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Protocol for a Tier 2 approach to generate region-specific enteric methane emission factors (EF) for cattle kept in smallholder systems

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Protocol for a Tier 2 approach to generate region-specific enteric methane emission factors (EF) for cattle kept in smallholder systems

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Abbreviations and acronyms

ADF	acid detergent fibre
AEZ	agroecological zone
BCS	body condition score
cm	centimetre
DM	dry matter
DMD	dry matter digestibility
DMI	dry matter intake
DMP	daily methane production
E_{milk}	energy content of milk
EF	emission factor
F	fat
g	gram
GE	gross energy
GPS	global positioning system
ha	hectare
HH	household
kg	kilogram
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
LW	live weight
m	metre
MER	metabolizable energy requirements
MLW	mean live weight
N	nitrogen
ODK	Open Data Kit
RHoMIS	Rural Household Multi-Indicator Survey
SDMD	seasonal dry matter digestibility
SMDMD	seasonal mean dry matter digestibility
SNF	solids nonfat
SSA	sub-Saharan Africa

Aim

The aim of the data collection and calculations described in this protocol, which is based on Goopy et al. (2018a) and Ndung'u et al. (2019), is to generate region-specific emission factors (EF) for enteric methane emissions of cattle; i.e. the amount of methane (CH_4) in kilograms produced per head of animal per year based on a Tier 2 approach (for more information on the Tier 2 approach and related methodology, see IPCC 2006, IPCC 2019). Tier 2 EFs are commonly derived locally and more precise than the currently used Tier 1 EFs. This is particularly necessary as countries (including low- and middle-income countries) are requested to report their national greenhouse gas inventory at minimum following the Tier 2 approach under the Paris Climate Agreement. The approach described in this protocol accounts for seasonal differences in feed availability, feed quality and related liveweight fluxes as often found in sub-Saharan Africa (Goopy et al. 2018a, Ndung'u et al. 2019). The calculations are based on or modified from equations published in 'Nutrient Requirements of Domesticated Ruminants' (CSIRO 2007) and thus use metabolizable energy requirements in contrast to the equations cited in IPCC (2006) which are based on net energy system.

Please note that this protocol is currently designed for cattle only. For small ruminants, partially different equations are required. An updated version of this document is foreseen in the near future. In addition, the two example studies cited here (Goopy et al. 2018a and Ndung'u et al. 2019) were conducted in two study regions in western Kenya in a context of mixed crop-livestock systems. Studies that aim at using this protocol in a different context (e.g. pastoral systems) need to make certain adjustments which are not fully considered in the present protocol.

1. Data requirements

The aim is to produce region-specific enteric methane EFs. If the field data collection cannot cover the entire region, the study sites need to be chosen carefully in order to be representative for the region. A stratified randomization based on agroecological zone (AEZ) and/or land use weighed by population (human or animals) is recommended (Goopy et al. 2018a and Ndung'u et al. 2019). Further classifications can be done by types of livestock systems, for instance.

Tier 2 estimates are based on feed characteristics and animal-specific performance data to calculate the feed intake from the energy required for different performance and activity parameters. The intake, together with methane conversion factors, can be used to calculate daily methane production and enteric methane EF. The approach of Goopy et al. (2018a) and Ndung'u et al. (2019) is based on continuous direct measurements of different performance and activity parameters on a large subset of individual animals on a seasonal basis, as well as seasonal assessments of quantity and quality of diet. For this, the following data is collected in the field.

1.1 Data on animal characteristics and weights

Animal identification and animal characteristics

Animal identification: because continuous measurements are carried out on the same animal throughout the data collection period which covers a year, it is important to be able to clearly identify the individual animals. Numbered ear tags are an easy method for identifying the experimental animals. In this case, ear tags, ear tagger and disinfectant for the tagged ear are required. National regulations need to be checked beforehand. Alternative forms of animal identification could be numbered collars.

Animal type/breed: the breed, if known, should be recorded. Breed identification (visually and by asking the household owner) can be done by using, for instance, the categories local breed, crossbred, exotic breed and further characterizations if possible. Equation 3 uses constants that differentiate between *Bos taurus* breeds, *B. indicus* breeds or crossbreeds.

Sex/age class: the enteric methane EF are reported for five different sex/age classes, i.e. adult females and adult males (> 2 years), heifers and young males (1–2 years) and calves (less than one year old) (Goopy et al. 2018a, Ndung'u et al. 2019). Therefore, the age of the animals needs to be recorded. If no reliable data on birth dates is available, the age of the individual animal can be estimated from dentition, e.g. following Torell et al. (1998) (see Photo 1). This information is used later to classify the experimental animals into the sex/age categories outlined above for separate calculation of methane EF per sex/age class. For adult males, it should be recorded if the animal is castrated or not as different constants are used for castrated and non-castrated males in Equation 3. Gloves are recommended for animal handling and dentition examination.

Photo 1. Age estimation using dentition

Cow-calf pair identification: for lactating animals, the daily milk yields need to be recorded and the milk amount suckled by the young calves calculated. Therefore, it is important to include the respective calves in the live weight (LW) measurements (mean LW and LW gain of the calves are needed for Equation 9) and to identify the cow-calf pair (i.e. which calf belongs to which mother).

Physiological status: if the animal is pregnant, lactating, both lactating and pregnant or neither of those, the lactation stage, i.e. days in milk, that can alternatively be calculated from the age of the respective calf, is information partially needed for the calculation of energy expenditure for lactation (MER_L).

Additional data: additional data that is not needed for the actual methane EF calculation but might be needed for later modelling and upscaling approaches can be collected during the weighing events. Additional data might include parity (number of calves born to a cow, information given by the household owner). Herd dynamics (i.e. animals coming on and off the household by being sold, slaughtered, born etc.) can be recorded at every weighing event, if needed. This additional information is given by the household owner and can be collected at every weighing event.

The livestock production system (e.g. agropastoral, pastoral) or the AEZ (Ndung'u et al. 2019) the animals are kept in, or the type of feeding (e.g. barn-fed, grazing) might be of interest and recorded during the data collection when further classification of the animals into different subgroups takes place based on management or feeding situation, apart from the age/sex categories outlined above, to calculate EF for different subgroups of cattle within the study region covered.

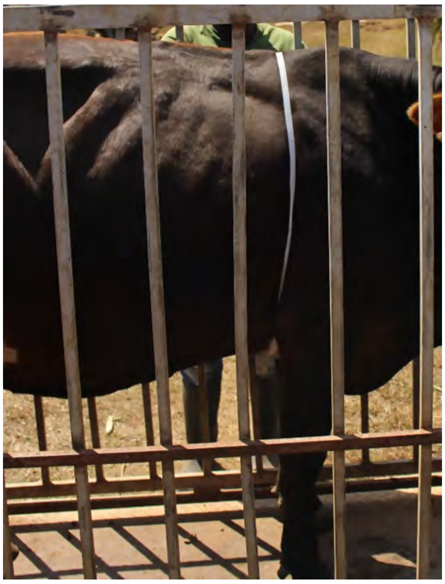
Live weight per animal (in kg)

The animal's live weight (LW) should be preferentially measured with a calibrated animal weighing scale (see Photo 2). A reference weight should be used in between the measurements to crosscheck accuracy during weighing. A good weighing time is during the morning hours before the animals are fed or released for grazing from barns or bomas. Ropes might be needed for animal handling. A single-cabin pickup truck could be used if needed for transporting the weighing scale to the different households where the animals are going to be weighed.

Photo 2. Cattle LW measurement in the field using a portable weighing scale

If no animal weighing scale is available, heart girth measurements (see Photo 3) and respective algorithms can be an (although less precise) alternative to estimate LW, e.g. Goopy et al. (2018b) which was developed for cattle types of West and East Africa. A measurement tape is required to measure the circumference of the experimental animals in centimetres. The tape needs to be fixed directly behind the forelegs and looped behind the hump (for humped animals). However, certain constraints of heart girth measurements when aimed at capturing seasonal liveweight fluxes need to be considered (Goopy et al. 2018b).

Photo 3. Heart girth measurement in the field using a measurement tape



The LW is assessed at the beginning/end of each season and should cover all seasons throughout the year. For example, in an area having four seasons, in total five LW measurements are performed at the beginning of each season per animal throughout the data collection period (Goopy et al. 2018a and Ndung'u et al. 2019). In an area having only two seasons, three LW measurements per animal are required in order to have an equal number of seasonal LW fluxes (i.e. LW change between beginning and end of a season). The measurement dates have to be recorded, as the number of days between the measurements are needed to calculate average daily LW changes.

The mean seasonal LW per animal, which can be generated by the average LW measured at the beginning and end of each season, is needed for Equation 3, 12 and 13 (if applicable). LW change per season and animal is needed for Equation 6 and 7.

The animal characteristics and LW data can be entered in field books, field sheets or open source data collection tools such as Open Data Kit (ODK: https://opendatakit.org/). In this case, a mobile phone or tablet is needed.

1.2 Data on milk yield and milk quality

Daily milk yield per lactating animal (in litre)

For calculating energy expenditure for lactation (MER_L), the daily milk yield per season is needed for the individual lactating animals (see Equation 11). Daily milk yield of the lactating animals included in the study could be recorded by the farmers (Goopy et al. 2018a and Ndung'u et al. 2019). Calibrated measurement jugs and field books for recording the milk yield on a daily basis per animal and throughout the entire data collection period are required per household. How to do milk yield and data recording in the record books might need to be explained and/or training might be provided. The daily milk production records of individual lactating animals from the household owner's record book should be copied regularly (for instance, by taking pictures with a cellphone or tablet) to another datasheet to avoid backlog and loss of data. The data can be cross-checked with data from milk collection hubs.

The daily milk yield of all lactating animals should be ideally recorded on a daily basis throughout the entire data collection period.

Milk quality per lactating animal, household herd or breed type/season

For the calculation of the milk energy content (E_{Milk}, Equation 10, a parameter needed for the calculation of MER_L, Equation 11), certain milk quality parameters are required such as milk fat, density, protein or solid nonfat (SNF), depending on the equation to be used in Step 2.9.3 for the MER_L calculation. Depending on the situation and the resources available, the seasonal milk quality can be assessed during a household visit either per animal or by using a mixed milk sample per household using, for instance, a portable milk analyzer. If it's not possible to perform the analysis in the field, the sample should be cooled on ice (for example, using an ice box) and analysed as soon as possible. The analysis can also be done in a milk factory or cooling plant nearby. The milk samples to be collected for analysis should be carefully homogenized (no heavy shaking of the milk samples, but thorough mixing).

Milk quality assessments should ideally be done on a seasonal basis.

Alternatively, and if resources are limited, default milk energy values can be used for European breeds. For local breeds, few subsamples can be collected and analysed, and an average value can be used to calculate E_{milk} (see Equation 10).

1.3 Data on feed availability and feed quality

For calculating the 'feed basket', which is the proportionate contribution of the single feed item to the seasonal diet (see Steps 2.1–2.5), the amounts of the different feedstuffs available per household and season need to be calculated.

The approach followed by Goopy et al. (2018a) and Ndung'u et al. (2019) in smallholder mixed crop-livestock systems of western Kenya was based on household sketches to collect information on fodder and crops produced on the farm and sizes of pasture and cropping land. The underlying assumption here is that what is produced on farm in terms of pasture, fodder and byproducts of cultivated crops is used for animal feeding, and that the diet of the animals is based on what is produced by the household.

Sizes of pasture and cropping land collected per household

In mixed crop-livestock systems where most of the feed resources for the cattle are produced on farm, a small farm survey/sketch drawing can help to indicate how the farm has been subdivided and what kind of plants have been allocated in each cropping area/plot (see Figure 1 as an example). Locations and boundaries of the plots (for the different areas of pasture, different cropping areas, fallow lands etc.) are to be provided by the farmers. For example, generic laser range finders or tape measures can be used for size estimations. The best time for the sketch drawing is during the cropping season/s.

Additional parcels of land apart from the household land that is covered by the sketch, such as cultivated areas or grazing land somewhere else, need to be included in the calculation.

The number of farm sketches depends on the number of cropping seasons, especially for the major crops grown in the study region.

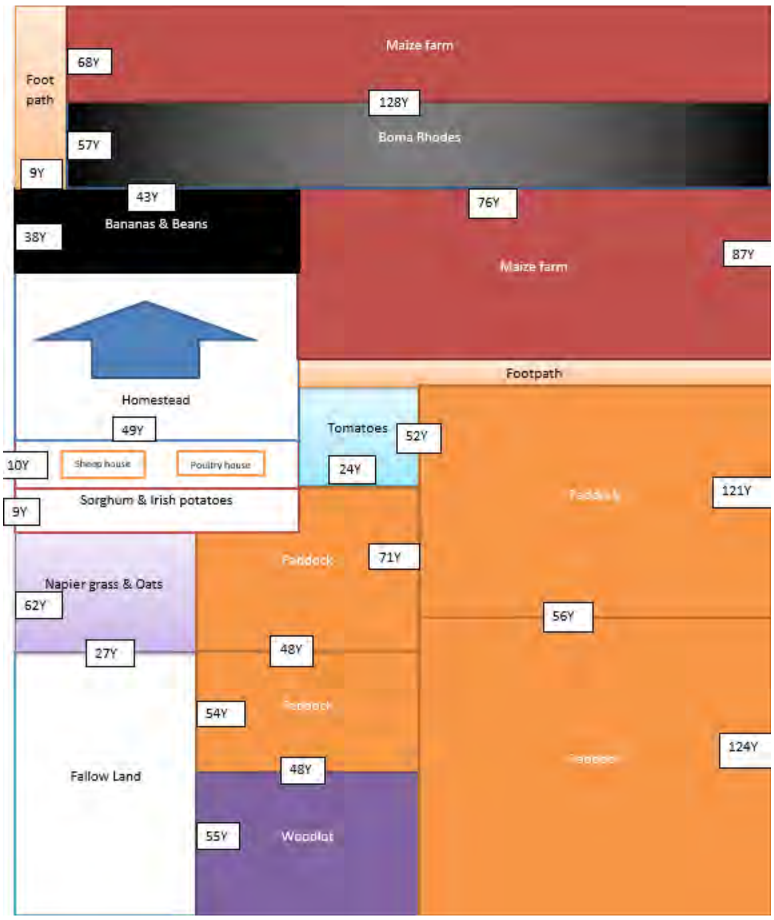
This sketching approach was suitable in a mixed crop-livestock system (Goopy et al. 2018a and Ndung'u et al. 2019) but might not be applicable in other contexts such as pastoral systems, or when the cropping areas are far away from the homestead where the animal and biomass measurements are realized. Where crop plots are far from the homestead, farmers may provide information on the sizes/estimated sizes under different crops.

For the collection of more detailed household information, a modified Rural Household Multi-Indicator Survey (RHoMIS: www.rhomis.org) can be used.

Biomass yield of pasture and cropping lands

Biomass yield from pasture lands can be measured directly by using exclosure cages and harvesting the biomass from the cages at the beginning and end of each season. The cages can be locally made from wire mesh with a size of 0.5 x 0.5 x 0.5 m for estimating both quantity and quality of pasture biomass (Goopy et al. 2018a and Ndung'u et al. 2019) (see Photo 4). The exclosure cages should be established at the start of the data collection period in pastures or rangelands used for grazing of the experimental animals per household, sublocation or village, depending on the number of households, exclosure cages available and study design. Placement of the exclosure cages should be done in a randomized manner.

Figure 1. Example of household sketch (Y=yard)



Source: Phyllis Ndung'u

When establishing the exclosure cages, the vegetation underneath is cut in order to record the actual seasonal growth of biomass until the next harvesting (i.e. the seasonal biomass yield). The exclosure cage needs to be replaced in the same position. The vegetation inside the exclosure cages should be cut to a height of about two centimetres above ground. The vegetation will be cut into small pieces and placed in pre-weighed paper bags. The bags and content are weighed on a balance immediately in the field to avoid water loss. Scissors and paper or plastic bags and table-top balance for biomass weight measurements are needed. The samples are sun- and oven-dried and the biomass is reweighed to get the dry matter (DM) weight.

The biomass yield harvested from the exclosure cages can be extrapolated to larger units like hectare (ha) (see Step 2.2.). Harvesting of the biomass grown in the exclosure cages should be done at the beginning/end of each season to calculate pasture biomass yield on a seasonal basis.

Information on yield of fodder grasses or crops/crop residues used for ruminant feeding can be provided by the household owner. Additionally, the farm sketches can be used to identify what crops and crop residues are available.

For crop residues used for cattle feeding, information on grain yield provided by farmers and harvest indices for these crops from the literature (Goopy et al. 2018, Ndung'u et al. 2019) could be used to produce an estimate of crop byproduct biomass produced (and fed) on the farm.

If 'cut and carry' is practiced, the amount of fodder brought into the farm can be calculated by counting and weighing the bags in which the fodder is transported. The fresh matter weight should be recorded and a fodder sample from the bags collected for later analysis of DM content. This can be extrapolated for the number of bags used in that season and taken into account when calculating fodder availability on the farm (see Step 2.3). This also applies for every other feed purchased and moved to the farm, like dairy meal.

Photo 4. Exclosure cage for pasture biomass yield estimations

Quality of pasture and feed samples

The quality of the different feed components of the seasonal feed basket is needed to calculate the dry matter digestibility (DMD) (Equation 1) and then seasonal mean DMD (SMDMD) (Equation 2). For the equation used in this protocol, contents of acid detergent fibre (ADF) and nitrogen (N, all in g/100 g DM) are needed (see Equation 1).

The content of gross energy (GE, MJ/kg DM) is needed for Equation 14. If GE content cannot be analysed, it could be assumed to be an average value of 18.1 MJ/kg DM (Ndung'u et al. 2019 and Goopy et al. 2018a, citing CSIRO 2007).

The pasture biomass harvested in the exclosure cages can be analyzed to get an indication of the seasonal quality of the pasture grass. After each harvest, the cut and dried samples are ground to pass through a 1 mm sieve and subjected to proximate analysis in a state laboratory or in the facilities of a local university.

It has to be noted that the nutritional quality of the cage grass samples do not fully represent the quality of the pasture vegetation actually ingested by the grazing animals as the animals express selection behavior and the diet selected usually has a higher nutritive value compared to random pasture sampling. Pasture protected from grazing inside the exclosure cages might also be more mature than the pasture on grazed pastureland containing some regrowth of higher nutritional value. Additional sampling from these grazed lands might be recommendable in this case.

Feed samples that form part of the seasonal feed basket should be collected separately per feed and analysed for chemical composition. When the feed samples are collected, additional information could be provided by the household owner on amounts fed per season, relative proportion of feed items in the daily diet, and/or duration (days) of feeding the different feed items.

Feed and pasture samples need to be dried in a dry place. A conventional (domestic) oven can be used for drying the samples at 50°C for a minimum of 24 hours. Weight should be recorded for fresh, sun-dry and oven-dry weights. Sun-drying is used if there is no other alternative. In this case, care has to be taken that the temperature does not get too hot. Feed sample collection should be done during at least one rainy and one dry season.

1.4 Activity data

Distance travelled

Locomotion data of the animals that are allowed to graze, such as distance travelled per day in the different seasons, are needed for Equation 12. The data can be collected for selected focal animals with the use of global positioning system (GPS) collars. These collars can be left on the animals for two to three consecutive days (Goopy et al. 2018a, Ndung'u et al. 2019) and help to quantify distance travelled as well as change in altitude during travelling. Since all animals cannot be sampled, representative animals are selected in advance. When selecting representative animals and defining the number of data to be collected and the periods of data collection, factors that might affect the distance travelled such as the livestock production system, feed and water availability or seasonal differences should be considered. The GPS data can be used for calculating average distances travelled during 24 hours for different seasons, livestock systems or AEZs, if applicable.

Work hours

If an animal is used for ploughing or traction, the working hours per day and the days of work per season need to be recorded (required for Equation 13, if applicable). This information can be collected per animal at every weighing event for the respective season.

2. Field data analysis and calculation of methane EF

Step 2.1. Calculation of area under pasture or cropping (in ha) per relevant season (feed basket calculation for mixed crop-livestock systems)

The area under pasture or cropping can be calculated for each household for the relevant seasons by using the information collected with the farm sketches (see Section 1.3 'Sizes of pasture and cropping land'). All areas that are used directly (pasture areas for grazing, plots used for growing fodder grasses) or indirectly (fields planted with crops whose byproducts are used for feeding) for feeding the targeted ruminant species need to be considered. The data can either be analysed separately per household and then be averaged and/or summed up to generate one average value per livestock system and/or AEZ, if applicable.

Step 2.2. Calculation of available pasture biomass (in t per ha) per season (feed basket calculation for mixed crop-livestock systems)

The available pasture biomass can be estimated by using the DM weight of the biomass sampled from the exclosure cages (see Section 1.3 'Biomass yields of pasture and cropping lands). The seasonal biomass yields (in g DM) recorded from cutting the areas of 0.25 m^2 covered by the exclosure cages can then be extrapolated to tons (t) of DM per ha on a seasonal basis.

These values, per household, sublocation or village, can then be averaged and extrapolated to generate one value for pasture DM biomass yield per reference unit (e.g. t per AEZ) and season, together with the information on land area under pasture calculated in Step 2.1.

> 'Available pasture biomass was estimated for the sampled farms in each zone by season (t dry matter (DM)/ha) by extrapolating sample mass by area under pasture for each farm and aggregating areas for all farms in the survey, by zone.' (Goopy et al. 2018a, p. 73)

Step 2.3. Calculation of available fodder grass biomass (in t per ha) per season (feed basket calculation for mixed crop-livestock systems)

If the yield of the different fodder grasses grown are not measured (see Step 2.2 for pasture biomass harvested using exclosure cages) the yield (t DM/ha) can be alternatively estimated by using yield information for these fodder grasses grown under comparable circumstances published elsewhere.

Together with the information on land area used to grow fodder grasses (see Step 2.1) the amount of fodder grasses available per season and reference unit (e.g. AEZ) can be calculated. If fodder grass is brought into the farm by 'cut and carry', this needs to be taken into account (see 1.3 'Biomass yields of pasture and cropping lands').

Step 2.4. Calculation of available crop residue biomass (in t per ha) per season (feed basket calculation for mixed crop-livestock systems)

Here, crop residues refer to residues from crops that are used for feeding the targeted livestock species to be estimated for the total area under the respective crop per reference unit (e.g. household, sublocation, village or AEZ). Information on the yield of the different crops can be collected from the household owners and harvest indexes could be used from the literature to estimate on-farm biomass availability of crop residues that are used for feeding (Goopy et al. 2018a, Ndung'u et al. 2019).

Step 2.5. Calculation of proportionate availability of the different feedstuffs in the feed basket (in percent) per season (feed basket calculation for mixed crop-livestock systems)

The amount of all single feed items fed to cattle, for instance pasture (Step 2.2.), cultivated fodder grass such as Napier or Rhodes grass (Step 2.3) and crop byproducts (Step 2.4), need to be listed and the proportions of each feed item in the respective season and reference unit (e.g. AEZ) to total feed availability can be calculated. The different proportions per season and reference unit (e.g. AEZ, if applicable), represent their contribution to the respective seasonal feed basket.

> 'Feed resources (i.e. pasture, crop stovers, Napier grass, etc.) were pooled by type of feed for the farms surveyed in each zone and each season and the representation of each feedstuff in the notional diet was deemed to be proportional to the availability of the different plant biomass in each zone/season.' (Goopy et al. 2018a, p. 74)

Step 2.6. Calculation of the digestibility of the individual feedstuffs per season and reference unit (e.g. AEZ)

Feed digestibility can be calculated using an equation by Oddy et al. (1983) per feedstuff per season and per reference unit (e.g. AEZ), if applicable.

For the calculation, the following values are needed for each feedstuff:

- ADF content of the single feed items (in g/100 g DM)
- N content of the single feed items (in g/100 g DM)

The equation reads as follows (from Oddy et al. (1983), cited in Goopy et al. (2018a), p. 74 and Ndung'u et al. (2019), p. 1138):

Equation 1

$$\mathrm{DMD}\ (\mathrm{g}/100\ \mathrm{g\,DM}) = 83.58\ - 0.824\ * \mathrm{ADF}\ (\mathrm{g}/100\ \mathrm{g\,DM}) + 2.626 * \mathrm{N}\ (\mathrm{g}/100\ \mathrm{g\,DM})$$

The DMD should be calculated for each feed item separately per season and reference unit (e.g. AEZ).

Step 2.7. Calculation of the seasonal mean dry matter digestibility (SMDMD) per reference unit (e.g. AEZ)

The SMDMD of the feed basket can be estimated using the following equation (Goopy et al. 2018a, p. 74):

Equation 2

$$\text{SMDMD} = \sum \frac{\text{\% diet of individual feedstuff} * \text{DMD (\%) of the individual feedstuff}}{100}$$

Where % diet of individual feedstuff is estimated in Step 2.5 and DMD (%) of the individual feedstuff is estimated in Step 2.6.

Step 2.8. Calculation of the average distance travelled per season and reference unit (e.g. AEZ)

The distance travelled, used for calculating the energy spent for locomotion needs to be taken into account for all animals that are sent out for grazing. GPS transponder fixed on collars can be used to track the distance covered per day and animal and average values can be calculated for different seasons, reference units (e.g. AEZ) and/or different livestock systems, if applicable (see Section 1.4. 'Distance travelled'). The average value can then be used in equation 12.

Step 2.9. Calculation of the total metabolizable energy requirements (MER_T) per individual animal and season

The total energy expenditure is calculated individually for all single animals per season and can later on be averaged per animal category (i.e. females > two years; males > two years; heifers (one to two years); young males (one to two years); calves (males and females < one year)), season and reference unit (e.g. AEZ, if applicable). Total energy expenditure is calculated by summing up the metabolizable energy requirements (MER) for maintenance (MER_M) and growth (MER_G, could be negative in the case of weight loss), lactation (MER_L) for lactating animals and travelling/locomotion (MER_T) or ploughing/traction (MER_P), if applicable.

- MER for maintenance (MER_M) (see Step 2.9.1)
- MER for growth (negative in case of weight loss) ($MER_{G/-G}$) (see Step 2.9.2)
- MER for lactation (MER_L) (see Step 2.9.3)
- MER for travelling/locomotion (MER_T) (see Step 2.9.4)
- MER for ploughing/traction (MER_P) (see Step 2.9.5)
- MER for thermoregulation (only needed when animals are kept partially outside of their thermoneutral zone. If the daily temperatures are likely to be outside the subject animals' thermoneutral zone, which should be determined in advance of the data collection period, the increased energy expenditure in animals outside of their thermoneutral zone can be calculated by e.g. equations cited in CSIRO 2007)
- MER for gestation/pregnancy (not covered here as included in the LW changes for the pregnant animals, see below)

‘Energy requirement for thermoregulation was not considered, because in the area surveyed environmental conditions were such that animals should mostly have been in a thermo-neutral zone year round (Mean annual temperature:17.0 (min)–29.4 (max) °C). Energy requirements for gestation were not specifically included, as this is only of significance with respect to energy requirements in the final 8–12 weeks of gestation and is partly captured in the dam's LW change. Calves under 3 months were treated as pre-ruminant (therefore not emitting CH_4) and the milk required for their maintenance and growth attributed to the milk production of the dam and included in the total energy expenditure for the dam. Calves over the age of three months were deemed to be weaned and on pasture.’ (Goopy et al. 2018a, p. 74)

Step 2.9.1. Calculation of the energy requirements for maintenance (MER_M, per individual animal and season)

Equations 3 and 4 can be used to calculate MER_M per single animal and per season. This calculation is based on three equations that were published in CSIRO 2007 (equation 1.20, 1.21 and 1.12A) and were combined into a sole equation (Goopy et al. 2018a, p. 74 and Ndung’u et al. 2019, p. 1138):

Equation 3

$$\mathrm{MER_M}\ (\mathrm{MJ/d}) = (\mathrm{K} * \mathrm{S} * \mathrm{M} * (0.26 * \mathrm{MLW}^{0.75}) * (\exp(-0.03 * \mathrm{A})))/((0.02 * \mathrm{M/D}) + 0.5)$$

where:

- **K**: 1.3 for crossbred cattle, i.e. the intermediate value of the value 1.4 that applies for *Bos taurus* breeds and 1.2 for *B. indicus* breeds (see CSIRO 2007, equation 1.20)
- **S**: 1.0 (for female and castrated cattle), 1.15 (for noncastrated male animals) (see CSIRO 2007, equation 1.20)
- **M**: 1 (when there is zero per cent milk in the diet) or for calves, when the dietary proportion of milk is unknown, M can be calculated (for further details, see CSIRO 2007)
- **Mean live weight (MLW):** (the average LW in kg per season calculated as: $(LW_{\text{Start of season}} + LW_{\text{End of season}})/2$ (Goopy et al. 2018a and Ndung’u et al. 2019)
- **A** (stands for age): to be given in years (for additional explication see CSIRO 2007, equation 1.20)
- **M/D**: stands for metabolizable energy (ME) content of the seasonal diet, in MJ ME per kg diet DM, to be calculated by the following equation (Goopy et al. 2018a, p. 74 and Ndung’u et al. 2019, p. 1138 citing CSIRO 2007 (equation 1.12 A)):

Equation 4

$$\mathrm{M}/\mathrm{D} = 0.172 * \mathrm{SMDMD} - 1.707$$

where:

SMDMD is calculated with equation 2.

Step 2.9.2. Calculation of the energy requirements for growth ($MER_{G/-G}$, per individual animal and season)

In the following, the energy requirements for growth (MER_G, i.e. weight gain/loss) per animal and season are calculated. At first, the seasonal daily weight gain (or loss) has to be calculated per animal (Goopy et al. 2018a, p. 74):

Equation 5

$$LW_{change}\ (kg/d) = \frac{LW_{End\ of\ Season}\ (kg) - LW_{Start\ of\ Season}\ (kg)}{\text{Number of days between the measurements}}$$

If the LW change in the respective animal and season is positive, equation 6 and 4 can be used for calculation; when it is negative then equation 7 is used (Goopy et al. 2018a, p. 75 and Ndung'u et al. 2019, p. 1138f, based on CSIRO 2007 (equations 1.29 and 1.36).

Equation 6

$$MER_G\ (MJ/d) = \frac{(LW_{change} * 0.92 * EC)}{(0.043 * {}^{M}/_{D})}$$

Equation 7

$$MER_{-G}\ (MJ/d) = \frac{(LW_{change} * 0.92 * EC)}{0.8}$$

where:

- **LW**$_{\textbf{change}}$ is calculated from equation 5
- **EC** (stands for energy content of the tissue (in MJ per kg)). Here, the value 18 can be used for all seasons and all animal categories, which is a mid-range value (Goopy et al. 2018a, p. 75, citing CSIRO 2007)
- **M/D**: stands for metabolizable energy (ME) content of the diet, in MJ ME/kg diet DM, which was generated by equation 4.

Step 2.9.3. Calculation of the energy requirements for lactation (MER_L, per individual animal and season)

The energy expenditure for lactation is calculated for all lactating animals using the equation 11.

At first, data on daily milk yields (in l) per season is needed, which can be calculated by using the following equation (Ndung'u et al. 2019, p. 1139):

Equation 8

$$MY\ (l) = \frac{\text{Total milk recorded per season } (l)}{\text{Number of days in season } (l)} + DCMC\ (l)$$

where:

- **DCMC** (l) stands for daily milk consumption (in l) of pre-ruminant calves (i.e. those ≤ 3.5 months, Ndung'u et al. 2019) required for all lactating females accompanied by a young calf, which is calculated by the following equation 9 (based on Table 4 of Radostits and Bell (1970)):

Equation 9

$$DCMC\ (l) = \left(0.107 * LW\ (kg)\right) + \left(0.00339 * LWG\ (g)\right)$$

where:

- **0.107** (in l/kg calf weight), i.e. per 1 kg of birth weight (if not available, life weight measured during the first 3.5 months can be used) the calf needs 0.107 l of milk (status quo, maintenance), value derived from Table 4 of Radostits and Bell (1970) by dividing 2.92 (milk requirement in l for a calf with a birth weight of 27.2) by 27.2 (birth weight in kg).
- **LW** is liveweight of the calf (in kg)
- **0.00339** (l per day) is the extra amount of milk needed for calf growth, i.e. per 1 g of liveweight gain the animal needs 0.00339 l of milk, value derived from Table 4 of Radostits and Bell 1970 by calculating 2.92 – 2.15 = 0.77, i.e. which is the amount of extra milk to grow 227 g per day and dividing 0.77 by 227, which is the extra amount of milk needed to grow 1 g/day.
- **LWG** is the live weight gain of the calf per day (in g)

The milk energy content (E_{milk}, in MJ/kg), needed for equation 11 is calculated by using the following equation for cow's milk (Ndung'u et al. 2019, p. 1138, citing Tyrrell and Reid 1965) if data on milk protein is not available:

Equation 10

$$E_{milk}\ (MJ/kg) = 0.0386 * F\ (g/kg\ milk) + 0.0205 * SNF\ (g/kg\ milk) - 0.236$$

where:

- **F** stands for milk fat (in g/kg milk), using the value analyzed per animal (or per household herd) of the respective season.
- **SNF** stands for solids nonfat (in g/kg milk), using the value analyzed per animal (or household herd) of the respective season. If needed, SNF can be calculated following Bector and Sharma (1980) (see Ndung'u et al. 2019).

Alternatively, if values for fat, protein and lactose are available (e.g. if milk samples were measured using a portable milk analyser), other equations could be used as well (see further equations cited in CSIRO 2007, e.g. equation 1.40). See also further alternatives outlined in Section 1.2 'Milk quality.

MER_L is calculated individually for all lactating animals and per season by using the following equation (Ndung'u et al. 2019, p. 1139, based on CSIRO 2007 equation 1.43)):

Equation 11

$$MER_L(MJ/d) = [(MY\ (l) * E_{milk}(MJ/kg))\ /\ ((0.02 * M/D) + 0.4)]$$

where:

- **MY** (l) is the daily milk yield per season as calculated with equation 8
- **M/D**: stands for metabolizable energy (ME) content of the seasonal diet, in MJ ME/kg diet DM, which was generated by equation 4
- **E_{milk}** stands for energy content of the milk (in MJ/kg) as calculated with equation 10

Step 2.9.4. Calculation of the energy requirements for travelling/locomotion (MER_T, per individual animal and season)

The energy expenditure for travelling/locomotion is calculated based on the information on distance travelled (in km) collected in the field using GPS collars in different seasons (see Section 1.4 'Distance travelled') by using the average value generated in Step 2.8 for different seasons and reference units (e.g. AEZ), if applicable. The following equation is used for calculating MER_T (Goopy et al. 2018a, p. 75, Ndung'u et al. 2019, p. 1139, based on CSIRO 2007):

Equation 12

$$\mathrm{MER_T}\ (\mathrm{MJ/d}) = \mathrm{DIST}\ (\mathrm{km}) * \mathrm{MLW}\ (\mathrm{kg}) * \ 0.0026\ (\mathrm{MJ})$$

where:

- **DIST** (in km) is the average distance travelled per season and/or reference unit (e.g. AEZ), if applicable (value generated in Step 2.8)
- **Mean live weight (MLW) per season** i.e. the average LW in kg per season calculated as: ($LW_{\text{end of season}}$ + $LW_{\text{beginning of season}}$)/2, as also used for equation 3
- **0.0026 MJ** stands for energy that is expended for each kg of LW and km, (Goopy et al. 2018a, p. 75 and Ndung'u et al. 2019, p. 1139, based on CSIRO 2007).

If the study area is hilly or mountainous, the slope and altitude, i.e. the energy expended for vertical movement, should be considered too (for more information and equations see CSIRO 2007).

Step 2.9.5. Calculation of the energy requirements for ploughing (MER_P, per individual animal and season)

MER_P is calculated based on the information from the farmers on how many hours per day the respective animal was used for ploughing or traction (as asked for each season and the individual animals) using the following equation (Goopy et al. 2018a, p. 75, based on work of Lawrence and Stibbards 1990 and Singh 1999. See direct quote below).

Equation 13

$$\mathrm{MER_P}\ (\mathrm{MJ/d}) = \text{Work hours}\ (\mathrm{h/d}) * \mathrm{MLW}\ (\mathrm{kg}) * 0.002\ (\mathrm{MJ})$$

where:

- **Work hours** (h per day) are the average hours the animal was used for work during the working days
- **MLW** per season, i.e. the average LW in kg per season calculated as also used for equation 3
- **0.002** is the assumed energy (in MJ) needed for ploughing per kg LW and hour of ploughing at a velocity of 0.8 m per second (Goopy et al. 2018a, p. 75).

If the animal was only used a certain number of days for ploughing, the days of work per season need to be taken into account in the equation.

'Values for energy expenditure from traction or ploughing are not well characterized in the literature. Lawrence and Stibbards (1990) calculations suggest an energy expenditure for walking of 2.1 J/m/kg LW and a work efficiency for ploughing of 0.3 for Brahman cattle. Singh (1999) suggested that cattle may maintain a traction effort equivalent to 12% of their LW, at a speed of 0.6–1.0 m/s. This indicates additional energy expenditure of 0.4 J/m/kg LW. From the above it may be inferred that ploughing requires (at 0.8 m/s velocity) 0.002 MJ/h/kg LW.' (Goopy et al. 2018a, p. 75)

Step 2.9.6. Calculation of the total energy expenditure (MER_{TOTAL}, summing up, per individual animal and season)

The calculation for MER_{TOTAL} is to be done separately for each animal and season. The following compilation is based on Ndung'u et al. (2019) and needs to be adapted to the respective situation (e.g. if animals spent energy on ploughing, traveling etc.).

For adult females (i.e. lactating animals):

MER_{TOTAL} (MJ per day) = MER_{M} (result of equation 3) + $MER_{G/-G}$ (results of equation 6 or 7) + MER_{L} (result of equation 11) + MER_{T} (result of equation 12, if applicable)

For the adult and young males and heifers:

MER_{TOTAL} (MJ per day) = MER_{M} (result of equation 3) + $MER_{G/-G}$ (results of equation 6 or 7) + MER_{T} (result of equation 12, if applicable) + MER_{P} (result of equation 13, if applicable)

For calves:

MER_{TOTAL} (MJ per day) = MER_{M} (result of equation 3) + $MER_{G/-G}$ (results of equation 6 or 7)

Step 2.10. Calculation of the Dry Matter Intake (DMI) per animal per season

DMI per season is calculated separately for each animal using the following equation (Ndung'u et al. 2019, p. 1139):

Equation 14

$$\text{DMI (kg)} = \text{MER}_{\text{TOTAL}}\ (\text{MJ/d}) / (\text{GE (MJ/kg)} * (\text{SMDMD}/100))\ /\ 0.81$$

where:

- **GE**, gross energy of the diet (in MJ per kg DM). If not analysed, it could be assumed to be 18.1 MJ/kg DM (Ndung'u et al. 2019 and Goopy et al. 2018a, citing CSIRO 2007)
- **SMDMD** (calculated with equation 2)
- **0.81**, the factor for converting metabolizable energy into digestible energy (Ndung'u et al. 2019 and Goopy et al. 2018a, citing CSIRO 2007).

Step 2.11. Calculation of the daily methane production (DMP) per animal per season

For the calculation of the DMP per animal and per season, the following equation of Charmley et al. (2016) can be used (Goopy et al. 2018a, p. 75, and Ndung'u et al. 2019, p. 1139):

Equation 15

$$\mathrm{DMP\ (g/d)} = 20.7 * \mathrm{DMI\ (kg)}$$

where:

- **20.7** is the conversion factor of Charmley et al. (2016)
- **DMI** per animal in kg per day as calculated in equation 14

Step 2.12. Calculation of the emission factor for enteric methane emissions (EF**,** in kg per animal per year)

The calculation of the EF requires the sum of the seasonal DMPs (number of DMPs depend on the number of seasons) calculated by equation 15 by considering converting g (DMP is expressed in g/day) in kg (EF is in kg per 365 days) and accounting for the length (i.e. number of days) per season.

$$EF\ (CH_4\ kg/head/year) = \frac{(DMP_{Season\ 1} * days\ of\ season) + (DMP_{Season\ 2} *\ days\ of\ season) + ..)}{1000}$$

The following example is an equation from Ndung'u et al. (2019), p. 1140, for a context with four different seasons of equal length:

Equation 16

$$\mathrm{EF}\left(\frac{\mathrm{CH_4}\ \frac{\mathrm{kg}}{\mathrm{head}}}{\mathrm{y}}\right) = \frac{(\mathrm{DMP_{Season\ 1}} + \mathrm{DMP_{Season\ 2}} + \mathrm{DMP_{Season\ 3}} + \mathrm{DMP_{Season\ 4}}) * 365}{4 * 1000}$$

where:

- **365** stands for 365 days
- **4** stands for the four seasons
- **1,000** is needed for converting methane from g to kg

Finally, the mean value per animal sex/age category and reference unit (e.g. AEZs, if applicable) can be calculated (see Goopy et al. 2018a and Ndung'u et al. 2019).

References

Bector, B.S. and Sharma, N. 1980. Estimation of solids-not-fat in milk using specific gravity lactometers. *Indian Dairyman* 33: 249–253.

Charmley, E., Williams, S.R.O., Moate, P.J., Hegarty, R.S., Herd, R.M. et al. 2016. A universal equation to predict methane production of forage-fed cattle in Australia. *Animal Production Science* 56: 169–180.

CSIRO. 2007. *Nutrient requirements of domesticated ruminants*. Australia: CSIRO Publishing.

Goopy, J.P., Onyango, A.A., Dickhoefer, U. and Butterbach-Bahl, K. 2018a. A new approach for improving emission factors for enteric methane emissions of cattle in smallholder systems of East Africa – Results for Nyando, Western Kenya. *Agricultural Systems* 161: 72–80.

Goopy, J.P., Pelster, D.E., Onyango, A., Marshall, K. and Lukuyu, M. 2018b. Simple and robust algorithms to estimate liveweight in African smallholder cattle. *Animal Production Science* 58: 1758–1765.

IPCC. 2006. Chapter 10: Emissions from livestock and manure management. In: *Guidelines for National Greenhouse Gas Inventories*. Volume 4: Agriculture, Forestry and Other Land Use. IPCC: 10.1–10.87.

IPCC. 2019. Chapter 10: Emissions from livestock and manure management. In: *Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Volume 4: Agriculture, Forestry and Other Land Use. IPCC: 10.1–10.209.

Lawrence, P.R. and Stibbards, R.J. 1990. The energy costs of walking, carrying and pulling loads on flat surfaces by Brahman cattle and swamp buffalo. *Animal Production* 50: 29–39.

Ndung'u, P.W., Bebe, B.O., Ondiek, J.O., Butterbach-Bahl, K., Merbold, L. and Goopy, J.P. 2019. Improved region-specific emission factors for enteric methane emissions from cattle in smallholder mixed crop: livestock systems of Nandi County, Kenya. *Animal Production Science* 59: 1136–1146.

Oddy, V.H., Robards, G.E. and Low, S.G. 1983. Prediction of *in vivo* dry matter digestibility from the fibre and nitrogen content of a feed. In: Robards, G.E. and Packham, R.G. (eds), *Feed information and animal production: Proceedings of the Second Symposium of the International Network of Feed Information Centres*. UK: Commonwealth Agricultural Bureau: Farnham Royal, Slough: 395–398

Radostits, O.M. and Bell, J.M. 1970. Nutrition of the pre-ruminant dairy calf with special reference to the digestion and absorption of nutrients: a review. *Canadian Journal of Animal Science* 50: 405–452.

Singh, G. 1999. Draught animal energy research in India. In: Kaumbutho P.G., Pearson R.A. and Simalenga T.E. (eds), *Empowering Farmers with Animal Traction. Proceedings of the workshop of the Animal Traction Network for Eastern and Southern Africa (ATNESA), 20–24 September 1999*. Mpumalanga, South Africa: 315–322.

Torell, R., Bruce, B., Kvasnicka, B. and Conley, K.1998. Methods of determining age of cattle. In: *Cattle Producer's Library - CL712*. Reno, Nevada: University of Nevada.

Tyrrell, H.F. and Reid, J.T. 1965. Prediction of the energy value of cow's milk. *Journal of Dairy Science* 48: 1215–1223.

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