Accounting for mitigation of N-fertiliser emissions at national and project scales

Working Paper No. 230

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

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RESEARCH PROGRAM ON
Climate Change, Agriculture and Food Security

CGIAR

CCAFS

Working Paper

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Correct citation:
Stirling CM. 2018. Accounting for mitigation of N-fertiliser emissions at national and project scales. CCAFS Working Paper no. 230. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available online at: www.ccafs.cgiar.org

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The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) is a strategic partnership of CGIAR and Future Earth, led by the International Center for Tropical Agriculture (CIAT). The Program is carried out with funding by the CGIAR Trust Fund, Australia (ACIAR), Ireland (Irish Aid), Netherlands (Ministry of Foreign Affairs), New Zealand Ministry of Foreign Affairs & Trade; Switzerland (SDC); Thailand; The UK Government (UK Aid); USA (USAID); The European Union (EU); and with technical support from The International Fund for Agricultural Development (IFAD). For more information, please visit https://ccafs.cgiar.org/donors.

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Abstract

This report provides an overview of the United Nations Framework Convention on Climate Change (UNFCCC) reporting process for national greenhouse gas (GHG) inventories with particular focus on the methodology used for estimating direct nitrous oxide (N_2O) emissions from mineral fertiliser. Examples are given of several schemes for sub-national or project-level approaches to monitor and estimate the impact of fertiliser best management practice (BMP) on direct N_2O emission reductions. The extent to which these approaches align with those of the national inventory is evaluated and conclusions drawn on actions needed to close any gaps.

Collectively, 63% of world fertiliser consumed is reported at the higher Tier 2 and Tier 3 levels. However, countries reporting at the Tier 1 level for direct N_2O emissions from fertilisers still predominate, accounting for 180 of the total 191 reporting countries.

Case studies of fertiliser BMP were generally found to align well with national inventory methods, mainly through the use of modifiers to Tier 1 & 2 emission factors (EFs). Good quality activity data (AD) is a main challenge to full alignment of project and national inventory-based estimates of fertiliser-induced emissions and emission reductions. Lack of quality AD also limits the extent to which national inventories can capture mitigation impacts. Given the early stage of developing accounting processes for agricultural GHGs, an opportunity now exists to design national GHG inventory processes to reflect emissions savings achieved through mitigation actions such as implementing fertiliser BMPs. To achieve this, it is necessary to strengthen the alignment among different policy instruments, inventory compilation processes and national data providers. In this respect, we should seize opportunities made available from instruments such as the Nationally Determined Contributions that would support development of project-specific, nationally consistent and inventory-aligned measurement, reporting and verification (MRV) methods for capturing mitigation actions, including the establishment of robust baseline AD.

Keywords

Greenhouse gas emissions; Fertiliser; Agriculture; Climate change mitigation; Nitrous oxide; Nitrogen; Best management practices

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Acknowledgements

Thanks to Dr. Laura Cardenas, Senior Research Scientist, Sustainable Agriculture Sciences, Rothamsted Research Institute, UK for her general comments and inputs with respect to UK's reporting to UNFCCC and Dr. Jessica Bellarby for comments and translations.

The International Fertiliser Association (IFA) provided support for this research. For details, please visit: https://www.fertilizer.org

Clare Stirling is the CIMMYT contact point for the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), which is carried out with support from CGIAR Fund Donors and through bilateral funding agreements. For details about CCAFS donors, please visit https://ccafs.cgiar.org/donors. The views expressed in this document cannot be taken to reflect the official opinions of these organizations.

Contents

Acronyms

AD	Activity data
AR	Assessment reports
BMP	Best management practice
C	Carbon
CEC	Cation exchange capacity
CFT	Cool Farm Tool
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CRF	Common reporting format
EF	Emission factor
FAO	Food and Agriculture Organisation of the United Nations
GHG	Greenhouse gas
GWP	Global warming potential
IEA	International Energy Agency
IFA	International Fertiliser Association
IPCC	Intergovernmental Panel on Climate Change
IPNI	International Plant Nutrition Institute
IPPU	Industrial Processes and Product Use
MRV	Measurement, reporting and verification
N	Nitrogen
N_2O	Nitrous oxide
NC	National Communications
NDC	National Determine Contribution (to the UNFCCC)
NERP	Nitrous Oxide Emissions Reduction Programme

NIR	National Inventory Report
NUE	Nutrient-use efficiency
REML	Residual maximum likelihood
RM_{PL}	Emissions Reduction modifier (corresponding to level of implementation (basic or intermediate/advanced) of 4R Plans)
TFI	The Fertilizer Institute
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WMP	World Meteorological Organisation

Executive Summary

Nitrous oxide (N_2O) is a potent greenhouse gas (GHG) that also contributes to the destruction of the stratospheric ozone layer. Atmospheric concentrations of N_2O have increased more or less linearly since monitoring began in the 1970s; concentrations are about 20% higher now than in pre-industrial times. Most of this increase has been attributed to reactive nitrogen (N) inputs from agriculture. The main form of agricultural N inputs are mineral N fertiliser and animal manure; both stimulate microbial nitrification and denitrification, from which N_2O is emitted. Globally, natural and anthropogenic sources of N_2O emissions amount to an estimated 16.2 Tg N_2O-N yr^{-1} (Teragrams (Tg) = 1,000,000 metric tonnes). Soil ecosystems comprise the largest source, emitting 6.8 Tg N_2O-N yr^{-1}, of which about 60% derives from mineral N fertiliser including indirect emissions, 30% from manure management and 7% from biomass burning.

Agriculture accounts for an estimated 11-15% of global anthropogenic GHG emissions, and N_2O constitutes 40% of agricultural emissions. As part of a global effort to address climate change, the United Nations Framework Convention on Climate Change (UNFCCC) requires member countries to submit annual inventories of their GHG emissions by sector and source, including fertiliser-related N_2O emissions. This report provides an overview of the UNFCCC reporting process for national GHG inventories with particular focus on the methodology used for estimating direct N_2O emissions from mineral fertiliser. This report also provides examples of several schemes for sub-national or project-level approaches to monitor and estimate the impact of fertiliser best management practice (BMP) on direct N_2O emission reductions. The extent to which these approaches align with those of the national inventory is evaluated and conclusions drawn on actions needed to close any gaps. The fertiliser BMPs covered by these schemes are based upon the principles of 4R Nutrient Stewardship that involves the Right fertiliser source applied at the Right rate, at the Right time and in the Right place, with the aim to match fertiliser supply with crop requirement as closely as possible and thereby reduce potential losses to the environment and hence N_2O emissions.

In terms of numbers, 180 of a total of 191 countries are reporting at Tier 1 for direct N_2O emissions from fertilisers, though 63% of world fertiliser consumed is reported at the higher Tier 2 and Tier 3 levels. The case studies of fertiliser BMP generally align well with national inventory methods, mainly through the use of modifiers to Tier 1 & 2 emission factors (EFs). Good quality activity data (AD), for example on the type and extent of use of fertiliser-related BMPs, is a main challenge to full alignment of project and national inventory-based estimates of fertiliser-induced emissions and emission reductions. Lack of quality activity data also limits the extent to which national inventories can capture mitigation efforts. Given we are in the early stage of developing accounting processes for agricultural GHGs, an opportunity now exists to design national GHG inventory processes to better reflect emissions savings achieved through mitigation actions such as implementing fertiliser BMPs. Capturing mitigation impacts is becoming increasingly important as more countries adopt mitigation measures in an effort to achieve their targets under the Paris Agreement.

In summary, most fertiliser-based BMP projects reviewed in this report are already well aligned with national inventory methods. Given that inventory processes are constantly evolving and being improved, we now have the opportunity to better integrate changes in emissions due to BMPs in national estimates. To achieve this, it is necessary to strengthen the alignment among different policy instruments, inventory compilation processes and national data providers. In this respect, we should seize opportunities made available from instruments such as the Nationally Determined Contributions (NDCs) that would support development of project-specific, nationally consistent and inventory-aligned measurement, reporting and verification (MRV) methods for capturing mitigation actions, including the establishment of robust baseline AD.

1 Introduction

Agriculture accounts for an estimated 11-15% of greenhouse gases (GHGs). Approximately 40% of the emissions are comprised of nitrous oxide (N_2O), which has a global warming potential 265 times that of carbon dioxide (CO_2) over a 100-year lifespan (IPCC 2014). Atmospheric concentrations of N_2O are 20% higher than pre-industrial levels and continue to rise almost linearly at a rate of 0.6–0.9 ppb $year^{-1}$ (IPCC 2007). Human-related activities, and in particular agriculture, are a major cause of the post-industrial increase in atmospheric N_2O levels. Direct and indirect emissions from nitrogen (N) fertiliser alone account for approximately half of all anthropogenic N_2O emissions.

Since the invention of the Haber-Bosch process in the early 20^{th} century, a large amount of inert atmospheric N has been converted to a reactive form to produce inorganic N fertiliser (Galloway et al. 2004), which has been responsible for driving the growth in crop yields that now feed half the world's population (Erisman et al. 2008). The necessity to feed a continuously growing number of people has impacted the environment.

Through the UNFCCC and its Paris Agreement (2015, ratified in 2016), the international community agreed to limit global warming to 2°C and if possible 1.5ºC above pre-industrial levels by the end of this century. To meet this target, significant emissions abatement is needed. Fertiliser-related N_2O emissions account for 6% of global emissions (Blanco et al. 2014). Given the scale of ambition in the Paris Agreement, all sectors will need to play their part in emission reductions. An estimated reduction of 1 $GtCO_2e$ yr^{-1} emissions are required globally from agriculture over the next 15 years to meet a 2ºC target; more is needed to reach 1.5ºC. (Wollenberg et al. 2016).

The UNFCCC is the international body overseeing the science-policy interface for addressing the challenges of climate change. Within this framework, the Intergovernmental Panel on Climate Change (IPCC) has produced a series of guidelines to support national GHG emissions reporting which serve to inform progress against UNFCCC targets. Alongside the national GHG emissions inventory, a myriad of sub-national and project-level approaches aim to promote BMPs for fertiliser; GHG emissions savings are associated with the implementation of BMPs. In this context, there are questions concerning a) how and if project-based BMP mitigation efforts are being captured by national inventory data and reports and b) the extent to which MRV systems can be aligned to better account for fertiliser-based BMP and associate mitigation measures in the UNFCC national GHG inventory and other UNFCCC initiatives.

Thus, the main objectives of this report are to:

- Explain recommended IPCC methods for estimating (mineral) fertiliser-related emissions.
- Evaluate project-level initiatives for measuring fertiliser-related mitigation, illustrated by several case studies;
- Evaluate the extent to which fertiliser-related BMP initiatives align with national inventories and draw conclusions on actions needed to close any gaps.

Annex 1 provides an overview of the IPCC reporting process and procedures, and Annex 2 explains the origin of the nitrogen fertiliser emission factor (EF) value of 1%.

2 National GHG inventories and fertiliser-related emissions

All developed (formerly known as Annex I) countries are obliged to use the 2006 IPCC Guidelines for their National Greenhouse Gas Inventories, whereas developing countries are only required to use the 1996 version. In addition, the IPCC 2006 Guidelines are currently under revision and will be published next year as the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2019 Refinement). The guidelines provide internationally agreed-upon methods that help ensure that the inventories are consistent; data is internationally comparable; double accounting or omissions are avoided; and the time series reflect actual changes in emissions. This section summarises the methods used for estimating direct and indirect GHG emissions from mineral fertilisers and draws heavily on Chapter 11 of the 2006 IPCC Guidelines “N_2O emissions from managed soils and CO_2 emissions from lime and urea application”.

2.1 Emissions covered by IPCC guidelines

2.1.1 Direct N_2O emissions from soil

Nitrous oxide is produced naturally in soil. The amount of emissions depends on the amount of N and other environmental conditions. The human-induced part of this emission is estimated.

2.1.2 Indirect N_2O emissions from soil

Part of applied fertilisers is volatilised and leached, leading to secondary N_2O emissions elsewhere. In cases in which indirect emissions are transported in water and air to areas some distance from where the fertiliser was originally applied, the IPCC method allocates indirect emissions to the country where the fertiliser is applied rather than where the emissions are deposited.

2.1.3 CO_2 emissions from urea (and liming)

Adding urea to soils during fertilisation leads to a loss of CO_2 that was fixed in the industrial production process. Urea ($CO(NH_2)_2$) is converted into ammonium (NH_4^+), hydroxyl ion (OH-) and bicarbonate (HCO_3-) in the presence of water and urease enzymes. Bicarbonate that is formed evolves into CO_2 and water. This source category is included in the IPCC Guidelines because the CO_2 removal from the atmosphere during urea manufacturing is estimated in the Industrial Processes and Product Use (IPPU) Sector.

2.2 IPCC tiered system reporting

IPCC inventory reporting uses a three-tiered system for emissions, which is discussed here in the context of N_2O emissions accounting from mineral fertilisers. The complexity of the estimation method increases from Tier 1 to Tier 2 to Tier 3. Calculations of emissions for Tier 1 and Tier 2 are based on the following equation:

*Emissions = Emission Factor (EF) * Activity Data (AD)*

2.2.1 Tier 1

Tier 1 is designed to use readily available national or international statistics in combination with default EFs. It is designed to be feasible for use by all countries. Default EFs are provided by the IPCC for direct and indirect emissions and urea and lime applications. AD for mineral fertiliser requires the annual amount of mineral N fertiliser applied to soils. Annual fertiliser consumption data may be collected from national statistics; if these are not available then they can be collected from the International Fertiliser Association (IFA) or the Food and Agriculture Organisation of the United Nations (FAO).

2.2.2 Tier 2

Tier 2 uses the same basic approach as Tier 1, except Tier 2 uses EFs and AD that have a higher level of resolution, usually based on country- or region-specific data. Depending on data availability, EFs can be used in Tier 2 reporting with a higher level of disaggregation according to environmental factors (e.g. climate, soil organic C, drainage, soil pH) and management conditions (e.g. fertiliser source, mode of application, crop type). Equally, AD may be disaggregated by fertiliser type, crop type and climatic regime for major crops and applied to Tier 2-level reporting.

2.2.3 Tier 3

Tier 3 reporting is the most complex and requires the most data. The methodology used is not prescribed by the IPCC but decided by national experts with the provision that they follow stringent rules with regard to transparency and replicability of methods used. Tier 3 usually involves detailed modelling and inventory measurement systems tailored to address national circumstances, repeated over time and driven by high resolution AD disaggregated at sub-national level. Such systems may include: comprehensive field sampling repeated at regular time intervals; GIS-based systems for collecting production data, soils data, and land-use and management AD; and integrating several types of monitoring. The IPCC recommends that models should be used only after independent validation.

2.3 Default emission factors (EFs)

2.3.1 EFs for direct N_2O emissions from fertiliser

Current guidelines (IPCC 2006) for calculating national direct N_2O emissions from the application of mineral N fertiliser include a default global EF of 1% (Table 1). This EF is defined as the emissions from fertilised plots minus the emissions from unfertilised control plots expressed as a percentage of the N applied.

It should be noted that the IPCC also provides default EFs for flooded rice drained/managed organic soils (EF_{1FR} and EF_2, respectively); these are not discussed in this report.

Table 1. Default emission factors (EFs) for direct (D) and indirect (I) N_2O emissions from fertilisers and corresponding fractions (FRAC) required for the calculation of emissions from indirect sources (adapted from *IPCC Chapter 11 2006 Guidelines*).

Default values	Type of Emissions	Default value	Uncertainty range
EF_1 [emission factor for fertiliser-N]	D	0.01 (1%)	0.003-0.03 (0.3-3%)
EF_4 [emission factor for N volatilisation and re-deposition]	I	0.01 (1%)	0.002-0.05 (0.2-5%)
$FRAC_{GASF}$ [fraction of fertiliser-N volatilises as NH_3 and NOx]	I	0.1 (10%)	0.03 – 0.3 (3 – 30%)
EF_5 [emission factor for leaching/runoff]	I	0.0075(0.75 %)	0.0005-0.025(0.05-2.5%)
$FRAC_{LEACH-(H)}$ [conditional leaching fraction] (*wet conditions*)	I	0.3 (30%)	0.1 – 0.8 (10 – 80%)
$FRAC_{LEACH}$ [conditional leaching fraction from fertiliser –N] (*dry conditions*)	I	0	
EF for CO_2 from urea* (expressed per unit of product)	D	0.2 (20%)	-0.5 (-50%)

EF_1: Bouwman et al., 2002a,b; Stehfest & Bouwman, 2006; Novoa & Tejeda, 2006;

EF_4: see IPCC (1996) effectively uses EF_1

EF_5: Hiscock et al., 2002, 2003; Reay et al., 2004, 2005; Sawamoto et al., 2005

$FRAC_{LEACH-(H)}$ – Σ(rain in rainy season) – Σ(PE in same period) > soil water holding capacity, OR where irrigation (except drip irrigation) is employed ; PE is potential evaporation ; rainy season is the time when rainfall is > 0.5 * pan evaporation.

$FRAC_{LEACH}$ – regions that the conditions of $FRAC_{LEACH-(H)}$ do not apply.

2.3.2 EFs for indirect N2O emissions from fertiliser

The method for estimating indirect N_2O emissions includes two EFs: one associated with volatilised and re-deposited N (EF_4) and the second associated with N lost after leaching/runoff (EF_5). The method also requires values for the fractions of applied mineral N that are lost through volatilisation ($FRAC_{GASF}$) or leaching/runoff ($FRAC_{LEACH}$). The equation changes to:

*Emissions = Emission Factor (EF) * Fraction (FRAC) * Activity Data (AD)*

using the respective EF and FRAC for volatilisation and leaching, respectively (Table 1).

The IPCC notes that country-specific values for EF_2 should be used with caution because of the special complexity of transboundary atmospheric transport and the fact that deposited N may not have originated in their country and vice versa. The value of EF_2 is very difficult to determine, and for this reason the current *IPCC 2006 Guidelines* attributes all indirect N_2O emissions resulting from inputs to managed soils to the country of origin rather than to the country where atmospheric N-forms may have been transported.

2.3.3 CO_2 emissions from urea

A review of the most recent national GHG emissions inventory submissions indicates that all countries are reporting at the Tier 1 level and using EFs = 0.2 (Table 1). It should be noted that Tier 1 EFs assumes all the carbon (C) in urea is lost as CO_2, but in practice some C may be retained in the soil as inorganic C and not emitted as CO_2, at least in the year of application. Consequently, default EFs can lead to systematic bias in emission estimates.

Because default EF of 0.2 is used ubiquitously for the estimates of CO_2 emissions from urea, this component of fertiliser-related emissions is not discussed further in this report.

2.3.4 Uncertainties

The uncertainty range reflects the lack of knowledge relating to true EF values and the fact that EFs do not represent all prevailing conditions. Because N_2O emissions are influenced by several interacting biological and physical factors, the uncertainty range for EFs relating to fertiliser is high, raising questions as to the value of investing significant resources in refining EFs for all but major emissions hotspots. Two recent studies reviewed the latest global and regional datasets on EFs and concluded that the 1% default value of the IPCC remains fit for purpose (Albatino et al. 1997; Wang et al. 2017). In general, the reliability of AD is greater than the reliability of EFs.

2.4 Current tier status of reporting on emissions from fertilisers

Figure 1 summarises the tier status of reporting on direct N_2O emissions for mineral fertilisers in developed and developing (formerly known as Annex 1 and non-Annex 1) countries in 2017. In general, the tier-level reporting for indirect N_2O emissions reflects the tier-level reporting for direct emissions. Of the total of 191 countries (i.e. 41 developed and 150 developing) reporting N_2O emissions from fertiliser, 180 (94.2%) are reporting at the Tier 1 level and 10 (5.2%) at Tier 2 level. Only the USA currently reports at a Tier 3 level for N_2O emissions from mineral fertiliser. A detailed evaluation of what Tier 3 reporting involves follows.

Table 2 summarizes how countries are reporting at the Tier 2 level. The way Tier 2 reporting is applied is strongly dependent on the same factors that were identified as influencing N_2O emissions within a specific country. At the Tier 2 level, EFs and/or AD are disaggregated according to a range of factors, including land use, agro-climatic conditions, soil type, major crops, fertiliser type and management (Table 2). Two developing countries, China and India, state that they are reporting at a Tier 2 level, but the approaches used are not specified in detail in the National Communications (Table 2). It is difficult to categorise some countries, such as Switzerland, in terms of tier-level reporting on emissions from mineral fertiliser because their overall reporting on emissions from fertiliser (mineral and organic) is Tier 2, but they use a Tier 1 EF for mineral fertiliser and AD based on country-level sales. There is no further disaggregation of emissions according to land use, etc. in the case of mineral, fertiliser-related emissions.

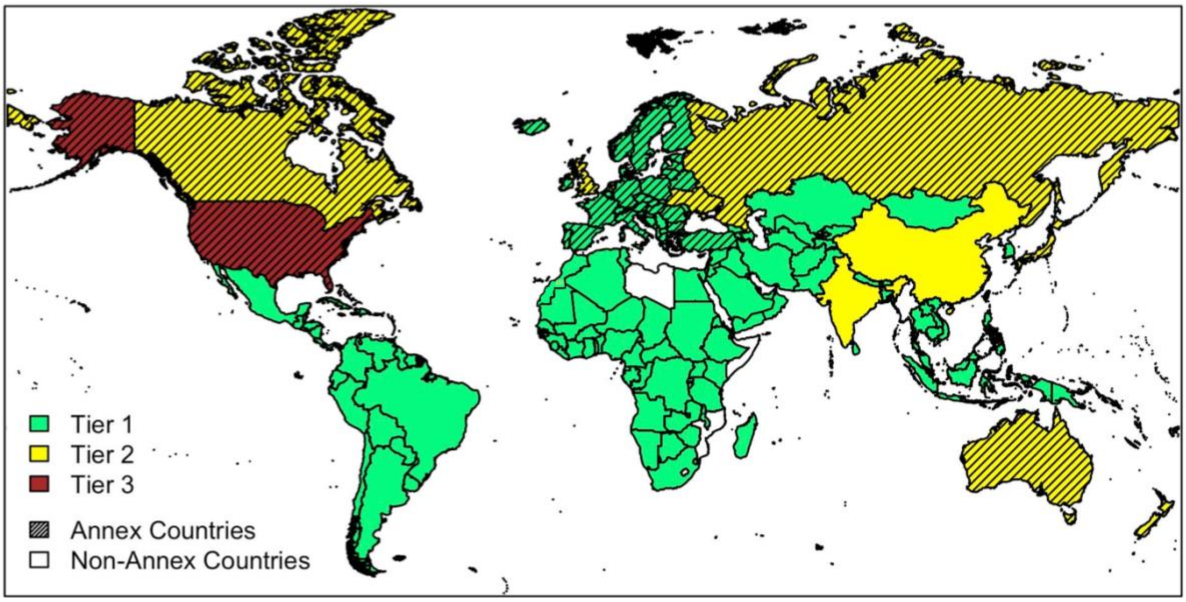

Figure 1. Overview of IPCC tier-level reporting on direct N2O emissions from mineral fertiliser taken from 2017 submissions.

Source: http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/10116.php

Table 2. Summary of how countries are interpreting and reporting at the Tier 2 level for fertiliser-related N2O emissions with an emphasis on direct N2O emissions from mineral fertilisers.

Country	Comment on approaches used
Developed (Annex 1)	
Australia	EFs disaggregated by land use (irrigated/non-irrigated pasture/cropland) and major crops (sugarcane, cotton and horticulture).
Canada	EFs disaggregated by eco-district based on long-term climate, soil texture and topographic characteristics. Applies EF modifiers for tillage, summer fallow and irrigation.
Japan	EFs for major crops (rice, tea and 'other'). Applies an EF reduction factor (26%) for nitrification inhibitor.
Netherlands	EFs disaggregated by inorganic N fertilisers and mineral and organic soils.
New Zealand	EFs for fertiliser source (urea and Tier 1 for all other mineral sources.) Apply a modified EF for inhibitors (urease and nitrification).
Russian Federation	EFs for specific soils: chernozems and sod-podzolic soils.
UK	EFs for fertiliser source applied to grassland or arable land (urea, UAN, other).
Developing (Non-Annex 1) *	
China	Regional N cycle model (IAP-N) used with different EFs applied according to land type, which have been statistically derived from observational data.

India	States “drawing on expert knowledge” and no further details are provided.

Where EF = emission factor

**From the most recent National Communication Report (NC2) submissions (2012).*
(http://unfccc.int/national_reports/non-annex_i_natcom/items/10124.php)

Unlike developing countries, developed countries must provide a detailed account of the methodologies used to calculate GHG emissions as part of their commitment to the UNFCCC. An example of the Tier 2 approach used by the United Kingdom is given in Box 1. The improved methodology was developed based on spatially disaggregated available data, and new values for EFs were derived from field experiments. These new data were produced from a five-year research programme funded by DEFRA to improve inventory methods (at a cost of ca. £3 million). It disaggregates fertiliser application at field level for some crops such as wheat; lesser crops have lower disaggregation. Crop areas are attributed to combinations of crop/soil type/rainfall.

Box 1: Description of Tier 2 methodology used by UK in national inventory reports

The UK estimates direct N_2O emissions from fertiliser N applications using EFs derived from UK-based experimental studies (Topp et al. 2016). Direct N_2O emissions are related to fertiliser type, application rate and average rainfall, with the relationship for synthetic fertilisers given as:

$$\mathrm{Ln}(CumN_2O + 1) = 0.1616(\pm 0.13526) + 0.00006093(\pm 0.000240365) * NRate + 0.0005187(\pm 0.00016259) * RainYr + 0.00000354(\pm 0.0000002785) * NRate * RainYr$$

Where:

- $CumN_2O$ is the cumulative annual N_2O-N emissions (g ha^{-1})
- NRate is the rate of fertiliser N applied (kg ha^{-1})
- RainYr is the annual average rainfall (mm)
- EFs are calculated as: (($CumN_2O$ at a given NRate) – ($CumN_2O$ in the control))/Nrate

To calculate national emissions, calculations are made at a 10km spatial resolution, using:

- Information on crop type within each spatial cell from the June Agricultural Survey for each Devolved Administration (England, Wales, Scotland, Northern Ireland).
- Information of crop-specific N fertiliser application rates from the British Survey of Fertiliser Practice for England, Wales and Scotland and the Farm Business Survey for Northern Ireland
- 30-year average rainfall for each 10km cell from the UK Met Office.

Crop type and fertiliser use data

Crops are categorised according to 49 crop types, representing the major cereal crops and roles (e.g. winter and spring sown, milling and non-milling wheat, malting barley and non-malting barley), oilseed crops, vegetables, forage crops, and fruit crops. This enables consistent aggregation and discrimination across the time series and association with different fertiliser and residue management practices (see Williams et al. 2018 for details).

For fertiliser use, data from the British Survey of Fertiliser Practice (from 2004) were disaggregated by country and Robust Farm Type (representative of UK farms) as far as possible. The same data were used to disaggregate N rate by month and the proportion of N by fertiliser type (Ammonium Nitrate, Ammonium Sulphate or Diammonium Sulphate, Calcium Ammonium Nitrate, Urea, Urea Ammonium Nitrate, other N).

Improved grassland is categorised as temporary (sown within the last 5 years) and permanent. Rough grazing and common land are excluded from the estimation of emissions from fertiliser applications and reside returns for the grassland sector. Grassland area is associated with Robust Farm Type for association with data on management including fertiliser application rate. Model calculations of grass offtake and N leached are made for soil-climate zones that aggregate areas of the same soil type (the RB209 classification) and climate (annual rainfall and temperature) within each country. Individual 10km grid cells are aggregated if they fall within the same 100 mm annual rainfall band and 0.5°C annual average temperature band.

The British Survey of Fertiliser Practice (1990 to 2016) and the Northern Ireland Fertiliser Sales (1990 to 2016) survey are used to calculate the proportion of N applied by fertiliser type as well as the monthly distribution of total N applied to grassland.

2.4.1 Tier 3 reporting in the USA

The USA's methodology to estimate direct N_2O emissions from agricultural soils is based on a combination of IPCC Tier 1 and Tier 3 approaches. The Tier 3 component uses the process-based model DAYCENT to estimate direct emissions from a variety of crops that are grown on mineral soils. DAYCENT is a daily-time-series biogeochemical model used in agroecosystems to simulate fluxes of C and N between the atmosphere, vegetation, and soil (Del Grosso et al. 2005). The Tier 3 modelling also enables the inventory to address soil C stock changes from mineral cropland soils at the same time as estimating direct N_2O emissions. This has the potential to capture better the interactions between C and N cycling in soils.

The USA's Tier 3 approach uses data from cropping and land use histories recorded in the United States Department of Agriculture National Resource Inventories (USDA NRI) survey (https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri/). The NRI is a statistically-based sample of all non-federal land and includes 363,286 points on agricultural land for the contiguous United States that are included in the Tier 3 method. The Tier 1 approach is used to estimate the emissions from the remaining 205,487 points in the NRI survey that are designated as cropland or grassland. Each sampling point is associated with an area of the same land-use/management history, so that modelling results of these samples can be extrapolated to this area ("Expansion Factor") and all of the USA will be represented. DAYCENT is only used to provide emissions for major crops on mineral soils and currently represents 91% of total cropland in the USA. The IPCC (2006) Tier 1 methodology is used to estimate direct N_2O emissions for mineral cropland soils that are not simulated by DAYCENT.

2.4.2 Comparison of Tier 2/3 level emissions estimates with Tier 1 estimates

Figure 2 shows differences in estimates of direct N_2O emissions from mineral fertiliser using Tier 2/3 and Tier 1 approaches. The countries in this figure and in Table 2 are the same, and the Tier 1 estimates use the same AD.

The size and direction of change caused by moving from lower to higher tier reporting varies by country, ranging from a 35% reduction in estimates for Australia to a 36% increase in estimates for Russia. The Tier 3 estimate in the USA was 3% greater than the Tier 1 estimate. This demonstrates that moving from a lower to higher tier does not automatically result in lower GHG emission estimates; the increased precision will help identify emission hotspots and so inform where mitigation efforts should be concentrated.

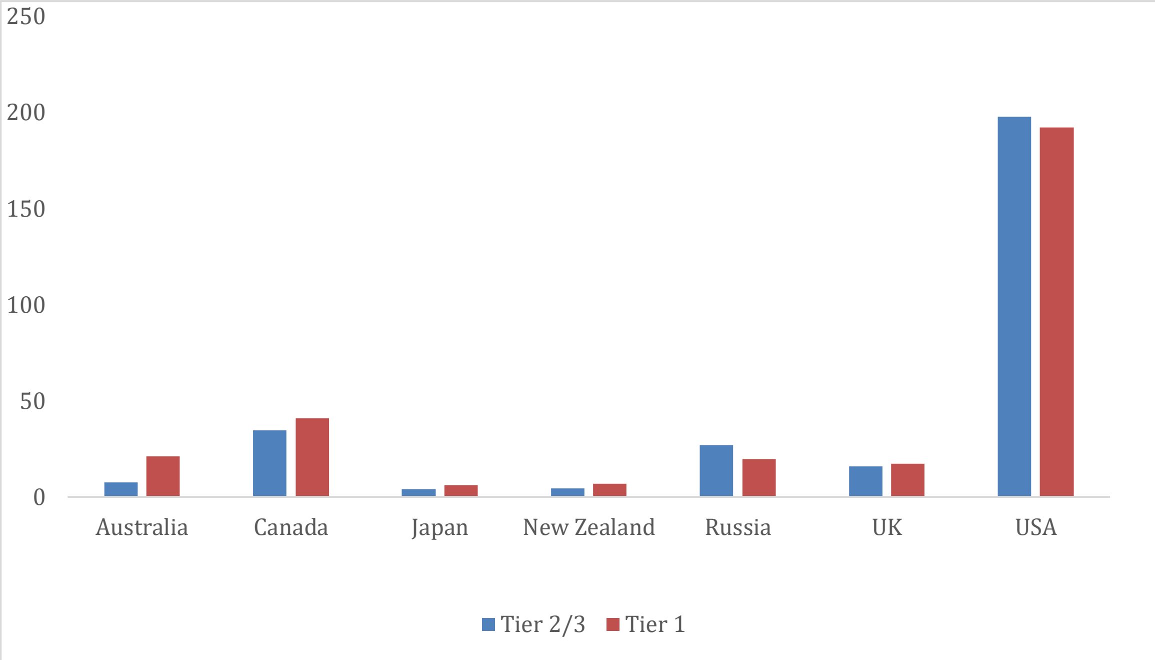

Figure 2. Comparison of direct N_2O emissions (kt) from mineral fertilisers estimated using Tier 2/3 compared with Tier 1 approaches.

Table 3 summarises the amount and percentage of fertiliser N consumed by developed and developing countries and the associated level of tier reporting for direct N_2O emissions. Data confirm that when considering reporting from both developed and non-developing countries, higher tier reporting is used for the bulk of fertiliser N (i.e. 63%) consumed.

Table 3. Summary of developed and developing countries' fertiliser consumption levels and tier-level reporting on direct N_2O emissions from mineral nitrogen fertilisers (2015; IFADATA).

Category	Fertiliser consumed	
	Amount (Tg N)	Percentage of Total
World	103.9	100%
Developed countries (Annex 1_	32.5	31%
Developed countries (Annex 1) reporting at Tier 2 and 3 levels	20.7	20%
Total (developed and developing countries) reporting at Tier 2 and 3 levels	65.4	63%

Source: IFA website IFADATA http://ifadata.fertilizer.org

2.5 IPCC Tier 1 default value for direct emissions from fertilisers

Use of the IPCC Tier 1 method for estimating N_2O emissions from fertilisers continues to dominate national GHG inventories and emission estimates. What is often not appreciated is that this IPCC default value of 1% resulted from a rounding up of the average global percentage of emissions from fertiliser inputs produced from a global run of an exponential and non-linear model (Bouwman et al. 2002b; see Box 2 for details). This was simplified by the IPCC to a linear model and rounded to the factor of 1% in the light that the EF was reduced from the earlier value of 1.25% and the value is associated with a high level of uncertainty anyway. Therefore, it is not surprising that there are several publications that concluded that their plot/field-level EFs differ from

Box 2: Using the Bouwman et al. (2002a) model to calculate a mean global emission factor for fertiliser

In the studies of Bouwman et al. (2002a, 2002b), Residual Maximum Likelihood (REML) models were developed using N_2O measurements from 29 studies. This gave relationships to a series of factors. The REML based models were run at the global level using country data for each crop type in terms of fertiliser-N application rates and crop area actually fertilised i.e. excluding fallow areas and areas not fertilised. A range of source data were used, including country data on synthetic N fertiliser rates. Areas of fertilised grasslands, rice and leguminous crops were taken from FAO inventory (1999). In the absence of data, national fertiliser-N rates were assumed to be similar to those of neighbouring countries for which data were available, for example the Soviet Union was assumed to be the same as Eastern Europe.

N_2O emissions from fertilisers were calculated for each 0.5 x 0.5 degree grid cell as the emissions from fertilised area minus the emissions for zero-N application from the same area; all other conditions held the same. N_2O emissions from fertilisers were then presented as a global aggregated mean for different fertiliser types and expressed as a % of the N applied, i.e. an EF. Areas with leguminous crops were excluded based on the assumption that they receive little fertiliser and rely on symbiotic N fixation.

The REML models were run with the value of the model term for the measurement period set at >300 days. Averaged across the globe, this gave a mean global emissions factor for N_2O of 0.9%.

the IPCC 1% value, and that the observed relation between N_2O vs fertiliser-N application rate is non-linear, unlike the IPCC Tier 1 model. Here, it is also important to note that in their original paper, Bouwman et al. (2002b) emphasised that the EF value of 0.9% (which the IPCC rounded to 1%) was a global mean and should not be used to compare with EFs at scales much less than this and certainly not with plot/field-level data. A more detailed historical summary of the origins of the IPCC Tier 1 EF value of 1% is given in the Appendix 2.

In addition to the strong relation between N_2O emissions and fertiliser N rate, recent analyses (e.g. Vyn et al. 2016) have established a strong positive relationship between N_2O emissions and N surplus (i.e. difference between N fertiliser rate and grain N removal), which explains the observed rapid increase in N_2O emissions at N rates that exceed crop requirements (Hoben et al. 2011; Millar et al. 2018; Scherbak et al. 2014). Notably, Vyn et al. (2016) found that the relation between N_2O emissions and N surplus was more consistent than for other N metrics, such as total plant N uptake and N recovery efficiency.

2.6 Description of issues likely to be examined in the revision of the 2006 Guidelines

The IPCC 2006 Guidelines are currently under revision and will be published as the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2019 Refinement). The deadline for submissions to the Expert Review of the First Order Draft ended in February 2018. The government/expert review of the Second Order Draft is scheduled for 2 July to 9 September 2018.

As the title of this publication would suggest, changes are likely to involve updates and refinements rather than major structural changes to the methodologies. In the case of calculations of direct N_2O emissions from soils, the 2019 Refinement is likely to consider revisions of:

- Default Tier 1 EF (EF_1) based on new experimental data
- Further disaggregation of EF_1 based on:
    - Climatic zone (e.g. temperate/boreal wet, temperate/boreal dry, tropical wet, tropical dry)
    - Environmental factors (e.g. soil organic C content, soil texture, drainage and soil pH) management-related factors (e.g. N application rate by fertiliser type, crop)

The Technical Support Unit (TSU) of the IPCC National Greenhouse Gas Inventories Programme (IPCC-NGGIP) developed an online, freely accessible emission factor database (EFDB; https://www.ipcc-nggip.iges.or.jp/EFDB/main.php). This comprises a library of EFs for all GHGs and sectors including agriculture and direct N_2O from managed soils where the EFDB summarises the source of N2O EF data in terms of how they are derived (e.g. modelled or measured), management and biophysical conditions and region. New data entries are subject to quality control through the EFDB Editorial Board.

3 Project-level approaches to estimating emissions savings from use of fertiliser-related best management practices

A variety of carbon calculators exist that estimate GHG emissions from agriculture; there are also a number of BMPs, such as the 4Rs (described earlier in this paper), that are being integrated into GHG emission accounting to better reflect the impact of sustainable intensification practices. All of these efforts have in common that they involve bottom-up approaches to estimating emissions associated with the adoption of BMPs and work mainly at a sub-national level. However, the extent to which these approaches align with national GHG inventories and whether the emissions saved from such programs are, or have the potential to be, reflected in the national inventory data for emissions from fertiliser use in agriculture, remains unclear. The following is an evaluation of a selection of project-level initiatives including BMP-based projects, a carbon calculator and the European N Expert Panel's multi-N indicator framework, which unlike the others does not provide an estimate of GHG emission savings but is included here because the framework could be extended to include this calculation and provides a useful framework to set desirable targets for N use. The case studies selected cover a diverse range of methods and approaches to achieving emission reductions, including the use of reduction modifiers of EFs, semi-life cycle analysis (Cool Farm Tool - CFT) and nitrogen-use efficiency (NUE) indicators (Table).

3.1 Field to market

3.1.1 Overview

"Field to Market" (www.fieldtomarket.org) is a multi-stakeholder initiative that was originally established under the stewardship of the Keystone Policy Centre with the overall aim of improving the sustainability of the U.S. agricultural supply chain. Membership is wide and includes growers; agribusinesses; food, beverage, restaurant, and retail companies; conservation groups; universities; and public-sector partners. Central to the "Field to Market" system is a common framework for the measurement of environmental and socio-economic indicators that can be applied at scales from field to national level. "Field to Market" identified 8 key areas for measurement of environmental indicators: (i) greenhouse gas emissions, (ii) energy use, (iii) biodiversity, (iv) irrigation water use, (v) land use, (vi) soil carbon, (vii) soil conservation and (viii) water quality.

The GHG emissions calculations include CO_2 (from fuel), methane and nitrous oxide. Field-scale emissions are measured using the Fieldprint Calculator, which is capable of estimating sustainability metrics for environmental indicators listed above. The following focusses on the N_2O emissions from fertiliser method.

Table 4. Summary of case studies reviewed in this report

Name of scheme	Field to Market	Nitrous Oxide Emissions Reduction Programme (NERP)	European N Expert Panel Multi-N indicator framework	Swiss Carbon Offset Programme – stabilised fertilisers	Cool Farm Tool (CFT)
Website	www.fieldtomarket.org	http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/cl14145	www.eunep.com	www.firstclimate.com	https://coolfarmtool.org
Overview	Not-for-profit multi-stakeholder (public, private & NGO) programme established in 2007. Methods for both national- and farm-level emissions estimates. Farm-level fertiliser component embedded in the Fieldprint Calculator, which measures performance across a wide range of environmental parameters.	Development of farm-level protocol supported by Fertiliser Canada and approved for use under Alberta's Carbon Offset programme in 2010. Based on a before (baseline) and after (project) measure of BMP validated by an Accredited Professional Adviser.	N Expert Panel is composed of research, policy & industry experts and first convened by Fertiliser Europe in 2014. Does not have a specific focus on fertiliser-related GHG emissions but on improving NUE across the whole food supply chain.	Carbon Offset Programme managed by First Climate. Introduced to Switzerland in October 2016 with offsets generated through use of the stablised fertiliser ENTEC 26 (based on nitrification inhibition).	Developed by University of Aberdeen with support from Unilever and now hosted by multi-stakeholder Cool Farm Alliance. Initially developed as a carbon footprint tool from cradle to farmgate and extended to include modules for biodiversity and water use.
Focus of best manageme nt practice (BMP) in fertilisers	4Rs applied at three levels: Basic, Intermediate and Advanced.	4Rs (Comprehensive 4R Nitrogen Stewardship Plan) applied at three levels: Basic, Intermediate and Advanced.	Framework for benchmarking several N indicators and using this to identify 'safe' corridor for sustainable fertiliser N use.	Use of stablised fertiliser ENTEC 26, with the amount used derived from sales through supplier Omya (Schweiz) AG. National inventory data used for reference N fertiliser use.	General farm-level fertiliser BMPs.

Geography (where used)	USA	Alberta, Canada	Europe	Switzerland	Global
Alignment with IPCC national inventory	Most recent version applies a 'reduction factor' to USDA model-based (Tier 3) estimates of N_2O emissions. Modelled emissions are reduced by 7% and 14% for intermediate and advanced use of 4Rs.	Applies a 'reduction factor' to relevant Tier 2 EFs for field/farm location. Direct and indirect N_2O emissions are expressed as emission intensity (i.e. divided by crop mass), to which a 'Reduction Modifier' is applied – 15% for intermediate and 25% for advanced practices.	None.	Apply a 73% and 23% reduction to Tier 1 EF for direct and indirect emissions, respectively.	Calculates emissions using Bouwman et al. (2002a, 2002b) model plus default Tier 1 EFs for leaching and volatilization.
Relevant IPCC tier level	Tier 3	Tier 2	NA	Tier 1	Tier 2 to 3 for direct and Tier 1 for indirect emissions.

Where BMP = best management practice; NUE = nitrogen use efficiency.

3.1.2 Field-level assessment of N_2O emissions from fertiliser

The original version of the *Fieldprint Calculator* (pre-2011) used a method for estimating N_2O emissions from fertiliser based on the IPCC Tier 1 method, whereby the amount of fertiliser applied is multiplied by a default EF. The EF value used by the *Fieldprint Calculator* combined the IPCC default values for both direct (0.01) and indirect (0.0035) emissions to arrive at a rounded value of 0.014 (or 1.4%). The advantage of this approach was that it was simple, transparent and made use of readily available data. That said, members of "Field to Market" were aware of the high uncertainty of the N_2O emissions derived using a method based on a global default EF value.

As more data became available over time and understanding of the influence of environmental and management conditions on N_2O emissions increased, the International Plant Nutrition Institute (IPNI) and The Fertilizer Institute (TFI) agreed to coordinate and fund a science-based effort to improve the methodology and explore the potential for greater alignment of methods and estimates used by the national GHG inventory. In the case of the USA, the latter involved Tier 3 modelling approaches as described in section 2.4.1 of this report. A series of N expert workshops were held to discuss and agree on a refined methodology. As full details of the issues discussed and science underpinning the decisions are described elsewhere (Field to Market 2017; Vyn et al. 2016), a brief summary of the main issues follows.

Improvements in the *Fieldprint Calculator* estimates of fertiliser-related N_2O emissions included:

i. Use of a three-tier system to describe the level of farmer-implementation of 4R (source, rate, time and place of application) N management: basic, intermediate and advanced.
ii. Development of reduction factors of 7% and 14% for intermediate and advanced level 4R N management.
iii. Application of the above reduction factors to USDA model-based N_2O emissions calculated for a given location.

Discussions revealed that the USDA Tier 3 modelling approach used for USA's national inventories is not currently capable of capturing 4R-based fertiliser practices. As an alternative, "Field to Market" now recommends that they apply the reduction factors to the

Tier 3 estimates of fertiliser-related N_2O emissions in order to capture best N management practices and their mitigation benefits. This update allows for better alignment with the USDA DAYCENT-based N_2O-N emission estimates and captures sensitivity of emissions to crop, Land Resource Region, soil texture and farmer-applied N rates (Field to Market 2017). Currently, the practice system modifiers are available for corn, soybean and wheat production in different regions of the USA.

3.1.3 Data requirements and verification

Data requirements include field-level N rates and field location from which the USDA Land Resource Region is determined and with this associated soil characteristics. The revised Field to Market makes use of a database of published outputs from the USDA DAYCENT model to adjust the emissions factors based on crop, geographic location, soil texture and nitrogen application rate. The reduction factors then are used to emissions based on nitrogen management practices. As a subscriber to ISEAL, (a global membership association that sets standards for sustainability, any changes to methodologies are subject to a multi-step review process followed by an open period for public comment, prior to implementation in the Fieldprint Platform. The Fieldprint Calculator is a voluntary scheme with no accreditation or control.

3.2 Nitrous oxide emission reduction protocol

The Nitrous Oxide Emission Reduction Protocol (NERP) is another 4R-based approach to estimating fertiliser-related mitigation of N_2O emissions from farmers' fields. The development of NERP was supported by Fertilizer Canada and was approved in 2010 for use under Alberta's carbon offset program, whereby farmers could claim carbon credits by adopting 4R N management practices. The various 4R practices were integrated into a package called a Comprehensive 4R Nitrogen Stewardship Plan (Right Source at the Right Rate, the Right Time and the Right Place) hereafter referred to as 4R. Depending on the level of adoption of a set of prescriptive 4R practices, the 4R Plan can be applied at three levels: basic, intermediate and advanced. The 4R Plan conditions for each of the three levels are described in NERP documentation.

As applied under the Alberta carbon offset program, NERP takes account of on-farm reductions in GHG emissions from N sources and fuel use associated with the management of fertiliser, manure and crop residues for each annual or perennial crop type grown.

3.2.1 NERP method for estimating N_2O emissions from fertiliser

NERP quantifies direct and indirect N_2O emissions per unit of crop produced for each crop type on each farm using Canada's Tier II method and specified according to the EcoDistrict where the farm is located.

NERP calculates N_2O reductions by comparing a historic emissions baseline to project or post-4R implementation emissions. The baseline is generated from 3 years of yield and N-use data for each crop and expressed as an average emission in crop event units (kgCO_2e/kg crop). This allows comparison and averaging across different production years.

For each farm, N_2O emissions for the baseline and for the project (i.e. where the 4R has been implemented) are calculated for each crop, eco-district and level of 4R plan implemented using on-farm data on fertiliser application to the respective crop (AD) and the appropriate Tier 2 EF for the respective EcoDistrict.

N_2O emissions from direct and indirect sources are summed for a given crop and divided by the crop mass to express total N_2O emissions on a unit crop mass basis i.e. as an emission intensity (kgCO_2e/kg crop). This is done for both project and baseline emissions. In order to account for the effect of 4R adoption on N2O emissions, the project emission intensity is adjusted by a Reduction Modifier (RM_{PL}) as shown:

$$\textit{Emission Intensity}_{Project} = (N_2O\ \textit{Emissions}_{Direct\ mineral\ fertiliser} + N_2O\ \textit{Emissions}_{Indirect\ fertiliser}) * RM_{PL} / \textit{Crop Mass}_{Project}$$

The total emissions reductions are estimated by subtracting the project emissions from the baseline, and then multiplying by mass of crop produced to give total kgCO2e per crop. Adding savings from all crops will then provide a total farm N_2O emissions savings.

*Emission Reductioncrop = (Emissions IntensityBaseline – Emissions IntensityProject) * Crop MassProject*

The Reduction Modifiers (RM_{PL}) currently used are a 15% reduction for intermediate and a 25% reduction for advanced 4R best management practice. RMPL values are determined from research studies and agreed by majority vote of scientists, using a process defined by ISO 14064-2.

3.2.2 Data requirements and verification

NERP was developed using ISO 14064-2 guidelines for quantification and reporting of GHG reductions. The major quantitative data requirements are: N inputs and crop outputs for each crop grown on the farm for each baseline and project year. Qualitative data requirements include location of fields enrolled in the project and the 4R practices used on each field. A complete list of data requirements can be found on the website. In order to apply under NERP for carbon offsets, farmers must work through accredited agricultural professionals who provide support in the design and implementation of the 4R Plan and will authorize the project. Farmers Edge, Inc. is an example of a NERP offsets aggregator that owns and operates the project and is verified annually by an independent verification team.

3.3 Cool Farm Tool – fertiliser component

The Cool Farm Tool (CFT) (https://www.coolfarmtool.org) was originally developed as a farm-level carbon footprint tool by the University of Aberdeen, UK in partnership with Unilever and the Sustainable Food Lab (Hillier et al. 2011). The tool is now managed by the not-for-profit Cool Farm Alliance, whose membership comprises a diverse group of businesses from the food and drink sector, retailers, fertiliser companies, consultancies, NGOs, and academic organisations. In recent years the tool has become freely available online and expanded from the original GHG focus to include modules for farm biodiversity and water use.

The CFT adopts a semi-life cycle approach to estimating GHG emissions from cradle to farmgate. The tool comprises a generic set of empirical models using a mix of IPCC Tier 1, Tier 2, and simple Tier 3 approaches. GHG emissions are estimated from inputs including: general information about soil and climate and a set of management options on the farm inclusive of fertilisation, pesticide and herbicide use, residue management, and machinery and energy use.

3.3.1 CFT method for estimating N_2O emissions from fertiliser

GHG emissions up to the farm gate are reported in CO_2 equivalent (CO_2e) per ha of crops using the 100-year global warming potential (GWP) used in national GHG accounting (IPCC, 2006). For comparison, all results are also presented on a per kg production basis. As this is a semi-lifecycle carbon footprint tool, calculation of GHG emissions from fertiliser also includes emissions associated with fertiliser production and distribution. The CFT takes EFs from the Ecoinvent database for these calculations (Ecoinvent Centre 2007).

The Bouwman et al. (2002a, 2002b) model is used to estimate N_2O emissions and takes the form:

$$Emission = e^{constant + \sum_{1}^{n=i} Factor\ class(i)}$$

> Where the factor classes are; fertiliser type x fertiliser application rate, crop type, soil texture, soil organic carbon, soil drainage, soil pH, soil cation exchange capacity (CEC), climate type, and application method.

Indirect N_2O emissions are calculated using a slightly different model for NH_3 emissions given in FAO/IFA (2001) and which takes the form:

$$NH_3 = FA \cdot e \sum_{1}^{n=i} \text{Factor class}(i)$$

> Where FA is the amount of fertiliser applied. Factors were determined by statistical analysis and from Bouwman et al. (2002a, 2002b). The default EF of 0.01 (IPCC 2006) is used to convert NH_3 due to volatilisation losses to N_2O. IPCC (2006) default EFs and fraction of N lost through leaching are also applied to indirect N_2O emissions from leaching, 0.01 and 0.3*N, respectively.

3.3.2 Data requirements and verification

The open availability of the CFT, full publication of the methods used (Hillier et al. 2011) and its widespread testing and use has benefitted the tool in terms of usability, refinement, and transparency. The CFT allows for farm-level, management and climate-sensitive N_2O emissions from fertiliser to be calculated based on relatively simple data inputs such as fertiliser type, fertiliser rate, +/- inhibitors, crop and yield, soil, climate, and study locations.

On one hand, the site-specific and complex nature of N_2O emissions from fertiliser requires methods more refined than those devised for national or regional scale inventories for accurate estimation of emissions related to practice. On the other hand, Tier 3 methods typically require data and a level of understanding of soil processes that are often not available. By using a mix of Tier 1, 2 and simple Tier 3 methods together with default data options, this open-source tool aims to address these shortcomings whilst providing educational and practical benefits as a decision-support tool, and as a useful first step of engagement for crop producers wishing to explore mitigation options.

3.4 Swiss Carbon Offset Program – stabilised fertilisers

The Swiss Carbon Offset Program not a tool, method or protocol for calculating N_2O emissions savings or NUE indicators like the previous studies. It is an offset program in which savings are calculated from data on the amount of stabilised fertiliser used. The Swiss Carbon Offset Program is managed by First Climate, which specialises in voluntary and compliance carbon trading. The Program aims to generate carbon offsets from a reduction in fertiliser-related N_2O emissions which can then be sold on the open market (within Switzerland). The program works by using the proceeds from the sale of certified emission reductions to reduce the price of the stabilised N fertiliser for farmers.

In collaboration with Omya AG, which produces ammonium-stabilising chemical fertiliser, First Climate has applied to the Swiss Environment Agency (BAFU – Bundesamt für Umwelt) to allow the stabilised fertiliser (ENTEC 26) to be permissible under the Swiss CO_2 law. The technology is based on a nitrification inhibitor (Dimethylpyrazolphospate, DMPP – 3,4) developed by BASF in the 1990s and generally available on the fertiliser market under the brand of ENTEC fertiliser mix by the company EuroChem Agro GmbH. It is the most important nitrification inhibitor in Europe and has no known side effects. Other nitrification inhibitors are available (e.g. Ntropyrin in the USA) but are not necessarily permissible in Europe.

Originally, the only incentive for farmers to use ENTEC fertilisers was that it increased the availability of ammonium to plants. Across Europe, however, only 400,000 t of ENTEC fertiliser is sold; this is. only about 1% of the European N market. Limited sales mainly are due to the higher cost of ENTEC compared to the equivalent non-stabilized fertiliser product.

3.4.1 Approaches used to account for N_2O emissions reductions from ENTEC fertilisers

The Swiss Carbon Offset program uses the same method and data to establish a baseline as is used for the National Inventory. The emission reductions resulting from use of ENTEC use the following assumptions to modify the national inventory EFs for direct and indirect N_2O emissions:

Direct emissions – The default IPCC EF of 0.01 (1%) is reduced by 73% to 0.0025 (0.25%).

Indirect emissions – The default IPCC EF for N leaching is 30% of applied N which is reduced by 23%. Note that no change is made to baseline calculations for N losses by ammonia volatilisation.

In some cases, application times can be reduced when using ENTEC and in these cases emissions from machinery is reduced as well (First Climate 2018, October).

The Swiss National Inventory Report states that they use Tier 2 reporting for fertiliser but. in fact, reporting for direct N_2O emissions from mineral fertiliser uses the IPCC Tier 1 default EF, and most of the Tier 2 level reporting relates to emissions from manure and other biological sources such as N fixation and crop residues. National sales statistics from storekeepers and importers are used for mineral fertiliser sources. and so the existing inventory method should be able to achieve expected changes in emissions due to the ENTEC Offset Program.

Due to the timelag in production of National Inventory Reports any emissions savings resulting from the Swiss Offset Program, which began in 2016, will not be captured by the Swiss National Inventory calculations of emissions from the agricultural sector until 2018.

3.5 European NUE indicator system (EU N Expert Panel)

The European NUE indicator system has been developed by the EU Nitrogen Expert Panel, which was established in 2014 with the support of Fertiliser Europe. The Panel's website (http://www.eunep.com) states that the Panel's overall objective is to improve NUE in food systems in Europe, through (i) communicating a vision and strategies on how to improve NUE in agriculture and food systems in Europe; (ii) generating new ideas and recommending effective proposals and solutions; and (iii) acting as referee in controversial issues and communicating with authority about nitrogen issues. Unlike the previous two case studies, this framework does not produce estimates of N_2O emissions from fertiliser; instead, it focuses on developing benchmark metrics for several N indicators to help define a safe 'corridor' for sustainable fertiliser N use with a current focus on Europe. The Panel states that 'considering that N_2O is the main agriculture GHG emissions may potentially be estimated via NUE. However, the Panel also indicates that there is no intention at present to evaluate this. The greatest progress in this area so far seems to be the work that has been done to underpin the 'Reduction Factors' used by the "Field to Market" Fieldprint Calculator, as informed by the study of Vyn et al. (2016). They use the partial net N balance (= N surplus) as indicator, which is part of the NUE composite indicator.

Key feature of the NUE indicator system are its simplicity, its flexibility, its wide applicability to crops, livestock and supply chains, and its low demand on data, as it requires only N input and N output data (Table 5). This data is often systematically collected at scales from plot through to national level.

Table 5. Summary of data requirements for the NUE indicator at the farm level

N input data	N output data
Mineral fertiliser	Crop products
Feed & fodder	Animals (net)
Biological N fixation	Animal products (milk, eggs, wool)
Atmospheric N deposition	
Compost & sewage sludge	
Seed and planting material	
Bedding material (straw, sawdust)	
Animal manure (net)	

Source: Adapted from Brentrup and Lammel 2016, Proceedings of the 2016 International Nitrogen Initiative Conference. Melbourne, Australia, 2016.

The above data are used to produce three key N indicators that provide measures of:

- Resource use efficiency: $\sum(N_{output})/\sum(N_{input})*100 = NUE(\%)$
- Productivity: $\sum(N_{output}) = N_{yield}$ (kgN/ha)
- Potential for N loss to the environment: $\sum(N_{input}) - \sum(N_{output}) = N_{surplus}$ (kgN/ha)

The Panel aims to define benchmarks for each of the above indicators that represent targets for sustainable intensification trajectories against which current performance is evaluated. The benchmarks include measures of resource use efficiency (NUE), food production (N_{yield}) and potential contribution to environmental pollution ($N_{surplus}$).

Figure 4 shows a graphical representation of the NUE indicator system together with benchmarks taken from the EU N Expert Panel report (2015).

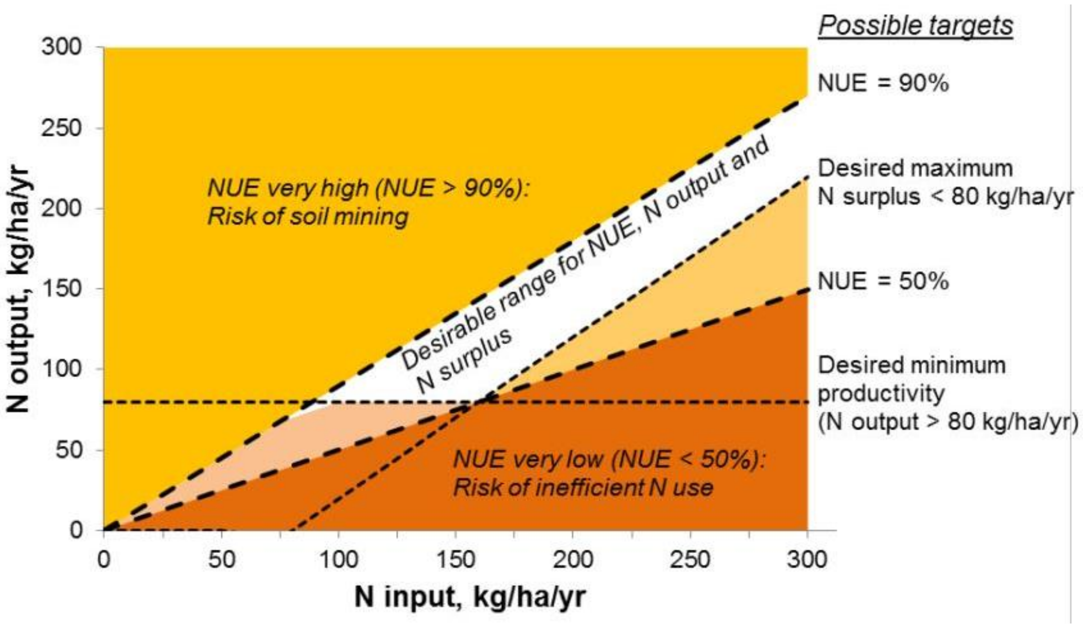

Figure 4. Schematic presentation of the NUE indicator system that can be constructed using N input and N output data and guided by sustainable intensification benchmarks. Performance can fall into three different levels of NUE: too high (>90%) leading to soil nutrient mining; too low (<50%) risking inefficient N use and high losses when N inputs are also high and a desirable range between these two extremes. For any given system, benchmarks for N output corresponding to a minimum level of productivity and N surplus corresponding to a maximum level of N losses to the environment can be defined. These additional benchmarks will likely have the effect of narrowing the desirable range for system performance and NUE.

So far, this approach had not been aligned with national inventories, while it is quite different to that of the previous case studies, the target outcomes are similar, and all systems provide a means of capturing the benefits of improved fertiliser management – including precision N management in all its forms – on sustainable intensification targets. In that respect, all of the case studies add value to the national inventories approach.

4 Conclusion

A major objective of this report was to review the UNFCCC national inventory methods for estimating GHG emissions from fertiliser and project-level initiatives that promote fertiliser BMP and associated mitigation benefits. A second objective was to consider how current and emerging fertiliser-N_2O emission savings from these projects are reconciled with current national GHG inventory methods. The premise is that national GHG inventories should be able to capture the mitigation benefits of these projects. Recognition of the mitigation benefits could serve to motivate farmers and the industry to further engage with climate change mitigation measures.

There are clear opportunities for national GHG inventories and project-level 4R/BMP initiatives to complement one another. Compiled reporting will help decision-makers understand emission trends and associated mitigation strategies that can deliver on targets, such as those of the Paris Agreement. Currently, project-level initiatives operate largely independently of national inventory programs and emissions savings are not currently accounted for in inventory data. In the case of the carbon offset NERP project in Alberta, Canada, whilst closely aligned with the national inventories (making use of baseline data and Tier 2 EFs), emissions savings generated from projects do not appear to be reflected by the national inventory data for agriculture. On the other hand, because national inventories use data from two years previous, emissions savings from the Swiss Offset Program will be incorporated in national inventory reports from 2018 at the earliest.

It is worth noting that because the national inventory uses sectoral boundaries, the fertiliser supply chain is broken up in national inventory accounting. This means that the mitigation benefits of using fertilisers produced from clean technologies, for example, will be allocated to the energy sector and not agriculture. This is not an issue for the national inventory if the methods used are unbiased, accurate and transparent; but it can lead to issues around incentives at the project-level if the benefits of climate-smart agriculture application methods are not fully attributed to the farmer.

There are three potential approaches to incorporating mitigation actions in the national inventories:

i) through direct changes in AD e.g. through reduced fertiliser use;

ii) through use of a 'Reduction Factor' applied to specific EFs, such as those used in the Field-to-Market, NERP and Swiss Offset program; and

iii) through use of Tier 3 methods such as the process-based DAYCENT model used by USA.

Currently, 22% of developed countries plus China and India report at the Tier 2 or Tier 3 level; this collectively accounts for 63% of global fertiliser consumption (IFA 2018). It is assumed that more countries will move to higher tier reporting as knowledge of key sources and data collection improves. For example, the UK will continue to improve its inventory beyond what has already been achieved as new data is produced.

Whilst the case study project-level BMP mitigation actions are not currently captured in national inventory data, there is nevertheless close alignment in the methods and data used. All the case studies (and even the European NUE indicator framework which uses compatible activity data) in this report use metrics that closely align with national inventory methods in terms of EFs (with reduction factors often applied) and AD for baselines (see Table 2). The European NUE indicator framework adopts a different approach from the other case studies, as it does not have a specific GHG mitigation savings output; however, this approach is useful and practical in that it makes use of data that are generally widely available and collected at the national level. Adapting this framework to include GHG emission measures and targets should be possible.

4.1 Generating good quality AD is one of the biggest challenges to improving national inventory estimates

Refinements can be made to the national inventory to reflect potential uptake of specific mitigation options, but the accuracy of the reporting will depend on the quality of data on the emissions savings, for example associated with adoption of 4Rs, and the accuracy of the data on area and location where the mitigation action is applied. In theory, at its most refined level (i.e. Tier 3), the inventory method would be capable of capturing field-level variations in emissions associated with mitigation measures used either individually or in various combinations. Interactions with soils and climatic conditions would also be considered.

The case studies show good promise in aligning BMP initiatives with national GHG inventories. Examples of how EFs can be modified to account for BMP benefits have already been illustrated in by the case studies. The major barrier at present appears to be the quality of AD; a lack of appropriate data on the nature and extent of use of fertiliser-BMP is preventing the capture of emission changes in national inventories. For example, the USA Tier 3 DAYCENT model can capture some of the 4R practices, and the team is currently developing new algorithms to address a few more practices, such as better placement of fertiliser. However, the inventory is still limited by availability of AD on 4R practices at the national scale, and the USA's inventory team is now working with USDA to incorporate new questions into farmer surveys to collect these data in the future.

4.2 NDCs as a key entry point for fertiliser BMP mitigation actions

Countries are increasingly interested in linking mitigation actions with the national GHG inventory to measure and report progress in relation to NDCs. As shown in Figure 2, the majority of countries are still using Tier 1 reporting, yet Tier 1 is insensitive to changes in fertiliser use efficiency and reduced N losses. However, the case studies illustrate examples of how BMP mitigation impacts can be captured using modifiers to Tier 1 and Tier 2 EFs and similar approaches could be adapted for use in other countries and regions provided good quality baseline data were available/collected. As many as 43 countries have included fertiliser in their mitigation strategies yet few have developed specific policies or plans related to these actions. There appears to be no uniform institutional and technical requirements for NDC implementation at present, so there is a clear opportunity to support the development of MRV methods based on learnings from projects such as those reviewed here.

It is encouraging to note the 2017 SBSTA breakthrough in negotiations to recommend a COP decision to include agriculture in both SBSTA and SBI for implementation (where funds are allocated). Discussions will be organised under the Koronivia Joint Work on Agriculture which is due to report back to COP26 in 2020. Improved nutrient use and manure management towards sustainable and resilient agricultural systems is one topic that has been flagged up for discussion (http://unfccc.int/resource/docs/2017/sbsta/eng/l24a01.pdf).

In summary, most of the 4R-based projects reviewed in this report are already well aligned with national inventory methods. The process is constantly evolving and being improved. So far, however, there has not been a close alignment between the development of different policy instruments, inventory compilation processes and national data providers, which has limited harmonization, alignment and reporting. This situation should improve with opportunities opening to provide support for the development of project-specific, yet nationally consistent (and inventory aligned) MRV methods for fertiliser-BMP mitigation measures in NDCs.

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ANNEX 1: Overview of the UNFCCC as it pertains to climate change mitigation in agriculture

In view of the complexity of the UNFCCC, this annex provides a brief overview and history of the Convention and its related bodies, including the IPCC, with the aim of providing a better understanding of the UNFCCC decision-making process and potential entry points for informing the UNFCCC (or the 'Convention").

A1 Overview of the UNFCCC

The Convention was signed at the United Nations Conference on Environment and Development at Rio de Janeiro in 1992 and came into force in March 1994. Countries that ratify the Convention are known as Parties to the Convention, of which there are now 197 (196 countries and the EU), who meet at least yearly the Conferences of the Parties (COP).

The UNFCCC sets different levels of obligations for climate change action for different member nations consistent with the concept of 'common but differential responsibilities'. Countries are divided into two main groups: developed countries (formerly known as Annex I Parties) and developing countries (formerly known as non-Annex I Parties). As part of this commitment, Parties to the Conference are obliged to submit regular reports, the contents and timetable of which vary between developing and developed countries

A1.1 Conference of Parties (COP)

Whilst the UNFCCC provides the supporting framework for international negotiations on climate change, the annual meeting of the COP serves as the overarching decision-making body (Figure 1). The Kyoto Protocol and Paris Agreement represent two major milestones in COP negotiations, each with the intent to set binding international agreements for GHG emissions reductions.

A1.1.1 Kyoto Protocol

The Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16th February 2005. The detailed rules for the implementation of the Protocol were adopted at COP 7 in Marrakesh, Morocco in 2001 and are referred to as the "Marrakesh Accords." Its first commitment period started in 2008 and ended in 2012; it set an average emission reduction target of around 5% relative to 1990 levels. Emission targets only related to developed countries, and the USA failed to commit. Whilst the Kyoto Protocol was an important first step in global climate change diplomacy, the failure of a sufficient number of countries to ratify the second commitment period meant the Protocol stalled.

A1.1.2 Paris Agreement

The Paris Agreement was adopted at COP21 in 2015 and ratified in 2016. It is a separate instrument to that of the Kyoto Protocol. The agreement sets out a global action plan limiting global warming to 2^{o} C, and 1.5^{o} C if possible, above pre-industrial levels. In addition to emission reduction targets, the Paris Agreement also includes goals for adaptation to climate change and the creation of financial instruments to support low emission and climate-resilient development, including a collective developed-country commitment to contribute USD 100 billion of climate finance per year by 2020.

Box A1: Nationally Determined Contributions

Under the Paris Agreement, each country is obliged to submit national post-2020 climate action plans known as (Intended) Nationally Determined Contributions (NDCs). The current commitment level is not yet sufficient to limit global warming below 1.5^{o} C, or even 2^{o}C, but the Paris Agreement aims to map the way to achieving this target through activities such as the ‘global stock take’ (Box 3). NDCs are to be submitted every five years to the UNFCCC Secretariat. To increase the ambition over time, it has been agreed that successive NDCs will represent a progression compared to the previous NDC.

All Parties are requested to submit the next round of NDCs (new NDCs or updated NDCs) by 2020 and every five years thereafter (e.g. by 2020, 2025, 2030), regardless of their respective implementation timeframes.

A summary of the current status of NDC submissions and the extent to which agriculture is included in national adaptation and mitigation plans is given by Richards et al. (2015). Of the 160 NDCs submitted, these authors found that 103 included agricultural mitigation. Most NDCs with specific agricultural mitigation targets relate to livestock, with only seventeen NDCs mentioning fertiliser as a specific mitigation target (Richards et al. 2015).

The Paris Agreement marked the end of the division of roles between developed and developed countries, with each country now legally bound to pursue domestic mitigation measures to achieve their NDCs. Because NDCs represent a potentially important instrument for mobilising future national mitigation efforts, they are described in more detail in Box A2.

Parties have agreed to undertake a five-yearly ‘global stock take’ to assess emissions and emission reduction efforts before the next round of new commitments (NDCs). This exercise will not attempt to assess the performance of individual NDCs; instead, it will assess the extent to which, in aggregate, the NDCs match up to the overall ambition of the Paris Agreement.

A1.2 Subsidiary bodies of the UNFCCC

To support the work of the COP, the UNFCCC established two subsidiary technical bodies: one for scientific and technological advice (SBSTA) and the other for implementation of the Convention (SBI).

An important role of SBSTA is to provide a link between the scientific information provided by expert sources such as the IPCC, from which it frequently requests reports, and the policy-orientated workings of the COP to which SBSTA reports (Figure). SBSTA meets twice a year, once at the same time as the COP.

Key areas of SBSTA work include:

- Assessment of impacts, vulnerability and adaptation to climate change.
- Promoting development and transfer of environmentally-sound technologies and conducting technical work to improve the guidelines for preparing and reviewing GHG emission inventories for developed countries.

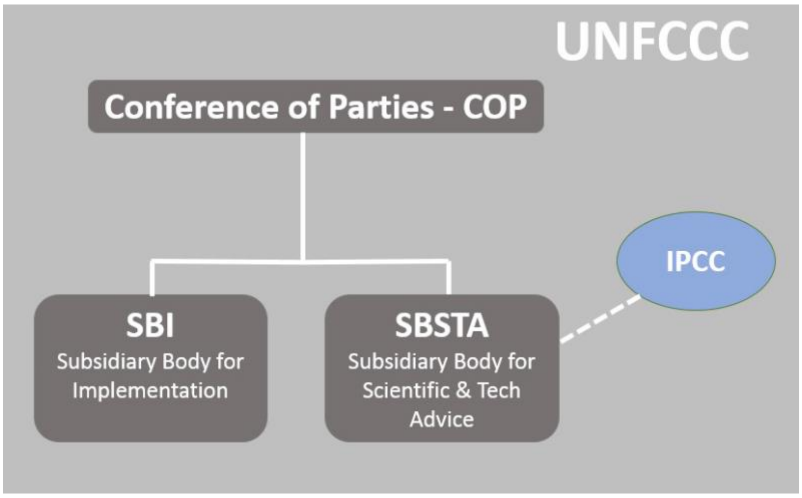


Figure A1. Organisation of the UNFCCC and related bodies.

A1.3 Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) is an independent scientific body established in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP).

The first plenary session of the IPCC was held in November 1988, when it was agreed to create three working groups to address the following tasks:

- WGI: Assessment of available scientific information on climate change
- WGII: Assessment of environmental and socio-economic impacts of climate change
- WGIII: Formulation of response strategies

The role of the IPCC is summarised in (Box A2). The IPCC's role is to review and evaluate published and peer-reviewed climate change literature and produce a range of scientific and technical guidance reports to support the UNFCCC. The IPCC publishes several types of reports including: Guidelines to assist countries to prepare their national GHG emissions inventories, technical papers, and assessment reports (ARs). The latter are produced every 4 to 5 years.

The IPCC published its first IPCC Assessment Report (AR1) in 1990. It was closely followed by several Supplementary Reports in 1992. One of the six tasks addressed by the IPCC Supplementary Reports in 1992 was an assessment of national GHG emissions, which formed the basis of what we now know as the IPCC National GHG Inventory programme. The National GHG Inventories Programme was originally managed (from 1991) by WG1 in collaboration with the Organisation for Economic Co-operation and Development (OECD) and based in Japan in 1999.

Box A2: IPCC's role as defined in the Principles Governing IPCC Work

"...to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. IPCC reports should be neutral with respect to policy, although they may need to deal objectively with scientific, technical and socio-economic factors relevant to the application of particular policies."

A2 Reporting to the UNFCCC

Developed countries comprise 43 countries in total: 23 industrialised countries that were all OECD countries at the year of 1992, the EU and 14 countries with economies in transition. Under the Convention, developed countries are obliged to reduce GHG emissions, to protect and develop carbon sinks, to report the measures they take to prevent climate change, and to submit annual GHG emissions inventories.

Developing countries (153 in total) have no obligations under the Convention but are encouraged to reduce GHG emissions, to cooperate on research and technology, and to protect sinks.

Both developed and developing countries have reporting requirements under the UNFCCC that relate to GHG emissions and national strategies for climate change. Consistent with the UNFCCC principles of 'common but differential responsibilities', the reporting requirements of developing countries are less stringent and more flexible than those for developed countries.

A2.1 National communications

National communication (NCs) reports contain information on previously submitted national GHG emissions inventory; national policies and measures; vulnerability assessment; financial resources and transfer of technology; education, training, and public awareness; and any other details of the activities a country has undertaken to implement the Convention.

NCs are submitted by developed countries every 4 years, based on agreed IPCC reporting guidelines, and are reviewed by international expert review teams (ERTs) following the general procedures agreed upon by the COP. The UNFCCC secretariat prepares the "compilation and synthesis reports" on developed country NCs, which are considered by the Subsidiary Bodies and COP as a basis for a discussion on the implementation of the Convention by developed countries. Less stringent and much more flexible reporting is required of developing countries, which are expected to submit NCs every 4 years.

A2.2 National GHG inventories

National GHG inventories provide an account of GHG emissions including AD, EFs. and methodologies used to estimate these emissions. National GHG inventories are reported annually by developing countries following reporting guidelines agreed by the COP and methodology developed by the IPCC. They are reviewed annually by ERTs. Reporting comprises a National Inventory Report (NIR) and Common Reporting Format (CRF) tables. The NIR includes qualitative and quantitative information, such as a description of methodologies used, EFs, AD, emission trends and analysis of uncertainties, quality assurance and quality control. The CRF tables include data and results from inventory estimates. Developing countries are required to submit national inventory reports on a much less frequent basis, usually as part of the NCs submitted every four years.

Guidelines on methodologies for national GHG inventories have been updated and revised at intervals throughout the IPCC history to account for new evidence and understanding. Following the *1996 IPCC Guidelines,* the report *Good Practice Guidance and Uncertainty Management in Greenhouse Gas Inventories* was completed in 2000. A further revision was produced in 2006; '*The IPCC 2006 Guidelines'* are used for current developed country GHG inventories. Developing countries are encouraged to use the 2006 Guidelines but are required to use at least the *1996 Guidelines*. A further refinement is currently taking place and due to be published in 2019.

ANNEX II: Origins of the IPCC Tier 1 EF value of 1%

The earliest method used by the IPCC for calculating Tier 1 (and Tier 2) N_2O emissions from fertilisers derived from a study by Eichner (1990). This study utilized emissions data from 24 articles published between 1979 and 1987 comprising 104 field experiments conducted at nine locations in five countries and all in temperate regions. Eichner calculated the average emissions for different fertiliser types using data extracted from the 104 field experiment where:

%N_2O-N emissions = N_2O-N over sampling period/applied fertiliser-N

Data were screened to exclude sampling periods that were too short and experiments from flooded rice. Due to insufficient data, there was no attempt to analyse the effects of climate, soil or crop type on N_2O emissions. The author also excluded experiments where fertiliser rates >250 kg N ha-1 on the basis that these application rates were much greater than typically used in agricultural systems.

Eichner estimated values for loss of direct N_2O emissions as a percentage of applied fertiliser N in the range of 0.1-1.5%, with an average of 0.5%. A number of uncertainties were associated with these this estimate, including:

- The small number of climatic, soil and management conditions covered by the analysis. For example, Eichner based the median and range of N_2O emissions induced by anhydrous NH_3 on only a few experiments, mostly carried out in Iowa, USA.
- The short duration of the measurement period in most studies with most of the emissions covering only the cropping crop season or shorter periods. Sample periods ranged from 32 to 155 days.

Bouwman (1996) * 'Direct emissions of nitrous oxide from agricultural soils' and used by 1996 IPCC Guidelines

* This was the journal version of the original article that informed the 1996 IPCC Guidelines: Bouwman A.F. (1994). Method to estimate direct nitrous oxide emissions from agricultural soils. Report 7773004004. National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands p.28.

Bouwman proposed an update to Eichner (1990) using a least squares fitting of published data from studies of at least one year's duration to produce a linear function as shown:

$$E = 1 + 0.0125*F_{rate}$$

Where E = emission rate, 1 = background emission rate and Frate is the fertiliser N application rate.

The linear model was based on only 20 experiments with measurements covering a full year and with an absolute range of uncertainty of 0.25 to 2.25%. Bouwman emphasised the importance of study length, as studies less than a year tended to underestimate emission rates. Bouwman's model assumed then that emissions were a fixed percentage 1.25+/-1% of the N applied with data from temperate regions (see Figure A2.1 below).

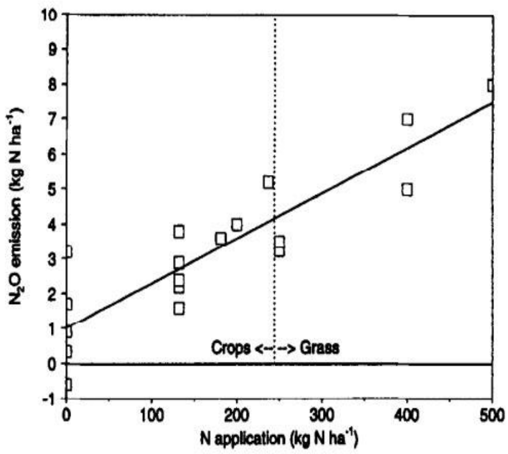


Fig A2.1 Relationship between N fertiliser application and N_2O emissions for experiments on plots with mineral soils for N application rates <500 kg N ha^{-1} yr^{-1} with a measurement period of one year. The squares indicate both measurements in crop fields and ungrazed grasslands.

Bouwman, A.F., Boumans L.J.M. and Batjes N.H. (2002b) Modeling global annual N2O and NO emissions from fertilised fields. Global Biogeochemical Cycles 16 art no. 1080 and used by 2006 IPCC Guidelines

By the time the IPCC 2006 Guidelines were published, a new model and EF value for N_2O emissions from fertiliser were published and used in the IPCC update. The EF for fertiliser was reduced to 1% with an uncertainty range of 0.0.03 to 3% (IPCC 2006). Two papers from Bouwman et al (2002a,b) significantly advanced on the previous methods used to produce EFs. Instead of using regression analysis (Bouwman, 1996 used in IPCC 1997), they used the residual maximum likelihood (REML) directive of Genstat for developing models relating emissions to controlling factors. The N_2O emissions were log-transformed in the analysis of 126 studies and data from 846 N_2O measurements.

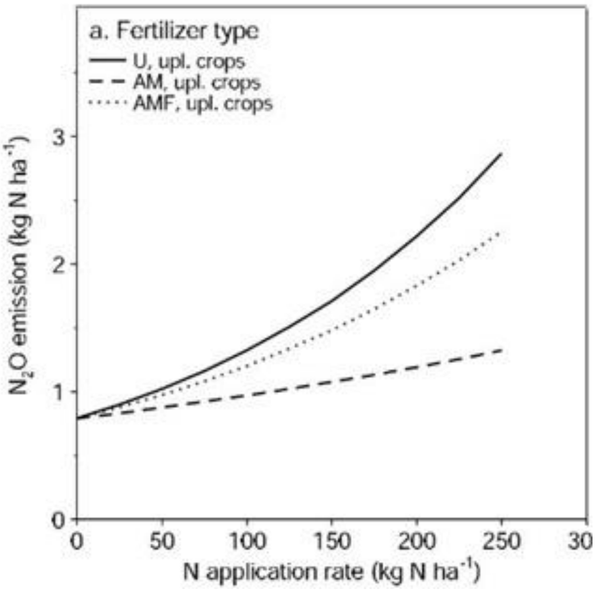
The N_2O-N emissions were calculated as:

$$Emission = e^{constant + \sum_{1}^{n=i} Factor\ class(i)}$$

Factors with significant N_2O effect were:

- N-application rate x fertiliser type;
- climate;
- soil;
- organic C content;
- soil texture; drainage and pH;
- crop type; and
- length and frequency of measurement period.

It is often not appreciated that this model, upon which the IPCC default EF of 1% was derived, came from an exponential function and not a straight-forward linear regression as



was the case for the earlier Bouwman (1996) model from which the IPCC 1.25% was derived. The exponential equation implied that N_2O emissions increased more than proportionally with Nrate (Fig A2). Also, Bouwman et al (2002b) came up with an EF = 0.9%.

Figure A2.2. Example of the Bouwman et al. (2002b) model of N_2O emissions and N application rates for different fertiliser types (U=urea; AM=Animal manure and AMF=combination of animal manure plus N fertiliser).

Based on the more comprehensive analysis of Bouwman et al. (2002), the IPCC decided to change the default EF value for fertiliser from 1.25% (IPCC Guidelines 1997) to 1% (IPCC Guidelines 2006). Although Bouwman et al. (2002b) actually calculated a value of 0.9%. it was considered that 1% was appropriate given the uncertainties associated with this value.

Stehfest and Bouwman (2006) used an extended dataset to Bouwman et al (2002b), but this did not yield a considerable improvement or reduction of uncertainty in the N_2O emissions from agricultural soils compared with the earlier smaller dataset. This was because the representation of environmental and management conditions in agricultural systems did not improve, since most new studies being were in temperate regions which were already well represented by earlier datasets. The representation of tropical climates did not increase substantially; the relative contribution of subtropical and tropical systems was 13% and 11% in the subset of Bouwman et al. 2002b this increased to 14 and 13% respectively. Their EF based on a similar global analysis of emissions divided by fertiliser consumption resulted in a global EF of 0.91%. Albatino et al (2017) addressed the issue of poor representation of tropical regions by reviewing and analysing N_2O emissions data from 42 studies including those in the Stehfest and Bouwman (2006) database. They used a Generalised Additive Mixed Model (GAMM) and came up with an overall N_2O-EF of 1.2% for the tropics and sub-tropics, within the uncertainty of the 1% value. Similarly, a recent study of 1,104 field measurements concluded that the 1% default value holds globally for mean soil pH of 6.76 (Wang et al. 2017).

In conclusion, there is no new evidence to suggest a better alternative to the current default global EF value of 1% for fertilisers. N_2O emissions are strongly influenced by environmental factors, including climate and soils, as well as management. Developing countries are encouraged to disaggregate their EFs and AD as much as possible to capture country-specific conditions.

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