Description of the optimized CLEANED tool

Version 2

By Catherine Pfeifer (ILRI), Joanne Morris (SEI), Mats Lannerstad

August 2016

Contents

1 Introduction

CLEANED (Comprehensive Livestock Environmental Assessment for Improved Nutrition, a Secured Environment and Sustainable Development along Livestock Value Chains) is a quick ex-ante environmental impact assessment tool that allows the user to explore multiple impacts of intensifying a value chain in a spatially explicit way.

CLEANED models the impact of intensifying livestock along three pathways, namely pressure on water, greenhouse gas emissions and biodiversity loss. (Soils is still up-coming)

The tool is meant to be used in on-going innovation processes in value chains to support decision makers to understand environmental impacts of intensification and develop more inclusive and sustainable livestock intensification plans that mitigate negative impacts and enhance the positive ones. Such a tool requires, therefore, that it can be implemented with relatively little effort and data collection in new areas, yet be locally relevant and allow for near real time scenarios testing.

CLEANED therefore relies mainly on secondary data, namely on a set of geographical layers that are available at least for the African continent and parameters that can be extracted from open access databases. The CLEANED approach, the procedure for using the tool in an innovation process, also foresees a preliminary participatory GIS workshop that not only validates the secondary data, but also defines the locally relevant livestock system, namely the feed basket and manure management. In addition, an initial scenario exercise at this stage helps to understand plausible futures that are in the decision-makers' minds and allow where necessary to adjust the code to make these visions testable.

The current version of the CLEANED tool has been optimized and now runs each pathway within minutes, given alternative scenarios, and therefore can be used live in a workshop. This first version of CLEANED is coded and parameterized for the small-scale dairy value chain in Lushoto, Tanzania.

The structure of this report is as follows. First the overall approach is discussed. Then major dynamics that are modelled are described for each pathway as well as all the data that is used in the CLEANED tool. The code section discusses how the major dynamics have been implemented in a spatially explicit way.

2 Approach

This section describes the overall approach as well as the resulting base assumptions of the model.

2.1 Choice of the modelled pathways

'*Livestock's long shadow*' (Steinfeld et al., 2006) identifies 3 environmental issues resulting from livestock, namely :

A. Climate change and air pollution that is sub-divided into
    a. Carbon cycle
    b. Nitrogen cycle
B. Water depletion and pollution

C. Biodiversity

Climate change is the disturbance of the fragile equilibrium of different key environmental processes that regulate temperatures and distribute water on earth. Livestock production impacts climate change mainly by intervening in the carbon and the nitrogen cycle.

Livestock contribute to an increase in carbon dioxide in different ways. Next to livestock respiration, methane is released from the breakdown of manure, and carbon dioxide is released through land-use change for feed production, land degradation or fossil fuel use in order to maintain a cold chain for animal products.

CLEANED computes the impact of livestock on the carbon cycle by computing the emission in CO_2 equivalents in the greenhouse gas pathway; next to enteric fermentation, it also includes manure management and the impact of land use change for feed production.

'*Livestock's long shadow*' focuses mainly on the livestock contribution to nitrogen emissions to the atmosphere, through losses when fertilizing feed and fodder crops, losses from manure storage and wasting of nitrogen in the livestock production chain in relation to fertilization of crop. CLEANED models the nitrogen losses from stored manure within the greenhouse gas pathway. However the wasting in the production chain is addressed in the (upcoming) soil health pathway. Indeed, soil health is a good indicator for assessing the balance or deficit between the nitrogen that is consumed in producing biomass for feed and fodder to support livestock and nitrogen that is returned to the soil in manure. This also allows CLEANED to explore an until-today untapped opportunity to investigate a potentially positive impact of livestock intensification on soil health. Nitrogen loss from badly-managed fertilization is at the current stage not modelled in CLEANED.

Livestock water consumption comes mainly from the feed and fodder production rather than from livestock drinking water. Water depletion is therefore modelled in CLEANED in the water pathway that compares the volume of water required for feed and fodder production (as evapotranspiration) with the volume of rainfall received. Irrigation and water pollution is not yet part of the CLEANED assessment.

Finally, livestock threatens biodiversity through habitat change that results from any additional land use change to meet the feed and fodder demand. CLEANED assesses biodiversity by focusing on endangered species and their habitat change.

2.2 The landscape scale approach

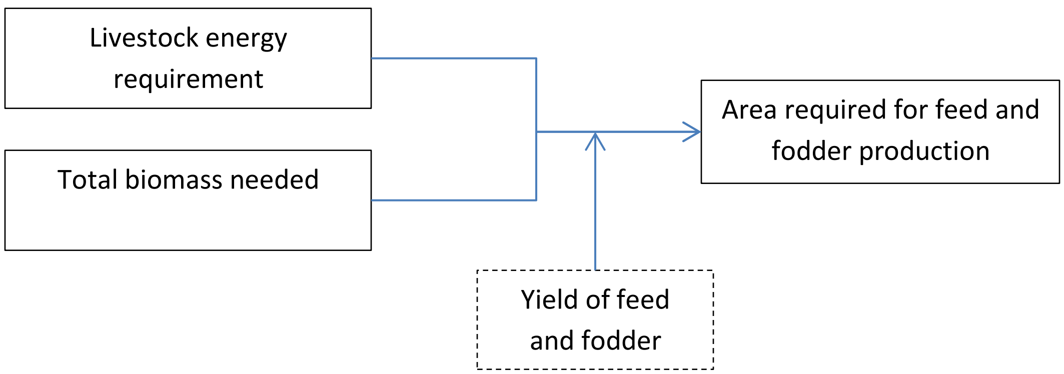
Livestock intensification can take very different shapes at farm scale: smallholders are getting more animals, some smallholders are commercializing and becoming small and medium agri-entrepreneurs, and some big commercial farms are industrializing the sector. The outcome in a given value chain is likely to be context specific. In order to avoid making assumptions about the evolution of farm sizes, CLEANED models the landscape as a whole and uses a spatial allocation model to assign the environmental impact.

3 Major dynamics

3.1 The core of the CLEANED model: the feed basket computation

At the core of the CLEANED model is the feed basket computation that computes the feed intake requirement of landscape's herd of livestock, which also drives most environmental impacts.

In most simple words, CLEANED first computes the energy requirement from an average animal (dairy cow in Tanzania). Then the energy from an average feed basket is computed. The comparison of both allows to define the volume of biomass, in the ratio of the feedbasket, needed to feed the livestock in the value chain. Yield of each feed allows to compute the land necessary for feeding the livestock in the value chain. This computation is an input to all CLEANED pathways.



3.1.1 Energy requirement

Energy requirement is computed for the average animal. For the particular case of Tanzania, a simplified version of the (Tier 2) calculations in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories have been used to compute the energy requirement of dairy cattle. The simplification made was to base the energy required only on a lactating dairy cow, without considering the herd composition or growth rates, assuming that the lower energy requirement of the young is balanced by the higher energy requirement of bulls.

As such we used the following Tier 1 equations in *Chapter 10: Emissions from Livestock and Manure Management* of *Volume 4: Agriculture, Forestry and Other Land Use*:

A. net energy requirement for maintenance (Equation 10.3)

$$NE_m = Cf_i \times (weight)^{0.75}$$

Where:

NE_m = net energy required by the animal for maintenance (MJ day^{-1})
Cf_i = a coefficient which varies for each animal category, for lactating cattle is 0.386 (MJ day^{-1} kg^{-1})
Weight = weight of the user-defined average animal (kg)

B. Net energy requirement for activity (Equation 10.4)

$$NE_a = C_a \times NE_m$$

Where:

NE_a = net energy required by the animal for activity (MJ day^{-1})

C_a = a coefficient corresponding to animals feeding situation; semi-intensive and intensive system have been considered as zero grazing and extensive system as pasture. C_a is therefore a weighted average of 0.0 (zero grazing) and 0.17 (pasture) depending on the percent of each animal in both systems

NE_m = net energy required by the animal for maintenance (computed above, Eq. 10.3)

D. Net energy requirement for lactation for beef cattle, dairy cattle and buffalo (Equation 10.8)

$$NE_l = milk \times (1.47 + 0.4 \times fat)$$

Where:

NE_l = net energy required by the animal for lactation (MJ day^{-1})

milk = milk production of the average animal, for Tanzania a cow in the extensive system was assumed to be 200 kg and 250 kg in the semi-intensive system (kg milk day^{-1})

fat = fat content has been assumed 3.5% (% by weight)

Total energy per cow is then given by:

$$ERC = NE_m + NE_a + NE_l$$

ERC can be multiplied by the number of cows in the landscape which is given by statistics, to give the total average energy requirement of the landscape's livestock.

The following equations in the guidelines have been omitted as we do not model the herd:

1. net energy for growth (Equation 10.6)
2. net energy for work (Equation 10.11)
3. net energy for pregnancy (Equation 10.13)

In addition, the concept of gross energy requirement is often required within the greenhouse gas pathway and is computed as follows (Equation 10.16) adjusted for CLEANED (i.e. no herd model)

$$GE = \left[\frac{\frac{NE_m + NE_a + NE_l}{REM}}{\frac{DE\%}{100}} \right]$$

Where:

GE = gross energy (MJ day^{-1})
NE_m = net energy required by the animal for maintenance (MJ day^{-1}, Eq. 10.3)
NE_a = net energy for animal activity (MJ day^{-1}, Eq. 10.4)
NE_l = net energy for lactation (MJ day^{-1}, Eq. 10.8)
REM = ratio of net energy available in a diet for maintenance to digestible energy consumed (Eq. 10.14)
DE% = digestible energy expressed as a percentage of gross energy (average based on DE per crop in the feedbasket ratio)

REM is given by Equation 10.14:

$$REM = \left[1.123 - (4.092 \times 10^{-3} \times DE\%) + [1.126 \times 10^{-5} \times DE\%^2] - \frac{25.4}{DE\%}\right]$$

Where:
REM = ratio of net energy available in a diet for maintenance to digestible energy consumed
DE% = digestible energy expressed as a percentage of gross energy

3.1.2 Total biomass needed

To compute the total biomass required per cow, the fresh weight required of each item in the average feed basket has to be computed as follows:

$$fw_i = \frac{f_i \times ERC}{ME_i}$$

Where:
fw_i = fresh weight of feed basket item i (kg)
f_i = fraction of item i in the whole feed basket
ERC = energy requirement per cow (MJ day^{-1})
ME_i = metabolisable energy in terms of fresh weight of item i (MJ kg fw^{-1})

Metabolisable energy is usually reported in terms of dry matter content, therefore needs to be computed to fresh weight as follows:

$$ME_i = DM_i \times MEdm_i$$

Where:
DM_i = dry matter content of item i (%)
$MEdm_i$ = Metabolisable energy in terms of dry matter content of item i (MJ kg DM^{-1})

The total biomass needed from the landscape is therefore:

$$fw = \sum_i fw_i$$

3.1.3 Area need for feed and fodder production

Area needed per item i is computed as follows:

$$A_i = \frac{fw_i}{yield_i}$$

Where:

A_i = area needed for item i (ha)

fw_i = fresh weight needed of item i (kg)

$yield_i$ = yield of item i (kg ha^{-1})

However, the yield of a given item might not be straight forward. Indeed, when the fodder is crop residue, the yield in terms of grains has to be transformed into a yield in terms of crop residue. Also there are post-harvest losses. We have summarized all these computations into a variable *residue factor*.

$$yield_i = rf_i * raw\_yield_i$$

Where:

rf_i = residue factor for item i

raw_yield = yield as usually reported for item i, in terms of grain for cereals, biomass for grazes (kg ha^{-1})

The area needed for feed and fodder production will also define imports. To define the import, a maximum of land available for a given feed or fodder has to be defined. Feed have therefore to be split in categories based on which land use they correspond to. Whereas natural grass comes from grazing land, crop residues and planted fodder comes from cropland. Because CLEANED is a landscape level model, and in Tanzania the information about where each feed and fodder is grown is not available due to the heterogeneous nature of vegetation cover, CLEANED makes the assumption that every cell classified in one land use produces every item in the feed basket proportionally. Therefore, the maximum area available for a given item in the feed basket will be the proportion of that item compared with the other items growing on the same land use. For example, crop residues, legume residues and planted fodder are all grown on crop land, so the share of crop residue out of the three cropland feed/ fodder types will be used to define the maximum of area available to growing crops.

$$MaxA_i = \frac{A_{i,LU}}{\sum_i A_{i,LU}} \times A_{LU}$$

The difference between the maximum area allocation to an item and the area need for production defines if there is an import.

3.2 Water pathway

The water pathway at this stage in CLEANED just computes the water needed for the feed production that is assumed to be rainfed. As such, the current model ignores irrigation, soil moisture and water quality.

The retained indicator is water use intensity to assess impact on water, which is therefore given by the ratio of water used for feed and fodder production to the rainfall received, over the study area:

$$WUI = \frac{WU}{R}$$

Where:
WUI = water use intensity
WU = volume of water used for feed and fodder production over the study area ($m^3\ yr^{-1}$)
R = volume of rainfall received over the study area ($m^3\ yr^{-1}$)

Water use is computed as follows:

$$WU = \sum_f ET_f \times A_f$$

Where:
WU = volume of water used for feed and fodder production ($m^3\ yr^{-1}$)
ET_f = evapotranspiration of feed/fodder item f ($m\ yr^{-1}$) (converted from $mm\ yr^{-1}$)
A_f = area that produces feed/fodder item f (m^2)

Rainfall received over the study area is computed as follows:

$$R = MAR \times A$$

Where:
R = volume of annual rainfall received over the study area ($m^3\ yr^{-1}$)
MAR = mean annual rainfall for the study area ($m\ yr^{-1}$) (converted from $mm\ yr^{-1}$)
A = area that produces feed/fodder item f (m^2)

3.3 Greenhouse gases

The greenhouse gas pathway has three components and subcomponents as shown in Figure 1:

1. Enteric fermentation
2. Emissions from manure
3. Emissions from feed and fodder production

For each component IPCC Tier 2 computations have been used with some little modification, except for the land management and land use change part for which Tier 1 computations have been used.

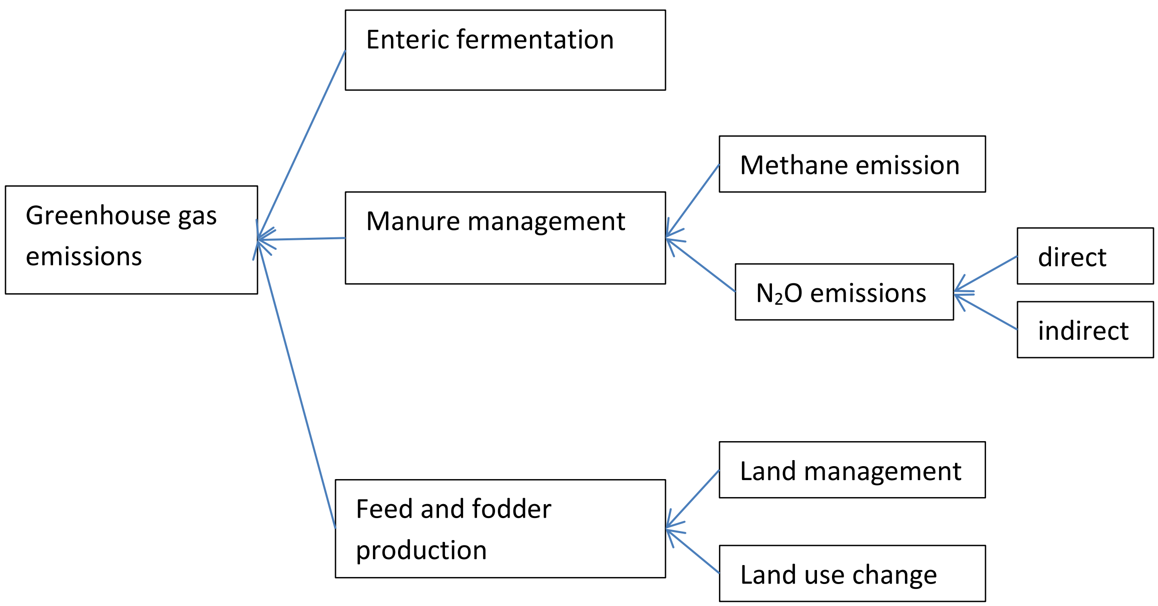


Figure 1 : Graphical representation of the greenhouse gas pathway

3.3.1 Enteric fermentation

Enteric fermentation has been computed by applying the updated IPCC Tier 2 approach for which a methane conversion factor (Y_m) has been computed as follows as proposed by Gerber (2011) as an improvement of the IPCC guideline for dairy systems.

$$Y_m = 9.75 - 0.05 * Digestiblity\ rate\ of\ feed$$

Digestibility rate of feed is computed based on the average feed basket.

The total emission is then computed based on Equation 10.21:

$$EF = \left[\frac{GE \times \frac{Y_m}{100} \times 365}{55.65}\right]$$

Where:

EF = emission factor (kg CH_4 head^{-1} year^{-1})

GE = the gross energy intake (MJ head^{-1} day^{-1}) and is computed following IPCC guideline by using equation 10.16 and presented in the feed basket computations (section 3.1.1)

Y_m = methane conversion factor as computed above

The factor 55.65 (MJ/kg CH4) is the energy content of methane

3.3.2 Emissions from manure

Emissions from manure are also based in IPCC Tier 2 computations. The calculation distinguishes between methane and N_2O emission. Also methane emission have two different sources, namely from manure storage and from manure spreading.

3.3.2.1 Methane emissions from manure management

Firstly, methane emissions from manure management are computed based on equation 10.23 that computes the emission factor in terms of kg CH_4 /animal/year for one livestock categories. For Tanzania, we used all parameters linked to dairy cows (dc).

$$EF_{dc} = (VS_{dc} \times 365) \times \left[B_{o,dc} \times 0.67 kg/m^3 \times \sum_{S,k} \frac{MCF_{S,k}}{100} \times MS_{dc,S,k}\right]$$

Where:

EF_{dc} = annual CH_4 emission factor for a dairy cow (kg CH_4 animal^{-1} yr^{-1})

VS_{dc} = daily volatile solid excreted for a dairy cow (kg dry matter animal^{-1} yr^{-1})

365 = basis for calculating annual VS production (days yr^{-1})

$B_{0,dc}$ = maximum methane producing capacity for manure produced by dairy cattle (m^3 CH_4 kg^{-1} of VS excreted)

0.67 = conversion factor of m^3 CH_4 to kg CH_4

$MCF_{(S,k)}$ = methane conversion factors for each manure management system S by climate region k (%)

$MS_{(dc,S,k)}$ = fraction of dairy cows' manure handled using manure management system S in climate region k (dimensionless)

For $MCF_{(S,k)}$ IPCC has standard values for dairy cows in different climatic zone (Table 10.17 in guidelines). For $MS_{(dc,S,k)}$ CLEANED uses either the user defined fraction or the IPCC standard value.

Volatile solids are driven by the feed basket as follows (Equation 10.24):

$$VS = \left[GE \times \left(1 - \frac{DE\%}{100}\right) + (UE \times GE)\right] \times \left[\left(\frac{1 - ASH}{18.45}\right)\right]$$

Where:

VS_{dc} = daily volatile solid excreted for dairy cows (kg dry matter animal^{-1} yr^{-1})
GE = gross energy intake resulting from the feed basket (MJ day^{-1})
DE% = digestibility of feed in percent
UE x GE = urinary energy expressed as fraction of GE. The typical value 0.04 as value for UE was used as suggested by the guidelines
ASH = ash content of manure as a fraction of the dry matter feed intake, when no country specific values are available then IPCC suggests to use 0.08 for cattle.
18.45 = conversion factor for dietary GE per kg of dry matter (MJ kg^{-1}). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock

The total emission from manure management is:

$$EM = EF_{dc} \times L$$

Where:
EM = total emission from manure (kg CH_4 yr^{-1})
EF_{dc} = annual CH_4 emission factor for a dairy cow (kg CH_4 animal^{-1} yr^{-1})
L = total amount of animals in the landscape

3.3.2.2 N_2O emissions from manure management

N_2O computation is split between direct and indirect emission.

Direct N_2O is computed according to Equation 10.25 of the guidelines:

$$N_2O = \left[\sum_S (N_{dc} \times Nex_{dc} \times MS_{dc,S}) \times EM_{3,(S)}\right] \times \frac{44}{28}$$

Where:

N_2O = direct N_2O from manure management (kg N_2O yr^{-1})
N_{dc} = number of dairy cow in the study area
Nex_{dc} = annual average excretion per head of dairy cow in Tanzania, this is computed based on IPCC standards (kg N animal^{-1} yr^{-1})
$MS_{dc,S}$ = fraction of total annual nitrogen excretion for dairy cow that is managed in manure management system S, which are either user defined or IPCC standards (dimensionless)
$EM_{3,(S)}$ = emission factor for direct N_2O emissions from manure management system S, we used IPCC standard namely 0.02 (kg N_2O-N/kg N in manure management system S)
S = manure management system
44/28 = conversion of N_2O-N emissions to N_2O emissions

Indirect N_2O emissions in Tier 2 methodology is the result of:

- N losses due to leaching from manure management systems
- Indirect N_2O emissions due to leaching from manure management system

Equation 10.28 defines the N losses due to leaching from manure management systems and is given by:

$$N_{leaching-MMS} = \sum_{S}\left[\left(N_{dc} \times Nex_{dc} \times MS_{dc,S}\right) \times \left(\frac{Frac_{leachMS}}{100}\right)_{dc,S}\right]$$

Where:

$N_{leaching\text{-}MMS}$ = amount of manure nitrogen that leached from manure management systems (kg N yr^{-1})

N_{dc} = number of dairy cow in the study area

Nex_{dc} =annual average N excretion per head of dairy cow in Tanzania, this is computed based on IPCC standards (kg N $animal^{-1}$ yr^{-1})

$MS_{dc,S}$ =fraction of total annual nitrogen excretion for dairy cows that is managed in manure management system S, which are or user defined or IPCC standards (dimensionless)

$Frac_{leachMS}$ = percent of managed manure nitrogen losses for dairy cows due to runoff and leaching during solid and liquid storage of manure, we used IPCC suggested standard

Equation 10.29 defines indirect N_2O emissions due to leaching from manure management:

$$N_2O_L = \left(N_{leaching-MMS} \times EF_5\right) \times \frac{44}{28}$$

Where:

N_2O_L = indirect N_2O emissions due to leaching and runoff from manure management (kg N_2O yr^{-1})

EF_5 = emission factor from N_2O emissions from nitrogen leaching and runoff, we used IPCC suggested standard (kg N_2O-N/kg N leached and runoff (default value 0.0075 kg N_2O-N (kg N leaching/runoff)$^{-1}$)

3.3.3 Emissions from feed and fodder production

Beyond emissions that are resulting directly from livestock production, feed and fodder production as such also produces emissions that the greenhouse gas pathway needs to account for. More specifically, feed and fodder production contribute to:

- carbon stock changes due to land use management,
- emissions from biomass decomposition and burning,
- fertilizer and lime application and production,
- anaerobic soil processes in rice production,
- the utilization of fossil fuels and electricity

- carbon stock exchange due land use change

As a matter of simplification, the current version of CLEANED focuses only on carbon stock change due to land-use management and to land use change.
The following dynamics where omitted because they are not significant or very difficult to model in the Tanzanian context:

- based on expert knowledge very little biomass is burned and could hardly be transformed into feeds
- rice production seems to outside of the current study area
- there is not yet much (if any) mechanization

Also CLEANED does not at this stage model any use of inorganic fertilizer, as very little fertilizer is used in the study area, only by a few farmers.

3.3.3.1 Carbon stock changes due to land use management

Carbon stock change due to land use management is modelled based on the IPCC tier 1 computation in *Chapter 2: Generic Methodologies Applicable to Multiple Land-use Categories* of *Volume 4: Agriculture, Forestry and Other Land Use.* The annual change in carbon stocks in soils is calculated according to Equation 2.24:

$$\Delta C_{soils} = \Delta C_{Mineral} - L_{organic} + \Delta C_{inorganic}$$

Where:

ΔC_{Soils} = annual change in carbon stocks in soils (tonnes C yr^{-1})
$\Delta C_{Mineral}$ = annual change in organic carbon stocks in mineral soils (tonnes C yr^{-1})
$L_{Organic}$ = annual loss of carbon from drained organic soils (tonnes C yr^{-1}). No organic soils in Africa so this was ignored
$\Delta C_{Inorganic}$ = annual change in inorganic carbon stocks from soils (tonnes C yr^{-1}). This is usually only modelled in Tier 3 and therefore omitted from CLEANED

Annual change in carbon stocks in mineral soils is calculated according to Equation 2.25:

$$\Delta C_{Mineral} = \frac{SOC_0 - SOC_{(0-T)}}{D}$$

Where:

$\Delta C_{Mineral}$ = annual change in organic carbon stocks in mineral soils (tonnes C yr^{-1})
SOC_0 = soil organic carbon stock in the last year of an inventory time period (tonnes C)
$SOC_{(0-T)}$ = soil organic carbon stock at the beginning of an inventory time period (tonnes C)
D = Default time period for transition between equilibrium SOC values (yr). Commonly 20 years

And:

$$SOC_0 = \sum_{c,s,i}\left(SOC_{REF_{c,s,i}} \times F_{LU_{c,s,i}} \times F_{MG_{c,s,i}} \times F_{I_{c,s,i}} \times A_{c,s,i}\right) \text{ and}$$

Where:

SOC_{REF} = reference carbon stock (tonnes C ha^{-1}) using IPCC standard values

F_{LU} = stock change factor for land-use systems or sub-system for a particular land-use (dimensionless)

F_{MG} = stock change factor for management regime (dimensionless)

F_I = stock change factor for input of organic matter such as crop residues and manure (dimensionless)

A = area of the stratum being estimated (ha). All land in the stratum should have common biophysical conditions (i.e., climate and soil type) and management history over the inventory time period to be treated together for analytical purposes

c = represents the climate zones

s = the soil types

i = the set of management systems

For the initial period we compute as follows

$$SOC_{0-T} = \sum_{c,s,i}\left(SOC_{REF_{c,s,i}} \times F_{LU_{c,s,i}} \times A_{c,s,i}\right)$$

Indeed CLEANED only model land use change to cropland. This means that the original land use is grazing land or forest, for which no management regime or inputs applies.

Although not included in current CLEANED calculations, the loss of carbon from drained soils will become important when rice is included in the modelling, and is calculated according to Equation 2.26:

$$L_{Organic} = \sum_{c}(A \times EF)_c$$

Where:

$L_{Organic}$ = annual loss of carbon from drained organic soils (tonnes C yr^{-1})

A = land area of drained organic soils in climate type *c* (ha)

EF = emission factor for climate type *c* (tonnes C ha^{-1} yr^{-1})

3.3.3.2 Land use change

Following the LEAP guidelines (2014), emissions from land use change should either be calculated using the IPCC 2006 / PAS2050 (BSI 2012) 20 year depreciation method, or Vellinga et al. (2013) global marginal annual land use change method.

To compute the emission from land use change we apply the stock-difference method (Equation 2.5) assuming the 20 years depreciation. Equation 2.5 computed carbon (C) that needs to be converted in CO_2. Resulting into the following equation

$$CO_{2(\frac{ha}{year})} = (CSR - CA) \times \frac{44}{12} \times \frac{1}{20}$$

Where:

$CO_{2(ha/year)}$ = CO_2 equivalent hectare^{-1} yr^{-1} over 20 years

CSR = carbon stock of reference scenario

CA = carbon stock of land use change scenario

44/12 = conversion rate from C to CO_2 (chapter 2.2.3 of guidelines)

1/20 = amortization over 20 years

3.4 Biodiversity

The biodiversity pathway computes two indicators, the species richness index and the number of species that become critically threatened as a result of the value chain development.

The species richness index is based on the full red list of endangered and critically endangered species whereas the numbers of species that are critically endangered in the landscape are those species who are critically endangered and make a critical use of the landscape. This is for example the case if a critically endangered bird is endangered because of the lack of brooding space and uses the landscape for brooding. However, if the landscape is not the brooding space, but just a stop during migration, then this bird does not fall within this category.

The species richness index is computed based on the endangered and critically endangered species list as follows:

$$SR_{LU} = \frac{\sum_i S_{i,LU}}{\sum_{i,LU} S_{i,LU}}$$

Where:

SR_{LU} = the species richness index on a given land use

S_i = species *i* from the endangered and critically endangered species list

Basically, the species index computed the ratio of species making use of a pixel given its land use to the total amount of species.

The amount of threatened critically endangered species in the landscape is given by:

$$CES_{LUC} = \sum_i CS_i$$

Where:

CES_{LUC} = number threatened critically endangered species in the landscape that make use of a given land use as habitat and that will be subject of a land use change.

CS_i = critically endangered species making a critical use of the landscape

4 Overall structure of the tool

The CLEANED tool is implemented in R and comes in a folder called CLEANED version 2. This folder has subfolders:

0. Raw data: this folder contains the original data, note that all spatial layers have WGS84 projection
1. Input: this file contains processed data that CLEANED calls upon
2. Preparation code: are codes that need be run before running CLEANED, either to process the raw data or to define a land use change scenario.
3. Cleaned: this is the core codes of CLEANED
4. Output: this is where the maps for the end user are stored
5. Documentation: documents and references that explain in further detail what the code does.

The core code of CLEANED also has different numbering. Codes starting with 0 are codes in which the end-user can set the definitions for the CLEANED run.

Codes starting with 1- are codes that run the different pathways, so *1-water* runs the water pathway. In principle, these codes should not be opened or touched by the end user.

Codes starting with 2- are base computation codes that are required by more than one pathway, these codes should not be opened or touched by the end user.

Note that the code is annotated with comments so that the code can be linked to this document.

5 Data (0-raw input)

CLEANED makes use of spatial and non-spatial data within its code, that cannot be influenced by the end user and therefore are part of the parameterization of CLEANED for a particular location and value chain.

5.1 Spatial data

With the exception of the land use layer, all other layers are globally available. All layers have to be in WGS84 long lat format. The land use map defines the resolution and the study area defines the boundary for which CLEANED is run.

Layer	Name	Source	Derived layers used in CLEANED (in 1-input)
Study area	Lushoto	GADM	Lushoto
Land use	Tanzania Land Cover 2010 Scheme II	RCMRD http://servirportal.rcmrd.org/layers/servir%3Atanzania_landcover_2010_scheme_ii	Cropland (annual and perennial) Grazing land Forests (planted, mangrove, dense, moderate, sparse, woodland) Grassland (open and closed) Bushland (open and closed) Wetland and waterbodies

			Settlement
Evapotranspiration	Lowland, highland and temperate maize Pulses Grassland with legumes Grassland	GAEZ http://gaez.fao.org/	Evapotranspiration maize Evapotranspiration pulses Evapotranspiration grassland Evapotranspiration legumes Evapotranspiration grassland
Yield	Maize Pulses	GAEZ	Yield maize Yield pulses
Suitability	Cereals Legumes	GAEZ	Suitability cereals Suitability legumes
Rainfall	Baseline precipitation	GAEZ	Rain
climate	IPCC climatic zones	JRC http://esdac.jrc.ec.europa.eu/projects/renewable-energy-directive	Tropical (montane, wet, moist, dry) Warm temperate (moist, dry) Cool temperate(moist, dry)
Soil	IPCC soil type classification	JRC (same than above)	Soilref (combined with climate)

5.2 Non-spatial data (0-raw input\data)

There is a certain amount of non-spatial data that need to be defined.

5.2.1 Feed basket parameters

These parameters are set in the 'parameter' excel, which has several sheets that compute the final parameters. Therefore the summarizing sheep 'para' needs to be saved into 1-input as *para.csv*.

The parameters that need to be defined need to be adjusted for the location in which CLEANED is run and for the feed basket.

Parameter	Source
Metabolizing energy for - Grass - Cereal residue (maize stover) - Legume residue - Planted fodder	ILRI feed database http://192.156.137.110/feeddb/FeedDB.html
Yield : - Grass - Planted fodder	ILRI feed database
Dry matter content : - Grass - Cereal residue - Legume residue - Oil seed cake - Cereal concentrate	ILRI feed database
Digestibility	ILRI feed database

- Grass - Cereal - Legumes - Planted fodder - Soil seed cake - Cereal concentrate	
Crop residue factor - Grass - Maize - Legume - Planted fodder	This is a factor that computes the relation between the reported yield (grain yield) and fodder, taking the harvest index and post-harvest loss Computed in the tab 'area_requirement' of sheet 'parameters' in 0-raw input folder

Another source of data could be the feed wiki under www.feedipedia.org .

5.2.2 The greenhouse gases parameters

The greenhouse gas parameters are Tier 2 IPCC global standards, made available in the IPCC 2006 guidelines. The code allows to select the country and species for which CLEANED is run, and selects the right standards automatically.

File name	Variables	
ghg_soil_reference_carbon	SOC_{REF}	From IPCC 2006, Volume 4, Table 2.3. All values in tonnes C ha^{-1} in 0-30 cm depth.
ghg_soil_stock_change	FLU, FMG, FI	From IPCC 2006, Volume 4, Table 5.5
GlobalForestResourcesAssessment2010	Dead organic matter forest (gfrdom)	Global Forest Resources Assessment 2010: http://www.fao.org/forestry/fra/fra2010/en/
MMS_Nloss	Nitrogen loss	From IPCC 2006, Volume 10, Table 10.22
MMS_Nrate	Excretion rate	From IPCC 2006, Volume 10, Table 10.19
MMSn2oEF	Emission factor for enteric fermentation	From IPCC 2006, Volume 10, Table 10.11
MMSparams	Manure management parameters for Equation 10.23 and percentage in each manure management system	From IPCC 2006, Volume 10, Table 10A-5
MMSspeciesTemp	Manure management methane emission factor	From IPCC 2006, Volume 10, Table 10.14

5.2.3 Species list for the biodiversity pathway

To assess biodiversity, the IUCN list has been used, from http://www.iucnredlist.org/. The endangered and critically endangered species have been extracted for the CLEANED area. Based on the habitat description of each species on the red list, habitat has been defined in terms of land use categories from the land use layer.

Also based on the red list description, species who are critically endangered and have a critical use of the landscape are identified. This information is provided in file *threatenedspecies.csv*.

6 Coding of the CLEANED tool

This section describes the different codes that constitute the CLEANED tool.

6.1 The preliminary modules (2-preparation code)

6.1.1 Spatial processing (spatial data)

The spatial processing code takes all the spatial data presented in Chapter 5.1 (Spatial data), clips all layers to the extent of the study area, resamples all raster to the same resolution as land use and creates all the derived layers.

In addition, this code also computes all the parameters for the carbon stock exchange rates namely for F_{LU} for cropland, perennial cropland, set aside and rice (see chapter 3.3.3.1 carbon stock changes due to land use management).

6.1.2 Land use change module

At current stage, CLEANED can only handle land use change to cropland. The tool requires a layer indicating which cells will be transformed to cropland, *addcrop*.

Land use change is exogenous to the CLEANED tool : the *addcrop* layer has to be defined by the end user. This layer can be defined during a stakeholder meeting, where decision makers have defined areas that will be converted to cropland. However, most of the time cropland is encroached from other land uses next to already existing plots. There are some user friendly land use change models, such as for example the CLUE model[1] , that lets stakeholders define land use change rules and recursively computes land changed over a certain period of time. However, studying land use change with this tool is a process on its own. Therefore CLEANED comes with a simplified land use change module, that computes a land use change as a one off (not recursive) calculation and converts only from any land use to cropland.

The conversion rule is based on distance to existing cropland and the suitability of land (from GAEZ database) for low input rain-fed cereal production. Both distance and suitability are normalized for the study area. Both normalized variables are multiplied, to create a variable that can be ranked. Pixels such as settlement, waterbody and bare rock cannot be converted and therefore cannot be ranked.

The user defines a percentage of additional cropland wished, then the code computes an *addcrop* layer as well as the new yield of each feed/fodder that is coming from cropland, based on the GAEZ yield layer. The code does not yet automatically look for the percent of land that has to be changed for getting a user-defined amount of additional feed/fodder. Yet a user can test different percentages of land until she/he gets the desired new production.

The code produces an *addcrop* layer that is saved in the 1-input folder and can be read into CLEANED (in the 0-user definition code) to run a land use change driven scenario.

[1] http://www.ivm.vu.nl/en/Organisation/departments/spatial-analysis-decision-support/Clue/

6.2 The core CLEANED code (3-cleaned)

This section describes how the dynamics described in Chapter 3 (Major dynamics) have been implemented in a spatially explicit way as well as how the code processes the input data.

6.2.1 User definition (0- user definition)

This is the only code that the end-user is supposed to open and define his/her run. For every user input there is a value in brackets that represents the base run value.

The user starts by defining the amount of animals in the landscape (herd), in the base run this is the number from the national statistics (2007/08 Sample Agricultural Census, NBS 2012).

The user then is asked to define the whole value chain. In a first stage, the end user defines, for each livestock system (currently 3 systems are coded, namely intensive, semi-intensive and extensive, yet Lushoto only uses the latter two):

- the feed basket, i.e. the types of feed and what proportion of each is used (in percent of energy absorbed by an animal);
- animal mature live weight (kg);
- yield per animal per year of product of interest from the value chain(e.g. in Lushoto, kg milk per cow per year, base value taken from national statistics, 2012);
- manure management type (lagoon, liquid slurry, solid storage, dry lot, pasture, daily spread, digester, fuel, other); and
- percentage of the animals (the herd) in each system.

The values for the base run are defined through expert knowledge collected during a Participatory GIS workshop or expert interview, or through existing surveys (ImpactLITE or FEAST).

Note that for manure management, the user can request that standard IPCC values are used.

Then there are a certain amount of parameters for the management of feed and fodder production, namely type of soil tillage (tilled, reduced till, no till), exogenous crop yield increase (%) and soil fertility management (low input, medium input, high input without manure, high input with manure) that can be defined by the end user.

The user also needs to indicate if she/he wishes to run a land use change scenario, in which case she/he needs to indicate the file path to the raster that indicates which pixels are to be converted to cropland, i.e. define the *addcrop* layer (see section 6.1.2).

6.2.2 Feed basket computation and system-wide production (2-feedbacket)

This module transforms the information entered by the user about the feed basket, the animal weight and product yield into the definition of an average animal (dairy cow in Tanzania) that represents the overall herd in the landscape.

The code then computes the equations presented in Chapter 3.1 (The core of the CLEANED model: the feed basket computation) with the average values and produces an area required of each type of feed/fodder to feed the herd, both fresh weight and dry weight for each type of feed/fodder, as well as the net and gross energy requirement of the herd.

6.2.3 Land use change scenario processing (2-luccomp)

This code re-computes every land use, such as cropland, grazing land, forest based on a cropland change layer. This cropland change layer can be introduced manually, for example when there is a stakeholder defined area to be converted to cropland or created in the land use change module (6.1.2 Land use change module). This code gets activated if *lucs=1* is in the 0-user definition code, and all layers derived from land are then re-computed based on the new cropland that is now enhanced with the crop land change layer.

6.2.4 The environmental dynamics module

6.2.4.1 Water pathway (1-water)

For the spatial modeling of the water pathway, the feed/fodder is classified into two categories based on which land use each type of feed/fodder is grown: the feed/fodder that grows on cropland (f_c) and feed/fodder that grows on grazing land (f_g). It is assumed that every pixel in one category (cropland or grazing land) produces all feed items in basket proportionally to the feed basket.

For every type of feed/fodder, the evapotranspiration is extracted to the relevant land use (i.e. evapotranspiration of maize on cropland, evapotranspiration of natural grass on grazing land). Then the average evapotranspiration on a land use of a given feed/fodder is computed.

The evapotranspiration on a given land use is then computed as:

$$ET_{LU} = \sum_i \left(\frac{A_i}{A_{LU}} \times avg(ET_{i,LU})\right)$$

Where:

ET_{LU} = the evapotranspiration on a given land use (mm yr^{-1})

A_i = the total area needed for growing the feed/fodder i computed in the feed basket module (ha)

A_{LU} = the total area available for a given land use (cropland or grazing land) (ha)

Avg ($ET_{i,LU}$) = the average evapotranspiration of feed/fodder i across its relevant land use (mm yr^{-1}).

For the Tanzania case, two land uses were defined: i) cropland that produces the crop residue, the legume residue and planted fodder; and ii) grazing land from which the natural grass is produced. So ET_{pixel} can have one of 3 values, 0 on non-crop non-grazing land, and different values for cropland and grazing land.

Water use intensity is computed by dividing ET_{pixel} with the rainfall map (average mm rainfall yr^{-1}) with a pixel by pixel division.

6.2.4.2 Greenhouse gas pathway (1-ghg)

The greenhouse gas pathway is computed in several steps and computes the different sub-pathways separately, namely enteric fermentation, manure management and feed and fodder production.

Emissions from enteric fermentation

Enteric fermentation is computed as described in Chapter 3.3.1 (Enteric fermentation) based on the users' entered data and the parameters on feed (digestibility and dry matter), together with the average dairy cow, average feed basket, and gross energy needed (computed in the feed basket code).

Enteric fermentation should ideally be allocated to the animal distribution in the landscape, and therefore be computed as follows:

$$EF_{pixel} = \frac{L_{pixel}}{L} \times EF$$

Where:

EF_{pixel} = enteric fermentation from each pixel (kg CH_4 $head^{-1}$ $year^{-1}$)
L_{pixel} = the number of livestock on a pixel
L = total livestock in the study area
EF = enteric fermentation from the herd

Global livestock distribution layers are highly modelled layers whose relevance at local scale, such as the CLEANED landscape, is low. Therefore, for Tanzania we preferred to assume that the livestock distribution is uniform in the landscape, i.e. that L_{pixel}= L / N where N is the amount of pixels in the study area.

Direct emissions from manure management

The CLEANED code is set up in such a way that, by defining the livestock species and the region, all parameters necessary for the manure management module are automatically retrieved from the IPCC standard tables. Also if IPCC=1 in the user definition, then the distribution of manure management options used is overwritten with the IPCC standards for the area.

Similarly to the water pathway, manure management options are classified into categories in terms of land use: those practices that are linked to cropland (for example lagoon or dryland storage) and those linked to grazing land (pasture).

Emissions from manure management are calculated as described in Chapter 3.3.2 (Emissions from manure management). In the equation for cropland:

$$EM_{dc,cropland} = (VS_{dc} \times 365) \times \left[B_{o,cd} \times 0.67 \times \sum_{Sc,k} \frac{MCF_{Sc,k}}{100} \times MS_{dc,Sc,T} \right] \times L$$

Sc refers to manure management options that are linked to cropland, namely-:

1- Lagoon storage
2- Liquid slurry
3- Solid storage
4- Drylot
5- Daily spread
6- Digester
7- Fuel
8- Others

And L = total number of animals in the landscape

On grazing land the computation is the same but taking only the manure management option "left on pasture" into account.

At pixel level, emissions are distributed across the landscape as follows:

$$EM_{dc,pixel} = \frac{EM_{dc,LU}}{A_{LU}}$$

Where:

$EM_{dc,\ pixel}$ = Emissions from manure per pixel (kg CH_4 animal^{-1} yr^{-1})
$EM_{dc,LU}$ = Total Emissions from manure on a given land use
A_{LU} = the number of pixel under the given land use (cropland or grazing land)

Direct and Indirect N_2O emission from manure management

Both direct and indirect N_2O emissions have been computed for cropland and grazing land separately, and then allocated spatially over the respective land use.

Emissions from feed and fodder production

IPCC standard tables exist for parameters needed to compute emissions from feed and fodder. These parameters are however dependent on the climatic zones or soil type for which IPCC provides a global layer. In a first stage, for each parameter, a layer is created by assigning to each pixel the relevant value from the table.

The Table 1 shows which of the IPCC layers have been used to create the parameter layers.

Table 1 : layers used to compute spatial parameter layers used in the ghg pathway

Parameter	**Layer**
SOC_0	Climate layer
SOC_{ref}	Soil and climate layer
F_{LU} (cropland, rice, perennial crop, set aside)	Climate (computed in spatial processing)

F_{MG} (full till, reduce till, no-till)	Climate
F_I (low, medium, high without, high with manure, input)	Climate

As a result the carbon stock change, the SOC computation, namely $SOC_0 = \sum_{c,s,i}\left(SOC_{REF_{c,s,i}} \times F_{LU_{c,s,i}} \times F_{MG_{c,s,i}} \times F_{I_{c,s,i}} \times A_{c,s,i}\right)$ and $SOC_{0-T} = \sum_{c,s,i}\left(SOC_{REF_{c,s,i}} \times F_{LU_{c,s,i}} \times A_{c,s,i}\right)$ can be computed on a pixel by pixel base, allowing then to compute $\Delta C_{Mineral} = \frac{SOC_0 - SOC_{(0-T)}}{D}$ on a pixel base.

Emissions from land use change

There is a pre-parametrized tool to compute emissions from land, http://blonkconsultants.nl/tools/land-use-change-tool/. CLEANED follows the computation of this tool, that can be found in 5-documentation. This tool follows IPCC guidelines Tier 2.

The land use change model only can handle land use from any land use to cropland, therefore the only relevant emissions from land use change that are modelled are the emissions from changing forest to cropland and grazing land to cropland. The emissions are computed for the pixel representing such a land-use change, applying different reference carbon values for previous grazing land and previous forest, as given in *GlobalForestResourcesAssessment2010* parameter table.

6.2.4.3 Biodiversity pathway (1-biodiver)

The biodiversity pathway is implemented in quite a simple way. For the species richness index, for each land-use the amount of species was computed and divided by the total number of species in the list. Then this number is assigned to the corresponding land use. See details of the equations used in Chapter 3.4 (Biodiversity).

For the second indicators, the amount of species that were identified as critically endangered in the landscape per land use was computed. Then pixels with a land use change (from *addcrop* layer that is user defined or could result from land use change module), depending on their original land use, get the value of critically endangered species in the landscape.

7 References

Gerber, P., Vellinga, T., Opio, C., Steinfeld, H., 2011. Productivity gains and greenhouse gas emissions intensity in dairy systems. Livestock Science, Special Issue: Assessment for Sustainable Development of Animal Production Systems 139, 100–108. doi:10.1016/j.livsci.2011.03.012

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Haan, C., 2006. Livestock's long shadow.

NBS. 2012. Sample Census of Agriculture 2007/08 Smallholder Agriculture: Volume Vd: Regional Report: Tanga Region. Ministry of Agriculture, Food Security and Cooperatives, Ministry of Livestock Development and Fisheries, Ministry of Water and Irrigation, Ministry of Agriculture, Livestock and Environment, Zanzibar, Prime Minister's Office, Regional Administration and Local Governments, Ministry of Industries, Trade and Marketing, The National Bureau of Statistics and the Office of the Chief Government Statistician, Zanzibar. Dar es Salaam.