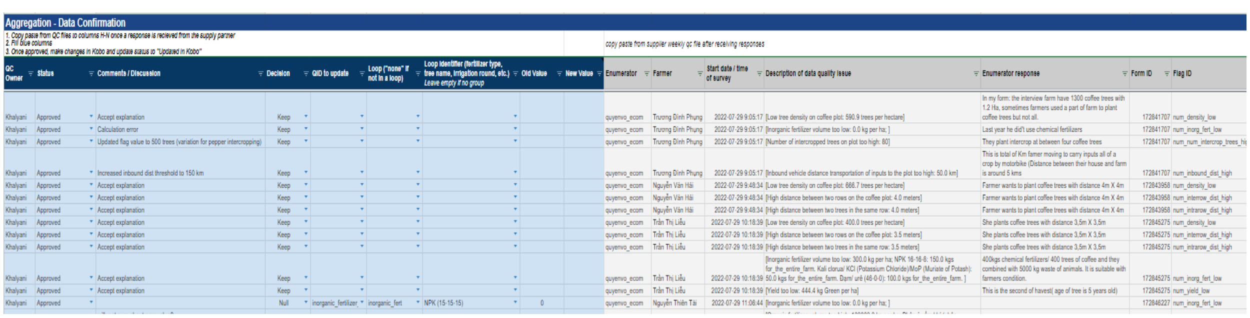
Although in some districts fewer than the target number of surveys were conducted, in others more than the target number were completed. This did not lead to any imbalance in the results as samples were reweighted based on the districts' production volumes.

4.6 Data Cleaning and Analysis

4.6.1 The data cleaning process

While the QC process ensured consistent standards and specifications for the survey data, data cleaning by Enveritas was where decisions were made on the feedback provided by enumerators on flagged values. There were two sub-steps in the data cleaning process.

First, all flagged values and feedback collected from enumerators during the QC process were aggregated into a spreadsheet, and based on the enumerators' comments, a decision was made on whether to update, keep, or replace each flagged value with a null value. To ensure optimal decision making, there were always two reviewers for each flagged value. Once the decision had been made and approved by the second reviewer, the data was updated directly in the KoboToolbox database.



Aggregation - Data Confirmation

1. Copy paste from QC files to columns H-N once a response is recieved from the supply partner
2. Fill blue columns
3. Once approved, make changes in Kobo and update status to "Updated in Kobo"

copy paste from supplier weekly qc file after receiving responses

QC Owner	Status	Comments / Discussion	Decision	QID to update	Loop ("none" if not in a loop)	Loop Identifier (fertilizer type, tree name, irrigation round, etc.) *Leave empty if no group*	Old Value	New Value	Enumerator	Farmer	Start date / time of survey	Description of data quality issue	Enumerator response	Form ID	Flag ID
Khalyani	Approved	Accept explanation	Keep						quyenvo_ecom	Trương Đình Phụng	2022-07-29 9:05:17	[Low tree density on coffee plot: 590.9 trees per hectare]	In my form: the interview farm have 1300 coffee trees with 1.2 Ha, sometimes farmers used a part of farm to plant coffee trees but not all.	172841707	num_density_low
Khalyani	Approved	Calculation error	Keep						quyenvo_ecom	Trương Đình Phụng	2022-07-29 9:05:17	[Inorganic fertilizer volume too low: 0.0 kg per ha;]	Last year he did't use chemical fertilizers	172841707	num_inorg_fert_low
Khalyani	Approved	Updated flag value to 500 trees (variation for pepper intercropping)	Keep						quyenvo_ecom	Trương Đình Phụng	2022-07-29 9:05:17	[Number of intercropped trees on plot too high: 80]	They plant intercrop at between four coffee trees	172841707	num_num_intercrop_trees_hi
Khalyani	Approved	Increased inbound dist threshold to 150 km	Keep						quyenvo_ecom	Trương Đình Phụng	2022-07-29 9:05:17	[Inbound vehicle distance transportation of inputs to the plot too high: 50.0 km]	This is total of Km famer moving to carry inputs all of a crop by motorbike (Distance between their house and farm is around 5 kms	172841707	num_inbound_dist_high
Khalyani	Approved	Accept explanation	Keep						quyenvo_ecom	Nguyễn Văn Hải	2022-07-29 9:48:34	[Low tree density on coffee plot: 666.7 trees per hectare]	Farmer wants to plant coffee trees with distance 4m X 4m	172843958	num_density_low
Khalyani	Approved	Accept explanation	Keep						quyenvo_ecom	Nguyễn Văn Hải	2022-07-29 9:48:34	[High distance between two rows on the coffee plot: 4.0 meters]	Farmer wants to plant coffee trees with distance 4m X 4m	172843958	num_interrow_dist_high
Khalyani	Approved	Accept explanation	Keep						quyenvo_ecom	Nguyễn Văn Hải	2022-07-29 9:48:34	[High distance between two trees in the same row: 4.0 meters]	Farmer wants to plant coffee trees with distance 4m X 4m	172843958	num_intrarow_dist_high
Khalyani	Approved	Accept explanation	Keep						quyenvo_ecom	Trần Thị Liễu	2022-07-29 10:18:39	[Low tree density on coffee plot: 400.0 trees per hectare]	She plants coffee trees with distance 3,5m X 3,5m	172845275	num_density_low
Khalyani	Approved	Accept explanation	Keep						quyenvo_ecom	Trần Thị Liễu	2022-07-29 10:18:39	[High distance between two rows on the coffee plot: 3.5 meters]	She plants coffee trees with distance 3,5m X 3,5m	172845275	num_interrow_dist_high
Khalyani	Approved	Accept explanation	Keep						quyenvo_ecom	Trần Thị Liễu	2022-07-29 10:18:39	[High distance between two trees in the same row: 3.5 meters]	She plants coffee trees with distance 3,5m X 3,5m	172845275	num_intrarow_dist_high
Khalyani	Approved	Accept explanation	Keep						quyenvo_ecom	Trần Thị Liễu	2022-07-29 10:18:39	[Inorganic fertilizer volume too low: 300.0 kg per ha; NPK 16-16-8: 150.0 kgs for_the_entire_farm. Kali clorua/ KCl (Potassium Chloride)/MoP (Muriate of Potash): 50.0 kgs for_the_entire_farm. Đạm/ urê (46-0-0): 100.0 kgs for_the_entire_farm.]	400kgs chemical fertilizers/ 400 trees of coffee and they combined with 5000 kg waste of animals. It is suitable with farmers condition.	172845275	num_inorg_fert_low
Khalyani	Approved	Accept explanation	Keep						quyenvo_ecom	Trần Thị Liễu	2022-07-29 10:18:39	[Yield too low: 444.4 kg Green per ha]	This is the second of havest(age of tree is 5 years old)	172845275	num_yield_low
Khalyani	Approved		Null	inorganic_fertilizer_	inorganic_fert	NPK (15-15-15)	0		quyenvo_ecom	Nguyễn Thiên Tài	2022-07-29 11:06:44	[Inorganic fertilizer volume too low: 0.0 kg per ha;]		172848227	num_inorg_fert_low

Figure 4: Snapshot of the spreadsheet where all feedback collected during the QC process is aggregated

Second, the overall quality of each survey was reviewed, and a decision was made on whether to accept or reject the survey based on the following criteria: survey length, survey location, and number of data quality issues (nulled or updated values). As with the assessment of flagged values, two Enveritas reviewers performed the survey quality assessment.

Pilot assessments indicated the survey length should be near 45 minutes; the actual duration averaged 33 minutes in the Central Highlands and 47 minutes in Southern Sumatra. However, 6–7 percent of the farmer interviews conducted in each origin were completed in less than 15 minutes, which may indicate a rushed, incomplete, or poorly completed survey. These surveys were flagged and eventually rejected.

Distances between the surveyed farms and the target GPS points (pins) were closely monitored, and any survey conducted more than 10 km from the pin was removed from the dataset. This quality control measure minimized any potential bias related to bad randomization, though some risk of enumerator bias regarding the choice of farms to survey once at the GPS point remained. For example, enumerators might have minimized distances traveled and stayed on the main roads, undersampling the more remote farms, or prioritized larger, more accessible, or certified farms.

Visual checks on the survey locations (see examples below from Dak Nong and Lam Dong) highlight that enumerators did collect surveys in more remote areas, thanks in part to efficient pin randomization. However, at 11 percent in the Central Highlands and 7 percent in southern Sumatra, the share of farms that were surveyed where farmers reported holding a certification was higher than that of the general population in some areas where the surveys were conducted, highlighting oversampling of the more accessible farms (which are more likely to be visited by certification agents).

Figure 5: Snapshot of GPS coordinates of surveyed farms, Dak Nong

Figure 6: Snapshot of GPS coordinates of surveyed farms in remote areas, Lam Dong

Surveys with more than three data quality issues confirmed by the enumerators were also rejected.

Once all surveys were reviewed, the surveys marked for rejection were removed from the dataset. A total of 164 surveys were rejected in Vietnam and 172 surveys in Indonesia.

Survey Status NB: surveys may have been rejected for more than one reason	**Number of Surveys (Vietnam)**	**Number of Surveys (Indonesia)**
Accept - With Data Updates	976	1,197
Accept - As Is	1,401	838
Accept - With Nulled Values	162	10
Reject - Survey Too Short	108	67
Reject - Too Far from Pin	33	64
Reject - Too Many Data Quality Issues	27	43

Table 3: Survey status, summary

Upon completion of these two stages, the clean data was ready to be used for analysis.

4.6.2 The data analysis process

The analysis phase involved the following five sub-steps conducted by Enveritas:

1. **Pre-processing of data:** Raw survey data had to be pre-processed to create usable dimensions for the subsequent analyses and inputs to the Cool Farm Tool. The following pre-processing steps were carried out:
    - **Translate local terms:** Vietnamese and Bahasa Indonesian terms for fertilizers, chemicals, trees, etc. were translated into English to be made readable by an audience unfamiliar with local languages and terminology.
    - **Merge known and estimated values:** For some dimensions, such as farm size or fertilizer volume, the farmer was first asked whether they knew the answer. If they did not, they were asked to provide an estimate. The "known value" and "estimated value" answers were merged into one dimension to simplify the dataset.
    - **Harmonize units:** Numerical values such as amount of water used for irrigation were reported by farmers with different units (liters, cubic meters per hectare, cubic meters per tree, etc.). They were all converted into the same standard units.
    - **Create calculated dimensions:** Dimensions such as yield, fertilizer volume, and chemical volume were derived from a set of survey answers. For example, fertilizer volume was calculated using the volume of fertilizer per application, the volume unit used, the number of applications per year, and the coffee plot area.
    - **Remove all unnecessary columns:** Survey answers that were not useful for the analyses were removed from the dataset to make it cleaner.

2. **Formatting the data into CFT inputs:** The farm survey results were mapped to the inputs required by the CFT. Mapping of answer choices, adjustment of units, assumptions for missing inputs, and modeling assumptions made necessary by gaps in the CFT (e.g., on residue management) were aligned with the Technical Committee, which comprises other technical partners involved in this initiative. The validated list of all assumptions presented to the Committee is available in Appendix 9.5.

3. **Running the data through the CFT:** The formatted surveys were fed into the CFT using an API supplied by the Cool Farm Alliance (CFA). Enveritas staff completed training sessions run by CFA technical staff to ensure they were using the tool correctly, and used the quick start guide and data schemas provided by the CFA as supporting material.

4. **Post-processing of CFT results:** The resulting outputs were sense-checked and aggregated at the district, province, and origin levels. Some of the important variables, such as yield, farm size, and fertilizer use, were compared with Enveritas sources to ensure that they were within the expected bounds.[10]

Central Highlands	Survey data	Comparative data
Average landholding [ha]	1.12	1.04
Yield [kg GBE/ha]	2,947	2,540
Inorganic fertilizer volume [kg/ha]	1,678	1,500

Table 4: Results sense-check, Central Highlands

Southern Sumatra	Survey data	Comparative data
Average landholding [ha]	1.14	1.05
Yield [kg GBE/ha]	705	540
Inorganic fertilizer volume [kg/ha]	179	200

Table 5: Results sense-check, Southern Sumatra

The results were then presented to the Core Committee and partners for feedback.

5. **Analyzing results:** A handful of analyses were carried out on the outputs of the model and the dataset, including:
    - **Uncertainty assessments:** Margins of error were calculated for each aggregated output (district/province/origin levels).
    - **Deep dives on drivers of emissions:** The carbon footprint of each origin was split among the emission sources (fertilizers, energy, chemicals, residue management, wastewater, transport, land use change), and each driver was analyzed to obtain further insights.
    - **Correlation analyses:** Correlations between emission levels and various indicators were calculated to identify the relationships between farm characteristics and emissions. Further analyses were conducted on the relevant relationships.
    - **Carbon sequestration potential:** Although carbon sequestration was excluded from the model for accuracy reasons,[11] on the Core Committee's advice some analyses were conducted on the carbon sequestration potential of farms based on the CFT's carbon stock changes component and external data collected during the survey period.

[10] Enveritas (2020) and Enveritas (2022)

[11] Current carbon sequestration estimates from the Cool Farm Tool are not adapted to coffee; however, the CFA is working on a perennial module that will be added to the tool and better take into account coffee's specificities. Refer to section 6.7 for further details.

- **Co-products analysis:** As intercropping is frequent in both origins, it was important to separate the on-farm emissions that could be attributed to other crops grown in the same plot, so they could be reported on separately. Related analyses were carried out to better understand the importance of co-products to the overall footprint.
- **Farmer archetypes:** Farmers were split into three groups based on certain archetype-defining farming practices and farm characteristics (namely input usage and shade level). Comparative analyses were conducted between the different archetypes.
- **Comparative analysis with other models:** Results from CFT were compared against those produced by three other carbon accounting tools, using the same farmer survey datasets (Sphera's LeanAg model, 4C's Carbon Footprint Add-On, and Lavazza Group's SimaPro model).

6. Results

6.1 Carbon Footprint Results

6.1.1 Results at the origin level

All individual farm-level carbon footprint results estimated with the CFT were first aggregated at the district level. These results were then aggregated to respective provinces, based on the weighted average of each district's production volume. Finally, the origin-level emissions were derived based on the weighted averages of the provinces' production volumes. The results at the origin level are displayed in Table 6.

	Central Highlands	Southern Sumatra
Carbon footprint [kg CO_2e/kg GBE]	1.83	2.38
Margin of error [kg CO_2e/kg GBE]	±0.07	±0.11
Margin of error [%]	3.94%	4.49%
Carbon footprint [kg CO_2e/ha]	4,059	593
Carbon footprint [kg CO_2e/farm]	4,533	739
Yield [kg GBE/ha]	2,947	705

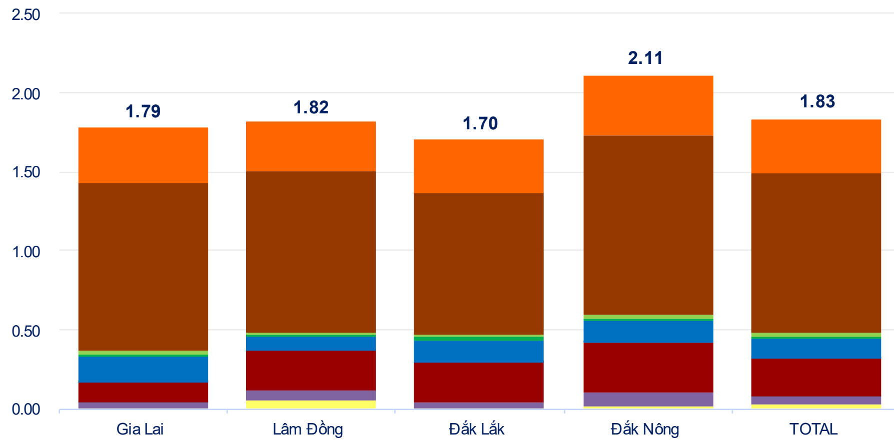
Table 6: Carbon footprint data at the origin level

The carbon footprint per kg GBE produced is significantly lower in the Central Highlands than in Southern Sumatra, due to greater productivity and shorter transportation distances. Although farmers in the Central Highlands practice input-intensive farming, higher yields compensate for the emission intensity on a per kg GBE basis. In the case of Southern Sumatra, although the carbon footprint per kg GBE is higher, footprints per ha and per farm are much lower as inputs are used in smaller quantities.

The margins of error around 4 percent for both origins are within the target 10 percent set initially as part of the sampling strategy. They point toward a high degree of precision in the origin-level estimates.

6.1.2 Results at the province level

6.1.2.1 Central Highlands



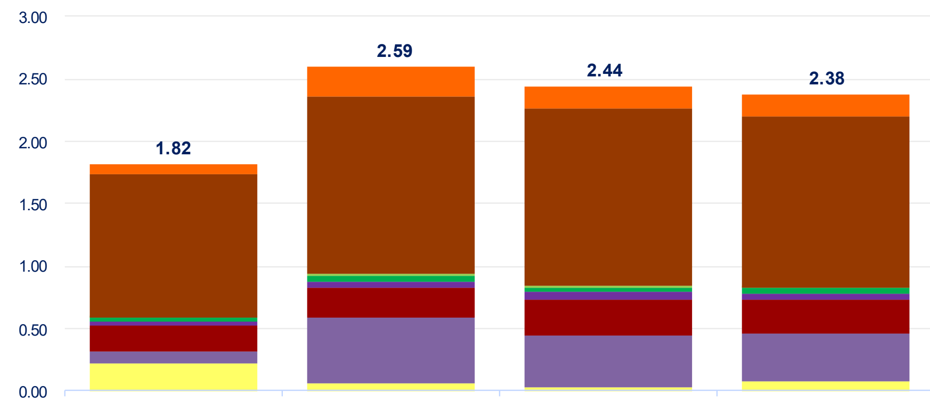
	Gia Lai	Lâm Đồng	Đắk Lắk	Đắk Nông	TOTAL	
Fertilizer production	0.35	0.32	0.34	0.38	**0.34**	(19%)
Fertilizer use and soil	1.06	1.02	0.89	1.14	**1.01**	(55%)
Energy use (field)	0.02	0.02	0.02	0.03	**0.02**	(1%)
Energy use (processing)	0.01	0.01	0.02	0.01	**0.01**	(<1%)
Energy use (irrigation)	0.17	0.08	0.15	0.13	**0.13**	(7%)
Crop protection	0.00	0.00	0.00	0.00	**0.00**	(<1%)
Residue management	0.12	0.26	0.25	0.32	**0.24**	(13%)
Waste water	0.00	0.00	0.00	0.00	**0.00**	(<1%)
Transport	0.04	0.06	0.04	0.08	**0.06**	(3%)
Land use change	0.00	0.05	0.00	0.02	**0.02**	(1%)

Figure 7: Carbon footprint per province, split by emission source, Central Highlands (kg CO_2e/kg GBE)

At an origin level, the carbon footprint of coffee produced in the Central Highlands is 1.83 kg CO_2e/kg GBE. At a province level, Gia Lai, Lam Dong, and Dak Lak have similar levels of emissions, while Dak Nong stands out with emissions 15 percent higher than the origin's average. This difference can be explained by lower productivity despite similar quantities of fertilizer application, which results in a larger carbon footprint on a volume produced basis.

The shares of emission sources are relatively constant across provinces, with inorganic fertilizers (production and soil-related emissions) representing 74 percent of the total. Residue management is another significant source of emissions, accounting for 13 percent of the overall footprint. Emissions related to the use of energy for irrigation, in particular the use of diesel and electricity to operate pumps, account for 7 percent of the footprint. Together, these sources represent 94 percent of the total carbon footprint. Transportation is a minor contributor (3 percent), and other emission sources are negligible (1 percent or less).

6.1.2.2 Southern Sumatra



	Bengkulu	Lampung	Sumatera Selatan	TOTAL	
Fertilizer production	0.09	0.23	0.18	**0.18**	(8%)
Fertilizer use and soil	1.14	1.43	1.42	**1.38**	(58%)
Energy use (field)	0.01	0.01	0.01	**0.01**	(<1%)
Energy use (processing)	0.02	0.05	0.04	**0.04**	(2%)
Energy use (irrigation)	0.00	0.00	0.00	**0.00**	(<1%)
Crop protection	0.03	0.04	0.06	**0.05**	(2%)
Residue management	0.22	0.24	0.29	**0.26**	(11%)
Waste water	0.00	0.00	0.00	**0.00**	(<1%)
Transport	0.10	0.52	0.41	**0.39**	(16%)
Land use change	0.22	0.07	0.04	**0.08**	(3%)

Figure 8: Carbon footprint per province, split by emission source, Southern Sumatra (kg CO_2e/kg GBE)

At an origin level, the carbon footprint of coffee produced in Southern Sumatra is 2.38 kg CO_2e/kg GBE. Lampung and Sumatra Selatan provinces have similar levels of emissions, while Bengkulu stands out with emissions 31 percent lower than the origin's average. This difference can be explained by lower levels of fertilizer application (without a corresponding drop in yields, resulting in higher fertilizer efficiency) and lower transportation-related emissions.

With these exceptions, the shares of emission sources are relatively constant across provinces. Inorganic fertilizers (production and soil-related emissions) are the largest contributor, representing 66 percent of the total. The next highest contributor (16 percent) is transportation, which is explained by the fact that farmers in Southern Sumatra typically must transport their produce and farm inputs over relatively long distances (note, however, that this may be an overestimation due to a limitation of the CFT; see section 6.2.6 for details). Residue management is another significant source of emissions, accounting for 11 percent of the footprint. Together, these sources represent 93 percent of the total carbon footprint in this origin. Other emissions related to land use change, energy use for processing, and crop protection account for the remaining 7 percent. Unlike farmers in the Central Highlands of Vietnam, farmers in Southern Sumatra benefit from more abundant rainwater and do not irrigate their farms, so energy use for irrigation is not a driver of emissions in this origin.

6.1.3 Results at the district level

The average carbon footprints at a district level are provided below, along with the margin of error and precision levels.[12] Results that have low precision are presented in the tables for information only and should not be taken as reliable estimates of emissions at a district level.[13]

6.1.3.1 Central Highlands

Province	District	Number of Observations	Initial Target	Carbon Footprint [kg CO_2e/kg GBE]	Margin of Error [kg CO_2e/kg GBE]	Precision*
Đắk Lắk	Buôn Đôn	16	10	**1.19**	±0.40	Low
	Buôn Ma Thuột	25	30	**1.62**	±0.44	Low
	Cư Kuin	36	35	**1.88**	±0.31	Medium
	Cư M'gar	136	120	**1.58**	±0.25	Medium
	Ea H'leo	62	115	**1.51**	±0.44	Low
	Ea Kar	5	10	**3.80**	±4.64	Low
	Krông A Na	41	35	**1.32**	±0.20	Medium
	Krông Bông	15	15	**3.39**	±1.33	Low
	Krông Búk	49	60	**1.67**	±0.58	Low
	Krông Năng	103	110	**1.56**	±0.18	Medium
	Krông Pắc	47	50	**1.77**	±0.31	Medium
	Lắk	10	10	**2.02**	±0.52	Low
	Thị Xã Buôn Hồ	44	40	**1.63**	±0.34	Low
Đắk Nông	Cư Jút	18	20	**2.21**	±1.57	Low
	Đắk Glong	70	70	**1.90**	±0.35	Medium
	Đắk Mil	106	110	**1.95**	±0.39	Low
	Đắk R'Lấp	98	100	**2.37**	±0.45	Medium
	Đắk Song	122	125	**2.26**	±0.62	Low
	Gia Nghĩa	39	40	**1.95**	±0.32	Medium
	Krông Nô	98	90	**1.95**	±0.33	Medium
	Tuy Đức	97	95	**2.18**	±0.64	Low
Gia Lai	Chư Păh	62	65	**1.66**	±0.16	High
	Chư Prông	81	90	**1.32**	±0.19	Medium
	Chư Pưh	22	20	**2.25**	±0.61	Low
	Chư Sê	63	65	**1.72**	±0.29	Medium
	Đăk Đoa	178	175	**2.04**	±0.24	Medium
	Đức Cơ	46	40	**1.64**	±0.53	Low
	Ia Grai	126	125	**1.87**	±0.19	Medium
	Mang Yang	32	30	**2.08**	±0.75	Low
	Pleiku	26	25	**1.33**	±0.13	High
Lâm Đồng	Bảo Lâm	147	155	**1.84**	±0.23	Medium
	Bảo Lộc	44	45	**1.28**	±0.14	Medium
	Đam Rông	40	40	**1.37**	±0.24	Medium
	Di Linh	186	175	**1.94**	±0.15	High
	Đức Trọng	67	70	**1.86**	±0.43	Low
	Lâm Hà	169	165	**1.94**	±0.19	Medium

Table 7: Carbon footprint per district, Central Highlands. Districts highlighted in blue had larger sample sizes intended to result in more precise district-level estimates

[12] Precision levels according to MoE: high = 0–10%; medium = 10–20%; low = >20%.

[13] Readers should ensure that the confidence intervals of two compared districts do not overlap before drawing any conclusions about their differences. For example, it cannot be concluded that Krong Nang has a lower footprint per kg GBE produced than Bao Lam (1.56 vs. 1.84 kg CO_2e), because the confidence interval of Krong Nang is 1.56 ± 0.18 while that of Bao Lam is 1.84 ± 0.23. However, Krong Nang has a lower footprint than Di Linh (1.94 ± 0.15).

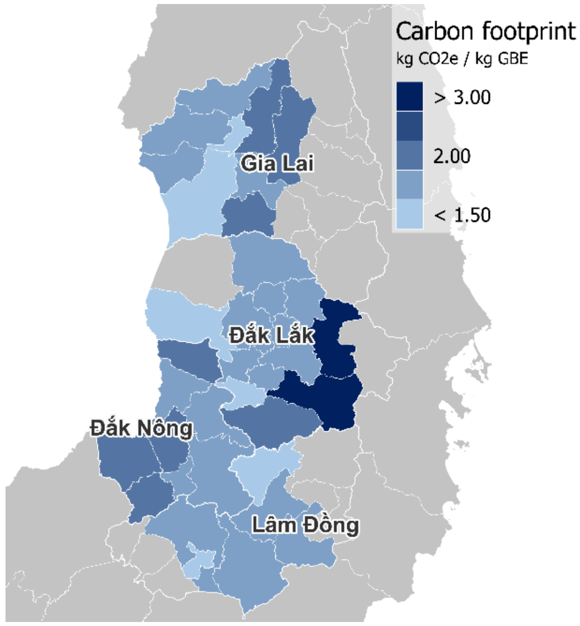
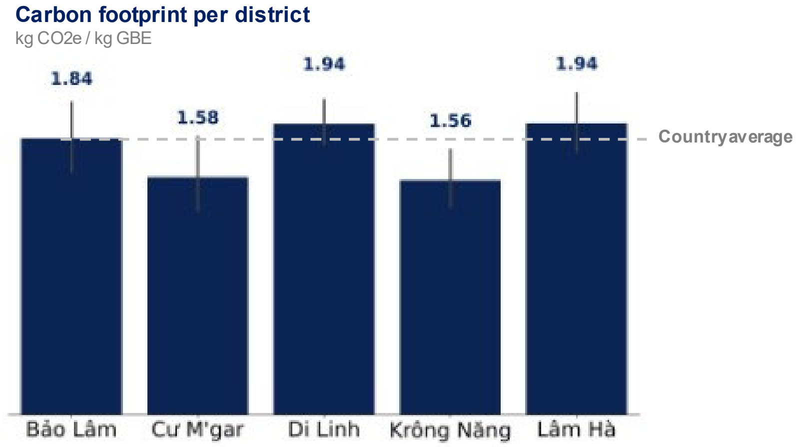


Figure 9: Carbon footprint per district, Central Highlands

Overall, the carbon footprints of districts in the Central Highlands span from 1.32 kg to 2.37 kg CO_2e per kg GBE (districts with low precision are excluded). There is no strong geographical disparity.

A comprehensive district-level comparison is not feasible as this was not the intention of the sample design, and given that many district-level emission estimates fall under low precision. However, the districts of Cu M'gar, Ea H'leo, Krong Nang, Bao Lam, Di Linh, and Lam Ha (highlighted in blue in Table 7) were initially selected as strategic due to their high production volumes, and the sampling plan was designed to achieve medium or high precision at a district level in these areas. Comparing these districts (apart from Ea H'leo, where the number of observations was significantly lower than the target initially defined) leads to some useful insights.



		Bảo Lâm	Cư M'gar	Di Linh	Krông Năng	Lâm Hà	
		Within MoE*	Below average	Above average	Below average	Above average	**Country average**
Key indicators	**Yield [kg / ha]**	3,526	2,905	3,124	2,890	3,932	**2,947**
	Total production [kg]	4,614	2,614	3,242	2,625	4,913	**3,294**
	Inorganic fertilizer volume [kg / ha]	1,891	1,458	1,814	1,527	2,341	**1,678**
	% farmers who irrigate	48%	100%	89%	99%	85%	**92%**
	% farmers who sell cherry	3%	7%	10%	23%	8%	**25%**

*Margin of error at 95% confidence level.

Figure 10: Carbon footprint details for selected strategic districts in the Central Highlands

While the district-level carbon footprint of Bao Lam does not significantly differ from the Central Highlands average of 1.83 kg CO_2e/kg GBE, those of Di Linh and Lam Ha are higher while those of Krong Nang and Cu M'gar are lower. These variations can largely be explained by differences in inorganic fertilizer usage. Farmers in Di Linh and Lam Ha[14] use 8 percent and 40 percent more fertilizer, respectively, than the country average, while those in Cu M'gar and Krong Nang use 13 percent and 9 percent less, but without a significant drop in yield. Farmers in Bao Lam also use more fertilizers than the origin-level average (13 percent), but this is offset by high yields and significantly lower levels of energy use for irrigation.

[14] Given these results, Lam Ha could be recommended as a target district for fertilizer optimization training and emissions reductions.

6.1.3.2 Southern Sumatra

Province	Regency	Number of Observations	Initial Target	Carbon Footprint [kg CO_2e/kg GBE]	Margin of Error [kg CO_2e/kg GBE]	Precision*
Bengkulu	Bengkulu Selatan	25	20	**1.88**	±0.35	**Medium**
	Bengkulu Tengah	29	35	**3.36**	±0.99	**Low**
	Bengkulu Utara	37	35	**2.11**	±0.85	**Low**
	Kaur	56	65	**2.02**	±0.57	**Low**
	Kepahiang	198	200	**1.13**	±0.06	**High**
	Lebong	26	55	**1.49**	±0.35	**Low**
	Rejang Lebong	203	190	**2.22**	±0.75	**Low**
	Seluma	42	50	**1.84**	±0.30	**Medium**
Lampung	Lampung Barat	376	325	**2.87**	±0.24	**High**
	Lampung Utara	18	55	**1.51**	±0.36	**Low**
	Pringsewu	2	0	**1.81**	±0.63	**Low**
	Tanggamus	210	200	**2.77**	±0.42	**Medium**
	Way Kanan	32	50	**1.35**	±0.20	**Medium**
Sumatra Selatan	Empat Lawang	292	190	**2.04**	±0.09	**High**
	Lahat	63	65	**1.28**	±0.12	**High**
	Muara Enim	103	110	**3.16**	±0.51	**Medium**
	Ogan Komering Ulu	69	65	**1.86**	±0.20	**Medium**
	Ogan Komering Ulu Selatan	196	175	**3.57**	±0.50	**Medium**
	Pagar Alam	46	45	**1.10**	±0.15	**Medium**

Table 8: Carbon footprint per district, Southern Sumatra. Districts highlighted in blue had larger sample sizes intended to result in more precise district-level estimates

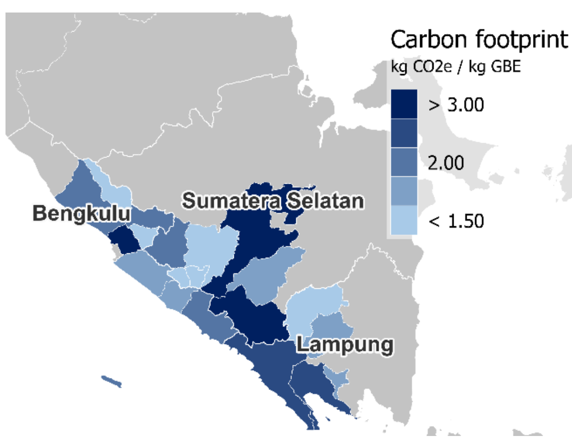
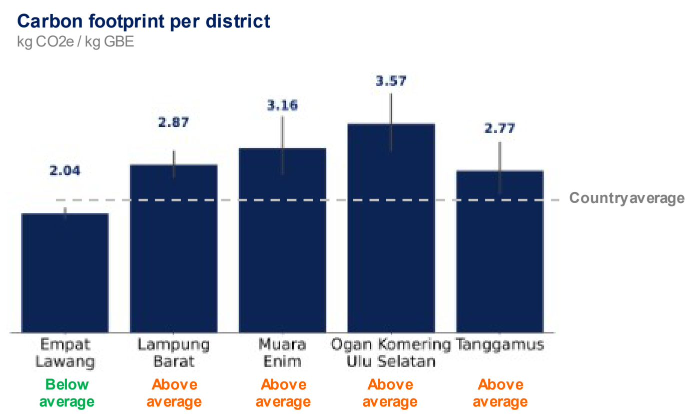


Figure 11: Carbon footprint per district, Southern Sumatra

The carbon footprints of districts in Southern Sumatra show significant differences, ranging between 1.10 and 3.57 kg CO_2e/kg GBE (districts with low precision are excluded). The two districts that emit the most are found in Sumatra Selatan: Muara Enim at 3.16 kg CO_2e/kg GBE and Ogan Komering Ulu Selatan at 3.57 kg CO_2e/kg GBE.

As in the Central Highlands, five districts – Lampung Barat, Tanggamus, Empat Lawang, Muara Enim, and Ogan Komering Ulu Selatan (highlighted in blue in Table 8) – were initially selected as strategic due to their high production volumes, and the sampling plan was designed to achieve medium or high precision at a district level in these areas.

The four districts that have a high level of precision indicate a low level of variability among their farmers. Most of the other districts have moderate precision, while a cluster of five districts have a low level of precision, mostly driven by small sample sizes and the high variability associated with estimated land use change emissions.



Key indicators		Empat Lawang	Lampung Barat	Muara Enim	Ogan Komering Ulu Selatan	Tanggamus	Country average
Key indicators	Yield [kg / ha]	546	826	514	750	650	**705**
	Total production [kg]	536	975	711	973	640	**783**
	Inorganic fertilizer volume [kg / ha]	146	322	201	216	232	**179**
	Average distance travelled [km / year]*	262	529	205	1,422	269	**368**
	% farmers who use husks as mulch	98%	63%	68%	38%	54%	**58%**

*Sum of distances travelled inbound (for transportation of inputs) and outbound (for transportation of coffee)

Figure 12: Carbon footprint details for selected strategic districts in Southern Sumatra

Empat Lawang is the only one of the five selected districts with a carbon footprint lower than the Southern Sumatra average of 2.38 kg CO_2e/kg GBE. This difference is explained by a combination of shorter transportation distances and lower fertilizer usage by coffee farmers in this district.

Farmers in the other four districts use higher quantities of inorganic fertilizers than the country average. Despite comparatively low transportation-related emissions in Muara Enim and Tanggamus, the below-average yields experienced by farmers in these districts result in high emissions per kg GBE produced.

Conversely, farmers in Lampung Barat and Ogan Komering Ulu Selatan have above-average yields but much higher levels of transportation-related emissions, as farmers in these districts tend to be more isolated and must travel longer distances to get their inputs or sell their coffee.

6.2 Analyses per Emission Source

6.2.1 Fertilizer production and use

Multiple studies and estimates have shown that fertilizers are the main contributors to coffee's carbon footprint at the farm level.[15] Hence, special attention was paid to collecting accurate information about farmers' fertilizer use. Reports of fertilizer types used, rounds of application, and quantities applied were thoroughly checked during the quality control process, which led to low variability and high data quality for this important component of the model.

Incomplete details on the origins of the inorganic fertilizers applied by farmers, however, is a key source of uncertainty that plays a non-negligible part in the modeling. Emission factors of fertilizer production vary according to the country/region of manufacture. Surveyed farmers were not always aware of where the fertilizers they used were produced. In such cases, the enumerators were instructed to look for a "Made in XXX" label on the fertilizer bags where possible. On 2 percent of farms in Vietnam and 23percent of farms in Indonesia, enumerators could not determine the country of origin of fertilizers used by the farmers. In these cases, Southeast Asia was taken as a proxy value because it was the most widely reported origin among the farmers who knew where their fertilizers were produced.

However, even in cases where farmers reported the manufacturing location, they may instead have mistakenly reported the place of purchase or the address of the local branch of the fertilizer company supplying the product. Furthermore, for NPK, the manufacturing country listed on the packaging is often the country where the products are mixed, yet the most important emission factor is the one related to the production of the N component (mostly in urea form), which may be imported from another country. Therefore, to provide additional context for this indicator, supplementary information on fertilizer origins and emission factors was requested from Yara, a fertilizer company and one of the initiative's technical partners.

Figure 13: Pictures of fertilizer bags observed in the Central Highlands. The bag on the left provides a clear mention of the country of production, while the bag on the right does not provide clear information (the address at the bottom of the bag could be misinterpreted as the place of production).

[15] E.g. Kuit et al. (2019).

Yara's data (Figure 14) shows that most the fertilizers imported to Indonesia and used by coffee farmers (mainly NPK and urea) are produced locally (i.e., in Southeast Asia) or in Russia.[16] Since the emission factor of NPK produced in Russia is the same as in Southeast Asia (see Table 9), in this origin the impact of wrongly classifying the fertilizer producing country as either Southeast Asia or Russia is very low.

In the Central Highlands, however, Yara reports that about three-quarters of the urea used is imported from China, while the major sources of NPK are China and Russia (each accounting for about one-third). As the emission factors of fertilizers produced in China are 1.4x and 2.1x higher than in Southeast Asia for NPK and urea, respectively, the impact of wrongly classifying a fertilizer's country of manufacture in this origin is high. Using the emission factor for China instead of Southeast Asia for all the farmers in the Central Highlands who reported Southeast Asia as the manufacturing location would raise the estimated emissions from fertilizer production by about 20 percent and would increase the total carbon footprint by 0.07 kg CO_2e/kg GBE (i.e., +4 percent of the total). It is, therefore, important to remember when interpreting the results presented here that the emission estimates from this source are based on farmer reporting of producing countries, that default values were used where necessary, and that the share of farmers misclassifying the fertilizer origin is unknown.

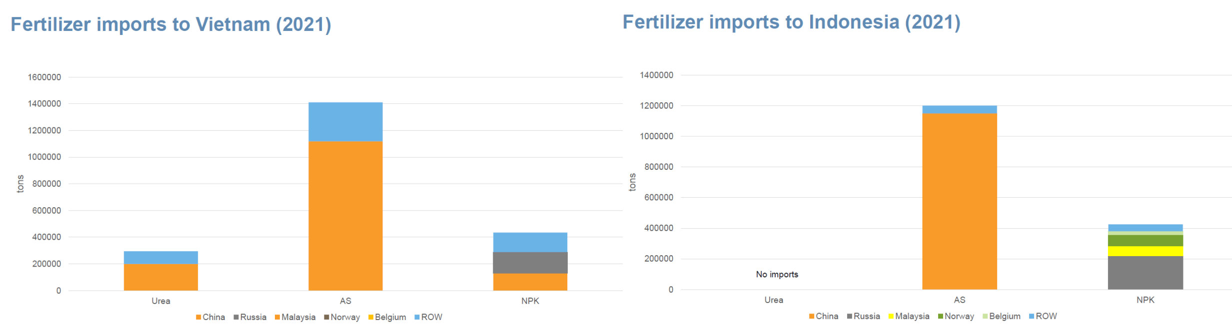


Figure 14: Origins of fertilizers imported to Vietnam and Indonesia (source: Yara)

	Southeast Asia	Europe	Russia	China
NPK (15-15-15)	100	55	100	142
Urea	100	95	118	214

Table 9: Emission factors of most common inorganic fertilizers per origin, expressed as % of Southeast Asia emission factors (source: Yara)

[16] Yara's data covers all fertilizer imports to Vietnam and Indonesia and is not specific to coffee farming. As such, while it provides useful context, this data cannot constitute a source of truth against which farmer-reported data can be directly compared.

6.2.1.1 Central Highlands

About three-quarters of the total carbon footprint of coffee farms in the Central Highlands comes from the production and application of fertilizers and related nitrous oxide (N_2O) emissions. High rates of application of inorganic fertilizers compared to organic alternatives, which contain less nitrogen and thus emit less, is a defining feature of coffee farming in this origin.

The emission factors in the CFT for inorganic fertilizers are about ten times higher than those of organic fertilizers. Almost all coffee farmers in the Central Highlands use inorganic fertilizers, mostly NPK 16-8-16 or NPK 16-16-8. In comparison, 46 percent of farmers report applying organic fertilizers, most commonly manure and compost.

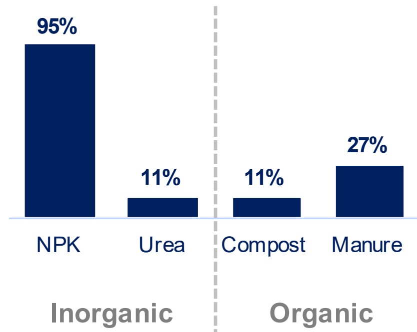


Figure 15: Most common fertilizers and percentages of farmers using them, Central Highlands

Although farmers in Lam Dong use more fertilizers than those in other provinces, they do not have the highest level of emissions because the high usage is complemented by high productivity (21 percent above the country average). The best predictor of a farm's carbon footprint is the inorganic fertilizer volume applied per kg GBE produced, also called "fertilizer efficiency." The correlation coefficient between fertilizer efficiency and carbon footprint is very high (79 percent).

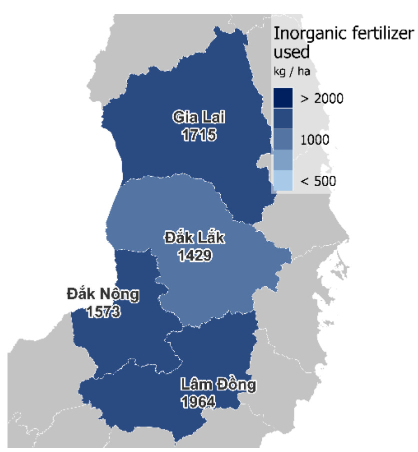


Figure 16: Inorganic fertilizer usage per province, Central Highlands

6.2.1.2 Southern Sumatra

A lower share of farmers in Southern Sumatra uses inorganic fertilizers (64 percent), and they apply an average quantity ten times lower than that applied by farmers in the Central Highlands. Nevertheless, the production and use of fertilizers is also the primary source of emissions in this origin, accounting for two-thirds of the total carbon footprint.

The most common inorganic fertilizer used by farmers in Southern Sumatra is an NPK compound (15-15-15), followed by urea. One out of five farmers use organic fertilizers, most frequently compost or manure.

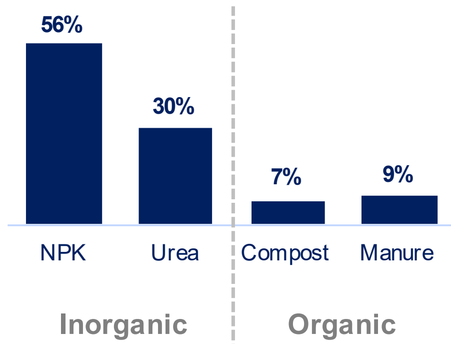


Figure 17: Most common fertilizers and percentages of farmers using them, Southern Sumatra

Farmers in Bengkulu, despite applying 46 percent fewer inorganic fertilizers than the country average of 179 kg/ha, have similar yields: 707 kg GBE/ha vs. a country average of 705 kg GBE/ha. This higher fertilizer efficiency – together with lower transportation-related emissions in this province, where farms are generally less remote – helps explain Bengkulu's lower carbon footprint.

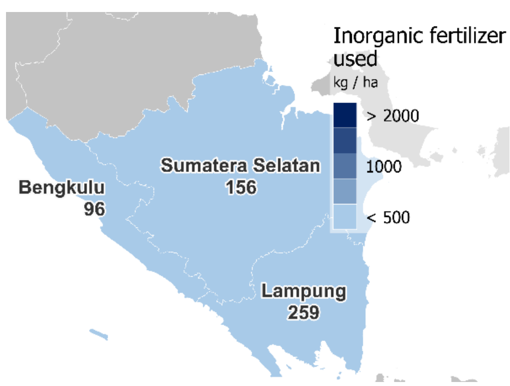


Figure 18: Inorganic fertilizer usage per province, Southern Sumatra

6.2.2 Energy use

6.2.2.1 Central Highlands

Energy use is the third largest contributor to the carbon footprint of coffee farmers in the Central Highlands (7 percent). The use of mechanical hose and pump and sprinkler systems to irrigate coffee farms accounts for 78 percent of energy emissions. These systems run on diesel or electricity; as the emission factor of diesel is higher than that of electricity, the 44 percent of systems that run on diesel emit more than those linked to the grid.

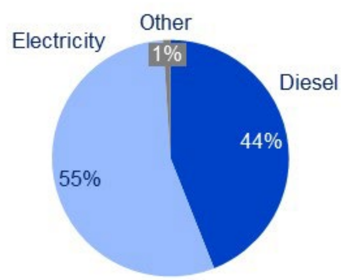


Figure 19: Energy sources used for irrigation, Central Highlands

Although irrigation is very common across the Central Highlands, a smaller share of farmers in Lam Dong irrigates, which leads to lower energy emissions in that province.

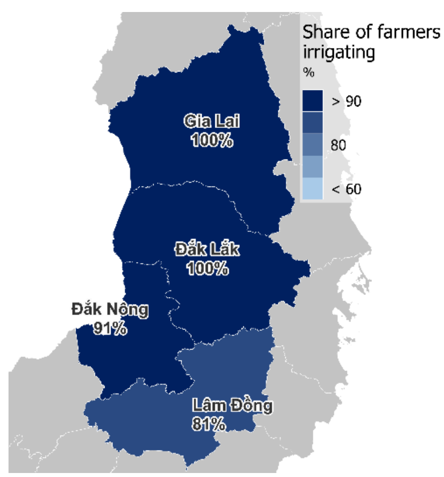


Figure 20: Share of farmers who irrigate per province, Central Highlands

Energy-related emissions from field activities, such as mechanical weeding, spraying, or harvesting, account for 14 percent of the total energy emissions in the Central Highlands, while processing activities such as mechanical pulping, hulling, or drying account for the remaining 8 percent. Field activities overwhelmingly rely on petrol, whereas processing activities tend to rely on diesel.

6.2.2.2 Southern Sumatra

Emissions related to energy use represent a smaller share of the overall carbon footprint of coffee farmers in Southern Sumatra (3 percent). This is mostly explained by the fact that mechanical irrigation is not common in this origin. Most of the energy-related emissions come from processing activities that rely on petrol or diesel. The most common activity is mechanical hulling, as a wide majority of farmers (93–98 percent across the three provinces) sell their coffee in green form.

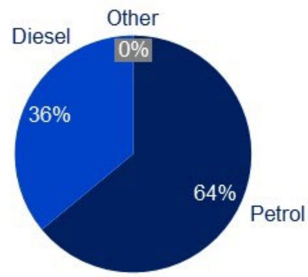


Figure 21: Energy sources used for processing activities, Southern Sumatra

Figure 22: Share of farmers who sell green coffee per province, Southern Sumatra

6.2.3 Pesticide and herbicide use

6.2.3.1 Central Highlands

In the Central Highlands, 39 percent of farmers report using pesticides and 17 percent report using herbicides. Pesticide usage rates are significantly higher in Dak Nong and significantly lower in Dak Lak than in the other two provinces, but this variation has a negligible impact on carbon footprint as the emission factor of pesticide and herbicide use is very low. The combined emissions from all crop protection chemicals represent less than 1 percent of the overall footprint.

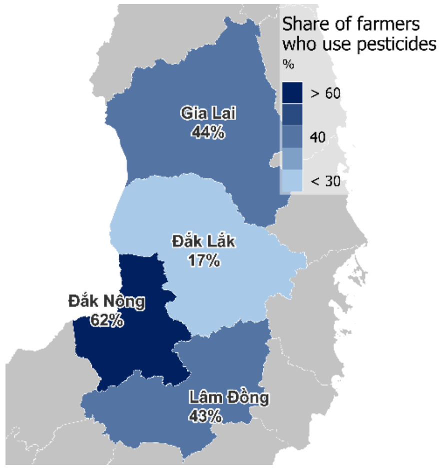


Figure 23: Share of farmers who use pesticides per province, Central Highlands

6.2.3.2 Southern Sumatra

The share of farmers who use pesticides in Southern Sumatra is similar to that in the Central Highlands, but herbicide application rates are much higher. Near 62 percent of farmers in Southern Sumatra report applying herbicides, mostly glyphosate. As in the Central Highlands, the application of such chemicals has a very minor impact on the overall footprint; combined emissions from all crop protection chemicals represent 2 percent of the total.

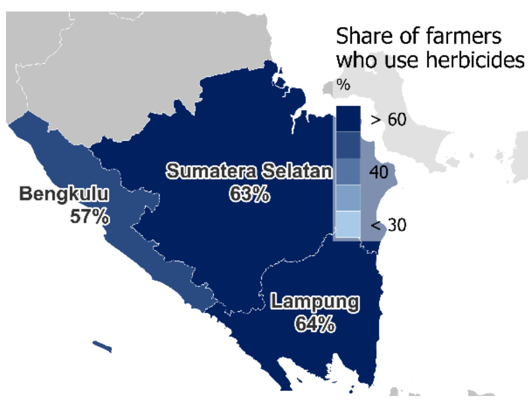


Figure 24: Share of farmers who use herbicides per province, Southern Sumatra

6.2.4 Residue management

Crop residues on coffee farms come from two sources: coffee husks (including any dry matter remaining after hulling dried cherries) and leaf litter. For each kg GBE produced, approximately 0.90 kg of dry coffee husks and 0.36 kg[17] of dry leaf litter are generated. These residues can be a source of methane (CH_4) and nitrous oxide

[17] Assumptions suggested by the Cool Farm Alliance and agreed by the project's Core Committee.

(N_2O) emissions, depending on the disposal methods. As per the CFT's emission factors, l**eaving the residues untreated in piles leads to 7x more emissions compared to composting (generally non-forced aeration), which in turn emits 5x more than applying the residues to the farm as mulch.**

Residue Management Method	**EF [kg CO_2e/kg residue]**
Removed; left untreated in heaps or pits	1.96
Removed; non-forced-aeration compost	0.28
Removed; forced-aeration compost	0.18
Left on field; incorporated or mulch	0.06
Burned	0.09
Exported off farm	0

Table 10: CFT emission factors for residue management

Due to the high variability in emission factors, it is important to capture the correct residue management method to ensure accuracy. The CFT has a limitation in this regard: the tool does not allow the user to specify more than one disposal type on the same farm. Many farmers in Vietnam and Indonesia leave their husks in piles and use them when they need mulching or composting. In other cases, enumerators observed that portions of the husks were composted while the rest were left untreated for composting later (see pictures below)

Because the CFT is not currently equipped to deal with this farm-level intricacy, on advice from the CFA and the Core Committee, it was decided to adjust the tool so that residue volumes would be discounted according to the disposal methods.

However, the resulting approach still does not fully capture all the complexities of the disposal practices at a farm level, and further studies need to be conducted to understand whether current estimates are above or below the actual emission values from residue management. This is an area of exploration and learning for future projects.

Figure 25: Pictures from the Central Highlands. From left to right: pile of husks left untreated; pile of husks progressively composted; pile of husks fully composted.

6.2.4.1 Central Highlands

Residue management is the second highest source of emissions in the Central Highlands, accounting for 13 percent pf the carbon footprint. It is a common practice among farmers from this origin to leave coffee husks untreated, which causes significant levels of methane ($CH_{4)}$ emissions as husks decompose under anaerobic conditions. Composting the husks also produces CH_4 emissions, but to a lesser extent as husks decompose under partially or fully aerobic conditions. Given that compost is a good source of organic fertilizer (emissions included under the residue management section were removed from the fertilizer emissions to avoid double counting) and has a much lower emission factor than inorganic fertilizers, the practice of composting husks remains a better alternative for reducing synthetic inputs without compromising much on productivity.

Nonetheless, the best disposal method both from a Good Agriculture Practice (GAP) and a carbon mitigation perspective is the application of crop residues as mulch. Mulching improves soil quality, reduces emissions, and decreases the prevalence of weeds.

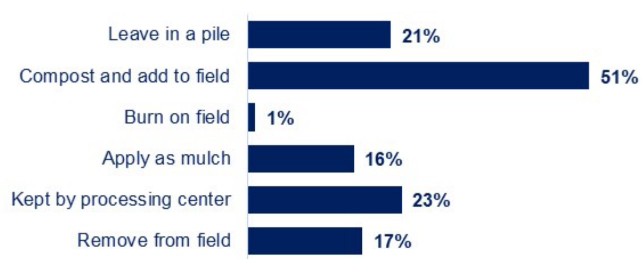


Figure 26: Frequency of husk disposal methods, Central Highlands. Categories are sorted from most emitting (top) to least emitting (bottom).

Farmers in Gia Lai have comparatively lower emissions from residue management because they frequently sell their coffee in cherry form (42 percent vs. 22 percent in other provinces). Hence, the emissions related to decomposition of the husks are attributed to the processing center and do not contribute to farm-level emissions. Many processing centers use these husks as fuel for coffee dryers (see picture below).

Figure 27: Coffee husks used for drying, Central Highlands

6.2.4.2 Southern Sumatra

Residue management is the third largest contributor to the carbon footprint of coffee farmers in Southern Sumatra, accounting for 11 percent of total emissions. Sixty-one percent of farmers leave their coffee husks in piles, which leads to higher emissions; 58 percent apply some or all the husks as mulch, which results in negligible emissions. About one-quarter of farmers (26 percent and 23 percent, respectively) leave their husks at the processing center or remove them from the field. Husks are generally removed from the field to be applied as mulch or compost to other crops, in which case the resulting emissions are not attributed to coffee but to those other crops.

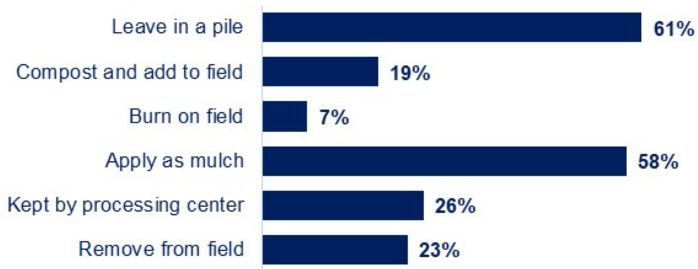


Figure 28: Frequency of husk disposal methods, Southern Sumatra. Categories are sorted from most emitting (top) to least emitting (bottom).

Farmers in Lampung more commonly apply their husks as mulch on the farm, which explains why this province has lower emissions from residue management.

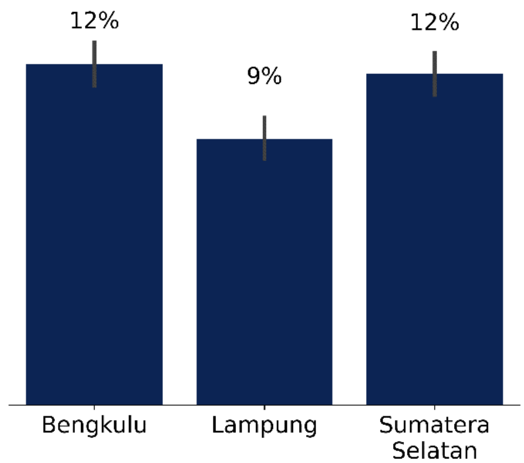


Figure 29: Share of residue management in total footprint per province, Southern Sumatra

6.2.5 Wastewater

Water use for farm-level processing of Robusta coffee is insignificant in both the Central Highlands and Southern Sumatra, as most farmers use dry processing methods. However, wastewater represents a significant share of emissions in origins where wet processing methods are used, especially with Arabica coffee. To ensure the current approach would be applicable to other coffee origins, the wastewater section was kept, and survey questions were designed including wastewater components.

6.2.6 Transportation

The CFT includes both inbound and outbound transportation as potential sources of emissions at a farm level. Inbound transportation refers to the movement of goods or materials such as inputs that a farmer transports to the farm. Outbound transportation refers to the movement of farm produce or byproducts that a farmer transports away from the farm, for example to a buyer.

A major limitation of the CFT for the purposes of this study is the lack of an option to input motorbike as a means of transportation. Motorbikes are widely used by farmers in Vietnam and Indonesia to transport goods and coffee. The emission factor of light goods vehicles was used as a proxy, but this approach is likely to overestimate the associated transportation emissions, especially in Southern Sumatra where most farmers exclusively use motorbikes for transportation.

6.2.6.1 Central Highlands

In the Central Highlands, the average reported travel distances for both inbound and outbound transportation are low (47km, or about 29.2 mi) and 56 km, respectively). This is largely due to the relatively high concentration of coffee farmers in this origin, and the accessibility of nearby marketplace towns. Transportation-related emissions are therefore minimal. Most farmers use light goods vehicles (less than 3.5 tons, per the CFT’s definition) for transportation.

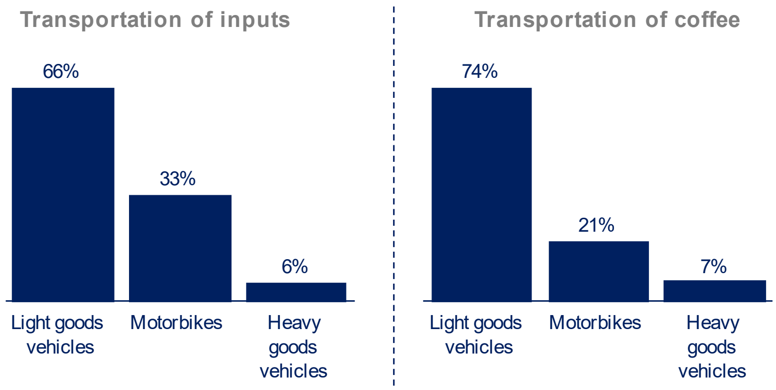


Figure 30: Vehicles used for the transportation of inputs (left) and coffee (right), Central Highlands

6.2.6.2 Southern Sumatra

Apart from in Bengkulu, where farmers are less isolated and have easier access to inputs and coffee buyers, farmers in Southern Sumatra typically have to travel longer distances to get their inputs or sell their coffee than those in the Central Highlands (an average of 239 km (about 148.51 mi)/yr. and 129 km/yr., respectively). Consequently, transportation-related emissions are a more significant contributor to the overall carbon footprint in this origin, accounting for an estimated 16 percent of the total. Due to the previously mentioned limitation of the CFT, however, this is likely to be an overestimation. Almost all farmers in Southern Sumatra use motorbikes for transportation; as this is not one of the options the tool provides, light goods vehicles were used as a proxy, but motorbikes are likely to emit less.

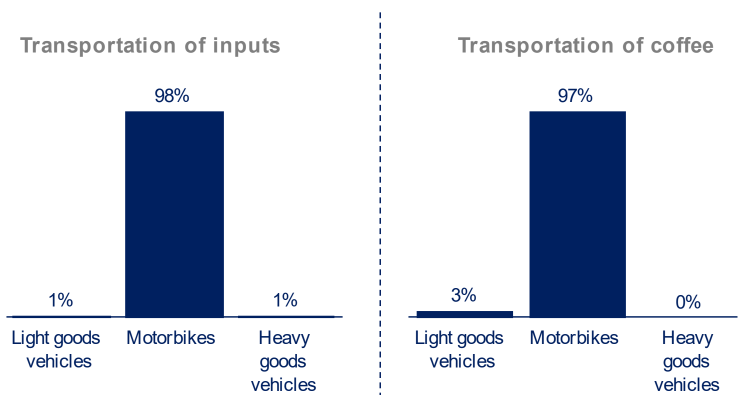


Figure 31: Vehicles used for the transportation of inputs (left) and coffee (right), Southern Sumatra

6.2.7 Land use change[18]

In both origins, emission estimates from land use change come with medium to high variability. This is due to the nature of deforestation events, which are low in frequency but high in impact. This variability has a large effect on the overall margin of error of the carbon footprint in Southern Sumatra in particular, where deforestation events are considered more frequent. In addition, it's important to be aware that farmers may have underreported deforestation to avoid potentially exposing themselves to regulatory risks by disclosing such practices to the enumerators.

For these reasons, estimates of land use change-related emissions presented in this report should be interpreted with caution, especially when disclosing such figures separately. It is also recommended to complement these figures with other sources of data, such as remote sensing, to increase the accuracy of the results and avoid underreporting of emissions from deforestation.

6.2.7.1 Central Highlands

Just 3 percent of farmers in the Central Highlands report having expanded their coffee plots in the past 20 years. Most such expansions reportedly involved replacing other tree crops (rubber, cashew) and pepper plantations with coffee trees, which, per the CFT methodology, does not lead to any LUC-related emissions. Only the replacement of natural vegetation and forest trees, which were very rarely reported by the surveyed farmers, leads to a farm-level increase in carbon footprint.

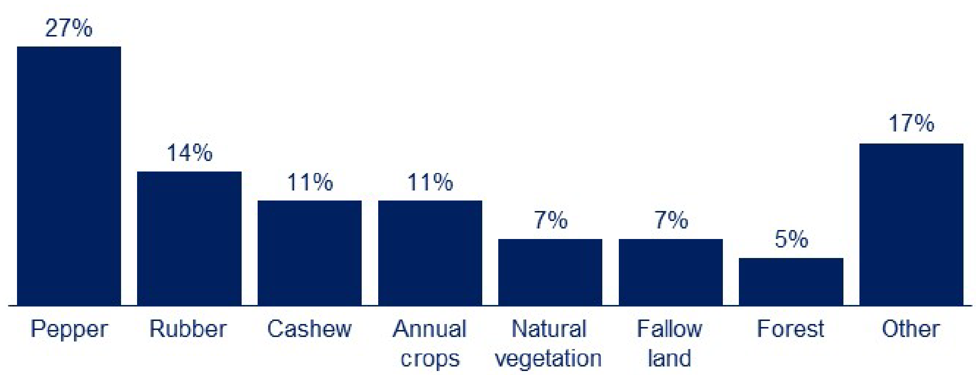


Figure 32: Land type before coffee farm expansion (share of all farmers that expanded their farm), Central Highlands

The share of the overall carbon footprint related to the loss of carbon stock due to LUC is therefore minimal in the Central Highlands, with a moderate level of variability. Lam Dong has the highest share, due to a few farmers in this province reporting deforestation events for coffee farm expansion. Those few reports skewed the CO_2e distribution to the right, increasing the average but also the variability of the results. Nevertheless, the LUC emissions remain very low in the other provinces, with a high level of precision.

[18] The land use change numbers were extracted from the land management section of the CFT. They had to be distinguished from the biomass stock change figures, which are reported separately (see section 6.7).

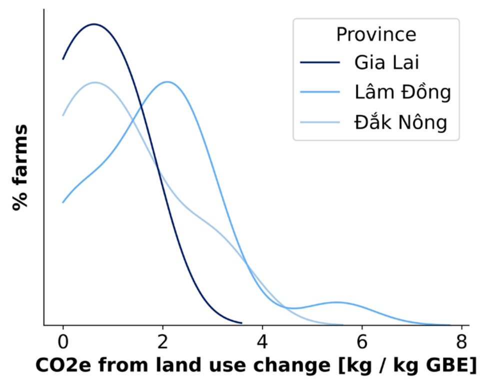


Figure 33: Distribution of farm-level carbon footprint from land use change per province, Central Highlands

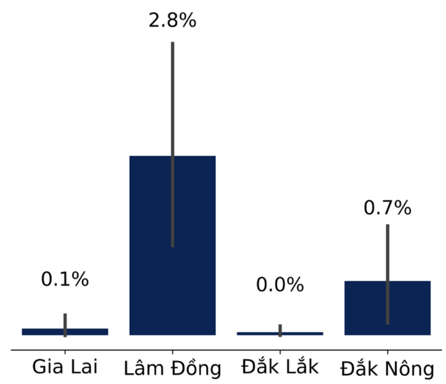


Figure 34: Share of land use change in total footprint per province, Central Highlands

To account for the uncertainties associated with land use change emissions, an extra analysis was performed to calculate and report emissions with and without LUC (Table 11). Despite the high variability in Lam Dong, the LUC component does not appear to have a significant impact on the uncertainty of the overall results, as the margin of error stays the same; the overall footprint is just reduced by 1 percent.

	Including LUC	Excluding LUC
Carbon footprint [kg CO_2e/kg GBE]	1.83	1.81
Margin of error [kg CO_2e/kg GBE]	0.07	0.07
Margin of error [%]	4.0%	4.0%

Table 11: Carbon footprint including and excluding land use change–related emissions, Central Highlands

6.2.7.2 Southern Sumatra

A similar share of farmers in Southern Sumatra (2 percent) reported expanding their coffee plots in the past 20 years; however, unlike in the Central Highlands, where farm expansion mostly happened at the expense of tree crops, more farmers in Southern Sumatra reported having cleared natural vegetation or forests, leading to a larger impact on the overall carbon footprint.

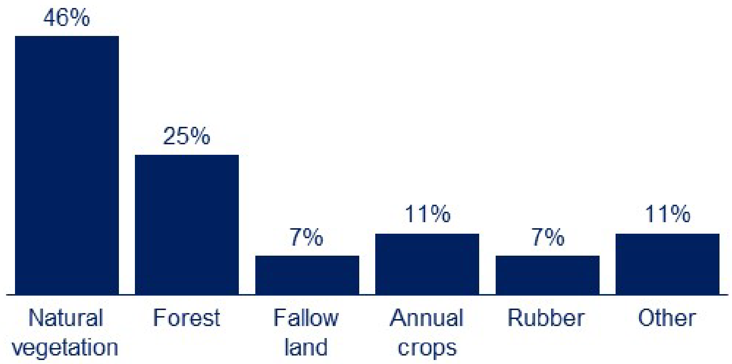


Figure 35: Land type before coffee farm expansion (share of all farmers that expanded their farms), Southern Sumatra

The variability of the results is higher in Southern Sumatra. The long-tailed distribution of the LUC-related emissions in Bengkulu highlights a great degree of variability due to a few farms that skew the entire dataset because of the considerable level of emissions caused by the clearing of relatively large areas (a few hectares) of forest. For some farms, these emissions can reach 60 to 70 kg CO_2e per kg GBE produced per year.

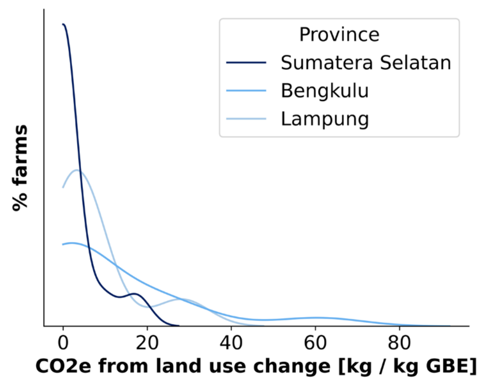


Figure 36: Distribution of farm-level carbon footprint from land use change per province, Southern Sumatra

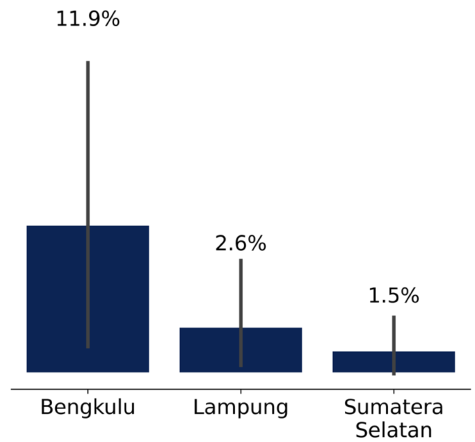


Figure 37: Share of land use change in total footprint per province, Southern Sumatra

As for the Central Highlands, the carbon footprint calculations were made both including and excluding LUC emissions, for the purposes of comparison (Table 12). Excluding LUC emissions decreases the total footprint for this origin from 2.38 to 2.30 kg CO_2e/kg GBE (3 percent) and reduces the margin of error by 0.4 percentage points. Although land use change does not seem to make a substantial difference at the origin level, mostly because the variability of Bengkulu is counterbalanced by the low values of Sumatra Selatan, it has a considerable impact at the province level: excluding land use change decreases the margin of error for Bengkulu from 13 percent to 7 percent, well within initial precision targets.

	Including LUC	Excluding LUC
Carbon footprint [kg CO_2e/kg GBE]	2.38	2.30
Margin of error [kg CO_2e/kg GBE]	0.11	0.09
Margin of error [%]	4.5%	4.1%

Table 12: Carbon footprint including and excluding land use change–related emissions, Southern Sumatra

6.3 Uncertainty Assessment

The uncertainty of the results was captured via the margin of error attached to each result, calculated at a 95-percent confidence level following the methodology outlined in Appendix 9.1. It measures the error incurred by the sampling approach. However, the uncertainty related to the Cool Farm Tool's modeling, its assumptions, and its emission factors are not included in this uncertainty assessment as this information is not made available by the Cool Farm Alliance.

6.3.1 Central Highlands

For the Central Highlands the margin of error at the origin level is ±0.07, which implies that the carbon footprint is between 1.76 and 1.90 kg CO_2e/kg GBE at a 95-percent confidence level.

The margins of error and confidence intervals at a per-province level are provided in Table 13.

Province	Margin of Error [kg CO_2e/kg GBE]	Margin of Error [%]	95% Confidence Interval
Gia Lai	±0.10	6%	[1.69, 1.89]
Lam Dong	±0.10	5%	[1.72, 1.92]
Dak Lak	±0.16	9%	[1.54, 1.86]
Dak Nong	±0.20	9%	[1.91, 2.21]
ALL	**±0.07**	**4%**	**[1.76, 1.90]**

Table 13: Margins of error per province, Central Highlands

6.3.2 Southern Sumatra

For Southern Sumatra, the margin of error at the origin level is ±0.11, meaning that the carbon footprint is between 2.27 and 2.49 kg CO_2e/kg GBE at a 95-percent confidence level.

The margins of error and confidence intervals at a per-province level are provided in Table 14.

Province	Margin of Error [kg CO_2e/kg GBE]	Margin of Error [%]	95% Confidence Interval
Bengkulu	±0.24	13%	[1.58, 2.06]
Lampung	±0.18	7%	[2.41, 2.77]
Sumatra Selatan	±0.16	6%	[2.28, 2.60]
ALL	**±0.11**	**4%**	**[2.27, 2.49]**

Table 14: Margins of error per province, Southern Sumatra

Bengkulu has a margin of error above the initial target of 10 percent province established with the Core Committee during the design of the sampling approach (see section 5.2.1). The high variability is caused by land use change emissions, which are more frequent in this province (see section 6.2.7.2

6.4 Impact of Co-products

Farmers in Vietnam and Indonesia often intercrop coffee with other species, producing commodities such as avocado, pepper, or durian in the same plots. These co-products may receive the same inputs and benefit from the same energy-intensive activities as coffee, such as irrigation or chemical application. Therefore, the estimated carbon footprint of the plot should be allocated between coffee and any co-products, based on their relative financial value.[19]

All results presented elsewhere in this report reflect the net carbon footprint of only coffee, removing the share attributable to co-products. However, this section attempts to provide some context about the impact of co-products by looking at the total emission footprints including co-products.

6.4.1 Central Highlands

The most important co-products of coffee in the Central Highlands, in terms of financial value, are cashew (present on 20 percent of farms and earning farmers an average of approximately VND 10.9 million, or US $438,[20] per year) and pepper (present on 18 percent of farms and earning farmers an average of VND 19.2 million, or US $772, per year). Avocado and durian, although commonly observed on farms in the Central Highlands, each provide less than half the revenue of cashew.

Compared to the average gross annual revenue from coffee of VND 132.9 million (US $5,343), intercrops typically account for only a small share of farmers' total revenue.

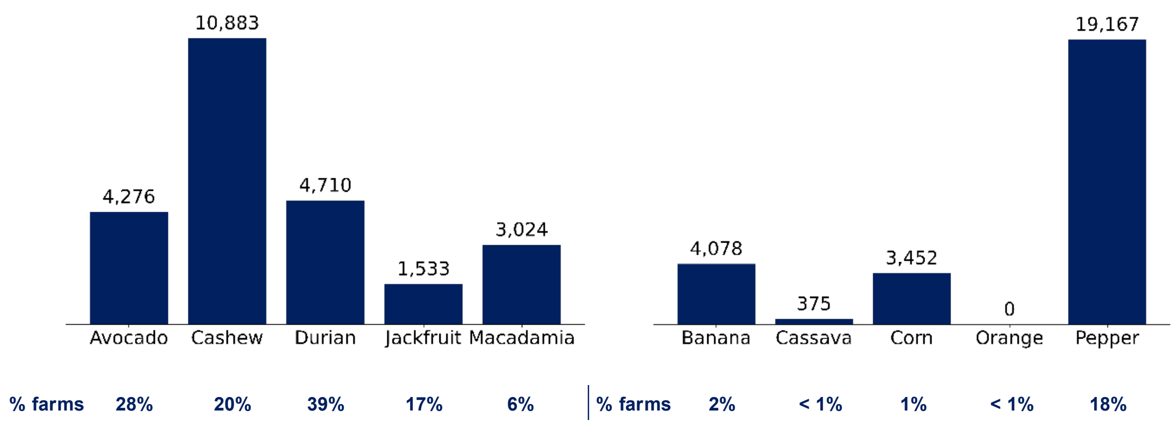


Figure 38: Average revenue from top 5 intercropped trees (left) and field crops (right), Central Highlands ('000 VND / year)

[19] Revenue data was provided by the farmer. Any intercropped crop that was not sold was considered to have no financial value. Plot-level emissions from such crops were attributed to coffee.
[20] Using an exchange rate from the end of the data collection period (Oct. 31, 2022) of 24,866:1 (https://www.forbes.com/advisor/money-transfer/currency-converter/usd-vnd/?amount=1).

Including the emissions attributable to co-products on coffee farms across the Central Highlands increases the overall carbon footprint by 8 percent. The effect is most pronounced in Dak Lak (+13 percent), where intercropping is much more common; in the districts of Ea Kar, Krong Bong, and Krong Pac, for example, including co-products raises the plot-level emissions by more than 30 percent. Conversely, in Lam Dong, where intercropping is relatively rare, the overall footprint does not change significantly with and without co-products included in the calculation.

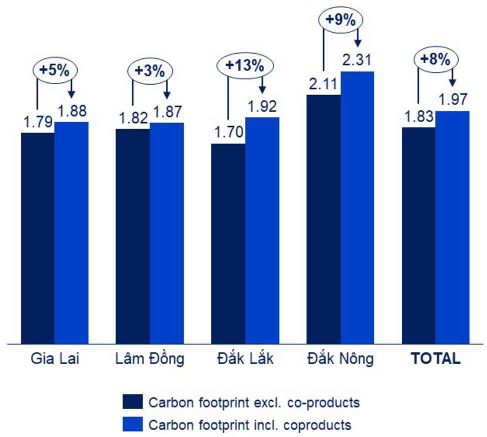


Figure 39: Emissions excluding/including co-products grown on plot, Central Highlands (kg CO_2e / kg GBE)

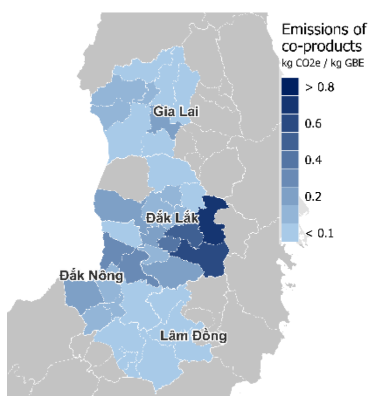


Figure 40: Emissions allocated to co-products, Central Highlands

6.4.2 Southern Sumatra

Avocado, banana, durian, and jengkol[21] are the most common co-products of coffee in Southern Sumatra, observed on 16 percent to 27 percent of farms. On average, they bring in between IDR 1.15 and IDR 1.46 million (approximately US $73 - US $93[22]) per year. This represents 6–8 percent of the average gross annual revenue from coffee sales, which stands at about IDR 17.7 million (US $1,130) per year.

[21] *Archidendron pauciflorum*, a species of flowering tree in the pea family, *Fabaceae*, native to Southeast Asia, where the seeds are a popular dish.
[22] Using an exchange rate from the end of the data collection period (Oct. 31, 2022) of 15,674:1 (https://www.forbes.com/advisor/money-transfer/currency-converter/usd-idr/?amount=1).

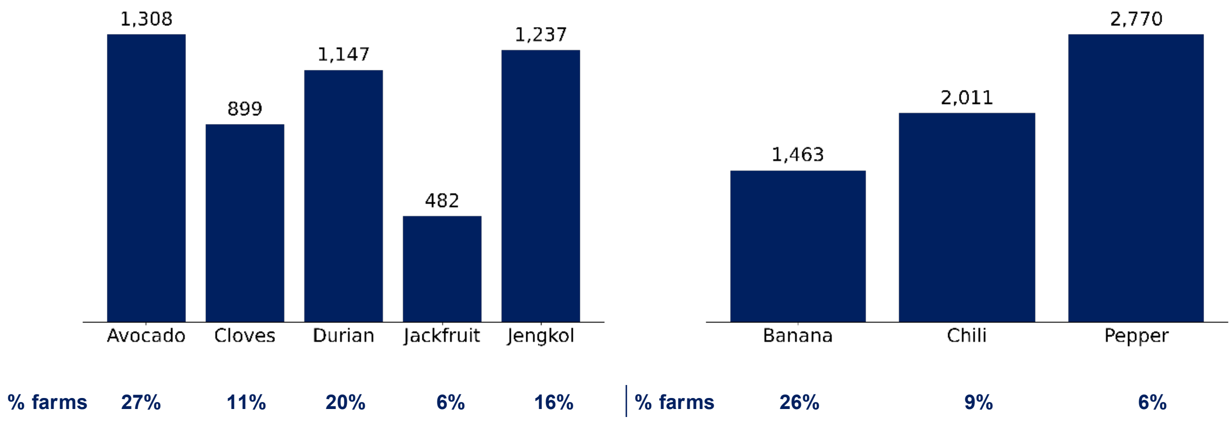


Figure 41: Average revenue from top 5 intercropped trees (left) and top 3 intercropped field crops (right), Southern Sumatra ('000 IDR / year)

Overall, emissions attributable to co-products account for a higher share of the total carbon footprint than in the Central Highlands: including emissions from co-products increases the overall footprint by 14 percent. The difference is most pronounced in Lampung, where including co-products in the calculation results in an increase of 21 percent.

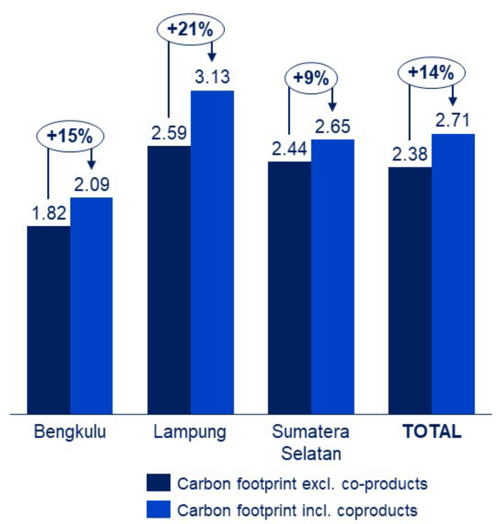


Figure 42: Emissions excluding/including co-products grown on plot, Southern Sumatra (kg CO_2e / kg GBE)

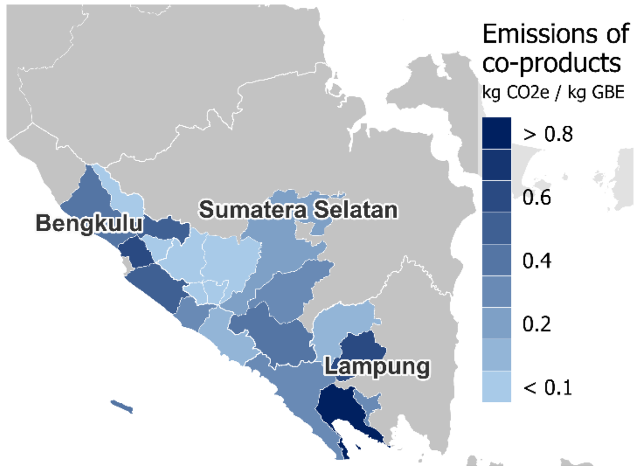


Figure 43: Emissions allocated to co-products, Southern Sumatra

6.5 Farmer Archetypes

The goal of the archetypes analysis was to identify patterns in farming practices and farm characteristics and form sub-groups of farmers with different levels of emissions. Therefore, the archetype-defining indicators should be closely related to emissions to create groups with statistically significant differences. After testing a wide range of indicators, two were identified as relevant: input usage (or volume of inorganic fertilizer applied per ha) and shade level. Consideration of these results in two classification systems, is presented in the subsections below.

Other indicators commonly used to group farmers in Southeast Asia, such as crop diversification, intensity of coffee farming, farm size, or regenerative agriculture practices, were not determined to have a significant impact on carbon footprint.[23] Such variables, therefore, could not be used to define archetypes or draw any meaningful insights.

6.5.1 Archetypes based on input usage

6.5.1.1 Definition

Three archetypes emerged based on input usage: low users, medium users, and high users. The breakpoints between the three categories in each origin were selected via the Jenks natural breaks classification method, adjusted so each category would have statistically different levels of emissions than the other two. More details on the methodology are available in Appendix 9.2.

[23] Because carbon sequestration, and more broadly carbon stock changes (apart from land use change), were excluded from the carbon footprint calculation, the impact of variables such as intercropping or regenerative agriculture practices in defining archetypes is minimal.

6.5.1.1.1 Central Highlands

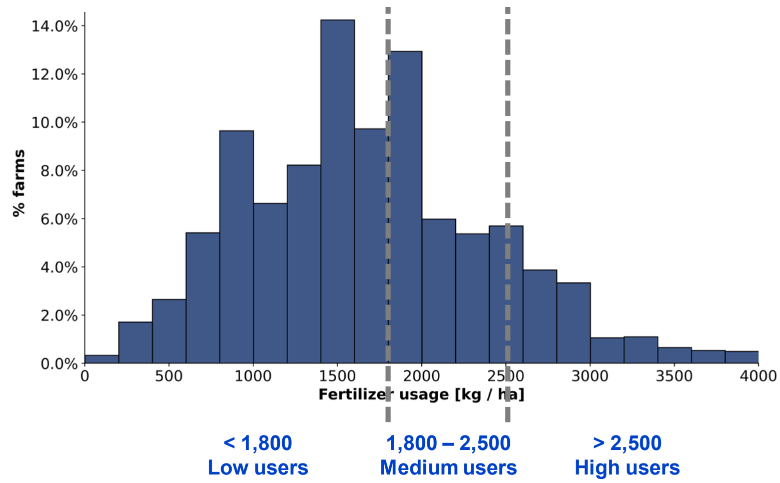


Figure 44: Distribution of volume of inorganic fertilizer applied per hectare per year, Central Highlands

In the Central Highlands, the three archetypes are defined using the following breakpoints:

	kg inorganic fertilizer / ha	% farms
Low input users:	**0 – 1,800**	59%
Medium input users:	**1,800 – 2,500**	28%
High input users:	**> 2,500**	13%

Table 15: Breakpoints used for the definition of archetypes based on fertilizer use, Central Highlands

Vietnam's Western Highlands Agriculture & Forestry Science Institute (WASI) provides guidelines on recommended fertilizer quantities for Robusta coffee. Although they vary according to the crop type, soil type, geographical location, and fertilizer type, they point toward an average recommendation of 2,000 kg (about 4409.24 lb) of inorganic fertilizer per hectare per year. Thus, farmers categorized as medium input users are aligned with WASI's recommendations. On the other hand, the high input users are at risk of applying excessive amounts of fertilizer, leading to significantly higher nitrous oxide emissions as the plant uptake reaches its maximum. WASI is currently running a project, with support from Enveritas, to better define recommended fertilizer quantities and understand the impacts of fertilizer overuse.

The prevalence of each archetype varies per province: Lam Dong has the highest proportion of high-input users, while Dak Lak has the lowest.

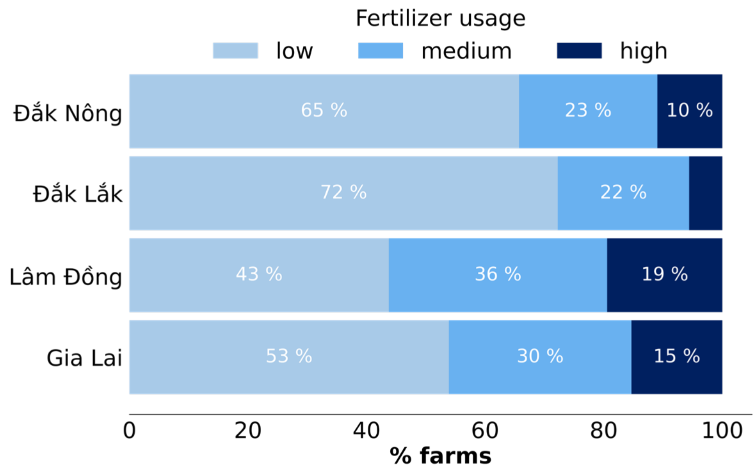


Figure 45: Prevalence of fertilizer archetypes per province, Central Highlands

Levels of emissions per kg GBE produced are higher for the high-input users, which can be explained by the fact that the gains in productivity induced by greater use of inputs do not fully counterbalance the additional emissions associated with their use.

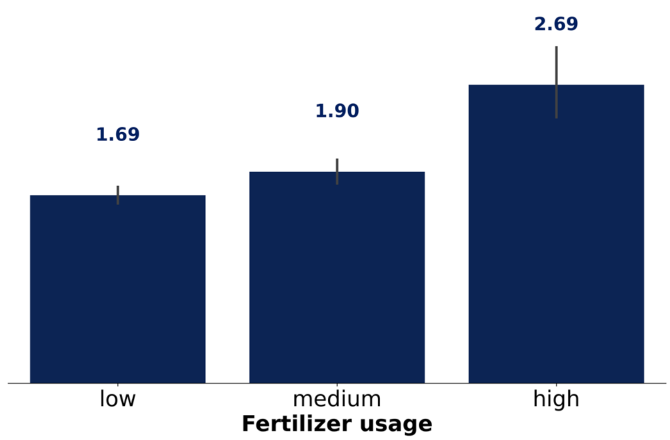


Figure 46: CO_2e emissions per fertilizer archetype [kg CO_2e/kg GBE], Central Highlands

6.5.1.1.2 Southern Sumatra

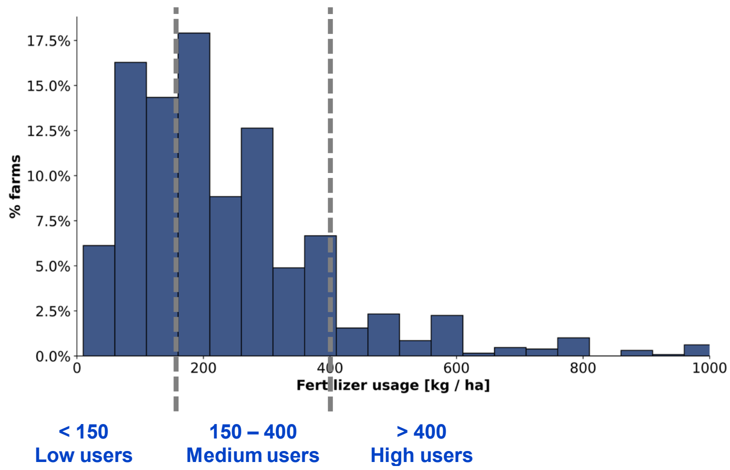


Figure 47: Distribution of volume of inorganic fertilizer applied per hectare per year, Southern Sumatra

The breakpoints used to define the three archetypes in Southern Sumatra are as follows:

	kg inorganic fertilizer / ha	% farms
Low input users:	**0 – 150**	60%
Medium input users:	**150 – 400**	32%
High input users:	**> 400**	8%

Table 16: Breakpoints used for the definition of archetypes based on fertilizer use, Southern Sumatra

The breakpoints for this origin are significantly lower than in the Central Highlands because of the smaller quantities of inorganic fertilizers applied. Almost no farmers in Southern Sumatra are at risk of fertilizer overuse based on the 2,000 kg/ha threshold.

Bengkulu has a higher share of low-input users than the two other provinces; the high-input users are mostly concentrated in Lampung.

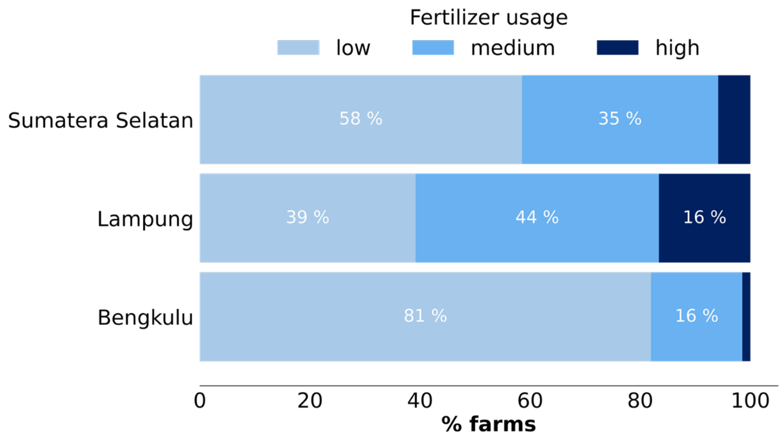


Figure 48: Prevalence of fertilizer archetypes per province, Southern Sumatra

The difference in levels of emissions per kg GBE produced across categories is even higher in Southern Sumatra than in the Central Highlands, with farmers in the high-input category emitting approximately almost twice as much per kg GBE as those in the other two groups.

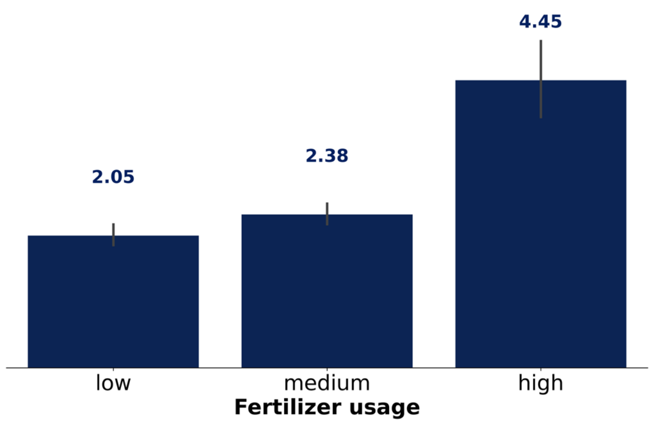


Figure 49: CO_2e emissions per fertilizer archetype [kg CO_2e/kg GBE], Southern Sumatra

6.5.1.2 Comparative analyses

The following two tables show the average values of some descriptive factors per archetype. Statistically significant differences between archetypes ($p < 0.05$ using t-tests) are highlighted in bold; for example, in both origins the average yield values in all three categories are statistically different from each other.

6.5.1.2.1 Central Highlands

	Low input users	**Medium** input users	**High** input users
Average yield [kg / ha]	**2,527**	**3,308**	**3,614**
Average coffee plot size [ha]	1.16	1.20	1.19
% households where coffee is the main source of income	**73%**	82%	80%
Average income from coffee ['000 VND / year]	**114,520**	163,607	168,036
% farmers with a high carbon sequestration potential	19%	17%	22%
% farmers part of a certification scheme	**10%**	**12%**	**15%**

Table 17: Comparative analysis across fertilizer archetypes, Central Highlands. Statistically significant differences are highlighted in bold (using t-test with max p-value of 0.05)

Low-input users in the Central Highlands have significantly lower yields than the other two archetypes. Consequently, these farmers have a lower average income from coffee and are less likely to report it as their main income source. The low-input users are also less likely to be members of a certification scheme.

6.5.1.2.2 Southern Sumatra

	Low input users	**Medium** input users	**High** input users
Average yield [kg / ha]	**630**	**762**	**1,032**
Average coffee plot size [ha]	1.14	1.18	1.19
% households where coffee is the main source of income	**52%**	79%	80%
Average income from coffee ['000 IDR / year]	**15,470**	**20,517**	**27,683**
% farmers with a high carbon sequestration potential	**22%**	**14%**	**9%**
% farmers part of a certification scheme	**4%**	**7%**	**13%**

Table 18: Comparative analysis across fertilizer archetypes, Southern Sumatra. Statistically significant differences are highlighted in bold (using t-test with max p-value of 0.05)

Among the archetypes in Southern Sumatra, yields and average incomes from coffee are significantly higher for medium and high-input users than for low-input users. Low-input users are less likely to be financially dependent on coffee than those in the other two groups and are also less likely to be members of certification schemes. Additionally, unlike in the Central Highlands, a statistically significant difference between archetypes can be observed regarding carbon sequestration potential: low-input users have the highest sequestration potential, with the rate progressively declining across the medium and high-input use groups. Farmers in this origin who use more inputs are more likely to practice intensive coffee farming and tend to intercrop less to optimize productivity.

6.5.2 Archetypes based on shade level

6.5.2.1 Definition

The shade level of a coffee plot is defined as the percentage of canopy cover above the coffee trees. The canopy can be composed of a variety of trees, which may be present on the plot for shade or intercropping purposes.

During field surveys, plots were assigned one of the following shade levels: no shade, light shade (1–30 percent canopy cover), medium shade (30–60 percent canopy cover), or heavy shade (more than 60 percent canopy cover). Simulations were conducted to assess which groupings of categories were most adapted to the definition of archetypes (i.e., created clusters of farmers with statistically different emission levels and a comparable population size). The most adapted grouping consisted of two clusters: the "unshaded farming system" cluster, which includes all farms with no or light shade (canopy cover below 30 percent), and the "shaded farming system" cluster, which includes all farms with medium to heavy shade (canopy cover above 30 percent). Attempts to cluster farmers into three different groups did not yield statistically significant results.

6.5.2.1.1 Central Highlands

Seven out of ten farmers in the Central Highlands (72 percent fall into the unshaded farming system group. However, this split varies greatly across provinces: while only 10 percent of Lam Dong farmers have more than 30 percent canopy cover on their farms, more than half of Dak Lak farmers grow their coffee under shade.

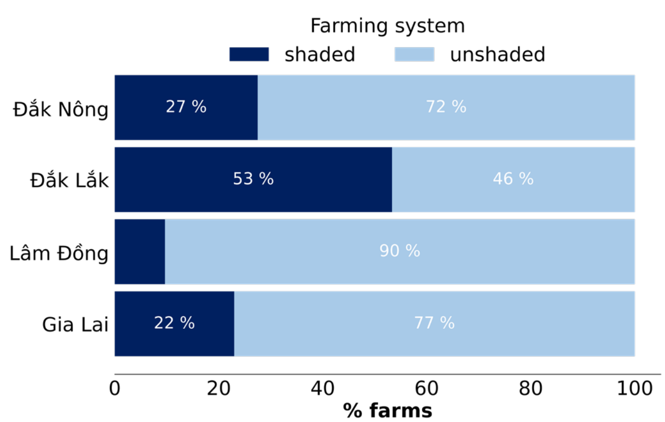


Figure 50: Prevalence of farming systems per province, Central Highlands

On average, farmers who practice shaded coffee culture have emission footprints 16 percent lower than those who produce sun-grown coffee, mostly because coffee farming is less input-intensive on such farms.

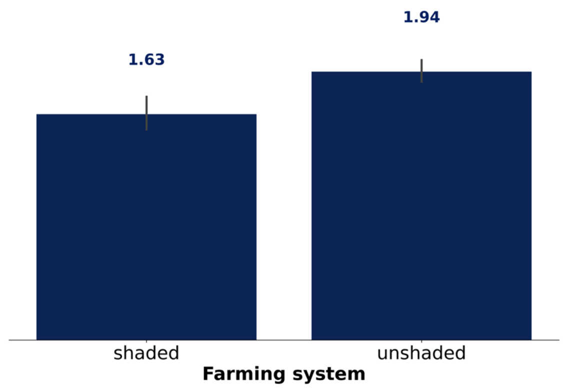


Figure 51: CO_2e emissions per farming system [kg CO_2e/kg GBE], Central Highlands

6.5.2.1.2 Southern Sumatra

The share of farmers who practice shaded coffee culture is much higher in Southern Sumatra than in the Central Highlands: 57 percent grow their coffee under medium to heavy shade. The province-level differences are less substantial but still visible: farmers in Bengkulu are most likely to maintain medium to heavy canopy cover, while more than half of farmers in Lampung grow their coffee under no or light shade.

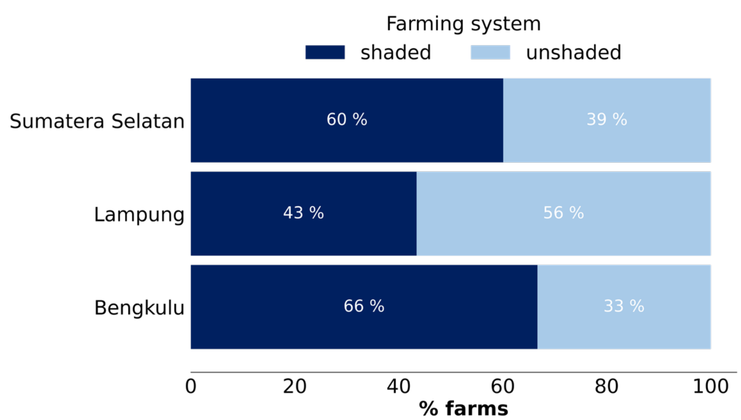


Figure 52: Prevalence of farming systems per province, Southern Sumatra

As in the Central Highlands, shaded coffee culture emits less CO_2e: there is a 12 percent reduction in emissions when moving from sun-grown to shaded coffee production.

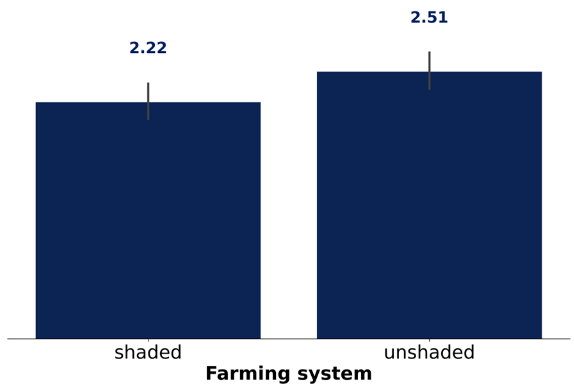


Figure 53: CO_2e emissions per farming system [kg CO_2e/kg GBE], Southern Sumatra

6.5.2.2 Comparative analyses

6.5.2.2.1 Central Highlands

Unshaded farming systems are characterized by more intensive farming: yields and input application rates are significantly higher, and farmers are less likely to intercrop and more likely to rely on coffee as their primary source of income. Unsurprisingly, shade-grown coffee farming systems have a significantly higher carbon sequestration potential, as trees that provide shade can act as a carbon sink.

	Unshaded farming systems	**Shaded** farming systems
Average yield [kg / ha]	**2,925**	**2,746**
Average coffee plot size [ha]	1.18	1.14
Average inorganic fertilizer usage [kg/ ha / year]	**1,760**	**1,630**
% households where coffee is the main source of income	**79%**	**70%**
Average income from coffee ['000 VND / year]	**138,877**	**121,882**
% farmers with a high carbon sequestration potential	**14%**	**33%**
% farmers part of a certification scheme	10%	13%
% farms with intercropped trees	**60%**	**83%**

Table 19: Comparative analysis across farming system archetypes, Central Highlands. Statistically significant differences are highlighted in bold (using t-test with max p-value of 0.05)

6.5.2.2.2 Southern Sumatra

Unshaded farming systems are also linked to intensive farming in Southern Sumatra. Farmers who grow their coffee in light or no shade use 24 percent more inorganic fertilizer per hectare than those who practice shaded coffee culture, resulting in higher yields and increased likelihood of reliance on coffee as the main source of household income.

As in the Central Highlands, shaded plots have a carbon sequestration potential more than twice as high as plots with minimal shade; however, in Southern Sumatra the levels of intercropping are similar in both types of farming systems. This points to the fact that, unlike coffee farms in the Central Highlands, Southern Sumatran farms have tree species that are not considered intercrops but provide shade (this is the case on 73 percent of all farms). The most common such tree species are gamal (*Gliricidia sepium*), sengon (*Paraserianthes falcataria*), and lamtoro (*Leucaena leucocephala*). They often play multiple roles, such as providing fodder or timber as well as fixing nitrogen and providing shade to the crops. The greater canopy cover and tree diversity in this origin highlights a higher level of biodiversity than in the Central Highlands, despite the overall higher carbon footprint.

	Unshaded farming systems	**Shaded** farming systems
Average yield [kg / ha]	**730**	**687**
Average coffee plot size [ha]	1.13	1.17
Average inorganic fertilizer usage [kg/ ha / year]	**309**	**249**
% households where coffee is the main source of income	**71%**	**57%**
Average income from coffee ['000 IDR / year]	18,730	17,583
% farmers with a high carbon sequestration potential	**11%**	**24%**
% farmers part of a certification scheme	6%	6%
% farms with intercropped trees	53%	56%

Table 20: Comparative analysis across farming system archetypes, Southern Sumatra. Statistically significant differences are highlighted in bold (using t-test with max p-value of 0.05)

6.6 Correlation Analyses

6.6.1 Correlation matrix

A relevant set of descriptive variables was selected from the database and the correlation coefficient (*r*) between each of those variables and the carbon footprint was calculated, using data aggregated at the district level. This section provides details on some results from the following two figures.

6.6.1.1 Central Highlands

Figure 54: Correlation coefficients between descriptive variables and carbon footprint, Central Highlands

6.6.1.2 Southern Sumatra

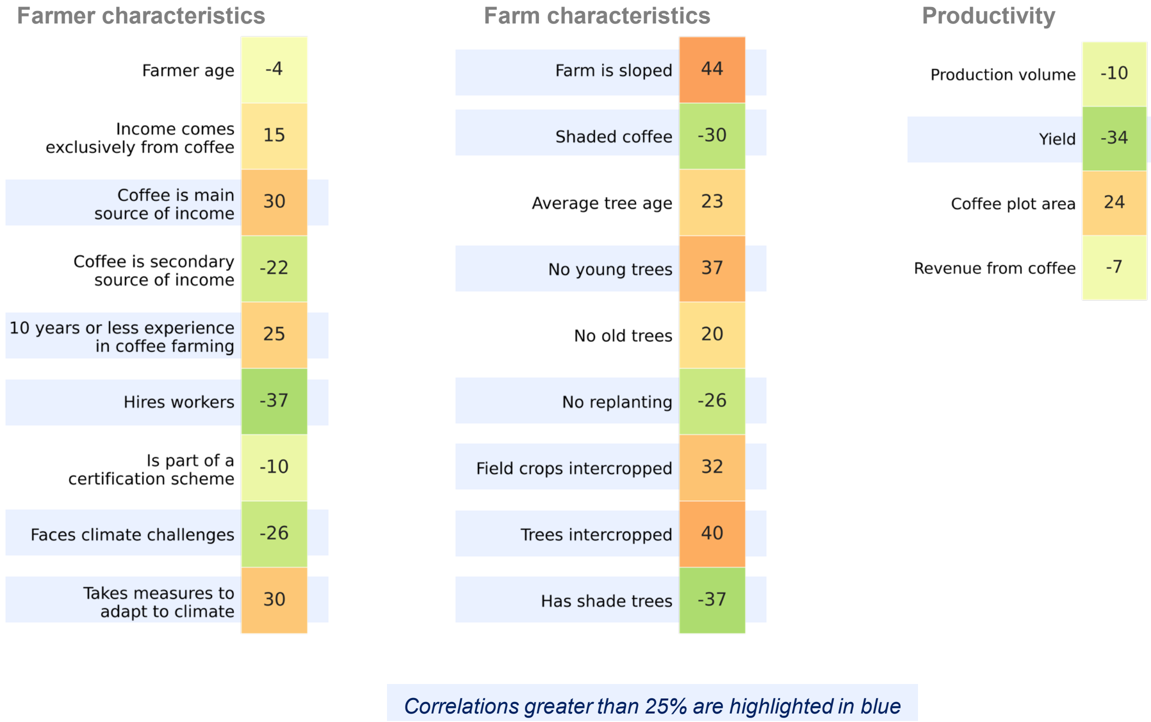


Figure 55: Correlation coefficients between descriptive variables and carbon footprint, Southern Sumatra

6.6.2 Deep dives on some correlated variables

6.6.2.1 Certification

6.6.2.1.1 Central Highlands

In the Central Highlands, 11 percent of the farmers surveyed report being certified, with the highest concentration in Dak Lak (20 percent) and the lowest in Dak Nong (2 percent). 4C is by far the most common certification scheme, followed by Rainforest Alliance.

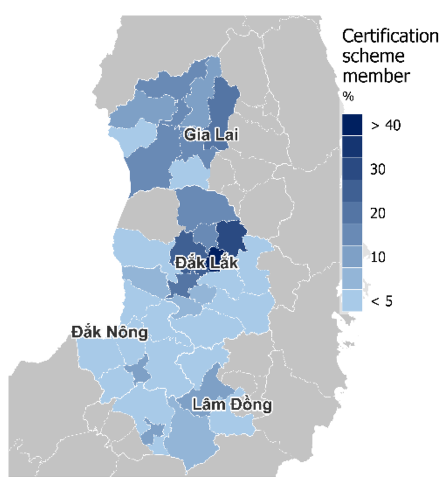


Figure 56: Share of certified farmers per district, Central Highlands

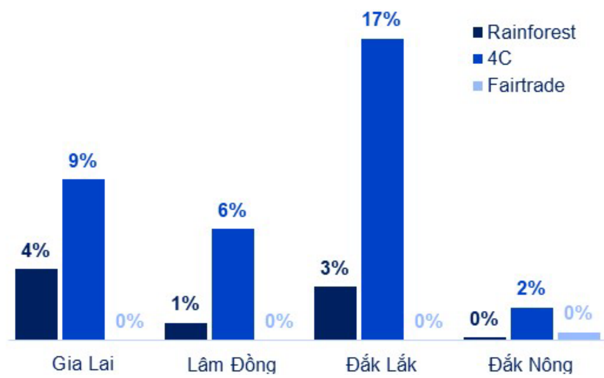


Figure 57: Share of certified farmers per province, split by certification scheme, Central Highlands

Farmers who are members of certification schemes have 9 percent lower emissions by volume produced than non-certified farmers. This difference can be explained by higher yields among this group, which more than counterbalance their increased use of inorganic fertilizers.

	Certified	Non-certified
Share:	**11%**	**89%**
Yield [kg/ha]:	**3,041**	**2,854**
Fertilizer volume applied [kg/ha]:	**1,832**	**1,711**
Total emissions [kg CO2e /kg GBE]:	**1.70** ±0.11*	**1.87** ±0.07*
Emissions per category [kg CO2e /kg GBE]:		
Fertilizer production	0.30	0.35
Fertilizer use and soil	0.94	1.34
Energy use (field)	0.01	0.02
Energy use (processing)	0.01	0.01
Energy use (irrigation)	0.12	0.13
Crop protection	0.00	0.00
Residue management	0.25	0.23
Waste water	0.00	0.00
Transport	0.05	0.06
Land use change	0.01	0.02

Table 21: Certified vs. non-certified farmer characteristics, Central Highlands

6.6.2.1.2 Southern Sumatra

In Southern Sumatra, only 7 percent of surveyed farmers report being certified. The share is close to 0 percent in Bengkulu. The only scheme certified farmers mentioned is 4C.

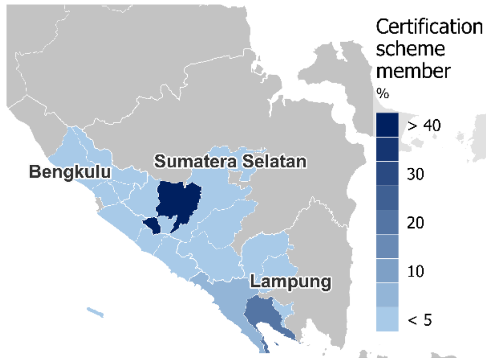


Figure 58: Share of certified farmers per district, Southern Sumatra

The sub-sample of certified farmers in this origin is too small to draw any meaningful conclusions about the carbon footprints of certified vs. non-certified farms.

	Certified	Non-certified
Share:	7%	93%
Yield [kg/ha]:	818	698
Fertilizer volume applied [kg/ha]:	352	269
Total emissions [kg CO2e /kg GBE]:	2.50 ±0.41*	2.34 ±0.13*

Table 22: Certified vs. non-certified farmer characteristics, Southern Sumatra

6.6.2.2 Yield

6.6.2.2.1 Central Highlands

As carbon footprint is reported on a per kg GBE basis, yield is one of the strongest drivers. With a yield 20 percent lower than the average across the three other provinces, Dak Nong has the highest carbon footprint of the four provinces in the Central Highlands.

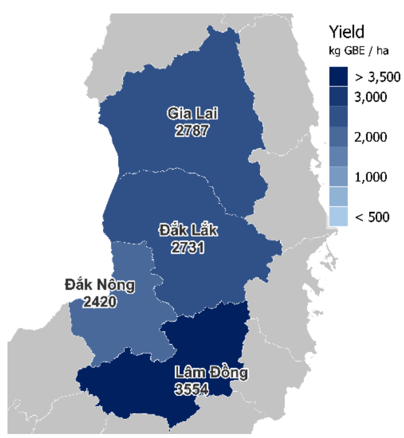


Figure 59: Coffee yield per province, Central Highland

The relationship between yield and carbon footprint in the Central Highlands is presented in the following figure. In general, the higher the yield, the lower the emission intensity per kg GBE produced.

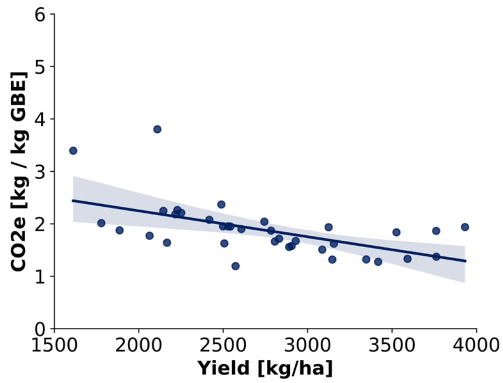


Figure 60: CO_2e emissions vs. yield (district level), Central Highlands

However, Lam Dong, despite having a yield 34 percent higher than the average across the other three provinces, does not have a significantly different carbon footprint because of the high use of inorganic fertilizers by farmers in this province. As mentioned previously, **fertilizer efficiency (volume applied per kg GBE produced) is the best predictor of carbon footprint; this indicator has a 79 percent correlation with CO_2e emissions.**

6.6.2.2.2 Southern Sumatra

Productivity does not significantly differ across the provinces of Southern Sumatra. Yields in all three provinces in this origin are close to the weighted country average of 705 kg GBE/ha.

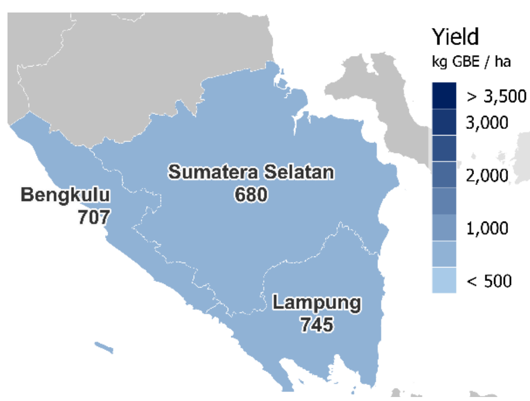


Figure 61: Coffee yield per province, Southern Sumatra

While there is some correlation between yield and carbon footprint in Southern Sumatra, it is not as strong as in the Central Highlands because the contribution of fertilizer production and use to the overall footprint is lower in this origin.

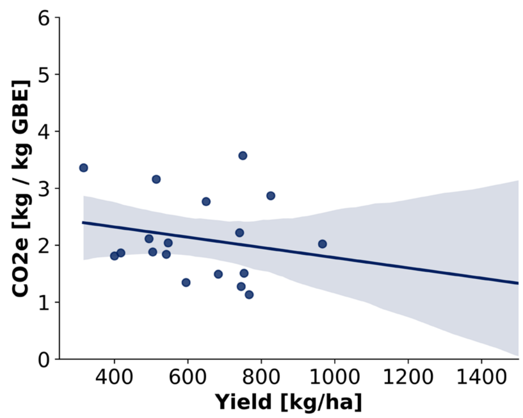


Figure 62: CO_2e emissions vs. yield (district level), Southern Sumatra

6.6.2.3 Coffee farm size

6.6.2.3.1 Central Highlands

The average size of coffee plots in the Central Highlands is 1.12 ha, but there is a large amount of variation across provinces. For example, the average landholding of farmers in Dak Nong is 80 percent larger than that of farmers in Dak Lak.

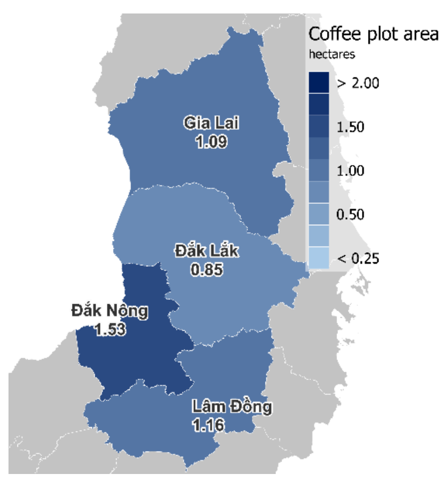


Figure 63: Coffee plot area per province, Central Highlands

As the following distribution shows, the differences in plot sizes do not have any discernible impact on carbon footprint.

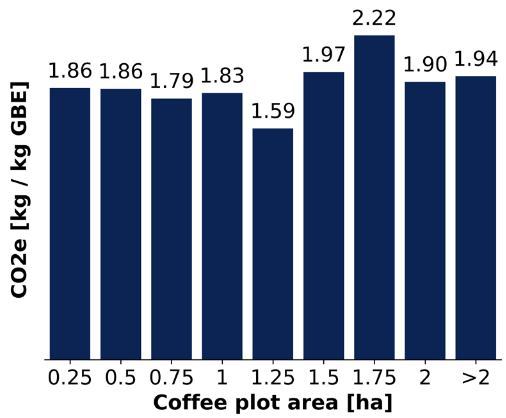


Figure 64: CO_2e emissions vs. average coffee plot area (farm level), Central Highlands

6.6.2.3.2 Southern Sumatra

The average farm size in Southern Sumatra is very similar to that in the Central Highlands, at 1.14 ha. There is little variation in farm sizes across provinces, and plot size does not appear to have an influence on carbon footprint.

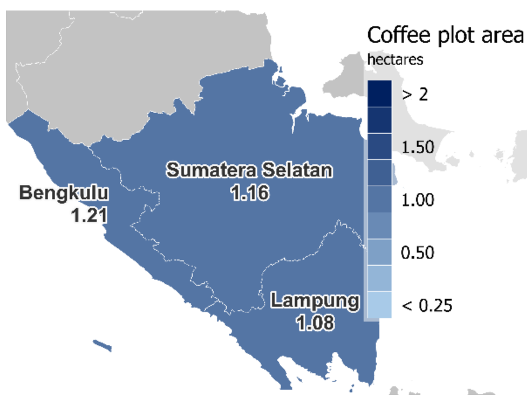


Figure 65: Coffee plot area per province, Southern Sumatra

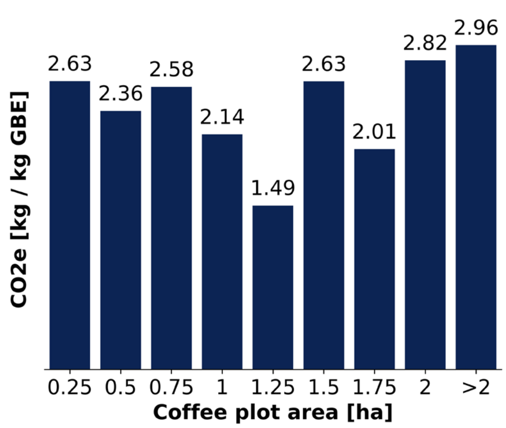


Figure 66: CO_2e emissions vs. average coffee plot area (farm level), Southern Sumatra

6.6.2.4 Coffee tree age

6.6.2.4.1 Central Highlands

The productive age of a typical coffee tree is between five and 20 years. The average age of coffee trees is similar in Gia Lai, Dak Lak, and Dak Nong provinces (approximately 12 years old), while farmers in Lam Dong have coffee trees that are on average three years older.

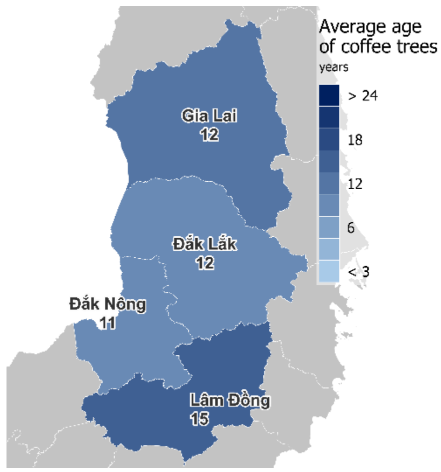


Figure 67: Average age of coffee trees per province, Central Highlands

Although there is no relationship between the age of trees and carbon footprint, the share of very young trees on the farm has a positive correlation with CO_2e emissions. Plots with more than 10 percent of trees that are less than three to four years old have a carbon footprint 34 higher than the country average of 1.83 kg CO_2e/kg GBE. The reason for this is that young trees do not produce as much coffee as mature ones, but still require sizable inputs to grow. Conversely, the share of older trees on a farm has no impact on the footprint. This is because whereas old trees, like younger ones, do not produce much, they do not require the application of extra inputs.

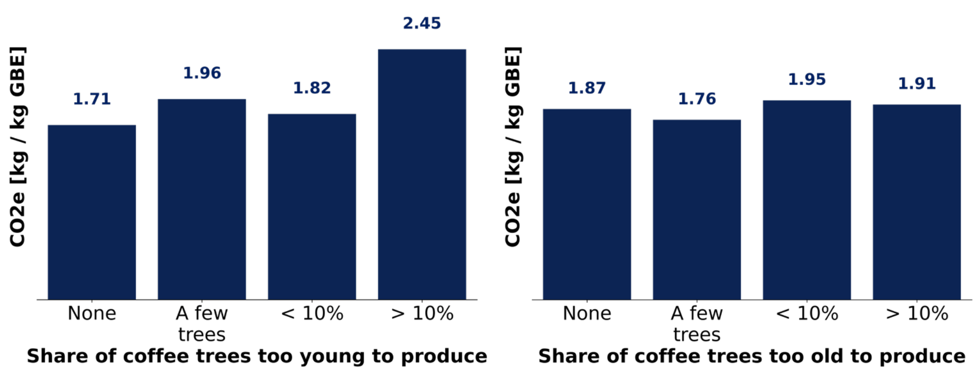


Figure 68: CO_2e emissions vs. share of coffee trees too young/old to produce optimally, Central Highlands

6.6.2.4.2 Southern Sumatra

There is considerable variation in average coffee tree ages across provinces in Southern Sumatra, from 13 years in Bengkulu to 21 years in Lampung, and the average tree age at an origin level is higher than in the Central Highlands (17 years vs. 12.5 years).

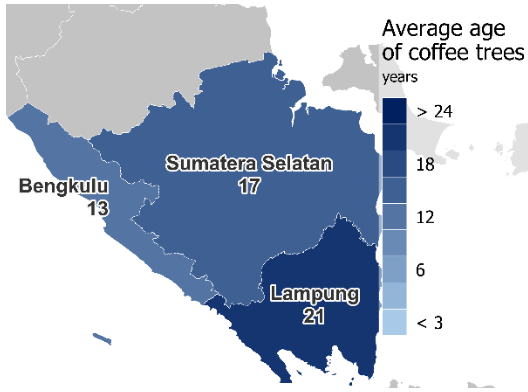


Figure 69: Average age of coffee trees per province, Southern Sumatra

As in the Central Highlands, farms with more than 10 percent of the trees under three to four years old have emissions 34 percent above the country average (2.38 kg CO_2e/kg GBE). Meanwhile, the share of trees on a farm that are too old to produce optimally does not show any visible correlation with carbon footprint.

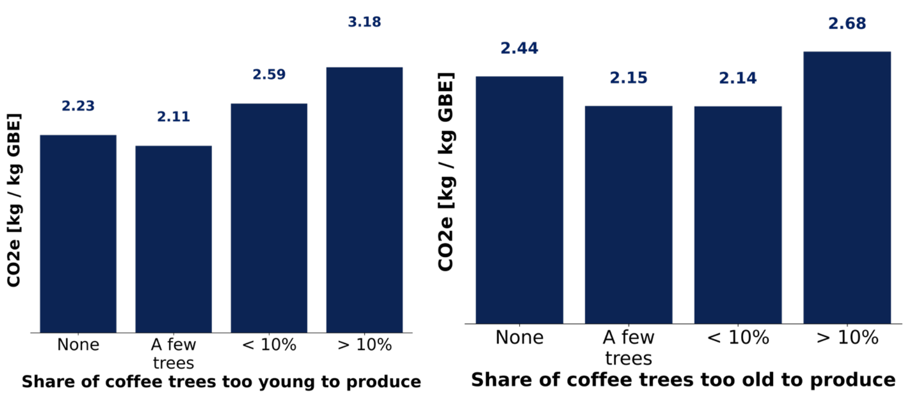


Figure 70: CO_2e emissions vs. share of coffee trees too young/old to produce optimally, Southern Sumatra

6.6.2.5 Intercropping

6.6.2.5.1 Central Highlands

About one in five farmers in the Central Highlands (19 percent intercrop their coffee with field crops (most commonly pepper). Two-thirds of farmers intercrop with tree crops such as durian, avocado, and cashew.

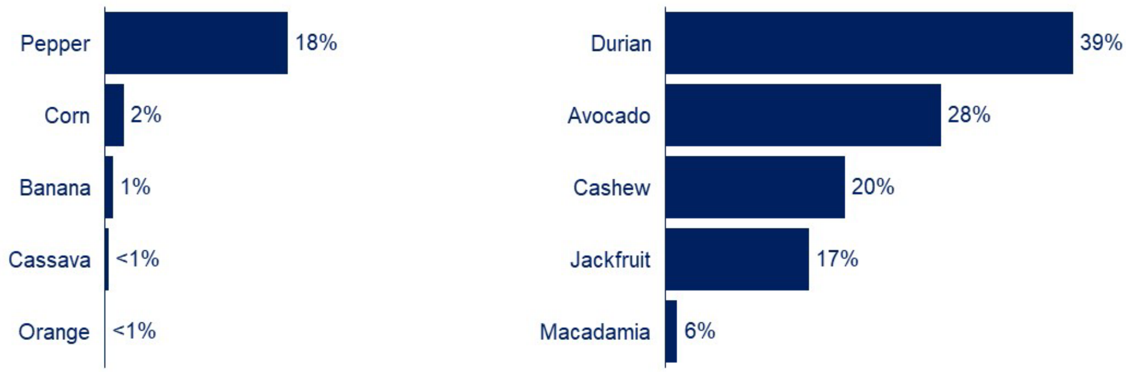


Figure 71: Field/tree crops most commonly intercropped with coffee, Central Highlands

There is a positive correlation between intercropping and emissions. A plausible explanation is that the per-hectare productivity is generally lower on farms where coffee trees compete with other crops, despite similar levels of input application. As explained in section 6.4, the estimated carbon footprint of a plot has been allocated between coffee and any co-products based on their relative financial value; however, not all crops grown on coffee plots are sold, and crops with a lower financial value than coffee account for proportionally less of the plot-level emissions.

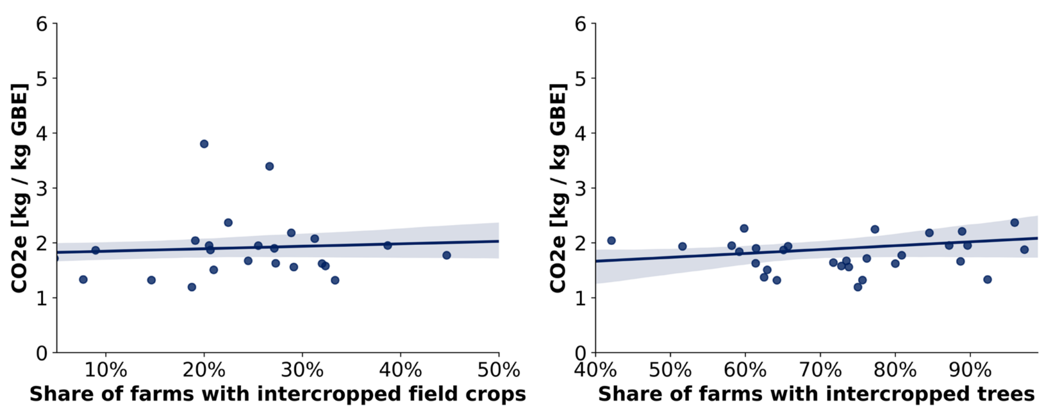


Figure 72: CO_2e emissions vs. share of farms with field/tree crops intercropped (district level), Central Highlands

6.6.2.5.2 Southern Sumatra

Thirty-one percent of farmers in Southern Sumatra intercrop their coffee with field crops, and 56 percent intercrop with tree crops. The most frequently intercropped field crop is banana, and common tree crops include avocado, durian, and jengkol.

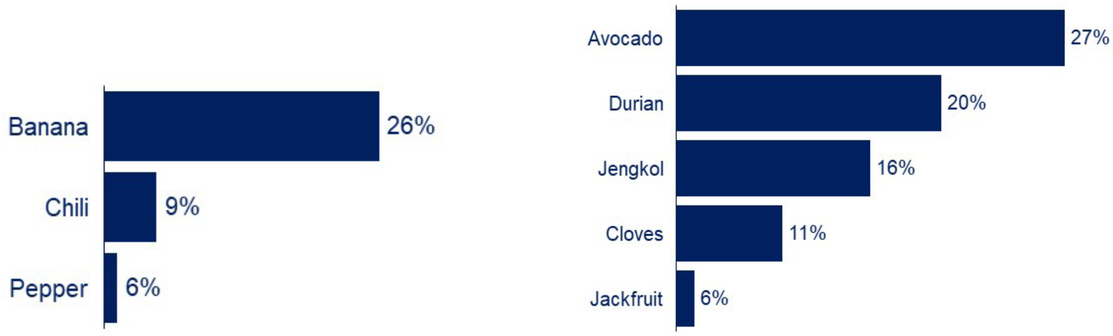


Figure 73: Field/tree crops most commonly intercropped with coffee (share of all farmers intercropping field/tree crops), Southern Sumatra

As in the Central Highlands, there is a positive correlation between intercropping and emissions. However, the correlation is stronger in Southern Sumatra because farmers in this origin generally receive less from the sales of the co-products. The share of farm-level emissions attributed to the intercropped products is therefore lower, and proportionally more emissions are attributed to coffee.

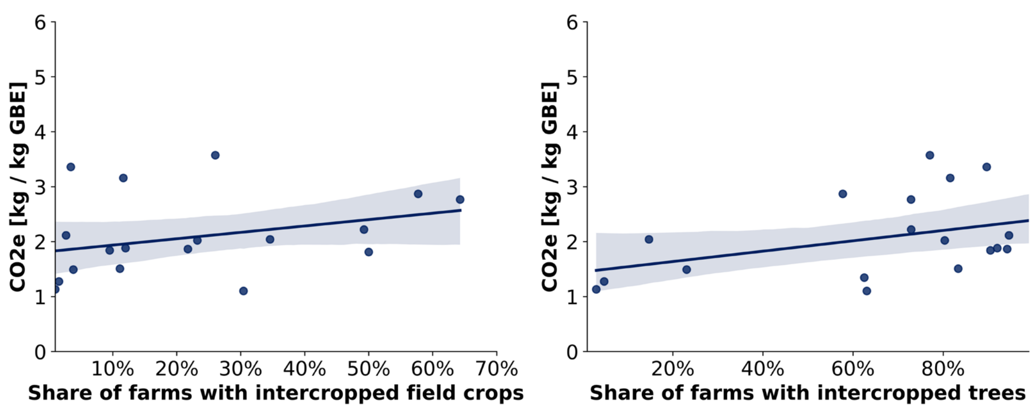


Figure 74: CO_2e emissions vs. share of farms with field/tree crops intercropped (district level), Southern Sumatra

6.6.2.6 Farmer income

Data collected provides sufficient information to assess farmers' gross income from coffee for the past year. However, net income cannot be reported as it requires modeling farmers' production costs, for which additional data is required.

6.6.2.6.1 Central Highlands

Revenue from coffee is correlated with productivity in the Central Highlands. For example, the average income is higher in Lam Dong, due to the high productivity in this province. Conversely, there is a negative correlation between income from coffee and emissions, which is explained by the differing impacts of yield on revenue and carbon footprint (as reported in section 6.6.2.2, farmers with lower yields tend to have a higher carbon footprint).

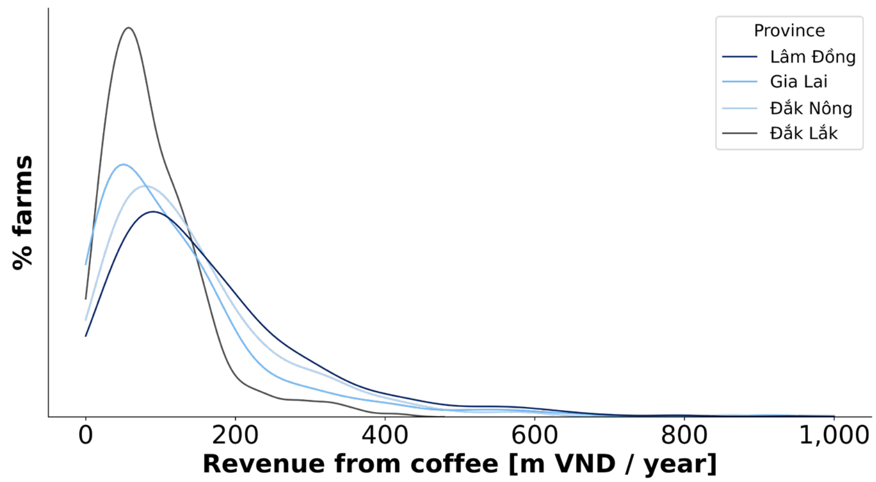


Figure 75: Revenue from coffee, distribution per province, Central Highlands

Around 77 percent of coffee-farming households in the Central Highlands rely on coffee as a primary source of income. The share is highest in Lam Dong, where farmers tend to earn higher incomes from coffee due to greater productivity. Financial dependence on coffee, however, is not linked to emissions; farmers who rely on other sources of income have similar carbon footprints to farmers whose major source of income is coffee.

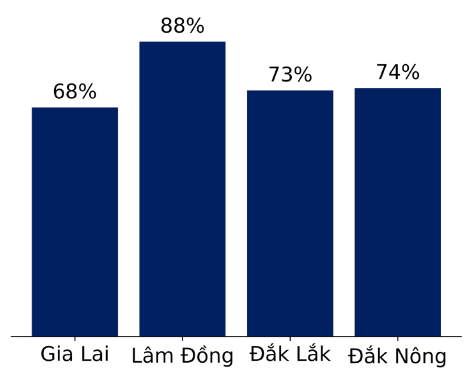


Figure 76: Share of farmers for whom coffee is the primary income source, Central Highlands

6.6.2.6.2 Southern Sumatra

Unlike in the Central Highlands, where the main driver of differences in revenue from coffee is productivity, differences in revenue in Southern Sumatra are driven by coffee prices. Farmers in Lampung earn more revenue from coffee than those in Bengkulu or Sumatra Selatan. Productivity is broadly comparable across provinces, but in addition to having slightly higher yields (745 kg GBE vs. a country average of 705 kg GBE/ha), farmers in Lampung receive IDR 24k (US $1.53) per kg GBE sold, compared to IDR 22k (US $1.40) in the other provinces.

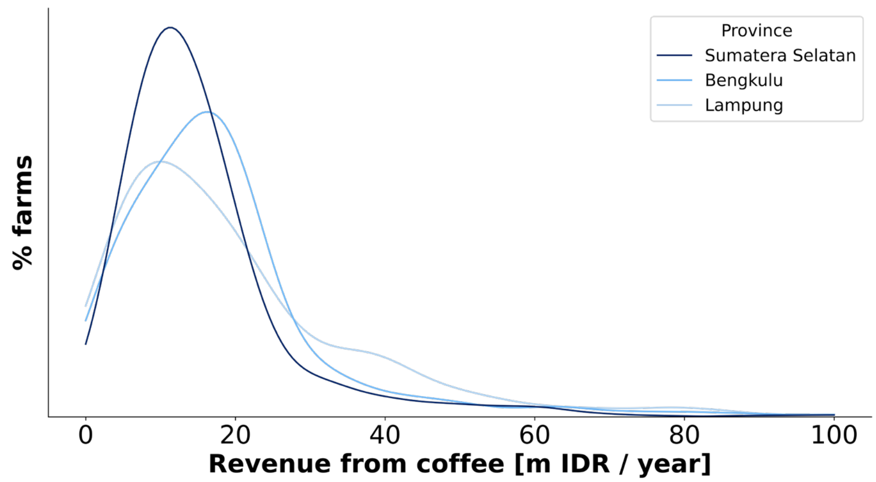


Figure 77: Revenue from coffee, distribution per province, Southern Sumatra

There is a correlation between farm-level carbon footprint and share of revenue derived from coffee. Farmers who rely on coffee for more than half or all of their income are likely to use more fertilizers to increase their productivity, which leads to higher emissions. For example, farmers who derive all of their income from coffee apply on average 319 kg of inorganic fertilizer per hectare, compared to 217 kg among farmers who rely on coffee for less than half of their household income. The correlation is not linear because, as described previously, in this origin, intercropping is correlated with higher per kg emissions from coffee, as coffee productivity on a per hectare basis is typically lower on farms where intercropping is practiced. This is the case where the economic value derived from intercrops (and thus the share of emissions attributed to them) is lower.

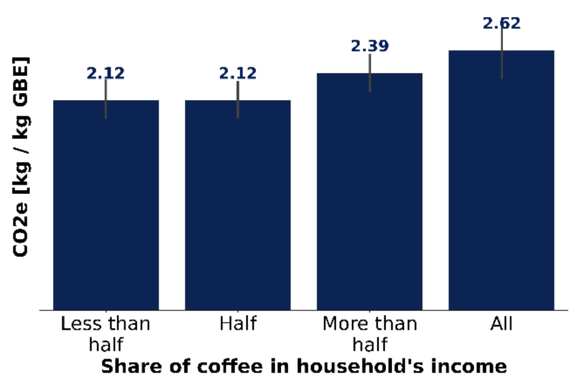


Figure 78: CO_2e emissions according to share of coffee in the farming household's income, Southern Sumatra

6.7 Carbon Sequestration Potential

International conventions suggest that carbon sequestration potential should be reported separately from emissions. Results from the Cool Farm Tool's land management section were split into two values, separating the carbon stock changes related to land use change (emissions from removal of trees or natural vegetation) and the biogenic carbon stock changes from intercropped or shade trees, or changes in farming practices that impact soil carbon.[24] The former is included in the carbon footprint results, while the latter are reported separately as "carbon sequestration potential" in this section. Following guidance from the Cool Farm Alliance (CFA), the team excluded any on-farm carbon stock changes in coffee trees (sequestration or removal) from the carbon footprint results in this report.

The CFA is currently working on a perennial module that will more accurately assess carbon sequestration for crops such as coffee (more details on the new methodology are available in their 2022 Technical Report[25]), but the new module will not be available before mid-2024.

The CFT currently has limited ability to provide robust farm-level estimates of carbon stock changes, so on the advice of the Core Committee it was decided to report the carbon sequestration potential in terms of categories (low/medium/high potential). While this will not provide a precise estimate of a farm's sequestration potential, it could be a useful indicator for year-on-year comparisons or for future projects whose aim is to improve the on-farm carbon stock assessments.

The categories were defined using the outputs from the CFT's land management section, excluding LUC-related emissions, on an area basis in order to remove the effect of yield. The breakpoint between low and medium potential was set at 200 kg CO_2e/ha/yr., which is equivalent to the yearly growth of about five shade trees of 50 cm diameter.[26] The breakpoint between medium and high potential was set at 1,000 kg (about 2204.62 lb) CO_2e/ha/yr., equivalent to the yearly growth of around 25 shade trees of 50 cm diameter. More details on the methodology are available in Appendix 9.4.

[24] Refer to section 2.9 of the CFT's technical documentation (Cool Farm Alliance (2022)) for further information on biomass stock change accounting.
[25] Cool Farm Alliance and Quantis (2022)
[26] According to the CFT.

6.7.1 Central Highlands

Dak Nong and Dak Lak have a higher share of farms with medium to high-carbon sequestration potential (over half) than the other two provinces in the Central Highlands.

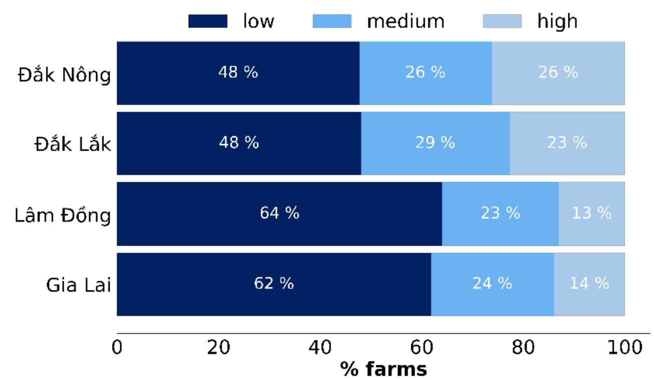


Figure 79: Carbon sequestration potential per province, Central Highlands

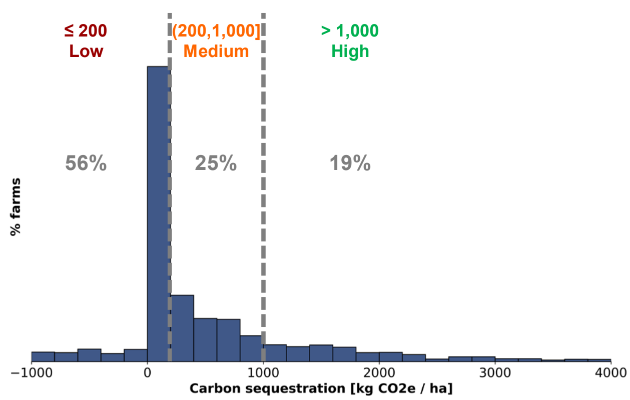


Figure 80: Carbon sequestration estimates from the CFT and classification into categories, Central Highlands

This difference is due to several factors that feed into the carbon stock change calculations of the CFT. First, use of cover crops (typically legumes, such as desmodium or crotalaria), which increase the amount of carbon stored in the soil, is more prevalent in those two provinces. This trend is particularly noticeable in Dak Lak, where more than 30 percent of farmers – almost twice the country average – plant cover crops. Second, shaded farming systems are more prevalent in Dak Lak and Dak Nong, with 53 percent and 28 percent farmers, respectively, growing coffee under medium to heavy shade (corresponding to more than 30 percent canopy cover). Shade trees are a major source of above- and belowground carbon storage, according to the CFT.

Third, the density of intercropped trees is higher in both provinces, leading to a higher carbon stock on the farm and a higher potential for sequestration as those trees grow.

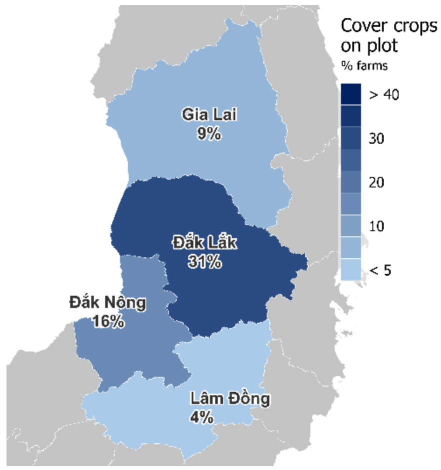


Figure 81: Share of farms with cover crops per province, Central Highlands

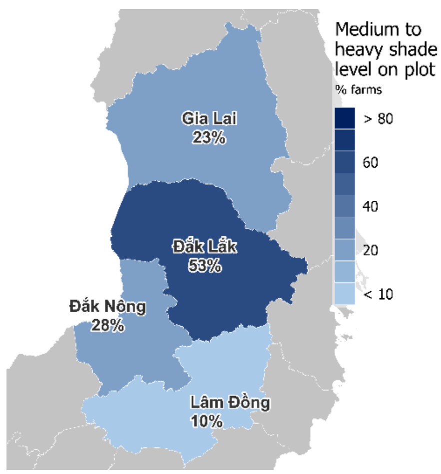


Figure 82: Share of shaded farms per province (>30% canopy cover), Central Highlands

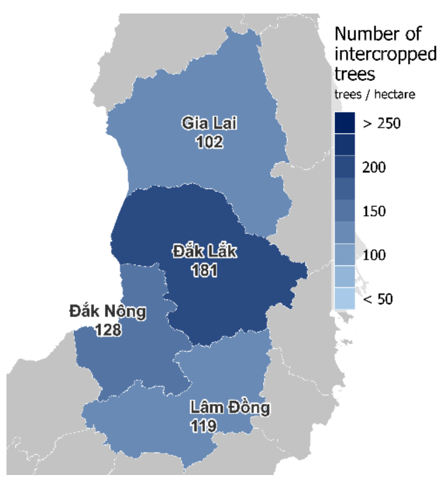


Figure 83: Density of intercropped trees per province, Central Highlands

6.7.2 Southern Sumatra

In Southern Sumatra, Bengkulu has a remarkably higher share of farms with medium to high-carbon sequestration potential than the other two provinces, with almost three-quarters of coffee farms falling into these categories.

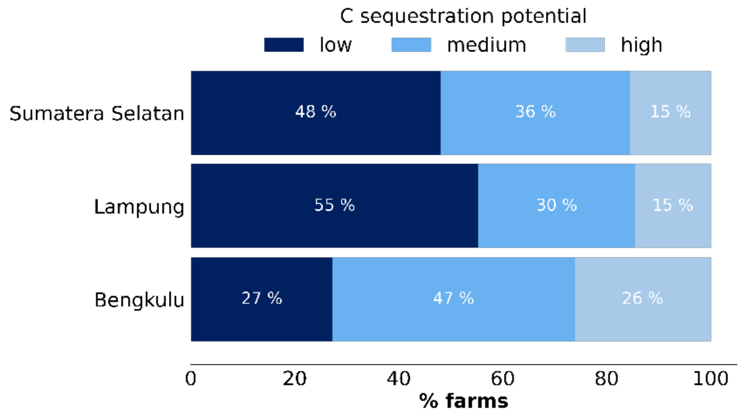


Figure 84: Carbon sequestration potential per province, Southern Sumatra

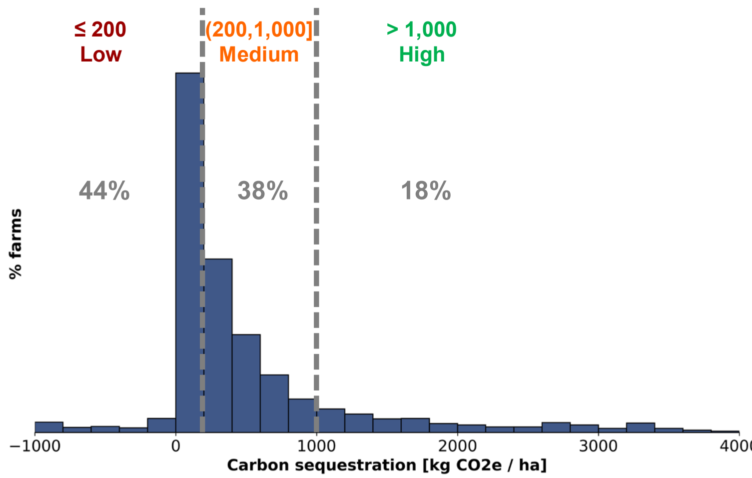


Figure 85: Carbon sequestration estimates from the CFT and classification into categories, Southern Sumatra

Like Dak Lak and Dak Nong in the Central Highlands, Bengkulu is characterized by a higher share of farms where farmers plant cover crops (20 percent vs. an average of 5 percent in the other provinces), more shaded farms (67 percent vs. 53 percent), and a higher density of intercropped trees (104 vs. 71 trees/ha).

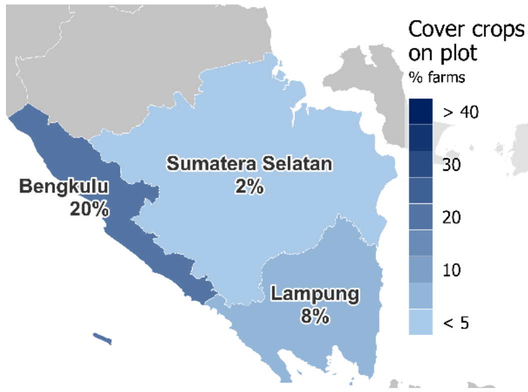


Figure 86: Share of farms with cover crops per province, Southern Sumatra

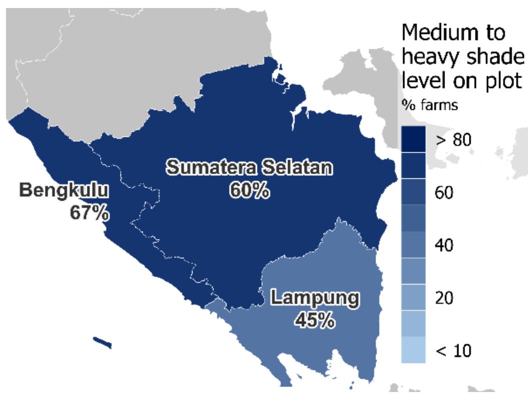


Figure 87: Share of shaded farms (>30% canopy cover) per province, Southern Sumatra

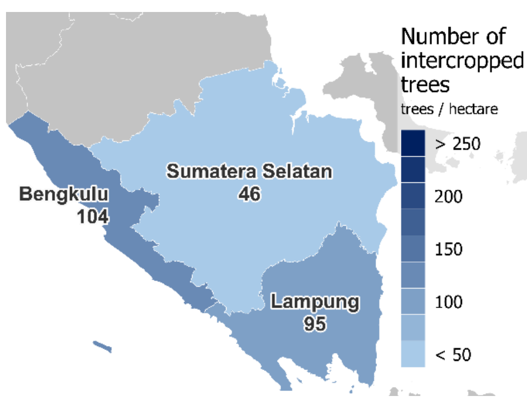


Figure 88: Density of intercropped trees per province, Southern Sumatra

6.8 Comparative Analysis

6.8.1 Overall approach

The goal of the comparative analysis is to highlight key areas of consistency and differences among various carbon footprint tools, and to attempt to explain the reasons for any identified discrepancies. To achieve this, the Core Committee requested that technical partners with their own tools and models run them on the raw farmer survey data collected for this project for the purposes of comparison. Lavazza Group, Sphera, and 4C agreed to do so and provided insights on their approaches and methodologies, along with carbon footprint results disaggregated by activity.

The results were then compared with those of the CFT, and any significant differences were highlighted. Further research was conducted to identify which model components (emission factors, assumptions, calculation methodologies, etc.) were accountable for the gaps, and recommendations were formulated on how to reconcile the issues.

6.8.2 Overview of the selected carbon footprint tools

6.8.2.1 SimaPro (Lavazza Group)

Lavazza Group uses SimaPro[27] for its internal carbon footprinting. As a comprehensive life cycle assessment tool, SimaPro calculates carbon footprint values not only at the farm level but also for downstream stages, such as packaging and transportation, as well as for field preparation activities and emissions at the nursery stage. While the latter are excluded because they are outside the CFT's scope, Lavazza Group kept emissions related to packaging and transportation in their overall result.

The main discrepancies between the methodologies of the CFT and Lavazza Group's tool are the following:

- SimaPro uses the Blonk LUC Impact Tool, which assigns fixed emission factors to any farm expansion within the past 20 years. Any farm less than 20 years old is considered to have caused land use change and is assigned a default country-level emission factor. As the default emission factor (EF) is null for Vietnam, this approach does not have a noticeable effect for this origin; however, it creates a large discrepancy in the tool's overall carbon footprint estimate for Indonesia, where the EF is not null.
- SimaPro uses different databases and EFs for several sources, including fertilizer emissions from production, as detailed below.
- Lavazza's modelling approach was documented in a detailed report available as an annex.

[27] SimaPro, "Home"

6.8.2.2 LeanAg (Sphera)

Sphera's LeanAg model is an agricultural model that relies on the GaBi LCA databases,[28] a suite of datasets provided by Sphera and widely used by the public and international institutions. In addition to providing carbon footprint baselines, the LeanAg model also includes other impact assessments relevant to LCA which are outside the scope of this project.

The methodologies of the LeanAg tool are similar to those of the CFT, and the model's assumptions are largely in line with those agreed upon with the Technical Committee. However, some differences were identified:

- Sphera did not conduct any assessment on biomass stock changes. Because biomass stock changes are reported separately in this report, this has no effect on the comparability of the results.
- Sphera uses province-level averages as inputs to the model instead of making farm-level assumptions, as is done by the CFT.
- Sphera uses background data (fertilizer production, provision of energy) from the GaBi databases, while the CFT uses background data from other databases (e.g., ecoinvent).
- Sphera uses the Intergovernmental Panel on Climate Change (IPCC) Tier 1 disaggregated emission factors to model emissions from fertilizer use (field emissions), while the CFT uses other sources.
- Due to miscommunication, Sphera did not allocate emissions to co-products; hence, all results provided by Sphera in this section include farm-level emissions from both coffee and co-products.
- Sphera's modelling approach was documented in a detailed report available as an annex.

6.8.2.3 Carbon Footprint Add-On (4C)

The 4C Carbon Footprint Add-On, developed with the consultancy Meo Carbon Solutions,[29] is a carbon footprint model for ascertaining and verifying changes in GHG emissions in coffee supply chains. Its methodologies are aligned with recognized standards such as ISO 14067, PAS 2050, the GHG Protocol Product Standard, and several IPCC guidelines. The model can be applied to the whole coffee supply chain from farm to final roasted coffee product (covering different levels of production activities beyond cultivation at farm level, such as processing, packaging, storing, transportation, and distribution), or tailored to a specific part of the supply chain by defining the relevant system boundaries.

For this project's purposes, the system boundaries were restricted to farm-level emissions. Emissions from seedlings were excluded, in alignment with the recommendations of the Core Committee.

While the methodologies of the 4C Carbon Footprint Add-On and the CFT align in their basic approaches, a few key differences were identified:

- The selected sources and emission factors partially differ from the CFT's, particularly regarding fertilizer production, use of crop protection products, diesel use, and soil-related emissions including from LUC.

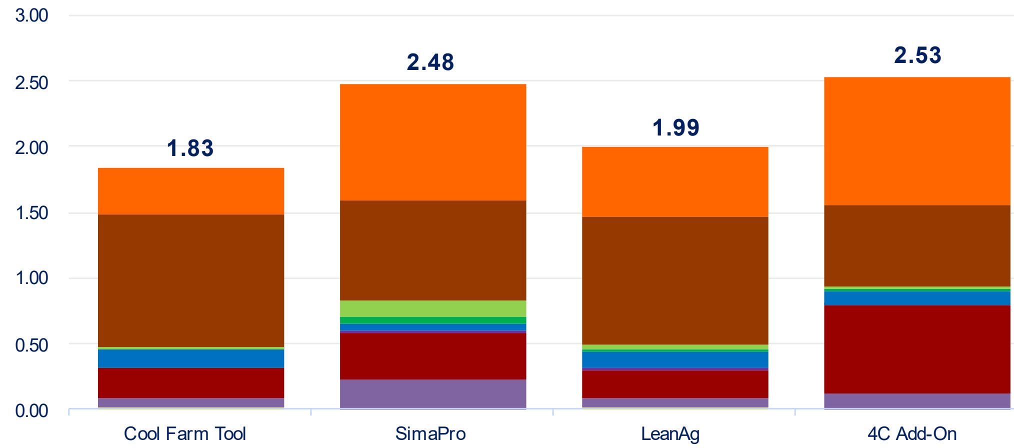
[28] Sphera, "Managed LCA Content (GaBi Databases)"
[29] Meo Carbon Solutions, "Carbon Footprint Improvement"

- 4C normally follows the latest IPCC methodology (2019) for land use change emission calculation, including emissions from vegetation changes and dead organic matter in addition to changes in soil carbon to make a comprehensive statement. However, in this project scope the emissions from LUC are not provided due to the incomplete dataset and incomparable methodologies.

- 4C's modelling approach was documented in a detailed report available as an annex or upon request to: nguyen@4c-services.org and/or ostrowski@meo-carbon.com

6.8.3 Results and key findings

6.8.3.1 Central Highlands



TOTAL	1.83	1.06	1.99	2.36
Fertilizer production	0.34	0.90	0.53	0.98
Fertilizer use and soil	1.01	0.75	0.96	0.61
Energy use (field)	0.02	0.12	0.04	0.02
Energy use (processing)	0.01	0.06	0.02	0.02
Energy use (irrigation)	0.13	0.05	0.12	0.10
Crop protection	0.00	0.02	0.01	0.00
Residue management	0.24	0.36	0.22	0.68
Wastewater	0.00	0.00	0.00	0.00
Transport	0.06	0.22	0.07	0.12
Land use change	0.02	0.00	0.02	0.00

Figure 89: Carbon footprint results of the different models, origin level, Central Highlands [kg CO_2e/kg GBE]

The origin-level results produced by Sphera's LeanAg model for the Central Highlands are close to those produced by the CFT. The slight increase (+9 percent is explained by emissions from co-products not being excluded from Sphera's analysis – as mentioned in section 6.4. Including the emissions attributable to co-products on coffee farms across the Central Highlands would increase the overall carbon footprint estimate produced by the CFT for this origin by 8 percent The LeanAg model also has a higher estimate of emissions from fertilizer production. This discrepancy can be explained by the emission factors of fertilizer production used by this model, which are based on a dataset representative of Indian production, the best proxy available for Southeast Asia. As discussed in section 6.2.1, this is also an area of uncertainty in the results produced by the CFT, due to a potential bias toward Southeast Asia (where EFs are lower than in other countries in Asia, such as India and China) as the reported country of origin. Further research on actual fertilizer origins, especially for NPK and urea, should be conducted to improve the accuracy of emission estimates for this source.

The total carbon footprint estimates produced by the 4C Carbon Footprint Add-On and SimaPro are higher than the CFT's (+38 percent and +36 percent, respectively). Looking at the breakdown per activity, the estimates of the SimaPro and 4C models are closely aligned on fertilizer-related emissions. Regarding fertilizer production, the differences from the CFT's estimate are likely related to the emission factors used. SimaPro uses the World Food LCA Database (WFLDB), while the CFT uses ecoinvent v2. 4C also uses the ecoinvent database, but it uses a more recent version (v3.9.1) and it applies emission factors for fertilizers produced in countries categorized as "rest of the world" (RoW). These factors explain the difference between the 4C and CFT estimates for this source.[30] On the other hand, the modeling approach is the main source of the differences in these tools' estimates of emissions from fertilizer application: SimaPro and 4C apply the IPCC Tier 1 methodology, which is the widely recognized standard and generic approach for modeling emissions, while the CFT uses a more elaborate approach based on the Bouwman model.[31] It is more granular than the IPCC Tier 1 approach as it includes soil pH, soil moisture and texture, application method, and other parameters in the calculation, but it requires more inputs and assumptions. As a result, the Bouwman model can be considered more accurate when all relevant parameters are accurately measured, but it is unclear whether it performs better than the IPCC Tier 1 approach in such large-scale data collection projects, where assumptions and regional averages must be taken for many parameters, such as soil moisture.

Other notable disparities between SimaPro and the CFT include energy-related emissions from field activities and transportation-related emissions. SimaPro has a higher estimate of energy emissions from field activities because it allocates a fixed quantity of diesel used for these activities on each farm. This approach is conservative but likely overestimates emissions in this category for the origins in question, as many farmers in the Central Highlands and Southern Sumatra do not practice any mechanical harvesting, weeding, or spraying. SimaPro also uses different emission factors than the CFT for transportation, which results in higher emission estimates for this activity.

Beyond fertilizers, the major difference between 4C and the CFT is in the estimate of emissions from residue management. The gap is mainly caused by a difference in emission factors, especially for composting, where the CFT uses an EF of 0.29 kg CO_2e/kg husks[32] while 4C uses the IPCC default value of 0.49.

Province-level results for the Central Highlands highlight that the differences between the models are consistent across geographies and therefore stem from diverging global modeling approaches.

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[30] As fertilizers used by farmers in the Central Highlands mostly come from countries not included in this grouping, namely China and Russia (as per Yara data – see section 6.2.1 for details), RoW emission factors might not be entirely accurate in this context.
[31] Bouwman et al. (2002)
[32] From Brown et al. (2009).

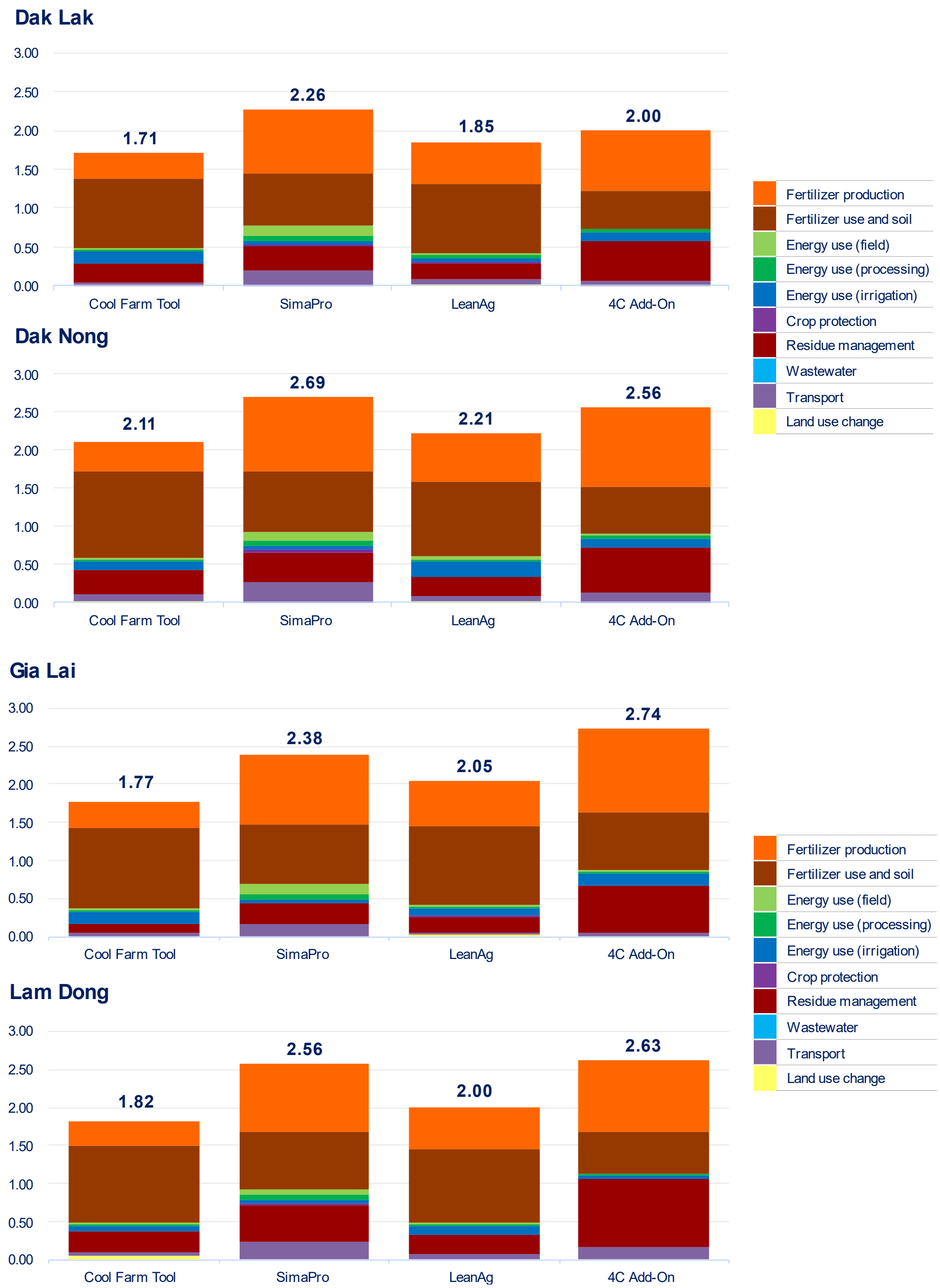
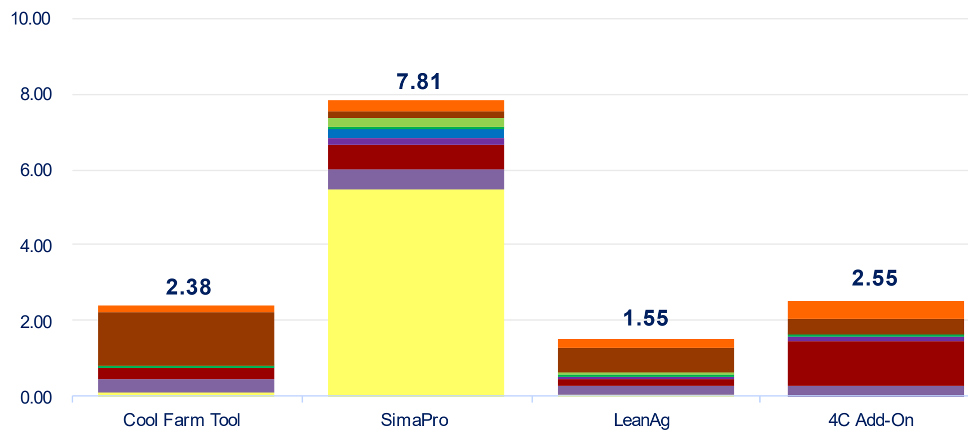


Figure 90: Carbon footprint results of the different models, province level, Central Highlands [kg CO_2e/kg GBE]

6.8.3.2 Southern Sumatra



TOTAL	2.38	7.81	1.55	2.55
Fertilizer production	0.18	0.27	0.26	0.49
Fertilizer use and soil	1.38	0.21	0.66	0.41
Energy use (field)	0.01	0.23	0.08	0.01
Energy use (processing)	0.04	0.06	0.04	0.03
Energy use (irrigation)	0.00	0.19	0.00	0.00
Crop protection	0.05	0.22	0.08	0.17
Residue management	0.26	0.63	0.17	1.15
Wastewater	0.00	0.00	0.00	0.00
Transport	0.39	0.52	0.19	0.29
Land use change	0.08	5.49	0.07	0.00

Figure 91: Carbon footprint results of the different models, origin level, Southern Sumatra [kg CO_2e/kg GBE]

Origin-level results for Southern Sumatra are less consistent across models, for various reasons. In this case SimaPro's estimate is by far the highest, while the estimates produced by the other two tools differ in terms of certain activities' contributions.

The main difference in the result produced by Lavazza Group's model stems from the land use change estimate, at 5.49 kg CO_2e/kg GBE vs. 0.00 to 0.08 kg CO_2e/kg GBE for the other models.[33] SimaPro uses the Blonk LUC Impact Tool, which for Indonesia assigns a non-null fixed EF to any farm expansion within the past 20 years, regardless of how the land was used in the past.[34] This modeling approach is highly conservative and creates a large degree of variability in the dataset, but has the benefit of tackling potential underreporting of deforestation by farmers in Indonesia.

[33] As mentioned in section 6.8.2.3, 4C decided to exclude land-use change emissions from its overall results as the methodologies used are too different to allow any relevant comparison.

[34] This was not a factor for Vietnam because the EF the tool assigns for that origin is 0 tons CO_2e/ha/yr.

Despite near-negligible estimated emissions from fertilizer production and use, this factor, coupled with significantly higher estimates of emissions from energy use for field activities[35] and irrigation (a very rare practice in Southern Sumatra, as reflected by the other models' null estimates for this source) results in a global carbon footprint estimate of 7.81 kg CO_2e/kg GBE for Southern Sumatra, 3x to 5x higher than the estimates of the other models.

Sphera's LeanAg model produces the lowest origin-level carbon footprint estimate for Southern Sumatra, due to differences in the emission factors used for residue management and transportation and a significantly lower estimation of emissions from fertilizer application. The latter is mainly explained by differences in the modeling approach applied (in particular, CFT's use of the Bouwman model, as mentioned in the previous section). In addition, the CFT assigns a non-null level of emissions to soils even without the application of fertilizers, which for default soil characteristics (moist soil with good drainage and pH below 5.5) amounts to around 500 kg (about 1102.31 lb) CO_2e/ha. While this has a negligible effect in the case of the Central Highlands, where fertilizer usage rates and application volumes are much higher, it has a significant impact in Southern Sumatra, especially in regions such as Bengkulu where fertilizer use is less common, and volumes applied are lower. As a result, the CFT's estimate of emissions from fertilizer use and soil is higher than that of all the other models, which are consistent. This discrepancy calls into question the CFT's approach of applying a fixed volume of emissions from soils for all farms.

The estimate produced by the 4C model is the closest to the CFT's (7 percent higher). As was the case for the Central Highlands, the most significant differences in the results produced by these two tools are related to fertilizer production and use: while 4C's estimate for emissions from fertilizer production is over 2.5x higher than the CFT's due to differences in EFs, its estimate for emissions from fertilizer application – by far the largest contributor to the CFT's total – is 70 percent lower. 4C's results also show significantly higher estimates of emissions from residue management, due to differences in the modeling approach used and different EFs for residue management methods (see the previous section for explanations of these discrepancies). This model's estimate of emissions from crop protection are also higher, as the EFs used by 4C (from ecoinvent v3.9.1) are up to 2x higher than those used by the CFT (from WFLDB).

Province-level comparisons show similar trends in the tools' results. Most strikingly, the CFT's estimates of emissions from fertilizer use are consistently higher than those of the three other models, for the reason explained above. As a result of this approach, in Bengkulu, where farmers apply 50 percent less fertilizer than the origin average, the CFT's estimate of emissions from this source is only 17 percent lower than the average value. The other models show a proportional reduction in the level of emissions for this province.

[35] The trends with regard to emissions related to fertilizer and energy use were also observed for the Central Highlands; see the discussion in the previous section for details.

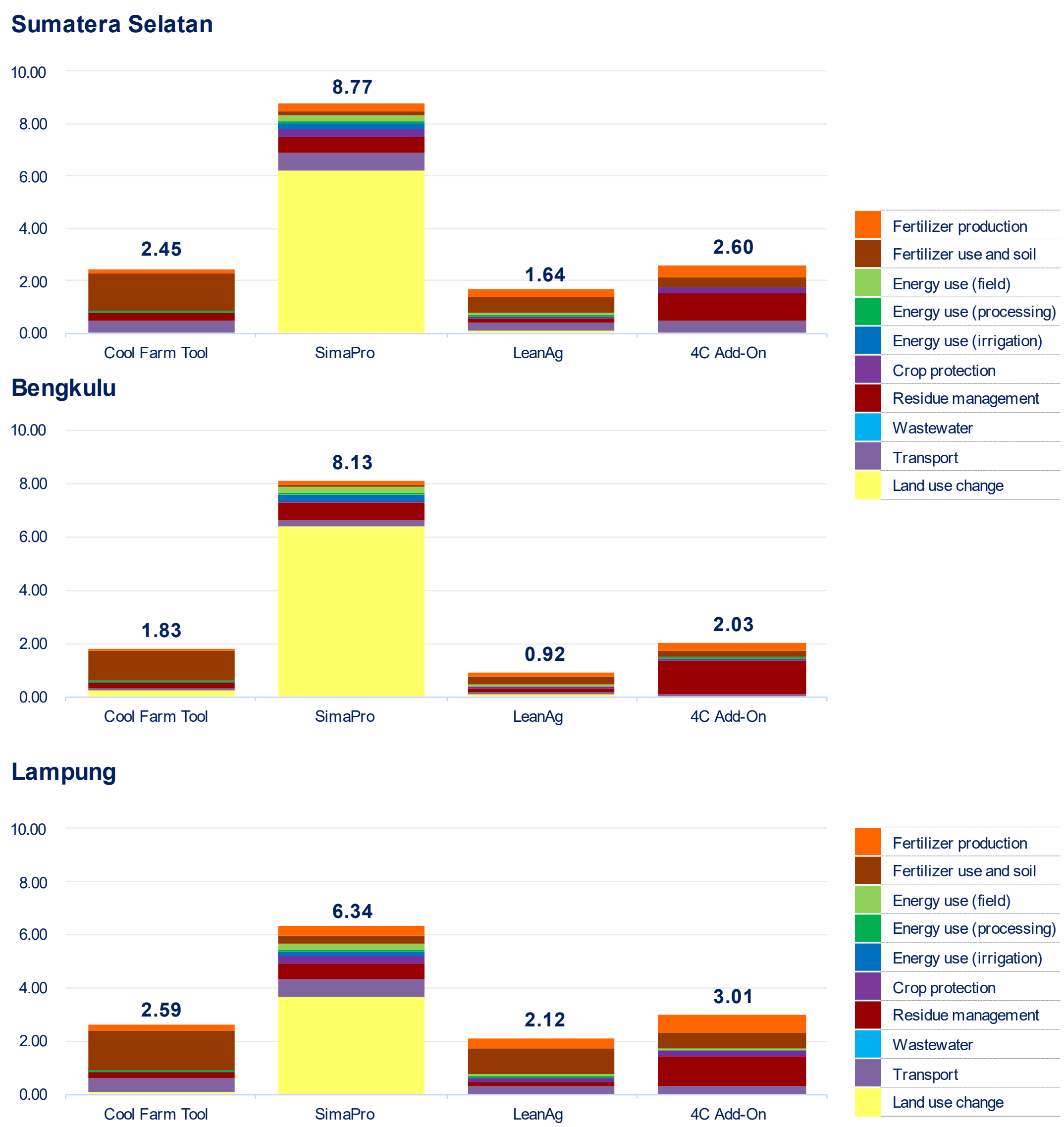


Figure 92: Carbon footprint results of the different models, province level, Southern Sumatra [kg CO_2e/kg GBE]

6.8.4 Literature review

Several carbon footprint analyses have been conducted across the Central Highlands and Southern Sumatra in the past. A detailed comparison of their results and those of the present study is not possible, considering that they use different sets of inputs and tools with methodologies and assumptions that differ from those of the CFT. In addition, the information provided by these papers is not sufficient to highlight the origins of any discrepancies. However, they provide useful points of comparison at the origin level, which can complement the comparative analysis performed with the models from Lavazza Group, Sphera, and 4C.

Carbon footprint estimates retrieved from various reports show that the results of this initiative are in line with the literature:

- USAID Green Invest Asia (2021) provides carbon footprint estimates for coffee production in Vietnam for all crop years between 2015/16 and 2019/20. Values range from 1.03 kg CO_2e/kg GBE (2018/19) to 3.21 kg CO_2e/kg GBE (2015/16). In addition, the report estimates the contribution of fertilizer production and application at 83 percent of the total footprint.
- Trinh et al. (2020) estimates the carbon footprint of Vietnamese coffee at between 0.644 and 0.935 kg CO_2e/kg GBE, depending on the archetype (from organic intensive to conventional intensive).
- Pramulya et al. (2019) provides carbon footprint estimates for Arabica production in Indonesia, with values ranging from 1.48 to 1.93 kg CO_2e/kg GBE.

6.8.5 Recommendations

The following are some of the recommendations derived from the comparative analysis:

- While each model has its pros and cons, a key factor that drives variability in emission footprint estimates across these tools is the choice of emission factors and background datasets used. Further research is required to derive EFs that accommodate the realities of the origins in question. For example, given that fertilizers are the single biggest source of emissions in both the Central Highlands and Southern Sumatra, it would be useful to have bespoke and widely accepted datasets on the impact of fertilizer production that take better account of more precise nutrient compositions and manufacturing locations.
- There is room for improvement in the modeling of emissions from residue management. This is especially true in the context where farmers use multiple husk disposal methods on the same farm, as selecting more than one method and weighing the results proportionally is not currently possible with the CFT. Emission factors vary greatly depending on the methods used. In line with the above recommendation, it would be helpful to have a consensus on a set of EFs and a classification of the various husk disposal methods seen on farms.
- The modeling of urea emissions is not aligned between the CFT and other models. Further discussions on how to best account for them should take place between industry stakeholders and the scientific community.
- Methods used to calculate land use change emissions can lead to large differences. It is recommended to avoid using country-level estimates and seek more precise sources of data to estimate LUC emissions. In addition, tools should always use an internationally recognized methodology such as the latest version of the IPCC guidelines.

7. Lessons Learned and Recommendations

Recommendations with regard to specific emission sources include:

- **Residue management:** Efforts should be made to explore or develop tools that better reflect coffee farming practices with regard to residue management. For example, enumerators should try to assess the volume of husks composted vs. left in piles vs. applied as mulch, and better identify what kind of composting takes place (fully vs. non-fully aerated). A mechanism should be developed for taking into account the different practices used by farmers on the same farm and weighing the associated emissions appropriately.
- **Transportation:** As the EF of motorbikes is not available in the CFT, an alternative approach needs to be found for calculating emissions related to transportation by motorbike (common in both origins, and in particular in Southern Sumatra). Alternatively, the distance traveled by motorbike could be adjusted proportionally to the ratio between the EF of motorbikes and that of light goods vehicles.
- **Land use change:** Given the high variability in Bengkulu and the expected underreporting of deforestation events by sensitized farmers, it is recommended to complement farmer reports with other data sources, such as remote-sensing databases.
- **Fertilizer production:** The question asked about the manufacturing origins of inorganic fertilizers was misunderstood by some farmers and some enumerators; they sometimes reported or asked for the location of the supplier instead of the manufacturing location. It can be difficult to accurately identify this location when the country of manufacture is not reported on the packaging. Therefore, it is recommended to 1) improve farm-level data collection by training enumerators on how to better prompt the farmer and identify the relevant data where possible (i.e., by checking the packaging, available paperwork, etc.) and 2) complement the farmer reports with national statistics on fertilizer origins, such as those provided by Yara.

Recommendations for the survey process include:

- Farmer surveys should ideally be conducted during or soon after the harvest season to ensure the highest degree of recall and therefore the most accurate reporting of elements such as input use and energy use. While the surveys in Southern Sumatra were conducted in this scope of time, in the Central Highlands the survey period began a few months after the harvest.

- Replicating this exercise on an annual basis should be considered, as data collected over multiple seasons is more reliable. In addition, looking at time series not only helps to detect inconsistencies in the results but also to identify where real improvements are taking place.

- A simplified, streamlined approach to replicate and/or repeat this exercise annually could be implemented by measuring only the indicators responsible for the greatest share of the emission footprint (e.g., more than 90 percent of the total). In Vietnam this would be indicators related to fertilizer production and use, energy use for irrigation, and residue management. In Southern Sumatra, it would be indicators related to fertilizer production and use, transportation, and residue management.

- For the comparative analysis, additional effort should be made to fill in gaps in understanding of the differences between the models. This will help the sector avoid setting goals and reporting progress on baselines that are vastly different from one another.

- Estimating the carbon sequestration potential of a farm is a critical component in carbon footprint estimation, particularly for farms that have perennial crops. Carbon sequestration was not fully assessed under this study due to the lack of proper tools, but the CFT is currently in the process of developing a perennial module. Further research is recommended in this space to get a comprehensive view of farm-level net carbon footprint considering carbon sequestration.

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9. Appendices

9.1. Data collection methodology and tools

9.2. Methodology to calculate the margin of error

9.3. Methodology to define the farmer archetypes based on inorganic fertilizer usage

9.4. Methodology to define the carbon sequestration potential

9.5. Attached files

9.1 Data collection methodology and tools

This section is aimed at providing the necessary tools and methods to ensure replicability of the project and ease any effort from value chain partners or organizations seeking to repeat the exercise.

1. **Design a representative sampling framework:**
    - **Defining number of samples – technical document (.pdf)** describes the methodology and approach used to determine the proper sampling framework and identify an optimal sample size from both an operational and a statistical perspective.
    - **Sample calculation workbook final (.xlsx)** describes the sample size calculations at the province and district levels, along with the assumptions made.
    - **Randomization strategy – technical document (.pdf)** describes the farm randomization strategy (pin dropping and farm selection).

2. **Design and author the survey:**
    - **Farmer questionnaire – Vietnam (.xlsx)** is the full questionnaire, including questions, answer choices, constraints, and display logic, in English and Vietnamese.
    - **Farmer questionnaire – Indonesia (.xlsx)** is the full questionnaire, including questions, answer choices, constraints, and display logic, in English and Bahasa Indonesia.

3. **Build a training module for enumerators:**
    - **Training module – English (.pdf)** is the full enumerator training module, in English. It is not included in the attached files due to its size, but the file can be requested to Enveritas. Alternatively, the training module can be accessed on the Genial.ly platform via this link: https://view.genial.ly/62b913826681c40012a5b700 (password: *coffeecarbon123*).
    - **Training module – Vietnamese (.pdf)** is the full enumerator training module, in Vietnamese. It is not included in the attached files due to its size, but the file can be requested to Enveritas.
    - **Training module – Bahasa (.pdf)** is the full enumerator training module, in Bahasa Indonesia. It is not included in the attached files due to its size, but the file can be requested to Enveritas.

4. **Implement a quality control process:**
    - **Quality Control – Numeric flags – Vietnam (.xlsx)** is a list of all numeric flags used for quality control in Vietnam.
    - **Quality Control – Numeric flags – Indonesia (.xlsx)** is a list of all numeric flags used for quality control in Indonesia.
    - **USAID Carbon Footprint Baseline – Weekly Team Report – [dd_mm_yy] – [Name of Supplier_Partner] (.pdf)** is a template of Weekly Team Reports to be sent to supplier partners.

5. **Clean and process the data:**
    - **Data cleaning and processing package (.zip)** is a zipped folder containing iPython scripts that clean the raw data and convert it into Cool Farm Tool inputs. The zipped folder includes all the necessary dependencies.

9.2 Methodology to calculate the margin of error

At district level:

As observations come from a random sample at the district level, the margin of error is calculated using the standard formulas:

$$MoE = z_\gamma * SE$$

$$SE = \sqrt{\frac{\sigma^2}{n}}$$

,with:

- z_γ : z-score for confidence level γ. We use 95% as the confidence level.
- SE : Standard error
- σ : Standard deviation of sample
- n : Sample size

At province / origin level:

As the sampling at the province / origin levels is a stratified random sampling (using production volumes as weight), we used the following formula to calculate the standard error (unbiased estimator):

$$MoE = z_\gamma * SE$$

$$SE = \sqrt{\sum_{i=0}^{k} w_i^2 * \frac{\sigma_i^2}{n_i}}$$

,with:

- z_γ : z-score for confidence level γ. We use 95% as the confidence level.
- w_i : Normalized weight of strata (district i), based on production volume
- SE : Standard error
- σ_i : Standard deviation of strata (district i)
- n_i : Sample size of strata (district i)

9.3 Methodology to define the farmer archetypes based on inorganic fertilizer usage

Identify the variable(s) used to define the archetypes:

To define the farmer archetypes, we first needed to identify the optimal descriptive variable(s) that could be used to classify farmers into groups with statistically significant differences in levels of emissions. These variables should be highly correlated with the farms' carbon footprints.

Two variables met this requirement: volume of inorganic fertilizer applied and yield. It was decided to use the inorganic fertilizer volume as the archetype-defining variable because it is a descriptive dimension, unlike yield, which is a cross-cutting variable impacted by several others. In addition, yield is only relevant when considering the carbon footprint per volume of coffee produced; the correlation becomes too light when considering the carbon footprint per area.

Variables such as crop diversification and the use of regenerative practices could not be used to define the archetypes as they have negligible impact on the overall footprint, due to carbon stock changes being excluded from the calculations.

Define the number of archetypes:

The number of archetypes needs to be sufficient to provide interesting insights but is limited by the sample size. Having too many archetypes creates the risk of removing the statistical significance of the differences between them.

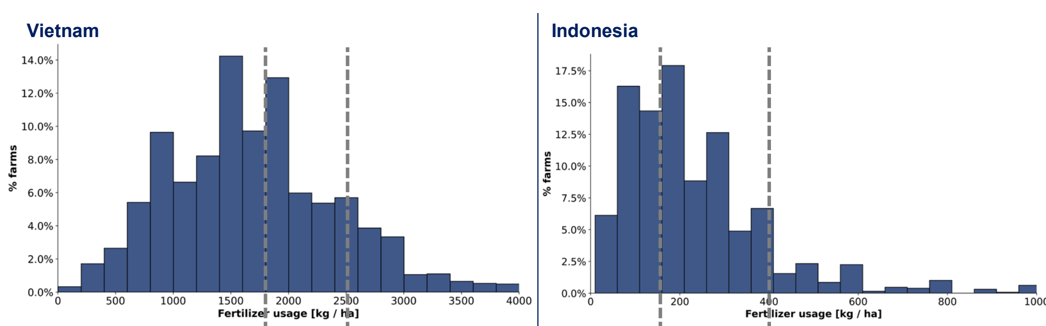
After a few checks on the margin of error of carbon footprint averages, the optimal number of archetypes was set at three.

Identify the breakpoints:

Farms are classified into three archetypes based on their input usage. The breakpoints that define the three archetypes were determined via the following process:

1. Apply the Jenks natural breaks classification method to define three clusters with minimum intra-cluster variance and maximum inter-cluster variance.
2. Adjust the breaks so that the carbon footprint results at the origin level are statistically different between clusters.

Results:



	Vietnam: < 1,800 Low users	1,800 – 2,500 Medium users	> 2,500 High users	Indonesia: < 150 Low users	150 – 400 Medium users	> 400 High users
% farms	59%	28%	13%	60%	32%	8%
Footprint [kg CO2e / kg GBE]	1.69	1.90	2.69	2.05	2.38	4.45

9.4 Methodology to define the carbon sequestration potential

Rationale:

The Cool Farm Tool is limited in providing accurate estimates of carbon sequestration and carbon stock changes. As the results produced by the tool carry too much uncertainty, it is preferable to report a "carbon sequestration potential" instead of an actual "carbon stock change" value. This potential is split into three categories (low, medium, high) in order to reduce variability and to report with an adapted level of accuracy.

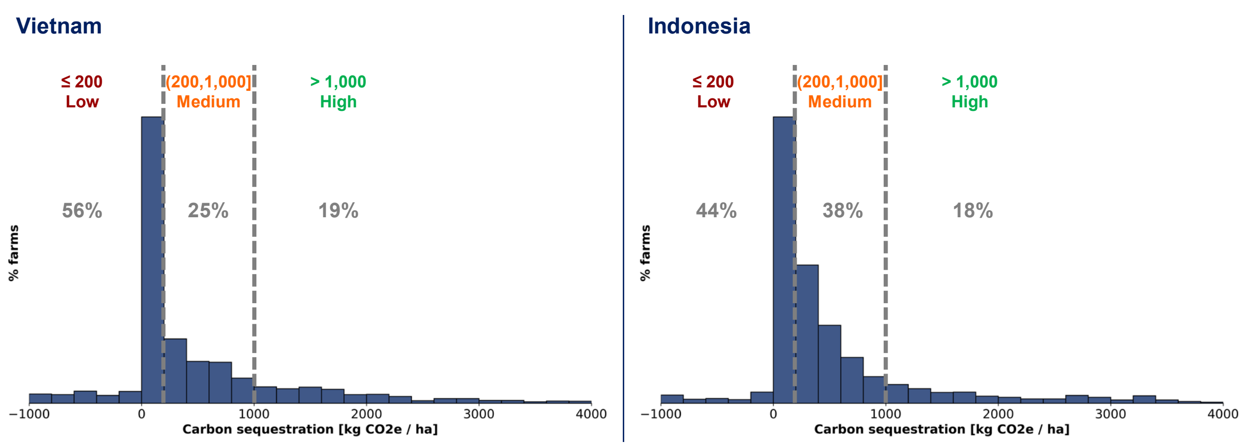
Methodology:

1. Retrieve carbon stock change results from the CFT (excluding land use change, which is counted in the CO_2e emissions).
2. Convert the results into values per hectare (to remove the effect of productivity).
3. Aggregate all results from both origins and identify "natural" breakpoints.
4. Classify each observation under one of the three categories: high, medium, or low potential.
5. Cross-check province-level results with other collected data (e.g., level of shade) to verify correlation.

Calculations:

Carbon sequestration results were retrieved from the CFT by removing the land use change part from the results of the land management section. They were converted to values per hectare and split into three categories, using breakpoints defined as follows:

- The **low/medium breakpoint** (200 kg (about 440.92 lb) CO_2e/ha/yr.) was set so that around half of farms are in the low category. A sequestration of 200 kg CO_2e/ha/yr. is equivalent to the yearly growth of around 5 shade trees of 50 cm (about 1.64 ft) diameter per hectare, or to the addition of around 13 percent of cover crop coverage per hectare over the past 20 years (the added biomass value is distributed over the 20 years). Farms with a negative carbon sequestration value – meaning that the biomass stock decreased, e.g. because some trees were cut down – were assigned to the low category.
- The **medium/high breakpoint** (1,000 kg per ha per year) was set at the nearest round value that split the remaining farms into two subsets comparable in size. A sequestration of 1,000 kg CO_2e/ha/yr. is equivalent to the yearly growth of around 25 shade trees of 50 cm diameter per hectare, or to the addition of around 65 percent of cover crop coverage over the past 20 years.



9.5 Data and results

I. **Database of survey answers and carbon footprint results – [Country] (.xlsx)** – the full databases (one for Vietnam and one for Indonesia) with all the farmer survey data and the carbon footprint results, disaggregated by activity type, for public distribution (GPS points are removed, only districts are included)

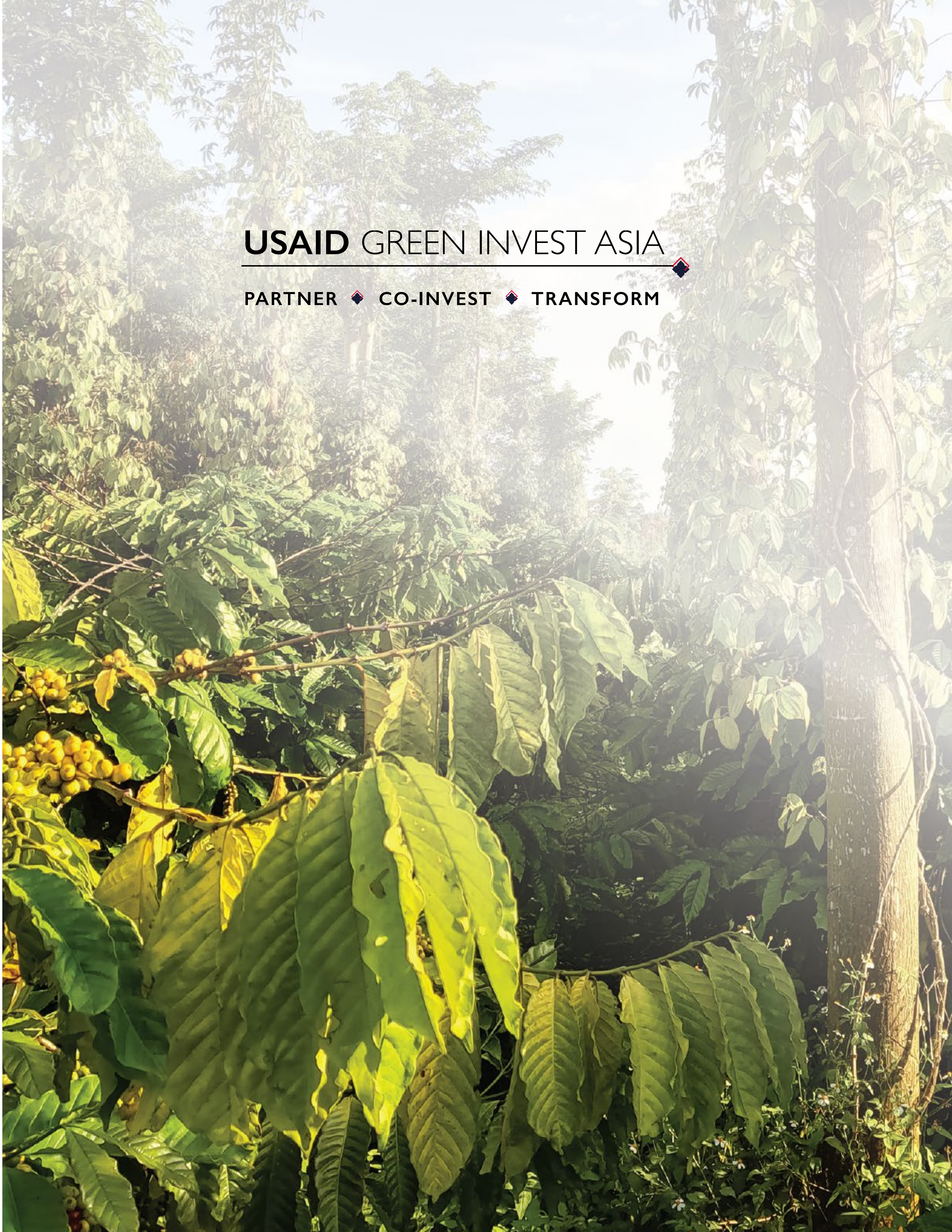
II. **Description of databases with carbon footprint results – Vietnam and Indonesia (.pdf)** – a glossary that briefly describes all database columns; i.e., indicators collected during the survey and their interpretations, calculated dimensions, and results

III. **Survey answers and carbon footprint results aggregated at the province level – [Country] (.xlsx)** – survey answers and carbon footprint results averaged at the province level for Vietnam/Indonesia, for public distribution

IV. **Survey answers and carbon footprint results aggregated at the district level – [Country] (.xlsx)** – survey answers and carbon footprint results averaged at the district level for Vietnam/Indonesia, for public distribution

V. **Description of aggregated indicators – Vietnam and Indonesia (.pdf)** – a glossary that briefly describes all columns of the aggregated databases (III and IV)

VI. **Validated list of all assumptions for CFT (.pdf)** – a document that lists and describes all assumptions made by Enveritas to be able to run the Cool Farm Tool on the collected data.


USAID GREEN INVEST ASIA
PARTNER ◆ CO-INVEST ◆ TRANSFORM