IFC FOOD LOSS IMPACT TOOL

Methodology

Tool version 3

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1. Introduction

1.1 Context

The FAO estimates that approximately one third of the food produced in the world is lost or wasted before it is consumed. Given that the world's population is expected to grow, one effective way to meet the demand for more food is to reduce the significant food loss and waste[1] occurring in the supply chains.

The IFC's activities are addressing the challenge of food loss and waste in many parts of the developing world by making investments to improve storage, transportation, cold chains, and management of food.

The IFC, supported by the Carbon Trust, developed the Food Loss Impact Tool to enable their staff, clients and potentially others to quickly and easily estimate the Greenhouse Gas (GHG) emissions reductions and other environmental and food security benefits associated with investing in projects that help to reduce food losses. The tool calculates the cumulative GHG emissions and other impacts associated with preventing food loss and waste at either the farm, transportation, storage, processing, retail or landfill decomposition stages of the value chain. The calculator was designed as a simple tool for users to easily quantify the GHG mitigation benefit derived from supply-chain investments across countries and food types.

As of 2025, version 3 of the tool covers 80 crops and animal protein products across 160 countries globally. The tool enables the user to select an agricultural commodity on which to focus the analysis. By providing the food loss rate after the project, the user can calculate the potential food loss improvement and the avoided greenhouse gas emissions achieved by a reduction in food losses. The tool contains a database for food loss rates and greenhouse gas emission factors for 80 crops and edible livestock products for 160 countries and their respective regions, which are used as default data when no input is provided by the user.

At the same time, it allows the user to input their own values to calculate the food loss rate before and after the project, use their own commodity emission factor or provide additional input for increased granularity of results.

It is important to recognise that there is limited quantitative data available regarding food loss rates or associated GHG emissions for different crops and countries. To provide an estimate when user data is not available, the tool utilises FAO food loss and GHG and other databases

[1] Food loss is the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retailers, food service providers and consumers. Food waste refers to the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food service providers and consumers (SOFA, 2019). Boundaries and definitions for loss and waste used in this tool are reported in section 2.

to estimate current (pre-project) food loss, GHG and wider impact data points for different crop and country combinations. It is important to note that, although the tool can provide baseline food loss rates using existing estimates, it is highly recommended where possible to measure and report the actual food loss rates pre- and post-project to ensure greater data accuracy.

This methodology outlines the assumptions used to estimate these food loss rates and GHG emissions values from FAO data and a combination of lifecycle analysis studies. For crops the tool only takes into account the main agriculture emission categories (i.e., synthetic fertilizers, manure, residue burning, crop residues, cultivation on organic soils) during the production stage, as well as transportation, energy and refrigeration emissions during the transportation, storage, processing, and retail stages.

It is important to note that besides the negative effect of land use change, croplands can potentially be significant carbon sinks, absorbing carbon from the atmosphere. However, these are outside the scope of this tool. For animal protein products a different methodology was chosen based in part upon the FAO GLEAM tool.

The tool holds baseline data for GHG emissions and food loss rates associated with different food types in different countries. This should be used as a guide where there is no data available on pre-project food loss rates or the GHG emissions per food commodity. The tool provides the ability to input project specific loss rates as well as the ability to update manually emission / GHG factors when needed.

The baseline loss rate enables users to evaluate a project to assess the scale of projected savings that would result from financing a project. The scope of the evaluation is focused upon production (farming/slaughter), transport, storage, processing, retail and landfill value chain stages.

Additionally, as of 2025, version 3 of the tool includes several impact and risks indicators alongside the climate-related ones:

- Food security impacts in terms of equivalent number of people-fed from the avoided food losses or food waste, and country profiles on percentage of population at risk of hunger;
- Avoided water consumption and water risk profile of the country of production
- Avoided land use and biodiversity risk profile of the country of production
- Avoided nitrogen fertilizer and fossil fuel from transport indicators
- Orphaned losses and emissions - additional upstream avoided food loss and emissions (see section 4.5)

1.2 Overview of Methodology Document

This document outlines the key methodology used to define the food loss rates for food types and countries and also the GHG emissions per food type and value chain stage. It is organised in the following way:

Section 2	**Food Loss Rates**: Data sources and methodology to calculate food loss rates in the tool
Section 3	**Greenhouse Gas Emissions**: Overview of FAOSTAT data source and methodology used to calculated the food loss GHG emissions for food types and countries
Section 4	**Further impact indicators:** Overview of the data sources and methodology used for the indicators related to the avoided food losses
References	References for all data/sources used in the tool
ANNEX	Some background to the data used and implementation in Excel

2. Food Losses

The notion of food losses utilised in this work is defined as followed: [2]

"Food losses are all the crop and livestock human-edible commodity quantities that, directly or indirectly, completely exit the post-harvest/slaughter production/supply chain by being discarded, incinerated or otherwise, and do not re-enter in any other utilization (such as animal feed, industrial use, etc.), up to, and excluding, the retail level. Losses that occur during storage, transportation and processing, also of imported quantities, are therefore all included. Losses include the commodity as a whole with its non-edible parts."

Decreases in human-edible quantities may also happen in case of extreme events at preharvest or pre-slaughter, during harvest or slaughter, and after processing and packaging. In the latter case, these are considered food wastes. See Figure 1 below illustrating the different terms based on the supply chain stages.

Figure 1. Boundaries of the food supply chain

Source: Driven to waste: the global impact of food loss and waste on farms, p. 5

The Food Loss Impact tool primarily focuses on the early stages of the food supply chain and therefore addresses food loss. However, as it also includes the retail stage, food waste is partially considered as well. For simplicity reason, any reference to Food Loss from here onwards (as well as in the tool) includes both Food Loss and Food Waste as described below in the scope included in this work[3]:

- On-farm post-harvest/slaughter operations (including milking);
- Transport (pre- and post-processing);
- Storage (pre- and post-processing, in on-farm or off-farm dedicated facility).
- Processing
- Retail

[2] SDG 12.3.1: Global Food Loss - Methodology for monitoring SDG target 12.3. (p. 12).

[3] While losses in the growing of livestock feed may be significant, these are not included in the boundary of the tool

NB: Pre-harvest, harvest, food service & hospitality and consumption stages are not included.

Pre-harvest losses occur before the beginning of the harvesting process due to reasons like disease or insects and are not included. Harvest losses occurring after the commodities are mature but are not harvested, have been excluded from this analysis as they are usually due to economic or environmental events that are outside the control of the individual farmer.

Interpretation of the data included in the FAO Food Loss and Waste database is based on the Global Food Loss Index methodology.[4] The methodology documentation provides some guidelines on how food loss data should be collected and can therefore be used to understand how loss rates within the FAO data set should be interpreted when constructing the baseline loss rate in the tool. While some of the information are relatively straightforward (e.g., country and commodities), other require some level of interpretation.

The table below is taken from the FAO methodology[5] and represents the sources of information used to define food loss rates at different stages of the value chain.

Table 1: Recommended measurement tools by stage of the value chain

Stage	Tool	Notes
Production (post-harvest losses)	• Sample survey (smallholder farms) • Complete enumeration (large commercial farms)	May cover on-farm storage and on-farm transportation
Storage	• Sample survey (smallholder farms) • Inventory data (large storage facilities)	Can include controlled experiments for various length and storage conditions
Transport	• Sample survey of trucks (or other transport modes) at destination	Measurements of a product sample at destination
Processing	• Agreement with the private sector or through the producer associations. • Company's accounting records. • Complete enumeration or experimental design. • Additional data can come from existing National Industry Processing questionnaires to ascertain technical conversion factors, input and output quantities.	

The classification above leaves room for a degree of interpretation. The interpretation that the Carbon Trust used in building the tool is based on the identification of value chain stages, and in particular:

[4] SDG 12.3.1: Global Food Loss - METHODOLOGY FOR MONITORING SDG TARGET 12.3.
[5] Ibidem, p. 30.

- **Production:** every activity undertaken post-harvest/slaughter up until the point that the product is considered ready to move onto the next stage. This stage can be multi-phased and includes on-farm storage and transportation if this happens as a part of preliminary on-farm processing rather than a specific conservation/storage process.
- **Storage (pre-processing):** activities related to the storage of the commodity in a dedicated storage facility prior to processing. In the case of small producers, this may happen on the site of production.
- **Processing:** activities related to further processing activities to make the commodity market-ready (including packaging).
- **Storage (post-processing)**: additional storage activities after the processing stage.
- **Retail:** activities related to the sale of commodities to final consumers.
- **Transport:** activities related to transporting the final product to market or a dedicated storage facility. These can occur between several other activities, based on the relevant stages of the supply chain.

Apart from the production stage and processing stage which can both include several activities, each of the other stages cover only one type of activity.

The same assumption should be used for other commodities that might be produced under different circumstances (e.g. milk and eggs).

2.1 Methodology

2.1.1 Avoided food losses

The impact of food loss reduction projects in terms of GHG emissions is defined by two main components:

- The amount of food losses avoided by the project;
- The GHG emission factor of the commodity at the stages at which the loss is avoided;

Defining the correct amount of food loss avoided by a project is a fundamental step in calculating the economic, environmental and social impact of a project. This section explains how the tool calculates avoided food losses, presents alternative approaches that were considered at the design stage, analyses the different pros and cons of each approach, and explains the rationale and assumptions behind the chosen approach.

An important methodology point behind the tool's results is that it calculates each project's impacts separately. The combined impacts of multiple projects either concurrently or sequentially will not be the sum of the two. This means that the post-project quantities and post-project food loss rates indicated by the user for a project intervention at a specific value chain stage do not impact the avoided food losses and climate impact values of other project intervention(s) which the user might model at the same time for other supply chain stages. Nonetheless, any advanced inputs added by the user in the interface will impact the emission factor values across all project interventions where relevant.

2.1.2 Exploring different approaches

An intuitive way to measure avoided food losses would be to look at the actual food losses observed before and after the project was implemented, where the difference between these two quantities would represent the amount of food losses avoided by the project. Unfortunately, this approach presents major shortcomings, as it does not account for changes in the amount of production. That is, if a project decreases food losses while increasing production, it would underestimate the amount of avoided losses as higher production levels cause an increase in food losses (in absolute terms).[6]

Therefore, avoided food losses need to be assessed in a way that produces consistent estimates that are independent of changes in absolute production levels. This can be achieved by creating an (artificial) baseline production level against which to assess the reduction in food loss levels achieved by the project. There are several ways in which such a baseline can be constructed, and in particular: [7]

1) Estimating food losses that would occur while achieving pre-project gross production levels with the post-project (and improved) loss rates;
2) Estimating food losses that would occur while achieving pre-project net production levels with the post-project (and improved) loss rates;
3) Estimating food losses that would occur while achieving post-project gross production levels with the pre-project loss rates;
4) Estimating food losses that would occur when achieving post-project net production levels with the pre-project loss rates.

We use an example to illustrate the different approaches mentioned above, evaluating the food losses avoided by a project that achieves a 50% increase in gross production and a 50% reduction in food loss rates:

Approach (0): Actual	Before	After
Gross production (tons)	100	150
Net production (tons)	80	135
Loss rate (%)	20%	10%
Food losses (tons)	20	15

[6] See approach 1 in the example tables below.
[7] Gross production refers to the total amount produced (including the portion that is then lost during the production process), while net production refers to the amount of clean product that reaches the end of the production stage.

Approach (1): Pre-project gross production at post-project conditions	Before	After
Gross production (tons)	**100**	**100**
Net production (tons)	80	90
Loss rate (%)	20%	10%
Food losses (tons)	20	10

Approach (2): Pre-project net production at post-project conditions	Before	After
Gross production (tons)	100	88.89
Net production (tons)	**80**	**80**
Loss rate (%)	20%	10%
Food losses (tons)	20	8.89

Approach (3): Post-project gross production at pre-project conditions	Before	After
Gross production (tons)	**150**	**150**
Net production (tons)	120	135
Loss rate (%)	20%	10%
Food losses (tons)	30	15

Approach (4): Post-project net production at pre-project conditions	Before	After
Gross production (tons)	168.75	150
Net production (tons)	**135**	**135**
Loss rate (%)	20%	10%
Food losses (tons)	33.75	15

The avoided food losses for each approach are reported in the following table:

	Avoided food losses (tons)
Approach (0): Actual	5
Approach (1): Pre-project gross production at post-project conditions	10
Approach (2): Pre-project net production at post-project conditions	11.11
Approach (3): Post-project gross production at pre-project conditions	15
Approach (4): Post-project net production at pre-project conditions	18.75

Approach (1) and (2), based on the food losses avoided while achieving the same production levels recorded before the project was implemented, ignore whether the project has also improved gross production. If we consider two projects, one achieving a 50% reduction in food losses, and the other one achieving a 50% reduction in food losses and a 50% increase in gross production, the output would be the same in terms of avoided food losses. Conversely, approach (3) and (4) internalise the effects of higher food production: as production increases, so do avoided losses (if food loss rates have been improved).

Since a producer has decided to implement a project that will ensure a certain level of net food production, it is reasonable to assume that they knows the level of net food production that is optimal for their specific business needs, i.e. the amount of clean product that maximize their profits under current and future price and demand conditions. Once the desirable level of net food production is determined, a producer (or a group of producers that share similar characteristics) will then structure their operations in such a way that the combination of gross production and food loss rate results in the desired amount of net food production. Therefore, this approach directly includes the positive impact deriving from the fact that higher net production levels are achieved with more efficient practices rather than by an increase in gross production.

We now consider which approach is the most appropriate for our analysis. We have already seen that the output produced by approaches (1) and (2) are independent from the net production after the project and can therefore exclude these approaches. Conversely, approach (3) and (4) emphasise the fact that the increased production is beneficial insofar it avoids additional losses that might have occurred had the suppliers decided to simply increase gross production (to achieve the optimal level of net production) without improving efficiency (i.e. decreasing the food loss rate).

The choice between approach (3) and (4) is determined by the assumption that the producer (or a group of producers with identical features) is trying to achieve a level of net production that matches demand in a given market. This means that any additional net production delivered above the (optimal) level achieved by the project would decrease overall efficiency, because the market might not have enough demand to absorb the additional supply. Since approach (3) measures losses resulting from equal levels of gross production, a decrease in the food loss rate causes an increase in net production and results in sub-optimal net production levels.

On the contrary, approach (4) holds for all of our assumptions. It assumes that the net production level achieved by the project and by the baseline are consistent, and the level of avoided losses is therefore assessed against this net production level. It also accounts for the fact that optimal net production levels would otherwise be achieved by an increase in gross production (either by the same producer, or by a different producer with identical features).

> **Example: Avoided losses calculation**
>
> Based on current market conditions, a farmer estimates that she needs to deliver 90 tonnes of tomatoes to the market. In the past, the farmer used textile bags, which resulted in 20% of tomatoes being crushed or lost during transport. Therefore, the farmer knows that she needs to start the journey to the market with 112.5 tonnes of tomatoes in order to deliver 90 tonnes of clean product, after losing 20% (or 22.5 tonnes) of cargo in the process.
>
> The farmer decides to invest in plastic crates, which ensure a 10% loss rate from farm to market. After the project is implemented, the farmer can begin the journey with 100 tonnes of tomatoes and deliver 90 tonnes of clean product to the market, after losing 10% (or 10 tonnes) of cargo during the transportation phase.
>
> The avoided losses are thus equal to 12.5 tonnes (22.5 tonnes minus 10 tonnes).

Approach (4) is the one applied in the tool.

2.1.3 Tool calculations

As illustrated in the previous section, the methodology is defined on the basis of two main assumptions:

1) A producer (or any actor along the value chain) sets a target net amount of commodity, and the gross amount needed to achieve this target is derived based on the specific food loss rate;

2) Higher food losses along the supply chain must be counterbalanced by higher gross production, either by the same producer or by an external actor with identical characteristics (and thus identical food loss rates).

The inputs required by the model are the following:

- The food loss rate observed or expected after the project is implemented ($LR_{project}$). This value must be provided by the user;

- The food loss rate observed before the project is implemented ($LR_{baseline}$). It is recommended that the user also provide this value to best reflect site-specific characteristics, but the tool can provide a baseline level based on national or regional averages where this is not possible (see section 2.2);

- The production level (in kg or tonnes) observed or expected after the project is implemented, either gross ($GP_{project}$) or net ($NP_{project}$) of food losses. This value must be provided by the user.

Baseline gross production ($GP_{baseline}$) is defined as the production level that would have been necessary to provide the same amount of net production delivered by the project had the food loss rate not been improved:

$$GP_{baseline} = \frac{NP_{project}}{1 - LR_{baseline}}$$

Food losses in the baseline scenario ($L_{baseline}$) are then calculated as the product of the baseline gross production level ($GP_{baseline}$) and the food loss rate observed before the project is implemented ($LR_{baseline}$):

$$L_{baseline} = GP_{baseline} \times LR_{baseline} = \frac{NP_{project}}{1 - LR_{baseline}} \times LR_{baseline}$$

By definition, the net production is the same in both the baseline and project scenarios, so that we have the following equivalence:

$$GP_{baseline} - L_{baseline} \equiv NP_{baseline} \equiv NP_{project} \equiv GP_{project} - L_{project}$$

where $L_{project}$ is the amount of food losses observed or expected after the project is implemented:

$$L_{project} = GP_{project} \times LR_{project}$$

Finally, food losses avoided by the project are calculated as the difference between baseline and project food losses:

$$Avoided\ losses = L_{baseline} - L_{project}$$

The methodology is illustrated in Figure 3: Avoided food losses.

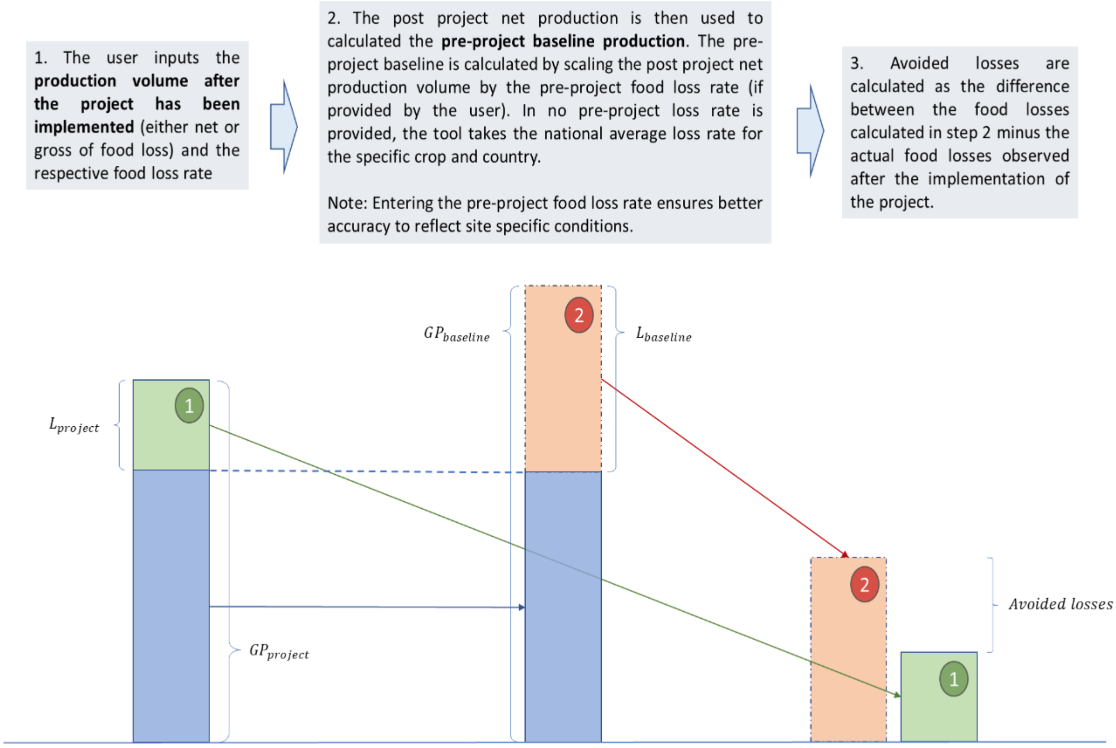


Figure 2: Avoided food losses

2.2 Benchmark food loss rates

Default food loss rates are used for two purposes:

- To provide a comparison for food loss rates reported by the user;
- To provide a default rate for the food loss rate observed before food loss reduction measures were implemented (or if a certain food loss reduction project were not implemented), when a site-specific estimate is not available from the user.

This section provides an overview of the methodology and the data sources used to calculate this variable, together with indication on how to interpret and correctly interpret the output of this analysis.

2.2.1 Data sources

The FAO's Food Loss and Waste Database is an open access database that collects data and information from a wide range of openly accessible reports and studies measuring food loss and waste across food products, different stages of the value chain, and geographical areas. The database gathers more than 480 publications and reports from various sources, including sub-national reports, academic studies, and reports from national and international organizations, and provides more than 20,000 data points.

For the purpose of this analysis, we have included all data points from year 2010 to 2022 (last year for which data was available). While some of the older estimates might now be outdated due to improvements in the food supply chain for some commodities and geographies, having more observations over a longer time interval reduces the variability due to differences in meteorological conditions between different years.

FAO recognises that some specific known issues are present due to the way the data was collected and collated, and these may affect overall data quality:

- Some studies sum the loss percentages across the supply chain and might not consider the decrease in volume due to losses and other utilizations through the supply chains;
- The database includes both national estimates (which might indicate the lower bound of loss rates) and other studies directed at specific commodities that experience higher food loss rates (and might therefore represent the upper bound);
- The studies included in the database apply different methodologies, and even the same measurements may have not be consistently repeated over time.

Certain commodities included within the scope of this work presented unique characteristics that required a separated approach, and in particular:

- **Meat:** For cattle, pig, and chicken meat, the FAO data considers losses 'at the point of production' to be the initial slaughter rather than 'farm' as per crops. Losses of live animals on-farm are not considered as these are modelled in the emission factors as 'herd dynamics' (see section 3.1.2) and cannot be adjusted in this tool. If project-specific information about on-farm losses of live animals is known, then this can be used to generate project-specific live-weight emission factors to be used in place of the defaults in the tool. The physical location of slaughter may vary and in fact may be located on a farm rather than at a dedicated facility. Transport losses relate to transfer of a carcass to storage, sale, or additional processing (e.g., a de-boning hall). Storage losses are specific to the carcass prior to sale or additional processing.

- **Milk**: From the FAO data collection methodology[8], we have assumed that milk losses at the production level include milking and temporary storage before collection. Transport includes transferring milk from the site of production to the storage and/or processing stage, and additional transportation and storage after processing.
- **Eggs:** No adequate loss data is currently available for eggs. Therefore, a default loss rate could not be provided and the tool requires users to provide project-specific data for both before and after project losses.
- **Aqua commodities (tilapia, tuna, catfish, salmon, shrimps):** the FAO sources, which include this commodity group under "Fish and seafood", do not have adequate loss data for the transport and storage stages for the following three regions: Europe & Central Asia, Oceania, North America. The tool requires users to provide project-specific data for both before and after project losses.
- **Oils (cotton seed oil, sunflower oil, olive oil, palm oil):** the FAO sources, which include this commodity group under "Oilseeds and pulses", do not have adequate loss data for the transport and storage stages for the following two regions: Oceania, North America. The tool requires users to provide project-specific data for both before and after project losses.

Although the tool includes estimated pre-project loss rates, it is strongly recommended that users provide project-specific data for both pre- and post-project food losses. If users have access to such data, they are encouraged to contribute it to the Technical Platform on the Measurement and Reduction of Food Loss and Waste (TPFLW), helping to enhance the global availability and quality of food loss and waste data.

2.2.1.1 Taxonomy

The differences in classification between the FAO Food Loss database and those used by the IFC's Food Loss Tool required some level of classification to reconcile inputs and final results. These differences are relevant for supply chain, region, commodity, and commodity group. All the tables mentioned within this section are reported in the annex.

[8] SDG 12.3.1: Global Food Loss

Each data point corresponds to a stage in the value chain that was examined in the source study, according to the FAO Global Food Loss Index's definition:[9]

- point of production (farm, slaughter, landing)
- storage (pre-processing)
- processing
- storage (post-processing)
- retail

In addition, the tool provides the possibility to calculate GHG emissions and food losses occurring during transportation between the supply chain stages listed above, including international shipping.

For some countries and commodities additional stages or activities have been included as they are critical loss points that were the object of the study. The classification between supply chain stages that are within the scope of this study and their respective FAO label is reported in the annex, section 6.1.

The list of commodities included in the FAO database is extensive and not consistent with the commodity nomenclature used within the scope of Food Loss Tool. We therefore needed to map the FAO's data and name conventions to the tool in order to adopt a consistent nomenclature. In some cases, the FAO commodity was too detailed for the purposes of this tool (for e.g., specifying a particular variety of the commodity), while in other cases, differences are simply due to different wording (e.g., commodities reported in the singular form rather than plural, or vice versa). The classification for FAO commodities that were included in the scope of this project is reported in the annex, section 6.1.

Once all items in the FAO database were matched with the nomenclature indicated for this project, each commodity was associated to a commodity group. The Tool's commodity group was indicated for each commodity in the scope of this project, while the classification for the FAO commodity group was performed by the Carbon Trust. The latter classification is required to match the Tool's commodity with the commodity group used by FAO for their food loss estimates by region. The classification is reported in the annex, section 6.1.

Regional classifications also differ among different sources. For example, in some cases, the region's name from the FAO Food Loss database cannot be matched with the World Bank Group's country classification. To solve this issue, the region name reconciled using the UN sub-region via the M49 country code. This classification is reported in the annex, section 6.1.

2.2.1.2 Calculation of default food loss rates

Recognising the lack of food loss rate data for many combinations of commodities and countries covered by this project, a step-by-step methodology was adopted in order to achieve

[9] SDG 12.3.1: Global Food Loss - METHODOLOGY FOR MONITORING SDG TARGET 12.3.

a comprehensive dataset for all countries, commodities, and supply chain stages. The five layers of this method are presented in the hierarchy below:

1. Average of corresponding observations from FAO dataset (commodity, country);
2. Average of corresponding observations from FAO dataset (commodity, sub-region);
3. Average of corresponding observations from FAO dataset (commodity group, country);
4. Average of corresponding observations from FAO dataset (commodity group, sub-region);
5. FAO regional estimates (commodity group, region).

For each combination of country and commodity, the tool produces an estimate based on the specific combination of inputs (step 1). Where the specific combination of country and commodity is not available within the dataset, the Tool uses the lowest value calculated in steps 2 through 5, in order to provide a more conservative estimate.

For step 1 to 4, the tool will return the arithmetic average of all available observations within the period of interest. Stage 5 ensures that the tool can always provide an estimate, if no data is available in the dataset.

Example: Default loss rates

When the user inputs are “Angola”, “Maize”, “Processing”, the tool uses the lowest values among the following data points:

1) Average of maize loss rates during processing in Angola;
2) Average of maize loss rates during processing in Sub-Saharan Africa;
3) Average of pulses & grain loss rates during processing in Angola;
4) Average of pulses & grain loss rates during processing in Sub-Saharan Africa;
5) FAO estimate for cereal loss rate during processing in Sub-Saharan Africa.

For the storage stages, the food loss rate calculated with the methodology described above is split between the pre- and post-processing stages to avoid potential double counting. The split is calculated by weighting the number of days in storage (for storage). As an example, if the average food loss rate for maize at storage is 10%, and the commodity is stored 4 days in storage (pre-processing) and 1 day in storage (post-processing), then the associated food loss rates will be 4% and 1% respectively.

Since the Food Loss database does not specifically distinguish between transport at different stages, the tool considers the food loss rate calculated from the database as the total losses occurring during all transport stages. That is, if the user includes only one transport stage, 100% of the default loss rate will be allocated to that stage, if two stages are included then each will be allocated 50% of the total default loss rate, and so on.

Additionally, when transport occurs internationally, then the tool accounts for the food loss rate for each of the three sub-stages (transport within origin country, in between the origin and destination country, and within destination country). The tool then calculates a weighted average of the food loss rate of these 3 sub-stages based on the distance travelled in each of them (see section 3.2.1.1 for more information on calculation of the distance):

- within origin country: from Origin site to border of country A
- in between: from border of country A to border of country B
- within destination country: from border of country B to destination site

As a proxy, the default loss rate value for the in-between sub-stage equals that of the origin country: it is assumed that the transport conditions (and ultimately the food loss rates during the journey) are set during the transport preparation in the origin country. Where the user inputs specific loss rates for a sub-stage, the tool uses that value instead of the default. However, the overall weighted average loss rate for that transport stage still follows the calculations described above.

The reason for adopting this approach is to be conservative in estimating food losses occurring during transport, assuming that loss rates provided by the FAO database are representative of a "whole value chain" estimate for losses occurring during transport, rather than losses occurring every time a commodity is moved from A to B.

Example: Transport loss rate calculation

A user is using the tool to calculate the impacts from an intervention project at retail. The commodity is produced and stored in Angola, then transported to Spain for processing and storage, and then transported to Belgium for retail, for a total of 4 transport stages between each of the supply chain stages.

When the commodity is transported between 2 countries, the transport stage includes 3 sub-stages (within origin country, between origin and destination countries and within destination countries). For example, during the transport stage from the storage location in Angola to the processing site in Spain.

When the commodity is transported within one country, then there is only 1 sub-stage (within country). For example, during the transport stage from the production site to the storage site, both in Angola.

"Full" default loss rate for each country	Sub-stage within Origin country	Sub-stage in between countries	Sub-stage within Destination country
Transport stage 1 (production to storage1)	Angola 1.6%	*N/A*	*N/A*
Transport stage 2 (storage to processing)	Angola 1.6%	Angola 1.6%	Spain 0.2%
Transport stage 3 (processing to storage2)	Spain 0.2%	*N/A*	*N/A*
Transport stage 4 (storage2 to retail)	Spain 0.2%	Spain 0.2%	Belgium 0.2%

Instead of summing the full default loss rates of the applicable country of each sub-stages, the tool divides each sub-stage rate by the total number of sub-stages. This ensures that the loss rate is allocated across all transport (sub-)stages.

In this example, there is a total of 8 sub-stages (one for transport stage 1, three for transport stage 2, one for transport stage 3, and three for transport stage 4).

Tool default food loss rates	Sub-stage within Origin country	Sub-stage in between countries	Sub-stage within Destination country
Transport stage 1 (production to storage1)	1.6% / 8 = 0.20%	*N/A*	*N/A*
Transport stage 2 (storage to processing)	1.6% / 8 = 0.20%	1.6% / 8 = 0.20%	0.2% / 8=0.025%
Transport stage 3 (processing to storage2)	0.2% / 8=0.025%	*N/A*	*N/A*
Transport stage 4 (storage2 to retail)	0.2% / 8=0.025%	0.2% / 8=0.025%	0.2% / 8=0.025%

To obtain a final food loss rate figure per transport stage, the tool then calculates a weighted average based on the distance travelled at each sub-stage:

Tool default food loss rates	Sub-stage within Origin country	Sub-stage in between countries	Sub-stage within Destination country	**Food loss rate: (weighted avg)**
Transport stage 1	1.6% / 8 = 0.20% 580km	*N/A*	*N/A*	**0.20%**
Transport stage 2	1.6% / 8 = 0.20% 580km	1.6% / 8 = 0.20% 7650km	0.2% / 8=0.025% 99km	**0.198%**
Transport stage 3	0.2% / 8=0.025% 99km	*N/A*	*N/A*	**0.025%**
Transport stage 4	0.2% / 8=0.025% 79km	0.2% / 8=0.025% 9725km	0.2% / 8=0.025% 245km	**0.025%**

To calculate the avoided food losses from transportation, the tool will then apply the 0.20% weighted average food loss rate for Transport stage 1, 0.198% for Transport stage 2, 0.025% for Transport stage 3 and 0.025% for Transport stage 4.

3. Greenhouse Gas Emissions

This section covers the methodology used for calculating emission factors for all commodity and all target countries.[10]

- Emissions were measured in tonnes of carbon dioxide (tCO_2), tonnes of carbon dioxide equivalent gases from methane (tCO_2e from CH_4) and tonnes of carbon dioxide equivalent gases from nitrous oxide (tCO_2e from N_2O)[11]
- Emission factors were measured in tonnes of carbon dioxide equivalent gases produced per tonne of commodity (tCO_2e/t).
- Global Warming Potential (GWP) values are from IPCC AR5 inventory guidance.[12] [13]

3.1 Production

3.1.1 Crops

The primary data source used for the production stage is the FAOSTAT database, which collects data supplied by governments through national publications and FAO questionnaires.[14] Unless specified, all data points are computed at Tier 1 following the IPCC Guidelines for National GHG Inventories.[15] Yield are calculated using a five-year average from FAO to smooth out year-on-year changes.

Agriculture production emissions from crops are aggregated using the following categories (all definitions are from the FAO methodology abstract): [16, 17]

- **Burning crop residues:** GHG emissions from burning of crop residues consist of methane and nitrous oxide gases produced by the combustion of crop residues burnt on-site[18].

[10] Alternative approaches for calculating emission factors that were considered at the design stage can be found in the Annex.
[11] For commodities for which there were no tonnes of carbon dioxide gas (tCO2) of greenhouse gases are primarily produced by nitrous oxide and methane.
[12] IPCC - Task Force on National Greenhouse Gas Inventories
[13] It is assumed that the grid emissions factors from UNFCC also align with AR5 GWP values.
[14] FAOSTAT database
[15] FAOSTAT emissions are estimated by FAO and may not coincide with GHG data reported by member countries to UNFCCC.
[16] Data on the Cultivation of Organic Soils has been discontinued in the latest version of the FAOSTAT database and has therefore been removed from the tool.
[17] FAO Methodology Abstract
[18] Note that CO_2 emissions from crop residue disposal are not included as the CO_2 released during burning or decomposition is a reversal of the CO_2 recently absorbed during crop growth.

- **Crop Residues**: GHG emissions from crop residues consist of nitrous oxide gas from decomposition of nitrogen in crop residues left on managed soils.
- **Manure applied to Soils**: GHG emissions from manure applied to soils consist of nitrous oxide gas from nitrogen additions to managed soils from treated manure.
- **Rice cultivation**: GHG emissions from rice cultivation consist of methane gas from the anaerobic decomposition of organic matter in paddy fields. Computed at Tier 1 following the Revised 1996 IPCC Guidelines for National GHG Inventories (IPCC,1997); the IPCC 2000 Good Practice Guidance and Uncertainty Management in National GHG Inventories (IPCC, 2000), and the IPCC Background Papers (IPCC, 2002).
- **Synthetic Fertilizers**: GHG emissions from synthetic fertilizers consist of nitrous oxide gas from synthetic nitrogen additions to managed soils.

Additional information supplied by other national or international agencies, organizations, and research institutions are used to complement missing or incomplete data, and in particular:

- Global averages for GHG emissions factors calculated based on a series of LCAs collected between 2000 to 2015,[19] as reported by Clune et al. This research reviewed 369 published studies that provided 1,718 global warming potential (GWP) values associated with the production of 168 varieties of fresh produce. The LCA results are reported in CO_2e/mass unit of raw produce reaching a regional distribution centre.[20] The LCA studies typically analysed farm inputs from chemicals and fertilisers, fuel and energy inputs from irrigation and machinery for cultivation, harvesting and processing, and transport and refrigeration. Outputs included emissions released from fertilised soils, plants, and animals in fields.

- Additional data was consolidated based on the research from Poore et al., which collected LCAs from 2000 to 2015 from 38,700 farms and 1,600 processors.[21] Emission factors reported in this study are used to complement the research reported above for gaps in emission factors.[22] More specifically, of the 74 Emissions Factors used to calculate the "Weighted average Clune/Poore global emission factor" (see section 3.1.1.4). For the case of Sugar Cane, two out fifteen data points were excluded as outliers, being from three to six times higher than the rest. More specifically, of the 74 Emissions Factors used to calculate the "Weighted average Clune/Poore global emission factor" (see section 3.1.1.4), 61 were from Clune's research, 6 from Poore, and the rest from the sources below.

[19] Clune S, Crossin E, Verghese K (2016) Systematic review of greenhouse gas emissions for different fresh food categories, Journal of Cleaner Production. DOI: 10.1016/j.jclepro.2016.04.082
[20] Not including manufacturing, further transportation, cooking, or any other subsequent stages along the value chain.
[21] Poore J, Nemecek T (2019) Reducing food's environmental impacts through producers and consumers. DOI: 10.1126/science.aaq0216
[22] The emission factors for bananas, cassava, soybeans, sugar cane, and sweet potatoes were sourced from this research.

- Emission factors for cotton were sourced from WWF data.[23] As India produces more than 25% of global cotton it was decided that this was a representative value.[24]
- Emission factors for cocoa were sourced from the Chocolate Sustainability Report.[25]
- Emission factors for coffee beans were calculated as the average between conventional and organic cultivation from Noponen M et al (2012).[26]
- Emission factors for buckwheat flour were sourced from Xu et al (2017).[27]
- Emission factors for sorghum, millet and coconut were sourced from Ecoinvent data (2022).
- Crop area by country was sourced from the FAOSTAT database (2017).
- Emission factors for the separate analysis for wheat flour were sourced from the World Food LCA Database.[28]

3.1.1.1 Rice

Rice is the only crop for which FAO provides specific emissions. Therefore, it is the only crop whose production can be directly linked to its emissions and an emission factor can be directly calculated.

Given that there are many factors in the production stage that would influence rice emissions, and often times country specific practices are not known, it is possible in some cases the rice emission calculation using the Tool might be either overestimated or underestimated. For example, dry production methods have a lower emission factor versus producing rice in flooded paddy fields which result in methane emissions and an overall higher emission factor. In addition, FAO emissions only count the Methane (CH_4) emissions, and not considering any CO_2 emissions from other source in the rice production. During the development of the tool, it was considered to include a portion of the other emission categories as well, such as "Synthetic fertilizers (N_2O)", "Manure applied to soils (N_2O)", "Crop residues (N_2O)" and "Burning–crop residues (CH_4, N_2O)". However, since there is no way to know exactly which countries employ dry/wet rice production systems, to what proportions those systems contribute to the country's production and how much of the other emissions categories contribute specifically to rice production emissions, it was decided to only include the "Rice

[23] Cutting Cotton Carbon Emissions (WWF, 2013)
[24] More information on the specific methodology followed by FAO can be found in the WWF report.
[25] Chocolate Sustainability Report
[26] Noponen M et al (2012) Greenhouse gas emissions in coffee grown with differing input levels under conventional and organic management.DOI: 10.1016/j.agee.2012.01.019.
[27] Xu et al (2017) Measurement and Evaluation of Carbon Emission for Different Types of Carbohydrate-rich Foods in China https://www.aidic.it/cet/17/61/066.pdf
[28] WFLDB 3.0 (2015). More information on the methodology followed by FAO can be found in the Methodological guidelines for the life cycle inventory of agricultural products (WFLDB).

Cultivation" emissions category. Thus, in some cases rice emission calculated with this tool might be underestimated.

Each country's emission factor for rice was calculated by dividing each country's rice cultivation emissions by the rice production:

$$\frac{Rice\ cultivation\ emissions\ (tCO_2e)}{Rice\ production\ (t)} = Rice\ emissions\ factor\ (tCO_2e)$$

For countries that do not have rice production and cultivation emissions data – either because rice is not cultivated or because data is missing – a regional average is calculated from the weighted regional average depending on the country of production. As a safeguard measure, where in some cases this method produces an unrealistically high or low emission factors, the final estimates are capped to the maximum or minimum value found in Clune et al.

3.1.1.2 Flour

A different methodology had to be devised for Flour as it was the only secondary product from plant-based products. It was assumed that all flour was derived from wheat. The difference between the average global emission factor of Wheat Flour and Wheat as grains at a farm level was calculated.[29] This absolute number was added to every country's individual emission factor for wheat in order to model the individual flour emission factors.

It was decided to use this absolute number, instead of a percentage increase for crops, because whether the wheat grains were produced by efficient or inefficient production systems, the energy or fuel consumption of flour processing would hardly be affected. For example, a developing country might not use any fertilizers or other carbon intensive measures in the wheat production, leading to a low wheat emission factor. However, that country would still need electricity or fuel to produce flour. If the improvement in food loss is taken in the form of percentage change for wheat, then the flour would have an unrealistically low emission factor. Similarly, countries with high emissions for crop production would have an even higher flour emission factor causing overestimation of emissions. At the moment, the Tool only takes fuel and electricity consumption when calculating flour emissions. This version of the Tool does not take the source of energy/fuel into consideration (e.g. fossil fuels vs. renewable, manual or animal labor) when calculating the emissions.

3.1.1.3 Oil crops

As of version 3 of the tool, oil crops were added as a new commodity group in the tool which include:

- cotton seed oil,
- sunflower oil,

[29] The wheat to flour ratio (0.9) is derived from existing industry data from the Carbon Trust.

- olive oil,
- palm oil

Oil commodities are processed crops. As such, users of the tool may only indicate projects starting from the processing stage to avoid any confusion regarding the quantities indicated in the interface.

Based on the quantities indicated by the user, the tool uplifts those quantities for the pre-processing stages. These uplift quantities are based on mass-based extraction rates from unprocessed to processed commodities. The extraction rates for oil commodities are sourced from FAO Food Balance Sheets[30], assuming fat content (g per 100g) as a straight percent oil yield. Those uplifted quantities for pre-processing stages are then multiplied by the respective emission factor of each stage. For the production stage, the emission factors are that of their corresponding unprocessed commodities, derived from FAO data (see section below).

3.1.1.4 All other crops

For all other crops, an *average emission factor* is calculated for each country using FAO data. This represents the emission factor that a crop would have in a specific country if all crops produced in that country had the same emission factor. The *average emission factor* is calculated by dividing each country's crop agricultural emissions by total crop production:

$$\frac{Crop\ agricultural\ emissions\ (tCO_2e)}{Total\ crop\ production\ (t)} = Average\ emission\ factor\ (tCO_2e/t)$$

where crop agricultural emissions for each country are calculated by aggregating the following FAO emission categories:

- Burning crop residues
- Crop Residues
- Cultivation of Organic Soils
- Manure applied to Soils
- Synthetic Fertilizers

Then, the percentage of each different global crop production in relation to the total global crop production is calculated:

$$\frac{crop_A\ production\ (t)}{\sum_{A=1}^{N} \sum crop_A\ production\ (t)} = crop_A\ share\ of\ total\ production$$

[30] FOOD BALANCE SHEETS - A Handbook – Annex 1 Food composition tables

Then the emission factor of each crop was weighted according to its percentage of total global crops production. To be conservative, any emission factors associated with greenhouse or heated greenhouse production were excluded from this average (Figure 8).

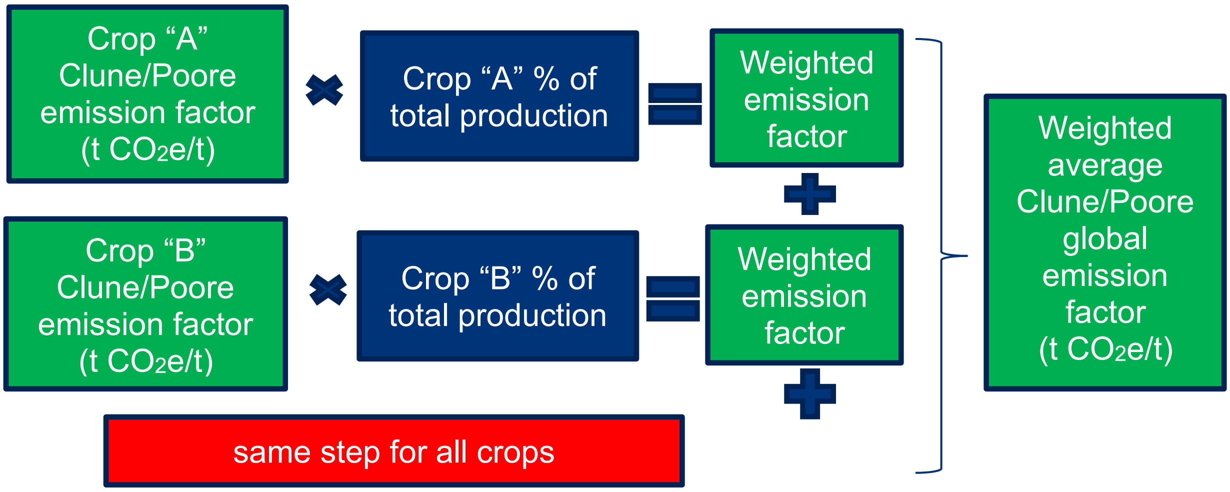


Figure 3. Weighted average emission factor for crops (Clune/Poore)

Each target crop's emission factor percentage difference was calculated from the weighted average Clune/Poore global emission factor (Figure 9).

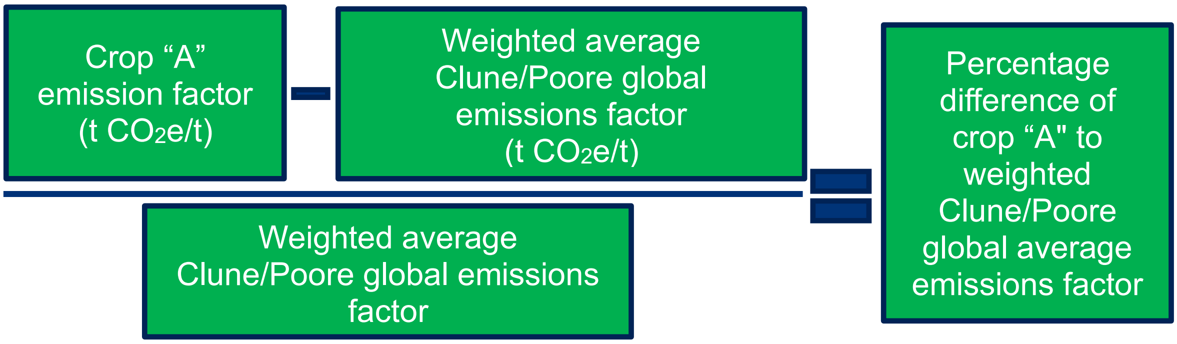


Figure 4. Percentage difference of crop to weighted average

Individual emission factors per crop per country are modelled by scaling the "Average emissions factor per crop per country" according to the "Percentage difference of crop to weighted average Clune/Poore global emissions factor" (Figure 10. Modelled emission per crop per country).

For example, if Argentina's "average emission factor" is 0.19 tCO_2e/t and the "percentage difference of apples to the weighted Clune/Poore global average emission factor" is -29%, then the "modelled emission factor for apples produced in Argentina" will be:

$$0.19 \times (1 - 0.29) = 0.13\ tCO_2e/t$$

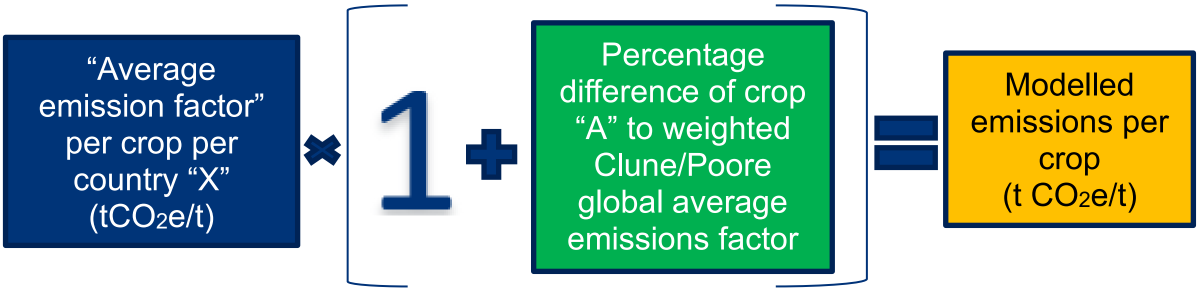


Figure 5. Modelled emission of Crop A in Country X

To guarantee that both the methodology and the data are robust, we ensured that all countries had "Average emission factor per crop" within acceptable parameters. This means that any country that has unrealistically high or low data need to be corrected. For this reason, any outlier country uses a regional weighted average of that crop instead.

With this approach, some crop emission factors were significantly higher for specific countries. This threshold was the maximum value of Clune/Poore research. This happened in 316 crop emission factors out of the total 6,579 calculated with this tool (about 4.80%). These particular crop emission factors are capped them to Clune's maximum value for the same reason why the countries were capped to a maximum value (see paragraphs below).

Based on each country's emission profile a percentage was calculated about the ratio of CO_2e emissions from CH_4 and N_2O. Therefore, all of the crops for the same country share the same percentage when calculating CO_2e emissions. For example, if Apples from Argentina have an emission factor of 0.135 tCO_2e/t and based on Argentina's emissions 98% of CO_2e comes from N_2O and 2% comes from CH_4. Then it would be 0.132 tCO_2e/t from N_2O and 0.003 tCO_2e/t from CH_4.

In some cases, countries have an "Average emission factor per crop" double or even triple than the rest of the countries. The upper bound of the acceptable range is set using Clune/Poore's weighted average maximum value, calculated as the highest possible "Average emission factor per crop" that could be calculated by using the highest global LCA value included in the Clune/Poore papers. If the country is still higher than that, then it means that there must be an error in the reporting, either under-reporting the crop production or overreporting the country emissions. For the sake of having a conservative estimate using this tool, it was necessary to scale down the "Average emission factor per crop" in these countries. This upward capping came in effect in 7 countries: Iceland, Ireland, Luxembourg, Mongolia, New Zealand, Norway, Trinidad and Tobago.

Additionally, all countries that were below Clune/Poore's most minimum value were also limited to it. This lowest limit cut-off point was chosen because this would be the "Average emission factor per crop" if that country only produced crops with the lowest emission factor and had calculated the emissions based only on the most conservative global LCAs from Clune/Poore papers. If the country is still lower than that, then it means that there must be an error in the reporting, either under-reporting the emissions or overreporting the country production.

For the sake of having an accurate estimate using this tool, it was necessary to scale up the "Average emission factor per crop" in these countries. This downward capping came in effect in only 1 country – Kiribati. It should be noted that for Marshall Islands FAO had no data on agricultural emissions so an estimation of the country's "Average emission factor per crop" could not be performed at all. For Kiribati, its factor was 0.0093, which is unrealistically low.

3.1.1.5 Fertilizer Manufacturing

Regional cradle-to-gate estimates for GHG emission per tonne fertiliser manufactured comes from Brentrup (2018) and is adjusted for emissions per kg N (see sections 3.1.1.5 to 3.1.1.7 for calculating the amount of N). Since actual emissions from nitrogen manufacture are not

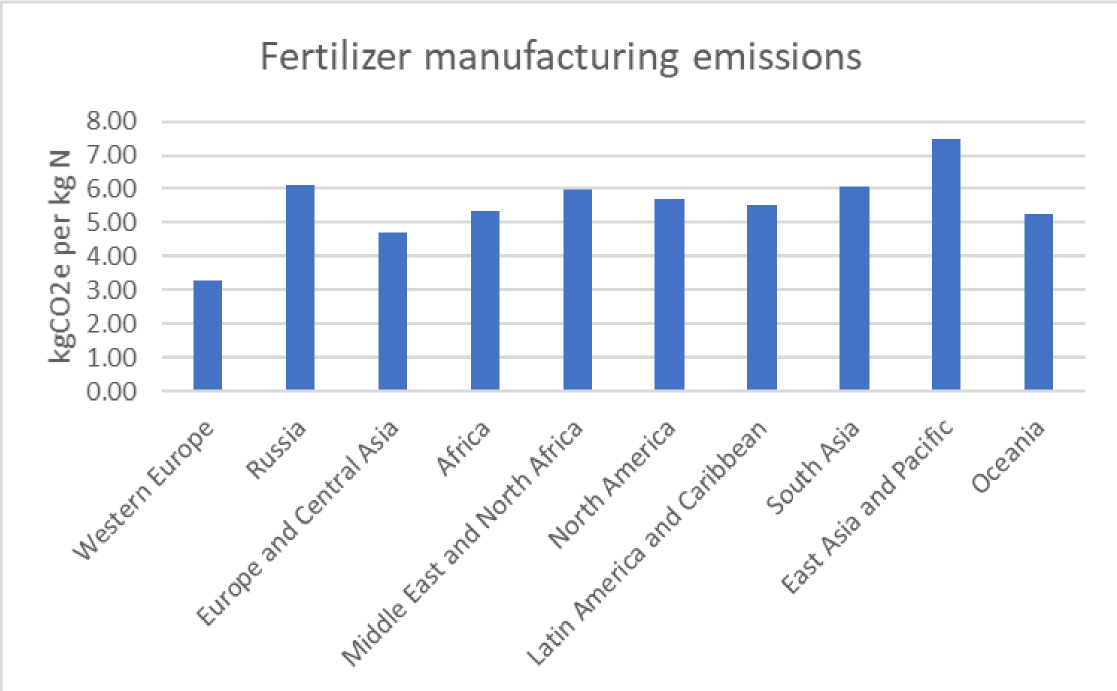


Figure 6. Regional fertilizer manufacturing emissions

available, the tool uses the average across different ammonium nitrate and urea fertilisers as the (Figure 4). Fertiliser manufacturing is included alongside field emissions to provide a more complete picture of significant emissions that will be avoided by preventing food loss. Note that the boundary for considering emissions from producing food is different from that used to determine which food losses to measure.

Brentrup et al (Brentrup 2018) used industry data and expert opinion (the authors are predominantly industry experts from Yara, a large fertiliser manufacturer) to generate cradle-to-gate emission factors for a range of 18 common fertilisers in all relevant IFC global regions. They used the online carbon calculator tool provided by Fertilizers Europe for the calculations ("Carbon Footprinting in Fertilizer Production" 2019). We believe this is a good approach as this tool has been assured by DNV. Additionally, manufacturing company-specific footprint results from the Fertilizers Europe tool have been verified by the Carbon Trust for use as emission factors in the Cool Farm Tool ("Cool Farm Tool | An Online Greenhouse Gas, Water, and Biodiversity Calculator" 2019).

Fertilizer manufacturing emissions vary according to the combination of NPK ratio, technology and local energy mix. In particular, different regions vary by the level of N_2O 'scrubbing' technology installed. This technology mitigates (or 'abates') emissions of this high GWP gas and can halve manufacturing emissions - see for example the difference between Western Europe (which includes fertilizer manufactured 100% in the EU-ETS) with East Asia and Pacific (which has relatively little abatement technology installed and high energy emissions). Without project-specific data on fertiliser sourcing (which may be difficult to obtain) there are some uncertainties, but these are out-weighed by the important contribution of manufacturing to overall emissions.

3.1.1.6 User-defined Nitrogen application rate and crop yields

The relationship between N and yield is defined in three ways, depending on the level of user input:

1) The FAOSTAT dataset is used to calculate default values for nitrogen per ha or tonne for each country
2) The user may input project-specific N and or yield values per ha or tonne
3) A background calculation checks the user's input to ensure that a reasonable relationship is maintained between N and yield

3.1.1.7 Default yield calculations

Default yield per hectare is calculated using FAO Data at country level from the production (tonnes) and production area (ha) . Where a combination of country and commodity is not available, the tool uses a regional or global average for the commodity of interest.

3.1.1.8 Default Nitrogen calculations

The modelled default emissions factors per crop and country provide a guide to crop emissions. However, it is feasible (and desirable) that users can provide project-specific nitrogen application rate for synthetic fertilizers and/or crop yield data. These data will generate more accurate emissions savings and potentially inform a process of improved N-management. As outlined in section 3.2.1, the crop emissions are generated by a range of sources – including fertiliser application. There is an implied N application rate and crop yield behind these numbers which can be calculated.

The FAO used the IPCC guidance ("IPCC - Task Force on National Greenhouse Gas Inventories" 2006) "tier 1" approach in volume 4 chapter 11 to convert the total national fertiliser use into associated emissions. We reverse this calculation to derive the original implied N/ha rate.

Nitrogen from manure is not included as there is no national data available for manure use (and its nitrogen content). The FAO data only contains national nitrogen use from synthetic fertilizer.

3.1.1.9 User-defined Nitrogen and yield

In order to generate a more accurate statement of project emissions savings, the user is able to enter either or both of project-specific data, per crop and country, for the N rate per ha and the crop yield. These data represent both current and expected values – there is no facility to input predicted change (e.g., improvements) as you can for loss rates. Also note that these calculations only apply to synthetic fertiliser, not manure.

The amount of N (either the default or provided by the user) is also multiplied by the fertiliser manufacturing factor in section 3.1.1.4.

The calculation to adjust the contribution to total country crop emissions from fertiliser is as follows. The result from this calculation is fed into the per crop weighting process to derive a new crop per tonne emissions factor for the country.

Note that the following calculation defines a simple relationship between N and yield that depends upon valid user-defined inputs, if provided (Figure 11. Fertilizer emissions calculation).

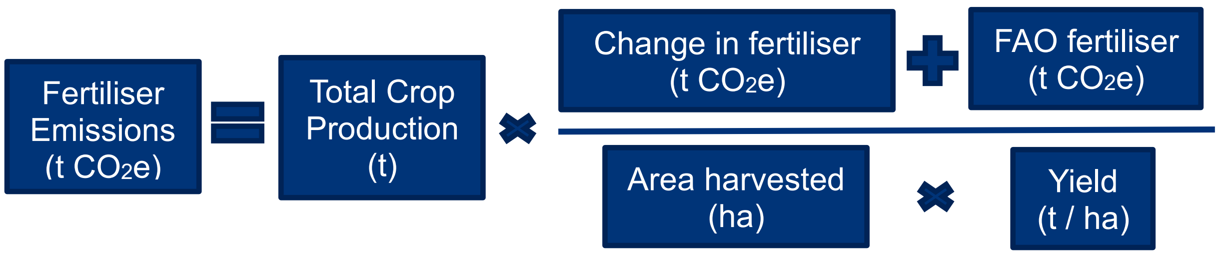


Figure 7. Fertilizer emissions calculation

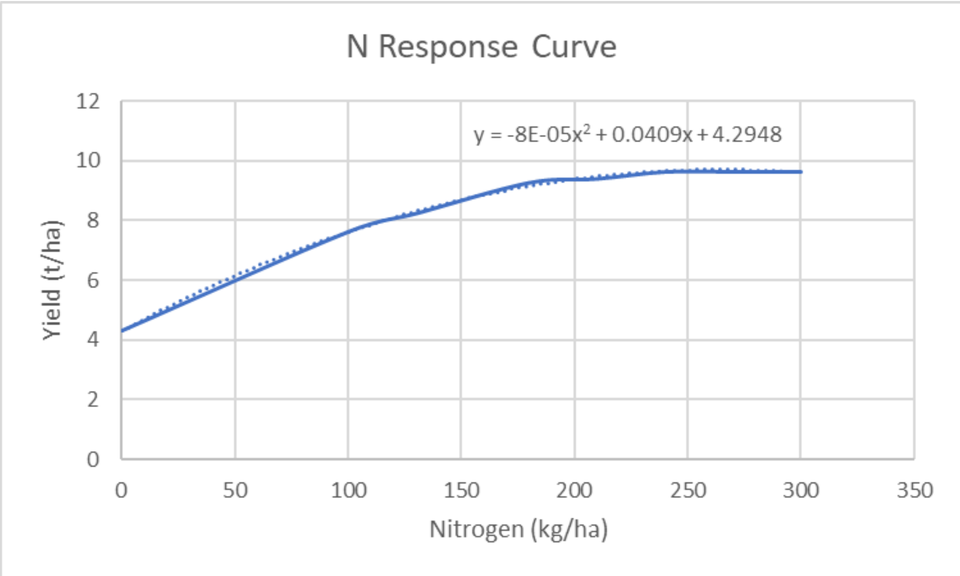
Where *yield* can be either the implied FAOSTAT value or user-defined, and *change in fertiliser* tCO_2e is the difference between emissions implied by the user-defined N/ha (or N/tonne) rate and that implied by FAOSTAT.[31] A separate check is made to warn the user if their N or yield values may be incompatible.

[31] This value is set at zero when no user-defined value is provided.

3.1.1.10 Checking user-define Nitrogen and yield

A model of the typical N-response curve is used, based upon the selected country's default N and yield data.

The typical N-response curve is based upon data from table 6 in Gilchrist et al (2012). This data was averaged and used to generate a curve as follows:



The equation takes the generic form $y = ax^2 + bx + c$ and was estimated using Excel's polynomial trendline tool.

The curve used to check user-defined data was adjusted to better represent the selected country by moving up or down the y-axis via c and the steepness of the curve was adjusted via b. That is, the curve above represents a particular crop and country, where c determines yield with no N and b (steepness) how sensitive yield is to N application rate. The FAO data suggests that these relationships vary quite a bit and so to make the checks of user-defined data more meaningful the N-response curve equation is modified.

Use of the N-response curve is two-fold, as it is used initially to calculate any country-specific adjustments to b and c needed to check user data. Then used again to validate user input as follows.

Firstly, b & c are adjusted. The size of adjustment in c was determined with the N-response equation above, using the user's N / ha. If there was a large difference between default yield (from FAOSTAT) and the yield implied by the user's input of N/ha then the value of c was adjusted up to compensate the check.

The size of adjustment in b was determined by the ratio of user-defined N / ha to yield / ha. A high ratio implies a steeper curve, as increasing N doesn't seem to increase yield much. Whereas a low ratio implies a shallower curve and a higher maximum yield.

Secondly, the new N-response curve is used to test the calculated relationship between user-defined N and yield compared to the actual input data.

3.1.2 Animal proteins – land-based livestock

Data was adapted from the FAO's report on regional livestock emissions (GLEAM).[32] The methodology applies the IPCC tier 2 approach for inventories[33] and GLEAM production data from 2010. LUC (deforestation) from expanded grazing and from feed production were excluded. Emissions from grassland/savannah burning are not included in the GLEAM model for Sub-Saharan Africa, which is inconsistent with FAOSTAT. The tool follows the GLEAM's methodology in order to be conservative (i.e., use the lower emissions estimate available to avoid overestimating emissions avoided).

The FAO data is reported by kg protein, which needs to be converted into kg meat, milk or egg.

For cattle, pig, and poultry, these values were converted from kg carcass protein to per kg carcass and per kg live-weight using the values in table 9.1 in the v2.0 Documentation and table 9.2 in Supplement S1 ("Resources | Global Livestock Environmental Assessment Model (GLEAM) | Food and Agriculture Organization of the United Nations" 2018).

Four emission factors were calculated per region, reflecting predominantly grazed or mixed feeding either with or without feedlot finishing. To include feedlots in the emission factor, the following equation is used:

$$\frac{Grazing\ emissions\ (tCO_2e) + Feedlot\ emissions\ (tCO_2e)}{Grazing\ production\ (t) + Feedlot\ production\ (t)} = Emission\ factor\ (tCO_2e/tonne)$$

For milk protein conversion, a value of 3.3% protein content was applied (Gerber 2010).

For egg protein conversion, the value of 12.4% protein content from section 9.1.3 of the GLEAM v2.0 Documentation was applied.

For milk-derived products (yoghurt, butter, cheese), added in version 3 of the tool, the production stage emission factor is that of milk. However, regarding the quantities, an uplift is applied to the quantities indicated by the user. These uplift is based on the mass-based extraction rates from unprocessed (milk) to processed commodities (milk-derived products). The extraction rates for milk-derived products are sourced from FAO[34].

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[32] Global Livestock Environmental Assessment Model (GLEAM). The GLEAM is a GIS framework that simulates the bio-physical processes and activities along livestock supply chains under a life cycle assessment approach. The aim of GLEAM is to quantify production and use of natural resources in the livestock sector and to identify environmental impacts of livestock in order to contribute to the assessment of adaptation and mitigation scenarios to move towards a more sustainable livestock sector. GLEAM differentiates key stages along livestock supply chains such as feed production, processing and transport; herd dynamics, animal feeding and manure management; and animal products processing and transport. The model captures the specific impacts of each stage, offering a comprehensive and disaggregated picture of livestock production and its use of natural resources. http://www.fao.org/gleam/results/en/

[33] See IPCC - Task Force on National Greenhouse Gas Inventories (2006).

[34] tcf.pdf

3.1.2.1 Methane and nitrous oxide

The FAO publications by MacLeod et al (2013) (figure 5) and by Opio et al (2013) (figures 6 and 28) provide a percentage breakdown of average livestock emissions. These percentages were applied to the regional footprints for each Animal Protein emission factor to determine the typical CH_4 and N_2O contributions.

3.1.2.2 Farming systems

The following table summarises the different farming systems for which emission factors were calculated. Full details are available in the GLEAM v2.0 Documentation (section 1.5.2).

Table 2. Livestock farming systems

	System	Definition
Cattle	Grassland	Pastures and rangelands, less than 10 livestock units per hectare.
	Mixed	Areas dominated by cropland, >10% feed is crop/by-products
	Combination with feedlot	As above but with finishing on specialised units
Pigs		
	Backyard system	Mainly subsistence driven or for local markets
	Intermediate system	Market-oriented; medium capital input requirements; local feed at least 30%
	Industrial system	Market-oriented; high capital requirements; purchased/intensive feed production
Poultry		
	Backyard system	Animals producing meat and eggs for the owner and local market, living freely
	Layers	Fully market-oriented; high capital input requirements; purchased/intensive feed
	Broilers	Fully market-oriented; high capital input requirements; purchased/intensive feed
Eggs		
	Backyard system	Animals producing meat and eggs for the owner and local market, living freely
	Layers	Fully market-oriented; high capital input requirements; purchased/intensive feed

3.1.2.3 Notes

Russia and Eastern Europe/Central Asia have a very low cattle meat emission factor. This is likely due to a combination of factors in the assumptions made by the FAO:

- Table 2.5 of the Supplementary Info
  - High mature weight and fertility values
  - Relatively low death rates and an early first birth rate
- Table 4.3
  - Manure management tends to be low temperature (lower CH_4) and liquid slurry (low N_2O)
- Potential role of dairy beef

3.1.3 Animal proteins – aquaculture

The following Aquaculture commodities have been added to version 3 of the tool:

- Tuna
- Tilapia
- Salmon
- Catfish
- Shrimp

The emission factor applicable to the production stage for tuna is from WWF[35], and from FAO[36] for the other aquaculture commodities. These emission factors are per kg of liveweight.

Similarly to oil commodities and milk-derived commodities, the quantity indicated by the user (assumed to be edible weight) needs to be uplifted to be applicable to the pre-processing stages. These uplift for the aquaculture commodities are based on FAO / INFOODS Global Food Composition Database for Fish and Shellfish.[37]

3.2 Emissions due to processes upstream of losses

Losses at the transport, storage, processing, or retail phase generate specific, or direct, emissions at that point due to the fuel and energy used for product subsequently lost. In addition, the upstream emissions generated to produce and get the lost food to a given stage must also be included.

The emissions from upstream stages are calculated by multiplying the amount of current stage losses by the per tonne product emission factors applicable to upstream stages.

[35] Measuring and Mitigating GHGs: Tuna
[36] Quantifying and mitigating greenhouse gas emissions from global aquaculture
[37] uFISH 1.0

For example, to support the processing phase in calculating upstream emissions, the storage emissions per tonne, transport emissions per tonne.km and farm production emissions per tonne are also multiplied by the quantities of avoided losses from processing. The following equation calculates the emissions for 10 tonnes of avoided losses at the processing stage.

$$
\begin{aligned}
&EmissionsAtProcessing \\
&\quad = (10 \times processingEmissionsPerTonne) \\
&\quad + (10 \times preProcessingtransport2EmissionsPerTonne) \\
&\quad + (10 \times preProcessingstorageEmissionsPerTonne) \\
&\quad + (10 \times preProcessingtransport1EmissionsPerTonne) \\
&\quad + (10 \times productionEmissionsPerTonne)
\end{aligned}
$$

3.2.1 Transport

The upstream transport emissions are calculated per transport stages, based on the countries indicated in the interface by the user.

If the whole supply chain happens within one country, the tool assumes there is only one transport stage. The emissions for that transport stage are based on the distance within the country, transport mode (road, rail, ship, flight, or non-motorized) and if relevant, road conditions.

If the supply chain happens is more than one country, the tool generates several transport stages based on the number of different countries indicated by the user. For each of those transport stages, an emission factor is determined per sub-stages (within the origin country, in-between countries and within the destination country). The final emission factor per transport stage is a weighted average of the 3 sub-stages emission factors, based on the distance travelled in each sub-stage.

In the case of international shipping, for the in-between sub-stage, the tool assumes as a default that the commodity travels:

- By sea when the origin and destination countries are located in two different regions
- By sea when the origin and destination countries are both located in one of the following regions: Africa, Latin America and Caribbean, South Asia, or East Asia and Pacific[38]
- By road when the origin and destination countries are both located in one of the following regions: Europe and Central Asia, Middle East and North Africa, North America.

[38] It is a known limitation that some countries are landlocked and as such, the in between sub-stage would involve another transport mode than by sea. The user is encouraged to adjust the distances and transport mode using the Advanced input section of the tool.

Emission factors for transport are mostly sourced from BEIS data,[39] with the default option being the emission factor associated with the average value for diesel trucks (includes all rigid and articulated trucks above 3.5 tonnes) with average laden (as defined by BEIS). Emission factors are uplifted by 50% to cover for backhaul.

Additional emissions from chilling are either sourced directly from the BEIS dataset (for trucks), or calculated by the tool based on the average percentage increase in emissions (18.6%) observed for refrigerated trucks (for van, rail, and ship).

To facilitate the calculations, transport emissions are reported in CO_2e only, not split between the different gas constituents. In the results table, it assumes that all transport emissions are CO_2.

The non-motorized option includes all transportation means that do not require energy sources and is therefore assumed to have zero emissions.

The user has the option to provide their own estimates, which will automatically override all default data applied by the tool. Data can be provided either in the form of emission factor ($kgCO_2e$/tonne.km), or fuel efficiency (litres/100km).[40]

3.2.1.1 Distance

Distance within country:

The default data for the transport distances for each country were taken from the 2018 World Bank Logistics Performance Index (LPI), based on a worldwide survey of logistics operators.[41] The chosen data for each country was the estimated average import distance, from port or airport. For countries that are not included within the LPI dataset, an average ratio between the square root of the country size (in km^2) and LPI import distance is used to extrapolate transport distances for missing countries based on their area.

In the tool, when there are several consecutive transport stages happening in one country, the distance applicable for each transport stage is the distance within the country divided by the number of transport stages involving this country. This is to avoid overestimating the distances and the avoided emissions from transport.

[39] Greenhouse gas reporting: conversion factors 2023 (BEIS)
[40] For fuel efficiency, the tool calculates the associated emission factors based on the litres/100km input provided by the user, assuming a gross weight of 18.25 tonnes and using the diesel emissions factor provided by BEIS (3.30 $kgCO_2$/litre).
[41] World Bank Logistics Performance Index (LPI)

Example: Transport distance calculation

A user is using the tool to calculate the impacts from an intervention project at Storage 2. The commodity is produced, stored and processed in Myanmar, then transported to India for storage 2. This is a total of three transport stages:

	Sub-stage within Origin country	Sub-stage in between countries	Sub-stage within Destination country
Transport stage 1 (production to storage1)	Within Myanmar	*N/A*	*N/A*
Transport stage 2 (storage1 to processing)	Within Myanmar	*N/A*	*N/A*
Transport stage 3 (processing to storage2)	Myanmar		India

There are 3 transport stages involving Myanmar, hence the default distance in Myanmar applied for transport stage 1, 2 and 3 is the whole country distance (683km) divided by 3. There is one transport stage involving India, hence the distance applied for India is divided by one:

	Sub-stage within Origin country	Sub-stage in between countries	Sub-stage within Destination country
Transport stage 1 (production to storage1)	683km / 3 = 227.7km	*N/A*	*N/A*
Transport stage 2 (storage1 to processing)	683km / 3 = 227.7km	*N/A*	*N/A*
Transport stage 3 (processing to storage2)	683km / 3 = 227.7km	Sea distance between the 2 countries = 3715km	569km / 1= 569km

Distance between countries:

The default transport mode differs based on the regions of the origin and destination countries.

When the default transport mode is road freight, the distance is derived from the countries' capital city coordinates. This distance is also applied when the user selects air or train freight transport mode (without providing a distance).

When the default transport mode is sea freight, the default sea distances are sourced from the CERDI SeaDistance database[42], corresponding to the length of the existing shortest sea route between two countries' main ports.

Users may enter their own distance inputs for any of the sub-stages of each of the transport stage(s) which the tool will use instead of the default value.

[42] The CERDI-seadistance database – Ferdi

3.2.1.2 Road conditions[43]

Default adjustments for road conditions are applied based on World Economic Forum data on the quality of road infrastructure.[44] The overall quality of road conditions is translated into an adjustment factor applied to the overall emission factor using the estimates reported in the following table (for road transport only):[45]

Table 3: Emission factor adjustment for road conditions

Road conditions	CO2e g/h/km	Adjustment
Very poor	21,393.7	2.8%
Poor	20,999.8	0.9%
Fair	20,941.9	0.6%
Good	20,871.1	0.3%
Very good	20,829.5	0.1%
Excellent	20,818.6	0.0%

3.2.2 Storage (pre- and post-processing)

The default emissions factor for storage is based upon energy and refrigeration data from the Global Logistics Emissions Council (GLEC) Framework version 2. Table 37 and explanatory text in the GLEC Framework for Logistics Emissions Accounting and Reporting includes survey data from 49 storage sites in Europe and records median ambient (34 sites) and temperature-controlled (15 sites) emissions per tonne. The latter includes emissions from refrigerant losses. Only generic storage data is used, excluding specific data for transhipment and maritime container terminals. The GLEC data are scaled from per 450 kg pallet to per tonne in the tool and do not indicate the time period (e.g. number of days) the storage emissions represent.

Actual energy use and length of storage will likely vary considerably by project instance. When assessing a specific client site, the user should consider requesting more precise data linked to a site energy audit or carbon footprint assessment (e.g. based on ISO 50001 or 14064-1). The default data for the length of time commodities are held in storage was taken from the World Bank LPI report discussed in section 3.2.6 and is based on land distance lead times. Where data is not available, a storage time of 1 day is assumed in order to be conservative in the analysis. This data is listed in the Data (Distances) tab.[46] User may enter their own input for days in storage at both pre- and post-processing stages. If data is provided provide on for both stages, the tool uses both values as provided by the user. If only one value is provided

[43] In addition to road conditions, the road relative elevation is another factor impacting fuel efficiency and emissions. However, this parameter currently is not accounted for in the tool.
[44] Quality of road infrastructure (World Economic Forum)
[45] The Effect of Pavement Condition on Vehicle Speeds and Motor Vehicles Emissions (2015)
[46] In future, users may be able to enter project-specific data regarding storage time and energy consumption

(i.e., either pre-or post-processing storage time), the tool uses the default data for the stage for which user data was not provided.

If there is temporary, unmanaged storage on farm, this is assumed to be included already in the crop emission factor and any losses are out-of-scope (associated with harvest). Dedicated storage of significant size and time (on-farm or off-site) is included in the storage phase.

By default, in the user interface, storage is assumed to be ambient and generate low emissions. The higher temperature controlled GLEC emission factor is applied for commodities considered to normally require refrigeration (i.e. milk and meat). The default data is shared equally between pre- and post-processing storage.

Users have the option to change this. If the storage of a commodity that is by default ambient but is actually temperature controlled (e.g. to prevent spoilage or for drying), storage emissions (per tonne) are based upon the GLEC temperature controlled emission factor.

The user can alternatively define energy consumption values per tonne. For electricity consumption (kWh/tonne/day) the time is multiplied by the grid emission factor for the country in question (kg CO_2e/kWh) and by the number of days spent in storage, and similarly for natural gas (although the emission factor does not vary by country). Default kWh values are provided as a guide only, based upon an assumption that 50% of the GLEC per tonne emissions are generated by electricity and 50% by natural gas. To estimate kWh electricity or gas the following calculation is used: (tonne CO2e / 2) / emission factor per kWh = amount of kWh.

Note – default chilling energy for eggs only includes electricity (no fuels).

3.2.3 Processing

Energy data is taken from the broad literature review conducted by Ladha-Sabur et al (2019), which provides energy consumption during processing of a wide variety of foods in various countries. The tool derives average electricity and natural gas usage per commodity group from this data set. Emissions per country and commodity are calculated based upon the country-specific grid and natural gas emission factors.

The approach therefore represents emissions per commodity across a broad approximation of the variety of different processing technologies and products within different countries.

Users may refine the results by entering a processor-specific emission factor or processor-specific electricity and natural gas consumption data.

There are two implications of the processing stage; processing energy and commodity transformation. The latter implies that the outgoing processed product is different from what came in – for example tinned fruit, flour from wheat or carcass meat from live animals. The difference is associated with losses for most commodities and this is modelled by the tool.

The review paper by Ladha-Sabur et al (2019) includes electricity and natural gas consumption data (in MJ) for a wide range of food processing scenarios (at least 100). The foods involved were mapped to the relevant Tool's commodities and the average electricity and gas use per commodity, multiplied by country-specific emission factors, is used in the tool. In addition, an adjustment ratio is applied to the emission factors, based on the likely processing intensity of each commodity. This Processing intensity factor is set as either high (100%), medium (50%) or low (10%).

User data entry and results for pre-processing stages are disabled for those commodities with significant transformation (meat and flour). Wheat (that remains wheat) is included as a separate commodity whilst live animals are excluded from the scope of the tool.

However, the necessary pre-processing emissions from producing, transporting, and storing the initial commodities (live animals and wheat) are included in meat and flour losses at processing and downstream.

Processing of meat and flour generates significant co-products, implying that more than 1 tonne of live animals or wheat are required to make 1 tonne of carcass or flour. The carcass and flour production emission factors take this into account, by applying a conversion factor based on typical industry data. The carcass and flour production emission factors are therefore much higher than those for live animals or wheat respectively.

Note that wheat is also included in the tool as a separate commodity itself, in which case processing and retail stages may not be needed. Wheat grain is sold as-is.

3.2.4 Retail

Retail emissions are estimated using the Footprint Expert™ tool created by the Carbon Trust. The tool uses UK-based supermarket energy data to estimate emissions per commodity per country. Additional user inputs can be provided, either in terms of emission factor per tonne, or by selecting the relevant store type. For the latter, the tool applies an adjustment based on the percentage difference in typical energy consumption for different stores based on their dimensions.[47]

The Carbon Trust tool Footprint Expert™ includes a retail emissions calculator. The scope of the calculator covers electricity and natural gas use, and refrigerant loss in supermarket temporary storage prior to shelving and on shelf. For on shelf storage, energy use is differentiated between ambient and open and closed chillers and freezers. The calculator allocates supermarket energy consumption data from industry sources to food according to storage method and time in store. The electricity grid factor for the relevant country is used per commodity.

[47] Energy consumption and conversation in food retailing (2009)

The split between ambient, chilled and frozen plus time in store is estimated per commodity type as follows:

	Frozen %	Chilled %	Ambient %	Days on shelf	Ambient temperature (deg C)	Specific heat capacity
Nuts/Seeds			100%	28	18	Vegetable
Tubers/Root Crops			100%	7	18	Vegetable
Fruits			100%	5	18	Fruit
Pulses & Grains			100%	28	18	Vegetable
Cotton			100%	28	18	Vegetable
Animal Protein	25%	75%		3	7	Meat
Flour			100%	28	18	Vegetable
Vegetables			100%	3	18	Vegetable
Mycoprotein			100%	3	18	Vegetable

Notes:

- Days on shelf is based on expert opinion, covering the very wide range of formats foods may be stored in and typical retail stocking practice
- The ambient temperature for Animal Protein indicates the temperature that freezing or chilling began (on the assumption this represents chilled temperature during transport)
- Specific heat capacity is an estimate which helps model the proportion of chilling or freezing energy allocated to the commodity

3.2.5 Grid emission factors

Grid emission factors for the countries included in the tool were obtained by IFC from the UNFCCC website and integrated in the tool.[48] Where grid emission factors for a specific country are not available from the UNFCCC database, the average from the respective region is used instead.

[48] For more information on the methodology used by the International Financial Institutions (IFI) Technical Working Group on Greenhouse Gas Accounting, see the Methodological Approach for the Common Default Grid Emission Factor Dataset (v 01.1, 20 January 2022).

3.3 Disposal

The avoided disposal emissions from the avoided food losses are included in the climate impact results for each of the intervention project which the user models in the tool.

Disposal emissions are based on the waste treatment, i.e. Food Loss Destination. The tool calculate these waste treatment emissions based on IPCC Solid Waste Disposal methodology. The majority of emissions from solid waste disposal is methane from the degradation of organic carbon in the waste in landfill. This disposal method also releases biogenic CO_2, which is considered netted out with the biogenic CO_2 removed during plant growth.

Landfill emissions are calculated on the Landfill Calculation worksheet using a model developed by the IPCC ("IPCC - Task Force on National Greenhouse Gas Inventories" 2006, Volume 5, Chapter 3). Although landfill rates vary considerably for agricultural products across the world, a landfill rate of 57% is set as default in accordance with data from the UN Statistics Division ("UNSD — Environment Statistics" 2020). The most appropriate climatic region out of temperate (dry), temperate (wet), tropical (dry) or tropical (wet) was first applied to each country for the default options.

The IPCC model ("IPCC - Task Force on National Greenhouse Gas Inventories" 2006) and further details can be viewed in the Landfill worksheet. This worksheet implements the equation below. Using this equation, the model assumes that 100% of the waste is 'food waste' and uses three main parameters to calculate emissions.

$$BE_{CH4,SWDS,y} = \varphi \cdot (1-f) \cdot GWP_{CH4} \cdot (1-OX) \cdot \frac{16}{12} \cdot F \cdot DOC_f \cdot MCF \cdot \sum_{x=1}^{y} \sum_{j} W_{j,x} \cdot DOC_j \cdot e^{-k_j \cdot (1-x)} \cdot (1-e^{-k_j})$$

The first is climatic region (sets value of *k*), the second is the percentage of methane that is captured or flared at the landfill site (value of *f*), and the third is the Methane Correction Factor (*MCF*). The MCF factor accounts for the fact that unmanaged solid waste disposal sites produce less CH_4 from a given amount of waste than managed sites (they are more aerated).

Default Methane Correction Factor (MCF) values were sourced from IPCC guidance volume 5 ("IPCC - Task Force on National Greenhouse Gas Inventories" 2006). A weighted MCF is applied for each country based on the percentage of waste going to different landfill types.[49] If a country-specific factor is not available, the tool uses the average associated with the corresponding region.

[49] What A Waste Global Database (World Bank)

Type of site	Methane Correction Factor (MCF) Values
Managed (without gas collection system)	1.0
Managed (with gas collection system)	0.0
Unmanaged - deep (>5 m waste)	0.8
Unmanaged – shallow (<5 m waste)	0.4
Uncategorized solid waste disposal sites	0.6
Compost	0.0
Other productive use	0.0

Users can specify the percentage of food losses going to landfill along the supply chain. In addition, the can user can either provide: a specific emission factor per tonne of food losses going to landfill; or additional information on the landfill type and climate zone.

Alternative routes for food not eaten are either considered as alternative use (rather than a loss), such as anaerobic digestion or composting, or difficult to model and so may be represented as landfill by tool users (e.g. crop harvested but left to decompose at field edges).

4. Further impact indicators

In addition to calculating the avoided emissions from the reduced food loss projects, the tool includes impact indicators on food security, avoided resource use and additional orphaned upstream avoided food loss and emissions.

These indicators provide context and information on the potential positive impacts from reduced food loss beyond GHG emissions.

4.1 Food security impact indicators

Three impact indicators related to food security are included in the tool.

The first one calculates the number of persons that can have their caloric needs met with the avoided food loss or food waste. It takes the total avoided quantities from all the project interventions inputted by the user and determines the corresponding calories based on the FAO Food Balance Sheets[50][51], providing the calories and protein content per 100g of food. The total calories of the avoided food loss are then divided by the minimum calories intake per person per day (World Bank reference) to get the number of people fed equivalent.

The second food security indicator is the number of people that can have their protein needs met with the avoided food loss or food waste. It follows a similar calculation method as the number of people fed equivalent indicator.

The caloric and protein requirements are based on the World Bank reference (please add link); however, since users may come from different countries where these averages can vary, there is also an option to manually enter both caloric and protein values.

	Default caloric requirements	2,000	*kcal/person/day*
	Default protein requirement	50	*g/person/day*
Advanced Inputs (Optional)			
	Enter specific caloric and / or protein requirement to over-ride default data		
	Caloric requirement		*kcal/person/day*
	Protein requirement		*g/person/day*

All of the commodities in the tool are covered in the FAO Food Balance Sheets. However, eight commodities are not relevant for the calculation of people fed equivalent, and are thus excluded from the Food Security indicators:

- Coffee, Cocoa,
- Sugar Cane
- Ginger

[50] FOOD BALANCE SHEETS - A Handbook – Annex 1 Food composition tables
[51] In the case of litchi and broccoli, the food composition is not available in the FAO Food Balance Sheets and was taken from the FoodData Central from USDA.

- Garlic (green) and onions (dry)
- Lemons
- Cotton

The values in the FAO Food Balance Sheets are based on retail weight ("as purchased"), hence are already adjusted to account for the percent of edible matter.

The last indicator is the percentage population at risk of hunger in the commodity's country of production and distribution country. It is there to provide additional context on food security risks in the countries of food loss reduction projects.

4.2 Avoided water consumption and water risk profile of the production country

The tool calculates the avoided water consumption by determining the estimated water footprint for the selected commodity and country of production. The water footprint is calculated based on data provided by the Water Footprint Network, which provides three different types of water footprints: [52,53]

- Green water footprint is water from precipitation that is stored in the root zone of the soil and evaporated, transpired or incorporated by plants. It is particularly relevant for agricultural, horticultural and forestry products.
- Blue water footprint is water that has been sourced from surface or groundwater resources and is either evaporated, incorporated into a product or taken from one body of water and returned to another, or returned at a different time. Irrigated agriculture, industry and domestic water use can each have a blue water footprint.
- Grey water footprint is the amount of fresh water required to assimilate pollutants to meet specific water quality standards. The grey water footprint considers point-source pollution discharged to a freshwater resource directly through a pipe or indirectly through runoff or leaching from the soil, impervious surfaces, or other diffuse sources.

For animal proteins, the estimate is also provided based on different production systems (grazing, industrial, mixed, and average). For aqua products, there is no water footprint estimation.

The water risk profile of the production country is provided based on the WWF's Water Risk Filters[54]. The water risk profile is split into 3 risk types:

- Physical risks covering water availability, drought, flooding, water quality, and ecosystem services status

[52] Mekonnen, M.M. and Hoekstra, A.Y. (2010) The green, blue and grey water footprint of farm animals and animal products, Value of Water Research Report Series No. 48, UNESCO-IHE, Delft, the Netherlands
[53] Mekonnen, M.M. and Hoekstra, A.Y. (2010) The green, blue and grey water footprint of crops and derived crop products, Value of Water Research Report Series No. 47, UNESCO-IHE, Delft, the Netherlands. http://www.waterfootprint.org/Reports/Report47-WaterFootprintCrops-Vol1.pdf
[54] WWF Water Risk Filter - Country Profiles

- Regulatory risks, covering enabling environment, institutions and governance, management instruments, WASH infrastructure
- Reputational risks, covering environmental factors, socioeconomic factors, additional reputational factors

Each risk type has a score (very low to very high) and a country ranking, based on the average risk score, where rank 1 represents the country or territory of least risk.

Regarding the interpretation of these water risk profiles in the context of the tool, it is important to note that they are not specific to the agricultural industry but use average industry weighting. There may potentially be large differences for different industry sectors, particularly in large countries. The geographical resolution of the risk profiles is at country level, however the datasets selection and combination to calculate the risk profile may vary per country. More information on the risk profiles can be found in the WWF's Risk Filter's data and methods[55].

4.3 Avoided land use and Biodiversity risk profile of the production country

Based on yields, the tool provides an estimation of the avoided land use in the production country from the reduced food loss rates. This indicator is applicable to crops only.

Associated to the avoided land use hectarage is the biodiversity risk score of the production country, sourced from WWF's Biodiversity Risk Profile[56]. These indicators cover several risk types:

- Physical Risk covering provisioning services, enabling regulating and supporting services, mitigating regulating services, cultural services, pressures on biodiversity
- Reputational Risk covering environmental factors, socioeconomic factors, additional reputational factors

As for the Water Risks, each risk type has a score (very low to very high) and a country ranking, based on the average risk score, where rank 1 represents the country or territory of least risk. They are also not specific to the agricultural industry but use average industry weighting.

More information on the risk profiles can be found in the WWF's Risk Filter's data and methods[57].

4.4 Avoided nitrogen fertilizer and fuel use impact indicators

The tool includes indicators on the use of several resource that are avoided from the reduced food loss rate projects:

55 WWF Risk Filter Suite - Data & Methods
56 WWF Biodiversity Risk Filter - Country Profiles
57 WWF Risk Filter Suite - Data & Methods

- Nitrogen fertilizer use: the amount of nitrogen saved per tonne of production, based on the total avoided food loss quantities. This indicator is applicable to crops only and relies on the calculations described in section and 3.1.1.8.
- Fuel use: the equivalent litres of diesel for transportation saved based on the total avoided food loss quantities. When Tuna is selected as a commodity in the tool, the avoided fuel use also covers the fuel quantities from transport during Tuna fishing.

4.5 Upstream orphaned losses

An additional indicator in the tool are the orphaned losses. These losses refer to the cumulative avoided upstream losses from an intervention project reducing food loss rates.

The main climate impacts from the tool represent the upstream emissions based on the quantity of avoided food losses at the supply chain stage where an intervention project takes place. Nonetheless, these avoided food losses imply that a higher quantity was avoided upstream because of the waste occurring at each stage. These additional and cumulative upstream avoided losses are referred to a orphaned losses.

To calculate these, the quantity of avoided food loss at the project stage is uplifted based on the waste rates of the respective upstream stages. Their associated emissions are calculated and summed based on those quantities, and include not only the emissions from the avoided processing / storage / transport / production, but also from the avoided landfill emissions at each of those stages.

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FAO, Food Balance Sheets – A handbook. FOOD BALANCE SHEETS - A Handbook

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6. ANNEX

6.1 Taxonomy

Table 4: Supply chain stages classification

FAO supply chain	Tool supply chain	Data points
Pre-Harvest	N/A	3
Harvest	N/A	385
Producer	Production	1,387
Processing	N/A	72
Stacking	N/A	5
Storage	Storage	661
Distribution	Transport	3
Transport	Transport	257
Wholesale	N/A	302
Traders	N/A	41
Export	N/A	31
Retail	N/A	126
Consumer	N/A	1
Total Supply Chain	N/A	5,553

Table 5: Commodity classification

FAO Commodity	Tool Commodity
Apple	Apples
apples	Apples
Avocados	Avocados
Banana	Bananas
bananas	Bananas
Barley	Barley
Beans	Beans (dry)
beans, dry	Beans (dry)
Beans, Green	Beans (dry)
Beans, Red	Beans (dry)
Carrot	Carrots
Carrots	Carrots
carrots and turnips	Carrots
Cashew	Cashew nuts
cashew nuts, in shell	Cashew nuts
cassava, fresh	Cassava
Chillies And Peppers	Peppers
chillies and peppers, green (capsicum spp. and pimenta spp.)	Peppers
Cocoa Beans	Cocoa
coffee, green	Coffee
Common Beans	Beans (dry)
Dry bean	Beans (dry)
edible offal of cattle, fresh, chilled or frozen	Meat (cattle)
edible offal of pigs, fresh, chilled or frozen	Meat (pig)
Eggs	Eggs
Fluid Milk	Milk (cattle)
Grape	Grapes

FAO Commodity	Tool Commodity
grapes	Grapes
Green bean	Beans (dry)
green corn (maize)	Maize
Green lentil	Lentils
hen eggs in shell, fresh	Eggs
Lentils	Lentils
lentils, dry	Lentils
Maize	Maize
Maize (Corn)	Maize
Maize (Corn) White	Maize
Maize (Corn, White)	Maize
Maize (Corn, Yellow)	Maize
Mangoes	Mangoes
Mangoes, Guavas, Mangosteens	Mangoes
Mangoes, Oranges, Pineapples And Lime	Mangoes
Meat	Meat (cattle)
meat of cattle with the bone, fresh or chilled	Meat (cattle)
Meat Of Cattle, Fresh Or Chilled	Meat (cattle)
Meat Of Chickens, Fresh Or Chilled	Meat (chicken)
meat of pig with the bone, fresh or chilled	Meat (pig)
Meat Of Pig, Fresh Or Chilled	Meat (pig)
Milk	Milk (cattle)
Milk, Cow	Milk (cattle)
onions and shallots, dry (excluding dehydrated)	Onions and shallots
onions and shallots, green	Onions and shallots
Orange	Oranges
Oranges	Oranges
other beans, green	Beans (dry)
Paddy Rice	Rice
Pepper	Peppers
pepper (piper spp.), raw	Peppers
Pepper, Bell	Peppers
Pepper, Chinese Hot	Peppers
Pepper, Sweet	Peppers
Peppers	Peppers
Potato	Potatoes
Potatoes	Potatoes
raw milk of cattle	Milk (cattle)
Red lentil	Lentils
Rice	Rice
sesame seed	Sesame seed
Sorghum	Sorghum
soya beans	Soybeans
sugar cane	Sugar cane
sunflower seed	Sunflower seeds
Sweet potatoes	Sweet potatoes
Tomato	Tomatoes
Tomatoes	Tomatoes
Tomatoes, green	Tomatoes
wheat	Wheat
Wheat (Durum)	Wheat

Table 6: Commodity and commodity group classification

Tool Commodity	Tool Commodity Group	FAO Commodity Group
Apples	Fruits	Fruits and vegetables
Avocados	Fruits	Fruits and vegetables
Bananas	Fruits	Fruits and vegetables
Barley	Pulses & Grains	Cereals
Beans (dry)	Pulses & Grains	Oilseeds and pulses
Carrots	Tubers/Root Crops	Roots and tubers
Cashew nuts	Nuts/Seeds	Oilseeds and pulses
Cassava	Tubers/Root Crops	Roots and tubers
Cocoa	Nuts/Seeds	Oilseeds and pulses
Coffee	Nuts/Seeds	Oilseeds and pulses
Cotton	N/A	N/A
Eggs	N/A	N/A
Flour	N/A	N/A
Grapes	Fruits	Fruits and vegetables
Lentils	Pulses & Grains	Oilseeds and pulses
Maize	Pulses & Grains	Cereals
Mangoes	Fruits	Fruits and vegetables
Meat (cattle)	Animal Protein	Meat
Meat (chicken)	Animal Protein	Meat
Meat (pig)	Animal Protein	Meat
Milk (cattle)	Animal Protein	Milk
Onions (dry)	Tubers/Root Crops	Roots and tubers
Oranges	Fruits	Fruits and vegetables
Peppers	Vegetables	Fruits and vegetables
Potatoes	Tubers/Root Crops	Roots and tubers
Sweet potatoes	Tubers/Root Crops	Roots and tubers
Rice	Pulses & Grains	Cereals
Sesame seed	Nuts/Seeds	Oilseeds and pulses
Sorghum	Pulses & Grains	Cereals
Soybeans	Pulses & Grains	Oilseeds and pulses
Sugar cane	Tubers/Root Crops	Roots and tubers
Sunflower seeds	Nuts/Seeds	Oilseeds and pulses
Tomatoes	Fruits	Fruits and vegetables
Wheat	Pulses & Grains	Cereals

Table 7: Region classification

Tool Region	UN region	FAO region
Oceania	Australia and New Zealand	North America and Oceania
Europe and Central Asia	Central Asia	North Africa, West and Central Asia
East Asia and Pacific	Eastern Asia	Industrialized Asia
Europe and Central Asia	Eastern Europe	Europe (incl. Russia)
Latin America and Caribbean	Latin America and the Caribbean	Latin America
East Asia and Pacific	Melanesia	North America and Oceania
Middle East and North Africa	Northern Africa	North Africa, West and Central Asia
North America	Northern America	North America and Oceania
Western Europe	Northern Europe	Europe (incl. Russia)
East Asia and Pacific	South-eastern Asia	South and Southeast Asia
South Asia	Southern Asia	South and Southeast Asia
Western Europe	Southern Europe	Europe (incl. Russia)
Africa	Sub-Saharan Africa	Sub-Saharan Africa
Europe and Central Asia	Western Asia	North Africa, West and Central Asia
Western Europe	Western Europe	Europe (incl. Russia)

6.2 Tool Decision Process

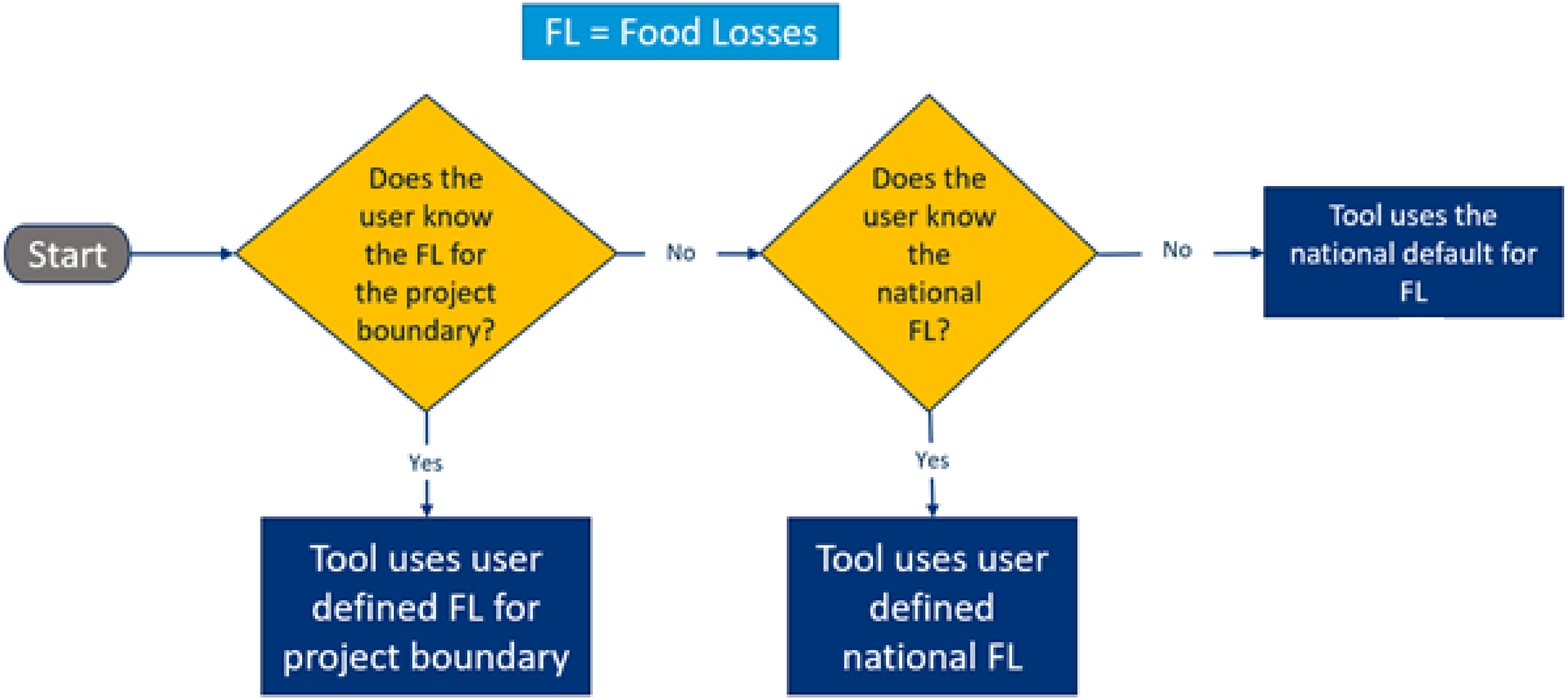

Figure 8. Tool decision process - Food losses

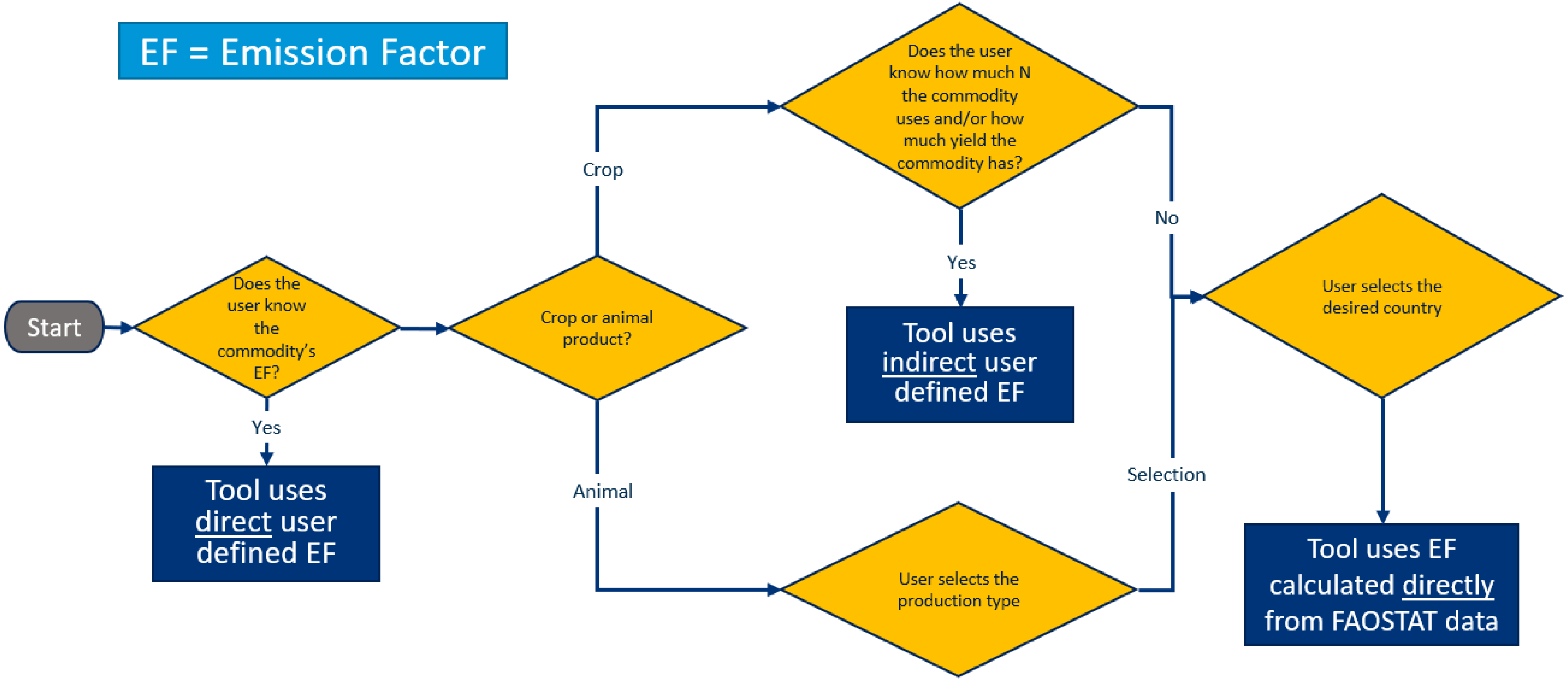

Figure 15. Tool decision process – Emission Factor

6.3 VBA code

The main purpose of the VBA code embedded within the Excel Workbook is to support user data entry with the display and updating of default values. The core code is associated with the '(Sheet1) Interface' tab and the module 'userData'.

There is a module 'nResponse' which implements checking that user N and yield inputs are reasonable, but in practice this is done in Excel on the NitrogenEmissions tab. The VBA code is retained in case problems arise with inter-dependent Excel calculations.

Any reference to cells within Excel is done through Names, to avoid fragility due to data moving location. In addition, VBA's error handling is used typically to ignore errors and continue with processing. This approach is used because the main source of errors is the removal or changing of a Name (in which case processing of the old name erroneously retained in VBA is no longer needed anyway) and the aim is to retain a functioning tool for the user.

Within the 'Interface' tab's code, there are broadly two sets of functions:

i. The in-built Sub 'Worksheet_Change' is extended to respond selectively depending upon which data input option the user has changed

ii. A set of custom subroutines (Subs) that handle specific actions (there are comments in the code describing their purpose and operation)

The 'userData' module contains some re-usable arrays (or lists) of Excel Ranges, defined by their Names, so they can be processed quickly and repeatably. For example, the array advancedRanges contains all the cells in the advanced input section of the Interface tab. It may be used to clear the content of these cells (using the resetAdvanced Sub) amongst other things. The arrays are configured when the Workbook is opened (relying upon the in-built Sub Workbook_Open).

A useful side-note is that when the code wants to make changes to other cells, in response to user input (e.g. clearing content or updating defaults), Excel is temporarily configured to stop responding to changes. This prevents knock-on loops of changes causing other changes, which slow the tool down and possibly leads to Excel crashing. The calls to Application.EnableEvents control this feature.

6.4 Alternative approaches considered

In this section some of assumptions used for calculating greenhouse gases from crops will be discussed. Here also previous methodologies that were considered will be discussed and why they were not selected in the end.

- Initially, FAOSTAT Rice emissions category was included in addition to the rest of the agricultural emissions categories. Emissions from Rice was a distinct agricultural emissions category provided by FAO. In addition, rice production techniques can be significantly different from country to country and in extent the emissions associated with it. In order to reduce error in the tool, rice production and its specific emissions were isolated and analysed separately. This allowed greater granularity for rice as an important crop. Finally, the rest of the 27 crops were analysed by themselves as there was no distinction in the broad agricultural emissions categories provided by FAO.
- FAOSTAT Burning Savanna emission category was originally included with the rest of the FAO agricultural emission categories ("Burning crop residues", "Crop Residues", "Cultivation of Organic Soils", "Manure applied to Soils" and "Synthetic Fertilizers"). In the case of some countries (mainly in the Africa region) this increased the aggregated emissions by a factor of 10. More information was sought from FAO which clarified that Burning Savanna accounts for the controlled combustion of grasslands and pasture management techniques. Therefore, it was more suited for livestock emissions than crops and was disregarded from further analysis in regards to crops.
- To minimise FAO emissions error, a 5-year average was calculated in order to compensate for any errors attributed to weather or data collection related impacts. However, the 5-year average emissions were almost identical to the latest year. Upon communication with FAO it was discovered that FAO faced real difficulties to get data from most countries regarding emissions, especially developing ones. So, they are using an algorithm to create yearly emissions based on older data scaled for production of the same year. For some of the countries that baseline data might be 10-20 years back. Therefore, any average we might calculate over many years it will always produce the exact same number.
- Besides FAO different sources were sought to pull reliable data for emissions and production. Alternative sources were the United Nations, the World Resource Institute and various individual research papers. However, these sources were not updated regularly for all the target countries and the target crops. FAO was the only source that not only updated its database on an annual basis, but also made assumptions for the missing data providing a full database. It is believed that the FAO database will allow the IFC tool the biggest future adaptability.

Some reliability indicators were developed in order to compare the devised methodologies:

- All of the above methodologies' results were compared to each other and to the results of the previous "IFC Crop GHG Calculator".[58]
- Each country's emissions were calculated bottom up by adding all the emissions from all crops. Emissions for each target crop were calculated by multiplying each crop's production with its modelled emission factor. For non-target crops the country's "average emission factor per crop" was assumed. Then this bottom-up total country emissions were compared to the FAOSTAT top-down total country emissions. The methodology that produced the best results, by being closer to the FAOSTAT data was the methodology that was chosen in the end.
- Finally, no correlation was seen between the percentage of target crops compared to the total crop production in target countries and the difference between modelled emissions and FAOSTAT emission.

[58] The previous IFC Crop GHG Calculator (2018) only focused on greenhouse gas emission factors and did not take into consideration Food Loss. It also had a limited scope of countries, as well as target crops. In addition, the only animal protein that was included was milk. In many ways, it was the precursor to "IFC GHG Food Loss Calculator" (2020). Therefore, the results from both versions of the tool were compared to check for discrepancies.

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