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Mitigation measures in the Agriculture, Forestry, and Other Land Use (AFOLU) sector

Quantifying mitigation effects at the farm level and in national greenhouse gas inventories

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Executive Summary

This document analyses potential greenhouse gas (GHG) mitigation measures in the Agriculture, Forestry and Other Land Uses (AFOLU) sector, looking at their reportability with the IPCC methods. The main conclusions that can be drawn from this analysis are:

Mitigation strategies target either 'observation' or 'parameter'

1. Mitigation strategies target either 'observations' that can be collected at the farm level or 'parameters' that require (complex) models or experimental observations. The differentiation between 'observations' and 'parameters' is different from 'activity data' and 'emission factors' as some activity data as used in GHG reporting are already the result of 'information flows' and are not directly measurable.

Systemic mitigation options usually have an effect on more than one emission category

2. Mitigation measures using the 'observation' mitigation strategies often have a systemic effect thus influencing more or less farm activities as a whole. It is important to take into account all the implications for the other emission categories, and evaluate the total effect of the measure.

All mitigation measures impact farmer's income

3. All mitigation measures have a cost, and most mitigation measures have positive or negative side effects on GHG or other pollutant's emissions, on productivity and on farm income. This document does not analyse economic feedbacks and assesses mitigation measures under the scenario of 'constant production level' at the farm.

Mitigation measures can be grouped in mitigation mechanism groups

4. Individual mitigation measures can be grouped among measures with similar mitigation mechanisms. Mitigation mechanism groups are defined by the 'term' in the standard IPCC methodology that is affected. Most mitigation mechanism groups use mainly either the 'observation' or 'parameter' mitigation strategy.

Measures using the mitigation strategy 'observation' are relatively straight-forward to be traced in GHG inventories with some additional data collection required

5. Mitigation measures using the mitigation strategy 'observation' are easy and in many cases even automatically reflected in national GHG emission inventories, including many indirect effects. Some mitigation measures though require the use of tier 2 methodologies, often however for source categories which are key sources and thus need to be estimated with tier 2 methodology anyway. For measures of some mitigation mechanism groups, adequate data collection systems to obtain relevant activity data are not yet in place.

Detailed parcel information, routinely collected within advanced data collection systems, such as the Integrated Administration and Control System (IACS) and its Land Parcel Identification System (LPIS), offer an important potential for GHG estimations, and are already used by some Member State. Other data sets could/would be worthwhile to improve, such as livestock feed rations by feed group.

Measures using the mitigation strategy 'parameter' often require research programs to develop (national) differentiated emission factors

6. For some mitigation measures using a 'parameter' mitigation strategy, IPCC default methodology is available, for example land management mitigation measures can be quantified with the use of land management factors. For other mitigation mechanism groups based on a reduction of emission factors, differentiated emission factors are not yet established and require additional experimental research. Yet, differentiated emission factors might also help to improve the quality of greenhouse gas emission inventories.

Assessing mitigation measures at the farm level is easier at the level of mitigation mechanism groups than at the level of individual mitigation measures

7. The data required to address 'observation' type mitigation measures at farm level in the source classes 'nitrogen management' and 'energy' require mainly economic data (mineral fertiliser and feed purchases, production and export of livestock and crop products, or purchase of external energy, respectively). Measures targeting CH_4 emissions from enteric fermentation using the 'FEED' mechanism group can be quantified with the use of a 'feed tool'. A possible 'soil tool' which monitors data relevant for C sequestration requires the collection of more complex (=spatial) data. A full 'GHG tool' calculating total farm GHG emissions would require the four individual modules and only little additional data (e.g. manure management systems).

A modular GHG calculator tool would provide highest flexibility for farm level GHG monitoring

8. A modular system building a GHG tool with independent – and individually selectable – modules focusing on nutrient management, enteric fermentation, carbon sequestration and land use changes, and energy use will 'measure' proxies for GHG emissions rather than the implementation of a specific measure. They will therefore give a direct idea of the cost-effectiveness of climate-payments while considering possible positive or negative side effects. Collecting required data might be interesting also for farmers as they will get the information on the GHG emission intensity of their products, which might give a market advantage and thus enhancing the motivation for GHG emission reductions.

1 Introduction

The 2030 climate and energy framework of the European Commission sets the target of a 40% reduction in GHG emissions by 2030, compared to 1990 emission levels (European Commission, 2014). To achieve this target, the the EU policy endows Member States with an emission trading system (ETS), based on a 'cap and trade' principle, which establishes a limit on total amount of certain greenhouse gases that can be emitted by installations covered by the system. Within the cap, the companies receive emission allowances, which they can trade with one another as needed, including international transactions (European Union, 2003). The system, however, does only cover 45% of total EU emissions, as there are some sectors which are not covered, among them road transport, buildings, waste and agriculture. For these non-ETS sectors, the Effort Sharing Decision (ESD) establishes binding annual targets per Member State, based on the principles of fairness, cost-effectiveness and environmental integrity (European Parliament and Council of the European Union, 2009).

According to the 2030 climate and energy framework, adopted in 2014 (European Commission, 2014), ETS sectors would need to cut emissions by 43%, while non-ETS sectors' target is a 30% reduction, compared to 2005. The proposal for the new ESR, still under discussion (European Commission, 2016), includes new flexibility to access credits from the land use sector. This is aimed to encourage additional mitigation action in the LULUCF sector and allows Member States to use up to 280 million credits over the entire period 2021-2030 from certain land use categories. This new rule will benefit mainly those countries with a high share of emissions coming from agriculture, and acknowledges the lower mitigation potential of agriculture, compared with other sectors.

According to the IPCC 5th Assessment Report (AR5, Smith et al., 2014), the AFOLU sector represents 20-24% of total GHG emissions (10-12 GtCO_{2eq}/yr) globally, being the largest emitting sector after energy. The sector is unique among the others as it accounts not only for emissions of GHG, but also for removals of CO_2 from the atmosphere due to the capacity of terrestrial ecosystems to act as a sink for carbon in carbon pools.

Agriculture covers emissions of non-CO_2 gases, with CO_2 emissions in the sector being limited to the application of lime, urea and other carbon-containing fertilisers. The subsector is the largest contributor to global anthropogenic emissions of non-CO_2 gases, accounting for 56% of these emissions in 2005 (U.S. EPA, 2011). In general, the subsector accounts for 5.2-5.8 Gt CO_{2eq} yr^{-1} (Tubiello et al., 2013), about 10-12% of total global anthropogenic emissions. Source categories within this sector include: synthetic and organic fertilisers applied to soils, manure deposited on pasture, crop residues (all these grouped into "agricultural soils"), paddy rice cultivation, enteric fermentation, manure management, biomass burning (as far as agriculture is concerned) and emissions from liming and from the application of other carbon-containing fertilisers. Enteric fermentation, manure left on pastures, synthetic fertilisers, paddy rice, biomass burning and manure management are the greatest emitters, with enteric fermentation and agricultural soils accounting together for about 70% of non-CO_2 emissions from the sector.

LULUCF covers anthropogenic GHG emissions and removals of CO_2 caused by management and/or conversion of land uses (forest land, cropland, grassland, wetlands, settlements, other land) and non CO_2 emissions from other sources (e.g. biomass burning, etc.). According to the IPCC 5th Assessment Report (Smith et al., 2014), around 27% of the global atmospheric CO_2 budget is absorbed by the terrestrial biosphere.

Emissions and removals of CO_2 account for about 4.3-5.5 Gt CO_{2eq}/yr, corresponding to 9-11% of total anthropogenic GHG emissions from 2000 to 2009. CO_2 emissions are the result of changes in terrestrial carbon stocks within carbon pools, identified in above and below ground living biomass, dead organic matter (dead wood and litter), and soil organic carbon. Non-CO_2 emissions are small in comparison, and are mainly produced by peat degradation through wetland drainage, other management practices on organic soils, and biomass burning.

Due to the characteristics of the AFOLU sector, mitigation options are twofold: (1)

- Reduction and prevention, by reducing emissions of CH_4 and N_2O and preventing further carbon loss;
- Sequestration, increasing the removal of CO_2 from the atmosphere.

Considering the contribution of the single sectors, Grassi and Dentener (2015) and Grassi et al. (2017) quantified the mitigation role assigned to the LULUCF sector according to different scenarios and trends as well as considering the contribution described within the Intended Nationally Determined Contributions (INDCs) submitted by parties in preparation to the COP21 conference and the negotiations that eventually led to the signature of the Paris Agreement. The full implementation of the INDCs would turn LULUCF from being a net source during 1990-2010 to being a net sink by 2030.

Adding conditional and unconditional measures (i.e. depending on funding from developed countries) the sector is foreseen to contribute up to -3.7 $GtCO_{2eq}$ yr^{-1}, with a mitigation contribution compared to all sectors between 20 and 25%. Land use, and forests in particular, emerge therefore as a key component of the Paris Agreement. Smith et al. (2013) review available mitigation estimates and conclude that reductions in direct N_2O and CH_4 emissions from agricultural sources could be around 600 Mt CO_{2eq} yr^{-1} (range 270-1900 Mt CO_2-eq yr^{-1}).

For a Member State having to comply with binding GHG emission reduction targets, the implementation of mitigation measures is not attractive if the emission reduction cannot be accounted in the official GHG inventories (Pellerin et al., 2013). A measure's effect can be captured by IPCC methods used in national inventories only if it fulfils the following conditions:

- The effectiveness of the measure should be demonstrated and acknowledged.
- The measure must have an effect on a pool or a parameter accounted for by the IPCC methodologies at the level of detail (tier) chosen by the country for the inventory.
- It must be possible to prove the implementation of the measure (through measurements, with statistical data etc.).

A large numbers of mitigation measures have been proposed in the scientific literature (compiled e.g. in the AR5, Smith et al., 2014) and/or are discussed in national programmes (see Annex 2). There is though the concern of how (cost-) effective the mitigation measures are, and if they will be reflected in the national GHG inventories. :

- Some measures have not been sufficiently studied and exact changes in emissions attained in the specific country conditions are not clear, needing additional experimental work. Such measures are only be useful to implement if the country has resources to undertake the research work needed. Other measures can only be captured if the estimation of emissions is done with a high level of detail (higher tiers) in the country but not with the basic methodology using default emission factors, therefore the choice of the tier level can limit accountability of mitigation effects. Sometimes the barrier for the estimation of the reduction in emissions is insufficient availability of data.
- An additional difficulty in the assessment of mitigation results is the interaction between different emission categories. Sometimes mitigation actions have an effect not only in the targeted emission category, but also in others. It is important to account for all the interactions to ensure a correct estimation of the GHG emission changes.
- The inclusion of the LULUCF sector within the UNFCCC process has been complex, due to uncertainties and methodological issues. In particular for forests, issues like additionality (separation of non-anthropogenic effects and proving that efforts go beyond BAU), leakage (displacement of land-use activities to other areas), and accounting rules have often led to controversies.

The JRC carries out different institutional and scientific tasks in the sector of AFOLU GHG accounting and mitigation.

In particular, the JRC is responsible for the LULUCF and the agriculture sections of the European Union's GHG inventory. Being a party to the UNFCCC as a whole, just as its single Member States, the EU has the same obligations of any other Annex I party in terms of reporting of its GHG emissions, and every year a EU inventory is prepared collecting and checking the inventory data prepared by the single MS and finally summing them up to obtain total EU values. The JRC is also in charge of following the review process managed by the UNFCCC, providing replies to the observations of the Expert Review Teams with reference to the LULUCF and Agriculture sectors.

The JRC also provides scientific policy support to different services within the Commission (e.g. DG CLIMA, DG AGRI) in charge of shaping the agriculture and climate policies of the EU and carry out negotiations in the context of international Climate Agreements (such as the UNFCCC, the Kyoto Protocol, and the Paris Agreement). In addition, the JRC is looking into the possibility of using existing data such as the "Land Parcel Identification System" (LPIS) of the "Integrated Administration and Control System" (IACS). The work is formalized through different Administrative Arrangements (LULUCF Accounting, MRV LULUCF, LULUCF 2030, LUC 2030, LULUCF+, IMAP). The tasks are accomplished through scientific research and specific ad-hoc analyses (Alkama and Cescatti, 2016; Bergamaschi et al., 2015; Bertaglia and Milenov, 2016; EEA, 2016; Fellmann et al., 2017; Grassi and Dentener, 2015; Grassi et al., 2017; Leip, 2010; Leip et al., 2010; Pérez Domínguez et al., 2016; van Doorslaer et al., 2015; Weiss and Leip, 2012).

JRC support is largely based on methodological development for the production of GHG emissions estimates at the continental or global scale, as well as the maintenance and use of models, such as the Carbon Budget Model (CBM) or the Common Agricultural Policy Regional Impact (CAPRI, Britz and Witzke, 2014) model. CBM simulates forest biomass patterns (Pilli et al., 2016a, 2016b, 2016c) and is maintained and calibrated for Europe and used for the analysis of past estimates and projections. CAPRI is used to assess the potential of GHG mitigation in agriculture under different policy options. In CAPRI, technological mitigation measures are 'endogenously' available so that the most cost-efficient choice of GHG mitigation between different technological options and structural changes is simulated at the regional level under given policy constraints (Fellmann et al., 2017; Pérez Domínguez et al., 2016; van Doorslaer et al., 2015).

Furthermore, the JRC is developing the new LULUCF component of the Emission Database for Global Atmospheric Research (EDGAR).

The objective of this report is twofold:

- Assess mitigation measures discussed in literature and national programmes and try to classify them according to how mitigation effects are achieved and what possible side effects they might have
- Analyse the mitigation measures according to their traceability in national greenhouse gas inventories.

To this end, we define the terms 'mitigation strategies' and 'mitigation mechanism groups' in chapter 3 and introduce the concepts of 'observations' and 'parameters' that are needed to quantify national GHG emissions. In chapter 4, we systematically assess the for each mitigation mechanism group the traceability and impact in national GHG inventories, describe the required Tier level, as well as possible side effects and data availability. In chapter 4 we provide illustrative examples for mitigation mechanisms using different mitigation strategies. Availability of farm-level information is a major bottleneck for accounting of GHG mitigation measures in national inventories; therefore, we propose in chapter 5 a modular 'farm level calculator' which could be used to collect relevant information and would give account of the interactions between different emission categories when new data is introduced.

2 Method

2.1 Calculation of emissions in AFOLU

According to the IPCC guidelines (IPCC, 2006), GHG emissions are in general calculated using the simple relationship given in equation (1):

$$\boldsymbol{E = AD \cdot EF} \quad \textbf{(1)}$$

Where *E* is the emission in a source category, *AD* is the activity data and *EF* the emission factor.

Activity Data (e.g. number of animals, kg of synthetic fertiliser applied) can be directly derived from statistics or be the result of a more complex calculation involving several different parameters. For example, the amount of nitrogen in manure applied to soil after being treated in manure management systems depends on the number of animals but is then estimated through a calculation that takes into account several variables: the N content in manure, the share of manure treated in different management systems, the losses to the atmosphere, etc.

In sector 3 Agriculture, Activity Data are animal numbers in source category 3A and 3B, area of cultivated rice in source category 3C, area of cultivated histosols in source category 3D16, N input from sources in other source categories 3D, total biomass burned in source category 3F, and amount of limestone or carbon-containing fertiliser applied in source categories 3G – 3I.

In sector 4 Land Use, Land Use Change and Forestry (LULUCF), Activity Data are typically the areas of lands either under different land uses or in conversion from a land use to another. Land is stratified according to different characteristics (climate, soil, etc.) and can be represented according to three approaches. The first approach simply considers areas in each category at the national level. The second approach builds a land use change matrix keeping tracks of all the areas converted from a land use category to each other category. The third, most advanced approach uses geo-referenced data thus making it possible to locate every land use conversion on the map. Default emission factors are given in the guidelines and can be applied if a Tier 1 approach is used.

The 'emission factor' (emissions per unit of activity data, e.g. N_2O emitted per tonnes of applied synthetic fertiliser) can thus be in the simplest of cases a coefficient derived from literature or a default value provided by the IPCC guidelines. The emission factor used should be representative for the 'activity' at the national scale. In the case of LULUCF, anthropogenic CO_2 emissions and removals are estimated indirectly from the net carbon stock change in the different pools due to annual vegetative cycles and to land use conversions.

IPCC guidelines provide three levels of methodological complexity for the estimation of emissions in each category, which are called 'tiers'. Complexity increases from Tier 1 (using mainly default data and emission factors) to Tier 2 (using country-specific parameters and/or methods or more detailed activity data) and Tier 3 (higher order methods). For higher Tier approaches, emission factors are obtained from experimental studies, are calculated with the help of additional parameters, or are estimated through disaggregated calculations. At the national level (the level at which emissions are reported), these are then aggregated to an 'implied' emission factor. Guidance for higher Tier approaches is given for several source categories, and default values of parameters might also be available.

Generalizing, an EF_a for an activity *a* is the 'implied' EF obtained according to equation (2) on the basis of stratified emission factors EF_s and activity data AD_s for sub-systems, while the emission factors for each sub-system are a function of a vector of emission parameters P_s and a vector of observations O_s as given in equation (3).

$$EF_a = \frac{\sum_s\{EF_s \cdot AD_s\}}{\sum_s\{AD_s\}} \quad \textbf{(2)}$$

$$EF_s = f\{\mathrm{P_s}, \mathrm{O_s}\} \quad \textbf{(3)}$$

Thus, one can distinguish three routes for obtaining higher Tier estimates:

(a) Stratification of the activity data (AD) for activity *a* into 'sub-activities' (*s*) if the EF of the sub-activities are assumed to be significantly different from each other.
(b) Development or application of (simple or complex) models to estimate the emission factor(s).
(c) Development of measurement programmes to quantify emission factor(s) or parameter(s) needed in the calculations.

Those three routes are independent. A country-specific emission factor can be developed based on one or more of these routes. For example, after appropriate stratification a model could be developed and missing parameters obtained with measurement programmes.

2.2 Mitigation strategies

Generally, a mitigation measure reduces GHG emissions by either (i) using available resources more efficiently thus maintaining production with decreasing input; or by (ii) reducing the emissions caused by an activity, typically through technological development (e.g. better management systems, different feeding techniques, etc.).

An activity in the AFOLU sector generates services, usually a crop or animal sourced food output in agriculture, and wood products or other services delivered by forestry in the LULUCF sector. This can be generalized as follows:

$$\boldsymbol{P = AD \cdot PF} \quad \textbf{(4)}$$

Where *P* is the product (service) of the activity and *PF* is the productivity. According to Schulte (2016), equation (1) and equation (4) can be combined, linking the emissions with the production (or desired outcome of the activity in general) and the ratio of greenhouse gas emission factor *EF* and the productivity *PF*, as shown in equation (5).

$$\boldsymbol{E = P \cdot \frac{EF}{PF}} \quad \textbf{(5)}$$

A mitigation measure is reducing emissions *E.* Here, we do not consider a change of production as a mitigation option, thus keep the output of the activity *P* constant. We can thus distinguish mitigation strategies that (case i) increase the productivity of the activity, often having those mitigation strategies often a systemic effect, and (case ii) target specifically the emission factor with minimum effects on other flows in the system.

Figure 1 shows an illustration of the concept of those 'Mitigation Strategies'. Panel 1a shows a reference situation where an input of 10 units produces an output of 6 units while emitting 0.5 units of GHG and wasting 3.5 units. The units are arbitrary but could be interpreted here as N (thus total N input = total N output). Panels 2a and 2b show the effect of a mitigation measure reducing specifically the emission factor. Usually, GHG emissions are associated with only a minor mass flow, however we assume in this example that the reduced emissions lead to a small proportional adjustment of output and waste flows. Panels 3a and 3b show the effect of increased input use efficiency (or reduced wastage). In the example we assume that GHG emissions are linked to the input level thus the emission factor is not directly changed by this measure. In both cases the effect was very large, at 30% for illustration (thus 30% decrease of EF and 30% increase of output).

Both mitigation strategies interact with the socio-economic environment of the farmer, as they (usually) are not available without cost and might have positive or negative impact on the farmers' returns. Therefore, Figure 1 shows two of the possible situations: in Panels 2a and 3a, the input level remains constant and the figure shows the effect on GHG emissions, losses and output. In Panels 2b and 3b, the output level remains constant, thus it is assumed that the farmer re-adjusts the production level, and the figure shows the effect on GHG emissions, losses, and input.

The effect of each mitigation measure is usually a combination of changing the emission factor (at constant input level) and changing the output level (at constant input level and with constant emission factor).

Both mitigation strategies will generate market feedbacks that could lead to production levels also outside the illustrated range, for example due to costs of the mitigation measure or as a consequence of market competitiveness and/or demand level via price changes (Pérez Domínguez et al., 2016; see e.g. van Doorslaer et al., 2015). Without further (economic) analysis, this effect is not predictable; we therefore assume here a 'standardized' effect at **constant output level**.

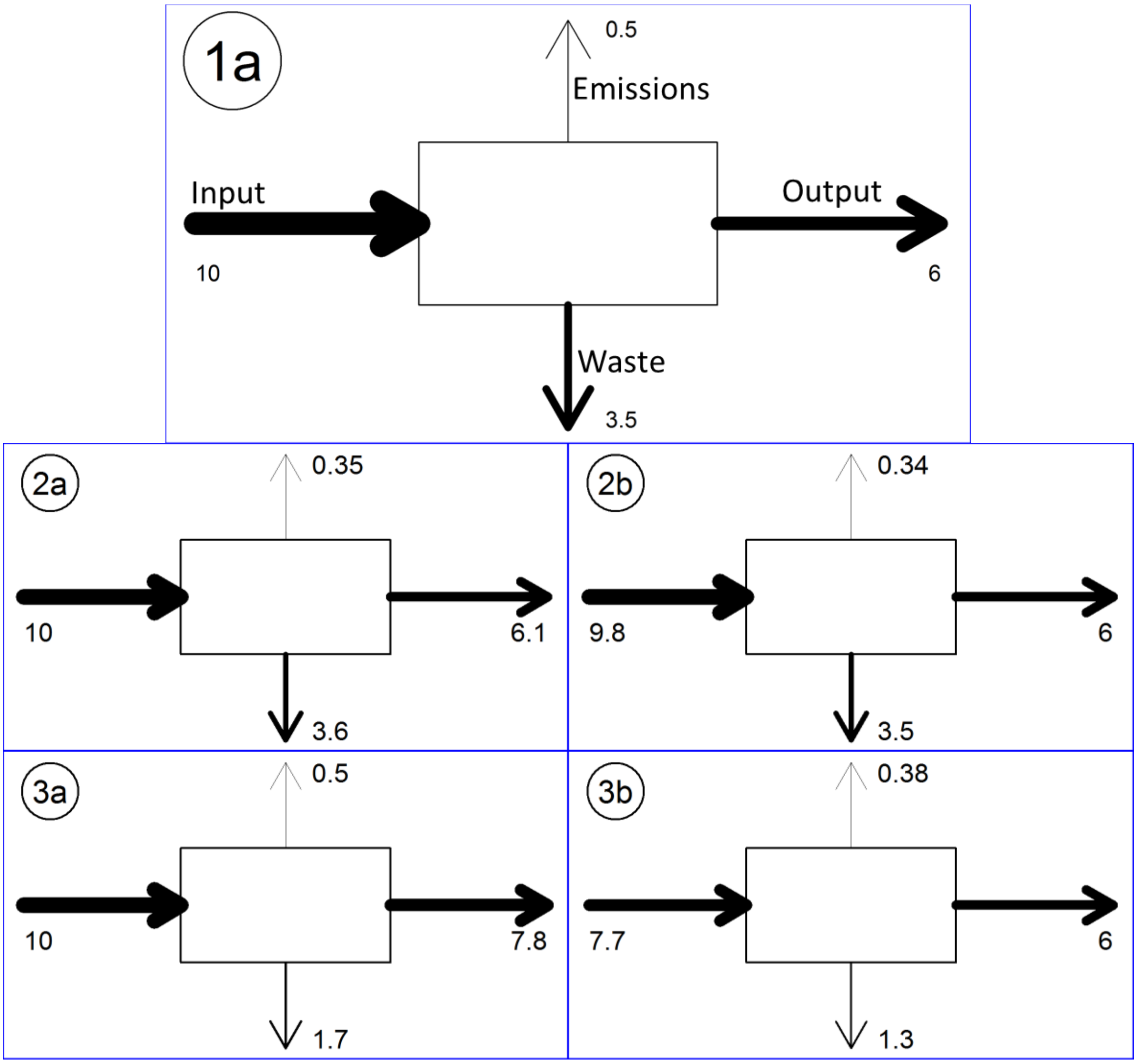

Figure 1. Illustration of the concept of 'Mitigation Strategies'. Panel 1a: reference situation Panels 2a and 2b: effect of a mitigation measure targeting the reduction of the emission factor; Panels 3a and 3B: effect of a mitigation measure targeting the increase of the productivity. The left hand panels show the effects with constant activity level (input constant) while the right-hand panels show the effects with constant production level (output constant).

2.3 Observations and parameters

For the current report, the differentiation between 'activity data' and 'emission factors' as they are used in the IPCC guidelines is not adequate to assess if the effect of mitigation measure can be traced in national GHG emission inventories. This is because some 'activity data' are derived from statistical information by applying one or more parameters that cannot be easily observed. For example, N lost through leaching and runoff is calculated using the leaching fraction $Frac_{LEACH}$ which is highly uncertain. From the perspective of 'tracing' mitigation options in national GHG inventories, a distinction between measureable data and parameters that are not straightforward to observe is important. The latter are often depending on environmental conditions, and are highly variable in time and space.

We propose therefore a differentiation between '*observations*' which can be collected at farm level with statistical surveys and '*parameters*' which require experimental measurements. The cut-off between 'observations' and 'parameters' is linked also to technology available to the farmers.

For example,

- Air temperature must be measured, but the technology is available to all farmers; in case a farmer does not record air temperature, data from measurement networks can be used to approximate the air temperature for the farm. Air temperature belongs thus to the category 'observation'.
- Soil nitrogen or soil carbon content are data that require elaborated procedures for sampling and analysis with equipment not generally available to farmers. Soil N and C content belong therefore to the category 'parameter'.
- Milk fat and protein content are usually recorded by dairies and data exist in national statistics; thus even though farm-level data are not (easily) available, these parameters belong to the category 'observation'.

Such a differentiation is particularly suitable for assessing the visibility of mitigation measures in national GHG emission inventories, as mitigation measures induce ***changes*** in greenhouse gas emissions; if these changes are mainly caused by 'observations', then a country must invest in the collection of the data, even though the efforts required for this data collection can vary. If, on the other hand, the emission changes are mainly caused by parameters, for which no suitable model is available to estimate the changes via 'observations', then, it is necessary that experimental evidence is collected or a suitable model be constructed. Usually, also model construction requires the collection of experimental evidence.

As a summary, for the current report we differentiate:

'**Observations**' referring to all data that are used for the stratification of the (main) activity data and which can be collected from national statistics or with farm surveys, or could be collected by farmers with available technology. Variables of the category 'data' could be finer animal categories, feeding systems, farming system (e.g. organic/conventional), manure management systems, fertiliser type, classification by farm technologies such as the tillage or fertiliser application technique, animal characterization (live weight, milk yield and quality, gross energy intake,…), administrative stratification or other geographic stratification (e.g. climate zone), to name just a few examples.

'**Parameters'** being a generalization of all variables that cannot be surveyed but require for their quantification measurement with technologies not available for individual farmers or models. This includes the emission factors themselves, volatile solid excretion and nitrogen excretion rates, etc.

Even though the link is not one-to-one we propose to use the terms 'observations' and 'parameters' also for the two mitigation strategies introduced above.

The ***mitigation strategy 'observation'*** affects data that are or can be measured with statistical surveys as indicated above. Often (but not necessarily) this goes hand in hand with systemic effects and increased productivity.

The ***mitigation strategy 'parameter'*** affects data that are difficult to measure or to obtain representative values valid for the national conditions. This can be 'emission factors' as in IPCC methodologies, but includes also other parameters used, such as $Frac_{LEACH}$ mentioned above. Often (but not necessarily) these mitigation measures are targeted and have little impact on productivity.

Note that national efforts to obtain country-specific emission factors can shift from 'parameters' to 'observation'. For example: a new manure management system is introduced in a country with lower CH_4 and N_2O emissions, but the effect is not yet quantified. This is a mitigation strategy 'parameters'. If a measurement program allows establishing new emission factors or a methodology to calculate emission factors, the mitigation problem is to increase the implementation level of this new technology, thus it is linked to obtaining statistical information. A shift towards this new technology in a country is a systemic mitigation strategy ('observation').

2.4 Mitigation Mechanism Groups

In this section, we define 'Mitigation Mechanism Groups' under which individual mitigation measures can be bundled. This is done based on a common mitigation strategy and the term in the standard estimation procedures of GHG emissions for the respective source category that is affected. Mitigation mechanism groups allow focusing the later discussion on the traceability of mitigation measures. This, in consequence, allows a more general assessment and being more comprehensive.

The assessment is done by IPCC source category, and the equation numbering follows the one used in the 2006 IPCC Guidelines.

2.4.1 CH_4 emissions from Enteric Fermentation (3.A)

Mainly produced by ruminants, this type of emissions depends on the livestock category and on the quantity and composition of the diet. In a tier 1 approach, emissions from enteric fermentation $CH_{4Enteric}$ of a given livestock category are calculated based on the number of heads and a default emission factor for that livestock category, using equation 10.19 from IPCC (2006):

Eq. 10.19: $$CH_{4Enteric} = \sum_{(T)} \frac{(EF_{(T)} \cdot N_{(T)})}{10^6}$$

$EF_{(T)}$ emission factor for the defined livestock population, CH_4 head^{-1} yr^{-1}
$N_{(T)}$ the number of heads of livestock species / category T in the country
T species/category of livestock.

When enteric fermentation is a key category, tier 2 must be used. A country specific EF is calculated according to equation 10.21 of the IPCC guidelines.

Eq. 10.21: $$EF = \left[\frac{GE \cdot \left({}^{Y_m}/_{100}\right) \cdot 365}{55.65}\right]$$

Where *GE* is the gross energy intake per head (MJ head^{-1} day^{-1}) and Y_m is the percentage of energy in feed converted to methane, called methane conversion factor. The factor 55.65 (MJ/kg CH_4) is the energy content of methane.

We can thus identify four mitigation mechanism groups:

- **HERD**: this group reduces GHG emissions by improving the herd's productivity but leaving the productivity of the individual animal constant. This allows reducing the livestock herd at constant production level. Example measures include sanitary control, increased health, optimised gender balance, etc. Looking at equation 10.19, the emissions $CH_{4Enteric}$ would be reduced through a decrease in $N_{(T)}$.

- **BREED:** this mitigation mechanism group increases the productivity of individual animals, through breeding programmes and allows decrease animal population while maintaining the same production level. This might have an (increasing) effect also on the emission level per animal from enteric fermentation, as well as on downstream emission from manure, but this is (partly) compensated by the reduction in the animal numbers. Therefore, as in the HERD group, the emissions $CH_{4Enteric}$ are mainly affected by a decrease in $N_{(T)}$ but $EF_{(T)}$ needs to be assessed as well.
- **METHGEN** (methanogenesis): these mitigation measures function over a reduction of CH_4 generation in the rumen without changing feed characteristics. Target parameter is thus the methane conversion factor Y_m in Eq. 10.21. This can be achieved with feed supplements that have the objective of reducing CH_4 generation per quantity of feed digested like fat additives or nitrate/sulphate additives. Another option is breeding programmes targeting the methanogenic activity in the rumen. Such measures are included in the mitigation mechanism group 'METHGEN' and not in the group 'BREED'.
- **FEED** (livestock feed): Mitigation measures which optimise feed rations to better match animal energy and nutrient requirements, using additives or multiphase feeding and reducing protein intake to avoid N excess over animal needs. Included are also measures that increase feed digestibility. Target parameter of this mitigation mechanism group relevant for emissions from source category 3.A is the required gross energy intake GE in Eq. 10.21. Gross Energy Intake is calculated from observations, using an enhanced characterisation of livestock, according to equations 10.14-10.16 of the IPCC guidelines.

We consider the mitigation mechanism groups HERD, BREED, and FEED to make use of the mitigation strategy 'observation', while METHGEN uses the mitigation strategy 'parameter'.

2.4.2 CH_4 and N_2O emissions from Manure Management (3.B.1 and 3.B.2)

During the storage and treatment of manure, both CH_4 and N_2O are produced. CH_4 is the result of the decomposition of manure under anaerobic conditions, which takes place mainly when manure is stored in liquid systems. N_2O emissions occur via combined nitrification and denitrification of nitrogen, requiring a combination of initial aerobic conditions to allow the production of nitrites and nitrates, followed by an anaerobic environment where those compounds are transformed into N_2O. The intensity of emissions depends on the nitrogen and carbon content of the manure, the duration of the storage and the type of treatment, and they are favoured in acidic environments. N_2O emissions also take place indirectly, through volatilisation in the forms of ammonia and NO_x and through leaching to the water system.

2.4.2.1 CH_4 emissions from manure management (3.B.1)

Factors affecting CH_4 emissions in this category are the amount of manure produced and the fraction of it that decomposes anaerobically, the latter depending not only on the type of manure management system, but also on the storage time and on the temperature. Tier 1 approach is based on livestock population data by animal category and climate region and default EFs.

Eq. 10.22: $$CH_{4Manure} = \sum_{(T)} \frac{(EF_{(T)} \cdot N_{(T)})}{10^6}$$

$CH_{4Manure}$ CH_4 emissions from manure management
$EF_{(T)}$ emission factor for the livestock category T
$N_{(T)}$ number of heads of livestock category T

The use of higher tiers requires more details on: (1) manure characteristics (volatile solids produced *VS*, which can be estimated based on feed intake and digestibility, and maximum methane production potential *Bo*), which depend on the animal species and feed regime, and (2) manure management practices (type of systems and associated methane conversion factor MCF), used to develop emissions factors for the particular conditions of the country. Tier 2 requires determining the weighted average of MCF using estimates of the manure managed by each waste system in each climate region. Some default values for these variables (animal mass, VS excretion and its components, Bo, MCF, fraction of livestock category in each system) are given to fill the gaps and allow countries to use tier 2 even if only part of the variables are available. VS excretion rates are taken from national published data or can be estimated based on feed intake (GE, DE, UE, GE, ASH).

In the previous equation, instead of taking default EFs, these are calculated as:

Eq. 10.23: $$EF_{(T)} = (VS_{(T)} \cdot 365) \cdot \left[B_{0(T)} \cdot 0.67 \cdot \sum_{S,k} \frac{MCF_{(S,k)}}{100} \cdot MS_{(T,S,k)}\right]$$

$VS_{(T)}$ daily volatile solid excreted for livestock category T
B_0 maximum methane producing capacity for manure produced by livestock category T
$MCF_{(S,k)}$ methane conversion factors for each manure management system S by climate region k;
$MS_{(T,S,k)}$ fraction of manure from livestock category T that is handled using management system S in climate region k.

If VS of manure is not available, it can be estimated from feed intake levels:

Eq. 10.24: $$VS = \left[GE \cdot \left(1 - \frac{DE\%}{100}\right) + (UE \cdot GE)\right] \cdot \left(\frac{1-ASH}{18.45}\right)$$

VS volatile solid excretion per day on a dry-organic matter basis, kg VS day^{-1}
GE gross energy intake, MJ day^{-1}
DE% digestibility of the feed in percent (e.g. 60%)
(UE·GE) urinary energy expressed as fraction of GE. Typically, 0.04 can be considered urinary energy excretion by most ruminants (reduced to 0.02 for ruminants fed with 85% or more grain in the diet or for swine).
ASH the ash content of manure calculated as a fraction of the dry matter feed intake (e.g., 0.08 for cattle).
18.45 conversion factor for dietary GE per kg of dry matter (MJ kg-1).

Thus we identify the following target mechanisms that could be used for reduction measures: (i) amount of manure excreted (or more specifically: amount of VS excreted), (ii) the distribution of the manure over manure management system, (MS), and (iii) specific practices that modify the MCF in manure management systems.

2.4.2.2 N_2O emissions from manure management (3.B.2)

N_2O emissions do not depend on the climate region, but on the quantity of nitrogen excreted and the type of manure management system used. The calculation of direct N_2O emissions is based on equation 10.25 of the IPCC guidelines:

Eq. 10.25: $$N_2O_{D(mm)} = \left[\sum_S\left[\sum_T\left(N_{(T)} \cdot Nex_{(T)} \cdot MS_{(T,S)}\right)\right] \cdot EF_{3(S)}\right] \cdot \frac{44}{28}$$

$N_{(T)}$ number of heads of livestock category T;
$Nex_{(T)}$ annual average N excretion per head of livestock category T;
$MS_{(T,S)}$ fraction of total annual nitrogen excretion for each livestock category T which is managed in manure management system S;
$EF_{3(S)}$ emission factor for direct N_2O emissions from manure management system S;

S manure management system.

In tier 1, calculations are done multiplying total N excretion in each manure management system by default EFs, using default excretion data and default manure management system data. In tier 2, the same calculations are performed as for tier 1 but using country-specific data for some of the variables (nitrogen excretion rates, for instance).

Within indirect N_2O emissions from manure management, losses due to volatilisation (in the forms of NH_3 and NO_x) and leaching are considered. These losses are calculated using equations 10.26 and 10.28 of the IPCC guidelines.

Eq. 10.26: $$N_{volatilization\text{-}MMS} = \sum_S \left[\sum_T \left[\left(N_{(T)} \cdot Nex_{(T)} \cdot MS_{(T,S)} \right) \cdot \left(\frac{Frac_{GasMS}}{100} \right)_{(T,S)} \right] \right]$$

Eq. 10.28: $$N_{leaching\text{-}MMS} = \sum_S \left[\sum_T \left[\left(N_{(T)} \cdot Nex_{(T)} \cdot MS_{(T,S)} \right) \cdot \left(\frac{Frac_{LeachMS}}{100} \right)_{(T,S)} \right] \right]$$

Indirect emissions depend on the amount of nitrogen excreted, the share managed in each manure management system and the fractions of volatilised and leached nitrogen ($Frac_{GasMS}$ and $Frac_{LeachMS}$). We do not consider specific mitigation mechanism groups targeting the reduction of indirect emissions from manure management, but changes in these will be a side-effect of measures targeting N, Nex or MS parameters.

From Equation 10.25 we can identify different potential mitigation mechanisms: (i) reducing nitrogen excretion by either increasing productivity and decreasing herd level ($N_{(T)}$) at constant total output or (ii) by reducing nitrogen excretion per animal at constant production level per animal (targeting $Nex_{(T)}$); (iii) changing the distribution of manure over manure management systems (targeting $MS_{(T,S)}$), and (iv) management practices that affect $EF_{3(S)}$ in a manure management system. For mitigation measures that affect manure management systems, trade-off effects with CH_4 emissions and indirect N_2O emissions need to be considered.

2.4.2.3 Mitigation mechanism groups for source category 3.B

As a summary for mitigation mechanism groups

- **HERD**: HERD measures presented in section 2.3.1, aimed to reduce the number of heads (N) while maintaining the production level, have a direct positive effect also on emissions in category 3.B.
- **BREED**: measures of the mitigation mechanism group BREED, presented in section 2.3.1, affect emissions from category 3.B – their effect must be quantified based on the Tier 2 methodology.
- **FEED**: measures optimizing feed intake for animal requirement of energy and nutrients. As defined in section 2.3.1, these measures target GE, therefore they will affect CH_4 emissions from manure by reducing VS (eq. 10.24). But feed rations could also be formulated to reduce N excretion $Nex_{(T)}$ in eq. 10.25, affecting N_2O emissions.
- **MANSYS**: measures changing manure management systems, (MS), such for example shifting from liquid system to solid systems to reduce CH_4 emissions or vice versa to reduce CH_4 or N_2O emissions; also measures such as cover or ventilations are included in this group, as long as the technologies are well defined and EF_3 values available from the IPCC guidelines. For several mitigation measures in this group the effect on CH_4 and N_2O emissions is in a different direction, thus the overall effect depends on the farming systems; for others the effect is synergetic (cover) if the increased nutrient content in the manure is accounted for upon application.
- **ADIG**: anaerobic digestion is principally a sub-group of MANSYS, but due to its specific characteristics (interlinked with the energy sector) and significant role for GHG mitigation, it

is considered separately. It leads to a reduction of CH_4 and N_2O emissions from manure management and application and a reduction of CO_2 emissions from energy production.

- **MANEF**: some measures (e.g. acidification of manure) have a direct effect on the emission factors of CH_4 and N_2O (and other gases) from manure, but they are not (yet) defined as a distinct manure management system in the IPCC guidelines.

We consider the mitigation mechanism groups HERD, BREED, FEED and MANSYS to make use of the mitigation strategy 'observation', while MANEF uses the mitigation strategy 'parameter'. ADIG uses also the mitigation strategy 'observation'; however, IPCC guidelines might give insufficient guidance.

2.4.3 CH_4 emissions from Rice Cultivation (3C)

The anaerobic decomposition of organic matter in flooded fields, such as those cultivated with rice, produces methane. The amount emitted depends on the number and duration of crops grown, on water regimes, on organic and inorganic soil amendments applied… Equation 5.1 of the IPCC guidelines indicated how emissions are calculated in this category.

Eq. 5.1: $$CH_{4Rice} = \sum_{i,j,k}\left(EF_{i,j,k} \cdot t_{i,j,k} \cdot A_{i,j,k} \cdot 10^{-6}\right)$$

CH_{4Rice} annual methane emissions from rice cultivation;
$EF_{i,j,k}$ daily emission factor for i, j and k conditions;
$t_{i,j,k}$ cultivation period of rice for i, j and k conditions;
$A_{i,j,k}$ annual harvested area of rice for i, j and k conditions;
i, j and k represent different ecosystems, water regimes, type and amount of organic amendments, and other conditions under which CH_4 emissions from rice may vary.

Mitigation measures could be designed to reduce emissions in this category through changes in management practices, by improving soil aeration. These measures are in general not very relevant in Europe, due to the limited area of cultivated rice, but can be regionally significant in certain areas (e.g. rice area in Northern Italy).

- **RICE**: management of rice fields changing the cultivation period or the area of rice for the different conditions to improve aeration and limit CH_4 emissions (mitigation strategy 'observation').

2.4.4 Direct and indirect N_2O emissions from agricultural soils (3.D)

Two main types of emissions are considered in this category: direct N_2O emissions from soils and indirect N_2O emissions from volatilisation, leaching and runoff. Sources of N_2O emissions from soils include synthetic fertilisers, organic fertilisers, manure deposited on pastures by grazing animals, nitrogen from crop residues left on the soil, mineralisation of organic matter resulting from land use or management changes, and histosols.

Direct N_2O emissions from managed soils are calculated using equation 11.1 of IPCC guidelines, based on (1) N inputs to soils, (2) area of cultivated organic soils and (3) urine and dung deposited while grazing:

Eq. 11.1: $$N_2O_{Direct}\text{-}N = N_2O\text{-}N_{N\,inputs} + N_2O\text{-}N_{OS} + N_2O\text{-}N_{PRP}$$

Where:

(1) $$N_2O\text{-}N_{N\,inputs} = (F_{SN} + F_{ON} + F_{CR} + F_{SOM}) \cdot EF_1 + (F_{SN} + F_{ON} + F_{CR} + F_{SOM})_{FR} \cdot EF_{1FR}$$

$$(2)\ N_2O\text{-}N_{OS} = F_{OS,CG,Temp} \cdot EF_{2CG,Temp} + F_{OS,CG,Trop} \cdot EF_{2CG,Trop} + F_{OS,F,Temp,NR} \cdot EF_{2F,Temp,NR} + F_{OS,F,Temp,NP} \cdot EF_{2F,Temp,NP} + F_{OS,F,Trop} \cdot EF_{2F,Trop}$$

$$(3)\ N_2O\text{-}N_{PRP} = F_{PRP,CPP} \cdot EF_{3PRP,CPP} + F_{PRP,SO} \cdot EF_{3PRP,SO}$$

F_{SN} synthetic fertilisers applied to soil
F_{ON} organic N applied as a fertiliser
F_{CR} N in crop residues, including from N-fixing crops
F_{SOM} N mineralisation associated with loss of organic matter resulting from change of land use or management of mineral soils
EF_1 emission factor for N_2O emissions from N inputs
EF_{1FR} emission factor for N_2O emissions from N inputs in flooded rice
F_{OS} area of drained/managed organic soils (histosols); guidelines differentiate between cropland and grassland (CG), forest land (F); temperate (Temp) and tropical (Trop) climate; nutrient rich (NR) and nutrient poor (NP) soils, with their corresponding emission factors: $EF_{2CG,Temp}$, $EF_{2CG,Trop}$, $EF_{2F,Temp,NR}$, $EF_{2F,Temp,NP}$, $EF_{2F,Trop}$.
EF_2 emission factor for N_2O emissions from organic soils.
F_{PRP} urine and dung N deposited on pastures, range and paddock by grazing animals; guidelines differentiate cattle, poultry and pigs (CPP) from sheep and other animals (SO), with two respective default emission factors: $EF_{3PRP,CPP}$, $EF_{3PRP,SO}$,
EF_3 emission factor for N_2O emissions from N deposited on pastures by grazing animals.

Tier 1 uses country specific activity data (from own sources, FAOSTAT or expert opinion) and default EFs. EF_1 varies with environmental factors (climate, soil organic C content, soil texture, drainage, soil pH) and management factors (N application rate per fertiliser type, type of crop: legumes, non-leguminous arable crops and grass, N application technique etc.).

Indirect N_2O emissions occur through volatilisation and leaching from the following sources: synthetic fertilisers (F_{SN}), organic N applied as a fertiliser (F_{ON}), urine and dung N deposited on pastures, range and paddock by grazing animals (F_{PRP}). Nitrogen sources contributing to indirect emissions through leaching (but not volatilisation) include N in crop residues (F_{CR}), N mineralisation associated with loss of organic matter resulting from change of land use or management of mineral soils (F_{SOM}).

Eq. 11.9: $N_2O_{(ATD)}\text{-}N = [(F_{SN} \cdot Frac_{GASF}) + ((F_{ON} + F_{PRP}) \cdot Frac_{GASM})] \cdot EF_4$

$Frac_{GASF}$ fraction of synthetic fertiliser N that volatilises as NH_3 and NO_x,
$Frac_{GASM}$ fraction of applied organic N fertiliser materials and urine and dung N deposited by grazing animals that volatilises, both with existing default values given by IPCC. For the synthetic fertiliser, tier 1 uses a unique value while tier 2 differentiates different conditions. Tier 3 uses methods involving modelling or measurements.

Eq. 11.10: $N_2O_{(L)}\text{-}N = (F_{SN} + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}) \cdot Frac_{LEACH\text{-}(H)} \cdot EF_5$

$Frac_{LEACH\text{-}(H)}$ fraction of all N added to / mineralised in managed soils in regions where leaching / runoff occurs (humid areas or dry areas with irrigation) that is lost through leaching and runoff.

Default emission factors (EF_4 and EF_5) and volatilisation and leaching fractions ($Frac_{GASF}$, $Frac_{GASM}$ and $Frac_{LEACH\text{-}(H)}$) are given in the guidelines.

We can thus identify three mitigation mechanism groups:

- **NMANAG** (nitrogen management): Measures designed to optimise the use of available nitrogen on the farm with the objective to reducing the need of external nitrogen sources, such as synthetic fertilisers, at constant output level. Mitigation measures include better adjustment to crop needs of quantity and timing of N applied, valorisation of organic fertilisers and legumes available etc.
- **LEGU** (leguminous): Introduction of nitrogen-fixing crops in rotations and grass mixes. Even though N-fixing crops are a source of nitrogen and allow a reduction in the application of mineral fertilisers, this measure is not included in the group 'NMANAG' due to the interaction of LEGU measures with animal feed and the challenges of collecting suitable data.
- **NEF** (nitrogen emission factors): Use of chemical substances or other techniques that reduce N_2O emission factors or emission factors from N_2O precursors. This includes also measures aiming at maintaining soil pH at a suitable level for crop/grass production and reduction of N_2O emissions from soils.
- **ORGSOILS** (management of organic soils): Reduction of the area of cultivated histosols.

We consider the mitigation mechanism groups NMANAG, LEGU and ORGSOILS to make use of the mitigation strategy 'observation', while NEF uses the mitigation strategy 'parameter'.

2.4.5 CH_4 and N_2O emissions from field burning of agricultural residues (3.F)

The estimation of greenhouse gas emissions from fire (L_{fire}, being tonnes of each GHG) follows the IPCC general equation 2.27 for the estimation of any type of emissions from fire:

Eq. 2.27: $$L_{fire} = A \cdot M_B \cdot C_f \cdot G_{ef} \cdot 10^{-3}$$

L	amount of greenhouse gas emissions from fire, tonnes of each GHG (CH_4, N_2O, etc.)
A	area burnt
MB	mass of fuel available for combustion
Cf	combustion factor
Gef	emission factor

There is only one mitigation mechanism group targeting this category of emissions:

- **BURN:** reducing emissions from biomass burning by reducing the area of residues burnt (mitigation strategy 'observation').

2.4.6 CO_2 emissions from the addition of limestone and dolomite to soils (3.G)

Liming is done to reduce acidity and improve plant growth in managed systems. It leads to CO_2 emissions when carbonate limes dissolve and release bicarbonate, which evolves into CO_2 and water. In a tier 1 approach, emissions would be estimated using equation 11.12 from IPCC (2006):

Eq. 11.12: $$CO_2 - C_{Emission} = M_{Limestone} \cdot EF_{Limestone} + M_{Dolomite} \cdot EF_{Dolomite}$$

$M_{Limestone}$	amount of calcic limestone applied
$M_{Dolomite}$	amount of dolomite applied
$EF_{Limestone}$	emission factor for limestone
$EF_{Dolomite}$	emission factor for dolomite

There is no mitigation measure targeting soil liming.

2.4.7 Agriculture - CO_2 emissions from urea application (3.H)

When urea ($CO(NH_2)_2$) is added to soils in the presence of water and urease enzymes, it is converted into ammonium (NH_4^+), hydroxyl ion (OH^-) and bicarbonate (HCO_3^-). As in the case of liming, bicarbonate evolves into CO_2 and water. The estimation of emissions is done using equation 11.13 from the IPCC (2006) guidelines.

Eq. 11.13: $$CO_2 - C_{Emission} = M \cdot EF$$

M for an applied amount of urea
EF M, having an emission factor for urea application EF.

There is no mitigation measure targeting CO_2 emissions from urea applications, even though the change of mineral fertiliser type (e.g. application of nitrates rather than urea as part of NMANAG) or the application of urease inhibitors (as part of NEF) will also have an impact on emissions in this source category.

2.4.8 Land Use, Land Use Change and Forestry (Sector 4)

The Land Use, Land Use Change, and Forestry (LULUCF) sector considers emissions and removals of CO_2 occurring in different land uses and in the conversions among them. The IPCC 2006 Guidelines identify six land use categories: Forest Land, Cropland, Grassland, Wetlands, Settlements, and Other Lands (e.g. rocks, ice). Emissions are estimated for land remaining in a certain category (e.g. Forest Land remaining Forest Land) as well as for land in conversion from a category to another category (e.g. Forest Land converted to Grasslands). A converted piece of land remains in the conversion category for a certain transition period, typically 20 years, an amount of time in which a new equilibrium is reached (typically applied to reach an equilibrium of disturbed soil organic carbon) and the converted land can finally be classified as a land remaining in its category. For example, Grassland converted to Forest Land needs a certain transition period to become Forest Land remaining Forest Land.

For each land use category, the carbon stored in the following pools is estimated: Living Biomass (above and below ground), Dead Organic Matter (dead wood and litter), and Soil Organic Carbon (in mineral or organic soils). Harvested Wood Products (HWP) are also considered an additional pool.

The LULUCF sector differs from other sectors (such as energy or waste) in several ways that make it quite peculiar and complex. Besides including both emissions and removals, the sector is ruled by natural processes and interactions, with anthropogenic influences that can be difficult to monitor and distinguish. Natural and often unpredictable events such as droughts, fires, or floods can have an important impact on the carbon cycle, which may present cyclical trends complex to model and monitor, and every human action can have important legacy long-term effects on the environment of difficult accountability. In addition, emissions come from a distributed source over the Earth surface, rather than from precise points as in other sectors. All these characteristics make LULUCF a complex sector, characterized by high uncertainties.

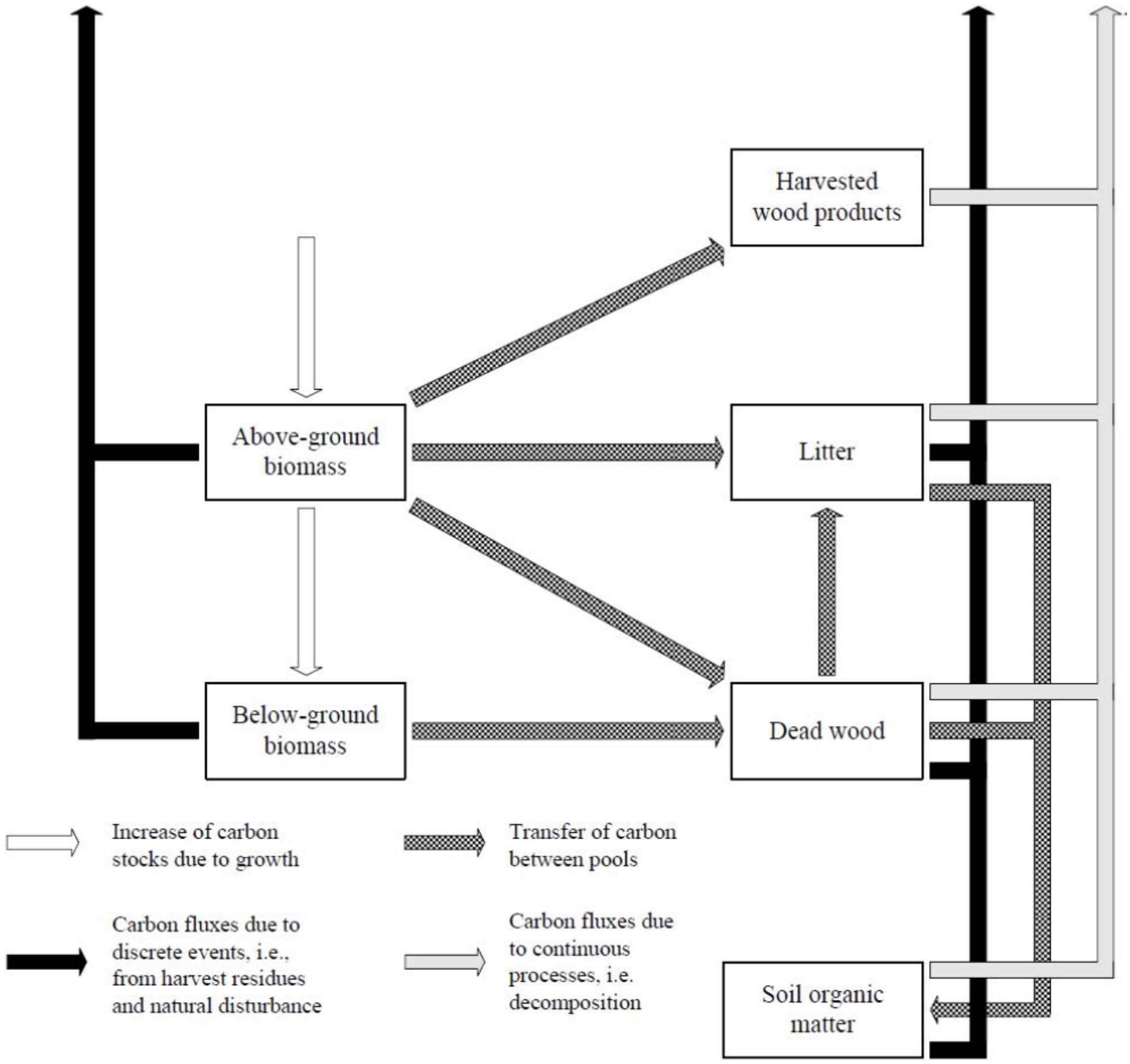

Figure 2: Generalized carbon cycle of terrestrial AFOLU ecosystems showing the flows of carbon into and out of the system as well as between the five C pools within the system (IPCC, 2006).

The total annual carbon stock change is the sum of the changes in the carbon stocks in all the land use sectors:

Eq.2.1 $$\Delta C_{AFOLU} = \Delta C_{FL} + \Delta C_{CL} + \Delta C_{GL} + \Delta C_{WL} + \Delta C_{SL} + \Delta C_{OL}$$

FL forest land
CL cropland
GL grassland
WL wetlands
SL settlements
OL other land

Changes in each category are the sum of the changes occurring in all the carbon pools, calculated for all the strata (combination of species, climate, soil, management regime, etc.).

The carbon stock change can be estimated as a function of gain-losses (gains minus losses) or the difference between the two actual carbon stocks in two points in time.

Δ_C=The Gain-Loss approach is generally used by countries that do not have a national inventory system designed to estimate biomass stocks, and is expressed through the following equation:

Eq. 2.4 $$\Delta C = \Delta C_G - \Delta C_L$$

ΔC annual carbon stock change in the pool
ΔCG annual gain of carbon
ΔCL annual loss of carbon

The Stock-Difference method requires a periodic estimation of carbon stocks. This method requires therefore Tier 2 or 3 approach. It is based on biomass stocks estimations that enter the following equation:

Eq.2.5 $$\Delta C = \frac{(C_{t_2} - C_{t_1})}{(t_2 - t_1)}$$

ΔC annual carbon stock change in the pool, tonnes C yr^{-1}
C_{t1} carbon stock in the pool at time t1, tonnes C
C_{t2} carbon stock in the pool at time t2, tonnes C

Carbon gains/losses are estimated for biomass and dead organic matter carbon pools as a function of the area under the considered land use (which constitutes the Activity Data) and different parameters to model biomass growing rates and biomass losses (due to harvest, mortality, decay, natural disturbances). In the case of land conversion, also changes in carbon stocks due to the conversion are taken into account, considering the biomass stocks before and immediately after the conversion. As mentioned before, after the conversion, the land remains in a conversion status for a transition period.

Recent initiatives (see the box below) highlight the potential role of Carbon sequestration within agricultural soils to compensate the growth in atmospheric CO_2. Soil organic carbon stocks are estimated as follows:

Eq. 2.24 $$\Delta C_{Soils} = \Delta C_{Mineral} - L_{Organic} + \Delta C_{Inorganic}$$

ΔCSoils annual change in carbon stocks in soils
ΔCMineral annual change in organic carbon stocks in mineral soils
LOrganic annual loss of carbon from drained organic soils
ΔCInorganic annual change in inorganic carbon stocks from soils (assumed to be 0 unless a Tier 3 modelling approach is used).

For Tier 1 and 2 methods, soil organic carbon stocks are computed at default depth of 30 cm. In the case of drained organic soils, emissions are calculated using the area of organic soils as activity data and a climate-dependent emission factor. For tier 1, management practices are not taken into account, but they can be considered when developing higher tier approaches. For mineral soils, the annual change in organic carbon stocks within the considered area is computed as the difference in the stock between two points in time (Equation 2.25a).

Eq. 2.25a: $$\Delta C_{Mineral} = \frac{(SOC_0 - SOC_{(0-T)})}{D}$$

$\Delta C_{Mineral}$ annual change in carbon stocks in mineral soils;
SOC_0 soil organic carbon stock in the last year of an inventory time period;
$SOC_{(0-T)}$ soil organic carbon stock at the beginning of the inventory time period;
D default time period for transition between equilibrium SOC values, years (commonly 20 years; in case a different number of years can be used, depending on the assumptions adopted in developing the stock change factors- see eq. 2.25b).

The soil organic carbon stock at different times is computed using eq. 2.25b, thus multiplying the reference soil organic carbon stock, which depends on climate and soil type, by three stock change factors describing the effect respectively of land use (e.g. long-term herbaceous cultivation, tree crops cultivation), management practices (e.g. tillage), and inputs applied (e.g. fertilization):

Eq. 2.25b $$SOC = \sum_{c.s.i}(SOC_{REF_{c,s,i}} * F_{LU_{c,s,i}} * F_{MG_{c,s,i}} * F_{I_{c,s,i}} * A_{c,s,i})$$

SOC_{REF}= the reference Soil Organic Carbon (SOC) stock, depending on soil and climate conditions;
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, dimensionless;
A= land 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, s, j= represent respectively the climate zones (c), the soil types (s), and the set of management systems (j).

Box 1: The 4 per 1000 Initiative: Soils for Food Security and Climate

The 4 per 1000 Initiative: Soils for Food Security and Climate

Before the 21st Conference of the Parties held in Paris in December 2015, which lead to the adoption of the Paris Agreement, the French government launched a voluntary action plan under the Lima Paris Agenda for Action (LPAA). The Initiative is aimed at supporting carbon sequestration in soils as a powerful way to achieve the goal of limiting the increase of temperature within the limits set by the UNFCCC while at the same time supporting food security.

The initiative estimates that a 4 per 1000 annual growth in soil carbon stocks within agricultural soils (in particular grasslands and pastures) and forest soils would be enough to compensate the present growth in atmospheric CO_2. At the same time, this would considerably improve soil fertility and increase agricultural production.

The activity is designed around two main strands of action:

1. a multi-partner programme of actions for better management of soil carbon, based on appropriate agricultural practices at local level (restoration of soils, increase of organic carbon stocks, protection of carbon rich soils)
2. an international research and scientific cooperation programme based on 4 themes: mechanisms and assessments of the potential for carbon storage in soils across regions and systems, assessment of best farming practices for soil carbon and their impact on other greenhouse gases, on food security, innovation: support and dissemination, and monitoring and estimating variations in soils carbon stock, especially at farmers level.

The proposal is open for stakeholders (state and non-state actors) to get involved. At 1st December 2015 around 100 countries and stakeholders had joined the initiative.

More information at http://4p1000.org

The mitigation measures for the LULUCF sector can be broadly divided into those focusing on land use and those referring to the selection of management options. Land use measures consist of strategies focusing on promoting the conversion towards land uses acting as sinks (e.g. afforestation) or avoiding conversions towards land uses acting as sources (deforestation). These measures fall therefore into the mitigation strategies 'observation'.

Management options focus on adopting practices that increase carbon stocks and reduce losses (e.g. fertilization strategies). It is important to assess the impact of each option not only on the soil carbon content but also on the emission of other GHG. These measures fall generally into the mitigation strategies 'parameter'. However, IPCC provides several default factors (see Equation2.25b) which can be used if appropriate data on the share of the management systems is available. In these cases, also the LMAN mitigation mechanism group can use the mitigation strategy 'observation'.

- **LUSE**: land use strategies focus on the allocation/conversion of land parcels to land uses that preserve and increase existing carbon content in soils and biomass.
- **LMAN:** land management strategies aim to maintain and increase carbon content in soils through appropriate management options (e.g. optimized livestock density, nutrient management, crop rotations, tillage strategies, etc).
- **ORGSOILS**: restoration and conservation of any type of soils with high content of organic matter (wetlands, peatlands and histosols). The activity makes use of the mitigation strategy 'observation'.

2.4.9 Sector 1: Energy use in agriculture

Within the energy sector, we focus on energy use in the agricultural sector, used to perform land operations, heating of stalls, etc.

- **ENER:** energy. Measures to reduce energy use in the farm, using carbon calculator tools and management strategies that optimise on-farm energy efficiency. This group of measures included all possibilities of on-farm generation and use of energy, which limits the requirement of external energy sources. These measures can be efficiently monitored by measuring the use of external energy only.

2.4.10 Summary mitigation mechanism groups

A summary of the mitigation mechanisms groups is given in

Table 1.

The definition of the mitigation mechanism groups presented in Table 1 and discussed in the previous sections have also been used to group a large set of concrete mitigation measures as discussed in a number of publications (both project reports and national programmes). The mitigation measures, they assignment to a mitigation mechanism group, as well as recommendations formulated in the publications are given in Annex 1.

Table 1. Definition of mitigation mechanism groups.

Mitigation mechanism groups	Mitigation strategy	Changes provoked	Tackles	Gas(es) targeted/ affected
HERD	Observation	Improves herd productivity, but not individual one	$N_{(T)}$	CH_{4Ent} CH_{4Man}, N_2O_{Man}
BREED	Observation	Improves animal productivity	$N_{(T)}$	CH_{4Ent} CH_{4Man} N_2O_{Man}
METHGEN	Parameter	Additives or breeding reducing selectively CH_4 production in rumen	Y_m	CH_{4Ent}
FEED	Observation	Adjust rations to (energy, N content) feed needs	GE/DE/Nex	CH_{4Ent}, N_2O_{Man} CH_{4Man} (through VS)
MANSYS	Observation	% manure in each MMS	MS	CH_{4Man}, N_2O_{Man}
ADIG	Observation	Anaerobic digesters, to reduce emissions form manure and produce energy	MS	CH_{4Man} N_2O_{Man} CO_2 energy
MANEF	Parameter	Additives, etc, affecting directly emission factors	MCF/ EF_3	CH_{4Man}, N_2O_{Man}
RICE	Observation	Management practices (e.g. aeration)	$t_{i,j,k}$, $A_{i,j,k}$	CH_{4Rice}
NMANAG	Observation	Improved use of available sources (% each type, timing....)	F_{SN}, F_{PRP} $Frac_{GASF}$, $Frac_{GASM}$, ...	N_2O_{Direct} N_2O_{ATD} N_2O_{LEACH}
LEGU	Observation	Increase leguminous share	F_{SN}, $F_{CR}^{(*)}$, F_{PRP}	N_2O_{Direct} N_2O_{ATD}, N_2O_{LEACH}, N_2O_{Man}, CH_{4Man}
NEF	Parameter	Substances/ techniques to reduce EFs	EF_1, EF_3	N_2O_{Direct}
BURN	Observation	Reduce burnt biomass	A	L_{fire}
LUSE	Observation	Increasing carbon sequestration/Reducing carbon losses	A	CO_2 CH_4 N_2O
LMAN	Parameter (Observation)	Reducing carbon losses	Stock Change Factors	CO_2 N_2O
ORGSOILS	Observation	Increasing carbon sequestration/ preventing carbon losses	Area	CO_2 CH_4 N_2O
ENER	Observation	Measures to reduce farm energy use	Energy data in agric.	CO_2

(*) Increase F_{CR} specifically for leguminous crops → reduced needs of other sources.

3 Assessing traceability of mitigation measures by mitigation mechanism groups in GHG inventories quantified with IPCC methodology

In this section we analyse the capacity of the IPCC guidelines to account for mitigation effects of the different mitigation mechanism groups. Table 2 shows accountability and data needs. In general, most of the mechanism groups are affecting observations and are thus easy to account for without the need for the countries to develop national methods/emission factors. Also mitigation measures from the 'parameters' mechanism groups can be reflected in national GHG emission inventories if the country is able to develop national emission factors based on available data or research programmes.

Table 3 summarises the level of detail (Tiers) needed for each of the mitigation mechanism groups proposed to be accounted in the GHG inventories. For some mitigation mechanism groups, Table 2 and Table 3 identify the need for Tier 2 methodologies. According to the IPCC (2006) guidelines, it is obligatory to use tier 2 methodologies if those emission categories are amongst the countries' key source categories. This is the case for example for emissions in source category 3.A Enteric Fermentation and 3.B.1 CH_4 emissions from manure management. An overview of the methodology used in the AFOLU sector for the GHG inventory 2016 is given in Annex 2.

Table 2. Accountability and data availability of mitigation mechanism groups

Livestock emissions (3A and 3B)

	HERD
GASES TARGETED	CH_4, N_2O
SIDE EFFECTS	Reduction of animal numbers (keeping the same production level) will reduce total emissions from all livestock-related emission categories; it also reduces feed requirements and consequently might have a positive effect on emissions from soil cultivation.
INVENTORY CATEGORIES AFFECTED (CRF TABLES)	3A, 3B.1, 3B.2, and indirectly 3D
MAIN PARAMETERS	Number of animals ($N_{(T)}$)
ACCOUNTABILITY WITH IPCC GUIDELINES (MIN REQUIREMENT)	**Tier 1** with regard to animal numbers and effect on reduced feed requirements.
AVAILABILITY OF DATA	Animal census and production statistics available. Changes in crop production available from statistics.
OTHER COMMENTS	One of the measures easiest to monitor but with implication in all livestock related emission categories.

	BREED
GASES TARGETED	CH_4, N_2O
SIDE EFFECTS	Reduction of animal numbers (due to increased productivity per animal but keeping the same production level) will affect total emissions from all categories related to livestock and manure; feed requirement changes. Some measures involve the use of substances to increase productivity, with possible effect on human

	health. Increased productivity can be accompanied by increased emissions per head; the balance has to be evaluated.
INVENTORY CATEGORIES AFFECTED	3A, 3B1, 3B2, and possibly 3D
MAIN PARAMETERS	Number of animals, livestock characterization (with increased productivity per head)
ACCOUNTABILITY WITH IPCC GUIDELINES(MIN REQUIREMENT)	**Tier 2** to account for possible increased in Nex, VS excretion and down-stream emissions.
AVAILABILITY OF DATA	Animal census and production statistics available. Requires collection of feed data and animal characteristics (live weight, growth rate …). Changes in crop production available from statistics.
OTHER COMMENTS	The objective is the number of animals, but emission factors and N excretion of improved breeds have to be controlled for potential side effects

	METHGEN
GASES TARGETED	CH_4
SIDE EFFECTS	Unclear
INVENTORY CATEGORIES AFFECTED (CRF TABLES)	3A
MAIN PARAMETERS	New methane emission factors (Ym)
ACCOUNTABILITY WITH IPCC GUIDELINES (MIN REQUIREMENT)	**Tier 2.** Requires development of country-specific EF
AVAILABILITY OF DATA	Evidence currently insufficient.
OTHER COMMENTS	Data should come from experiments; practical implementation is currently limited due to legal issues.

	FEED
GASES TARGETED	CH_4, N_2O
SIDE EFFECTS	Changes in feed composition could involve changes in cropping patterns (more oil crops instead of sugar crops, for example).
INVENTORY CATEGORIES AFFECTED (CRF TABLES)	3A, 3B1, 3B2, and indirectly 3D
MAIN PARAMETERS	Gross energy intake, digestibility of feed, VS excretion, Nex
ACCOUNTABILITY WITH IPCC GUIDELINES (MIN REQUIREMENT)	**CH_4 – Tier 2**. Emissions can be calculated from detailed composition of feed. NRC (2001) can be used to derive changes on digestibility. **N_2O – Tier 2**. Emissions from manure require the development of country-specific Nex factor.
AVAILABILITY OF DATA	Requires collection of feed data. Changes in crop

	production available from statistics.
OTHER COMMENTS	A feed calculator tool could be used to collect farm-specific data on feed. The tool could be also used to quantify directly CH_4 emissions from enteric fermentation based on shares of feed in the rations thus giving the farmer information on achieved mitigation. It also provides useful information for a N management plan if combined with monitoring nutrient retention in the animals.

	MANSYS
GASES TARGETED	CH_4, N_2O
SIDE EFFECTS	Indirect N_2O emissions from N volatilisation and leaching could also change.
INVENTORY CATEGORIES AFFECTED (CRF TABLES)	3B1, 3B2
MAIN PARAMETERS	% manure treated in each system
ACCOUNTABILITY WITH IPCC GUIDELINES (MIN REQUIREMENT)	**CH_4 – Tier 2**[1] **N_2O – Tier 1**
AVAILABILITY OF DATA	IPCC includes default MCF and N_2O emission factors.
OTHER COMMENTS	National Emission Ceilings directive could be a source for indirect N_2O emissions.

	ADIG
GASES TARGETED	CH_4, N_2O, CO_2
SIDE EFFECTS	Production of energy that can replace fossil fuel (and their CO_2 emissions).
INVENTORY CATEGORIES AFFECTED (CRF TABLES)	3B1, 3B2, 1A4
MAIN PARAMETERS	% manure, CH_4 and N_2O emission factors.
ACCOUNTABILITY WITH IPCC GUIDELINES (MIN REQUIREMENT)	**CH_4 – Tier 2** **N_2O – Tier 1** Energy produced accounted in the corresponding part of the inventories.
AVAILABILITY OF DATA	IPCC includes default MCF and N_2O EF for anaerobic digestion. Accounting of emissions from pre- and post-treatment is still not well guided.
OTHER COMMENTS	

[1] Tier 1 methodology for the estimation of CH4 emissions from manure management does only require livestock population data and climate region. Manure management systems are only required for a tier 2 approach. The tier 1 method for the estimation of N2O emissions from manure management already requires the quantity of manure managed in each manure management system (see pages 10.35 and 10.52 of Volume 4, Chapter10 of IPCC 2006 guidelines).

	MANEF
GASES TARGETED	CH_4, N_2O
SIDE EFFECTS	Indirect N_2O emissions through N volatilisation and leaching can also change.
INVENTORY CATEGORIES AFFECTED (CRF TABLES)	3B1, 3B2
MAIN PARAMETERS	New EFs for the manure management systems affected.
ACCOUNTABILITY WITH IPCC GUIDELINES (MIN REQUIREMENT)	**Tier 2** Changes in EFs usually not available.
AVAILABILITY OF DATA	New techniques to reduce emissions from manure management systems require experiments to derive new emission factors.
OTHER COMMENTS	Country specific MCFs and N_2O emission factors have to be developed.

Rice cultivation (3C)

	RICE
GASES TARGETED	CH_4
SIDE EFFECTS	
INVENTORY CATEGORIES AFFECTED (CRF TABLES)	3C
MAIN PARAMETERS	Area ($A_{i,j,k}$) and time of flooding period ($t_{i,j,k}$) for the different production conditions *i, j, k*... in the country.
ACCOUNTABILITY WITH IPCC GUIDELINES (MIN REQUIREMENT)	**Tier 1**, as far as there exists the EF for *i, j, k* conditions considered (mainly related to flooding time, and therefore aeration).
AVAILABILITY OF DATA	IPCC includes some EFs, areas and flooding time for the different conditions should be available from national statistics.
OTHER COMMENTS	

Soil emissions (3D)

	NMANAG
GASES TARGETED	N_2O
SIDE EFFECTS	Reduction of synthetic fertiliser use leads also a decrease in GHG emissions from fertiliser production and transport.
INVENTORY CATEGORIES AFFECTED (CRF TABLES)	3D(a), 3D(b)
MAIN PARAMETERS	N applied from the different sources. Any nitrogen savings on the farm are assumed to translate into a reduced requirement for additional external sources of nitrogen (mainly mineral fertiliser).

ACCOUNTABILITY WITH IPCC GUIDELINES (MIN REQUIREMENT)	**Tier 1**
AVAILABILITY OF DATA	Fertiliser use available from statistics. Default emission factors can be used.
OTHER COMMENTS	N from manure can be calculated from equations 10.34 and 11.3 of IPCC 2006 (with country-specific or default parameters, if not available). The best way of implementing it would be the use of nutrient management plans. Support to the farmers can be given in form of a 'farm nitrogen calculator', which captures also farmer's behaviour and helps identifying nitrogen saving opportunities. Note: for some of the options (e.g. fertiliser timing, fertiliser application technique, …) a higher tier methodology must be used in the farm-level calculator – but this is not necessary for national reporting.

	LEGU
GASES TARGETED	N_2O
SIDE EFFECTS	These measures can affect (reduce) also indirect emissions from soils (category 3D(b)). Reduction of synthetic fertiliser use implies also a decrease in GHG emissions from fertiliser production and transport. It might change digestibility and N content of grass and, therefore, CH_4 and N_2O emissions from livestock.
INVENTORY CATEGORIES AFFECTED (CRF TABLES)	3D1
MAIN PARAMETERS	Increase of share of legumes, reduced N from synthetic fertilisers. If leguminous are in grasslands, changes in digestibility.
ACCOUNTABILITY WITH IPCC GUIDELINES (MIN REQUIREMENT)	**Tier 1**
AVAILABILITY OF DATA	Little data availability on the share of leguminous crops in grasslands; LPIS or the new SAPM could be used.
OTHER COMMENTS	Mitigation effect on N_2O emissions via reduced fertilizer needs. Indirect effects on CH_4 emissions from enteric fermentation (through feed composition) can be calculated with Tier 2.

	NEF
GASES TARGETED	N_2O
SIDE EFFECTS	No side effects, only emissions per unit of N input
INVENTORY CATEGORIES AFFECTED (CRF TABLES)	3D1
MAIN PARAMETERS	New emission factors for direct N_2O emissions from

	soils: EF_1
ACCOUNTABILITY WITH IPCC GUIDELINES (MIN REQUIREMENT)	**Tier 2.** Requires development of country-specific EFs
AVAILABILITY OF DATA	IPCC has only default EFs
OTHER COMMENTS	It requires experimental/modelling data

Burning of agricultural residues (3E)

	BURN
GASES TARGETED	CH_4, N_2O, CO_2…
SIDE EFFECTS	If residues are left on the soil, they are a source of nitrogen and have to be accounted. They would allow a reduction of N input from other sources.
INVENTORY CATEGORIES AFFECTED (CRF TABLES)	Emissions from fires, 3F
MAIN PARAMETERS	Area burnt A
ACCOUNTABILITY WITH IPCC GUIDELINES (MIN REQUIREMENT)	**Tier 1**
AVAILABILITY OF DATA	Available from statistics. Only a few EU countries report some crop residue burning.
OTHER COMMENTS	

Land use (4)

	LUSE
GASES TARGETED	CO_2
SIDE EFFECTS	CH_4, N_2O
INVENTORY CATEGORIES AFFECTED (CRF TABLES)	4, 4.1, 4A-F, 4(I)-4(V)
MAIN PARAMETERS	Area under different land uses/conversions; forests/vegetation characteristics.
ACCOUNTABILITY WITH IPCC GUIDELINES (MIN REQUIREMENT)	**Tier 1**
AVAILABILITY OF DATA	Land use data.
OTHER COMMENTS	Potential data sources: Land surveys, IACS/LPIS, remote sensing.

	LMAN
GASES TARGETED	CO_2
SIDE EFFECTS	CH_4, N_2O
INVENTORY CATEGORIES AFFECTED (CRF TABLES)	4, 4.1, 4A-F
MAIN PARAMETERS	Stock Change Factors (e.g. referring to rotations, tillage, fertiliser application) and other parameters (e.g.

	share of crop residues left on the soil, N from residues, areas of cover/catch crops).
ACCOUNTABILITY WITH IPCC GUIDELINES (MIN REQUIREMENT)	**Tier 1.** Tier 2 estimations can be necessary for mitigation options not currently considered in the IPCC Guidelines.
AVAILABILITY OF DATA	At the moment very little information is available on agricultural/land management options actually applied on the field. Fertilizer statistics at the national level available from EUROSTAT and FAOSTAT, subnational data available in some countries.
OTHER COMMENTS	Tier 2 can be necessary in case some management option is not currently described in the Guidelines and new Land Use Factors have to be locally determined for it. NB: Effects of different management options on emissions from cultivated organic soils are not taken into account in default EF, which are only climate dependent (IPCC, 2014, 2006). In case the effect of different management practices on organic soils has to be taken into account, appropriate Tier 2 EF have to be developed for different management practices. Potential data sources: IACS/LPIS, new SAPM surveys, EUROSTAT, FAOSTAT, national statistics.

	ORGSOILS
GASES TARGETED	CO_2, CH_4, N_2O
SIDE EFFECTS	Drained soils emit CO_2. Saturated soils create anaerobic conditions with release of CH_4 and N_2O. Limited evidence of the mitigation potential of non-peat wetland. Reduced fertiliser needs. Cooling effect on climate.
INVENTORY CATEGORIES AFFECTED (CRF TABLES)	4(II), 4D, 3D, 4A-4F.
MAIN PARAMETERS	Area of organic soils and wetlands.
ACCOUNTABILITY WITH IPCC GUIDELINES (MIN REQUIREMENT)	**Tier 1.**
AVAILABILITY OF DATA	Land use data, soil maps (e.g. Harmonized World Soil Database), burned area maps. Limited information on the wetlands status (wetland maps).
OTHER COMMENTS	Beside the IPCC 2006 Guidelines, also the 2013 Wetlands Supplement is now available with updated parameters and EF.

Table 3. Summary of Tier levels needed for the accountability of each mitigation mechanism groups.

	Tier1	Tier 2	Comment

HERD	X		Cat. 3A, 3B1, 3B2, 3D
BREED		X	Cat. 3A, 3B1, 3B2, 3D
METHGEN		X	Cat. 3A
FEED		X	Cat. 3A, 3B1, 3B2, 3D
MANSYS	X (for N_2O)	X (for CH_4)	Cat. 3B1, 3B2, 3D
ADIG	X (for N_2O)	X (for CH_4)	Cat. 3B1, 3B2, energy sector
MANEF		X	Cat. 3B1, 3B2
RICE	X		Cat. 3C
NMANAG	X		Cat. 3D
LEGU	X		Cat. 3D
NEF		X	Cat. 3D
BURN	X		Cat. 3F
LUSE	X		Cat 4A, 4B, 4C, 4D, 4E, 4F
LMAN	X	X	Cat 4A, 4B, 4C, 4D, 4E
ORGSOILS	X		Cat 3D, 4A, 4B, 4C, 4D, 4E

4 Implementation of mitigation measures: three illustrative examples.

In this section, three specific mitigation measures are used to illustrate the concept of mitigation strategies:

- addition of propionate precursors is part of the METHGEN mitigation mechanism using the 'parameter' mitigation strategy;
- reduced/no tillage measures are under the LMAN mechanism implementing a 'parameter' mitigation strategy;
- and precision feeding, which is included in the FEED mitigation mechanism group and uses the 'observation' mitigation strategy.

4.1 Addition of propionate precursors

This measure is applicable to ruminants. Hydrogen produced in the rumen as a result of fermentation can react to produce methane or propionate. This mitigation action consists on adding certain substances to favour the reactions leading to the production of propionate, so that less hydrogen is available for the production of methane. This will affect the methane conversion factor of the animal Y_m, which has a direct relation with the emission factor (equation 10.21 of the IPCC guidelines). How Y_m is affected is characteristic of the animal and cannot be collected from available data, but has to be determined with experimental tests.

Figure 3 shows the main emission categories related to livestock production, including gases produced in each step (black arrows) and emissions affected by the addition of propionate precursors to ruminant diets (red circles). Blue arrows represent the links between the different activities.

In this case, as a 'parameter' mitigation strategy, the measure does not affect other than the emission category for which it was designed. From that point of view, it would be simple to account for it in the inventories if new value for the modified factor were known through measurements or specific models. However, on-farm measurements of CH_4 emissions are expensive and technologies, and not usually available for farmers.

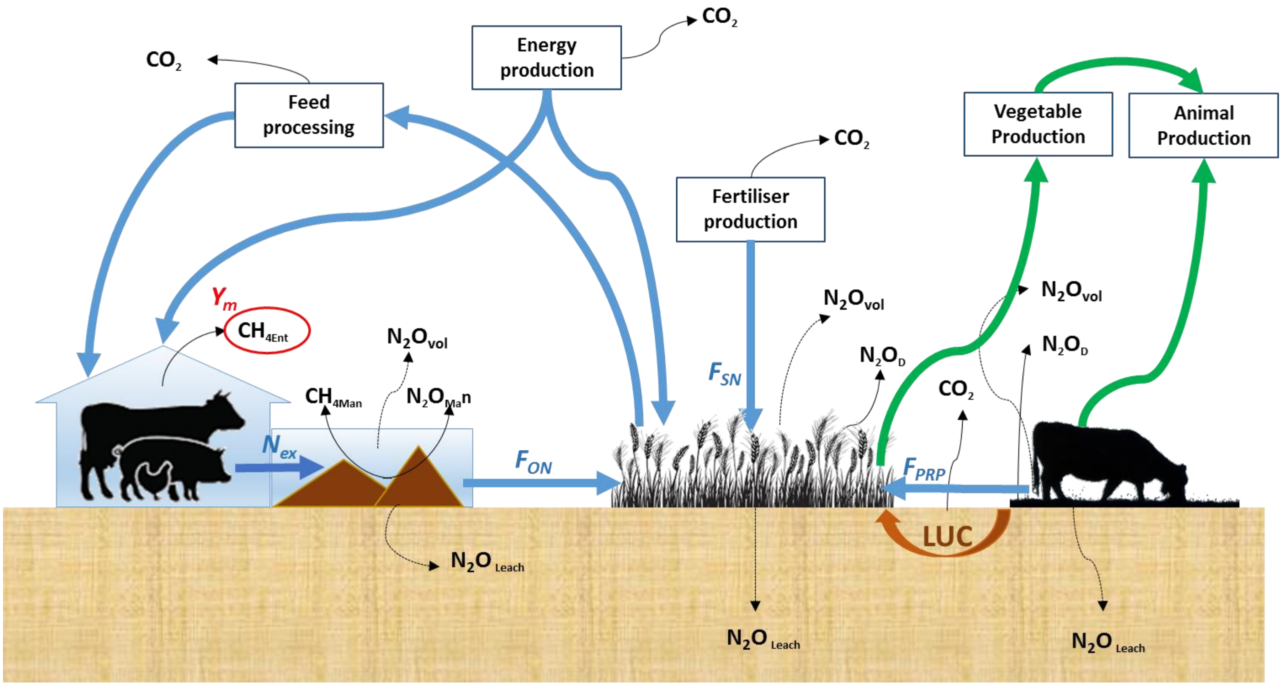

Figure 3. Example of specific mitigation measures: the effects of adding propionate precursors into ruminants' feed, shown in red circles. Blue arrows represent the links between the different activities. CO_2= carbon dioxide emissions; CH_{4Ent}= methane emissions from enteric fermentation; CH_{4Man}=

methane emissions from manure management; N_2O_{Man}= direct N_2O emissions from manure management; N_2O_D= direct N_2O emissions from soils; N_2O_{vol}= indirect N_2O emissions from volatilisation; N_2O_{Leach}= indirect N_2O emissions from leaching; Ym= methane conversion factor of feed in the rumen; Nex= nitrogen excretion; F_{ON}= nitrogen applied to cultivated soils from organic fertilisers; F_{SN}= nitrogen applied to cultivated soils from synthetic fertilisers; F_{PRP}= nitrogen applied to soils by grazing animals; LUC= land use changes.

4.2 Reduced Tillage/No tillage

Tillage is a fundamental practice in agricultural management, aimed at creating suitable conditions for the germination of the seeds and the growth of the plant. The mechanical processes increase the porosity of the soil and improve soil structure, with general positive effects, among the others in terms of weed control, water conservation and soil nutrient mineralization.

However, tillage can have negative side effects, among others soil erosion, nutrients loss, fuel/energy consumption, and GHG emissions. In particular, tillage causes a loss of soil carbon – and therefore CO_2- in the atmosphere.

Different strategies have been developed to reduce the negative side effects of tillage and improve soil carbon content, organic matter retention, cycling of nutrients, and soil fertility. Some of them involve reducing the soil disturbance by limiting tillage and soil layers inversion (e.g. conservation tillage, reduced tillage), while leaving the surface covered by previous year's cultural residues. 'No tillage' cultivation patterns completely eliminate tillage and use specialized equipment and appropriate techniques to prepare the seedbed without soil disruption and to plant the seed.

Mitigation options targeting tillage fall within the LMAN mitigation mechanism group.

In the case of mineral soils, the mitigation measures target a parameter clearly identified by the IPCC methodology, for which a default value can be obtained from the UNFCCC Guidelines 2006, or obtained from local field studies within a Tier 2 approach.

The parameter is the F_{MG} used in equation 2.25b (see above) describes the change in SOC (Soil Organic Carbon) occurring in the 20 years reference period.

The IPCC 2006 Guidelines identify at Tier 1 three main approaches to tillage (Full Tillage, Reduced Tillage, and No Tillage). Default values for F_{MG} are provided, depending on the temperature and moisture regimes (see table 5.5 of the IPCC 2006 Guidelines).

In the case of organic soils, the IPCC methodology uses a standard AD*EF approach, where activity data are the area of organic soils. However, for Tier 1 the IPCC 2006 Guidelines (IPCC 2006) and the IPCC Wetlands Supplement (IPCC 2013) only furnish default EF depending on climate and broad land uses (e.g. cropland, plantations, grasslands), without considering management options. In order to account for the effects of tillage on emissions from cultivated drained organic soils, local Tier 2 EF have to be developed, or Tier 3 modelling approaches have to be employed.

As far as non-CO_2 gases are concerned, there is not consensus in literature on the side effects that reduced tillage and no tillage mitigation measures can have in terms of CH_4 and N_2O emissions. The Catch-C project suggests that within an undisrupted soil, emissions of these gases may increase up to three times in the case of N_2O (Spiegel et al., 2015).

In terms of consequences besides the environmental effects already discussed for soil and emissions, reducing tillage can affect productivity (up to -4% in crop yields) while bringing savings in terms of fuel, machinery, and personnel.

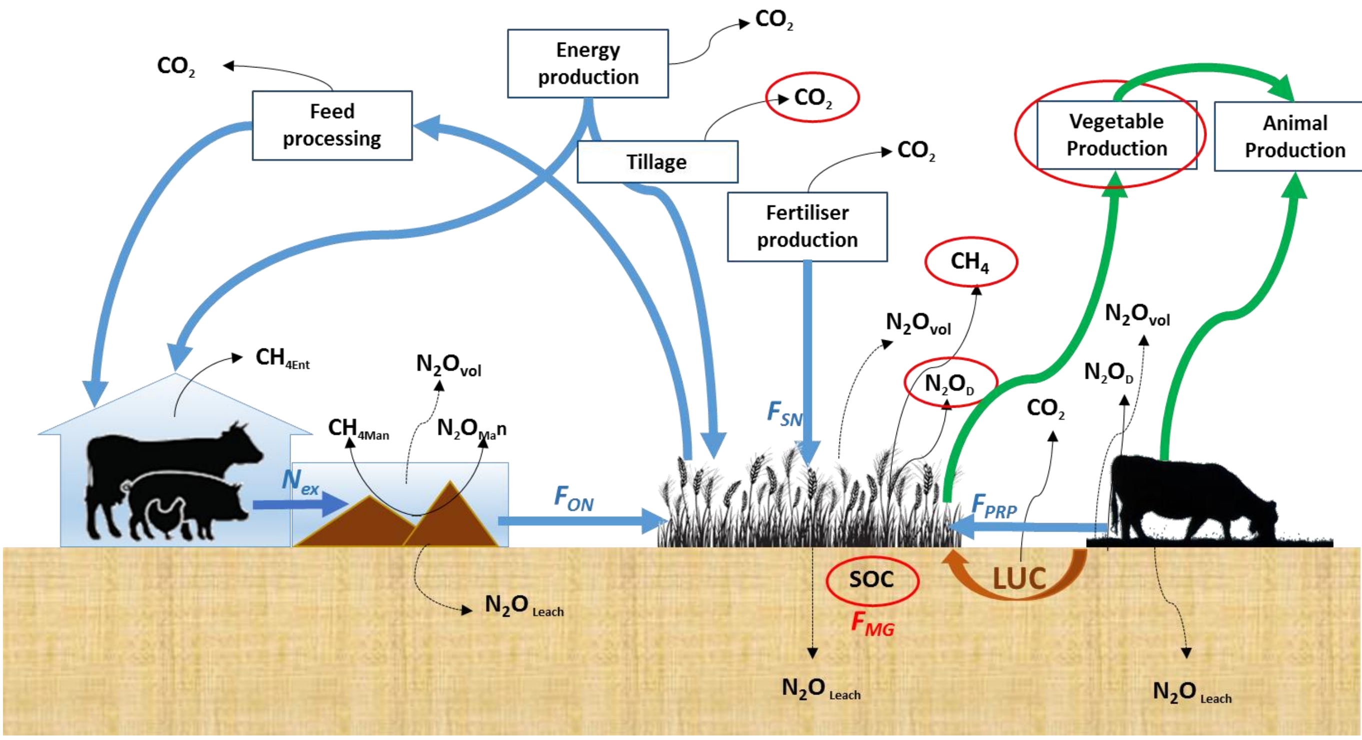

Figure 4. Example of specific mitigation measures: the effects of reducing or eliminating tillage shown in red circles. Blue arrows represent the links between the different activities. CO_2= carbon dioxide emissions; CH_4= methane emissions; N_2OD= direct N_2O emissions from soils; SOC: Soil Organic Carbon Content; FMG: stock change factor for management options.

4.3 Precision feeding

Precision feeding consists on optimising nutrient content in the diet to match the animal requirements, avoiding an excess of nitrogen that would be excreted. The optimisation includes matching feed to animal needs according to the age, time of the year, subgroup, etc. This can be applied to any animal type, although it is more common for pigs and poultry.

The target and immediate consequence of this mitigation measure is a reduction in Nex. This is considered as a 'observation' type of strategy, as can be calculated based on N intake and N retention, applying Equation 10.31 of the IPCC guidelines.

Eq. 10.31: $$Nex_{(T)} = N_{intake(T)} \cdot \left(1 - N_{retention(T)}\right)$$

Where $N_{retention}$ depends on the animal type and productivity, and N_{intake}, if not known, can be estimated from the composition of the diet:

Eq. 10.32: $$N_{intake} = \frac{GE}{18.45} \cdot \left(\frac{CP}{6.25}\right)$$

Being GE= gross energy intake, and CP= fraction of crude protein in the diet.

Unlike the previous example, the effects of this measure will not be restricted to one emission factor, but it will affect, directly or indirectly, more than one emission category. This is due to:

1) Nex is used for the calculation of different emission categories:

- N_2O direct emissions from manure management (see Equation 10.25)
- Indirect emissions due to volatilisation from manure management (see Equation 10.26)
- Indirect emissions due to N leaching from manure management (see Equation 10.28)

2) In addition, there could be other indirect consequences of the reduction in Nex:

- Reduced Nex means a reduced amount of manure N available for application to managed soils (see Equation 10.34 of the guidelines). This translates into a decrease of the amount of animal manure applied to soils (F_{ON}). If the farmer follows an N management plan, this), is compensated by an increase in the application of mineral fertilisers (F_{SN}) and the consequential increase in CO_2 emissions from fertiliser production.

- Some studies have concluded that precision feed guarantees an improved health and fertility, as well as a good state of the rumen flora. This would imply that smaller herd sizes could yield same production.
- Changing feed requirements affects crop cultivation choices and thus also N_2O emissions from soils. In pasture-based ruminants, precision feeding can be done replacing grass-based areas by cereals (maize or wheat). These changes in land use would involve an increase in CO_2 emissions (or decrease in C sequestration).

Figure 5 shows the main emission categories related to livestock production, including gases produced in each step (black arrows) and emissions affected by the implementation of precision feeding.

In this case, the mitigation action targets a parameter which can be calculated using IPCC equations, based on detailed information of feed, that the farmer should know (it is considered 'observation'). It is, therefore, more feasible to quantify for the farmer. But, unlike the use of propionate precursors, here the modification of one parameter (Nex) is going to have an impact in more than one category of emissions, and the effects will go beyond the reduction of the target gas.

In addition, it might happen that the measure has other side-effects which are not linked with the targeted parameter, like in this case, when land use changes may occur or methane emissions from enteric fermentation change as a consequence of the feed.

Side effects could enhance or offset the planned emission reduction. Therefore, it is important to keep an integrated vision of the system and to account for all the effects that a mitigation action can have, as the final mitigation potential will depend not only on the category targeted but on the overall effect.

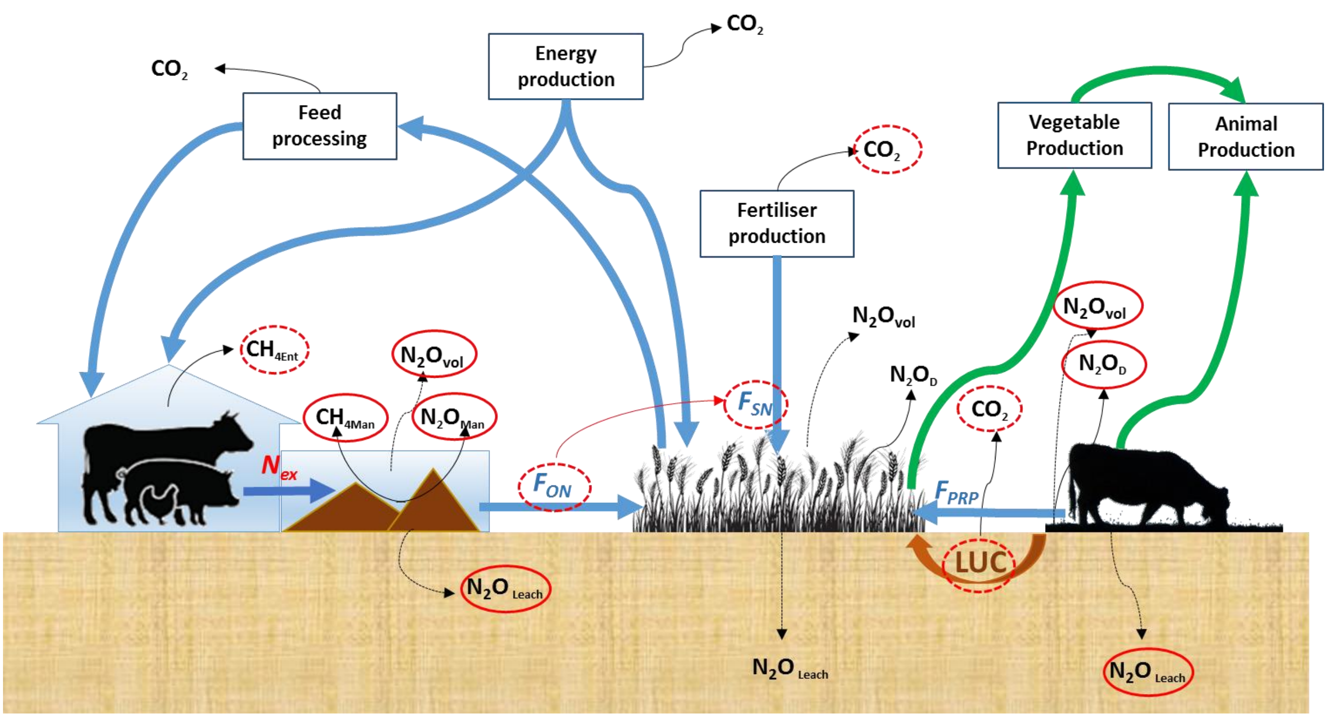

Figure 5. Example of specific mitigation measures: the effects of precision feeding in red circles. Blue arrows represent the links between the different activities. CO_2= carbon dioxide emissions; CH_4Ent= methane emissions from enteric fermentation; CH_4Man= methane emissions from manure

management; N_2OMan= direct N_2O emissions from manure management; N_2OD= direct N_2O emissions from soils; N_2Ovol= indirect N_2O emissions from volatilisation; N_2OLeach= indirect N_2O emissions from leaching; Nex= nitrogen excretion; FON= nitrogen applied to cultivated soils from organic fertilisers; FSN= nitrogen applied to cultivated soils from synthetic fertilisers; FPRP= nitrogen applied to soils by grazing animals; LUC= land use changes.

5 Farm level calculators

Based on the above assessment we propose a modular 'Farm-level GHG calculator framework' (Figure 6) that could on one hand provide a pragmatic way of assessing comprehensively farm-level GHG emissions. Most modules of the framework use relatively easily available data yet capturing the effect of most of the available mitigation measures. On the other hand, they deliver also important information required for national GHG emission inventories where availability of activity data is still insufficient in some countries, such as feed composition, land management data, etc.

Using farm level calculators ensures to capture most of the side effects so that comprehensive mitigation effects can be quantified. Collecting required data might be also interesting for farmers as they will get the information on the GHG emission intensity of their products, which might give a market advantage, and thus, enhancing the motivation for GHG emission reductions.

We focus here on measures relevant for climate change mitigation, however, such a modular approach might be also extended to include other impacts and ecosystem services provided by agriculture.

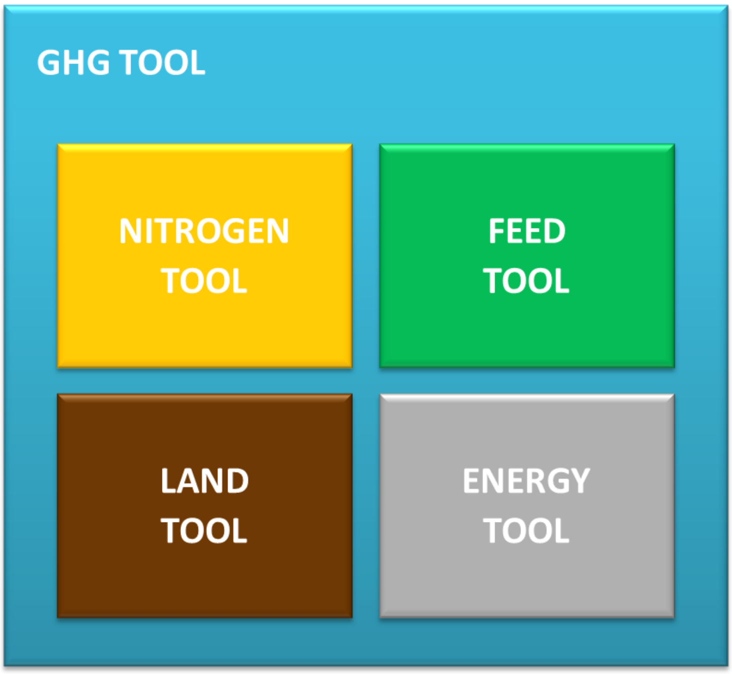

Figure 6. Illustration of a modular system for farm level calculator tools. These tools allow assessing the effect of most recommended mitigation measures in the land use sector. The four inner modules are largely independent and requiring mainly readily-available data. Only the soil tool requires spatial data. The combination of the four modules (with few additional data) provides sufficient information for a whole-farm GHG calculator.

5.1 Energy calculator

Many measures discussed above impact also energy use at the farm and upstream of the farms. At the farm, fuel consumption, energy requirement for housing, and livestock and soil management are all affected if the productivity is changed (animal efficiency, nitrogen use efficiency) as the same productivity can be achieved with less resources. Upstream of the farm, the energy requirements for production of fertilisers and other farm inputs and/or machinery and capital goods are impacted as well.

The magnitude of these effects is difficult to quantify. However, they are directly reflected in the annual energy balances used for the GHG inventories.

While most measures impact the energy requirement, there are also measures that specifically target energy use (production of renewable energy at the farm, energy saving measures). Those are captured equally by the inventories calculated with the IPCC methodology.

5.2 Nitrogen calculator

Out of 15 measures targeting the reduction of N_2O emissions (directly or indirectly via the reduction of NH_3 and NO_x volatilisation or N leaching and run-off, see Annex 2). Most have been found to act mainly via changes of the requirement of external sources of nitrogen. For anaerobic digestion and slurry covered by natural crust, default EFs for N_2O (and CH_4) are provided by IPCC (2006). The indirect effect on emissions due to changes in fertiliser type and application rate is captured by the CORINAIR methodology, used to estimate NH_3 and NO_x volatilisation rates.

The impact of the relevant measures on the direct or indirect N_2O emission factors from soils is (scientifically) highly uncertain and no methodology is available in the IPCC guidelines. Experience shows that the development of national N_2O emission factors is expensive as, due to the high spatial and temporal variability of N_2O emissions, the number of observations needs to be high to obtain a robust set of stratified EFs covering the relevant measures; each observation needs to contain a long-term time-series of N_2O flux measurements (e.g. using chamber or eddy covariance technology). Only few countries so far were able to develop stratified direct N_2O emission factors.

A nitrogen calculator tool gives the farmers the possibility to monitor the effectiveness of N mitigation measures by putting external N sources (mineral N fertiliser purchased, external feed stuff purchased, etc.) in relation to the 'production' of N in goods sold from the farm or consumed by the farmers themselves. The difference of N-sources and N-production gives a direct measure for the N surplus and the changes in the N surplus over time are a good approximation of changes of N_2O emissions.

Mitigation effects through changes in activity data are fully captured in IPCC GHG inventories.

These measures can be easily verified at the farm level by monitoring the import of external nitrogen sources to the farm, mainly mineral fertiliser or nitrogen containing feed, against the export of nitrogen in products generated by farm activities. Such a 'nitrogen tool' would be more efficient in controlling the measures grouped into the NMANAG mitigation mechanism group as it includes also farmer's behaviour (who might not reduce fertiliser input even under conditions when this would not cause productivity decreases).

N calculators need to be based largely on the farm nitrogen balance concept, even though differences between N calculator tools and the farm N balance might be required to give proper incentives to the farmers. For example, the substitution of mineral fertiliser with N from biological fixing crops does not necessarily lead to a reduction of N_2O emissions, but has other positive effects, e.g. on feed digestibility (if used as feed), or on biodiversity. Thus, it could be argued that biological nitrogen fixation could be not included in the list of external N sources to be considered in an N calculator tool.

As a conclusion, while an N calculator tool is judged as a very effective measure targeting N_2O mitigation (with positive effects on emissions of air and water pollutants) it is at the same time a very simple measure (requiring only few data which are easily accessible to the farmer). Some additional development of the most appropriate design is required.

5.3 Feed calculator

Most measures targeting the reduction of CH_4 emissions from enteric fermentation and manure management are captured if the feed composition is known. The IPCC Tier 2 methodology estimating feed intake via the quantification of the gross energy requirements is not sufficient as the measures act mainly through a change of feed digestibility and its effect on the CH_4 production potential. Thus data on actual feed intake, in contrast to data on feed supply by the farmers, need to be collected.

Exceptions targeting the CH_4 production for a given feed intake are measures such as genetic improvement or some feed additives which require the development of national data either with measurement programs (genetic improvement) and/or Tier 3 modelling (feed additives).

Applying feed calculators is an effective measure to collect such data for national GHG inventories in countries in which data are not yet available, and to monitor CH_4 emissions from enteric fermentation at the farm level if the quantification of feed digestibility and CH_4 production based on available methodologies is implemented.

5.4 Land calculator

A land calculator aims at capturing carbon sequestration measures and measures linked to land use changes. Information required include: tillage practices; periods a field is covered or un-covered during a year; input of carbon with crop residues; manure (including bedding material) or from other sources to the fields.

Compared to energy and N-calculator, the land calculator tool requires spatial (land use and land management) data, and is thus more complex to implement and requires more efforts from the farmer to be used. Nevertheless, systems collecting many of the data that a land calculator tool would need are already in place (e.g. the Land Parcel Identification System – LPIS within the Integrated Administration and Control System- IACS) and are used by some Member State. However, for other Member States data collected within these systems are often not easily available for the purpose of GHG accounting (at farm level or at national level) due to data property issues among the different national and regional authorities. An extension of these data collection systems to include missing data could be a cost-efficient way of assessing farm level and national mitigation measures targeting carbon sinks and sources.

5.5 GHG calculator

A full GHG calculator tool gives the most accurate estimate of GHG emissions at the farm level. It combines the information that is collected in the Energy, N, Feed and Soil calculator tools and requires only few additional information in order to capture also emissions that are not included in either of the four specific tools:

- Emissions from N sources not included in the N calculator tool (e.g. atmospheric deposition, biological nitrogen fixation)
- Data on the manure storage and management systems used
- Embedded emissions in purchased feed: this is particularly important if emission leakage is to be de-incentivised: the mitigation of GHG emissions at the cost reduction of production. This can be monitored with GHG emission intensities (emission per kg of product or similar). A method to account for upstream emissions needs to be developed (based on LCA thinking).
- Upstream energy use. Energy for fertiliser or other farm input products, and capital goods.

In principle, a GHG calculator tool can 'run' based on IPCC methodologies but offers also the possibility to include mitigation measures acting through changes of EFs and other parameters, on the condition that:

- National EFs or parameters have been developed
- The measure is accompanied at the measurement program at the farm
- Calibrated higher tier models are implemented and possible additional data (e.g. meteo-information, etc.) are collected

6 Conclusions

Measuring and monitoring the effect of GHG mitigation actions requires understanding how the targeted emission type is calculated, which parameters are changing when applying the mitigation action, as well as which side effects it may have.

Mitigation activities can be designed to target 'observations' or 'parameters'. In the first case, changes in data are usually easily quantified gathering new statistics or available information. Their effect is generally easily accountable using the IPCC guidelines. Changes in 'parameters' have a more localised effect, and often need experimental work to establish the new values needed.

The definition of mitigation mechanism groups helps transparently and comprehensively assessing if mitigation measures will 'show' up in national GHG emission inventories. Our analysis suggest that this is possible for most mitigation mechanism groups, in several cases however only with the use of tier 2 methodology, which are required nevertheless for key source categories. Even though mitigation measures making use of the strategy 'observation' are potentially simple to be traced in GHG emission inventories, not all data required are currently collected or available for the use of GHG accounting.

Calculator tools can help dealing with mitigation in an integrated approach and support data collection. They can be designed to focus on results, giving the farmers the possibility to choose their mitigation strategies according to their specific constraints and mitigation opportunities.

An integrated analysis takes the overall effects of any mitigation action into account and therefore it avoids the application of measures which offset each other or which have undesirable side-effects.

7 REFERENCES

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ANNEX 1: Examples of mitigation actions from previous studies.

In this document, a set of 'Mitigation Mechanism Groups' have been identified. These are characterised by the gas(es) and the parameter(s) they target and can be implemented using specific mitigation actions. Within each mitigation mechanism group, we can find a set of potential mitigation actions which have been used in practice or designed by scientist and policy makers. This annex includes some examples of specific mitigation actions that have been described in literature. The following studies were reviewed:

[1] Meta-review of Common Agricultural Policy (CAP) mainstreaming. Effective performance of tools for climate action policy. DG-Clima.

[2] ECAMPA project: 'Economic assessment of GHG mitigation policy options for EU agriculture'. It selected a set of measures to be implemented in CAPRI (Common Agricultural Policy Regional Impact model) to allow the assessment of measures.

[3] Pellerin, S., Bamière, L., Angers, D., Béline, F., Benoît, M., Butault, J.,… Pardon, L. (2013). Quelle contribution de l'agriculture française à la réduction des émissions de gaz à effet de serre? Potentiel d'atténuation et coût de dix actions techniques (Synthèse du rapport d'étude). Paris: INRA.

[4] Finnish Ministry of Agriculture and Forestry (2014). Climate Programme for Finnish Agriculture- Steps towards Climate Friendly Food. ISBN 978-952-453-871-8.

[5] Osterburg, B., Rüter, S., Freibauer, A., de Witte, T., Elsasser, P., Kätsch, S., Leischner, B., Paulsen, H.M., Rock, J., Röder, N., Sanders, J., Schweinle, J., Steuk, J., Stichnothe, H., Stümer, W., Welling, J., Wolff, A. (2013). Handlungsoptionen für den Klimaschutz in der deutschen Agrar- und Forstwirtschaft. Thünen Report 11.

Table A.1: Examples of specific mitigation actions for each of the mitigation mechanisms defined. References show in which studies those examples can be found. When those references are in brackets, that means the measure is analysed but not recommended (because of lack of effectiveness, side-effects or insufficient data); without brackets means the measure is analysed and recommended in the study.

MITIGATION MECHANISMS	SPECIFIC MITIGATION ACTIONS	REFERENCES
HERD	• Livestock disease management	1, (3), 4
	• Use of sexed semen for breeding dairy replacements	(1), (2), (5)
	• Genetically improved cow replacement rate	(2)
BREED	• Animal breeding for enhanced productivity	2
	• Livestock selection based on growth, milk production and fertility	(3)
	• Use of products to increase production (meat or milk) per animal (like somatotropin)	(3)
METHGEN	• Feed additives to reduce CH_4 (lipids, nitrates or sulphates, propionate precursors, plant bioactive compounds)	2, 3, 4, (5)
	• Breeding low methane emissions in ruminants	(1), (2)
	• Vaccination against methanogenic bacteria in the rumen	2
	• Develop cross-breeding with lower emissions	(3)
	• Change fodder composition, favouring non-	(3)

	methanogenic compounds (increase sugar, tannins…)	
	• Use of antibiotics to regulate microorganisms producing methane in the rumen	(3)
	• Use of biotechnology to control microorganisms in the rumen	(3)
FEED	• Feed advisory tool	--
	• Optimised feed strategies (multi-phase feeding)	1
	• Changes in composition of animals' diet (optimising feed mix in ruminants)	2, 4, 5
	• Low nitrogen feed	2, 3
	• Genetic improvement of cattle based on feed use efficiency	(3), 5
	• Increase concentrates in feed rations	(3)
MANSYS	• Optimised manure storage and application	4, 5
	• Covering slurry pits	(2), (4)
	• Incorporation of slurry	4
	• Decrease the quantity of manure stock	(3)
	• Optimise the type of manure produced to balance N_2O/CH_4 emissions	(3)
ADIG	• Anaerobic digestion	1, 2, 3, 4
	• Produce dihydrogen from manure in anaerobic conditions	(3)
MANEF	• Slurry acidification	(2)
RICE	• Rice	(2), (3)
NMANAG	• Soil and nutrient management plans	1, 4
	• Improved nitrogen efficiency	(1), 2, 3, 4, 5
	• Variable Rate Technology (VRT)	2, 5
	• Precision farming	2, 4
	• Genetic improvement of crops for better nitrogen uptake and use efficiency	(3), 4
	• Delay in applying mineral N in crops that have had slurry applied	(1)
	• Reducing soil compaction and avoiding fertilization in the traffic lanes	(5)
LEGU	• Biological N fixation in rotations and in grass mixes	1, 3
	• Increase legume share in temporary grassland	2
	• Substitution of mineral fertilizer by N from legumes	5
NEF	• Use of urease inhibitors and next-generation nitrification inhibitors	(1)

	• Nitrification inhibitors	2, (5)
	• Modify microbial communities in the soil, introducing microorganisms which reduce N_2O and N_2	(3)
	• Maintain soil pH at suitable level for crop/grass production	(1), (3)
BURN	• Burn	1, (3)
LUSE	• Agro-forestry, short rotation forestry	1, 3, 5
	• Maintaining permanent grasslands	4, 5
	• Conversion of arable land to grassland to sequester carbon in the soil	(1), 4
	• Woodland creation (afforestation, including new shelterbelts, hedgerows, woody buffer strips and in-field trees)	1, (4)
	• Woodland management: preventing deforestation	(1)
	• Woodland management (including existing shelterbelts, hedgerows, woody buffer strips and in-field trees)	1
LMAN	• Improving grassland management (e.g. optimizing productivity, livestock density, nutrient management, grass varieties) to increase carbon sequestration	1, 3, 4, (5)
	• Extend the perennial phase of crop rotations	(1), 4
	• Leaving Crop Residues on the soil surface	1, 4
	• Use cover/catch crops, green manure, and reduce bare fallow	1, 3, 4
	• Restauration of degraded soils to increase the production and stock of organic matter	(3)
	• Increase biomass production by optimising the input use, increasing carbon return to the soil	(3)
	• Select crops providing higher carbon return to soils	(3)
	• Measures targeting C-sequestration (reduced tillage, crop rotation, cover crops...)	4, (5)
	• Reduced Tillage	(1), (2)
	• Zero Tillage	(1), (2), 3
	• Biochar applied to soil	(1), (3), (5)
ORGSOILS	• Wetland and peatland conservation/restoration	1, 4, 5
	• Fallowing histosols	2, (3)
ENER	• Carbon calculator	(1), 4
	• Improved on-farm energy efficiency	1, 4, 5
	• Reduce the use of fossil energy use on-farm in buildings and machinery	3

	• Use of solar energy to dry agricultural products	(3)
	• Use of solar, wind, and geothermal energy	4
	• Biofuel production and use on site	4, (5)
	• Produce energy on-farm through biomass burning to decrease CO_2 emissions	(3)

Below, some explanations are given for each measure about the reasons for recommendation or rejection in the reports examined:

- HERD:

"Livestock disease management" is recommended by [1] because abatement is achieved and accountable through the reduced mortality of animals and thus though enhanced productivity. This action is also selected by [4], although their justification is more related to adaptation needs. It is discarded by [3] but not because of its lack of effectiveness, but because of the already existing good health conditions of livestock.

The "Use of sexed semen for dairy replacements" is analysed in several studies [1, 2] and discarded in all of them. They argue that, even though it is already commercially available, it needs further examination to parameterise the measure, and there is not enough data reporting reductions in GHG emissions by adopting it.

- BREED:

"Animal breeding for enhanced productivity" is proposed by [2] among their list of potential mitigation actions. This is, according to the experts, the most effective solution to reduce methane emissions per head and is already a broad breeding goal in the dairy sector in the EU.

"Livestock selection based on growth, milk production and fertility" and "the use of products to increase production per animal" are both analysed and discarded by [3]: the first one because selection based on productivity is already done in France (this would not apply for other regions), and the second one due to legal problems; like the use of antibiotics, somatotropin, which is the only additive whose efficacy for increasing productivity has been proven, is forbidden in the EU.

- METHGEN:

Most of the reviewed documents address methanogenesis through feed additives (substances such as lipids, nitrates or sulphates, propionate precursors, plant bioactive compounds) that inhibit methane generation or provide hydrogen receptors etc. and thus decrease methane emissions. The strategy includes also feed components which have nutritional value but have an effect on methane generation by enteric fermentation which is not captured in the IPCC Tier 2 approach. Other options to modify the methanogenesis in ruminants comprise antibiotics, microorganism, genetic breeding, but none of these measures had been evaluated suitable to be recommended at this stage.

The measure "feed additives to reduce CH_4 emissions" is analysed by all the studies reviewed. Additives comprise propionate precursors, fat supplementation, probiotics and ionophores, of which the last ones are forbidden in the EU due to potential unfavourable side-effects (increase of metabolic disorders in the animals). Other types of additives are reviewed in [2], while [3] focuses on fat additives and [4] proposes specifically turnip rape oil. In contrast, [5] argues that side effects on animal welfare are not well known and long-term effects still difficult to assess. Dietary lipids are the additives most commonly considered in literature and they are already being used in many countries. Also nitrates and sulphates have high reduction potential but require careful dosage to avoid negative health effects. Other substances such as propionate precursors or direct inhibitors are not recommended for the moment, as they need further tests to assess their effectiveness in vivo or there is still uncertainty about possible trade-offs.

Within the METHGEN strategy, [1] and [2] also analyse "breeding low methane emissions in ruminants" and they conclude that the measure is not yet sufficiently developed and its practical application does not seem realistic; "selection for enhanced productivity" is recommended instead, as it leads to the same goal of reducing emissions per unit of product and is already a goal in breeding programs.

"Develop cross-breeding with lower emissions", "change fodder composition favouring non-methanogenic compounds", "use of antibiotics to regulate microorganisms producing methane in the rumen", "use of biotechnology to control microorganisms in the rumen" are only covered by [3], and none of them is recommended due to different reasons: need of further research to understand their real effects in the field, uncertain mitigation potential and impact in livestock farming systems or, for the last measure, due to legal problems (it is currently forbidden in the EU).

- FEED:

Measures following this mechanism are very efficient and their effect on CH_4 emissions and manure excretion are easy to monitor if feed composition is known. Within this group, we find:

"Multi-phase feeding" and "optimising feed mix in ruminants", two simple measures applicable to all livestock categories, which would involve collecting information about animal requirements and feed formulation, and this could be an important part of a feed advisory tool. However, [5] notes that sufficient data on the quality of feed used is so far lacking.

The following measures are only analysed (and not recommended) by [3]: "genetic improvement of cattle based on feed use efficiency", "increase of concentrates in feed rations". The first one is not selected because of a lack experience on these selection criteria and insufficient knowledge about direct selection based on CH_4 emissions, while the second one is considered to have uncertain effectiveness due to compensation effects between different GHG, in addition to the doubts about the sustainability of high concentrate feed systems.

- MANSYS:

"Optimised manure storage and application" and "covering slurry pits" reduce ammonia emissions and thus lead to an overall increase in available nitrogen, even though interactions with e.g. N_2O emissions are not clear. Therefore [5] points out that optimised manure storage and application should be combined with low-emissions application techniques. According to [2], covering slurry pits entails a considerable mitigation potential, but does not select it because of further data needs to be modelled; although it looks a promising measure which reduces NH_3 emissions and, according to recent studies, also CH_4 emissions, it needs further research to verify the overall effects.

"Decrease the quantity of manure stock" and "optimise the type of manure produced" are also proposed and discarded only by [3], the first one because of a low mitigation potential, compared to other actions, while the last one still needs further research.

- ADIG:

According to literature, the measure can only be applied to big farms (it is not economically viable for small ones) and only to those using liquid manure management systems. The energy can be generated as electricity and heat. The digestate can be used as fertiliser on fields. It results in considerable emission reduction potential for pig farms, smaller potential and higher costs for cattle. In the selected studies we found:

All studies recommend "anaerobic digestion" but they point out that the measure is only profitable from a certain farm size. For smaller farms, community digesters can be a solution to make it cost-effective. In Germany [5], subsidies have already been high and in-depth assessments on possible side effects are required. "Produce dihydrogen from manure in anaerobic conditions" is not selected because it is not sufficiently developed at the moment.

- MANEF:

Within the reference documents, we only found "slurry acidification" [2] as a MANEF type of strategy where, despite seeming a promising measure, it is not recommended due to a need for further research on its overall effects.

- RICE

Emissions from rice cultivation are not much relevant in Europe, due to limited rice area. "Rice measures" are mentioned in [3], but not recommended because, despite the effectiveness of the measure in terms of mitigation per area unit, the mitigation potential in France is low due to a limited surface of rice crops. Similarly, [2] considers this emission type of minor importance in the EU, where rice contributes to a minor share of agricultural emissions.

- NMANAG:

The most recurrent measure in this group is "improved nitrogen efficiency", which is considered in all the studies and which is very similar to "nitrogen advisory tool" and "soil and nutrient management plans". It is understood by [1] as a combination of not exceeding crop N requirements, making full allowance for manure N supply, spreading manure at appropriate times and increasing livestock nutrient use efficiency. They discard this strategy because of expected heterogeneous mitigation capacities in different areas, given that these measures are already implemented in many nitrate vulnerable zones in the EU. However, all other studies select this strategy.

"Genetic improvement of crops for a better N uptake" is selected by [4] but not by [3], because of the need of a long process of identification and genetic selection of crop varieties, and could not yield results in the short term.

Even though [5] assesses the "substitution of mineral fertiliser with legumes" as positive due to the enhanced N use efficiency, it notes that higher N_2O emissions might be a consequence under certain conditions.

"Reducing soil compaction and avoiding fertilisation in the traffic lanes" is addressed by the [5]. It concludes that the measure, having positive effects with regard to better nutrient management, could be included in farm recommendations. However, it is not recommended at national level because of difficulties in controlling and reporting.

- LEGU:

This group includes "biological N fixation in rotations and in grass mixes" and "increase legume share in temporary grassland", both selected by the studies analysing them [1, 3].

- NEF:

These measures are not recommended without further research due to potential side effects and/or lacking evidence to quantify the mitigation effect. Some of the measures were discarded by all the documents including them: "delay in applying mineral fertilisers" [1] is not retained due to lack of evidence about effectiveness of the measure; "use of urease inhibitors and next generation nitrification inhibitors" [1] seems an effective measure but costly and with potential side-effects on food safety.

The implementation potential of "nitrification inhibitors" in Europe is uncertain, although they are used in the USA. They act (partly) also over an increased availability of nitrogen for the plants – as such it belongs also to the group NMANAG. However, there is discussion about their application in other regions in the world due to traces in dairy products. According to [5], these products might have a large mitigation potential but, due to insufficient information on long-term and side effects, does not recommend it. "Modify microbial communities in the soil" [3] is not retained due to lack of evidence of effectiveness outside laboratory conditions.

"Maintain soil pH at suitable level" is also analysed by several studies [1, 3]. They consider that there is insufficient evidence on the effectiveness of the measure, partly due to the complexity of physic-chemical and other soil factors influencing emissions.

- BURN:

Reduction of vegetation area burned and prohibition to burn agricultural residues, decreasing CO_2 emissions and allowing organic carbon to be kept in the soil. The mitigation potential is very low, being already forbidden in most EU countries. Within the documents reviewed, [1] selects "ceasing burning of vegetation and crop residues" because burning residues leads to a high number of emissions of different gases. However, it is discarded by [3] because of the low mitigation potential in France, where burning residues is already not common, but crop residues are usually incorporated to the soils instead. This is the case in most EU countries, which banned this practice under the GAECS standards.

- LUSE:

This group deals either with measures for the allocation of land under land uses characterized by higher carbon sequestration rates, such as permanent grasslands and forests, or measures to avoid changes towards uses characterized by lower carbon sequestering uses. Measures of this second type comprehend conservation of vegetated areas with high carbon content (e.g. forests, permanent grasslands) and transitions towards land uses with higher sequestration rates (e.g. transition from cropland to grassland, and afforestation).

"Conversion of arable land to grassland": [4] considers it as a candidate measure, but [1] does not retain this measure because the carbon sequestration happening when cropland is converted to grassland is only maintained while the land remains as grassland; after some time an equilibrium is reached and there is no further C storage. Furthermore, the amount of sequestered C depends of many factors (soil type, climate, grassland management…). [5] rejects it as the maintenance of permanent grassland is more effective, given that the losses of C (if permanent grassland were converted to arable land) are by a factor of 4-5 times as fast as C-sequestration when land is converted to grassland and thus the priority must be maintaining high-carbon systems.

"Woodland creation" and "woodland management": Afforestation is selected by the [1] to be included in Rural Development Policies. However, it is not considered an option in [4] because forest land is already quite abundant while cropland, in turn, is scarce and further reducing cropland in the benefit of forest could compromise supply security. These measures are not considered by any of the other studies.

- LMAN:

“Extend the perennial phase of crop rotations” is chosen by [4] but discarded by [1] because of its potential side-effects related to displacement of crops and consequent emission leakage, whose magnitude would depend on market demand of displaced crops.

Despite additional environmental benefits, tillage related measures did not present enough evidence about mitigation capacity as to be recommended. According to the most recent literature, different tillage techniques contribute to changes in the stratification of soil organic carbon but it is not clear if the total carbon content changes, which depends on the climate and its potential effect is reversible. Furthermore, the interaction between tillage and N_2O emissions and consequently potential trade-off effects is unclear. “Reduced tillage” is considered by two of the studies but not recommended by any of them, mainly because of lack of consistent evidence about higher carbon sequestration than under conventional tillage [1]. The same for “zero tillage”, for which the possible small difference with conventional tillage in C sequestration would not justify the much higher costs. The study [2] discards these measures because tillage effects are often mixed with other effects. In addition, N_2O emissions, and in general the GHG balance, are little affected by tillage. Non-tillage is rather beneficial for soil quality than for GHG mitigation. INRA [3] also argues that, despite the theoretical high mitigation potential, controversy exists around this measure. Similarly, “biochar application” is analysed by several studies and discarded by all of them: [1] does not select it due to the impossibility of applying the measure on a landscape scale at the moment, to the uncertainty in the outcomes for GHG emissions and the need of further research to understand the potential side effects. The measure is rejected in [3] and [5] because of an uncertain unitary mitigation potential and because consequences for soils and crop production are not sufficiently known.

“Restauration of degraded soils”, “increase of biomass production by optimising the input use” and “selecting crops which provide higher carbon return to soils” are only analysed in the [3], but none of them is selected for implementation, for different reasons, including a small margin of improvement, potential side-effects (changes in crop patterns, in productivity, etc.) which implies uncertain mitigation capacity. In [5] they argue that measures related to C-sequestration might be generally positive for soil quality but should not be seen as recommended climate mitigation measures.

- ORGSOIL:

Within this mitigation mechanism we found the measures “wetland and peatland conservation” and “fallowing histosols”. The second one is regarded as a high priority measure, given the high relevance of GHG emissions from histosols and the relatively low costs for mitigation and positive side effects on other ecosystem services. However, it is not retained by [3] because, despite the high potential of the measure by surface unit, the area where it could be applicable in France is low. However, this argument cannot be extended to the EU as a whole. Report [2] concludes that this mitigation action is more important than rice measures, but that the aggregated effects tend to be overestimated.

- ENER:

The mitigation mechanism focused on emissions from energy use comprises a set of different measures:

“Improved on-farm energy efficiency” [1, 4, 5], “reduce the use of fossil energy use on-farm in buildings and machinery” [3], “use of solar, wind and geothermal energy” [4] are recommended. Other analysed measures [3] are the “use of solar energy to dry agricultural products” and “produce energy on-farm through biomass burning”, both discarded: the first one because an important part of the effect happens downstream the farm, and the second one because it was out of the scope of the study and it is partly covered by other measures. “Biofuel production and use on site” [4, 5] is another option, although it could be associated with emission leakage effects.

ANNEX 2: Methodology (tiers) used by Member States by emission category, as specified in their National Inventoruy Reports 2016.

MEMBER STATE	3.A.1 Dairy cattle	3.A.1 Non-dairy cattle	3.A.2 Sheep	3.B.1 Dairy cattle, CH_4	3.B.1 Non-dairy cattle, CH_4	3.B.3 Swine, CH_4	3.B.1 Cattle N_2O	3.B.3 Swine N_2O	3.B.4 Other N_2O
Austria	T2	T2	T1	T2	T2	T2	T1	T1	T1
Belgium	T1/T2	T1/T2	T1	T2	T2	T2	T2	T2	T2
Denmark	T2	T2	T2	T2	T2	T2	T2	T2	T2
Finland	T2	T2	T3	T2	T2	T2	T2	T2	T2
France	T3	T3	T2	T2	T2	T1	T1	T1	T1
Germany	T3	T2	T1	T2	T2	T1	T2	T1	T1
Greece	T2	T2	T2	T2	T2	T1	T2	T1	T1
Ireland	T2	T2	T1	T2	T2	T2	T2	T2	T2
Italy	T2	T2	T1	T2	T2	T2	T2	T2	T2
Luxembourg	T2	T2	T1	T2	T2	T2	T1	T1	T1
Netherlands	T3	T2	T1	T2	T2	T2	T2	T2	T2
Portugal	T2	T2	T2	T2	T2	T2	T2	T2	T1
Spain	T2	T2	T2	T2	T2	T2	T2	T2	T1
Sweden	T3	T3	T1	T2	T2	T2	T2	T2	T2
United Kingdom	T2	T2	T2	T2	T2	T2	T2	T2	T2
Bulgaria	T2	T2	T2	T2	T2	T2	T1	T1	T1
Croatia	T2	T2	T2	T2	T2	T2	T2	T2	T2
Cyprus	T2	T1	T1	T1	T1	T1	T1	T1	T1
Czech Republic	T2	T2	T1	T2	T2	T1	T2	T1	T1
Estonia	T2	T2	T1	T2	T2	T2	T2	T2	T1
Hungary	T2	T2	T1	T2	T2	T2	T2	T2	T1
Lithuania	T2	T2	T2	T2	T2	T2	T1	T1	T1
Latvia	T2	T2	T1	T2	T2	T1	T1	T1	T1
Malta	T2	T1	T1	T1	T1	T1	T2	T2	T2
Poland	T2	T2	T1	T2	T2	T2	T1	T1	T1
Romania	T2	T2	T2	T2	T2	T2	T1	T1	T1
Slovenia	T2	T2	T1	T2	T1	T1	T1	T1	T1
Slovakia	T2	T2	T2	T2	T2	T1	T2	T2	T2

MEMBER STATE	3.D.1.1 Inorganic fertilisers N_2O	3.D.1.2 Organic fertilisers N_2O	3.D.1.3 Urine dung grazing N_2O	3.D.1.4 Crop residues N_2O	3.D.1.5 Mineralis. organic matter N_2O	3.D.1.6 Cultivation of organic soils N_2O	3.D.2.1 Atmosph. deposition N_2O	3.D.2.2 Leaching N_2O	3.G.1 Limestone CO_2	3.G.2 Dolomite CO_2
Austria	T1	T2	T2	T1	NA	NA	T3	T3	T1	NA
Belgium	T1	T1	T1	T1	T1	T1	T1/T2	T1/T2	T1	T1
Denmark	T1	T1	T1	T1	T1	T1	T1	T2	T1	NA
Finland	T1	T1	T1	T1	T3	T2	T1	T1	T1	T1
France	T1	T1	T1	T1	NA	T1	T1	T1	T1	T1
Germany	T1	T1	T1	T1	NA	T1	T2	T1	T1	T1
Greece	T1	T1	T1	NS	NA	T1	T1	T1	NS	NS
Ireland	T1	T1	T1	T1	T1	T1	T1	T1	T1	NA
Italy	T1	T1	T1	T2	T1	T1	T1	T1	T1	T1
Luxembourg	T1	T1	T1	T1	NA	NA	T1	T1	T1	NA
Netherlands	T2	T2	T2	T1/T2	T1/T2	T1/T2	T1	T1	T1	T1
Portugal	T1	T1	T1	T1	T2	NA	T1	T1	T1	T1
Spain	T1	T1	T1	T1	T1	T1	T1	T1	T1	T1
Sweden	T2	T1/T2	T1	T2	T2	T1	T1	T3	T1	T1
United Kingdom	T2	T2	T2	T1	T1	T1	T1	T1	T1	T1
Bulgaria	T1	T1	T1	T1	T1	NA	T1	T1	NA	NA
Croatia	T1	T1	T1	T1	T1	T1	T1	T1	T1	NA
Cyprus	T1	T1	NA	T1	NA	NA	T1	T1	NA	NA
Czech Republic	T1	T1	T1	T1	T1	NA	T1	T1	T1	NA
Estonia	T1	T1	T1	T1	T1	T1	T1	T1	T1	T1
Hungary	T1	T1	T1	T1	T1	NA	T1	T1	T1	T1
Lithuania	T1	T1	T1	T1	T1	T1	T1	T1	T1	T1
Latvia	T1	T1	T1	T1	NA	T1	T1	T1	T1	T1
Malta	T1	T1	NA	T1	NA	NA	T1	T1	NA	NA
Poland	T1	T1	T1	T1	T1	T1	T1	T1	T1	T1
Romania	T1	T1	T1	T1	NA	T1	T1	T1	T1	T1
Slovenia	T1	T1	T1	T1	T1	T1	T1	T1	T1	T1
Slovakia	T1	T1	T1	T1	NA	NA	T1	T1	T1	T1

MEMBER STATE	4.A Forest Land	4.B Cropland	4.C Grassland	4.D Wetlands	4.E Settlements
Austria	T1/T2/T3	T1/T2	T2/T3		T2
Belgium	T1/T2/T3	T1/T2	T1/T2		T1
Denmark	T1/T2/T3	T2/T3	T1	T2	T1
Finland	T2/T3	T2/T3	T2/T3	T1/T2/T3	T2/T3
France	T1/T2	T1/T2	T1/T2	T2	T2
Germany	T2	T2			T2
Greece	T1/T2	T1/T2	T1		T1/T2
Ireland	T1/T2/T3	T1/T3	T1/T3		T1/T3
Italy	T1/T2/T3	T1	T1		T1
Luxembourg	T1/T2	T1	T1		T1
Netherlands	T2	T1/T2	T1/T2		T1/T2
Portugal	T2	T1/T2	T1/T2		T1/T2
Spain	T1/T2	T1/T2	T1/T2		T1/T2
Sweden	T3	T2/T3	T2/T3		T1/T2/T3
United Kingdom	T3	T1/T3	T1/T3		T3
Bulgaria	T1/T2	T1/T2	T1/T2	T1	T2
Croatia	T1/T2	T1	T1/T2		T1/T2
Cyprus					
Czech Republic	T1/T2	T1/T2/T3	T1/T2/T3	T1	T1
Estonia	T1/T2/T3	T1/T2	T1/T2/T3	T2	T2
Hungary	T1/T2	T2	T1/T2	T1	T1/T2
Lithuania	T1/T2	T1	T1	T1	T1/T2
Latvia	T1/T2	T1/T2	T1/T2	T1	T2
Malta		T1			
Poland	T1/T2/T3	T1/T2	T1/T2	T1	T1/T2
Romania	T1/T2/T3	T1	T1/T2		
Slovenia	T1/T2/T3	T1/T2	T1/T2/T3		T2
Slovakia	T1/T2	T1/T2	T1/T2		T1/T2

Where: T1= Tier 1; T2= Tier 2; T3= Tier 3; NA= not applicable (emission in the category have not been reported)

NB: the tiers used may change in the same land use category according to the carbon pools considered.

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