Establishing carbon footprint baselines for Robusta coffee in two key origins

Cradle to gate study

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List of Acronyms

AN	Ammonium Nitrate
AI	Active Ingredient
AWaRe	Available Water Remaining
CaCO3	Calium Carbonate
CFT	Cool Farm Tool
ISO	International Organization for Standardization
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
KCl/MOP	Kalium Chloride/Muriate of Potash
LCA FE	Life Cycle Assessment for Experts
LCA	Life Cycle Assessment
LUC	Land Use Change
NPK	Nitrogen Phosphor Kalium
PEF	Product Environmental Footprint
TSP	Triple Superphosphate

1. Introduction

This study was initiated in response to a request for proposals for Pact. Inc. (hereinafter referred to as "client") who works to connect investors with sustainable agriculture and forestry within their project USAID Green Invest Asia. For this project, the client commissioned Enveritas, an organisation which provides sustainability assurance services for the coffee industry. Enveritas facilitated the collection of data from coffee farmers in two key production countries and performed a carbon footprint assessment using the Cool Farm Tool (CFT). The intended purpose of this document is to support Pact. Inc. by delivering additional insights and value to the assessments performed by Enveritas, using alternative data compilation approaches and modelling methodologies. The intended audience is therefore all partners of Pact. Inc., such as funding partners (Nestle, JDE-Peet's, Lavazza Group, and Costa Coffee), technical partners, and participating coffee supplier companies. This report is neither intended to support comparative assertions nor to be disclosed to the public in its current form. This report is not ISO conformant nor has it been externally reviewed.

1.1. Goal of the study

The intended application of this study is to support the establishment of carbon footprint baselines for Robusta coffee production in two key countries of origin. The following table provides an overview of the provinces per country as considered in the study:

Table 1-1: Overview of provinces for the study

Indonesia	Vietnam
Bengkulu	Đắk Lắk
Lampung	Đắk Nông
Sumatera Selatan	Gia Lai
	Lâm Đồng

The carbon footprint calculation has been conducted using Sphera Solutions' Lean AgModel, an agricultural model established in the LCA FE database (Life Cycle Assessment for Experts, formerly known as "GaBi ts"). The focus of the assessment was to establish the carbon footprint baselines based on a common dataset facilitated by Enveritas. Nevertheless, Sphera's LCA software allows for the inclusion of additional impact categories relevant to life cycle assessments, such as eutrophication, acidification or water use – which are included in the annexes. The carbon footprint results are provided together with a scenario analysis. Moreover, Annex B: highlights comparisons between Sphera's and Enveritas' approaches by providing some insights into differences in methodologies, data mapping and default data.

1.2. Scope of the study

The product systems considered in the assessment are coffee cultivation farms in Indonesia and Vietnam, representing the Robusta coffee cultivation regions of USAID Green Invest Asia's participating supplier companies. The harvested and processed crop is used for the production of coffee products. Therefore the functional unit of this study is defined as:

1 kilogram of harvested, hulled and dried green coffee bean (green bean equivalent) after processing

2. Materials and methods

2.1. Sphera's Lean AgModel

Sphera's generic agricultural model, the Lean AgModel, can be used to assess the impacts of crop cultivation from cradle to field gate. It is a robust and tested model, based on agreed standards for agricultural modelling in LCA. Its two main guiding standards are:

- IPCC Guidelines for National Greenhouse Gas Inventories 2019
  (Volume 4, Agriculture, Forestry and Other Land Use)
- PEF method 2021[1]

In combination with datasets from the LCA FE database, the model allows the inclusion of all impacts from upstream processes on the field and from downstream processing (in this case processing of harvested beans). The contribution of each subprocess can be evaluated separately. An overview of all model modules and approaches can be found in Table apx 1 in the Annex.

2.2. System Boundaries

The system boundaries include both the coffee cultivation and the post-harvest processing of the beans. Based on the functional unit, the impacts of processing are always included in the system boundaries, even if they take place externally. Thereby, consistency and comparability of the results are ensured.

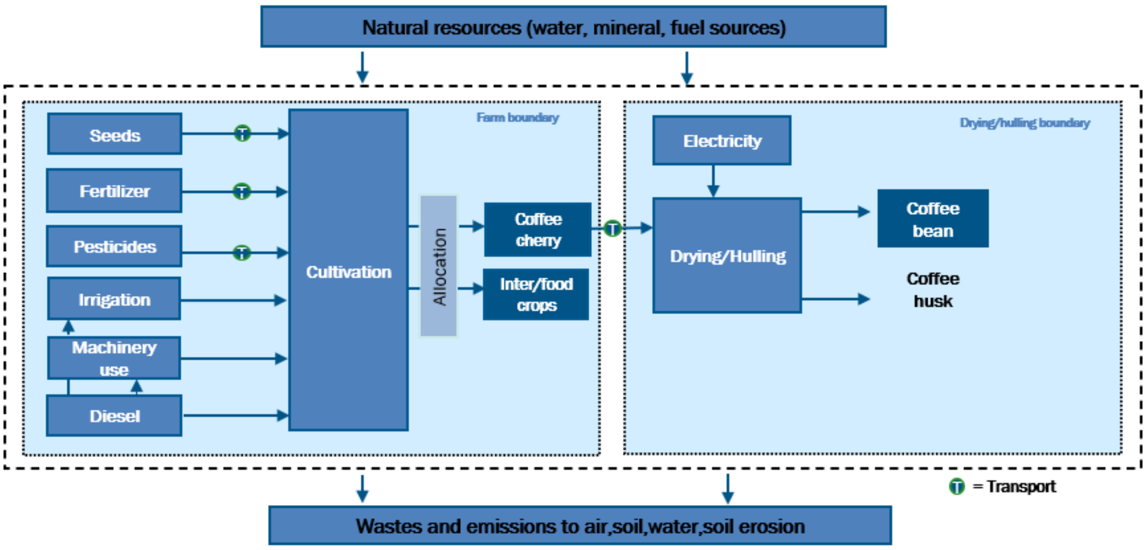


Figure 2-1: System boundaries of the study[2]

[1] Commission Recommendation (EU) 2021/2279 of 15 December 2021 on the use of the Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and organisations, C/2021/9332, http://data.europa.eu/eli/reco/2021/2279/oj
[2] Allocation considered in scenario analysis

Table 2-1 summarizes the system boundaries used in this study. Included in the study are all material and energy flows required for the two phases (cultivation and processing), as well as all associated waste and emissions of the system.

Wet processing (including pulping and washing) has been excluded since it is not a representative processing method for the cultivation system under assessment, proven by the data as provided by Enveritas (<1% of surveyed farmers process their beans wet).

The End of Life of the processing waste was only partly included. If the farmers stated that the residues were being sold, used for other purposes on the farm (e.g. as fuel) or treated at the milling level, then the system boundaries excluded residue management. Those residues are therefore leaving the system burden free and without any credits to the impacts of the main product. If the farmers stated that the residues were applied to the field (with prior composting/combustion or directly applied without) then the residues were considered as additional organic fertilizer, and included emissions occurring through the application on the field. More information can be found in chapter 2.3.11.

Impacts from production of organic fertilizer were excluded. It is still under debate whether organic fertilizer can be considered a waste product with no burden coming from the animal husbandry system, or if it is a valuable co-product of animal production systems and should carry an environmental burden. Most LCA models and studies assume that the fertilizer enters the plant production system free of burden. This approach was also followed in this study. Due to the low reported rates of organic fertilizer application, this approach is considered to have a low impact on the results. Emissions from application of organic fertilizers are considered.[3]

As is customary in LCA studies, construction of capital equipment and maintenance of support equipment are excluded due to their minimal contribution and extreme difficulty to measure. Social aspects are beyond the scope of this study and therefore, human labour was also excluded from the study.

Table 2-1: System boundaries

Included	Excluded
✓ Seed production	× Capital goods
✓ Fertilizer and pesticide production	× Social aspects (incl. human labour)
✓ Irrigation water consumption	× Animal draught
✓ Energy required for irrigation	× Impacts from organic fertilizer supply chain (assumed to be allocated to animal system)
✓ Machinery use	× Wet processing of green beans
✓ Transports	× Coffee husk (residue) management
✓ Soil erosion	
✓ Field emissions	
✓ Emissions from organic fertilizer application	
✓ Greenhouse gas (GHG) emissions from LULUC	
✓ Dry processing of green beans (hulling, drying)	
✓ Coffee husk management	

[3] The LEAP guidelines provided by the FAO (Food and Agriculture Organization 2016) on allocation procedures of manure exported off-farm differentiate between the options co-product, waste and residual. While the exact source of the fertilizer was not tracked in the data collection, the chosen approach represents the "residual" option from these guidelines.

2.3. Sphera's data compilation approach

The data collection procedure has been conducted by USAID Green Invest and their partners on farm and district level. Enveritas provided the primary data as an excel database to Sphera, with 210 parameters for both countries. In Indonesia, 2045 farmers participated in the survey, while in Vietnam it was 2539 farmers. While Enveritas performed their assessment on a farm-by-farm level, Sphera did not include all provided datapoints, as the assessment was performed with input data aggregated on province-level. Additionally, some input data have been either replaced or extended with proxy data in order to investigate possible simplification potentials for the client. Table 2-2 provides an overview of the most important input parameters for the baseline calculations, which will have the highest influence on the results.

Input values for the scenarios are explained in the corresponding sub chapters.

Table 2-2: Overview of most important input data for Indonesia and Vietnam (Baseline)

Parameter	Bengkulu	Lampung	Sumatera	Đắk Lắk	Đắk Nông	Gia Lai	Lâm Đồng
Yield [kg green bean eq./ha]	707.92	753.02	660.94	2738.13	2421.34	2772.95	3545.16
Fertilizer [kg/ha]							
NPK	70.74	135.48	91.05	527.18	490.18	437.36	529.96
Urea	16.22	88.83	45.85	31.39	25.90	70.91	42.39
AN	1.28	9.08	2.30	30.64	25.99	57.49	25.65
TSP	2.73	3.31	7.52	0	0	0	0
Phosphate	0	0	0	30.69	74.11	116.65	60.31
KCl/MOP	1.17	2.38	2.82	16.85	16.14	43.69	49.36
CaCO3				1.18	6.62	2.32	0
Organic	5.61	4.95	7.55	32.01	27.04	33.92	61.73
Other inputs							
Active Ingredient [kg/ha]	3.86	8.52	7.23	1.60	2.61	2.58	2.45
Irrigation water [m3/ha]	0	0	0	55.94	204.26	128.79	165.63
LUC [kg CO2 eq./ha]*	69.25	37.38	46.11	67.57	66.26	50.16	0.00
Soil erosion [kg/ha]*	273.32	208.86	73.91	50.63	75.99	65.69	58.90
Transport and diesel							
Diesel [l/ha]	15.74	14.87	17.84	29.91	31.24	28.95	35.94
Inbound distance [km]	83.20	275.17	309.39	43.1	38.8	25.9	22.9
Outbound distance [km]	35.29	167.82	227.29	45.71	47.86	27.63	68.01
Processing							
Diesel hulling [l/kg]	0	2.6E-02	6.4E-03	8.6E-03	5.3E-03	6.5E-03	5.3E-03
Electricity hulling [MJ/kg]	0	0	0	0	0	0	0
Diesel drying [l/kg]	2.19E-07	1.45E-07	4.41E-06	0	0	0	0
Electricity drying [MJ/kg]	0	3.23E-08	0	3.1E-03	5.2E-04	4.9E-03	3.4E-05
Husk and leaf treatment							
Combusted mass [kg/ha]	36.8	56.4	11.2	42.8	60.7	30.3	30.2
Composted mass [kg/ha]	487.2	602.5	491.6	2540.9	2499.9	2558.1	3795.6

*Proxy values have been used as input data for these parameters

The complete input data as entered into the model is available as a separate excel file. In the following chapter, the data compilation approach as applied by Sphera will be explained thoroughly. Each subchapter represents key parameters that are reflected in the Lean AgModel for the assessment.

2.3.1. Yields, product characteristics and allocation

Yield has a high influence on the results, since all results are scaled according to it. All data points regarding the yield for the main product (coffee beans) as provided by the partners have been used. In the model, the average yield per province was considered for both countries. The amount of crop residue (coffee husk and coffee leaf) has been calculated as a ratio to the main yield, as provided by the client. Hence, the ratio of coffee husks to coffee beans is 90%, while for the coffee leaves it is 35.6%.

Regarding the product characteristics, the most important parameter to consider is the nitrogen content. The nitrogen content of the coffee beans and coffee husks are based on a study from A.M. Covre et al.[4]. In order to find reliable data for the nitrogen content of the coffee residues, several publications were assessed – the absolute values varied but were in the same range as the nitrogen content of the husks. Hence, as conservative approach, the same nitrogen content has been applied to the coffee leaves as for the husks. More information can be found in chapter 2.3.11.

Table 2-3: Nitrogen contents of coffee bean, coffee husk and coffee leaf ([kg/kg] dry matter)

Nitrogen content coffee beans	Nitrogen content coffee husk	Nitrogen content coffee leaf
0.0128	0.0267	0.0267

A relevant fraction of farmers produces other valuable products (from food trees and intercrops) from the same plots where they produce coffee (see Table 2-4). From an LCA perspective, these products represent co-products that should receive some of the environmental burden of the production system. Ideally, the allocation of environmental impacts would be based on physical characteristics of the different products (e.g. energy content, carbon content). However, since the physical characteristics do not represent a meaningful relationship between the three products, it was decided to apply economic allocation, based on the revenue achieved (per plot) from coffee and co-products (i.e. only applicable if the farmer sold their respective co-products). In accordance with assumptions from Enveritas, the maximum percentage revenue of the co-product was assumed to be 100%. Any higher values were considered to be unrealistic and therefore excluded from the average calculation.

Table 2-4: Allocation ratios for main and co-products of the study [%]

Allocation ratios & fractions	Indonesia	Vietnam
Main product (coffee bean)	92%	89%
Co-product (intercrops)	5%	7%
Fraction of farmers selling intercrop	29%	24%
Co-product (food crops)	3%	4%
Fraction of farmers selling food crop	66%	20%

2.3.2. Mineral Fertilizers

Not all fertilizers utilized by the farmers in Indonesia and Vietnam were available in the LCA FE database. Therefore two steps have been conducted to create the best available proxies:

[4] Covre, A. M., et al. (2016) : Nutrient accumulation in bean and fruit from irrigated and non-irrigated Coffee canephora cv. Conilon. Emirates Journal of Food and Agriculture, 402-409.

1. Mapping the stated fertilizer to an available dataset in the software. This was done by comparing the nutrients contained in the stated vs. in the available fertilizers and selecting the closest dataset.

2. A correction factor was calculated for each fertilizer dataset in order to recalculate the amount of nutrients contained in the stated fertilizer to the correct amount of nutrients contained in the mapped fertilizer dataset (since they did not always have the same amount of nutrients contained).

In total, 5 fertilizer datasets have been included in the model, as can be seen in Table apx 3 in the Annex, which shows the mapping approach as explained in step 1. A few fertilizer types such as Monoammonium phosphate or Diammonium phosphate had application rates below 0.1 kg/ha on the province level average, and were thus excluded from the model. For each fertilizer, the average amount used per province was entered into the model for both countries.

2.3.3. Organic Fertilizers

For this parameter, the amounts of nitrogen and phosphate applied to the field were calculated based on the different types of organic fertilizers indicated by the farmers. As with the inorganic fertilizers, a similar approach for finding representative datasets was taken:

1. Mapping all organic fertilizer types and using assumptions to assign each fertilizer type to a dataset based on its contents. The corresponding mapping approaches and assumptions can be found in Table apx 4 in the Annex.

2. Entering nitrogen and phosphate contents for each fertilizer type. Values were based on literature findings[5].

For both countries, the values have been entered as average on province level. Furthermore, parts of the disposed coffee husk and leaf residues have been considered in addition to the amounts of organic fertilizers as stated by the farmers.

Table 2-5: Overview of organic fertilizers and their nitrogen and phosphate contents [kg/kg]

Organic fertilizer type	Nitrogen content [kg/kg]	Phosphate content [kg/kg]
Poultry manure	0.0181	0.0125
Sheep manure	0.01	0.0069
Cattle manure	0.0056	0.0029
Pig manure	0.0071	0.0065
Compost manure	0.00845	0.0041

2.3.4. Active Ingredients

This parameter only has a critical impact on the results if toxicity is being assessed. If the carbon footprint is the focus of the assessment (as it is in this case), then the parameter usually has no critical impact on the emissions results, since mainly the provision of the products is considered. In this case, the same approach has been applied to both countries. The average amount of product applied on province level has been multiplied by 50%, following a conservative assumption that only a portion of product applied is an active ingredient. Nevertheless, a characterization factor for toxicity as an average of the Top 20 most

[5] Landwirtschaftskammer NRW (2022): Ratgeber Pflanzenbau und Pflanzenschutz

used active ingredients[6] has been implemented to generically cover this impact category and allow assessment of all generally used LCA impact categories, in case the dataset is used for further assessments outside this study.

2.3.5. Irrigation

In the baseline calculations of this assessment, the irrigation values have been calculated with client data. For the scenario analysis the goal was to use data from literature. Since only a few farmers scattered across provinces in Indonesia stated that they irrigated their fields, the irrigation procedure was neglected in the baseline as it is not representative for the geographical area. The following table provides an overview of the fraction of farmers irrigating for each province, based on client data.

Table 2-6: Fraction of farmers irrigating for Indonesia and Vietnam [%]

Provinces in Indonesia	Bengkulu	Lampung	Sumatera	-
Fraction of farmers irrigating [%]	0%	0.62%	0.39%	-
Provinces in Vietnam	Đắk Lắk	Đắk Nông	Gai Lai	Lâm Đồng
Fraction of farmers irrigating [%]	20%	74%	45%	56%

For the few farmers in Indonesia irrigating their cultivation, the irrigation water sources were rivers, streams and manmade ponds. For Vietnam, the main sources were boreholes and wells, followed also by rivers, streams and manmade ponds.

This fraction of farmers irrigating their fields has been multiplied by the average water consumption on province level used for the irrigation, in order to reflect the impact of farmers that are not irrigating. An explanation of the structure and purpose of the scenario analysis can be found in chapter 3.2.1. Water inputs for the scenario analysis were derived from literature[7]. Both can be found in the table below, already weighted with the fraction of farmers irrigating, as seen above. For Đắk Lắk, no water input values were available, hence the country average of Vietnam has been used and weighted with the 20% of farmers irrigating in Đắk Lắk.

Table 2-7: Irrigation water used for Indonesia and Vietnam (Baseline + Scenario) [m^3/ha]

Provinces in Indonesia	Bengkulu	Lampung	Sumatera	-
Baseline - Amount of water irrigated	0	0	0	-
Scenario - Amount of water irrigated	0	5.97	3.27	-
Provinces in Vietnam	Đắk Lắk	Đắk Nông	Gai Lai	Lâm Đồng
Baseline - Amount of water irrigated	55.94	204.26	128.79	165.63
Scenario - Amount of water irrigated	305.21	1018.26	717.01	1125.17

For the assessment of impacts on water scarcity (additional environmental impacts, see Annex C: a crucial parameter is the water scarcity factor, also called AWaRe (Available Water Remaining). For each province a specific value is provided, as shown in Table 2-8.

[6] F. Maggi et al. (2019) : PEST-CHEMGRIDS, global gridded maps of the top 20 crop-specific pesticide application rates from 2015-2025
[7] Pfister et al. (2009): Assessing the environmental impacts of freshwater consumption in LCA

Table 2-8: AWaRe characterization factor for Indonesia and Vietnam

Provinces in Indonesia	Bengkulu	Lampung	Sumatera	-
AWaRE characterization factor	0.46	1.05	0.41	-
Provinces in Vietnam	Đắk Lắk	Đắk Nông	Gai Lai	Lâm Đồng
AWaRE characterization factor	6.25	5.88	3.54	3.63

Lastly, the energy consumption used for irrigation represents an important parameter in the assessment. In the baseline, the reported data from the surveys was used. Since irrigation is only applicable to Vietnam, the table below summarizes the input data for Vietnam only.

Table 2-9: Diesel and electricity consumption of irrigation pump for Vietnam (Baseline calculation)

Provinces in Indonesia	Bengkulu	Lampung	Sumatera	-
Diesel consumption [l/ha]	n.a.	n.a.	n.a.	-
Electricity consumption [MJ/ha]	n.a.	n.a.	n.a.	-
Provinces in Vietnam	Đắk Lắk	Đắk Nông	Gai Lai	Lâm Đồng
Diesel consumption [l/ha]	19.52	115.37	30.97	106.07
Electricity consumption [MJ/ha]	548.58	317.83	835.92	101.15

As a scenario, water consumption values from literature have been combined with Sphera's irrigation pump model. In order to use this model, which automatically calculates the required amount of energy used for the irrigation process, the respective fuel source needs to be stated. To correctly reflect the fuel source, the fraction of farmers using electricity for irrigation has been calculated. Assumptions for this calculation can be found in the annex.

Table 2-10: Fraction of farmers using electricity (irrigation) in Indonesia and Vietnam (Baseline)

Provinces in Indonesia	Bengkulu	Lampung	Sumatera	-
Fraction of farmers using electricity	0*	0*	0*	-
Provinces in Vietnam	Đắk Lắk	Đắk Nông	Gai Lai	Lâm Đồng
Fraction of farmers using electricity	0.80	0.33	0.83	0.19

*For Indonesia no energy source has been stated by the farmers, therefore the worst case has been applied (low relevance to results see Table 2-7). "0" represents 100% diesel, "1" represents 100% electricity used for the irrigation process in the Lean AgModel

2.3.6. Diesel consumption, field work

For the diesel consumed for field work activities such as spraying or weeding, the average amount on province level has been entered into the model for both countries. Electricity used for field work has been excluded from the assessment due to its low relevance to the results.

2.3.7. Land use change

Sphera has created a land use change (LUC) tool which follows the PAS 2050:2011 and 2050-1:2012 guidelines for calculating statistical GHG emissions from land use and land use change. The LUC tool calculates emissions in kg CO_2 eq. per ha and year for over 210 countries and 170 crops, considering a timeframe of 20 years. The basis for the statistical land use change models are values retrieved from the

FAOstat[8] and Forest Resource Assessment[9], as well as default values from the IPCC Guidelines for carbon stocks (biomass, soil organic carbon and dead organic matter). Currently, the reference period of the tool is 2019 since this represents the last available data provided by the FAOstat. The values for Indonesia and Vietnam as retrieved from the tool have been weighted by the fraction of farmers with farm expansion in the last 20 years, thereby considering a province average for both countries. The fractions can be found in the table below, while the emissions considered in the study can be found in Table 2-2.

Table 2-11: Fraction of farmers with farm expansion in the last 20 years for Indonesia and Vietnam

Provinces in Indonesia	Bengkulu	Lampung	Sumatera	-
Fraction of farmers (farm expansion)	0.029	0.016	0.019	-
Provinces in Vietnam	Đắk Lắk	Đắk Nông	Gai Lai	Lâm Đồng
Fraction of farmers (farm expansion)	0.04	0.04	0.03	0.00

2.3.8. Soil erosion

Soil erosion has no direct impact on the carbon footprint results[10], but affects eutrophication, as nutrients contained in the soil leach into water bodies. In order to reflect the impact of soil erosion, data has been retrieved from the Joint Research Centre[11]. These values are specific to each province of the study. Because coffee plantations are considered perennial cropland and some farmers in the survey practice soil conservation measurements, the values as retrieved have been multiplied with the following values:

- *20% for the assumption that only 20% of eroded soil enters surface water bodies
- *10% for the assumption that perennial cropland aids in preventing soil erosion
- *10% if farmers practiced measures to prevent soil erosion

The fraction of farmers practicing soil conservation measurements on province level can be found below.

Table 2-12: Soil erosion specifications for Indonesia and Vietnam

Provinces in Indonesia	Bengkulu	Lampung	Sumatera	-
Initial soil erosion value [kg/ha]	273.32	296.01	85.65	
Fraction of farmers (soil conservation)	0.22	0.33	0.15	-
Provinces in Vietnam	Đắk Lắk	Đắk Nông	Gai Lai	Lâm Đồng
Initial soil erosion value [kg/ha]	300.66	548.05	439.79	227.30
Fraction of farmers (soil conservation)	0.92	0.96	0.95	0.82

2.3.9. Transports

Two transportation processes have been considered in the model (refer to annex for further information):

1. Inbound transports: representing the transports needed for the provision of materials, such as fertilizers or pesticides. Values have been used as average on province level for both countries.

[8] https://www.fao.org/faostat/en/#home
[9] https://www.fao.org/forest-resources-assessment/en/
[10] Soil erosion could result in a loss of soil organic carbon from the system. However, the extend is unclear and there are no emission factors available in the IPCC 2019 guidelines used in this study. In addition, these emissions should be part of a complete assessment of changes in soil carbon stocks, that is outside the scope of this study.
[11] Borrelli Pet al. (2017): An assessment of the global impact of 21st century land use change on soil erosion. Nature Communications, 8 (1): art. no. 2013. https://esdac.jrc.ec.europa.eu/content/global-soil-erosion

2. Outbound transports: representing the transports needed to manoeuvre the harvested product to the processing stage. Values have been used as average on province level for both countries.

2.3.10. Processing of harvested coffee cherry

To complement the cultivation process developed using the Lean AgModel, the processing of harvested coffee cherries was also modelled. The post-harvest processing consists of two steps:

1. Hulling: this process removes the parchment skin of the bean
2. Drying: this process preserves the coffee quality

As can be seen in the table below, not all farmers used a hulling machine directly on their farm – in some cases, the hulling machine was the property of a friend or neighbour, or the buyer hulled the product. Since hulling is an essential post- harvest process, it is included in the system boundaries (Figure 2-1).

Table 2-13: Overview of processing specifications for Vietnam and Indonesia

Provinces in Indonesia	Bengkulu	Lampung	Sumatera	-
Fraction of farmers using hulling machine	0.78	0.86	0.83	-
Fraction of farmers using drying machine	0.010	0.002	0.014	-
Provinces in Vietnam	Đắk Lắk	Đắk Nông	Gai Lai	Lâm Đồng
Fraction of farmers using hulling machine	0.88	0.91	0.99	0.86
Fraction of farmers using drying machine	0	0	0	0

The diesel and electricity consumption used for hulling and drying can be found in Table 2-2.

2.3.11. Residue treatment methods applied by farmers

To model the residue treatment (both coffee husk and leaves), certain assumptions are made and are summarised in Table 2-14.

Table 2-14: Mapping approach for residue treatment methods

Residue treatment methods used by farmers	Modelling approach for residue treatment	Index*
Compost of residues and application to other crops	Residues go into composting process, while composting 15% of the nitrogen content is lost as emissions, the rest is considered as additional organic fertilizer that is applied to the field	1
Compost of residues and application to coffee farm		
No composting and application to other crops	Nitrogen content of residues considered as additional organic fertilizer applied to the field	2
No composting and application to coffee farm		
Mulching of the residues		
Piling residues and leave them on the field	Residues go into composting process	3
Burning of residues on the field	Residues go into combustion process	4
Removing residues from the farm	Cut-off: assumes to leave system burden free, but no credits are given	-
Selling residues to buyer		
Using residues for fuel		
The mill or processing center keeps residues		

* Index is used to categorize the treatment methods in order to provide a better overview in the following tables

The amount of residue (see ratio in chapter 2.3.1) is weighted by the corresponding fraction of farmers:

Table 2-15: Fraction of farmers treating residue for Indonesia and Vietnam

Provinces in Indonesia				
Index (for husk treatment)	Bengkulu	Lampung	Sumatera	-
2	0.504	0.307	0.404	-
1	0.112	0.144	0.215	-
3	0.337	0.469	0.368	-
4	0.047	0.080	0.014	-
Index (for leaf treatment)	Bengkulu	Lampung	Sumatera	-
2	0.165	0.243	0.344	-
1	0.055	0.071	0.035	-
3	0.744	0.627	0.581	-
4	0.026	0.007	0.013	-
Provinces in Vietnam				
Index (for husk treatment)	Đắk Lắk	Đắk Nông	Gai Lai	Lâm Đồng
2	0.135	0.121	0.193	0.135
1	0.665	0.483	0.296	0.811
3	0.187	0.389	0.502	0.046
4	0.014	0.007	0.009	0.008
Index (for leaf treatment)	Đắk Lắk	Đắk Nông	Gai Lai	Lâm Đồng
2	0.525	0.239	0.395	0.149
1	0.105	0.058	0.074	0.032
3	0.350	0.636	0.501	0.810
4	0.008	0.054	0.007	0.003

As stated in Table 2-14, if residues were eventually returned to the field, their nutrient input was considered in the emission modelling. For modelling emissions from the treatment (e.g. composting, combustion) literature values have been used (see Table apx 1: Overview of model modules and approaches).

3. Carbon footprint results

The following chapter presents the results for the carbon footprint calculation only. Results for additional impact categories can be found in Annex C: The table below provides the description of the impact category used for the carbon footprint calculations:

Table 3-1: Description of climate change (GWP) impact category

Impact Category	Description	Unit	Method
Climate change (global warming potential)	A measure of greenhouse gas emissions, such as CO_2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may in turn have adverse impacts on ecosystem health, human health and material welfare.	kg CO_2 equivalent	EF 3.0

3.1. Study results

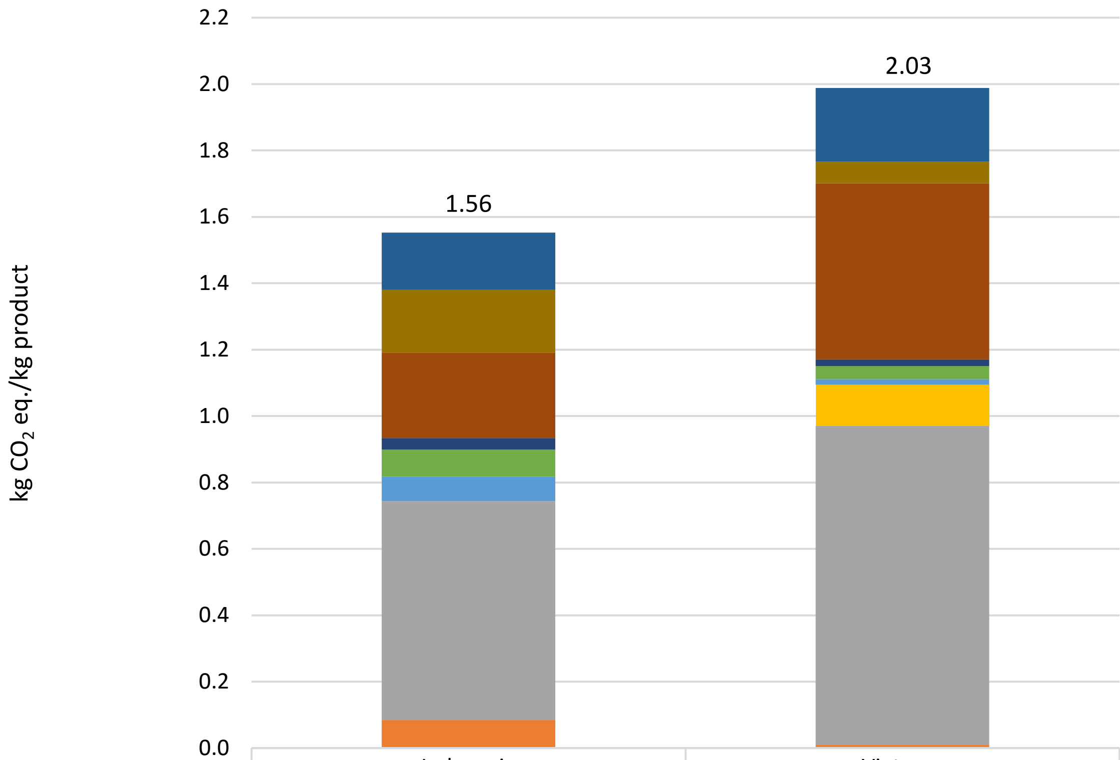
In this section, the main results for the carbon footprint baseline calculation for each province are presented. Two graphs will display the results for the carbon footprint baselines. Figure 3-1 shows the carbon footprint baseline results on origin level – for Indonesia and Vietnam. Meanwhile, Figure 3-2 shows a comprehensive overview of the total values accompanied with a contribution analysis for each province. A detailed description on the different contributors can be found in Annex A: . The included data table provides further insights into the results.

In order to calculate the results on origin level for Indonesia and Vietnam, the province results (as extracted from the LCA FE software) have been offset against the corresponding production volumes of each province for all groupings (e.g. Provision of fertilizers, field emissions, residue treatments, ...). The following table provides an overview of the production volumes as used in the calculations.

Table 3-2: Overview of production volumes per province for both Indonesia and Vietnam

Provinces in Indonesia	Bengkulu	Lampung	Sumatera	-
Production volume (% of total)	35.1%	34.6%	30.2%	-
Provinces in Vietnam	**Đắk Lắk**	**Đắk Nông**	**Gai Lai**	**Lâm Đồng**
Production volume (% of total)	17.4%	27.8%	23.3%	31.5%

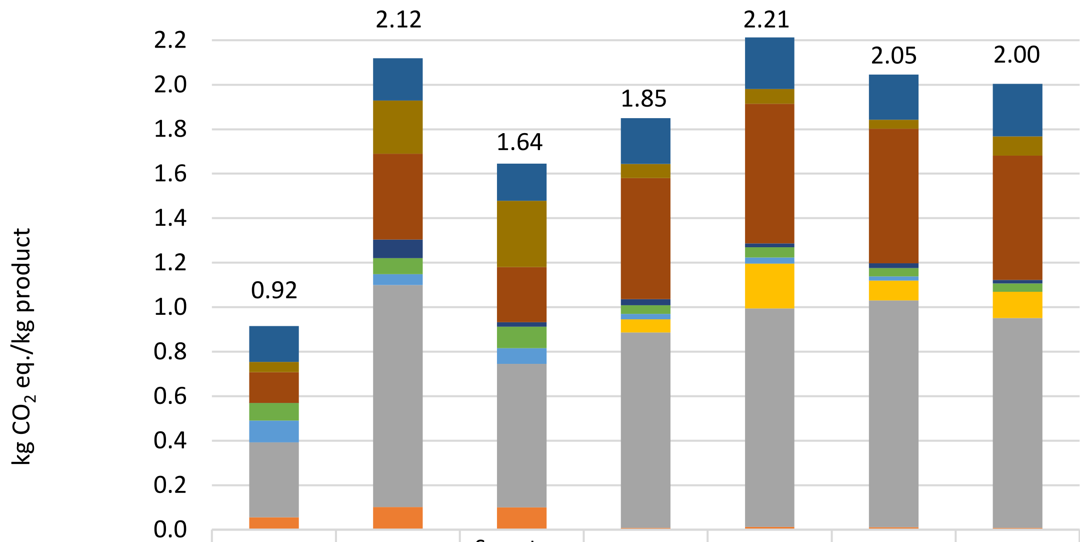
As the first graph down below shows, the origin level average baseline calculation for Indonesia is 1.56 kg CO_2 eq./kg product, while for Vietnam the average is higher with 2.03 kg CO_2 eq./kg product. A more detailed analysis will be stated down below for the province level results.



	Indonesia	Vietnam
Residue treatment	0.172	0.222
Transports	0.189	0.066
Provision of fertilizer	0.257	0.530
Processing	0.035	0.020
Machinery	0.082	0.040
LUC	0.073	0.016
Irrigation	0.000	0.124
Field	0.659	0.961
Crop protection	0.085	0.010

Figure 3-1: Results for the carbon footprint baseline calculations on origin level (w/o allocation)

The province level results appear to be more consistent in Vietnam compared to Indonesia, with the province Lampung showing the highest results within Indonesia. While Lampung has the highest yield of all provinces in Indonesia, it also has considerably higher amounts of applied fertilizer and consequently higher impacts for the provision of fertilizers. For all provinces, the highest contributions to the results originate from the field emissions. Those are elated to fertilizer application, which in turn leads to the release of potent greenhouse gases such as N_2O and, in the case of urea application, CO_2. Higher crop yields lead to relatively lower emissions per kilogram, compared to lower yielding systems (scaling effect). Provision of fertilizer (fertilizer production) is associated with the amount of fertilizer applied and is one of the main contributors alongside field emissions. The residue treatment of husks and leaves has a visible impact in the contribution to the carbon footprint baseline. GHG emissions released due to land use change, combustion of fossil fuels used in machinery and for irrigation, as well as the application of crop protection products, all yield relatively lower impacts, as can be visualized in Figure 3-2. The processing of the harvested crop (hulling and drying) also only has a small impact.



	Bengkulu	Lampung	Sumatera Selatan	Đắk Lắk	Đắk Nông	Gia Lai	Lâm Đồng
Residue treatment	0.16	0.19	0.17	0.21	0.23	0.20	0.24
Transports	0.05	0.24	0.30	0.06	0.07	0.04	0.09
Provision of fertilizer	0.14	0.39	0.25	0.54	0.63	0.61	0.56
Processing	0.00	0.08	0.02	0.03	0.02	0.02	0.02
Machinery	0.08	0.07	0.10	0.04	0.05	0.04	0.04
LUC	0.10	0.05	0.07	0.02	0.03	0.02	0.00
Irrigation	0.00	0.00	0.00	0.06	0.20	0.09	0.12
Field	0.34	1.00	0.65	0.88	0.98	1.02	0.94
Crop protection	0.06	0.10	0.10	0.01	0.01	0.01	0.01

Figure 3-2: Results for the carbon footprint baseline calculations on province level (w/o allocation)

Since this study did not model bottom up (farm by farm) but used aggregated input data, it is not straight forward to provide margin of error estimates. A simplified Monte Carlo Analysis considering the most important parameters (yield, fertilizer application, energy use on farm, pesticide use, transport distances, residue mass) is provided in Annex D to estimate a range of results, incl. standard deviation.

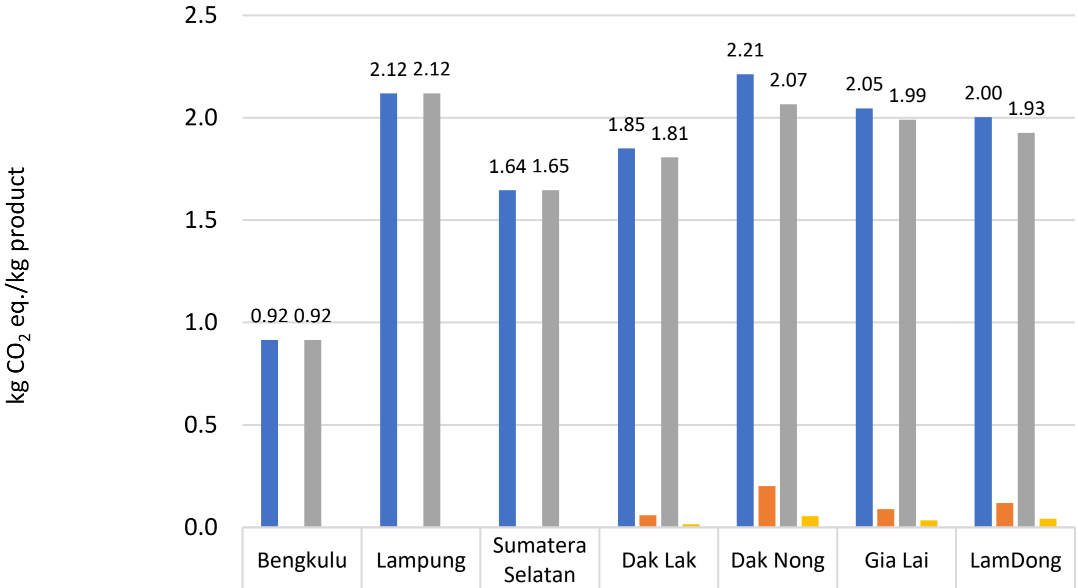
3.2. Scenario Analysis

3.2.1. Scenario analysis for irrigation

The main goals of the irrigation scenario analysis were to compare collected primary data (Baseline) with literature values (Scenario) for benchmarking purposes, and to investigate simplification potentials, especially since data on the amount of water consumed was only available for very few farms. The literature values used for the scenario have been described in the preceding chapter, 2.3.5. Additionally, Sphera's irrigation pump model was utilized, which automatically calculates the amount of diesel or electricity required for the irrigation pump. The impacts of irrigation in Indonesia are negligible, given the minute fraction of farmers irrigating in that region. For Vietnam, the differences in diesel and electricity consumption for irrigation between primary data and calculated data (per kilogram yield) are shown in Table 3-3.

Table 3-3: Overview of diesel/electricity consumption of irrigation (primary + calculated data) Vietnam

Vietnam	Dak Lak		Dak Nong		Gai Lai		Lam Dong	
[l/kg],[MJ/kg]	Diesel	Electricity	Diesel	Electricity	Diesel	Electricity	Diesel	Electricity
Baseline	7.13E-03	2.00E-01	4.76E-02	1.31E-01	1.12E-02	3.01E-01	2.99E-02	2.85E-02
Scenario	8.03E-04	5.78E-02	9.66E-03	9.11E-02	1.51E-03	1.41E-01	8.92E-03	3.75E-02



	Bengkulu	Lampung	Sumatera Selatan	Dak Lak	Dak Nong	Gia Lai	LamDong
Total baseline	9.15E-01	2.12E+00	1.64E+00	1.85E+00	2.21E+00	2.05E+00	2.00E+00
Irrigation process baseline	0.00E+00	0.00E+00	0.00E+00	5.83E-02	2.02E-01	8.94E-02	1.18E-01
Total scenario	9.15E-01	2.12E+00	1.65E+00	1.81E+00	2.07E+00	1.99E+00	1.93E+00
Irrigation process scenario	0.00E+00	1.03E-03	6.45E-04	1.45E-02	5.48E-02	3.37E-02	4.14E-02

Figure 3-3: Results of the scenario analysis for irrigation

As can be seen in Figure 3-3, there are nearly no impacts for Indonesia, since only 0-0.62% of farmers irrigated. In comparison, 20-74% of farmers irrigated in Vietnam with around 568 m^3/ha according to literature[12]. The impacts to the carbon footprint are related to the energy used for the irrigation pump. As Figure 3-3 and Table 3-3 show, these values were considerably higher in the collected data (Baseline) compared to the calculated values by the irrigation pump model (Scenario). This can be due to the fact that according to Aquastat[13] only 1% of the irrigation water in Vietnam derives from groundwater, and the model therefore considers a lower energy requirement for the horizontal pumping of water compared to pumping higher amounts of groundwater. The following table provides an overview on the relative contribution of the irrigation process in comparison to the total values, for both, the baseline and the scenario:

Table 3-4: Relative contribution of irrigation process to total results value for Indonesia and Vietnam

Provinces in Indonesia	Bengkulu	Lampung	Sumatera	-
Baseline calculation	0%	0%	0%	-
Scenario calculation	0%	0%	0%	-

[12] D. Tran et al. (2021) : Improving irrigation water use efficency of Robusta Coffee (Coffee canephora) production in Lam Dong Province, Vietnam
[13] https://www.fao.org/aquastat/en/

Provinces in Vietnam	Đắk Lắk	Đắk Nông	Gai Lai	Lâm Đồng
Baseline calculation	3%	9%	4%	6%
Scenario calculation	1%	3%	2%	2%

In conclusion, there is a degree of uncertainty related to calculating water consumption and related energy consumption based on secondary data. The results deviate from the primary data, however, the estimated values are close to values from other studies as seen above. Hence, at least to fill data gaps for water consumption (amount of water used) or when data of energy consumption in irrigation is incomplete, the literature values provide a simplification potential that can be realized in future studies. In these cases, the focus of data collection can lie with the fraction of farmers irrigating and the energy sources utilized.

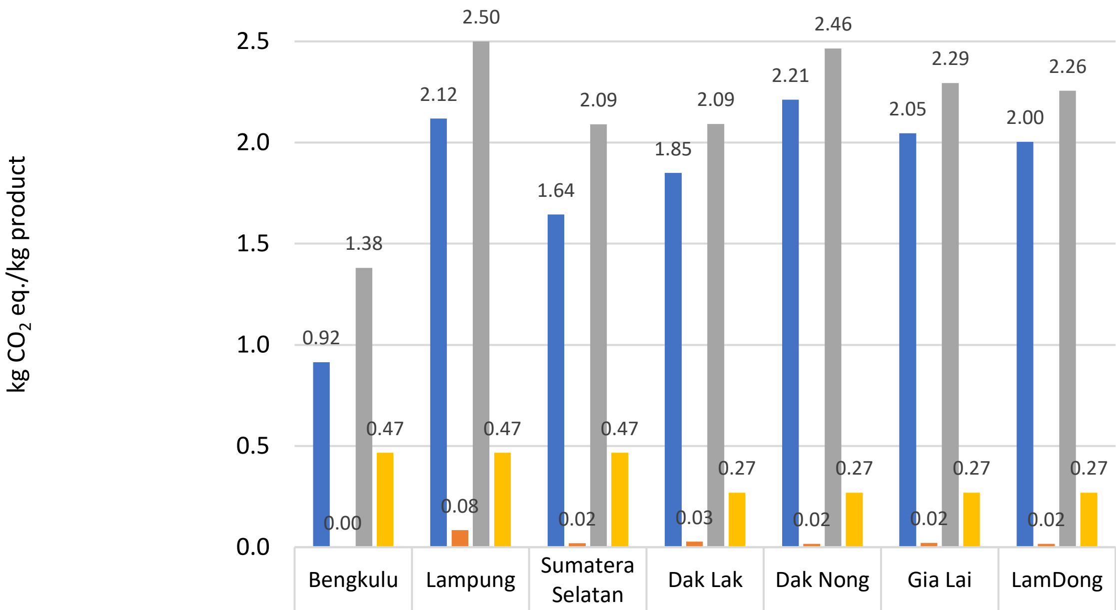
3.2.2. Scenario analysis for processing

The main goals of the scenario analysis for processing were to compare primary data to literature values for benchmarking purposes and to investigate simplification potentials. Therefore, primary data has been implemented for the baseline calculations (Table 2-2), while the following literature values[14] were used in the scenario calculations:

- Diesel used for hulling process: 0.003 litre/kilogram green bean equivalent
- Electricity used for drying process: 1.67 MJ/kilogram green bean equivalent

For reasons of clarity, in this scenario, it was assumed that 100% of farmers relied on electricity as the source of energy for drying. This is of course unrealistic, but the scenario was calculated to test the maximum potential impact of processing, also in view of applying the same data collection procedure to other regions.

[14] R. Pramulya et al. (2022) : Life Cycle Assessment of Gayo Arabica Coffee Green Bean at Aceh Province



	Bengkulu	Lampung	Sumatera Selatan	Dak Lak	Dak Nong	Gia Lai	LamDong
Total value baseline	9.15E-01	2.12E+00	1.64E+00	1.85E+00	2.21E+00	2.05E+00	2.00E+00
Processing value baseline	6.95E-07	8.43E-02	2.01E-02	2.76E-02	1.69E-02	2.15E-02	1.67E-02
Total value scenario	1.38E+00	2.50E+00	2.09E+00	2.09E+00	2.46E+00	2.29E+00	2.26E+00
Processing value scenario	4.66E-01	4.66E-01	4.66E-01	2.70E-01	2.70E-01	2.70E-01	2.70E-01

Figure 3-4: Results of scenario analysis for processing

As can be seen in Figure 3-4, for both countries, the scenario results are higher than in the baseline - up to 32.04% higher for Indonesia and up to 12.32% for Vietnam. These increases are caused by the assumption of electricity use for the drying process (set to 100%) and less attributed to the actual value of energy consumption on a per kg basis. In conclusion, it can be said that the assumed energy consumption for processing could be taken from literature, while it is important to know how many farmers are using which processing technique.

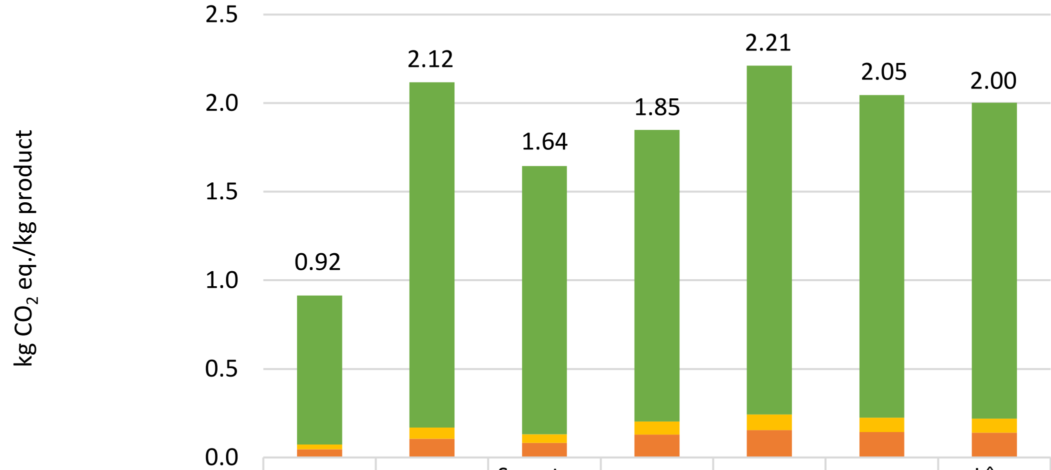
The following table shows the relative contribution of the hulling and drying process in comparison to the total values for both the baseline as well as the scenario analysis calculations:

Table 3-5: Relative contribution of processing

Provinces in Indonesia	Bengkulu	Lampung	Sumatera	-
Relative contribution of processing to total value of baseline calculation	0%	4%	1%	-
Relative contribution of processing to total value of scenario calculation	34%	19%	22%	-
Provinces in Vietnam	**Đắk Lắk**	**Đắk Nông**	**Gai Lai**	**Lâm Đồng**
Relative contribution of processing to total value of baseline calculation	1%	1%	1%	1%
Relative contribution of processing to total value of scenario calculation	13%	11%	12%	12%

3.2.3. Scenario analysis for allocation

This scenario analysis was primarily conducted to provide some insights into the collected data regarding co-products as well as deliver results with allocated impacts, thus enabling more comprehensive comparisons to other studies. The allocation ratios, based on an economic allocation approach as described section 2.3.1 , have been applied to the total impact values from the baseline calculation (where no allocation has been applied). As can be seen in Figure 3-5, this fraction then represents the allocated burden for each of the main- or coproducts.



	Bengkulu	Lampung	Sumatera Selatan	Đắk Lắk	Đắk Nông	Gia Lai	Lâm Đồng
Main product (coffee bean)	0.84	1.95	1.51	1.65	1.97	1.82	1.78
Co-product (from food trees)	0.03	0.06	0.05	0.07	0.09	0.08	0.08
Co-product (from intercrops)	0.05	0.11	0.08	0.13	0.15	0.14	0.14

Figure 3-5: Results of the scenario analysis for allocation

The allocation factors for the intercrops account to 5% in Indonesia and 7% in Vietnam. In comparison to the intercrops, the allocation factors for food crops are lower, with an average of 3% in Indonesia and 4% in Vietnam. In conclusion, the allocation procedure with a minimum of 3% (food crops in Indonesia) and a maximum of 11% (sum of inter- and food crops in Vietnam) shows how much of the burden associated with the coffee cultivation could potentially be shifted towards co-products of the system.

It should be noted that the reported allocation fractions consider that many farmers do not sell co-products (see Table 2-4). For farmers that sold co-products, the reported revenues were sometimes as high as those for coffee (or even higher, but those values were capped in this study, see section 2.3.1). This means that on average, allocation of impacts to co-products does not have a very large impact on the results, but for single farms the impact could be large.

4. Interpretations and Conclusions

4.1. Data quality assessment and limitations

In general, it is rare to have such an extensive breadth of primary data that covers so many relevant aspects of farming activity and works with such a large sample size. Primary data collection is considered to yield the best data quality, and therefore the data quality of this study would be considered to be high from a classical LCA perspective.

The carbon footprint values calculated in this study seem to be in range compared to literature values:

- Pramulya et al (2022)[15] calculated a carbon footprint for coffee production (arabica) in Indonesia between 1.48 and 1.93 kg/ CO2 eq. per kg green beans
- Trinh et al (2020) [16] calculated a carbon footprint for coffee production in Vietnam of 0.935 kg CO_2eq. (conventional intensive), 0.729 kg CO_2eq. (conventional moderate) and 0.644 kg CO_2eq. (organic intensive) per kg green bean equivalent
- Sphera calculated impacts from coffee production in Vietnam based on data from Ho (2018) [17] to be 1.57kg of CO2 eq. per kg green bean (internal dataset).

The reported values do not consider allocation of byproducts.

Sphera has no on-ground expertise on the assessed cultivation systems and is therefore not able to provide a detailed assessment of the plausibility of the reported data. Nevertheless, in working with the collected data some observations were made and are provided below as third party suggestions for reviewing and validating some of the collected data further:

- The **revenue values for intercrops and food crops** vary very widely. While on average (i.e. considering farmers that do not sell co-products), **allocation** of impacts to co-products **does not have a very large** impact on the results, for single farms the impact could be large. Economic allocation is always difficult since it is based on variable prices and not on fixed product characteristics. However, the large variation in the reported revenue would justify a more detailed assessment of the economics of the farming systems under study, e.g. comparing the combined revenue of intercrops and coffee to farms that grow only coffee. It would also be worthwhile to further explore why total revenue varies to this extent within “neighboring” farms in the same region.
- For **irrigation**, it was obviously difficult for farmers to report the amount of water applied. The ranges in the reported energy consumption could therefore be related to different amounts of water applied, but also to different irrigation practices. For a clearer interpretation, it would be beneficial to have both values (also because water consumption itself is an environmental impact that is usually included in full LCAs). The use of literature values could - to some extent - help in this regard, though the approach tested in this study showed clear deviations in results based on literature compared to those based on primary data (see section 3.2.1).

[15] Pramulya, Rahmat, et al. "Life Cycle Assessment of Gayo Arabica Coffee Green Bean at Aceh Province." *HABITAT* 33.03 (2022): 308-319.
[16] Trinh, L. T. K., et al. "Comparative life cycle assessment for conventional and organic coffee cultivation in Vietnam." *International Journal of Environmental Science and Technology* 17 (2020): 1307-1324.
[17] Ho, Thong Quoc. "Economic analysis of sustainable coffee production in Vietnam." *Queensland University of Technology: Brisbane, Australia* (2018).

- Data on **processing energy** also varied very widely, over orders of magnitude if related to 1kg of processed product. The variation does not have a large impact on the results, because not many farmers used electricity for drying. But the results could be an argument to use fixed values (researched, collected or from literature) for processing energy. While processing did not have significant impact in this study, the impacts could be much larger for single farms or in other regions, e.g. if machine drying is applied, see 3.2.2.

Further limitations beyond the input data should be considered as follows:

- Due to the timeline of the study, the **comparison of the results to the results from the Cool Farm Tool** or other assessments could not be included. For the report at hand, only an overview of assumptions as stated by Enveritas was available (see Annex B:) and the approach taken by Sphera has been transparently documented. Nevertheless, in-depth analysis and interpretation of the results will become more robust once detailed information about parameter specifics (e.g. nutrient contents of organic fertilizers or if organic fertilizers also enter the system burden free or not) and the results as calculated from Enveritas become available.
- **Changes in soil carbon stocks** can have a significant impact on the results. Emissions occurring through changes in land use are at least covered on screening level in the LUC category. However, there could also be the potential that the assessed coffee plantations contribute to an increase in soil carbon stocks (**soil carbon sequestration**). The potential impact on results is large, if the sequestration potential can be reliably assessed. However large uncertainties lead soil carbon sequestration to often be omitted from LCA studies, or, if at all, reported separately from the overall impacts[18]. An investigation of the assessment options and results was outside the scope of this study.
- **Fertilizer production datasets** used in this study (background datasets, mainly representing Indian production data) might not be entirely representative for the fertilizer origin countries in Vietnam and Indonesia.

4.2. Simplification potentials

Firstly, it is important to note that **the scope of data collection** for a study completely depends on its intended use. For example, a detailed farm by farm assessment is necessary if interventions or trainings should be targeted to farmers with the highest improvement potential. However, for the establishment of representative carbon footprint baselines, **for reporting purposes or hot-spot analysis**, data collection and assessment could be simplified (compared to the very extensive dataset that builds the basis of this study). To our knowledge, comprehensive coffee cultivation data covering multiple cultivation regions is scarce, and companies that have coffee in their supply chains often must use dated proxy data e.g. for their scope 3 reporting. Therefore, at least from a reporting perspective, focusing on a set of key parameters in data collection and having these reliably assessed over many cultivation areas and over several cultivation seasons might be preferred over the slow and resource intensive buildup of very detailed datasets.

From the contribution analysis of the carbon footprint results (see Figure 3-2), a few **hotspots** become apparent. First, the relation of fertilizer application to yields is the most important direct driver of results (as fertilizer application contributes twofold with field emissions and the production of fertilizer). Residue management, machinery use, irrigation and LUC also show relevant contributions which might even be higher if assessments are repeated in other cultivation regions (this might also be true for processing, which only shows marginal contributions in this study).

[18] see e.g. PEF method 2021

These hot-spots **can be covered with a comparatively small set of parameters:**

- Yield (green bean equivalents)
- Revenue from yield and byproducts
- Fertilizer type and application rates (organic and inorganic)
- Irrigation water applied and energy consumption for irrigation
- Machinery use (diesel consumption for field work)
- Fraction of farms where LUC occurred (and year of occurrence)
- Crop protection (active ingredients applied if toxicity is assessed, else, total amount of pesticides used)
- Processing options and fraction of farmers applying them
- Residue management: treatment pathways

This does not mean that all **other aspects** should be ignored. However, including them based on more **generic approaches** (and applying worst case assumptions where uncertainty is large) will not lead to significant limitations in the overall results. Some of the examples from this study include:

- Soil erosion; low relevance for carbon footprint results (higher for e.g. eutrophication), can be assessed based on GIS data, generic reduction factors can be applied were farmers report reduction measures.
- Pesticide application; if data will not be used for toxicity assessments, the total amount of pesticides applied will cover the impact on carbon footprint sufficiently.
- Processing; most relevant are the processing options and fraction of farmers applying them. Inventories for the different processing options could be based on literature as they are technical processes where variation can be expected to be low (compared to farming practices).

For the assessment of **LUC**, a refinement of the generic approach (assessment of statistical LUC) can be considered for regions where the generic approach indicated high relevance. The original dataset in this study contains many questions targeted at a detailed assessment of the **above ground biomass** (tree ages, density etc.) targeted to assess carbon stock changes in above ground biomass within the same land use category. Again, at least from a reporting and hot-spot analysis point of view it should be evaluated if such an assessment would be robust enough to be included in the baseline results, and if it is worth the large effort in data collection.

Regarding **allocation**, using primary data will have the highest precision. However, since there can be a lot of uncertainty to these values (regarding yields of co-products, prices, seasonal variation etc.) a simplification could be to work with fixed allocation ratios for different groups of co-products and then just assess the fraction of farmers selling them. This will also make comparison across regions and countries easier.

Regarding **data processing**, aggregating input data to **regional averages** of course means less granularity of the results. However, there are also advantages of this procedure. The most obvious might be the technical simplicity. The aggregated input data can be easily reviewed and checked for plausibility (also considering the overall variation). Data can be easily adjusted; the relevance of certain assumptions can be tested, and scenarios calculated. Also, reproducibility is high as the same input data can be used in several models with low effort. Interpretation of results can be related directly to the respective input parameter. Not least, the calculation effort is less time consuming (the most time-consuming step in this study was the aggregation of data to regional averages). As stated in the beginning, the depth of detail required depends on the intended use of the data and results. If such assessments should be scaled, the ease to conduct such assessments might be a relevant factor in deciding for simplified approaches.

4.3. Conclusions and recommendations

This study shows the carbon footprint baselines for two key origins (Indonesia and Vietnam) for Robusta coffee cultivation using Sphera's Lean AgModel and LCA approaches. Inventory data and results were calculated as province averages, the primary data as collected by the client can be considered as reliable and of high data quality. The data was collected on farm level and facilitated by Enveritas. The functional unit assessed was 1 kilogram of harvested, hulled and dried green coffee bean (green bean equivalent) after processing.

All carbon footprint baselines are in expected ranges (compared to previous assessments and literature data). There are no major outlier provinces or contributions detected in the study. The country average value for Indonesia (1.56 kg CO^2 eq./kg product) is lower than for Vietnam (2.03 kg CO^2 eq./kg product). It can be concluded that the carbon footprint baselines in Vietnam are more evenly distributed, and regional variation is higher in Indonesia.

The relation of fertilizer application to yields is the most important direct driver of results (as fertilizer application contributes twofold with field emission and the production of fertilizer). This might be an indication of where the largest reduction potentials may lay (see recommendations). Machinery use, irrigation and LUC also show relevant contributions which might even be higher if assessments are repeated in other cultivation regions (this might also be true for processing, which only shows marginal contributions in this study). The residue treatment of husks and leaves plays a minor role in the contribution to the carbon footprint baseline. Considering allocation of impacts to co-products reduces the impact of coffee green beans up to 11%.

Simplification potentials (depending on the intended use of the data) in data collection and the assessment to be evaluated are:

- focusing on parameters that drive hot-spot contributions,
- working with proxy data or more generic assumptions on other aspects (this way they are still included and completeness of the assessment is assured while data collection efforts might be reduced), and
- working with aggregated regional input data might simplify data processing and benchmarking.

Recommendations

Based on the above-mentioned aspects, the following recommendations are made:

- In general, it is considered necessary to collect agricultural cultivation data over **several cultivation seasons**, as seasonal variation due to climatic conditions or stressors (e.g. pests) is known to be large. Even if not all data can be collected for several years, at least some of the key parameters (see simplification potentials) could be collected for several years, potentially retroactively.
- **Conduct data collection at regular intervals** to measure and understand changes in management practices over time.
- As fertilizer application is identified as a hotspot, the **assessment** of a simplified **nutrient balance** at least for nitrogen (N balance) could be a valuable exercise to get a better understanding of the reduction potentials of fertilizer application.
- The **simplification potentials** identified in this study should be evaluated for further use. This also does not need to be an "either/or" question. For example, a simplified assessment can be conducted to **improve availability of benchmarking data** and data for reporting over several cultivation regions (and seasons). A **detailed assessment** such as the one building the foundation of the dataset used in this study could be limited to **longer intervals** (e.g. every 5 years) or to a set of representative farms to assess the dynamics in coffee cultivations systems in more detail. The findings could then be extrapolated to more farms in the same region.

Annex A: Overview of model modules

The following table gives an overview of the different modules of the model and the emission modelling approach. Grey cells give the general description of the module, white cells provide the sub-modules and specific descriptions. The modules are also used to group the results in the contribution analysis.

Table apx 1: Overview of model modules and approaches

Module	Description	Approach
Field Clearance	Emissions related to the combustion of biomass after cultivation to clear the field	(see below)
Emissions from combustion of biomass	Methane, ammonia, nitrous oxide and other emissions related to the combustion process	Modelled based on the amount of biomass burned, its carbon and nitrogen content, based on emission factors from (Battye & Battye, 2002).
Field emissions	Emissions from agricultural soil related to fertilizer application, crop residues and soil erosion	(see below)
Emissions from fertilizer application (direct and indirect field emissions)	Nitrous oxide emissions to air from microbial nutrient turnover (denitrification), ammonia emissions to air from mineral and organic fertilizer, nitrate emissions to water through leaching, carbon dioxide emissions from carbon contained in fertilizer (urea, lime)	Based on approach and emission factors provided in 2019 IPCC guidelines; fuel consumption considered under field work
Emissions from crop residues	Additional nitrogenous emissions due to nitrogen contained in crop residues	Included in residue management modelling
Emissions from soil erosion	Nutrients contained in the soil reaching surface water bodies with soil erosion	Based on data from Global Soil Erosion Modelling platform (GloSEM) and default nutrient content in soil
Emissions from LUC	Carbon emissions related to the conversion of forest (or other land use type) to agricultural land.	Based on primary data and FAO statistical data using approach from PAS 2050
Irrigation	Emissions from water irrigation	(see below)
Irrigation water requirement	Water used in irrigation	Based on collected primary data
Irrigation energy	Energy consumption from pumps, includes impacts of provision of energy and combustion emissions (in case of diesel pumps)	Based on pump model in GaBi 10.6
Machinery	Emissions from tractor use and provision of fuel	(see below)

Module	Description	Approach
Tractor use	Emissions from fuel combustion	Based on tractor and truck model in GaBi 10.6
Provision of Diesel	Upstream emissions in the fuel supply chain (e.g. refinery)	Based on energy provision datasets from GaBi 10.6 database (yearly updated)
Provision of fertilizer	Emissions related to fertilizer production	(see below)
Fertilizer production	Upstream emissions in the fertilizer supply chain (e.g. energy consumption of production)	Based on fertilizer production datasets from GaBi 10.6 database
Crop protection	Emissions related to production and application of crop protection agents	(see below)
Pesticide production	Upstream emissions in the pesticide supply chain (e.g. energy consumption of production)	Based on pesticide production datasets from GaBi 10.6 database
Pesticide application	Emission of pesticides into the environment	EF 3.0 characterization factors used for toxicity impact. Generic emission factors to air, water and soil used according to PEF method (90% to soil, 9% to air, 1% to water).
Processing	Additional module added to the Lean AgModel. Emissions related to processing (hulling and drying).	
Provision of electricity and diesel	Upstream emissions in the fuel and electricity supply chain (e.g. refinery)	Based on energy provision datasets from GaBi 10.6 database (yearly updated)
Transports	Transports of agricultural inputs (fertilizer and pesticides to the field	Based on transport distance, using the truck model in GaBi 10.6 and provision of diesel
Transports to processing	Transport of harvested beans	Based on transport distance, using the truck model in GaBi 10.6 and provision of diesel
Residue treatment	Additional modules added to the Lean AgModel.	
Composting process	Emissions released through composting process of residues.	Methane and N2O emission factor for composting (residue management) IPCC default of 4g CH4/kg biomass.[19].

[19] IPCC 2006 Guidelines for National Greenhouse Gas Inventories 4.1, Biological Treatment of Solid waste

Module	Description	Approach
Combustion process	Emissions released through combustion process of residues.	Based on emission factors from literature[20].

[20] Battye & Battye. (2002). *Development of Emissions Inventory Methods for Wildland Fire*.

Annex B: Overview of assumptions

Table apx 2: Overview of consensus of assumptions

Parameter	Assumption Enveritas	Assumptions Sphera	Consensus	Comment
Climate	Tropical climate	Tropical climate with associated emission factors	Same approach	-
Residues				
Ratio husk	90% of volume of green bean produced	90% of volume of green bean produced	Same approach	-
Ratio leaf	35.6% of volume of green bean produced	35.6% of volume of green bean produced	Same approach	-
Treatment method	If several approaches are selected by the farmer then the method with the lowest emission factor is selected	All treatment methods are considered as stated by the farmer (all treatment methods are counted and then averaged on province level)	Different approach	*1
	If farmers sell the residues emissions are not considered in the assessment	If farmers sell the residues the emissions are not considered in the assessment (“sell to buyer”, “the mill or processing centre keeps it”, “none of the above”, “remove it from the farm for other uses” & “use as fuel for mechanical dryer” not considered)	Same approach	-
	If farmer does not know their "husk disposal method" the residues are considered as “removed, left untreated in heaps or pits"	If farmer does not know their "husk disposal method" the residues are considered as “removed, left untreated in heaps or pits"	Same approach	-
Active ingredients	For missing values default values of 20% in Vietnam (72/387 missing) and 30% in Indonesia (15/442 missing) have been applied	For both countries a default value of 50% of active ingredient per product has been considered as conservative approach	Similar approach	*1
Irrigation				

	Irrigation system	Hose and pump system does not exist as an option in CFT, therefore direct energy component with average energy usage values has been applied	Sphera's Lean AgModel uses an irrigation pump model which therefore only considers one type of irrigation system. This pump model can reflect the direct energy use or calculate the required energy per irrigation water applied	Similar approach	-
		If the farmer answers "none of the above" to the irrigation system question then "rain gun" is applied (sprinkler irrigation)		Similar approach	-
	Allocation	Share of plot irrigated assumed to be 100%	Share of plot irrigated assumed to be 100%	Same approach	-
	Energy source	If farmers use both electricity and diesel, then 100% diesel is assumed	If farmers use both electricity and diesel, then 100% diesel is assumed	Same approach	-
		If farmer stated "other" assume diesel	If farmer stated "other" assume diesel	Same approach	-
		If farmer stated "solar" assume zero emissions	If farmer stated "solar" assume zero emissions	Same approach	-
Fertilizer					
	Application volumes	For two farmers the application values was not available (farmer didn't know), therefore the value has been set to the country average	Not applicable	Similar approach	*1
		Not available	Assumed that more than 1000kg fertilizer/ha is unrealistic, therefore limit introduced	n.a.	-
	Inhibitors	No inhibitors considered	No inhibitors considered. No information available regarding types of inhibitors.	Same approach	-
	Origin	If farmers doesn't know the origin of the fertilizers, the proxy is southeast asia	Sphera uses the fertilizer dataset representative to India for all calculations	Similar approach	-
Inorganic fertilizer					
	Fertilizer types	Potassium nitrate not available in CFT, therefore calcium nitrate used as proxy	Potassium nitrate not available in LCA FE, therefore potassium chloride used as proxy	Different approach	Change not possible due to the availability of datasets in the LCA FE database, see mapping approach in Table apx 3

	Ammonium phosphate sulphate not available in CFT, therefore Ammonium sulphate used as proxy	Ammonium phosphate sulphate not available in LCA FE, therefore ammonium nitrate used as proxy	Different approach	Change not possible due to the availability of datasets in the LCA FE database, see mapping approach in Table apx 3
	If farmer selected "Other" or "NPK" then the default was to use the most common fertilizer type in the country, e.g. NPK 15-15-15	Correction factor has been implemented to recalculate the amount of fertilizer as stated e.g. NPK 16-16-16 to the available dataset e.g. NPK 15-15-15, therefore all fertilizers are considered correctly as stated by the farmer	Different approach	See mapping approach in Table apx 3
	For custom NPK fertilizers, the nitrogen component can be “ammonium-N” or “nitrate-N” or “Urea-N”: using “Urea-N”		Not applicable	-
Organic Fertilizer				
Fertilizer specifications	Compost is considered as “non-fully aerated production” in the CFT	Based on emission factors from literature	Similar approach	-
	Microbial fertilizer is not available in CFT, therefore considered as zero emission	Microbial fertilizer assumed to have no emissions	Same approach	-
	If farmer does not know animal type assumed “cattle”	Assumed average of all animals as stated by farmers	Similar approach	-
	If farmer selected more than one animal type, then the first one stated by the farmer is considered	Assumed average of all animals as stated by farmers	Similar approach	-
	Not available	Organic fertilizers enter the system burden free	Not available	Enveritas is working on getting answer from the CFT
Wastewater	Included	Excluded since low relevance and representation	Different approach	USAID Green Invest approved Sphera’s approach
Direct energy				
Specifications	If the farmer answers “None of the above” zero emissions are assumed	If the farmer answers “None of the above” zero emissions are assumed	Same approach	-

	If energy source is unavailable, then the country's most frequent source for that activity is considered	If energy source was unavailable (blank) it was therefore excluded from the calculation of averages	Similar approach	*1
Land management				
Type	If farmers do not know what type of land was there before, assumed 100% forest	Sphera's LUC Tool uses statistical data, therefore not 100% forest for the land type before cultivation	Similar approach	-
	If farmers reported natural vegetation or land fallow assume "grass" in CFT	Sphera's LUC Tool uses statistical data, therefore this aspect is not applicable for Sphera	Similar approach	-
Time period	If the farmers doesn't know when the land was cleared, the default is set to country averages (2018 for Indonesia, 2015 for Vietnam)	Sphera's LUC Tool uses statistical data, therefore this aspect is not applicable for Sphera	Similar approach	-
Area	Share of farm expanded calculated as, average between [area expanded/plot area] and [number of trees added/number of trees on plot]	Fraction of farmers with farm expansion calculated to be applied on province level	Similar approach	*1
	If farmer doesn't know what share of the farm was expanded, defaulting to 10% of current plot area.	If farmers doesn't know what share of the farm was expanded, excluded from average calculation	Similar approach	*1
Transport				
Vehicle	Motorbike is not available in CFT, therefore light goods vehicle is assumed	Sphera uses LCA FE datasets for transportation matching the assumptions from Enveritas	Same approach	-
Weight carried	If farmer didn't know the weight carried, the default was set to the country average	For Sphera's Lean AgModel this parameter is not applicable	Different approach	-
Biomass	Included	Excluded	Different approach	-
Co-products				
	Any non-sold product produced on the farm is not considered as co-product	Implemented the approach as provided by Enveritas	Same approach	-
	CFT does not allow any product to go beyond 100% of the coffee value: Capping each product at 100% of the coffee value	Revenue above 100% from the coffee value assumed to be unrealistic, therefore capping each product at 100% of the coffee value	Same approach	-

	If coffee revenue is not available, then co-products are not included (0% of co-products)	Implemented the approach as provided by Enveritas	Same approach	-
Processing	Wet processing included	Wet processing excluded since not representative for the system (e.g. in Vietnam only 1 farmer used pulping machine, in Indonesia only 1 farmer stated amount of water used in washing).		

Table apx 3: Mapping approach for inorganic fertilizers

Fertilizer type as stated by farmers	Mapped dataset from the LCA FE database (with corresponding N-P-K contents)
NPK-fertilizer types	NPK (15-15-15)
“Other”	NPK (15-15-15)
“is different”	NPK (15-15-15)
Urea	Urea (46-0-0)
Ammonium sulphate	Ammonium Nitrate (33.5-0-0)
Phosphate	Raw phosphate (0-32-0)
Potassium chloride (KCl/MOP)	Potassium chloride (KCl/MOP) (0-0-60)
Potassium sulphate	Potassium chloride (0-0-60)
Potassium sulphate	Potassium chloride (0-0-60)
Potassium Nitrate (KNO3)	Potassium chloride (0-0-60)
Ammonium Phosphate Sulphate	DAP-Diammonium phosphate (18-46-0)
Phosphate/Fused Phosphate	Raw phosphate (0-32-0)
Limestone	Limestone flour (CaCO3; dried)
MAP - Monoammonium Phosphate	MAP-Monoammonium phosphate (11-52-0)
DAP - Diammonium Phosphate (18-46-0)	DAP-Diammonium phosphate (18-46-0)

Table apx 4: Mapping approach and assumptions for organic fertilizers

Fertilizer type as stated by farmers	Mapped fertilizer type by Sphera
Microbial fertilizer	Not included in calculation
Broiler waste (manure, animal feed residue, feathers)	Assumed as poultry manure
Poultry droppings or waste (poultry droppings, uneaten feed, feathers)	Assumed as poultry manure
Manure	Assumed as cattle manure
Livestock waste	Assumed as manure (animal specific)
Multiple options e.g. “cattle poultry”	Assumed as average of all animals stated by farmer (e.g. average of nutrient contents for both cattle and poultry)
Anaerobic compost (digestate)	Assumed as compost
"other"	Assumed as compost
"is different"	Assumed as compost

Annex C: Additional results

Detailed results

The following annex provides insights into results for three additional impact categories. The methodologies used for this additional assessment are explained in the table down below.

Table apx 5: Description of impact methodologies used for additional results

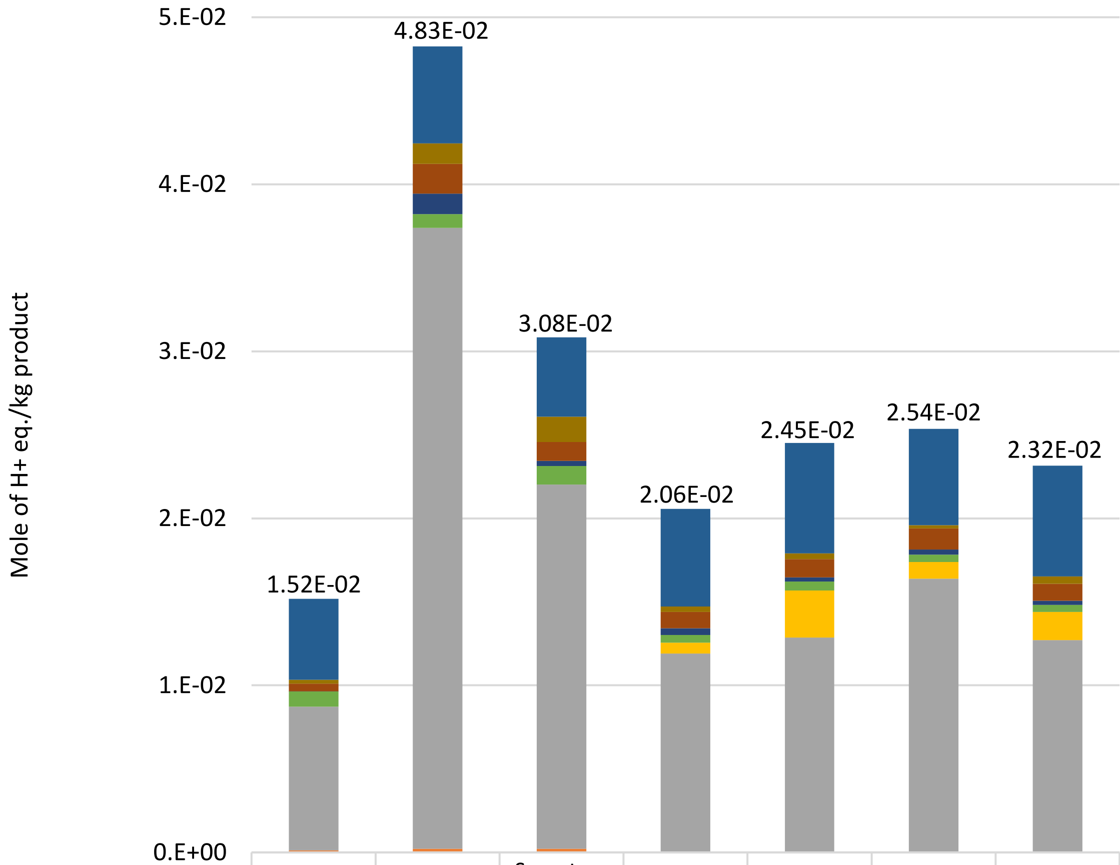
Impact Category	Description	Unit	Method
Acidification Potential	A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H^+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline and the deterioration of building materials.	moles H^+ equivalent	EF 3.0
Eutrophication (terrestrial, freshwater, marine)	Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition.	Terrestrial: moles N equivalent Freshwater: kg P equivalent Marine: kg N equivalent	EF 3.0
Water Use	An assessment of water scarcity accounting for the net intake and release of fresh water across the life of the product system considering the availability of water in different regions.	m^3 of water equivalent (H_2Oe)	EF 3.0

As mentioned previously, the inclusion of a toxicity assessment requires further refinements and the influence of the active ingredient as applied in this study and was not included in the current scope.

In the following, each impact category results are presented as well as main findings discussed.

Acidification potential

Figure apx 1 down below shows additional insights into the acidification potential of all cultivation systems of the provinces. The average of Indonesia is 3.14E-02 while it is 2.34E-02 for Vietnam. The highest impacts can be found in Lampung in Indonesia, the lowest in Đắk Lắk in Vietnam. As it can be seen in the graph, the highest contribution in all provinces derive from the field emissions – mainly due to ammonia emissions from fertilizer application, particularly from urea. Indicated by the primary input data for Lampung, with the highest fertilizer application rates, this province also has the highest results in this impact category. The second highest contribution comes from the treatment of husks and leaves. The emissions influencing the acidification potential mainly derive from nitrogen emissions caused by the composting process. Smaller impacts in the results derive from machinery, irrigation, or transports, where fossil energy carries influence the acidification potential.



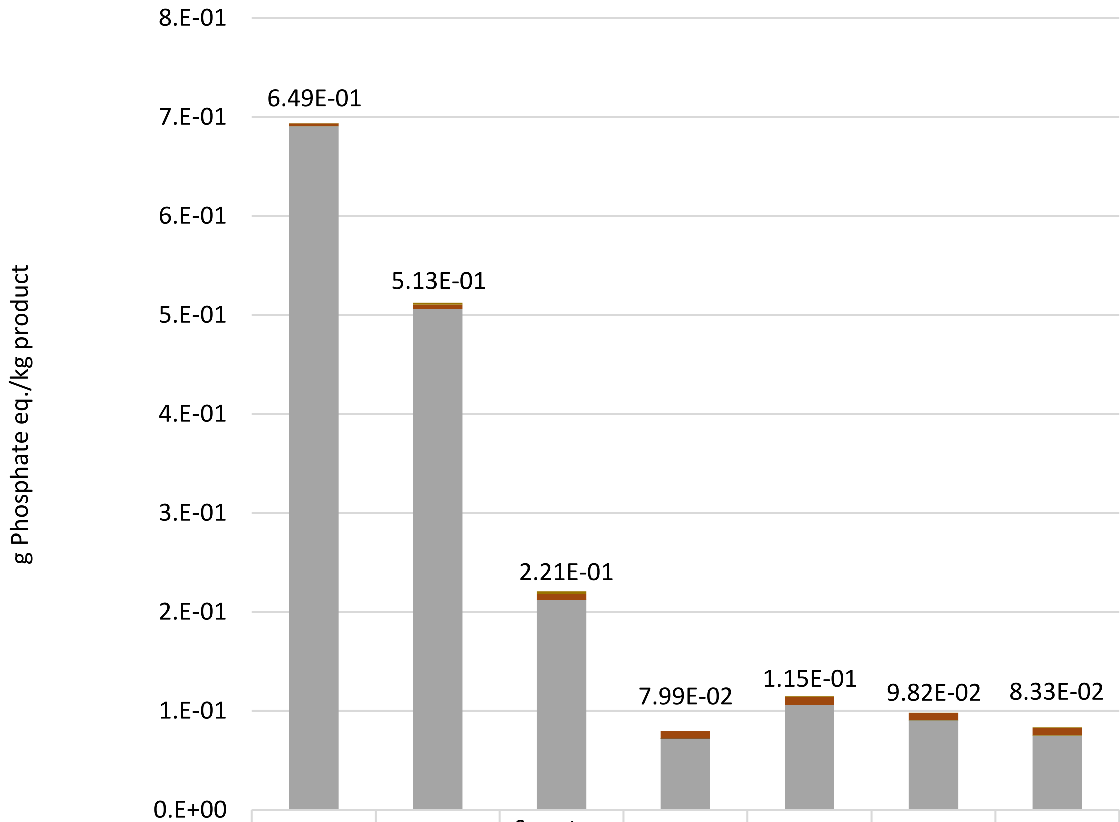
	Bengkulu	Lampung	Sumatera Selatan	Đắk Lắk	Đắk Nông	Gia Lai	Lâm Đồng
Residue treatment	4.84E-03	5.80E-03	4.75E-03	5.85E-03	6.61E-03	5.76E-03	6.64E-03
Transports	2.35E-04	1.22E-03	1.51E-03	3.27E-04	3.43E-04	2.03E-04	4.31E-04
Provision of fertilizer	4.63E-04	1.78E-03	1.13E-03	9.83E-04	1.10E-03	1.27E-03	1.03E-03
Processing	1.02E-08	1.23E-03	2.94E-04	4.01E-04	2.46E-04	3.09E-04	2.44E-04
Machinery	9.17E-04	8.15E-04	1.11E-03	4.51E-04	5.32E-04	4.31E-04	4.18E-04
LUC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Irrigation	0.00E+00	0.00E+00	0.00E+00	6.54E-04	2.82E-03	1.01E-03	1.70E-03
Field	8.61E-03	3.72E-02	2.18E-02	1.19E-02	1.28E-02	1.64E-02	1.27E-02
Crop protection	1.18E-04	2.18E-04	2.15E-04	1.64E-05	2.57E-05	2.22E-05	1.68E-05

Figure apx 1: Additional results for acidification potential

Eutrophication potential

Figure apx 2 shows detailed results for the eutrophication potential for all provinces. The country average for Indonesia is 4.76E-01 and for Vietnam it is 9.14E-02. The results for the eutrophication potential are also heavily influenced by the field emissions. These are again related to the application of fertilizer (leaching) and soil erosion. The higher the nitrogen surplus in the nitrogen balance, the more nitrogen compounds are released to soil, air and water bodies and the higher the eutrophication potential becomes. Yields can have an impact on the results and scale them up or down. The results are higher for Indonesia and highest for Bengkulu since the yields are significantly lower in Indonesia and Bengkulu faces the highest soil erosion values in the study.

It should be noted that nitrate leaching is influenced by many factors (e.g. soil type, precipitation and application time). A detailed assessment laid beyond the scope of this study. The reported values should therefore be interpreted with care.



	Bengkulu	Lampung	Sumatera Selatan	Đắk Lắk	Đắk Nông	Gia Lai	Lâm Đồng
Residue treatment	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Transports	4.29E-04	2.04E-03	2.76E-03	5.56E-04	5.83E-04	3.36E-04	8.27E-04
Provision of fertilizer	2.80E-03	4.50E-03	6.03E-03	7.20E-03	8.38E-03	7.60E-03	7.44E-03
Processing	8.36E-11	1.01E-05	2.42E-06	3.29E-06	2.02E-06	2.53E-06	2.01E-06
Machinery	1.02E-05	9.06E-06	1.24E-05	5.01E-06	5.92E-06	4.79E-06	4.65E-06
LUC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Irrigation	0.00E+00	0.00E+00	0.00E+00	4.73E-06	2.27E-05	7.31E-06	1.39E-05
Field	6.90E-01	5.06E-01	2.12E-01	7.21E-02	1.06E-01	9.02E-02	7.50E-02
Crop protection	1.83E-04	3.38E-04	3.33E-04	2.54E-05	3.98E-05	3.45E-05	2.60E-05

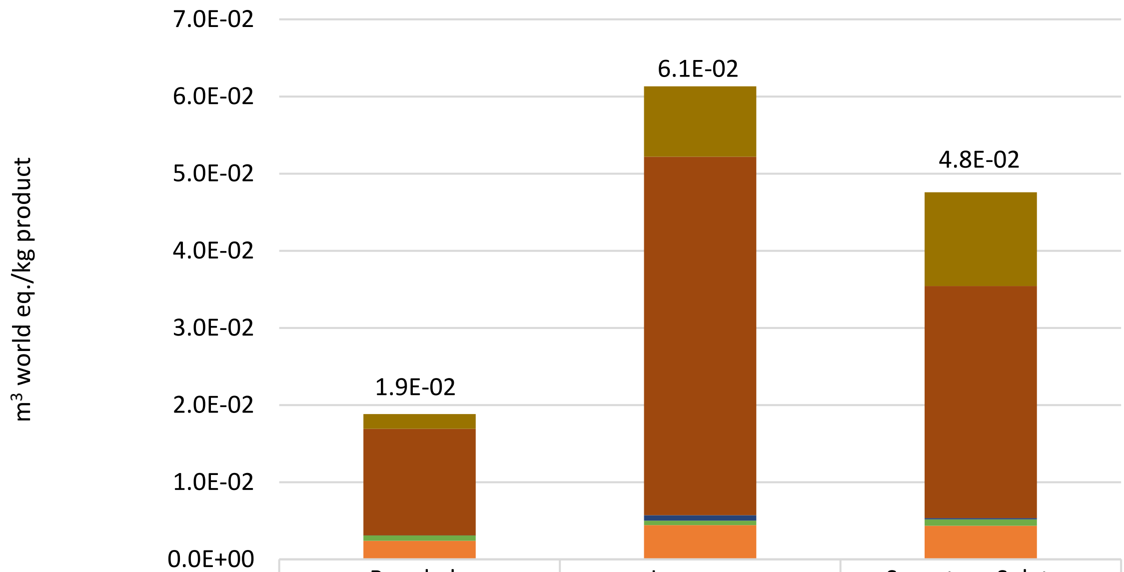
Figure apx 2: Additional results for eutrophication potential

Water use

For the following impact category, the graphs have been separated for Indonesia and Vietnam because the impacts are significantly different in the two countries.

Water use is strongly influenced by the country where the water is consumed. Characterization factors for each province are available in Table 2-8. As it can be seen in this table, the characterization factors for Indonesia are significantly lower than compared to the factors for Vietnam, ranging from 0.41 for Sumatera to 6.25 for Đắk Lắk. This is one reason why the results for Indonesia are comparably lower than for Vietnam. Other aspects can be found above the graph for Vietnam.

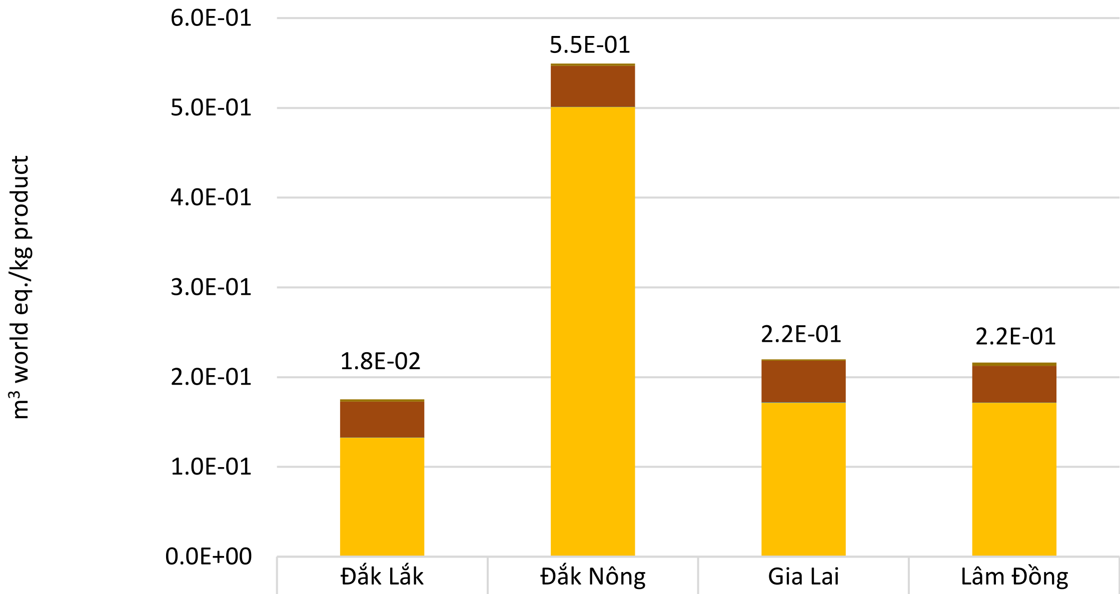
For Indonesia, the main contributors of water use are the processing stage as well as the provision of fertilizers. Electricity background datasets in the LCA FE software are associated with water consumption, since water evaporates from water storages used in the electricity production. Since little to no irrigation takes place, the other groupings have a higher influence on the results. But in conclusion, water use plays a minor role for the results of Indonesia.



	Bengkulu	Lampung	Sumatera Selatan
Residue treatment	0.0E+00	0.0E+00	0.0E+00
Transports	1.9E-03	9.1E-03	1.2E-02
Provision of fertilizer	1.4E-02	4.6E-02	3.0E-02
Processing	5.6E-09	6.8E-04	1.6E-04
Machinery	6.9E-04	6.1E-04	8.4E-04
LUC	0.0E+00	0.0E+00	0.0E+00
Irrigation	0.0E+00	0.0E+00	0.0E+00
Field	0.0E+00	0.0E+00	0.0E+00
Crop protection	2.4E-03	4.4E-03	4.4E-03

Figure apx 3: Additional results for water use for Indonesia

In comparison to Indonesia, the results for Vietnam are mainly influenced by the irrigation water used for the cultivation systems. Since irrigation plays a major role in this country, the other groupings do not have significant influences on the results. This is the main difference for the water use results between the two key origins of Robusta coffee.



	Đắk Lắk	Đắk Nông	Gia Lai	Lâm Đồng
Residue treatment	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Transports	2.5E-03	2.6E-03	1.5E-03	3.6E-03
Provision of fertilizer	4.0E-02	4.5E-02	4.6E-02	4.1E-02
Processing	2.8E-04	1.5E-04	2.7E-04	1.4E-04
Machinery	3.4E-04	4.0E-04	3.2E-04	3.1E-04
LUC	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Irrigation	1.3E-01	5.0E-01	1.7E-01	1.7E-01
Field	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Crop protection	3.3E-04	5.2E-04	4.5E-04	3.4E-04

Figure apx 4: Additional results for water use for Vietnam

Annex D: Uncertainty assessment

Uncertainty analyses test the combined effect of parameter uncertainties on the final results. The present analysis was performed using the Monte Carlo simulation in GaBi Analyst which draws random numbers from defined uncertainty intervals to calculate a multitude of possible results. The less these results vary, the lower the overall parameter uncertainty of the LCA model.

The use of a Monte Carlo Analysis requires the definition of the standard deviation for each parameter to be assessed. A simplified approach was taken, using the interregional standard deviation (i.e. stand deviation of input parameters between the assessed provinces) to define the uncertainty range. The standard deviation between farms can be larger, however, the simplified approach considers that not all key parameters are completely independent (e.g. yield and fertilizer use are correlated, though not completely dependent variables). Using interregional standard deviation prevents that extreme values are used in the Monte Carlo Analysis. The calculated results should therefore only be considered as an estimate because of this simplification approach. In addition, a normal distribution is assumed which might not always be the case in reality. However, it is considered that the estimates were sufficient for the purpose of this assessment.

The uncertainty analysis was performed for the parameters that are based on collected data. Not included were the emission factors, as the uncertainty of emission factors is reported in the respective guidelines (IPCC 2019) and is not specific to this study. The following parameters were included in the uncertainty assessment:

- Yield
- Fertilizer use
- Fuel use
- Crop protection
- Transport distance
- Amount of residue biomass

The Monte Carlo Analysis was conducted on origin level (country level). 1000 runs were conducted per analysis. Table apx 6 shows the result of the assessment.

Table apx 6 Results of uncertainty assessment via Monte Carlo analysis

Origin	Unit	Baseline	Mean value	Standard deviation	10% percentile	90% percentile
Indonesia	kg CO_2 eq./GBE	1.6	1.7	21.90%	1.2	2.1
Vietnam		2	2.1	21.30%	1.6	2.7

The mean value of the analysis was close to the baseline, meaning that the average of the 1000 runs with different parameter settings yielded almost the same results as the baseline settings of the parameter, confirming the validity of these settings. Combined standard deviation was around 21% for climate change for both countries. The percentile values mean that 1 out of 10 runs, with parameter settings varied randomly according to their standard deviation, lead to results that are below or above these values, and 80% of all values are between the percentile values.