Tackling climate change in agriculture - key mechanisms in GHG mitigation

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Abstract
We assessed the question of side effects and of the accountability of mitigation measures in the Agriculture, Forestry, and Other Land Uses (AFOLU) sector in national greenhouse gas inventories, proposing a novel classification system of available mitigation measures on the basis of 'mitigation strategies' and 'mitigation mechanisms'. While the first differentiates measures which require collection of data from those for which specific emission factors or parameters need to be developed, the second groups mitigation measures according to the 'term' that is exploited to achieve emission reductions. We find that current IPCC methodologies provide a good basis to account for the majority of mitigation measures. Most of them will be reflected in national greenhouse gas inventories if default tier 1 approaches or (in some cases) national level tier 2 approaches are used (according to IPCC terminology). Efforts should be concentrated on improving data availability especially about management options, which is often the major obstacle in accounting for the effect of mitigation efforts. Examples include mitigation measures focusing on the improvement of feed intake of animals, or actions aimed at incrementing the soil organic carbon stock in agricultural soils through appropriate management practices. We conclude that simple farm level tools may have a good potential in collecting the data required, and offer the opportunity of full flexibility for the farmers to select concrete farm practice changes and monitor their performance.

Key Words
greenhouse gas, mitigation measures, agriculture, AFOLU, IPCC, national greenhouse gas inventories

Introduction
The Agriculture, Forestry and Other Land Uses (AFOLU) sector accounts for 20-24% of total GHG emissions (10-12 $GtCO_{2eq}$/yr) globally, being the largest emitting sector after energy (Smith et al. 2014; Tubiello et al. 2015). Its importance is likely to increase with the further adoption of policies for the 'decarbonization' of economies (European Commission 2014). A wide range of mitigation actions have been identified, covering measures to sequester carbon in soils, to reduce nitrous oxide emissions from soils or methane emissions from livestock production, to name just a few (Smith et al. 2014). Important issues need to be clarified before taking (policy) action, amongst which: what is the effectiveness of measures? Do they have positive or negative environmental side effects? What is the cost per reduced emission unit? Is it possible to monitor the mitigation effect and account for its results within national greenhouse gas inventories produced with the IPCC Guidelines for National Greenhouse Gases Inventories (IPCC 2006) in the framework of global climate agreements? The objective of this study is to assess the question of side effects and accountability of mitigation measures.

Methods
A compilation of mitigation measures proposed in literature (Finnish Ministry of Agriculture and Forestry 2014; Martineau et al. 2016; Osterburg et al. 2013; Pellerin et al. 2013; van Doorslaer et al. 2015) was used to identify potential measures. For the assessment of the accountability of the measures, we provide a classification system that identifies which 'mitigation strategy' is used dominantly for a mitigation measure and available 'mitigation mechanisms':

Mitigation strategies
While mitigation measures indicate the practical way of addressing the mitigation plan, a mitigation strategy gives the approach that is used. Mitigation strategies target either 'data' that can be collected at different scales (from farm level or the assessment of land use changes at the national level) or 'factors' that require models or experimental observations to be developed. Mitigation measures using the 'data' mitigation strategies often have a systemic effect, influencing in some cases farm activities as a whole, often also impacting farm productivity. For comparison they need to be normalized under a scenario of equal productivity at the farm.

Mitigation mechanism

Mitigation mechanism groups are defined by the 'term' that is affected in the standard equation given by the IPCC methodology. Most mitigation mechanism groups use mainly either the 'data' or 'factor' mitigation strategy. Table 1 gives an overview of the mitigation mechanism groups identified, the mitigation strategy used, and direct and indirect GHG emissions affected.

Table 1. Definition of mitigation mechanism groups.

Mitigation mechanism groups	Mitigation strategy	Changes provoked	Parameters affected (IPCC Guidelines)	Gas(es) targeted	Other gases affected
HERD	Data	Improves herd productivity, but not individual one	$N_{(T)}$	CH_{4Ent}	CH_{4Man}, N_2O_{Man}
BREED	Data	Improves animal productivity	$N_{(T)}$	CH_{4Ent}	CH_{4Man}, N_2O_{Man}
METHGEN	Factor	Additives or breeding reducing selectively CH_4 production in rumen	Y_m	CH_{4Ent}	--
FEED	Data	Adjust rations to (energy, N content) feed needs	GE/DE/Nex	CH_{4Ent}/ N_2O_{Man}	CH_{4Man} (through VS)
MANSYS	Data	% manure in each MMS	MS	CH_{4Man}, N_2O_{Man}	
ADIG	Data	Anaerobic digesters, to reduce emissions form manure and produce energy	MS	CH_{4Man}, N_2O_{Man}	CO_2 energy
MANEF	Factor	Additives, etc, affecting directly emission factors	MCF/ EF_3	CH_{4Man}/ N_2O_{Man}	--
RICE	Data	Management practices (e.g. aeration)	$t_{i,j,k}$, $A_{i,j,k}$	CH_{4Rice}	--
NMANAG	Data	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	Data	Increase leguminous share	F_{SN}, $F_{CR}^{(*)}$, F_{PRP}	N_2O_{Direct}	N_2O_{ATD}, N_2O_{LEACH}, N_2O_{Man}, CH_{4Man}
NEF	Factor	Substances/ techniques to reduce EFs	EF_1, EF_3	N_2O_{Direct}	--
BURN	Data	Reduce burnt biomass	Area and residues burned	L_{fire}	
LUSE	Data	Increasing carbon sequestration/Reducing carbon losses	Land Use areas	CO_2	CH_4, N_2O
LMAN	Factors (Data)	Reducing carbon losses	C Stock Change Factors	CO_2	N_2O
ORGSOILS	Data	Increasing carbon sequestration/preventing carbon losses	Area of organic soils, drained wetlands, peatlands.	CO_2	CH_4, N_2O
ENER	Data	Measures to reduce farm energy use	Energy data in agric.	CO_2	
GLOBAL	Data	Measures to reduce total farm GHG emissions	Farm inputs, leakage effects etc. data	CH_4, N_2O, CO_2…	All
CIRCULAR	Data	Measures to reduce total GHG emissions by optimising biomass streams	All agric. data + other sectors	CH_4, N_2O, CO_2…	All

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

HERD: livestock herd; BREED: breeding programmes; METHGEN: methanogenesis; FEED: livestock feed; MANSYS: manure management systems; ADIG: anaerobic digestion; MANEF: emission factor in manure management systems; RICE: rice; NMANAG: nitrogen management; LEGU: leguminous; NEF: nitrogen emission factors; BURN: residues burning; LUSE: land use; LMAN: land management; ORGSOILS: organic soils; ENER: energy; GLOBAL: global measures; CIRCULAR: circular economy.

Results

Mitigation measures using the mitigation strategy 'data' are easily and in many cases even automatically reflected in national GHG emission inventories. Some mitigation measures require the use of national level tier 2 methodologies to be accounted for. For measures within some mitigation mechanism groups, adequate data collection systems to obtain relevant activity data are not yet in place – or information for other purposes cannot be currently used for the accounting of GHG emissions (and mitigation). Examples are the detailed information collected at parcel level by the European IACS (Integrated Administration and Control System) and LPIS (Land Parcel Identification System) systems. Other data sets are worthwhile to improve, such as livestock feed rations by feed group. Some mitigation measures using a 'factor' mitigation strategy act on specific parameters within the IPCC methodology, for example the effect of land management mitigation measures (e.g. different tillage or fertilization options) can be quantified with the use of the appropriate land management factors. For other mitigation mechanism groups based on a reduction of emission factors, the effect of the measure is not yet established and requires additional experimental research. Yet, differentiated emission factors accounting for mitigation options will also help to improve the quality of greenhouse gas emission inventories. Table 2 outlines the accountability of mitigation measures by mitigation mechanism group, i.e. describing if their effects can be accounted for by the IPCC methodology provided that data are available with the required characteristics (e.g. in terms of national coverage, statistical representativeness, approach for land representation adopted in the inventory).

Table 2. Accountability of mitigation measures by mitigation mechanism groups.

Mitigation mechanism	Inventory categories	Accountability with IPCC guidelines
HERD	3A, 3B.1, 3B.2, 3D	Fully accountable with tier 1 with regard to animal numbers and effect on reduced feed requirements.
BREED	3A, 3B1, 3B2,3D	Requires Tier 2 to account for possible increased in Nex, VSex and down-stream emissions.
METHGEN	3A	Requires development of country-specific EF.
FEED	3A, 3B1, 3B2, 3D	CH_4 accountable with tier 2, from detailed composition of feed. NRC (2001) can be used to derive changes on digestibility. N_2O from manure is accountable with tier 2 or development of country-specific Nex factor.
MANSYS	3B1, 3B2	Fully accountable with tier 1
ADIG	3B1, 3B2, 1A4	CH_4 with tier 2 (default EFs given by IPCC), N_2O with tier 1. Energy produced accounted in the corresponding part of the inventories.
MANEF	3C	Fully accountable, as far as there exists the EF for *i, j, k* conditions considered.
NMANAG	3D1, 3D(b)	Fully accountable with tier 1.
LEGU	3D1	N_2O from fertiliser use yes (tier 1). CH_4 can be calculated with tier 2, from feed composition. Change in N_2O emission factor from crop residues only be with tier 3, where new EF1 is calculated for the new grass characteristics.
NEF	3D1	Requires development of country-specific EFs
BURN	3F	Fully accountable, based on statistical data
LUSE	4, 4.1, 4A-F	Fully accountable.
LMAN	4, 4.1, 4A-F	Fully accountable. In case some management option is not currently described in the Guidelines, the development of new Land Use Factors may be necessary. Effects of different management options on emissions from cultivated organic soils are not taken into account in the default EFs, which are only climate dependent (IPCC 2006 and 2013). In this case Tier 2 EF can be developed for different management practices.
ORGSOILS	4(II), 4D, 3D	Fully accountable. The estimation needs the area-based assessment of natural, drained, and restored wetlands with the relative land use, as well as information on the status (deep drained, shallow drained, etc.) and management (e.g. peatlands managed for extraction). For fire emissions, burned area is necessary, possibly distinguishing drained areas from wetlands areas.
ENER	1A4	Fully accountable.

Assessing mitigation measures at the farm level is easier at the level of mitigation mechanism groups than at the level of individual mitigation measures – leaving the farmers/countries full flexibility about which specific measures to choose. A modular system building a GHG tool with independent – and individually selectable – modules focusing on nutrient management, enteric fermentation, carbon sequestration and land use, 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 the 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. Figure 1 shows an illustration of a modular system for farm level calculator tools.

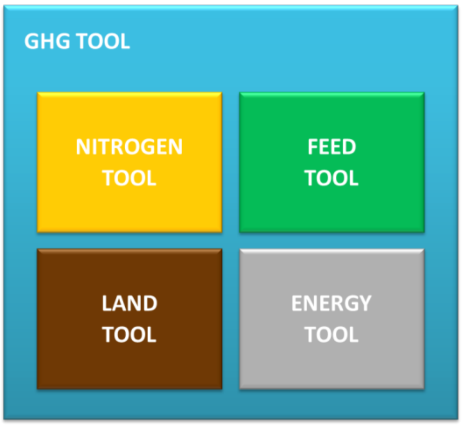

Figure 1. Illustration of a modular system for farm level calculator tools allowing the assessment of the effect of most recommended mitigation measures in the land use sector. The four inner modules are largely independent and requiring mainly readily-available data. Only the land tool requires spatial data. The combination of the four modules (with few additional data) provides sufficient information for a whole-farm GHG calculator.

Conclusion

There is a large variety of options to reduce greenhouse gas emissions from the AFOLU sector. Assessing the accountability of the measures – on the basis of mitigation strategies and mitigation mechanisms – we find that current IPCC methodologies provide a good basis to account for the majority of mitigation measures. Most of them will be reflected in national greenhouse gas inventories if tier 1 is used. Tier 2 is required for some cases. However, it should be noted that when a category is identified as a "key category" according to the IPCC terminology, based on its contribution to the overall level or trend of country emissions, Tier 2 or higher should always be used in preparing National Greenhouse Gas inventories. Efforts should be concentrated in improving data collection or data availability, for example for mitigation measures improving feed intake of animals or land use. We conclude that simple farm level tools could collect the data required and offer the opportunity of full flexibility for the farmers to select concrete farm practice changes and monitor their performance.

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