International Center for Tropical Agriculture
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CLEANED X Version 2.0.1

The CLEANED Excel tool to assess the environmental impacts of livestock production systems

TECHNICAL MANUAL AND USER GUIDE

Jessica Mukiri, An Notenbaert, Rein Van der Hoek, Celine Birnholz

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CGIAR
RESEARCH PROGRAM ON
Livestock

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Contents

Acronym list

AME	Adult Male equivalent
α	alpha
NH_3	Ammonia
Bha	Baseline hectare
β	Beta
BD	Bulk density
Cl	calving interval
CO_2e	Carbon dioxide equivalent
CLEANED	Comprehensive Livestock Environmental Assessment for Improved Nutrition, a Secured Environment and Sustainable Development along Livestock and Fish Value Chains
CP	Crude Protein
DE	Digestible Energy
DM	Dry Matter
EF	Emission Factor
ET	Evapotranspiration
FPCM	Fat-Protein Corrected Milk
ft.	Feet
FAO	Food and Agriculture Organization
GWP	Global Warming Potential
GHG	Green House Gas
GE	Gross Energy
ha	hectare
IPCC	Intergovernmental Panel on Climate Change
kcal	kilocalorie
Kg	Kilogram
Km	Kilometre
LWG	Live Weight Gain
MJ	Mega joule
ME	Metabolizable Energy
MP	Metabolizable Protein
CH_4	Methane
m	metre
mm	millimetre
NPV	Net present value
N	Nitrogen
N_2O	nitrous oxide
NUTMON	Nutrient monitoring
PC	Protein content
ROI	Return on investment
SD	Soil depth
SOC	Soil Organic Carbon
t	Time
TVP	Total value of production
USD	United States Dollar
UE	Urinary Energy

1 Preface

The production of livestock products has heavily influenced how we utilize land and an important avenue for livelihoods across our planet. However, the sector utilizes a big portion of our natural resources and causes negative environmental impacts such as land degradation, air and water pollution, greenhouse gas emissions and the decline in biodiversity. It is thus important to design sustainable livestock systems that work for people, communities and the planet.

The purpose of this user guide and manual is to show and demonstrate how **CLEANED** works and the calculation behind the assessments. This is a model which assess several environmental impacts of livestock enterprises along a value chain. The model is a culmination of work over several years from experts across different disciplines and organizations and initial funding from **CLEANED** LVCs project funded by the Bill and Melinda Gate Foundation (DCE23232) and further supported by the BBSRC (BB/L026503/1) and the CGIAR Research Program on Livestock. We would like to thank partners and colleagues at Commonwealth Scientific and Industrial Research Organization (CSIRO), International Livestock Research Institute (ILRI) and Stockholm Environment Institute (SEI) who were fundamental in developing **CLEANED**.

After reading this document you should be familiar with how **CLEANED** works and be able to carry out your own assessments on livestock enterprises. You will also have the general knowledge of the workings of the model and the calculations behind it.

What the this manual and user covers

This document is divided into five parts:

1. **Overview:** This explains the limitations and boundaries of the assessments
2. **Inputs sheet:** Which is a step by step guide on what data you will require to carry out and assessment
3. **Result sheets:** These give an overview of the quantified results across different multiple environmental impacts
4. **Parameter sheets:** This highlights the different parameters that are needed to meet the requirements for the specific livestock enterprise you are modeling
5. **Calculations:** You are given a walk through on the background calculations needed to carry out the ex-ante assessment

What you need for this manual and user guide

CLEANED is an open access model and can be downloaded from here https://doi.org/10.7910/DVN/G0G8IY. This model was developed with Microsoft Excel, Version: 2016. For this reason, users must have Microsoft Excel, Version: 2016 or 2019 to be able to run it. Please note with older versions this model will not work to its full capability.

Who are the users

This guide is intended to those who wish to carry out environmental impacts assessments on livestock enterprises using **CLEANED**, this includes but not limited to policy makers, research scientist and project managers.

Application of the model

The tool has been used on different livestock enterprises in different regions, Kenya, Tanzania and Nicaragua.

Osele V; Paul B; Mukiri J; Halder S; Sagala T; Juma A; Notenbaert A. 2018. Feeding a productive dairy cow in western Kenya: environmental and socio-economic impacts. Working Paper. CIAT Publication No. 472. International Center for Tropical Agriculture (CIAT). Nairobi, Kenya. 48 p. Available at: https://hdl.handle.net/10568/97557

Hoek, R. van der., Birnholz, C. and Notenbaert A.M.O. 2016. Using the CLEANED approach to assess environmental impacts in the dual-purpose cattle value chain in Nicaragua. Livestock and Fish Brief 20. Nairobi: handle: 10568/78473 http://hdl.handle.net/10568/78473

Notenbaert, A.M.O., Morris, J., Pfeifer, C., Paul, B., Birnholz, C., Fraval, S., Lannerstad, M., Herrero, M. and Omore, A.O. 2016. Using the CLEANED approach to assess environmental impacts in the dairy value chain in Tanga, Tanzania. Livestock and Fish Brief 21. Nairobi handle: 10568/78475 http://hdl.handle.net/10568/78475

Conventions

In this document, you will find a number of text styles that distinguish between different kinds of information. Here are some examples of these styles and an explanation of their meaning.

- When referring to the model " " will be used e.g "Inputs" sheet.
- When presented with ➡ **IMPORTANT NOTE:** short guidance on what no to do.
- All equations are in italics

Errata

Even though we have taken great care to ensure our material is correct, mistakes do happen. If you notice a mistake in this document, we would be grateful if you could report it to us.

To this email address: j.mukiri@cgiar.org

2 Overview

CLEANED is a static based model which assess multiple environmental impacts (Figure 3) of a livestock enterprises on an annual basis. **CLEANED** was developed on Microsoft excel 2016 and implemented as an excel work book. The model is used to carry out rapid ex-ante impact assessments with the data input requirements kept to a minimum. To read more on the framework behind **CLEANED** you can read the following[1].

The boundary for assessment extends to all the inputs needed to sustain the livestock enterprise but not the whole farm,Figure 1. This includes the area and other inputs used for feed grown for feeding the livestock, including crops whose residues are fed. It does not include the whole farm area or crops grown on the farm that are not fed to the animals Figure 2.

➡ **IMPORTANT NOTE:** this model, models livestock enterprise for ruminants.

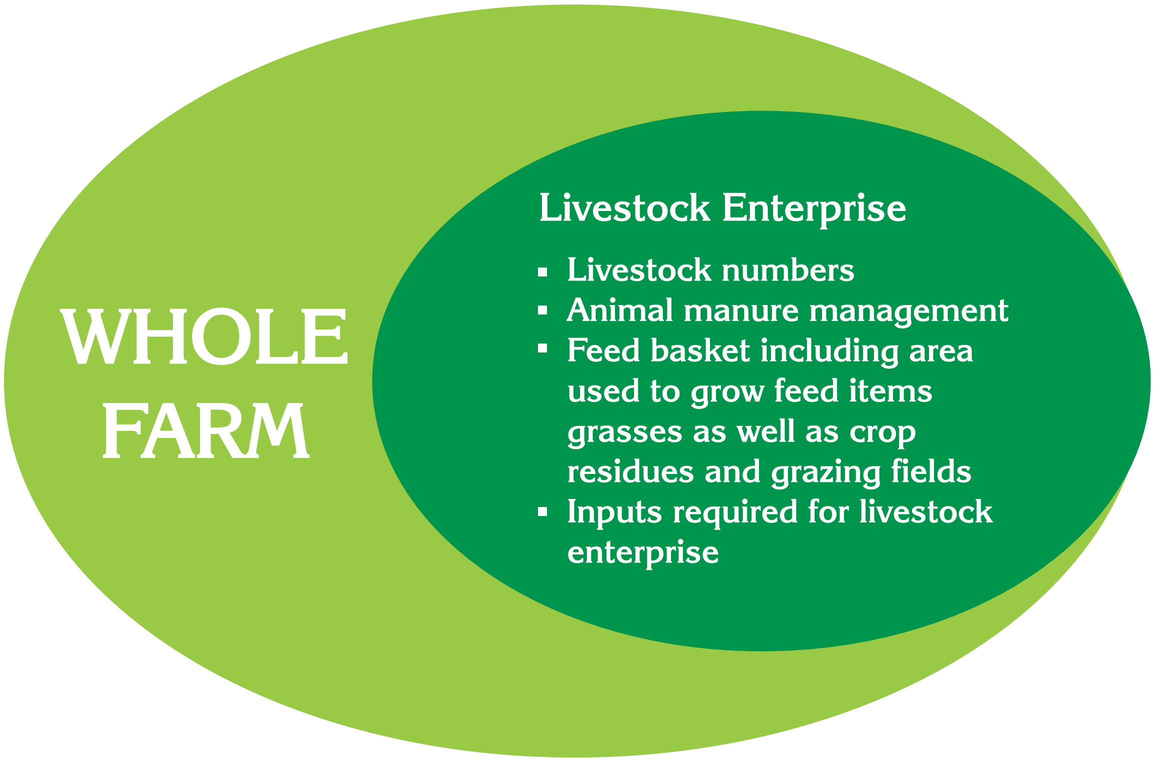


***Figure 1**: Boundary for assessing a livestock enterprise*

1 Notenbaert A., Lannerstad M., Herrero M., Fraval S., Ran Y., Paul B., Mugatha S., Barron J., Morris J. (2014). A framework for environmental ex-ante impact assessment of livestock value chains, 6th All Africa Conference on Animal Agriculture, Nairobi, Kenya, 26-30 October 2014. handle: 10568/56664 http://hdl.handle.net/10568/56664

Figure 2: *Marinana Ruffino (2004), example of a livestock enterprise*

Based on the “minimum data entry”, the tool calculates the environmental footprint of a livestock enterprise, in terms of:

- The area of land required for feed production
- Productivity
- Economics
- Soil impacts:
  - Erosion
  - N balance
- GHG emissions
- Water Impacts

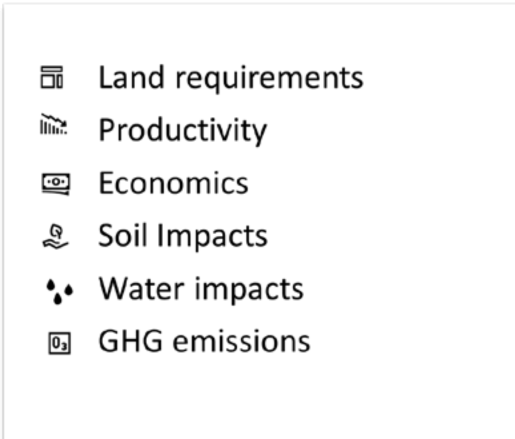


Figure 3: *Multiple impact pathways assessed in CLEANED*

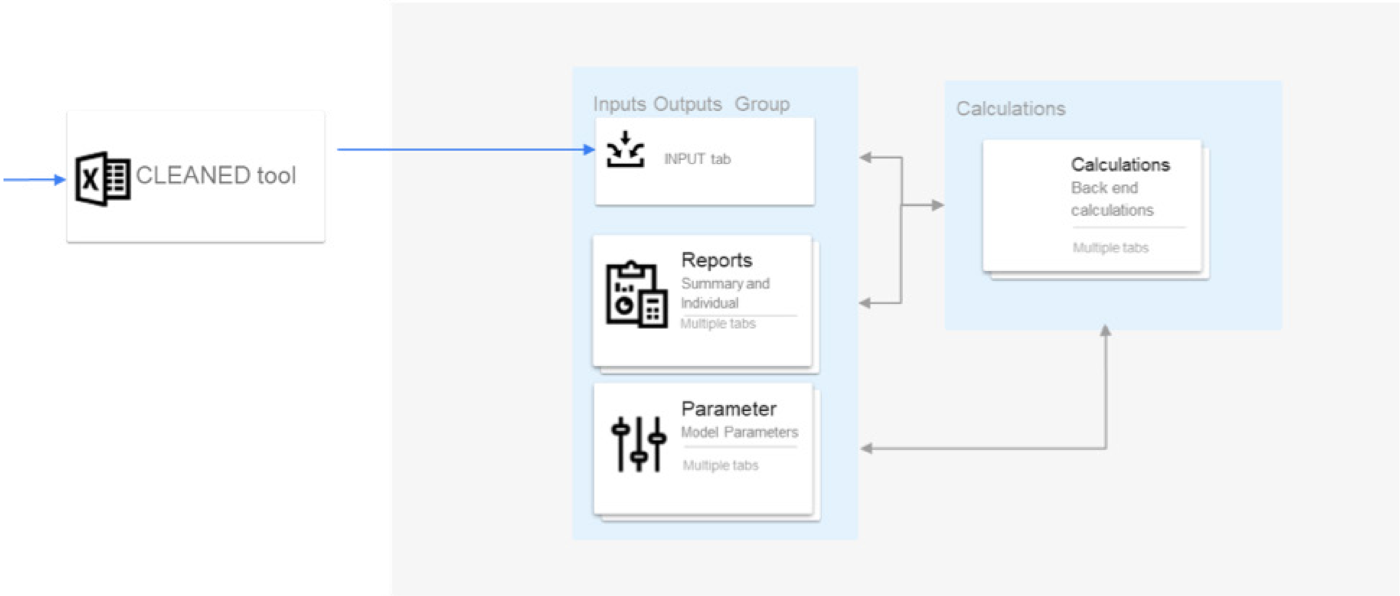


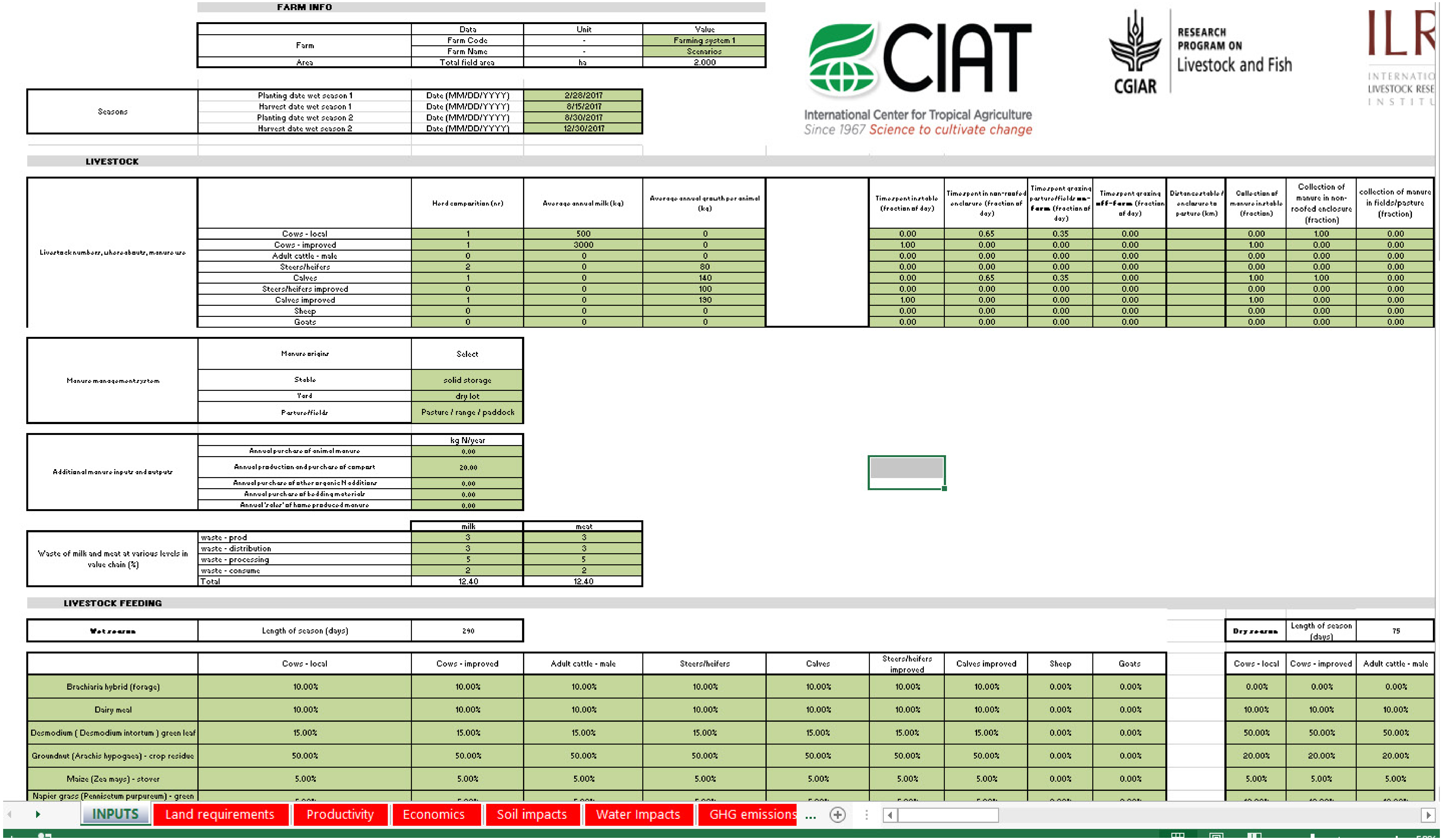
Figure 4: *Architecture of CLEANED*

Figure 4 gives the architecture of the model, Figure 5 and Figure 6 shows structure of the model as seen in excel:

- The first sheet — the blue one — is the sheet where you provide your input data, i.e. the description of the livestock enterprise.
- The next seven sheets — the red ones — are the results sheets:
  - The first six give you detailed results in terms of (i) land requirements, (ii) productivity, (iii) economics, (iv) soil impacts, (v) GHG emissions and (vi) water impacts
  - The last one gives you a quick overview or summary of all results
- The eight grey sheets contain the parameters. These are only to be accessed by more advanced users, e.g. for setting up the model for use in a different region
- The fifteen green sheets are where the calculations are implemented; they are not intended to be altered by users, they are only provided for expert users who wish to understand exactly how the impacts are being calculated.

The user must first construct the livestock enterprise based on the input data required which will be further discussed in section 4. The model works by first putting in data for a baseline livestock enterprise that you are assessing. After which the excel model automatically calculates environmental, climate and economic impacts. The user can explore the results on the red results sheets.

CLEANED is meant for users to assess how these impacts would change through the introduction of a new technology or an altered livestock production configuration. In order to do so, the user first presses the “save baseline” button which saves the baseline input. The user can then change input values and add economic information needed discussed in section 4 and compare the new output with the baseline values. To run more scenarios, the user can run the scenario manager discussed in section 4.



FARM INFO

	Data	Unit	Value
Farm	Farm Code	-	Farming system 1
	Farm Name	-	Scenarios
Area	Total field area	ha	2.000

Seasons	Planting date wet season 1	Date (MM/DD/YYYY)	2/28/2017
	Harvest date wet season 1	Date (MM/DD/YYYY)	6/15/2017
	Planting date wet season 2	Date (MM/DD/YYYY)	8/30/2017
	Harvest date wet season 2	Date (MM/DD/YYYY)	12/30/2017

LIVESTOCK

Livestock numbers, whereabouts, manure use		Herd comparition (nr)	Average annual milk (kg)	Average annual growth per animal (kg)		Time spent in stable (fraction of day)	Time spent in non-roofed enclosure (fraction of day)	Time spent grazing pastures/fields on-farm (fraction of day)	Time spent grazing off-farm (fraction of day)	Distance stable / enclosure to pasture (km)	Collection of manure in stable (fraction)	Collection of manure in non-roofed enclosure (fraction)	collection of manure in fields/pasture (fraction)
	Cows - local	1	500	0		0.00	0.65	0.35	0.00		0.00	1.00	0.00
	Cows - improved	1	3000	0		1.00	0.00	0.00	0.00		1.00	0.00	0.00
	Adult cattle - male	0	0	0		0.00	0.00	0.00	0.00		0.00	0.00	0.00
	Steers/heifers	2	0	80		0.00	0.00	0.00	0.00		0.00	0.00	0.00
	Calves	1	0	140		0.00	0.65	0.35	0.00		1.00	1.00	0.00
	Steers/heifers improved	0	0	100		0.00	0.00	0.00	0.00		0.00	0.00	0.00
	Calves improved	1	0	190		1.00	0.00	0.00	0.00		1.00	0.00	0.00
	Sheep	0	0	0		0.00	0.00	0.00	0.00		0.00	0.00	0.00
	Goats	0	0	0		0.00	0.00	0.00	0.00		0.00	0.00	0.00

Manure management system	Manure origins	Select
	Stable	solid storage
	Yard	dry lot
	Pastures/fields	Pasture / range / paddock

Additional manure inputs and outputs		kg N/year
	Annual purchase of animal manure	0.00
	Annual production and purchase of compost	20.00
	Annual purchase of other organic N additions	0.00
	Annual purchase of bedding materials	0.00
	Annual 'sales' of home produced manure	0.00

		milk	meat
Waste of milk and meat at various levels in value chain (%)	waste - prod	3	3
	waste - distribution	3	3
	waste - processing	5	5
	waste - consume	2	2
	Total	12.40	12.40

LIVESTOCK FEEDING

Wet season	Length of season (days)	290

	Cows - local	Cows - improved	Adult cattle - male	Steers/heifers	Calves	Steers/heifers improved	Calves improved	Sheep	Goats
Brachiaria hybrid (forage)	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	0.00%	0.00%
Dairy meal	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	0.00%	0.00%
Desmodium (Desmodium intortum) green leaf	15.00%	15.00%	15.00%	15.00%	15.00%	15.00%	15.00%	0.00%	0.00%
Groundnut (Arachis hypogaea) - crop residue	50.00%	50.00%	50.00%	50.00%	50.00%	50.00%	50.00%	0.00%	0.00%
Maize (Zea mays) - stover	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	0.00%	0.00%
Napier grass (Pennisetum purpureum) - green	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Dry season	Length of season (days)	75

	Cows - local	Cows - improved	Adult cattle - male
Brachiaria hybrid (forage)	0.00%	0.00%	0.00%
Dairy meal	10.00%	10.00%	10.00%
Desmodium (Desmodium intortum) green leaf	50.00%	50.00%	50.00%
Groundnut (Arachis hypogaea) - crop residue	20.00%	20.00%	20.00%
Maize (Zea mays) - stover	5.00%	5.00%	5.00%
Napier grass (Pennisetum purpureum) - green	[illegible]	[illegible]	[illegible]

Figure 5: The inputs sheet

EXTRA COST (only to fill for "scenarios", i.e. change from current situation/baseline)

Additional cost for baseline herd	herd size	Extra one-off cost (USD/animal)	Extra operational cost USD/animal/year	Extra labour - one-off (days/animal)	Extra labour (days /animal/year)	Description
Dairy cows - local	0					
Dairy cows - improved	1	0	0	0	0	no change
Adult cattle - male	1	0	0	0	0	no change
Steers/heifers	0					
Calves	1	0	0	0	0	no change
Sheep	0					
Goats	0					
Pigs	0					
Poultry	0					
Donkeys/horses	0					

Additional cost for new herd	herd size	Extra one-off cost (USD/animal)	Extra operational cost USD/animal/year	Extra labour - one-off (days/animal)	Extra labour (days /animal/year)	Description
Dairy cows - local	*0*					
Dairy cows - improved	*1*	200	50	1	12	
Adult cattle - male	*1*	0	50	1	12	
Steers/heifers	*0*					
Calves	*1*	0	20	1	12	
Sheep	*0*					
Goats	*0*					
Pigs	*0*					
Poultry	*0*					
Donkeys/horses	*0*					

Additional cost for already existing feed items	Extra hectares	Extra one-off / establishment cost (USD/ha)	Operational Cost (USD/ha/year)	Extra labour - one-off (days/ha)	Extra labour (days /ha/year)	Description
Naturally occuring pasture - green fodder	1.99	0	0	0	0	
Maize (Zea mays) - stover	0.78	0	0	0	10	
Napier grass (Pennisetum purpureum) - green fodder	0.05					
Maize (Zea mays) - cobs ground	0.00					
Cotton (Gossypium sp.) - seed meal	0.00					
Sunflower (Helianthus annuus) - seed cake	0.00					
	0.00					

Additional cost for new feed items	Hectares	Extra one-off / establishment cost (USD/ha)	Operational Cost (USD/ha/year)	Extra labour - one-off (days/ha)	Extra labour (days /ha/year)	Description
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
Red clover (Trifolium pratense) - hay	0.19	10	5	2	0	

Other additional costs					
other	Extra one-off / establishment cost (USD/ha)	Operational Cost (USD/ha/year)	Extra labour - one-off (days/item)	Extra labour (days /item/year)	Description
extra stable	100				

Figure 6: *The additional input data required to calculate the economic cost or benefits of intervention scenarios*

3 Inputs sheet

Introduction

The “inputs” sheet is where you, as a user, describe the current livestock keeping practice. This description covers (i) the agro-ecological context, (ii) the livestock herd, (iii) livestock feeding practices, and (iv) how the feed items are produced. At the end of the sheet, users are required to provide information on the extra cost associated with an intervention scenario (this is only required when evaluating costs for new interventions). This is needed to calculate the economic cost/benefit indicators.

As mentioned in section 2 the model is limited to the livestock enterprise only. E.g. it will not be necessary to input any data on the fruits or vegetables that are grown on the farm but not fed to the animals.

For each of the sub-sections, you are asked to fill a number of tables with specific values for a variety of different characteristics. You only have to fill the cells that are shaded in pale green. If the cell is white, the value is calculated on the basis of values you have provided in the parameters.

The livestock enterprise data provided in this sheet can be a real farm observation or the description of a typical or average livestock enterprise. In the latter case, data can be sourced from querying farm-level surveys or expert opinion.

FARM INFO

	Data	Unit	Value
Farm	Farm Code	-	Farming system 1
	Farm Name	-	Scenarios
Area	Total field area	ha	2.065

Seasons	Planting date wet season 1	Date (MM/DD/YYYY)	2/28/2017
	Harvest date wet season 1	Date (MM/DD/YYYY)	8/15/2017
	Planting date wet season 2	Date (MM/DD/YYYY)	8/30/2017
	Harvest date wet season 2	Date (MM/DD/YYYY)	12/30/2017

Figure 7: *CLEANED Farm Info and Agro ecological info*

Farm info

Before getting into the description, you are asked for a farm code and a farm name.

You are then asked to specify the start and the end of up to two plant growing seasons or “wet seasons” Figure 7. This is the basis for calculating season length[2]:

- **Planting date long rain:** the day of the year when planting starts in the first wet season
- **Harvest date long rain:** the day of the year when harvesting starts in the first wet season
- **Planting date short rain:** the day of the year when planting starts in the first wet season
- **Harvest date short rain:** the day of the year when harvesting starts in the first wet season

2 Planting date is based on the period in which the animals are feed a wet season basket and a dry season basket

Livestock

LIVESTOCK

		Herd composition (nr)	Average annual milk production per animal (kg)	Livestock leaving the farm (nr/year)		Time spent in stable (fraction of day)	Time spent in yard (fraction of day)	Time spent gra[…] pasture/fields […] Farm (fractio[…] day)
Livestock numbers, whereabouts, manure use	Dairy cows - local	0	0.00			0.00	0.00	0.00
	Dairy cows - improved	2	1400.00			1.00	0.00	0.00
	Adult cattle - male	2	0.00			1.00	0.00	0.00
	Steers/heifers	0	0.00	1		0.00	0.00	0.00
	Calves	2	0.00			1.00	0.00	0.00
	Sheep	0	0.00			0.00	0.00	0.00
	Goats	0	0.00			0.00	0.00	0.00
	Pigs	0	0.00			0.00	0.00	0.00
	Poultry	0	0.00			0.00	0.00	0.00
	Donkeys/horses	0	0.00			0.00	0.00	0.00

Manure management system	Manure origins	Select
	Stable	Solid storage
	Yard	Solid storage
	Pasture/fields	Pasture/range/paddock

Additional manure inputs and outputs		kg N/year
	Annual purchase of animal manure	0.00
	Annual purchase of compost	0.00
	Annual purchase of other organic N additions	0.00
	Annual purchase of bedding materials	
	Annual 'sales' of home produced manure	0.00

Waste of milk at various levels in value chain (%)	waste - milk prod	6.5
	waste - distribution	0.55
	waste - processing	1.5
	waste - consume	1.32
	Total	9.62

Figure 8: *Livestock information required*

In this section (Figure 8) you are asked to provide a wide array of information about the livestock herd; from livestock numbers, meat and milk production and their where-about up to the management of the manure. The feeding practices are, however, included in a separate section.

The first table "Livestock numbers, whereabouts, manure use" has a separate line for each of the pre-defined livestock types: local dairy cows, improved dairy cows, adult male cattle, steers/heifers, calves, sheep, goats and pigs.

For each of these types, you are asked to provide values for:

- **Herd composition:** the number of animals in this category
- **Annual milk production:** the total annual milk production (taking into account variances due to lactation period, etc.). This information is only provided for the relevant livestock types (e.g. not for the calves or the male cattle)
- The next four columns solicit information about the whereabouts of the animals. This information is used in the GHG emission calculations. All times are expressed as "fractions". E.g. if half a day is typically spent in the stable, the value listed under "time spent in the stable" should be 0.5. This number is an annual average across wet and dry seasons. The total time spent should add up to 1:
  - **Time spent in the stable:** the fraction of the day that an animal of this type normally spends inside a stable; a stable is any structure where there is some form of closed space, and where the manure that is produced by the livestock remains away until it is collected and displaced.
  - **Time spent in yard:** a yard is therein defined as an enclosure or tethering area not too far from the house where the manure produced in that area is subject to the elements.
  - Time spent grazing on-farm pasture or stubble/residue on an on-farm crop field.
  - **Time spent grazing off-farm:** the value in this column is calculated from the values you have input in the previous three columns. It is assumed that all time not spent in the stable, the yard or grazing on-farm, is spent grazing off-farm.

- **Distance stable/enclosure to pasture (km):** average distance between stable /enclosure and grazing grounds. This should be set to zero if no time is spent grazing.
- The next set of columns is about manure, i.e. (i) how much is collected and (ii) how much of the collected manure is used to fertilize crops. Again, the input is not required in absolute figures but in fractions. In this case, the fractions do not need to add up until 1 across types but can be between 0 and 1 for each type.
  - **Collection of manure in stable:** which fraction of the manure that is produced in the stable is collected vs. left on the floor.
  - **Collection of manure in yard:** which fraction of the manure produced in the yard is collected vs. left on the soi.l
  - **Collection of manure in on-farm fields/pasture:** which fraction of the manure produced in the field or on the pasture is collected vs. left on the soil.
  - **On-farm manure used as fertilizer:** Here you are asked to indicate which fraction of the collected manure is used as fertilizer (vs. other uses such as fuel or building material).

In the manure management system table, you are asked to specify the manure management system for the manure collected from (i) stable, (ii) yard and (iii) pastures/fields. You can pick from a drop-down list; the choices include:

- **Solid storage:** The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure can be stacked due to the presence of sufficient bedding material or loss of moisture by evaporation.
- **Dry lot:** A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically.
- **Pasture/range/paddock:** The manure from pasture and grazing animals is just deposited and not managed.

In the next table, the last set of information about manure and other organic inputs is been requested:

- **Annual purchase of animal manure:** if manure is bought, indicate here how much. This is expressed in kg N/year[3].
- **Annual purchase of compost:** if compost is bought, indicate here how much. This is expressed in kg N/year.
- **Annual purchase of other organic N additions:** if any other organic sources of N are bought, indicate here how much in kg N/year.
- **Annual purchase of bedding materials:** if bedding materials such as straw are bought, please indicate the amount in kg N/year.
- **Annual "sales" of home-produced manure:** If manure leaves the farm, either through sale or gift, please indicate the amount in kg N/year.

The last table in this section indicates global milk and meat wastes/losses in the various value chain components (in percentages)

- waste/losses –production
- waste/losses – distribution
- waste/losses – processing
- waste/losses – consumption
- Total: total waste/losses along the value chain

3 Manure contains roughly 3% of N

Livestock feeding

In this section (Figure 9), a fairly detailed description of the feed baskets for each of the livestock types is required. Differentiation is made between wet and dry season feed baskets. Feed baskets are described in terms of their composition, i.e. the different feed items that are fed to the animals and the percentage of each feed item of the total feed basket.

The feed basket that you are required to describe first is the one for the wet season. The wet season is defined based on the planting and harvesting dates you provided above. The rest of the year is considered to be dry season. The wet season feed baskets for the different livestock types are listed on the left—column C to K; the dry season feed baskets on the right—columns M to U.

You start by selecting up to a total of seven different feed items over a period of one year. You simply pick the relevant ones from the drop-down lists that are found just below the sub title “Wet season” in column B. If a feed item is missing in the dropdown list given, the user may proceed to feed parameters sheet and replace the new item with another feed item which is of no interest in the livestock enterprise.[4]

In the cell under the selected feed item, you indicate the percentage of the total feed basket that is made up by this feed item. This percentage is in terms of” as fed”/fresh weights. Make sure the percentages add up to 100%.

➡ **IMPORTANT NOTE:** You should list all feed items that are used on the farm; independent of livestock type or season. The list of items selected in the wet season basket for local dairy cows will be repeated for the other livestock types and for the dry season. The only changes you can make in those sections of the feed basket table are the percentages. Zeros are thus allowed.

LIVESTOCK FEEDING

Wet season	Length of season (days)	290

	Cows - local	Cows - improved	Adult cattle - male	Steers/heifers	Calves	Steers/heifers improved	Calves improved	Sheep	Goats
Brachiaria hybrid (forage)	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	0.00%	0.00%
Dairy meal	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	0.00%	0.00%
Desmodium (Desmodium intortum) green leaf	15.00%	15.00%	15.00%	15.00%	15.00%	15.00%	15.00%	0.00%	0.00%
Groundnut (Arachis hypogaea) - crop residue	50.00%	50.00%	50.00%	50.00%	50.00%	50.00%	50.00%	0.00%	0.00%
Maize (Zea mays) - stover	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	0.00%	0.00%
Napier grass (Pennisetum purpureum) - green fodder	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	0.00%	0.00%
Dairy meal	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	0.00%	0.00%
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	0.00%	0.00%

Figure 9: *Livestock data required*

4 If feed parameter is added it is important to note you must include a crop parameter.

Feed production

FEED PRODUCTION

Long rainy season	Length of season (days)	183				Short rainy season	Length of season (days)	182	

Crop areas and residue management

Feed item	Associated Crop	Crop product	intercropping (1 = yes/0 = no)	IF intercropping, fraction of field occupied by this	grazed (fraction of total grazing time)	Land cover	Slope	Length of slope (m)
Brachiaria hybrid (forage)	Brachiaria hybrid	Main	0.00	0.00	0.50	Dense grass	Hilly (5-20%)	15
Dairy meal	Purchased	Purchased	0.00	0.00	0.00	Pulses	Hilly (5-20%)	15
Desmodium (Desmodium intortum) green leaf	Green leaf desmodium	Main	0.00	0.00	0.00	Cereals	Hilly (5-20%)	15
Groundnut (Arachis hypogaea) - crop residue	Groundnut	Residue	0.00	0.00	0.00	Dense grass	Hilly (5-20%)	15
Maize (Zea mays) - stover	Maize	Residue	0.00	0.00	0.50	Pulses	Hilly (5-20%)	15
Napier grass (Pennisetum purpureum) - green fodder	Napier	Main	0.00	0.00	0.00	Other forest	Hilly (5-20%)	15
Dairy meal	Purchased	Purchased	0.00	0.00	0.00	Other forest	Hilly (5-20%)	15

Feed item		main product removal (fraction)	Crop residue removal from field (fraction)	Crop residue burnt (fraction)
Brachiaria hybrid (forage)	-	0.9		0
Dairy meal	-	1		0
Desmodium (Desmodium intortum) green leaf	-	0.9	0.8	0.2
Groundnut (Arachis hypogaea) - crop residue	Groundnut	1	1	0
Maize (Zea mays) - stover	Maize	1	0.75	0
Napier grass (Pennisetum purpureum) - green fodder	-	0.9		0
Dairy meal	-	1		0

Crop inputs

Feed item		Fertilizer rate per crop (**kg N/ ha**)	Application of organic fertilizer (collected and purchased manure/compost) for feed crop fertilization (fraction)
Brachiaria hybrid (forage)	Brachiaria hybrid	0.00	0.10
Dairy meal	Purchased	0.00	0.00
Desmodium (Desmodium intortum) green leaf	Green leaf desmodium	0.00	0.10
Groundnut (Arachis hypogaea) - crop residue	Groundnut	0.00	0.40
Maize (Zea mays) - stover	Maize	25.00	0.30
Napier grass (Pennisetum purpureum) - green fodder	Napier	0.00	0.10
Dairy meal	Purchased	0.00	0.00

Purchased Inorganic fertilizers	Quantity (N/year)	Fractions
Urea	0	
CAN	0	
DAP	0	
NPK	25	1.00
Lime	0	

Save Baseline

Rice

		Value
Harvest area	ha	0.00
Cultivation period	days	
Rice ecosystem type	select	None
Water regime prior to rice cultivation	select	non-flooded pre-season < 180 days(often in double cropping of rice)
Organic amendment inputs	select	Compost
Rate of application	t/ha	0.00

This section gathers information about the way the feed items are produced Figure 10.

__Figure 10:__ Feed production data required

In the first table, crop areas and residue management, you will see the list of selected feed items and their associated crop. For each of these you are required to indicate if the main product or the residue is used in the feed basket. The next three columns required to be filled are used in the erosion calculations. The user selects from drop down menus:

- **Crop product:** indicate whether the feed is the main crop, crop residue or purchased (i.e. concentrate)
- **Intercropping:** indicate whether the feed is intercropped with another crop (e.g., legumes with cereals)
- Fraction of field occupied if intercropped
  - **Land cover:** depends on the crop. i.e. for beans the cover crop is "pulses". In most cases, the user will select among "maize, cereals, pulses, dense or degraded grass". In the case of tuber crops, it is suggested to select either "cereals "or "pulses".
  - **Slope:** this is an estimation of the degree of the slope from flat to extremely steep.
  - **Length of slope:** average estimate (in m).

The table shown in Figure 10 is based on harvesting of feed or crop and management of crop residues. For removals, provide:

- **Main product removal:** if main crop is feed: the fraction of the crop that is removed from the field for feeding animals.
- **Crop residue removal from field:** if crop residue is feed: the fraction of the crop residues that is removed from the field for feeding animals.
- **Crop residue burnt:** the fraction of the total produced crop residues that is burnt.

In the crop input table, provide:

- For each crop associated with feed items:
  - **Fertilizer rate:** this is expressed in kg N/ha and thus requires conversions from the fertilizer type and respective N contents this information is used for calculating nutrient balances and N_2O emissions from each field.

- **Application of organic fertilizer:** fraction of purchased/collected used for each feed crop. Sum must be 1.
- **Purchased inorganic fertilizers:** fraction of purchased inorganic fertilizer used, the model uses this to calculate greenhouse gas emissions from fertilizers. Sum must be 1.

The above information should correspond to each other, but the model asks for the type of fertilizer as the emissions from fertilizer itself depends on the production process, so we cannot calculate from the N rate only.

The last table of the input sheet, rice, only needs to be filled if one of the feed items is sourced from on-farm rice production:

- **Harvest area:** calculated from the information provided above
- **Cultivation period:** number of days the rice cultivation takes
- **Rice ecosystem type:** select from the drop-down list
- **Water regime prior to rice cultivation:** select from the drop-down list
- **Organic amendment inputs:** select from the drop-down list
- **Rate of application:** filled out based on information provided above

Save baseline

After you have filled out the farm info, livestock, livestock feeding and feed production sections, you can explore the environmental footprint for this so-called "baseline" setup of the livestock enterprise.

If you are sure the input data is correct, you can save it by pressing the "save baseline" button and get ready to run "scenarios".

After "Save Baseline", insert the modifications in the Scenario model, make sure do not make changes into the baseline workbook. This workbook should remain open in the background but you should not make any scenarios or changes here.

Extra cost 'only to be filled for scenarios'

These tables shown in Figure 11 are only to be filled when the user is implementing scenarios and wants to analyse the economic cost/benefit of the implementation of a new technology or alternative livestock production setup.

The first table solicits information about the costs associated with improvements in the existing herd.

The user will add the extra operational costs and days of labor that would be needed to maintain those animals that were already there in baseline setup and remain so under the scenario. A small box is added to describe what the user has implemented.

The second table assumes that the user adds new livestock to his or her enterprise. Here the user is expected to put in:

- The one-off cost associated with adding or removing the animals of the different categories to the herd (e.g. market price, cost of artificial insemination).
- The operational (i.e. annually recurring) cost that would be required to maintain the animals using the new technology.
- The extra one-off days of labour.
- The operational days of labour that would be needed to maintain the animal.
- A short description of what the user has implemented.

The third table solicits information about extra costs associated with feed items that are also in the animal's baseline diet. The user will add the extra on-off/establishment costs and days of labour in the case of an increase in area, as well as the operational costs and days of labour needed to cover the changed management (e.g. application of fertilizer) or increase in area planted of the feed items. A small box is added to describe what the user has implemented.

The fourth table lists those feed items that the user has added as new feeds to the animal's baseline diet[5]. Here the user is expected to put in:

- The one-off/establishment cost for the new technology (e.g. new feed).
- The operational cost that would be required to maintain the feed items on an annual basis.
- The extra one-off days of labour.
- The operational days that would be needed to maintain the feed item.
- A short description of what the user has implemented.

The last table leaves the option for any additional changes the user would want to implement, changes that are not associated with changing herd composition or feeding strategies. This could, for example, be the construction of a feed trough or animal shed. Here the user is expected to put in:

- The one-off cost for the new technology that has been used to improve animal productivity.
- The operational cost that would be required to maintain the new technology.
- Extra one-off days of labour.
- The operational days that would be needed to maintain the new investment.
- A short description of what the user has implemented.

5 Scenario and baseline feed items need to listed in the same order; as we compare item 1 with item 1 through to item 7 if the feed is not being replaced with a new feed item into the diet.

EXTRA COST (only to fill for "scenarios", i.e. change from current situation/baseline)

Additional cost for baseline herd						
	herd size	Extra one-off cost (USD/animal)	Extra operational cost USD/animal/year	Extra labour - one-off (days/animal)	Extra labour (days /animal/year)	Description
Dairy cows - local	0					
Dairy cows - improved	1	0	0	0	0	no change
Adult cattle - male	1	0	0	0	0	no change
Steers/heifers	0					
Calves	1	0	0	0	0	no change
Sheep	0					
Goats	0					
Pigs	0					
Poultry	0					
Donkeys/horses	0					

Additional cost for new herd						
	herd size	Extra one-off cost (USD/animal)	Extra operational cost USD/animal/year	Extra labour - one-off (days/animal)	Extra labour (days /animal/year)	Description
Dairy cows - local	*0*					
Dairy cows - improved	*1*	200	50	1	12	
Adult cattle - male	*1*	0	50	1	12	
Steers/heifers	*0*					
Calves	*1*	0	20	1	12	
Sheep	*0*					
Goats	*0*					
Pigs	*0*					
Poultry	*0*					
Donkeys/horses	*0*					

Additional cost for already existing feed items						
	Extra hectares	Extra one-off / establishment cost (USD/ha)	Operational Cost (USD/ha/year)	Extra labour - one-off (days/ha)	Extra labour (days /ha/year)	Description
Naturally occuring pasture - green fodder	1.99	0	0	0	0	
Maize (Zea mays) - stover	0.78	0	0	0	10	
Napier grass (Pennisetum purpureum) - green fodder	0.05					
Maize (Zea mays) - cobs ground	0.00					
Cotton (Gossypium sp.) - seed meal	0.00					
Sunflower (Helianthus annuus) - seed cake	0.00					
	0.00					

Additional cost for new feed items	Hectares	Extra one-off / establishment cost (USD/ha)	Operational Cost (USD/ha/year)	Extra labour - one-off (days/ha)	Extra labour (days /ha/year)	Description
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
Red clover (Trifolium pratense) - hay	0.19	10	5	2	0	

Other additional costs					
other	Extra one-off / establishment cost (USD/ha)	Operational Cost (USD/ha/year)	Extra labour - one-off (days/item)	Extra labour (days /item/year)	Description
extra stable	100				

Figure 11: *The additional input data required to calculate the economic cost or benefits of intervention scenarios*

Scenario manager

"Scenario manager" is a built-in Excel tool that allows users to deal with changing up to 32 variables (cells) simultaneously. It can be accessed from the 'Data' tab on the Ribbon and is located using the 'What-If Analysis' icon in the Forecast' section.

Advantages of using this tool are:

- Allows multiple sets of what-if data to be entered and compared
- Each set is a scenario
- Scenario Manager tracks each scenario with a name
- Each scenario can be re-activated and changed at any time
- Range names can be used to help describe cell references

Example of use of Scenario Manager to compare the impact of traditional with improved forages on a selected range of results:

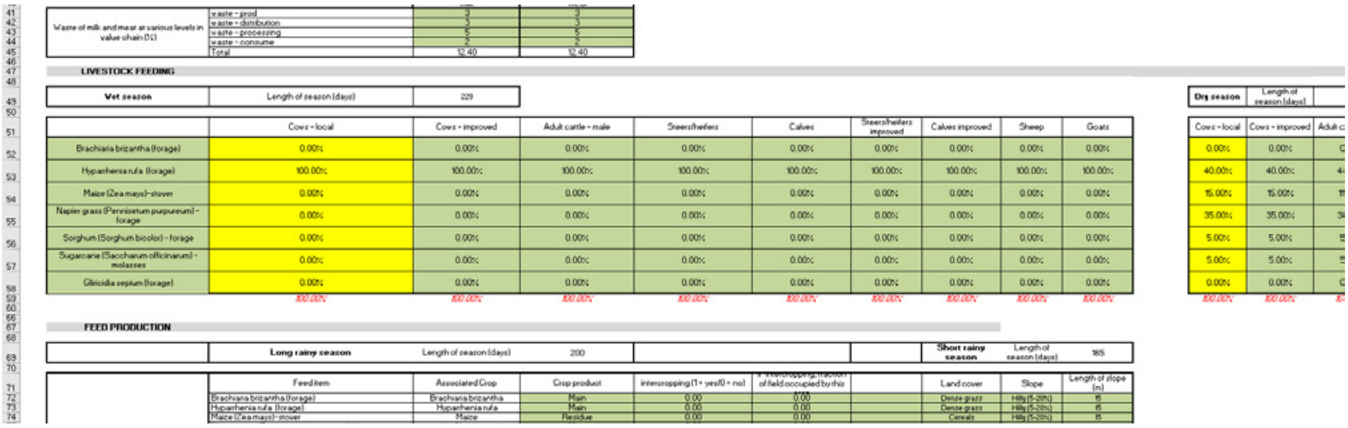


Figure 12: *Scenario manager example step (i)*

Select C52:C58,M52:M58 (the input cells, yellow in the Figure 12 above).

Click the Data tab.

In the Data Tools group, click the What-if Analysis drop-down and choose Scenario Manager

Click Add and give the scenario a name, such as "traditional forages", and click OK

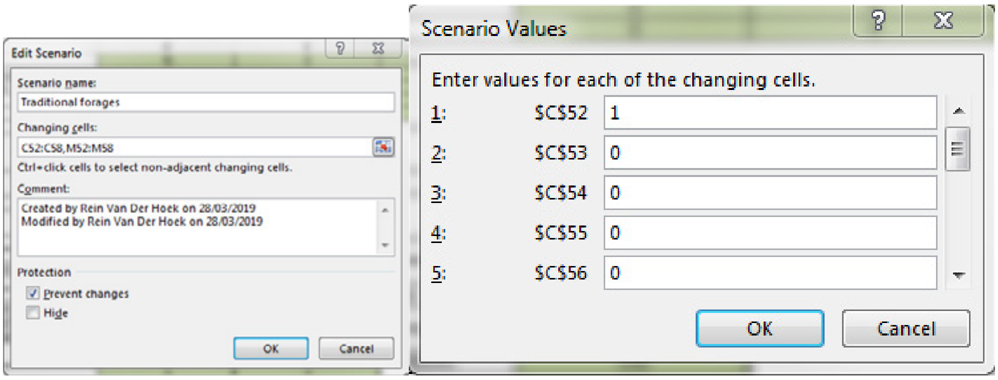


Figure 13: *Scenario manager example step(ii)*

Next, enter the "traditional values" for the different forages.

When you want to see only one set of values, click OK.

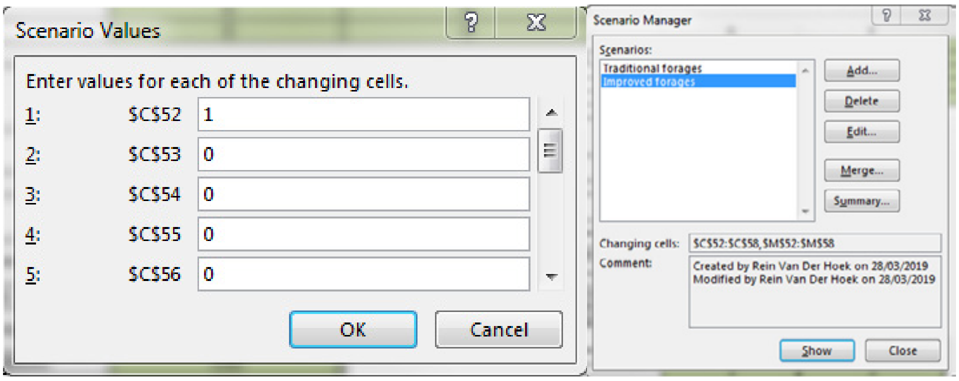


Figure 14: *Scenario manager example step (iii)*

However, in this case, we want to add more input values, so click Add, and enter the "improved values" for the same forages.

After adding all the scenarios, you want to consider, click "Summary".

In the resulting dialog, make sure the cells are selected in which you want the results to be reflected, for instance C181:C209, and select “Scenario summary” or “Scenario Pivot table report output”, the latter is a PivotTable comparing the different scenarios in all possible combinations. This is especially useful when the scenario manager includes different types of scenarios with different inputs, for instance “forages” (traditional and improved) and “breeds (traditional and improved). When including different scenario types, the result cells need to be the same. Another important characteristic of this tool is that the scenarios are defined at worksheet level, meaning that the input and result cells need to be in the same worksheet.

➡ **IMPORTANT NOTE:** for the scenario manager changing feed items would be saving a new workbook all together, as the scenario manager cannot read into the feed item list.

For those needing more guidance on using scenario manager use this link https://bit.ly/2wqvk1g

4 Result sheets

4.1 Summary sheet

An overview of all results is presented in the "Summary" sheet—the last red sheet (Figure 15). The indicators are calculated per livestock enterprise, per hectare and per product on a yearly basis. These are the land requirements for feed production, the milk productivity, the nitrogen balance in kg N, soil erosion in t soil loss, GHG emissions in t CO2e and productivity/energy in kcal and AME days.

The first table presents the results per livestock enterprise. The total land required for the specified herd and milk production is given in ha per year. The productivity of this enterprise is expressed as total milk production in kg FPCM produced and consumed. The total milk consumed is the production adjusted for the waste that occur along the chain until the milk is consumed.

The next indicator is the nitrogen (N) balance in kg N per year and Nitrogen Use Efficiency (NUE). A negative number indicates that N is being lost from the soil through mining. A positive N number indicates that the soil is not losing N, however if above 80% indicates leaching of N to surroundings. Another indicator shows the percentage are of N being mined or leached. The ideal would be that both percentage of N being mined or leached is zero.

Soil erosion is express in tons of soil lost per year from the land used for feed production. Negative value indicated net soil accumulation.

The results for the GHG emissions are presented as the total amount emitted in tons of carbon dioxide equivalent per year.

The last section of the first table gives results on productivity in terms of energy (food energy). Kilocalories per year is the unit used. Energy from milk, meat.

Energy productivity is also expressed in AME per year. AME stands for Adult Male Equivalent and represents energy requirement of an average adult male (2500 kcal/day). The result of AME days/year from milk is obtained by dividing the kcal from milk production by 2500. That number indicates how many days an average adult male could be fed just from milk to meet the daily requirements of 2500 kcal. The same indicator is calculated for meat. Then the total number of days that could sustain 1 AME from all the production (milk, meat) is given in AME days/year total.

Finally, the last result in the table Per livestock productivity is the number of AME that could be fed on energy produced by this enterprise. In the Per hectare table the same indicator in the Per livestock enterprise are presented, in per hectare.

The third and last table of the "Summary" worksheet presents the results Per product. That is the Land requirements, the N balance, the soil erosion and the GHG emissions are given per kg of Fat-Protein Corrected Milk (FPCM). The results are given per milk produced in the "Produced" column and per milk consumed in the "Consumed" column. The "Consumed" results are the "Produced" results minus the estimated losses along the value chain.

For each of the impact categories, separate result sheets are included:

- Land requirements
- Productivity
- Economics
- Soil impacts
- GHG emissions
- Water Impacts

The following sections take you through each of these.

Per livestock enterprise	
Land requirement	
Total land required (ha/year)	2.000
Productivity	
Total milk produced (kg FPCM/year)	3,674
Total milk consumed (kg FPCM/year)	3,218
Meat produced (kg/year)	490
Meat consumed (kg/year)	429
protein (kg/year)	260
N balance	
kg N/year	1
% area mining	79
% area leaching	0
Soil Erosion	
t soil/year	-6.48
GHG emissions	
t CO2 eq. / year	8.85
Water impacts	
% of precipitation used for feed productio	53.6
m3/year	1,931.5
Carbon stock changes	
t CO2 eq. / year	-3.71
Productivity / Energy	
kcal/year from milk	3,563,295
kcal/year from meat	1,078,000
kcal/year total	4,641,295
AME days/year from milk	1,425
AME days/year from meat	431
AME days/year total	1,857
Economics	
Value of Production (USD/year)	2,582

Per hectare	
Productivity	
Total milk produced (kg FPCM/ha/yr)	1,837
Total milk consumed (kg FPCM/ha/year)	1,609
Meat produced (kg/ha/year)	245
Meat consumed (kg/ha/year)	215
protein (kg/ha/year)	130
N balance	
kg N/ha/yr	0.39
/	
/	
Soil Erosion	
t soil/ha/yr	-3.24
GHG emission intensity	
t CO2 eq. / ha/yr	4.43
Water impacts	
m3/ha/year	965.62
Carbon stock changes	
t CO2 eq. / ha/ year	-1.85
Productivity / Energy	
kcal/ha/yr from milk	*1,781,440*
kcal/ha/yr from meat	*538,937*
kcal/ha/yr total	*2,320,377*
AME days/ha from milk	*713*
AME days/ha from meat	*216*
AME days/ha total	*928*
number of AME/ha that could be fed on calories produced for a year	3
Economics	
Value of Production (USD/ha/yr)	1,291

Per product	PRODUCED	CONSUMED
Land requirement		
Total land required (ha/MT FPCM)	0.5	*0.622*
Productivity		
/		
/		
/		
/		
/		
N balance		
kg N/ kg FPCM	0.0002	0.0002
/		
/		
Soil Erosion		
kg soil/ kg FPCM	-1.77	-2.02
GHG emissions		
kg CO2 eq. /kg FPCM	2.41	2.75
kg CO2 eq. /kg meat	18.07	20.63
kg CO2 eq. /kg protein	34.01	
Water impact		
m3/kg FPCM	0.53	0.60
m3/kg meat	3.94	4.50
m3/kg protein	7.42	8.47
Carbon stock changes		
kg CO2 eq. /kg FPCM	-1.01	-1.15
Total Carbon balance		
kg CO2 eq. /kg FPCM	3.42	3.90

Figure 15: *Summary Sheet*

4.2 Land requirements sheet

Introduction

On this sheet you can find the area of land that is required to produce sufficient feed for the animals in the livestock enterprise.

Land is an essential though limited productive resource, with rising and competing demands posed upon it, e.g.:

- Staple food production
- Animal production
- Forests and natural vegetation
- Wetlands
- Settlements and infrastructure
- Etc.

The less land is needed for feed production, the more is available for other purposes. If, on the other hand, non-agricultural land is converted for feed production, negative impacts on e.g. biodiversity can be expected. Expansion is especially problematic when forest or other natural vegetation is converted into cropland or pastures for feed production.

Land requirement for feed production per associated crop (ha):

In this table you will find the list of feed items used in the livestock enterprise. For each of these it is indicated how many hectares of the associated crop need to be planted to fulfil the feed requirements of the animals.

- **Wet season:** the area needed to produce the feed required to feed the animals in the wet season (in absolute value – hectares)

- **Dry season:** the area needed to produce the feed required to feed the animals in the dry season (in absolute value – hectares)
- **Total:** the area needed to be planted to fulfil the annual animal feed requirement
- **Total area used for feed production:** adds up the area requirements per feed item. This is thus the total area of land that the livestock enterprise should “set aside” for feed production.

  ➡ **IMPORTANT NOTE:** Purchased feed items will require 0 hectares of area as these are considered to be outside the system.

- **Area per milk unit (ha/kg FPCM):** in addition to the absolute values, the tool also calculates an efficiency indicator, i.e. how much land is required for the feed production of FPCM/kg. FPCM is calculated based on the milk fat and protein contents in percentage which are parameters found in the livestock parameters sheet.

Dry matter requirements (kg):

In the second table, the quantities in kg of dry matter per season per feed and in total are presented.

The land and dry matter requirements per crop and per season do not take into account the actual time at which the crop is cultivated, only what is required by the herd annually.

In this worksheet, the land requirement for feed production per associated crop is presented in the first table. Based on the feed item, the associated crop and the component of the crop and finally based on the length of the wet and dry feeding season, the area of land to produce the required quantity is calculated and present here per feeding season and per year. In the second table, the quantities in kg of dry matter per season per feed and in total are presented. The land and dry matter requirements per crop and per season do not take into account the actual period during which the crop is cultivated, only what is required by the herd during that time.

A	B	C	D	E
Land requirement for feed production per associated crop (ha)				
Feed item	**Associated crop**	**Wet Season**	**Dry Season**	**Total**
Naturally occuring pasture - green fodder	Natural pasture	3.595	0.794	4.389
Maize (Zea mays) - stover	Maize	0.767	1.321	2.088
Napier grass (Pennisetum purpureum) - green fodder	Napier	0.069	0.020	0.089
Maize (Zea mays) - cobs ground	Maize	0.000	0.000	0.000
Cotton (Gossypium sp.) - seed meal	Cotton	0.000	0.000	0.000
Sunflower (Helianthus annuus) - seed cake	Purchased	0.000	0.000	0.000
Red clover (Trifolium pratense) - hay	Red clover	0.136	0.056	0.192
	Total area used for feed production (ha)	**4.567**	**2.191**	**6.759**
	Area per milk unit (ha/ kg FPCM)			0.0024

Dry Matter requirements (kg)				
Feed item	**Associated crop**	**Wet Season**	**Dry Season**	**Total**
Naturally occuring pasture - green fodder	Natural pasture	5,177	1,143	6,321
Maize (Zea mays) - stover	Maize	1,444	2,487	3,931
Napier grass (Pennisetum purpureum) - green fodder	Napier	348	102	451
Maize (Zea mays) - cobs ground	Maize	748	307	1,054
Cotton (Gossypium sp.) - seed meal	Cotton	694	158	853
Sunflower (Helianthus annuus) - seed cake	Purchased	709	161	870
Red clover (Trifolium pratense) - hay	Red clover	1,467	602	2,069
	Total DM feed required (kg)	***10,587***	***4,961***	***15,548***

Figure 16: *Land Requirements*

4.3 Productivity sheet

Productivity is a potential supply indicator. It calculates the total amount of calories produced by the livestock enterprise from livestock products.

Livestock

This table lists productivity indicators for different livestock products, i.e.:

- Fat-Protein Corrected Milk
- Cattle meat
- Meat from small ruminants

The productivity indicators include:

- **Production:** the number of kilograms of this product that is produced in the year
- **Energy:** the number of kilocalories that this production represents (calculated by multiplying the quantity produced by the calorie content of the product)
- **AME (adult male equivalent) days:** assuming an adult male requires 2500 kcal/day, the value listed here represents the number of days that the livestock enterprise can fulfil the energy requirements of one adult male

	Total energy (kcal/year)	Total AME days
Total energy from livestock products (kcal/year)	4,641,295	1,857

AME = 2500 kcal

LIVESTOCK					
TLU		5.6			
Year					
	Production (kg/year)	Energy (kcal/year)	Protein		AME Days
Milk (FPCM)	3,674	3,563,295	133		1,425
Meat cattle	490	1,078,000	127		431
TOTAL		4,641,295	260	-	1,857

	Production (kg/year)
Manure	4022

Figure 17: Productivity indicator

4.4 Economics

Baseline farm

Economics are expressed in USD and USD per ha.

In the baseline calculation we look at the total value of production, this takes into how much the farm would make from production if they sold all there produce, this calculation does not take into account if the produce was consumed or the cost of the inputs.

Total Value of Production (USD)	$	2,540
Total Value of Production (USD) per/ha	$	376

Figure 18: Economic calculation CLEANED_T1_BAS

Farm scenarios

In the scenario calculation we want to know if new technologies are feasible. We look at various indicators such as the payback period, the return on investment and the net present value.

Net present value (NPV) is the value of all future cash flows (positive and negative) over the entire life of an investment discounted to the present. If a project has an NPV of $0 or negative value, the project should be rejected as it is not profitable

Return on investment (ROI) is a ratio between the net profit and cost of investment resulting from an investment of some resources. A high ROI means the investment's gains favorably to its cost.

Payback period is the period of time required to recoup the funds expended in an investment.

Gross Margins				
Year	Cash Flow	Return On Investment	Total cost (USD/yr)	Total Value of Production (USD) per/ha
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
Payback Period : Number of years necessary to pay back the Initial investment	0.00			
NPV				

Figure 19: *Economic calculation CLEANED_T1_SC1*

4.5 Soil impacts sheet

Overall soil impacts

The soil impacts are expressed in terms of NUE, N balance and erosion.

- **NUE:** A positive over 80% indicates leaching, a negative value indicates mining of N. The ideal is to have 0% leaching and mining.
- **N balance:** A positive N balance is desired; as otherwise nutrient mining might result in severe soil fertility depletion over time. However, a N balance of >150 kg N/ha is also undesirable as this could result in N leaching in groundwater and higher GHG emissions.
- **Erosion:** Erosion is expressed in annual t of soil loss.

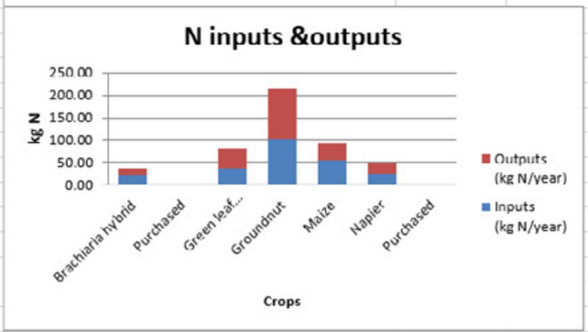
Feed items specific N balance:

For each feed item, the N inputs and N outputs as well as the resulting N balance are listed separately. In addition to a tabulation of these results, they are also represented as bar graphs. The N balance takes into account the N for feed production used for animal production and also the N balance for food production if the feed used to feed the animal is a food crop e.g. is maize stover are feed the N balance for the main grain crop is also calculated and can be used to assess the farm.

OVERALL SOIL IMPACTS		% area mining	% area leaching
N balance (kgN/year)	1	79	0
Erosion (t soil/year)	-6.48		

Feed items specific N balance

		Inputs (kg N/year)	Outputs (kg N/year)	N Balance food crop included (Kg N/year)	N Balance food crop included (Kg N/ha/year)	N Balance feed only (Kg N/year)	N Balance feed only (Kg N/ha/year)	N Balance food only (Kg N/year)	N Ba only N/ha
Brachiaria hybrid (forage)	Brachiaria hyk	21.74	14.44	7.30	87.45	7.30	87.45	0.00	
Dairy meal	Purchased	0.00	0.00	0.00		0.00		0.00	
Desmodium (Desmodium intortum) green leaf	Green leaf desmodium	36.82	44.07	-7.25	-30.53	-7.25	-30.53	0.00	
Groundnut (Arachis hypogaea) - crop residue	Groundnut	102.78	110.13	-7.35	-6.19	-3.23	-2.71	-4.13	
Maize (Zea mays) - stover	Maize	56.17	34.74	21.42	63.11	6.01	17.71	15.41	
Napier grass (Pennisetum purpureum) - green fodd	Napier	23.86	25.93	-2.07	-13.62	-2.07	-13.62	0.00	
Dairy meal	Purchased	0.00	0.00	0.00		0.00		0.00	
total		241.36	229.31	12.06		0.78		11.28	



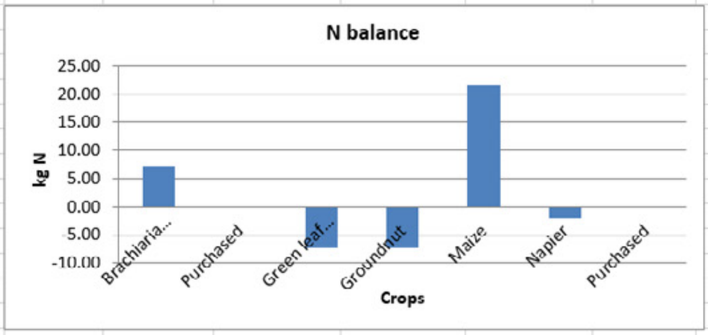


Figure 20: *Soil impacts table N balance, NUE and Erosion*

4.6 GHG emissions sheet

In this sheet you will find the results from the GHG emission calculations. The top two tables detail the total GHG balance according to the Tier 1 and Tier 2 methods in different units. The emissions are methane from enteric fermentation, methane emissions from manure production and storage, direct and indirect nitrous oxide emissions from manure production and storage, direct and indirect nitrous oxide emissions from inputs to the soil, off-farm direct and indirect nitrous oxide emissions from inputs to off-farm soil, carbon dioxide emissions from burning residues, methane emissions from rice production and off-farm carbon dioxide equivalent emissions from the production of various types of fertilizers and other soil inputs used.

The Tier 1 table presents the results following the Tier 1 methodology of the IPCC. The Tier 1 method is the simplest method; it uses very little data and depends a lot on default values, i.e. values that are not country or system specific. Tier 2, on the other hand, uses country specific emission factors and other data.

Tier 1:

In the Tier 1 table, the first column indicates the source of the GHG emissions. When both methane (CH_4) and nitrous oxide (N_2O) are emitted from the same source, the emissions are detailed per gas, i.e. Manure-Methane and Manure-Direct N_2O etc. The second column specifies the unit of the third column which is in kg of the GHG per ha. The values are in the third column of the table. The fourth and fifth column express the GHG emission in a common unit: Carbon dioxide equivalent CO2e which is obtained by multiplying the GHG emissions by their respective Global Warming Potential (GWP): 21 for methane (cell D23) and 310 for nitrous oxide (cell C24). Global warming potential were obtained from the IPCC 2013 – AR5. Emissions in the fourth column are in CO2e per area and in the fifth column in CO2e per kg FPCM. The sixth column indicates the contribution of the different GHG emissions to the total GHG on farm balance in percentage. The last row of table is the total GHG balance in CO2e per ha and CO2e per kg FPCM.

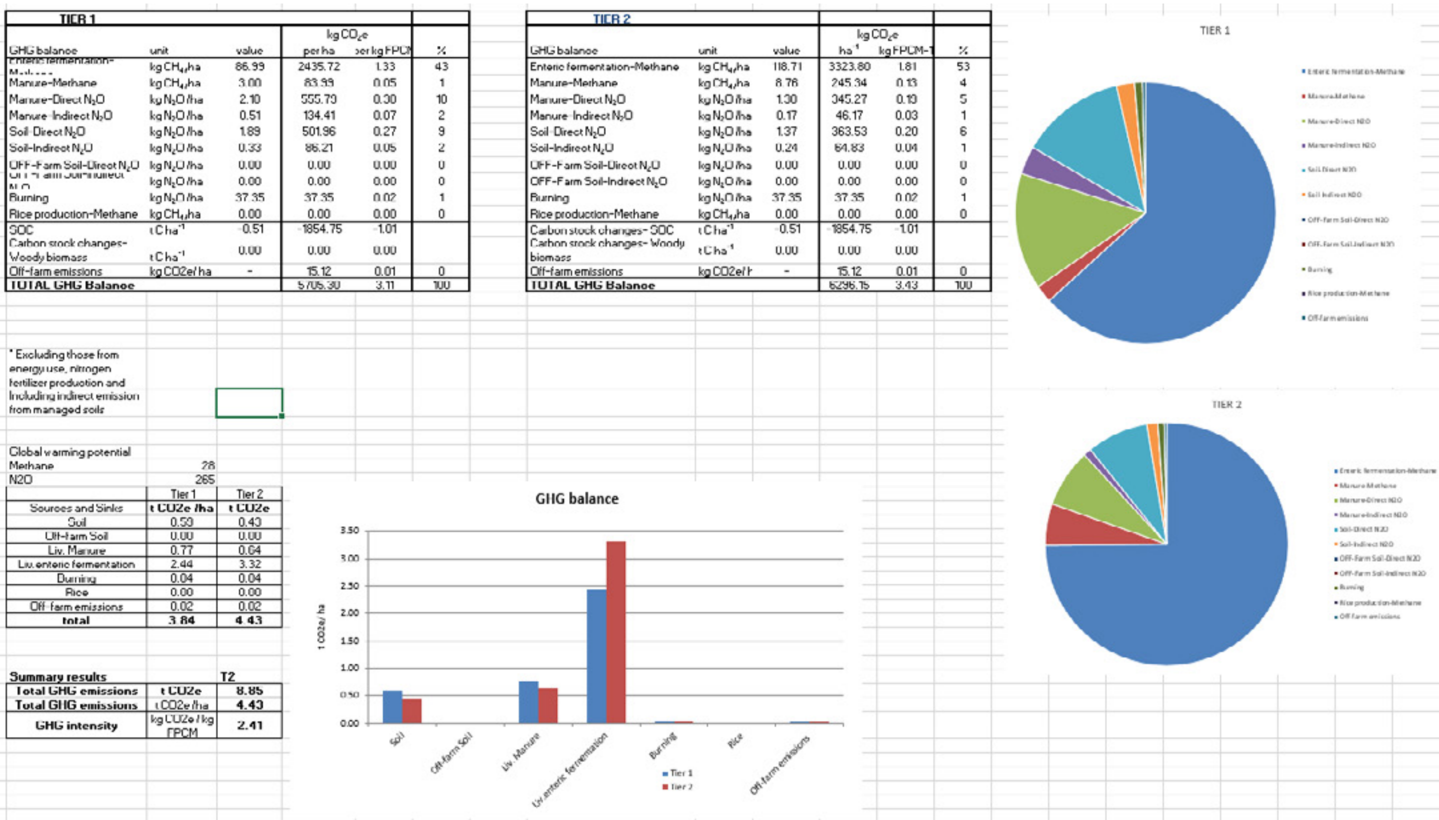
Tier 2:

In the Tier 2 the GHG emission values from emissions enteric fermentation, methane emissions from manure production and storage, direct and indirect nitrous oxide emissions from manure production and storage are calculated following the IPCC Tier2 formulas.

Summary tables:

There is a third table starting at cell B30. This is a summary table of the results in tables Tier 1 and Tier 2. The results are expressed in t CO2e per ha and grouped by into the following emissions sources: Soil (direct and indirect nitrous oxide emissions from inputs to the soil), off-farm soil (direct and indirect nitrous oxide emissions from inputs to the soil off-farm), livestock manure (methane emissions from manure production and storage, direct and indirect nitrous oxide emissions from manure production and storage), livestock enteric fermentation, burning, rice and off-farm emissions.

The last table, named Summary results, cell B43, summarizes the total emissions from the Tier 2 methodology as t CO2e, t CO2e per ha and t CO2e per kg FPCM.



TIER 1

GHG balance	unit	value	kg CO_2e per ha	kg CO_2e per kg FPCM	%
Enteric fermentation-Methane	kg CH_4/ha	86.99	2435.72	1.33	43
Manure-Methane	kg CH_4/ha	3.00	83.99	0.05	1
Manure-Direct N_2O	kg N_2O/ha	2.10	555.79	0.30	10
Manure-Indirect N_2O	kg N_2O/ha	0.51	134.41	0.07	2
Soil-Direct N_2O	kg N_2O/ha	1.89	501.96	0.27	9
Soil-Indirect N_2O	kg N_2O/ha	0.33	86.21	0.05	2
OFF-Farm Soil-Direct N_2O	kg N_2O/ha	0.00	0.00	0.00	0
OFF-Farm Soil-Indirect N_2O	kg N_2O/ha	0.00	0.00	0.00	0
Burning	kg N_2O/ha	37.35	37.35	0.02	1
Rice production-Methane	kg CH_4/ha	0.00	0.00	0.00	0
SOC	t C ha^{-1}	-0.51	-1854.75	-1.01	
Carbon stock changes-Woody biomass	t C ha^{-1}	0.00	0.00	0.00	
Off-farm emissions	kg CO2e/ ha	-	15.12	0.01	0
TOTAL GHG Balance			5705.30	3.11	100

TIER 2

GHG balance	unit	value	kg CO_2e ha^{-1}	kg CO_2e kg FPCM-1	%
Enteric fermentation-Methane	kg CH_4/ha	118.71	3323.80	1.81	53
Manure-Methane	kg CH_4/ha	8.76	245.34	0.13	4
Manure-Direct N_2O	kg N_2O/ha	1.30	345.27	0.19	5
Manure-Indirect N_2O	kg N_2O/ha	0.17	46.17	0.03	1
Soil-Direct N_2O	kg N_2O/ha	1.37	363.53	0.20	6
Soil-Indirect N_2O	kg N_2O/ha	0.24	64.83	0.04	1
OFF-Farm Soil-Direct N_2O	kg N_2O/ha	0.00	0.00	0.00	0
OFF-Farm Soil-Indirect N_2O	kg N_2O/ha	0.00	0.00	0.00	0
Burning	kg N_2O/ha	37.35	37.35	0.02	1
Rice production-Methane	kg CH_4/ha	0.00	0.00	0.00	0
Carbon stock changes-SOC	t C ha^{-1}	-0.51	-1854.75	-1.01	
Carbon stock changes-Woody biomass	t C ha^{-1}	0.00	0.00	0.00	
Off-farm emissions	kg CO2e/ h	-	15.12	0.01	0
TOTAL GHG Balance			6296.15	3.43	100

* Excluding those from energy use, nitrogen fertilizer production and Including indirect emission from managed soils

Global warming potential	
Methane	28
N2O	265

	Tier 1	Tier 2
Sources and Sinks	t CO2e /ha	t CO2e
Soil	0.59	0.43
Off-farm Soil	0.00	0.00
Liv. Manure	0.77	0.64
Liv. enteric fermentation	2.44	3.32
Burning	0.04	0.04
Rice	0.00	0.00
Off-farm emissions	0.02	0.02
total	3.84	4.43

Summary results		T2
Total GHG emissions	t CO2e	8.85
Total GHG emissions	t CO2e /ha	4.43
GHG intensity	kg CO2e / kg FPCM	2.41

Figure 21: *Greenhouse gas emissions*

4.7 Water impacts sheet

Overall water impacts:

	total	
ET (mm/year)	965.62	
fraction of precipitation used for feed production	0.54	
Total water use (m3)	1931	
Water use (m3/kg FPCM)	0.53	
Water use (m3/kg meat)	3.94	
Water use (m3/kg protein)	7.42	
Water use per crop (m3)	**feed**	**food**
Brachiaria hybrid (forage)	115	0
Dairy meal	0	0
Desmodium (Desmodium intortum) green leaf	208	0
Groundnut (Arachis hypogaea) - crop residue	611	518
Maize (Zea mays) - stover	132	139
Napier grass (Pennisetum purpureum) - green fodder	209	0
Dairy meal	0	0
total	1274	657

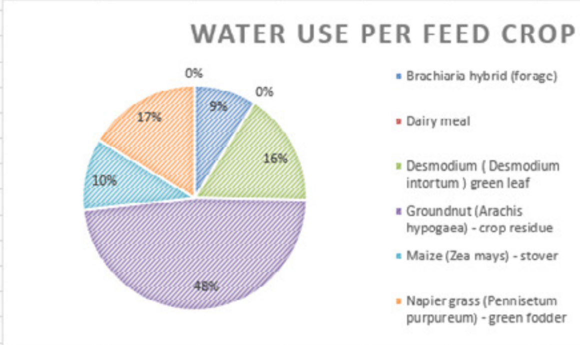


Figure 22: *Water Impacts*

The model calculates from the annual rainfall the percentage of water available which is utilized for feed production and the percentage of water used to produce a kg of milk, meat and protein. For this indicator the lower the amount the livestock enterprise needs the more efficient the system.

5 Parameter sheets

In addition to providing information about the type of livestock enterprise being modelled in the "Inputs sheet", the user will need to parametrize the model. Information pertaining to local agro-ecology, crop performance, feed items and livestock characteristics is needed for the various impact calculations (see section 7). These parameters need to be adapted to reflect the context, country and region for which the model is being used. The user can for example change crop parameters such as the yields and harvest index or livestock parameters such as their average live weight. Users can also add missing feed items in the 'Feed parameters' and associated crops in the 'Crop parameters' worksheet. Parameters can be extracted from published reviews, from expert knowledge or from online database, such as Feedipedia (http://www.feedipedia.org/). References to where the characteristics can be found in the parameters sheet.

5.1 Area parameters

This sheet gives the agro ecological information needed from that area and can be easily adapted. Characteristics include:

- **Annual precipitation:** average annual quantity of precipitation in mm/year
- **Rainy season:** the number of months in a year that significant rainfall occurs (more than 50mm/month)
- **Soil type:** the soil type according to the FAO classification scheme. A drop-down list is provided
- **SoilN:** the total nitrogen content of the top soil layer in grams/kg of soil
- **SoilC:** the total carbon content in the top soil layer in grams/kg of soil
- **Soil clay:** the content of clay in the soil in % (in terms of soil texture)
- **Bulk density:** the bulk density of the top soil layer in g/cm3
- **Soil depth:** the depth of top soil layer in m
- **ET_0:** Evapotranspiration the sum of evaporation and plant transpiration from the Earth's land and ocean surface to the atmosphere (mm). In a case where field measurements for ET_0 are missing, one can refer a value from FAO repositories (table 2) using the link given below.

http://www.fao.org/3/x0490e/x0490e04.htm

A separate table on land use (cropland, grassland) based on the SOC parameter sheet (see below) provides inputs for the changes in soil organic carbon (SOC sheet).

To help look for these parameters users can go to the following website:

https://www.isric.org/index.php/explore/soilinfo or download the soilInfo app from the mobile app store.

5.2 Feed parameters

Only the feed items that are listed in this sheet can be selected as being part of the feed baskets in the input sheet. Each row provides information about one specific feed item. Characteristics include:

- Feed: this is the name of the feed item. What is provided here is what will be appearing in the feed item drop down list in the input sheet
- DM content (%)
- ME content (MJ/kg DM):
- ME content (MJ/kg fresh):
- CP content (% DM):

- CP content (% fresh):
- DE (fraction):
- Origin of feed:
- Associated crop:

5.3 Crop parameters

Information for all crops that are associated with the feed items is needed in this sheet. Each row provides information about one specific crop item. Characteristics include:

- Fresh Yield of crop [grain/grass/cereal] (t FW/ha): The yields listed here indicate how much of the crop can be produced per ha/year (taking into account e.g. double cropping seasons).
- DM fraction of crop [grain/grass/cereal]
- Harvest index of crop
- Crop residue DM fraction
- N content of crop [grain/grass/cereal] (kg N/kg DM)
- N content of crop residue (kg N/kg DM)
- C (crop cover) factor
- N fixation by crop (kg N/ha/yr)
- Energy (kcal per FW 100g)
- Water content (g per 100 g)
- Energy (kcal per 100 g DM)
- Kc: Initial/Midseason/Late
- Category
- trees/ha
- trees DBH
- trees annual growth (kg)
- trees annual removal (kg)

Useful websites for crop and feed parameters include:

1. https://www.feedipedia.org/
2. http://www.tropicalforages.info/
3. https://ndb.nal.usda.gov/ndb/search/list
4. https://cowsoko.com/rumen8

➡ **IMPORTANT NOTE:** observe the units of measurement. Change the units to reflect what the tool requires e.g. from g to Kg.

5.4 Livestock parameters

Livestock parameters such as live weight and milk production, which will impact energy and protein requirements of livestock can be changed in the worksheet ‘Livestock parameters’. Calculations pertaining to livestock energy requirements are mainly based on the National Research Council publication for dairy cattle (2001).

Parameters needed include:

- Average Body weight (kg)
- Grazing displacement (km/day)
- Energy requirements and Crude Protein requirements for (Grazing, Pregnancy, lactation, live weight gain)
- Calving internal (years)

- Live weight gain (kg/year)
- Protein and fat content of milk (%)
- Carcass fraction

5.5 Economics parameters

These characteristics should be calculated in USD. They include:

- **Price of Cow/Goat/Sheep per kg:**
  - Manure
  - Meat
  - Milk
- **Opportunity Cost of land:** how much profit the land would obtain if business as usual.
- **Discount rate:** a percentage given by governments central banks
- Number of years indicates how many years you are running the technology for

5.6 SOC parameters

SOC parameters provide inputs for changes in carbon stocks in both mineral and organic soils and are expressed as relative stock change factors (IPCC default values) for both cropland and grassland.

- Relative stock change factors for different management activities on cropland
- Relative stock change factors for grassland management

Cropland

For cropland they depend on:

- Land use (long-term cultivated, paddy rice, perennial/tree crop and fallow)
- Tillage (full, reduced, no-tillage)
- Nutrient input level (low, medium, high without manure, high with manure)

in combination with:

- climate regime (temperate, tropical, tropical montane), and
- moisture regime (dry, moist, wet).

Grassland

For grassland they depend on management (nominally managed, moderately degraded, severely degraded, improved grassland) and, only for improved grassland, input level (medium, high), in combination with climate regime (temperate, tropical, tropical montane).

Land use changes (e.g., cropland to grassland) fall beyond the scope of this model.

5.7 Soil erosion parameters

These are characteristics are based of the calculations explained (in section 7.6). The data is based on (Adigun, A et al 2014), however it can be adjusted based on experimental or literature data. These include the:

- Management P factor
- Erodibility of soil (K value)
- Cover (C) factor
- LS factor
- Horizontal slope length in (m and ft.)

5.8 GHG parameters

These characteristic are adopted from IPCC guideline and they include:

- Methane Emissions from livestock
- Methane Emission factor
- Methane emissions from manure management
- N2O emission from managed soils
- Rice emissions factors
- N manure, N fertilizer & volatilization

6 Calculations

6.1 Feed

The green “feed” calculation sheet is the core of the **CLEANED** model. It estimates the feed intake requirements of the livestock enterprise’s animal herd.

In a first step, the quality of the animals’ feed baskets is calculated (section 6.1.1). In parallel, the energy and crude protein requirements of the animals are established (sections 6.1.3and 6.1.4). Matching these two, the actual feed intake requirements are estimated (section 6.1.5).

6.1.1 Feed Basket Quality (CP%, DE fraction, MJ/kg fresh matter, DM%)

The quality of the overall feed basket is calculated for each season. Feed basket quality characteristics calculated include the percentage of crude protein (CP%), the fraction of digestible energy (DE fraction), the metabolisable energy content (ME content) and dry matter content (DM content). The calculations are based on the quality characteristics of the individual feed items (described in the feed parameters sheet) and their relative importance/contributions to (i.e. fractions of) the overall feed basket as provided by users in the input sheet.

$$CP\% = \sum CP\%_i * fraction_i \tag{1}$$

$$E\,fraction = \sum DE_i * fraction_i \tag{2}$$

$$ME\ content = \sum ME_i * fraction_i \tag{3}$$

$$DM\ content = \sum DM_i * fraction_i \tag{4}$$

$fraction_i$ is the fraction of feed item i in the overall feed basket (as fed). This is a user input

$CP\%_i$ is the crude protein content of feed item i, expressed in %. This is a feed parameter

$DE_i\ fraction$ is the Digestibility Energy fraction of Gross Energy (GE) of feed item i. This is a feed parameter

ME_i is the Metabolizable Energy content of feed item i. This is a feed parameter

DM_i is the Dry Matter content of feed item i. This is a feed parameter

6.1.2 Feed item fractions expressed as dry matter (fraction)

$$DM\ Fraction_i = fraction_i * DM_i / DM\ Content \tag{5}$$

6.1.3 Feed requirements – energy (MJ)

The total energy requirements per animal per day are calculated as the sum of requirements for (i) maintenance, (ii) locomotion (mainly grazing), (iii) pregnancy, (iv) lactation and (v) growth.

Daily energy requirements per animal are expressed as MJ/day. The total annual requirements per animal category are calculated by multiplying this daily requirement by 365 days/year and the number of animals of that category.

As energy requirements are assumed to be equal throughout the year, the length of seasons (which is user input) determines differences between season 1 (rainy) and season 2 (dry).

$$ME_{season\ j} = \Sigma\ ME_{season_{ij}} \quad (15)$$

$$ME_{season\_ij} = ME_{tot_i} * j \quad (14)$$

$$ME_{tot_i} = ME_{daily_i} * 365 * N_i \quad (13)$$

$$ME_{daily\ i} = \Sigma\ ME_{m_i} + ME_{lo_i} + ME_{p_i} * ME_{la_i} + ME_{g_i} \quad (12)$$

$$ME_{m_i} = 0.5 * Metabolic\ Weight\ (LWi)^{0.75} \quad (6)$$

$$ME_{lo_i} = ME_{lo_i} = 2(\ GE_i * DP_i\ ) \quad (7)$$

For local cows:

$$ME_{p_i} = 1260/CIi/365 \quad (8)$$

For Improved cows:

$$ME_{p_i} = 1500/CIi/365 \quad (9)$$

[6]Daily ME requirements local cows and improved cows

$$ME_{la_i} = LacReq_i * Milkprod_i \quad (10)$$

$$ME_{g_i} = GrowReqi * LWG_i \quad (11)$$

Where i indicates the different animal categories and j the different seasons.

ME_{season_j} is energy requirement for season j.
$Seasonlength_j$ is length of growing season j. It is calculated on the basis of the planting and harvest dates provided by user in the input sheet.
N_i is the total number of animals in category i. This is user input.
ME_{m_i} is the daily energy requirements for maintenance.
LW_i is Live Weight gain for animal category I (expressed in kg). This found in the Livestock parameters.
ME_{lo_i} is the total energy requirement for locomotion. Locomotion is animal displacement from the stable/enclosure to the pastures plus animal displacement because of grazing.
GEi is ME required per day for grazing for category i. This is expressed in MJ/km and found in the Livestock parameters.
DPi is the distance from the stable/enclosure to the pastures (km). This is a user input.

6 **Daily ME local cows** is the requirements during the last 4 months are 4, 6, 12 and 20 MJ respectively for local cows: this corresponds to a total of 1260 MJ for the pregnancy period
Daily ME improved cows is the requirements during the last 4 months are 5, 8, 14 and 23 MJ respectively for improved cows: this corresponds to a total of 1500 MJ for the pregnancy period

ME_{p_i} is the total energy requirement for pregnancy.

CI is calving interval, in years. This is found in the Livestock parameter sheet

ME_{la_i} is the total energy requirements for lactation.

$LacReq_i$ is the energy requirement for lactation of animal category i(ME, expressed in MJ/kgFPCM). This is found in the Livestock parameter sheet and is a user input.

$Milkprod_i$ is the average annual milk production of animal category i. This is a user input.

ME_{g_i} is the total energy requirement for growth.

$GrowReqi$ is the energy requirement for growing. This is expressed in MJ/kg LWG and is found in the Livestock parameters.

LWG_i is the annual Live Weight gain for animal category i. This is user input.

6.1.4 Protein and requirements, expressed as kg crude protein (CP)

As protein requirements are assumed to be equal throughout the year, the length of seasons (which is user input) determine differences between season 1 (rainy) and season 2 (dry). Locomotion was excluded from this equation as the proportion of protein requirements for locomotion is very low in comparison to the other components and this component is therefore not taken into consideration[7].

$$CP_{season\_i} = \Sigma\, CP_{season_i} \tag{25}$$

$$CP_{season\_i} = CP_{tot_i} * Seasonlength_i \tag{23}$$

$$CP_{tot_i} = CP_{daily_i} * 365 * N_i \tag{22}$$

$$CP_{daily_i} = \Sigma\, CP_{m_i} + CP_{p_i} + CP_{la_i} + CP_{g_i} \tag{21}$$

$$CP_{m_i} = 0.001 * LW \tag{16}$$

For local cows:

$$CP_{p_i} = 9.64/Cl/365 \tag{17}$$

For Improved cows:

$$CP_{p_i} = 12.21/Cl/365 \tag{18}$$

$$CPCP_{la_i} = 0\,.09 * FPCM_{tot} \tag{19}$$

$$CP_{g_i} = 0.4 * LWG_{tot} \tag{20}$$

7 (N*6.25) 6.25 is a factor used to calculate how much protein is there when the value of N is known

[8]Daily Metabolisable Protein (MP) requirements local and improved cows

CI is calving interval, in years. This is found in the Livestock parameter sheet and is a user input.

CP_{la_i} is the total protein requirements for lactation.

CP_{m_i} is the total protein requirement for maintenance.

LW is Live Weight in kg. This found in the Livestock parameter and is a user input.

CP_{p_i} is the total protein requirement for pregnancy. CP requirement is 0.09 kg per kg of FPCM. This is found in the Livestock parameter sheet and is a user input.

$FPCM_{tot}$ is the total kg of fat and protein corrected milk produced at the farm. This is found in the Livestock parameter sheet and is a user input.

CP_{g_i} is the total protein requirement for growth. CP requirement is 0.4 kg per 1 kg of Live Weight Gain. This is found in the Livestock parameter sheet and is a user input.

LWG_{tot} is the total Live Weight gain.

6.1.5 Feed intake requirements

To estimate the actual feed intake requirements, the requirements to satisfy the energy and CP requirements are first estimated separately. The required dry matter intake associated with the energy and CP requirements are then compared and the maximum taken as the overall intake requirement to meet both energy and CP requirements. These calculations are done for each season and for all the animal categories. The summation of all provides an overall enterprise level feed intake requirement.

$$FIRE_{ij} = \frac{ME_{season\_j}}{ME_{content_j}} \tag{26}$$

$$DMIRE_{ij} = FIRE_{ij} * DM_{content_j} \tag{28}$$

$$FIRP_{ij} = \frac{CP_{season\_j}}{CP\%_j} \tag{27}$$

$$DMIRP_{ij} = FIRP_{ij} * DM_{content_j} \tag{28}$$

$$DMIR_{ij} = max(DMIRE_{ij}, DMIRP_{ij})$$

$$MEI_{ij} = DMIR_{ij} * ME_{content_j} \tag{29}$$

$$DEI_{ij} = MEI_{ij} * 0.81 \tag{30}$$

$$GEI_{ij} = DMIR_{ij} * 18.45 \tag{31}$$

8 **Daily Metabolisable Protein (MP) local cows**' requirements during the last 4 months are 20, 35, 60 and 110 g respectively: with a conversion factor of 0.7 from CP to MP this corresponds to a total of 9.64 kg of CP for the pregnancy period.
Daily Metabolisable Protein (MP) improved cows' requirements during the last 4 months are 25, 45, 75 and 140 g respectively: with a conversion factor of 0.7 from CP to MP this corresponds to a total of 12.21 kg of CP for the pregnancy period.

$$DEI = \sum DEI_{ij} \tag{29}$$

$\boldsymbol{FIRE_{ij}}$ is Fresh Intake Required to satisfy animal category $\boldsymbol{i}$'s energy requirement in season $\boldsymbol{j}$ (kg/year).

$\boldsymbol{DMIRE_{ij}}$ is the dry matter requirement to satisfy animal category $\boldsymbol{i}$'s energy requirement in season $\boldsymbol{j}$ (kg /year).

$\boldsymbol{FIRP_{ij}}$ is Fresh Intake Required to satisfy animal category $\boldsymbol{i}$'s protein requirement in season $\boldsymbol{j}$ (kg/year).

$\boldsymbol{DMIRP_{ij}}$ is the dry matter requirement to satisfy animal category $\boldsymbol{i}$'s protein requirement in season $\boldsymbol{j}$ (kg/year).

$\boldsymbol{DMIR_{ij}}$ is Dry Matter Intake required to satisfy both the energy and protein requirements of animal category $\boldsymbol{i}$ in season $\boldsymbol{j}$.

$\boldsymbol{MEI_{ij}}$ is ME intake required to satisfy both the energy and protein requirements of animal category $\boldsymbol{i}$ in season $\boldsymbol{j}$ (MJ/year).

$\boldsymbol{DEI_{ij}}$ is Digestible Energy intake required to satisfy both the energy and protein requirements of animal category $\boldsymbol{i}$ in season $\boldsymbol{j}$ (MJ/year).

$\boldsymbol{GEI_{ij}}$ is Gross Energy intake required to satisfy both the energy and protein requirements of animal category $\boldsymbol{i}$ in season $\boldsymbol{j}$ (MJ/year). This calculation is based on average contents of carbohydrates (17 MJ/kg), protein (17 MJ/kg) and fat (38 MJ/kg), the latter in usually very low proportion.

6.2 Land requirement

Total land area needed to grow the feed required to feed all animals in the livestock enterprise is calculated based on feed intake requirements and biomass production (crops and crop residues) parameters and removal values.

$$Area_{tot} = \sum Area_{ij} \tag{33}$$

$$Area_{ij} = DMI_j * \frac{DMFraction_i}{Yield_i * Removal_i} \tag{32}$$

With

$\boldsymbol{i}$ between 1 and 7 for all 7 feed items

$\boldsymbol{J, C}$ (dry season and wet season respectively)

$\boldsymbol{Area_{tot}}$ is the total area of landed needed to feed all animals that are part of the livestock enterprise; expressed in ha.

$\boldsymbol{Area_{ij}}$ is the area needed to grow the necessary quantity of feed item $\boldsymbol{i}$ in season $\boldsymbol{j}$ (ha)

$\boldsymbol{DMI_j}$ is the Dry Matter intake in season $\boldsymbol{j}$. Section 7.1 describes how this is calculated.

$\boldsymbol{DMFraction_i}$ is the dry matter fraction of the total feed basket consisting of feed item $\boldsymbol{i}$. Section 7.1.2 describes how this is calculated

$\boldsymbol{Yield_i}$ is the crop or crop residue yield (depending on the feed item type). This is a crop parameter.

$Removal_i$ is the fraction of the crop or crop residue production that is used as feed (in contrast to being left on the soil or burnt). This is a user input.

Purchased feed items are assumed to not require any land as these are considered to be imported from outside the system.

6.3 Productivity

The productivity is a potential supply indicator. It calculates the total amount of calories produced by the livestock enterprise by multiplying the quantity of livestock products by their calorie contents. Productivity is the annual energy produced from all farm products (kcal/yr).

6.3.1 Meat & Milk (kg/year, kcal/year, AME days)

In this worksheet there is a simple model that produces total live weight gains in kg/year, based on average weight gains of calves and heifers/steers for three productivity levels.

Apart from the weight gains, the following assumptions are made:

- Adult animals do not grow anymore
- Mortality is negligible

1. Milk_FPCM

Total annual milk production is calculated by multiplying the number of milking cows with an average milk production per cow.

$$Milk_{FPCM} = Milk_{raw} * (0.337 + 0.116 * Fat\ content + 0.06 * Protein\ content) \tag{35}$$

$$Milk_{raw} = Milk_{cow} * N \tag{34}$$

$Milk_{FPCM}$ is the total annual fat and protein corrected milk produced on the livestock enterprise (kg/year)

$Milk_{raw}$ is the total milk production on the livestock enterprise (kg/year)

$Milk_{cow}$ is the average annual milk production of a dairy cow (kg/year). This is user input.

N is the number of dairy cows in the livestock enterprise. This is a user input.

Fat content is the fat content of the milk expressed in %. This is a livestock parameter.

Protein content is the protein content of the milk expressed in %. This is a livestock parameter.

2. Milk_kcal

$$Milk_{kcal} = Milk_{FPCM} * energy\ content \tag{36}$$

$Milk_{kcal}$ is the total number of calories produced from milk (kcal/year).

energy content is the energy content of the milk (kcal/kg). This is a livestock parameter.

3. Milk_AME

$$Milk_{AME} = \frac{Milk_{kcal}}{2500} \tag{37}$$

$Milk_{AME}$ is the number of days that the milk produced by the livestock enterprise could meet the energy requirements of one Adult Male Equivalent (AME). The assumption is that one Adult Male Equivalent (MAE) requires 2500 kcal/day.

4. Meat_kg

Total annual meat production is based on the total weight gain of the livestock herd. As the model assumes that adult animals don't grow anymore, total weight gain is based on average weight gains of calves and heifers/steers only. The changes in the herd composition are assumed to be driven by:

- **Transition between categories:** each year 50% of the calves become a heifers/steers and 50% of the heifers/steers become adults.
- **Births/calving:** calculated based on the calving interval.

$$Meat_{kg\,i} = LWG_{kg\,i} * Carcas\%_i \tag{41}$$

$$LWG_{kg} = N_{growingcalves} * WGain_{calves} + N_{growingyoung} * WGain_{young} \tag{40}$$

$$N_{growingcalves} = 0.5 * \left(N_{calves} + \frac{N_{cows}}{Calving\ interval}\right) \tag{39}$$

$$N_{growingyoung} = 0.5 * (N_{calves} + N_{young}) \tag{38}$$

$Meat_{kg\,i}$ is Meat production by animal category ***i***.

$Carcass\%_i$ is the carcass fraction of animal category ***i***. This is a livestock parameter.

LWG_{kg} is total Live Weight Gain livestock

$N_{growingcalves}$ is average number of calves during one year

$N_{growingyoung}$ is average number of steers/heifers during one year

N_{calves} is the number of calves present in the livestock enterprise at the start. This is a user input.

N_{young} is the number of steers and heifers present in the livestock enterprise at the start. This is a user input.

N_{cows} is the number of (female) cows present in the livestock enterprise. This is a user input.

Calving interval is the period of time elapsing between two consecutive parturitions. It is expressed in years. This is a livestock parameter.

$WGain_{calves}$ is the average weight gain of calves expressed in kg/year. This is a user input.

$WGain_{young}$ is the average weight gain of heifers and steers expressed in kg/year. This is user input.

5. Meat_kcal

$$Meat_{kcal} = Meat_{kg} * energy\ content \tag{42}$$

$Meat_{kcal}$ is total number of calories produced from meat expressed as kcal/year.

Energy content is the energy content of the meat expressed in kcal/kg meat. This is a livestock parameter.

6. Meat_AME

$$Meat_{AME} = \frac{Meat_{kcal}}{2500} \tag{43}$$

$Meat_{AME}$ is the number of days that the meat produced by the livestock enterprise could meet the energy requirements of one Adult Male Equivalent (AME). The assumption is that one Adult Male Equivalent (MAE) requires 2500 kcal/day.

7. Protein_kg

$$Protein_{kg} = \sum \frac{Meat_{kg} \text{ x } PCMe}{100} + \frac{Milk_{raw} \text{ x } PCMi}{100} \tag{44}$$

$Protein_{kg}$ is the total amount of protein from the livestock enterprise.
$PCMe$ is the protein content percentage in meat. This a livestock parameter.
$PCMi$ is the protein content percentage in milk. This a livestock parameter.

6.3.2 Manure Production

This calculates the amount of N available in manure produced.

This is based on IPCC calculations and is described in section 7.8.2

$$Manure_i = \frac{DMIR_{ij}}{365} * 0.365 \tag{45}$$

$Manure_i$ is the total amount of manure produced in kg/year in each livestock category i.

6.4 Economics

6.4.1 Value of production

The only calculation done in terms of economics for the baseline farm is the Total Value of Production (VOP) of the livestock enterprise. Livestock commodities taken into account are meat, milk and manure. When introducing a new technology, additional economic calculations are performed. They are described in section 7.4.2 -7.4.46.4.2 – 6.4.4.

$$TVP_{base} = \sum Meat_{base} * MeatP_i + Milk_{base} * MilkP_i + Manure_{base} * ManureP_i \tag{46}$$

TVP_{base} is the total Value of Production of the livestock enterprise (expressed in $).

$Meat_{base}$ is the amount of meat produced in the enterprise with baseline setup. The method for calculating can be found in 6.3.1 equation 41.

$MeatP_i$ is the price of meat ($/kg). This is found in the economics parameter sheet.

$Milk_{base}$ is the amount of milk produced in the enterprise with baseline setup. The method for calculating can be found in 6.3.1 equation 33.

$MilkP_i$ is the price of milk ($/kg). This is found in the economics parameter sheet.

$Manure_{base}$ is the amount of manure produced in the enterprise with baseline setup. The method for calculating can be found in 6.3.2 equation 45.

$ManureP_i$ is the price of manure ($/kg). This is found in the economics parameter sheet.

$$TVP_{Bha} = \frac{TVP_{base}}{Area_{tot}} \tag{47}$$

TVP_{Bha} is the Total Value of Production (USD) per/ha in the baseline enterprise setup.

$Area_{tot}$ is the total area of land used for feed production. The calculations are described in section 7.2 equation no 33.

6.4.2 Gross Margin

6.4.2.1 Introduction

The Gross Margin indicator is the value of the extra cash flow that could be generated by the enterprise due to the introduction of the new technology or alternative livestock production setup (as described in the scenario). It is calculated on the basis of the potential increases of cash flow. It is calculated on a 10-year basis following formula 60.

$$Extra\ Gross\ Margin = \sum Extra\ Cashflow_i \tag{60}$$

With

i representing year 1 to 10

The extra cash flow is the difference between the extra income that can be obtained from the livestock enterprise due to the scenario implementation and the cost of implementing this scenario. Three investment or cost categories are being considered: investments in feed, investments in the animal herd, and other investments (e.g. infrastructure) – see also section *"Extra Cost 'Only to be filled for scenarios'"*. For each of these categories, different types of costs are included:

1. **One-off or establishment costs:** these only occur in year 1. They include both monetary investments and labour investments;
2. **Operational costs:** these are annual costs associated with the maintenance of the investment. Again, these include both monetary investments and labour investments. The operational costs are assumed to be constant over the 10 years' period of analysis.

For the feed items an extra "opportunity cost" is being considered. This represents the value of an alternative use of the land that used for feed production.

$$ExtraCashflow_i = \Delta TVP_i - TC_i \tag{59}$$

$$\Delta TVP_i = Meat_i * MeatP_i + Milk_i * MilkP_i + Manure_i * ManureP_i - TVP_{base} \quad (48)$$

$$TC_i = TOOC_i + TOPC_i + TOPPC_i \quad (58)$$

ExtraCashflowi is the total extra profits in year ***i***.

ΔTVP_i is the difference in value of production between the new setup and the baseline setup of the livestock enterprise.

TVP_{base} is the total value of production from the baseline farm (see above).

$Meat_i$ is the amount of meat produced in the enterprise with baseline setup. The method for calculating can be found in 6.3.1 equation 41.

$Milk_i$ is the amount of milk produced in the enterprise with baseline setup. The method for calculating can be found in 6.3.1 equation 33.

$MilkP_i$ is the price of milk ($/kg). This is found in the economics parameter sheet.

$Manure_i$ is the amount of manure produced in the enterprise with baseline setup. The method for calculating can be found in 6.3.2 equation 45.

TC_i is the total cost needed for the implementation of the technological innovation/scenario in year ***i***.

$TOOC_i$ is the total capital/one-off cost for the implementation of a technological innovation/scenario in year ***i***. This is assumed to be zero for years 2 to 10.

$TOPC_i$ is the total operational cost for the implementation of a technological innovation/scenario in year ***i***.

$TOPPC_i$ is the total opportunity cost for the implementation of a technological innovation/scenario in year ***i***.

6.4.2.2 One-off costs

One-off costs associated with changes in animal herd, feed baskets and other are included. They are only calculated for year 1.

$$TOOC_1 = \sum AOOC_j + \sum_{k=1}^{7} FOOC_k + \sum_{l=1}^{n} OOOC_l \quad (52)$$

With

j = 1 to 9 for each of the animal categories (cows-local, cows-improved, adult cattle, steers/heifers, calves, steers/heifers-improved, calves-improved, sheep, goats)

k = 1 to 7 for each of the feed items

l = 1 to n for each of the other investments

$$AOOC_j = \Delta Herdsize_j * [OODC_j + OOLC_j * PriceLabour] \quad (51)$$

$$FOOC_k = \Delta LR_k * [OODC_k + OOLC_k * PriceLabour] \quad (50)$$

$$OOOC_l = OODC_l + OOLC_l * PriceLabour \quad (49)$$

$AOOC_j$ is the total one-off cost associated with changes in the numbers of animals of category ***j***.

$FOOC_k$ is the total one-off cost associated with changes in the feed item ***ki***.

$OOOC_l$ is the total one-off cost associated with investment l.

$\Delta Herdsize_j$ is the change in herd size in terms of category j. This is calculated by the tool as the difference between the number of animals in category j in the scenario and the number of animals in category j in the baseline setup.

ΔLR_k is the change in land requirement for growing feed item k. This is calculated by the tool.

$OODC_j$ is the one-off cost associated with one animal of category j (\$/animal).

$OODC_k$ is the one-off cost associated with one hectare of feed item k (\$/ha).

$OODC_l$ is the one-off cost associated with investment l (\$).

$OOLC_j$ is the one-off labour days needed for an extra animal of category j (days/animal).

$OOLC_k$ is the one-off labour days needed for an extra hectare of feed item k (days/ha).

$OOLC_l$ is the one-off labour days needed for investment l (days).

$PriceLabour$ is the price of labor (\$/day). This is found in the economic parameter sheet.

6.4.2.3 Operational costs

Operational costs associated with changes in animal herd, feed baskets and other are included. They are assumed to be the same every year.

$$TOPC_i = \sum AOPC_j + \sum_{k=1}^{7} FOPC_k + \sum_{l=1}^{n} OOPC_l \tag{56}$$

With

j = 1 to 9 for each of the animal categories (cows-local, cows-improved, adult cattle, steers/heifers, calves, steers/heifers-improved, calves-improved, sheep, goats).
k = 1 to 7 for each of the feed items.
l = 1 to n for each of the other investments.

$$AOPC_j = \Delta Herdsize_j * [OPDC_j + OPLC_j * PriceLabour] \tag{55}$$

$$FOPC_k = \Delta LR_k * [OPDC_k + OPLC_k * PriceLabour] \tag{54}$$

$$OOPC_l = OPDC_l + OPLC_l * PriceLabour \tag{53}$$

$AOPC_j$ is the total operational cost associated with changes in the numbers of animals of category j in.

$FOPC_k$ is the total operational cost associated with changes in the feed item k in.

$OOPC_l$ is the total operational cost associated with investment l.

$\Delta Herdsize_j$ is the change in herd size in terms of category j. This is calculated by the tool as the difference between the number of animals in category j in the scenario and the number of animals in category j in the baseline setup.

ΔLR_k is the change in land requirement for growing feed item k. This is calculated by the tool.

$OPDC_j$ is the operational cost associated with one animal of category j (\$/animal).

$OPDC_k$ is the operational cost associated with one hectare of feed item k (\$/ha).

$OPDC_l$ is the operational cost associated with investment l (\$).

$OPLC_j$ is the labour days needed for maintaining one animal of category j (days/animal).

$OPLC_k$ is the labour days needed for maintaining one hectare of feed item k (days/ha).

$OPLC_l$ is the labour days needed for maintaining investment l (days).

$PriceLabour$ is the price of labor ($/day). This is found in the economic parameter sheet.

6.4.2.4 Opportunity costs

The scenarios almost always entail (direct or indirect) changes in feed baskets, feed requirements and thus the requirements for land for feed production. This land is assumed to be lost for other production purposes and thus to be associated with an opportunity cost (assumed constant over the different years).

$$FOPPC_k = \sum_{k=1}^{7} LR_k * OppLand \tag{57}$$

With

k = 1 to 7 for each of the feed items

$FOPPC_k$ is the opportunity cost associated with changes in the feed item k.

ΔLR_k is the change in land requirement for growing feed item k. This is calculated by the tool.

$OppLand$ is the opportunity cost of a hectare of land ($/ha). This is found in the economic parameter sheet.

6.4.2.5 Net present value

$$NPV = -TC_1 + \sum_{i=1}^{T} \frac{Cashflow_i}{(1+r)_i} \tag{61}$$

NPV is the net present value

T is the time which is 10 years

r is the discount rate which is a user input

6.4.3 Return on investment

$$ROI = \sum \frac{(TVP_1 - TC_1)}{TC_1} + \frac{(TVP_i - TC_i)}{TC_i} \tag{62}$$

ROI is the Return On Investment

6.4.4 Payback period

$$DPP = \ln\left(\frac{1}{1 - \frac{r \times TC_1}{Cashflowyear_1 + Cashflowyear_i}}\right) \div \ln(1 + r) \tag{63}$$

DPP is Number of years necessary to pay back the initial investment known as the payback period

r is the rate which a user input

6.5 N balance

The nitrogen balance is based on the Nutrient Monitoring (NUTMON) methodologies (Bosch et al., 1998; Stoorvogel et al., 1993).

6.5.1 Inputs

6.5.1.1 IN1: Mineral fertilizer

$$IN1 = F_{SN} \tag{64}$$

$IN1$ is the N content of the mineral fertilizer applied to fields per hectare (in N kg. yr^{-1})

F_{SN} is the annual amount of synthetic fertiliser N applied to soil (kg N.yr^{-1}). It is given by the user in the input worksheet.

6.5.1.2 IN2: Manure

$$IN2 = F_{ON} \tag{65}$$

$IN2$ is the N content of the manure applied to the field (in N kg. yr^{-1})

F_{ON} is the annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (kg N.yr^{-1}). It is calculated from (102, following Tier 1. Additional purchases organic fertilizers are given by the user in the input worksheet.

6.5.1.3 IN3: Atmospheric deposition

$$IN3 = 0.14 \times \sqrt{rainfall} \times A \tag{66}$$

$IN3$ is the N content of the atmospheric deposition (in N kg. yr^{-1})

0.14 is a coefficient of atmospheric deposition of N per hectare and per amount of rainfall in kg.ha^{-1}.$mm^{-1/2}$

$rainfall$ is the annual rainfall in the region given by the user in the input worksheet.

A is the area cultivated in ha. This information is given in by the user in the input worksheet.

6.5.1.4 IN4: Biological N-fixation

$$IN4 = Nnosymbiotic + Nsymbiotic \tag{67}$$

$IN4$ is the N fixation (in N kg. yr^{-1})

$Nnosymbiotic$is the Non symbiotic N fixation by crops. It is calculated from (67).

$Nsymbiotic$ is the Symbiotic N fixation by crops (N fixing crops only). It is calculated from (66).

$$Nnosymbiotic = (2 + (rainfall - 1350) \times 0.005) \times A \tag{70}$$

A is the area cultivated in ha. This information is given in by the user in the input worksheet.

$rainfall$ is the annual rainfall in the region. This information is given in by the user in the input worksheet.

$$Nsymbiotic = 0.5 \times \sum_{c} A_c \times Yl_c \times N_c \tag{71}$$

A_c is the area of cultivation (in ha) under crop c. This information is given in by the user in the input worksheet.

Yl_c is the yield of the crop c (in kg.ha^{-1}). The information is available in the crop parameter worksheet.

N_c is the N content of the crop c (in percentage of N in the total crop and crop residue produced). It is calculated from (72).

0.5 is a constant

$$N_c = (1 - HI_c) \times DMcr_c \times Nres_c + (HI_c \times DM_c \times Ncrop_c) \tag{72}$$

HI_c is the harvest index of the crop c (in %). The information is available in the crop parameter worksheet.

$DMcr_c$ is the Dry matter content of residues (in %). The information is available in the crop parameter worksheet.

DM_c is the Dry matter content of the crop (in %). The information is available in the crop parameter worksheet.

$Nres_c$ is the N content of the crop residue (kg N . kg CR^{-1}). The information is available in the crop parameter worksheet.

$Ncrop_c$ is the N content of the crop (kg N . kg crop^{-1}). The information is available in the crop parameter worksheet.

6.5.2 Outputs

6.5.2.1 OUT1: Crop yield

$$OUT1 = \sum_{c} A_c \times Yl_c \times HI_c \times DM_c \times Ncrop_c \tag{73}$$

$OUT1$ is the N content of crop harvested (in kg N .yr^{-1})

A_c is the area of cultivation (in ha) under crop c. This information is given in by the user in the input worksheet.

Yl_c is the yield of the crop c (in t.ha^{-1}). The information is available in the crop parameter worksheet.

HI_c is the harvest index of the crop c (in %). The information is available in the crop parameter worksheet.

DM_c is the Dry matter content of crop (in %). The information is available in the crop parameter worksheet.

$Ncrop_c$ is the N content of the crop (kg N. kg crop). The information is available in the crop parameter worksheet.

6.5.2.2 OUT2: Crop residue

$$OUT2 = \sum_{c} A_c \times Yl_c \times (1 - HI_c) \times DMcr_c \times Ncr_c \times (1 - mulch_c) \quad (74)$$

$OUT2$ is the N content of crop residue removed (in kg N .yr^{-1})

A_c is the area of cultivation (in ha) under crop c. This information is given in by the user in the input worksheet.

Yl_c is the yield of the crop c (in t.ha^{-1}). The information is available in the crop parameter worksheet.

HI_c is the harvest index of the crop c (in %). The information is available in the crop parameter worksheet.

$DMcr_c$ is the Dry matter content of residues (in %). The information is available in the crop parameter worksheet.

Ncr_c is the N content of the crop residue (kg N . kg CR). The information is available in the crop parameter worksheet.

$mulch_c$ is the fraction of crop residues that is kept as mulch . This information is given in by the user in the input worksheet.

6.5.2.3 OUT3: Leaching

From Smaling 1993:

$$OUT3 = (Ncontent \times A + IN1 + IN2) \times (\alpha_s \times rainfall + \beta_s) \quad (75)$$

$OUT3$ is the N content leaching (in N kg. yr^{-1}).

$Ncontent$ is the N content of soil (in kg N. ha^{-1}). The information is computed from (83).

A is the total area cultivated in ha.

$IN1$ and $IN2$ are defined previously and are respectively the N content from fertilizer—equation (64), and manure—equation (65).

$rainfall$ is the annual rainfall in the region.

α_s and β_s are parameters varying depending on the clay content of the soil. The clay content is defined by the user in the inputs worksheet.

$$Ncontent = 0.1 \times soilN \times BD \times SD \quad (76)$$

$soilN$ is the weight of N per unit of weight of soil in ppm (or mg N.kg^{-1})

BD is the bulk density (in g.cm^{-3}). The information is defined by the user in the input worksheet.

SD is the soil depth (in cm). The information is set at 20cm.

6.5.2.4 Out 4: Gaseous losses

$$OUT4 = (Ncontent \times A + IN1 + IN2) \times [(0.13 \times soilClay - 9.4) + (0.01 \times rainfall)] \quad (77)$$

$OUT4$ is the N content from gaseous losses (in N kg. yr^{-1})

$Ncontent$ is the N content of soil (in kg N. ha^{-1}). The information is computed from (76).

A is the total area cultivated in ha.

IN1 and ***IN2*** are defined previously and are respectively the N content from fertilizer—equation (64), and manure—equation (65).

rainfall is the annual rainfall in the region.

soilClay is the clay content of the soil (in %).

6.5.2.5 OUT5: Erosion

$$OUT5 = erosion \times Ncontent \times 1.5 \times A \tag{78}$$

OUT5 is the N content from erosion (in N kg. yr^{-1})

erosion is the soil loss in $kg.ha^{-1}$. It is calculated from (86).

A is the total area cultivated in ha.

Ncontent is the N content of soil (in kg N. ha^{-1}). The information is computed from (79).

1.5 is a constant

6.6 Soil erosion

This equation is based on the revised universal soil loss equation (Renard et al. 1991).

$$Erosion = R \times K \times LS \times C \times P \tag{79}$$

R is the erosivity of rainfall. This is calculated as a function of the average monthly rainfall (mm).

K is the erodibility of soil. ***K*** values are dependent on the soil type which is defined by the user in the input worksheet. The K-factors default values are stored in the soil erosion parameter worksheet.

LS is the length and steepness of slope. The ***LS*** values are dependent on the slope and length which are defined by the user in the input worksheet. The LS factors default values are stored in the soil erosion parameter worksheet.

C is the crop cover factor. The ***C*** values are dependent on the crop. The ***C***-factors default values are stored in the crop parameter worksheet

P is the management factor. The ***P*** values is set to a default of 0.8 for all agricultural land. Changes in the P values from different management practices have to be input manually to reflect their impact on soil erosion.

6.7 Water

This indicator estimated the amount of water used for feed production. This indicator is not only expressed as absolute value but also as the fraction of the total rainfall and per kg of proteins produced on the livestock enterprise.

Crop water requirements are represented by the actual crop evapotranspiration. Evapotranspiration (ET) is a term used to describe the water consumed by plants over a period of time.

$$Et = Et_o \times kc_{avg} \tag{80}$$

$$\%PPTfeed = \frac{Et}{Annual\ ppt} \tag{81}$$

$$TWU = Et \times Area_{tot} \tag{82}$$

$$WU_{protein} = \frac{TWU}{Protein_{kg}} \tag{83}$$

Et is Evapotranspiration is the crop water requirements represented as (mm/year)

Et_o is the reference evapotranspiration of a crop per day it should be multiplied by 365 to get the yearly total

kc_{avg} is the average crop coefficient

$\%PPTfeed$ is fraction of precipitation used for feed production

$Annual\ ppt$ is annual amount of rainfall

WU_{meat} is the water need to produce meat represented as (m3/kg meat)

$WU_{protein}$ is the water need to produce protein represented as (m3/kg protein)

In addition, the water use disaggregated per crop is estimated as follows:

$$WU_{cropfeedi} = Et_{ci} \times \frac{Area_{ij}}{Area_{tot}} \tag{85}$$

$WU_{cropfeedi}$ is the amount of water need for growth for each crop feed to the animals represented as (m^3)

$$Et_{ci} = avgKc_i * Annual\ ppt \tag{84}$$

Et_{ci} is the evapotranspiration per crop represented as

$$avgKc_i = Kc_i * Area_{ij} \tag{86}$$

$avgKc_i$ is the average crop co-efficient for crop i.

6.8 Greenhouse gas emissions

The majority of equations are based on the 2006 IPPC Guidelines for National Greenhouse Gas Inventories.

6.8.1 Enteric Fermentation

The methane emissions from enteric fermentation of the entire herd are derived from the sum of the methane emissions from enteric fermentation of each animal species present on the farm.

$$CH4_{enteric} = \sum_{g} EF_g \times N_g \quad (87)$$

$CH4_{Enteric}$ is the methane emissions from Enteric Fermentation (kg CH4.yr^{-1})

EF_g is the emission factor for the defined livestock species/category (kg CH4 head^{-1}. yr^{-1}). The value changes if we consider Tier 1 or Tier 2 calculation.

N_g is the number of head of livestock species g on the farm. This information is available is provided in the input worksheet.

IPCC Tier 1

We consider 10 categories of livestock:

Table 1 emission factors enteric fermentation Tier 1

	CATEGORY	EFG (KG CH_4.HEAD^{-1}.YEAR^{-1})
1	Dairy cows-Local	46
2	Dairy cows-Improved	32
3	Adult cattle-Male	41
4	Steers/heifers	41
5	Calves	16
7	Sheep	5
8	Goats	5

IPCC Tier 2

The Emission Factor Tier 2 is only computed for the cattle (dairy cows, calves or other cattle):

$$EF_g = \frac{GE_g \times 365 \times \left(\frac{YM_g}{100} \right)}{55.65} \quad (88)$$

EF_g is the emission factor of livestock species g, in kg CH4.head^{-1}.yr^{-1}.

GE_g is the daily gross energy intake of livestock species g, in MJ head^{-1}.day^{-1}. It is calculated from (31).

Ym_g is the methane conversion factor of livestock species g, i.e. the percentage of gross energy in feed converted to methane. Default values from the IPCC are used.

6.8.2 Methane emissions from manure

The methane emissions from manure of the entire herd are derived from the sum of the methane emissions from manure from each animal species present on the farm (4).

$$CH4_{manure} = \sum_{g} EF_g \times N_g \quad (89)$$

$CH4_{manure}$ is the methane emissions form manure management, in kg CH4. yr^{-1}

EF_g is the emission factor for the defined livestock species g, in kg CH4. head^{-1}. yr^{-1}. The value changes if we consider Tier 1 or Tier 2 calculation.

N_g is the number of head of livestock from species g. This information is given in the input worksheet by user.

IPCC Tier 1

Default values are in found under the Manure worksheet:

Table 2 Emission factor methane from manure Tier 1

CATEGORY	EFG (KG CH4.HEAD^{-1}.YEAR^{-1})
Dairy cows-Local	1
Dairy cows-Improved	1
Adult cattle-Male	1
Steers/heifers	1
Calves	1
Sheep	0.15
Goats	0.17

IPCC Tier 2

$$EF_g = (VS_g \times 365) \times \left(Bo_g \times 0.67 \times \sum_{s,c} \frac{MCF_{SC}}{100} \times MS_{gSC} \right) \tag{90}$$

EF_g is the annual methane emission factor for livestock species g, in kg CH4.head^{-1}.yr^{-1}.

VS_g is the daily volatile solid excreted for livestock species g, in kg DM.head^{-1}.day^{-1} . It is calculated in equation (91).

Bo_g is the maximum methane producing capacity for manure produced by livestock species g (m^3 CH_4. kg^{-1} of VS excreted). Default values are in the GHG parameters worksheet.

MCF_{SC} is the methane conversion factors for the manure management system S. Default values are in the GHG parameters worksheet. The manure management system is given by the user in the input worksheet.

MS_{gSC} is fraction of livestock category g's manure handled using manure management system S in climate region C.

$$VS_g = [GE_g \times (1 - DE_g) + (UE \times GE_g)] \times \frac{1 - ASH}{18.45} \tag{91}$$

GE_g is the daily gross energy intake of species g, in MJ head^{-1}.day^{-1}.

DE_g is the digestibility of the feed in % for the specie g. It is computed from equation (2).

UE is the urinary energy expressed as a fraction of GE. It is saved in the parameter list under the name 'UE'. Typically 0.04 x GE can be considered urinary energy excretion by most ruminants.

ASH is the ash content of the manure calculated as a fraction of the dry matter feed intake. It is saved in the GHG parameter worksheet (e.g. 0.08 for cattle).

18.45 is the conversion factor for dietary GE per kg of DM (MJ. day^{-1}). It is saved in the GHG parameter worksheet. This value is relatively constant across a wide range of forage and grain-based feed commonly consumed by livestock.

6.8.3 Nitrogen excretion from manure

IPCC Tier 1

$$Nex_g = N_{rate\ g} \times \frac{BW_g}{1000} \times 365 \tag{92}$$

Nex_g is the annual N excretion for livestock species g (kg N. head^{-1}.yr-1)

$N_{rate\ g}$ is the default N excretion rate for livestock species g, in kg N. t animal^{-1}. day^{-1}. The values are in the Manure worksheet.

BW_g is the body weight for livestock species g, in kg. It is given in the livestock parameter worksheet.

IPCC Tier 2

$$Nex_g = N_{intake\ g} \times (1 - N_{retention\ g}) \tag{93}$$

Nex_g is the annual N excretion for livestock species g (kg N. head^{-1}. yr^{-1}).

$N_{intake\ g}$ is the annual N intake per head of animal of species g (kg N. head^{-1}. yr^{-1}). It is calculated following equation (94).

$N_{retention\ g}$ is the fraction of annual N intake that is retained by the livestock species g. The values are in the Manure worksheet.

$$N_{intake\ g} = \frac{GE_g}{18.45} \times \frac{CP_g}{6.25} \times 365 \tag{94}$$

GE_g is the daily gross energy intake of species g, in MJ head^{-1}.day^{-1}. It is calculated from (31).

CP_g is the percent crude protein in diet for the specie g. It is computed from equation (25).

18.45 is the conversion factor for dietary GE per kg of dry matter (MJ. kg-1).

6.25 is the conversion factor from kg of dietary protein to kg of dietary (N.).

6.8.4 Direct N_2O emissions from manure

$$N2O_{dir} = \sum_g (N_g \times Nex_g \times MS_g) \times EF3_s \times \frac{44}{28} \tag{95}$$

$N2O_{dir}$ is direct N_2O emissions from Manure Management (kg N_2O. yr^{-1})

N_g is the number of head of livestock from species g. This information is given by the user in the input worksheet.

Nex_g is the annual average N excretion rate per head of livestock species g at the farm (in kg N . head^{-1} .yr^{-1}). It is calculated following equation (93)—Tier 1 and equation (94)—Tier 2).

MS_g is the percentage of the total manure excreted collected by the household. It is calculating following (96).

$EF3_s$ is the emission factor for direct N_2O emissions from manure management system S (kg N_2O^{-N}. kg N^{-1} in manure management system S). The manure management system is informed by the user in the input worksheet.

$44/28$ is the conversion of (N_2O^{-N}) emissions to N_2O emissions.

$$MS_g = \sum_{l} time_{g,l} \times collected_l \tag{96}$$

$time_{g,l}$ is the proportion of time spent by species ***g*** in the location ***l***. This is informed by the user in the input worksheet.

$collected_l$ is the percentage of manure collected in the location ***l***. This is informed by the user in the input worksheet.

6.8.5 Indirect N_2O emissions from manure

$$N_2O_{MM} = N_{volatilization\text{-}MMS} \times EF_4 \times \frac{44}{28} \tag{97}$$

N_2O_{MM} is the indirect N_2O emissions due to volatilization of N from Manure Management on the farm (kg $N_2O.yr^{-1}$)

$N_{volatilization\text{-}MMS}$ is the amount of manure nitrogen that is lost due to volatilisation of NH_3 and NO_x (in kg $N.yr^{-1}$). It is calculated from (98).

EF4 is the emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, in kg N_2O^{-N} (kg NH_3^{-N} + NO_x^{-N} volatilized)$^{-1}$. It is saved in the GHG parameters worksheet.

44/28 is the conversion of (N_2O^{-N}) emissions to N_2O emissions.

$$N_{volatilization\text{-}MMS} = \sum_{g} \left[(N_g \times Nex_g \times MS_g) \times \left(\frac{Fracgas_s}{100} \right)_g \right] \tag{98}$$

N_g is the number of head of livestock from species ***g***. This information is given by the user in the input worksheet.

Nex_g is the annual average N excretion rate per head of livestock species g at the farm (in kg N . head$_{-1}$ .yr$_{-1}$). It is calculated following equation (93)—Tier 1 and equation (94)—Tier 2).

MS_g is the percentage of the total manure excreted collected by the household. It is calculating following (105).

$Fracgas_s$ is the percent of managed manure nitrogen for livestock category ***g*** that volatilizes as NH_3 and NO_x in the manure management system ***s***. The manure management system is given by the user in the input worksheet and default values of EF2 are in the GHG parameters worksheet.

6.8.6 Direct N2O-N emissions from managed soils

$$N_2O_{direct}{}^{-N} = N_2O^{-N}{}_{N\,inputs} + N_2O^{-N}{}_{grazed} \tag{99}$$

N_2O_{direct}-N is the annual direct ***$N2O^{-N}$*** emissions produced from managed soils, in kg $N2O^{-N}.yr^{-1}$.

$N_2O^{-N}{}_{N\,inputs}$ is the annual direct ***$N2O^{-N}$*** emissions from N inputs to managed soils, in kg N2O-N.yr-1. It is calculated following equation (100).

$N_2O^{-N}{}_{grazed}$ is the annual direct ***$N2O^{-N}$*** emissions from urine and dung inputs to grazed soils, in kg $N_2O^{-N}.yr^{-1}$. It is calculated following equation (101).

$$N_2O^{-N}{}_{N\,inputs} = \sum_c (F_{SN} + F_{ON} + F_{CR}) \times EF1_c \tag{100}$$

F_{SN} is the annual amount of synthetic fertilizer N applied to soils, in kg N.yr^{-1}. The information is given by the user in the input worksheet.

F_{ON} is the annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils, in kg N.yr^{-1}. It is calculated from equation (111).

F_{CR} is the annual amount of N in crop residues (above-ground and below-ground), including N-fixing crops, and from forage/pasture renewal, returned to soils, in kg N.yr^{-1}. It is calculated from equation (112).

$EF1_c$ is the emission factor for N_2O emissions from N inputs, in kg N_2O^{-N}.(kg N.input)$^{-1}$. The value is different if the crop is rice or not. It is saved in GHG parameters worksheet.

$$N_2O^{-N}{}_{grazed} = \sum_g Nex_g \times N_g \times time_{field,g} \times (1 - collected_{field}) \times EF3_g \tag{101}$$

Nex_g is the annual average N excretion rate per head of livestock species g at the farm (in kg N . head^{-1} .yr^{-1}). It is calculated following equation (93)—Tier 1 and equation (94)—Tier 2).

N_g is the number of head of livestock species g. This information is given by the user in the input worksheet.

$time_{field,g}$ is percentage of time spent by species g on the field. This information is given by the user in the input worksheet.

$collected_{field}$ is the percentage of manure collected from the field. This information is given by the user in the input worksheet.

$EF3_g$ is the emission factor for N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals, in kg N_2O^{-N}.(kg N.input)$^{-1}$. The values are defined in the parameters and are different for Cattle, Poultry and Pigs (EF3.soil.CPP), and Sheep and Other animals (EF3.soil.SO).

$$F_{ON} = \sum_g (Nex_g \times N_g \times MS_g) \times \%fert + manure \tag{102}$$

$\%fert$ is the percentage of manure collected used on the field. This information is given by the user in the input worksheet.

$manure$ is the percentage of manure bought, in kg N.yr^{-1}. This information is given by the user in the input worksheet.

$$F_{CR} = \sum_c A_c \times Yl_c \times (1 - HI_c) \times DMcr_c \times Ncr_c \times mulch_c \tag{103}$$

A_c is the area of cultivation (in ha) under crop c. This information is given by the user in the input worksheet.

Yl_c is the yield of the crop c (in kg.ha^{-1}). The information is available in the crop parameters worksheet.

HI_c is the harvest index of the crop c (in percentage). The information is available in the crop parameters worksheet.

$DMcr_c$ is the Dry matter content of residues (in %). The information is available in the crop parameters worksheet.

Ncr_c is the N content of the crop residue (kg N. kg CR). The information is available in the crop parameters worksheet.

$mulch_c$ is the fraction of crop residues that is kept as mulch. The information is given by the user in the input worksheet.

Assumptions:

$N_2O^{-N}_{os}$, the annual direct N_2O^{-N} emissions from managed organic soils is ignored and assumed to be null , the annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management (kg $N.yr^{-1}$) is ignored and assumed to be null.

At the moment only above ground residues are considered in the calculations.

6.8.7 Indirect N_2O^{-N} emissions from managed soils

$$N_2O_{(ATD)} - N = [(F_{SN} \times Frac_{GAS\ F}) + (F_{ON} + F_{PRP}) \times Frac_{GAS\ M}] \times EF_4 \tag{104}$$

$N_2O_{(ATD)} - N$ is the annual amount of N_2O – N produced from atmospheric deposition of N volatilized from managed soils (in kg $N_2O^{-N}.yr^{-1}$)

F_{SN} is the annual amount of synthetic fertilizer N applied to soils, in kg $N.yr^{-1}$. This information is given by the user in the input worksheet.

$Frac_{GAS\ F}$ is the fraction of synthetic fertilizer N that volatilizes as NH_3 and NO_x, expressed in kg N volatilized. (kg of N applied)$^{-1}$. The value is saved the GHG parameters worksheet.

F_{ON} is the annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils, in kg $N.yr^{-1}$. It is calculated from equation (102).

F_{PRP} is the annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock (in kg $N.yr^{-1}$). It is similar to $N_2O - N_{grazed}$ calculated from equation (100) but without multiplying by EF3.

$Frac_{GAS\ M}$ is the fraction of applied organic N fertilizer materials and of urine and dung N deposited by grazing animals that volatilizes as NH_3 and NO_x, expressed in kg N volatilized. (kg of N applied or deposited)$^{-1}$. The value is saved in the GHG parameter worksheet.

EF_4 is the emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, expressed in kg N – N_2O (kg NH_3 – N + NO_x – N volatilised)$^{-1}$. The value is saved in the GHG parameter worksheet.

Rice - Methane emissions from rice production

$$CH_{4\ Rice} = \sum_i EF_i \times t_i \times A_i \tag{105}$$

$CH_{4\ Rice}$ is the annual methane emissions from rice cultivation in kg CH_4. yr^{-1}.

EF_i is a daily emission factor for i condition, in kg $CH_4.ha^{-1}.day^{-1}$. It is calculated from (106).

t_i is the cultivation period of rice for i condition in days. The values are given by the user in the input worksheet.

A_i is the annual harvested area of rice for i condition, in ha. The area is given input worksheet.

$$EF_i = EF_c \times SF_w \times SF_p \times SF_o \tag{106}$$

EF_c is the baseline emission factor for continuously flooded fields without organic amendments. The value is saved in the GHG parameter worksheet.

SF_w is the scaling factor to account for the differences in water regime during the cultivation period. The water regime during the cultivation period is given by the user in the input worksheet. Default values of SF_w are saved in the GHG parameter worksheet.

SF_p is the scaling factor to account for the differences in water regime in the pre-season before the cultivation period. The water regime in the pre-season is given by the user in the input worksheet. Default values of SF_p are saved in the GHG parameter worksheet.

SF_o is the scaling factor which vary for both type and amount of organic amendment applied. It is calculated following equation (107).

$$SF_o = 1 + F_{CR} \times CFOA_{cr} + F_{ON} \times CFOA_{man} \tag{107}$$

F_{CR} is the annual amount of N in crop residues (above-ground and below-ground), including N-fixing crops, and from forage/pasture renewal, returned to soils, in kg N. yr^{-1}. It is calculated from equation (103), only what is applied to rice is taken into account here.

F_{ON} is the annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils, in kg N.yr^{-1}. It is calculated from equation (64), only what is applied to rice is taken into account here.

6.8.8 Crop residue burning

$$L_{fire} = M_B \times C_f \times G_{ef} \tag{108}$$

L_{fire} is the amount of greenhouse gas emissions from fire (in kg $CH_4.yr^{-1}$, kg $N_2O.yr^{-1}$ and kg $CO_2.yr^{-1}$).

M_B is the mass of fuel available for combustion, in tons. It is calculated from (109).

C_f is the combustion factor, dimensionless. The value is saved in the worksheet burning.

G_{ef} is the emission factor, in g. kg dry matter burnt^{-1}) The values depend on the gas, they are saved in the burning worksheet.

$$M_B = \sum_c A_c \times Yl_c \times (1 - HI_c) \times DMcr_c \times burnt_c \tag{109}$$

A_c is the area of cultivation (in ha) under crop c. This information is given by the user in the input worksheet.

Yl_c is the yield of the crop c (in $t.ha^{-1}$). The information is available in the crop parameter worksheet.

HI_c is the harvest index of the crop c (in percentage). The information is available in the crop parameter worksheet.

$DMcr_c$ is the Dry matter content of residues (in %). The information is available in the crop parameter worksheet.

$burnt_c$ is the fraction of crop residues that is burnt. This information is given by the user in the input worksheet.

6.8.9 Off-farm emission

Off-farm emissions are currently calculated for the emissions generated from the production of various fertilizers: Urea, CAN, DAP, NPK and lime.

$$\textit{Emission off-farm fertilizers} = \sum_i EF_i \times q_i \tag{110}$$

Emission off-farm fertilizers is the annual greenhouse gas emissions from the production of fertilizers, off-farm in kg CO_2 eq. yr^{-1}.

q_i is the quantity of fertilizer ***i*** used on the farm. This information is given by the user in the input worksheet.

EF_i is the emission factor for the production of fertilizer ***i***. Default emission factors for the various fertilizers can be found the Off-farm emissions worksheet.

All the previous emissions are converted to CO_2 equivalent (either 23 kg CO_2.kg $CH3^{-1}$ or 310 kg CO_2.kg $N2O^{-1}$). GHG emissions intensities per milk production are given in Fat and Protein Corrected Milk (FPCM) following the conversions explained in FAO (2010).

6.9 Soil Organic Carbon

Annual changes in carbon stocks are calculated using the following equations, for both cropland and grassland.

$$RefCStock = BD \times SD \times Csoil \times 10$$

RefCStock: Reference carbon stock (tonnes/ha), default value: 30

BD: bulk density (g/cm^3). This is an area parameter.

SD: Soil depth (m). This is an area parameter.

Csoil: soil carbon content (g/kg). This is an area parameter.

$$\Delta C = \frac{(RefCstock \times FLU \times FMG \times FI) - RefCStock}{D} * A \tag{111}$$

ΔC: annual change in carbon stock (tonnes/year).

RefCStock: Reference carbon stock (tonnes/ha), default value: 30.

FLU: Stock change factor for land use. This is a SOC parameter.

FMG: Stock change factor for management. This is a SOC parameter.

FI: Stock change factor for input level. This is a SOC parameter.

A: area (ha).

D: Number of years over a single inventory time (default value: 20).

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