Datasets on technological GHG emissions mitigation options for the agriculture sector

Workshop proceedings

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Abstract
The 2030 EU policy framework for climate and energy confirms that all sectors, including agriculture, should contribute to climate stabilisation and greenhouse gas (GHG) emission reduction in the most cost-effective way. Since 2009, the European Commission's Joint Research Centre (JRC) analyses the economic impact of GHG mitigation policy options for EU agriculture. However, the lack of precise, integrated and harmonised data on the current and potential uptake, cost-effectiveness and GHG emissions reduction potential of technological (i.e. technical and management based) mitigation options hampers the analysis of the economic impacts of GHG mitigation in agriculture. Against this background, the JRC organised a workshop in Seville on 14th June 2016 which gathered European Commission staff and experts from diverse international institutions aiming to: i) identify current activities conducted by research institutes on the building of datasets for GHG mitigation technologies and their state and development, ii) establish synergies and working mechanisms among the different institutions working on the topic, iii) identify which are the current gaps and limitations of existing datasets and models and, iv) conceive a roadmap to build possible new datasets per mitigation technology. The present report is based on the workshop results and concludes on how to move forward.
Executive summary

Since 2009 the European Commission's Joint Research Centre (JRC) analyses the economic impacts of greenhouse gas (GHG) mitigation policy options for the EU agriculture sector using the agro-economic model CAPRI. In recent studies (e.g. Pérez Domínguez et al., 2016) specific technological (i.e. technical and management based) mitigation options have been included into the analysis. However, the lack of precise, integrated and harmonised data on the current and potential uptake, cost-effectiveness and GHG emissions reduction potential of technological mitigation options hampers the analysis of the economic impacts of GHG mitigation in agriculture.

Against this background, the JRC organised a workshop in Seville on the 14th June 2016 to discuss with international experts and modellers different approaches to build scientifically sound (new) datasets on technological GHG mitigation options for the agricultural sector. These datasets should bridge current data gaps, improve the accuracy of the economic modelling-based analysis and provide techno-economic evidence to support policy programs that may benefit the uptake of mitigation technologies. The event focused on a set of both non-CO_{2} and CO_{2} mitigation technologies that were considered most promising in previous JRC workshops and projects: Variable Rate Fertilization (VRF), Nitrification Inhibitors (NI), on-farm Anaerobic Digester (AD), Manure Management (MM), Conservation Agriculture (CA), and Agroforestry Systems (AS).

The workshop was organised in four sessions, each including presentations given by experts from different institutions and followed by a discussion among all participants. In the first session the objectives of the workshop and the policy context have been outlined. It was stressed that mitigation technologies may have a crucial role to determine the possible contribution of agriculture to the EU 2030 Climate and Energy Framework, which aims to reduce GHG emissions from the non-ETS sectors by 30% below 2005 levels by 2030.

The second session approached the data availability regarding abatement potential, costs, adoption rates and barriers of specific technological mitigation options. The presentations were grouped according to the type of emissions: nitrous oxide (N_{2}O) reductions via VRF and NI, methane (CH_{4}) reductions through AD and MM, and carbon dioxide (CO_{2}) reductions by CA and AS. All the presented mitigation technologies were considered to have significant mitigation potential, but participants emphasized and discussed that there is clearly a lack of primary data on current adoption rates and costs at global level and specifically in the EU context for most of the mitigation technologies. Moreover, mitigation potential and costs of the technologies are usually site- and location-specific which makes data upscaling and aggregation to regional or country level more difficult.

The third session explored current models that include the selected technological mitigation options for assessments at global and EU level. Some of the models presented are able to measure the impact of the technological mitigation options from the environmental perspective (e.g. DAYCENT, MITERRA, GLEAM), whereas others focus more on the socio-economic aspects (e.g. IFPRI, USEPA – MAC, CAPRI), i.e. some of them need to be combined with other models and/or methods to cover both dimensions. The main input data sources of the different models with respect to technological GHG mitigation options are expert knowledge and judgement, literature reviews, and previous research projects. Workshop participants stressed that one of the most important limitations of all models is the often weak data regarding the actual adoption rates of the mitigation technologies, which can hamper the model-based impact assessments. Moreover, regional cost data and specific data on barriers for adoption are often missing, but are actually key determinants for improving the model assessments of technological mitigation options. It was also highlighted that if the models are fed with accurate input data they can provide valuable output beyond the impact and mitigation potential of the technologies, like for example information on necessary incentives for technology adoption, and could also be used to fill regional data gaps.
The fourth session served to summarise and sound out the experts' views and recommendations on the approach to improve existing or generate new datasets on technological mitigation options for the agricultural sector at EU level. The discussions centred on nine open questions about the (1) most promising mitigation options, (2) relevant indicators that need to be included in the datasets, (3) limitations for generalising the data, (4) missing data that needs to be gathered, (5) best methods to gather missing information, (6) consideration of potential emission leakage, (7) categories specificity to be included, (8) importance to include both non-CO₂ and CO₂ technologies, (9) “double counting” impact of some mitigation technologies.

Participants contemplated the following technological mitigation options as most promising and recommended them for updated or new datasets: fallowing histosols (organic soils), nitrification inhibitors, precision farming-variable rate technology, higher legume share, rice measures, anaerobic digestion, low nitrogen feed, vaccination against methanogenic bacteria in the rumen (not proved to be very effective), feed additives (nitrate), grassland management, conservation agriculture, agroforestry, land retirement, increased animal and crops productivity, cover crops, use of residues on soil, and low carbon animal diet. The datasets should be technology-specific (i.e. not clustered by mitigated gases) and gather data on current adoption rates, costs and saving, mitigation potential, structural data of farm holdings, productivity increase due to the technology use, adoption drivers and barriers, and bioregional differences. Furthermore, it was highlighted that the datasets should also assess uncertainties linked to each of the indicators and variables.

Experts highlighted the difficulty to gather the necessary data as some parameters are specific to regions, farms and/or farmers and can therefore be quite heterogeneous. Furthermore, already existing data is often not available free of charge or open access (e.g. sales data on specific machinery or other agricultural inputs).

To overcome previous limitations, experts suggested that datasets could be improved or newly built by using massive and systematic literature reviews, already existing databases and research projects. A very important improvement could be achieved by collecting primary data. Methods to collect primary data and missing information could include focus group discussions and consultations (e.g. interviews) with the farming community (e.g. farmers, advisors, academics, policy makers, and agricultural enterprises among others), surveys to farmers and the related agro-industries. Model-based analysis (e.g. carbon calculator) could help to complement the collected data and potentially bridge some data gaps to further improve the datasets.

A major conclusion of the workshop is that there is certainly a need to build comprehensive and consistent datasets per agricultural GHG mitigation option. Collecting more primary and secondary data on EU adoption rates and barriers, costs and mitigation potential of technological mitigation options is fundamental for both understanding what is currently happening at farm level and assessing how this may evolve in the future. Even though the task of building the datasets would likely imply costly and time consuming efforts, such datasets seem to be imperative for the proper analysis of agriculture’s GHG mitigation potential.
1 Introduction

Since 2009 the European Commission's Joint Research Centre (JRC), commissioned by the Directorate-General for Agriculture and Rural Development (DG AGRI), analyses the economic impacts of greenhouse gas (GHG) mitigation policy options for the EU agriculture sector using the agro-economic model CAPRI (Leip et al., 2010; Pérez Domínguez et al., 2012). Within the project 'Economic Assessment of GHG mitigation policy options for EU agriculture' (EcAMPA; Van Doorslaer et al., 2015; Pérez Domínguez et al., 2016), several technological (i.e. technical and management based) mitigation options have been specifically included into the analysis. The main objectives of the EcAMPA project are to understand: i) how non-carbon dioxide emissions from agriculture are likely to evolve up to 2030, ii) how the application of different policies (e.g. subsidies for adoption) and mitigation technologies (e.g. precision farming) can help to achieve GHG emissions reductions, iii) what would be the cost-effectiveness of those mitigation technologies under different policy scenarios and iv) the impacts on production.

In the course of the EcAMPA project two mayor drawbacks with respect to the modelling of technological mitigation options became noticeable:

1. There is a lack of precise, integrated and harmonized data regarding the current and potential uptake, cost-effectiveness and GHG emissions reduction potential of technological mitigation options; are hampering the modelling of the economic impacts of climate change mitigation in agriculture.

2. Databases and datasets hosting some of the required data are usually not open access or otherwise easily available.

Furthermore, so far the analysis with the CAPRI model did not include carbon dioxide (CO₂) emissions. Although the vast majority of GHG emissions from agriculture are non-CO₂ emissions, namely methane (CH₄) and nitrous oxide (N₂O), the ability to model CO₂ agricultural emissions/removals can improve the understanding on the abatement potential of different mitigation options. Moreover, including CO₂ in the modelling exercises may help to determine the role of agriculture as a carbon sink (in soils and vegetation).

Comprehensive estimates of real costs and benefits of GHG mitigation technologies, and farmers' behaviour toward their adoption and potential incentives (e.g. subsidies) to increase adoption rates, are essential to establish achievable mitigation targets and build future EU rural development policies. Therefore, models analysing the impact of agricultural mitigation technologies need up-to-date, sound and referenced datasets that are technology specific and provide reliable costs and benefits, mitigation potential, current (and potential) uptake, and the associated socio-economic implications for farmers.

Based on these considerations, the JRC organised a workshop in Seville on the 14th June 2016. The general objective of the workshop was to discuss with international agricultural technology experts and modellers possible approaches to build scientifically sound new datasets on the potential of GHG mitigation technologies. These datasets should improve the accuracy of the economic modelling analysis and provide techno-economic evidence in support of rural development programs that may benefit the uptake of the technologies. The specific objectives of the workshop were to:

- identify current activities conducted by research institutions on the building of datasets for GHG mitigation technologies and their state of development;
- establish synergies and working mechanism among the different institutions working on mitigation technologies;
- identify which are the current gaps and limitations of existing datasets (and models) and propose approaches to overcome these constrains and;
- conceive a roadmap to build possible new datasets.
The event focused on a shortlisted set of both non-CO₂ and CO₂ mitigation technologies and tried to cover some of the most known models.

This report presents a synthesis of the workshop, summarising the presentations and discussions in the different sessions and concluding on the feasibility of and necessary way forward to build new datasets on mitigation technologies. The report is organized following the structure of the workshop. The first session of the workshop set the scene and briefly explained how the role of agriculture has evolved in the EU policies directly or indirectly related to climate change mitigation. The second session aimed at providing examples of existing data on technological mitigation options used in the EU. The third session further provided an overview of the existing datasets and models on mitigation technologies both globally and at EU level. Finally, the fourth session established the priorities for a possible construction of new EU-based datasets on technological mitigation options for the agricultural sector.
2 Policy context (First Session)

Mitigation of and adaptation to climate change are the two policy interventions that can be undertaken to reduce threats and risks posed by anthropogenic climate change (Füssel and Klein, 2006). Mitigation of climate change, the focus of the workshop and this report, refers to reducing GHG emissions and enhancing potential carbon sinks to limit long-term climate change at global scale. This first session of the workshop set the scene and briefly outlined the role played by the agriculture sector in the EU policies directly or indirectly related to climate change mitigation.

In the 2020 Climate and Energy Package, the EU has set a binding legislation to reduce EU GHG emissions by 20% by 2020 compared to 1990 levels. The reduction target is separated into an EU-wide target for large-scale facilities in the power and industry sectors (and aviation), covered by the European Emissions Trading Scheme (EU ETS), and a target for emissions in the non-ETS sectors, such as agriculture, buildings, transport, and waste. Non-ETS emission reduction obligations are broken down to different individual targets for the Member States depending on their emission levels and relative gross domestic product (GDP) per capita\(^1\). The non-ETS emissions are regulated by the Effort Sharing Decision (ESD), which sets emission reduction targets compared to the 2005 levels\(^2\). While the emission targets for the period up to 2020 include methane and nitrous dioxide emissions from agriculture, carbon dioxide (\(\text{CO}_2\)) emissions or sinks from land use and land-use changes and forestry (LULUCF).

The agricultural sector was particularly recognised by the United Nations Framework Convention on Climate Change (UNFCCC) for its significant mitigation potential in the global efforts to stabilize GHG concentrations in the atmosphere. Moreover, the commitments and responsibilities agreed by the UNFCCC Kyoto Protocol include the development, dissemination and adoption of mitigation technologies that reduce GHG emissions from agriculture (UNFCCC, 2008). Although there are currently no EU specific measures that oblige the agricultural sector to reach a mitigation target, environmental and agricultural policy measures have significantly contributed to mitigate agricultural emissions in the EU, for example the ban on stubble burning maintains soil organic matter and the EU Nitrates Directive\(^3\) has reduced animal manure spreading and mineral fertilizer use over time, and in turn the emissions of nitrous oxide from agriculture. Furthermore, since the 2013 reform of the EU's Common Agricultural Policy (CAP) farmers have to comply with new environmental requirements, the so-called greening, that includes measures with a climate change component, such as maintaining permanent grassland, crop diversification and maintaining an ecological focus area dedicated to ecologically beneficial elements that include e.g. the option to use catch and nitrogen-fixing crops) to perceive the full amount of their subsidies (about 30% of their direct payments\(^4\)).

The 21\(^{st}\) climate Conference of the Parties (COP21) of the UNFCCC was held in Paris in December 2015 and resulted in the Paris Agreement on climate change. This first-ever

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universal and legally binding global climate agreement sets out the objective of keeping global warming below 2°C and covers the period from 2020 onward. The Paris Agreement will enter into force in 2020 after 55 countries that make up at least 55% of global emissions have ratified it. Before and during the conference, countries submitted their Intended Nationally Determined Contribution (INDC) for the new global climate agreement. The EU was the first major economy to submit its INDC to the new agreement in March 2015 and it is already working on its commitment to reduce GHG emissions by at least 40% by 2030, compared to 1990. All Member States will have to modernise the economy and ensure a successful transition to a low-carbon economy by stimulating investment and innovation in new technologies and maintaining EU leadership in markets for goods and services such as low-emission vehicles and energy efficiency.

The submission of the EU’s INDC is based on the EU 2030 Climate and Energy Framework, which includes the commitment to reduce GHG emissions by 30% from the non-ETS sectors by 2030 compared to 2005 levels. Details of the policy framework are still under discussion, but the European Commission’s proposal also includes new flexibilities to reach the targets such as i) the option for eligible Member States to reach national targets by covering some emissions in the non-ETS sectors with EU ETS allowances (i.e. up to 100 million tonnes CO₂ over the period 2021-2030 for EU-wide); and ii) the option to access credits from the land use sector to be used for national targets for all Member States, specifically higher access will be granted to those Members with larger agricultural emissions (i.e. up to 280 million tonnes CO₂ over the period 2021-2030). Additionally to these new flexibilities, the formal compliance check will be organised every 5 years rather than annually to allow the inclusion land use mitigation and reduce administrative burden.

The storage of soil organic carbon from actions taken by farmers and forest owners (e.g. afforestation, reforestation, agroforestry implementation, improved land and forest management) has so far only been partially recognised in climate policy mainly because of the large uncertainty in the estimates of the amount of carbon stored in soils, crops and forests (Delbeke and Vis, 2015). The proposal to integrate the land use sector into the EU 2030 Climate and Energy Framework sets out a binding commitment for each Member State and the standardised accounting rules to determine compliance and carbon storage from forestry and agriculture. Land use and forestry include the use of soils, trees, shrubs, plants, biomass and timber. Farmers will be supported by the adoption of climate smart agriculture practices, and foresters and forest-based industries will be supported by enhancing the use of wood products which have a longer life-time and soil organic carbon capacity, while avoiding fire risk. The "no-debit" commitment for land use establishes that every accounted emission needs to be entirely compensated by an equivalent removal from actions taken in the same sector. The aim of this commitment is to incentivise the adoption of measures which increase the soil organic carbon sequestration (e.g. emissions derived from deforestation should be compensated by planting new trees or improving the sustainable management of their existing forest,

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5 Communication from the commission to the European Parliament and the council The Road from Paris: assessing the implications of the Paris Agreement and accompanying the proposal for a Council decision on the signing, on behalf of the European Union, of the Paris agreement adopted under the United Nations Framework Convention on Climate Change. COM/2016/0110 final. [http://europa.eu/!rH84nx](http://europa.eu/!rH84nx)
6 Conclusions on 2030 Climate and Energy Policy Framework. European Council, (23 and 24 October 2014), [SN 79/14]
7 Proposal for a regulation of the European Parliament and the Council on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 for a resilient Energy Union and to meet commitments under the Paris Agreement and amending Regulation No 525/2013 of the European Parliament and the Council on a mechanism for monitoring and reporting greenhouse gas emissions and other information relevant to climate change. COM/2016/482 final. [http://europa.eu/!Gr87bX](http://europa.eu/!Gr87bX)
croplands and grasslands). Flexibilities are also included in the proposal to meet the “no-debit” commitment. For example, when net CO₂ removals are higher than net emissions it can be banked for the next compliance period, and besides Member States are able to buy and sell net removals between them⁸.

The 2030 commitments for the non-ETS sectors to reduce GHG emissions by 30% will require significant efforts at national scale and in turn a robust and comprehensive framework for climate policies, including guidelines on how to comprise emission reductions from agriculture and LULUCF. In this context technical and management based mitigation options may contribute and facilitate GHG emission mitigation in the agricultural sector (Pérez Domínguez et al., 2016). The workshop sought to gather information on the potential of the technological options and which further data may be needed to provide techno-economic evidence and analysis in support of rural development programs that may benefit the uptake of the technologies.

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3 Data availability on technological mitigation options for the agricultural sector in the EU (Second Session)

This session assessed data availability regarding the mitigation potential, current and potential use, and cost-effectiveness of a set of selected GHG technological mitigation options. The objective was to answer the following questions:

- Are there available information regarding uptake, costs and mitigation potential of the presented technological mitigation options?
- Where are the main data sources that can be used at EU level?
- Which are the elements determining its costs, adoption and mitigation potential?
- Which are the main gaps on data availability?

The session was structured considering the main GHG emissions produced by agricultural activities: nitrous oxide (N\textsubscript{2}O), methane (CH\textsubscript{4}) and carbon dioxide (CO\textsubscript{2}) and focused on the following six promising mitigation technologies: Variable Rate Fertilization, Nitrification inhibitors, on-farm Anaerobic Digester, Manure Management, Conservation Agriculture and Agroforestry Systems.

3.1 Technological mitigation options for nitrous oxide (N\textsubscript{2}O)

Globally, agriculture contributes about 60% of the total anthropogenic N\textsubscript{2}O emissions (Ciais et al., 2013). Diverse agricultural activities (e.g. fertilization) increase nitrogen availability in soils, which leads to an increase of N\textsubscript{2}O emissions due to nitrification and denitrification processes. N\textsubscript{2}O arises from the microbial transformation of nitrogen (N) in soils and manures (during the application of manure and synthetic fertiliser to land) and via urine and dung deposited by grazing animals. The mayor sources of agricultural N\textsubscript{2}O emissions in the EU are agricultural soils (89%) and manure management (11%) (EEA, 2015).

The application of mineral fertiliser and animal manure to soils is an important source of agricultural soil emissions that can be reduced through the utilization of Variable Rate Fertilization and Nitrification Inhibitors. Variable Rate Fertilization technology allows the application of different rates of fertilizer at each location across fields, providing nitrogen to the crop according to the needs and reducing N\textsubscript{2}O emissions from N-fertilizers production and use. Nitrification inhibitors temporarily suppress the microbial conversion of ammonium (NH\textsubscript{4}+) to nitrite (NO\textsubscript{2}−) in soil, decreasing direct N\textsubscript{2}O emissions and nitrate leaching (Li et al., 2008).

3.1.1 Variable Rate Fertilization and Precision Agriculture

Presentation given by Ulrich Adam from the European Agriculture Machinery (CEMA).

CEMA represents over 4,500 manufacturers of agricultural machinery from different European countries and encourage farmers to adopt Precision Agriculture (PA) management including for example Variable Rate Fertilization (VRF). The VRF technology implies the accurate estimation and application of fertilisers per square meter in a field. This practice entails the mapping and analysis of site-specific data (e.g. soil properties, nutrient status, yield, water content and wind conditions), which is necessary to determine the specific application rate requirements for a projected yield. Once it is clear which amount of fertilizer has to be spread per square meter an advanced spreader technology is needed to achieve the exact boundary spreading. The adoption of VRF technology can help to avoid over and under-fertilisation, reduce GHG emissions and promotes uniform growth rates.
The current VRF technology uptake in Europe is relatively low and there is still a high adoption potential. Approximately 37% of the total sales of centrifugal fertilizer spreaders (with weighing systems) were sold in Europe (CEMA European statistical exchange). At the same time, in the US the machinery market reflected that on around 31% of arable land VRF technology was used (single and multiple nutrients fertilizer) and between 64-69% US farmers requested extension services of VRF technology for single and multiple nutrients respectively (Erickson and Widmar, 2015).

The initial investment costs for adopting VRF technology include the purchase of a new VRF spreader (approx. €15,000), an N-sensor and the supporting technology (between €19,000-40,000 depending on farm size). Economic benefits of PA will likely range from €10 to €100/ha (estimates obtained by CEMA from manufacturers), and additional agro-environmental benefits could be achieved from the adoption (e.g. higher yields, reduced fertilisers, higher energy use efficiency and faster applications). In addition, the VRF technology can provide monitoring evidence (i.e. activities geo-location and documentation) with respect to cross compliance accomplishments or other climate and environmental regulations (e.g. EU Nitrate Directive).

The high initial investment, the farm size and the technical management skills required are relevant barriers to adopt VRF. However, VRF adoption could be increased by (1) strengthening farmers’ investment capacity; (2) ensuring access to VRF technology (or corresponding contractual services) at all scales; (3) promoting training and skills (farm management acumen, technical/IT know-how); and (4) enhancing supportive efforts by the industry to promote ease of use, reduce complexity and ensure compatibility of machines and systems.

With respect to GHG mitigation potential (and other environmental benefits), there is a lack regarding data availability, as there seems to be no comprehensive clear-cut methodology and data on GHG emission reduction potential for specific precision farming technologies. Moreover, many of the existing data may not be representative at aggregated regional or country level.

3.1.2 Nitrification inhibitors

Presentation given by Andreas Pacholski from EuroChem Agro

About 26% of total agricultural N₂O emissions are derived from applied mineral fertilisers and about 24% are indirect emissions from nitrate leaching and NH₃ volatilization. Nitrification inhibitors (NI) block or slow down the first step of the nitrification process where N₂O emissions are released from soil. NI are also capable to abate N₂O emissions by decreasing the nitrate availability for denitrification, and reducing fertilization needs (i.e. ammonium nutrition) and nitrate leaching. NI technology has the potential to reduce up to 35% of N₂O emissions from agricultural soils (Ruser and Schulz, 2015) Abatements could be even larger when also considering N₂O emission reduction from nitrate leaching.

The current uptake of NI in Europe is low, only about 1-2% of N fertilizer use is applied with NI (for organic fertilizer, less than 1% of slurries are applied with NI). The application costs can largely vary among different active ingredients for each type of NI (as different NI require different application rates). For instance, costs for inhibition of mineral fertilizer are approximately 0.19€/kg N and for inhibition of organic fertilizers 0.19€/ha (assuming 100kg N/ha). There are no initial investment costs, but economic benefits related to cost savings of NI use, resulting from (i) reduced number of mineral fertilizer application (safe one passing/ha at least about 4.5 €/ha on EU average, not yet considering opportunity costs), (ii) less field traffic which preserves soil quality and hence reduces potential restoration costs, (iii) reduced fertiliser needs (about 5% of fertiliser can be saved), and (iv) potential yield increases (about 5% at actual prices for most common crops, Abalos et al., 2014). Other non-economic benefits associated to NI are the ease of application (spare one fertilizer application), the reduced N loss by
nitrate leaching and the positive yield and quality effects (ammonium nutrition) in particular for crops with high returns (vegetables, fruits, rapeseed, potatoes).

NI technology adoption is facing different social, technical and economic barriers. Social barriers are related to the limited awareness of and training on the technology and its management as well as to a lack of confidence regarding potential yield increases. Technical barriers involve the limited active ingredients and applicability for some N-fertilizers and the uneven effect according to soil types/field conditions. However, the technical limitations will probably be overcome in the near future (within the next 2 years) with actual technology developments and new active ingredients. Economic barriers are mainly due to higher prices per kg N compared to commodity fertilizers, and limited availability from retailers (distribution).

### 3.2 Technological mitigation options for methane (CH₄)

CH₄ emissions represent 54.5% of total EU agriculture emissions (EEA, 2016). There are two main sources of agricultural CH₄ emissions in the EU: enteric fermentation in ruminants and manure management. Enteric fermentation is the largest source of CH₄ emissions, representing about 2% of total EU GHG emissions, 18% of total EU CH₄ emissions and 43% of total agricultural emissions. CH₄ emissions from manure management represent 0.5% of total GHG emissions, 4% of total EU CH₄ emissions and 10% of total agricultural emissions (EEA, 2016).

In this workshop enteric fermentation mitigation was not directly addressed since there is still a large heterogeneity in management practices that can lead to reductions and from which abatements can be difficult to be accurately estimated (e.g. many different diets and emission reduction information varying with for example season, availability or price volatility in feed markets). Therefore, in this session the focus was put on farm-scale anaerobic digestion and other manure management activities.

**Farm-scale anaerobic digestion** and other manure management activities have the potential to significantly reduce agricultural CH₄ emissions. Anaerobic digestion degrades organic matter (e.g. manure, slurries and crop residues) to biogas (i.e. a mixture of methane, carbon dioxide and some trace gases) which can be used as an energy source. A by-product of the AD process is digestate which is usually used as fertilizer (Clemens, 2006) and hence helping to reduce GHG emissions from fertilizer production and bioenergy use. Other manure management mitigation practices can be implemented during the different stages of the manure processing chain, namely livestock housing (e.g. different animal diets, air scrubbing), storage of manure (e.g. covering, compaction, acidification) and manure application to land (e.g. different application techniques).

#### 3.2.1 On-farm anaerobic digesters- an economic perspective

Presentation given by Philip Jones from Reading University.

The on-farm anaerobic digester (AD) technology implies the digestion of organic material (mostly slurry and manure, food and amenity waste, or crops and crop residues) by bacteria in sealed tanks to yield biogas and digestate (a fibre and nutrient rich liquor). AD technology allows farmers to diversify income by selling green power and heat. Managing waste by AD can provide additional benefits such as reductions of GHG emissions at farm level, lower fertiliser needs, and biosecurity and weed control (most pathogens and seeds in AD feedstock are killed in the digestion process).

The current deployment of farm-based AD plants reflects large uptake differences between European countries. Data on deployment of AD plants is readily available. Germany shows by far the highest number of plants, but the annual increase in new AD plants profoundly declined between 2009 and 2015. UK and France are experiencing a rapid expansion of new plants. For the UK, the uptake projections show a significant increase in feedstock availability and a moderate increase in farmer willingness to adopt AD technology. However, official data on feedstock utilisation are still unreliable. This is
problematic as these data are necessary to estimate potential AD uptake and to establish sustainability criteria by governments (e.g. use of wastes/slurries or food/feed crops).

The economic benefits of AD plants are mainly those gained by revenues from nationally operated feed-in tariff systems (FIT) for electricity generated or supplied to grid, and any related enhancements to FIT (e.g. based on efficiency, use of certain feedstocks). There are high investment and operational cost for farm-based AD. The average costs of installation are similar across the EU (approx. 6000€/kWe of installed capacity; Jones & Salter, 2013) and may vary according to different factors (e.g. plant scale, nature of the feedstocks to be used, planning and advisory costs, subsidies and requirement for upgrading plant).

AD technology adoption is facing different social, technical and economic barriers. Social barriers are mainly related to legislative issues or burdensome regulation concerns to farmers, besides the ill-informed publics leading to low social popularity. Technical barriers include the farm structure (e.g. size, system, availability of feedstock), limited grid connectivity (both electricity and gas) and constraints to digestate utilisation (disposal and sale). Economic barriers are mainly due to high capital requirements (incl. availability grants, finance and cost of finance), considerable costs of production, operational complexity and the costly planning process. Data availability on AD costs of and barriers to adoption is very limited, location specific and is not regularly updated.

3.2.2 On farm anaerobic digesters and manure management

Presentation given by Jan Peter Lesschen from Alterra (Wageningen University and Research)

GHG emissions from manure management account for about 15% of total agriculture emissions (EEA, 2015). Current EU regulations are forcing enhanced recycling of manure (e.g. Nitrates Directive) and other residues and wastes. The manure processing can be undertaken by different technologies (e.g. digestion, composting, combustion, belt press separation, centrifuge separation or reversed osmosis), but slurry separation and acidification, and AD are dominant technologies in EU (Foged et al., 2011). At present, the biogas production in EU-28 is derived from landfill (18%), sewage sludge (9%) and mainly from farm based plants (72%; ENER/C1/2015-438 DG energy9) using manure, energy crops or agro-residues as primary feedstock. In addition to the use as manure storage and substitute for fossil fuels for electricity and heating, producing biogas achieved a net GHG abatement of about 4,967 KtCO₂eq in the EU-27 in 2008 (Pedroli and Langeveld, 2011). Therefore the adoption of AD technologies to produce biogas of manure should be reflected in the National Inventory Reporting.

According to a recent survey (Hou et al., 2016), the major determinants influencing the adoption of manure processing technologies are new policies and regulations, ease to export manure off farm and production of bioenergy (more than 40% of survey respondents' agreement). Other factors can also stimulate the adoption to a lesser extent, as for example increased fertilizers prices, increased income from processed products sales, higher control of disease, pathogens and odour (less than 40% of survey respondents' agreement). More than half of the respondents also stated that the most relevant barriers for adoption are economic constraints, particularly the lack of capital for investment and the high cost of processing. Other major constraints and barriers mentioned are legal constraints, a lack of knowledge, and the absence of a market for the AD output (e.g. limited grid connectivity).

3.3 Technological mitigation options for carbon dioxide (CO₂)

Carbon dioxide (CO₂) is the primary GHG emitted through human activities, mainly from transportation. While the agricultural sector is a major source of non-CO₂ emissions, its share in total CO₂ emissions is rather low. However, the agricultural sector has a large potential as a carbon sink to reduce GHG emissions. The implementation of CO₂ mitigation technologies could be beneficial and affordable for farmers, and in addition could generate important environmental co-benefits (e.g. soil conservation). Examples of technological mitigation options that seem to be attractive to farmers are conservation agriculture and agroforestry systems.

Conservation agriculture has been promoted as a “win-win” strategy for both farmers and society. It can provide emission reductions or other environmental benefits, like e.g. reducing soil erosion and enhancing agricultural sustainability (González-Sánchez et al., 2012), while providing financial savings to the farmer (Moran et al., 2013). The potential for carbon sequestration may vary depending on the region, but in general, higher rates may be expected in Mediterranean climate regions compared to high rainfall regions. Agroforestry systems can increase aboveground and soil carbon stocks, reduce GHG emissions (e.g. through the increase of the C inputs in the soils at deeper soil layers), and at the same time increase biodiversity and avoid soil degradation (Mutuo et al., 2005; Rigueiro-Rodriguez et al., 2009).

3.3.1 Conservation agriculture

Presentation given by Emilio Gonzalez-Sanchez from European Conservation Agriculture Federation and Cordoba University (Spain).

The conservation agriculture (CA) systems include a combination of agricultural practices that have to meet three concurrent principles: (1) avoid mechanical soil disturbance (e.g. direct seeding, no-tillage), (2) enhance and maintain soil organic matter cover (e.g. crop residues, cover crops) and (3) promote the diversification of species (intercropping, crop rotation, sequences or associations). CA may have a positive effect on the mitigation of climate change by both sequestering soil organic carbon into the soil and reducing the emissions of CO₂ released into the atmosphere.

Currently CA is practiced on about 157 million ha at global scale (Kassam et al., 2015), and Australia, US, Brazil, Paraguay, Argentina and Canada show the highest adoption levels of CA. In Europe the application of conventional tillage practices is still dominant. Recent CA experiments in Spain recorded an average increase of 30% in carbon sequestration compared to conventional agriculture. In addition, average reductions in energy use of 19% (while keeping yields of wheat, sunflower, legumes) were recorded as well as significant differences in the CO₂ emitted when comparing with tillage operations (6.7 and 10.5 fold-increase by disc harrow and mouldboard application respectively; Life + Agricarbon¹⁰ Project; Carbonell-Bojollo et al., 2011).

CA implementation comprises different economic and environmental benefits. Time and fuel savings, more efficient energy use and incentives from Rural Development Programs can provide cost savings to the farmer. Its environmental benefits include control of erosion, increased soil organic matter, less soil compaction, reduced CO₂ emissions, improved biodiversity, and lower risk of potential pollution to the water. An increase in CA uptake could be achieved by supporting training for farmers and incentives for investment in machinery.

¹⁰ LIFE+ Agricarbon. Sustainable agriculture in carbon arithmetics. Available online: www.agricarbon.eu
3.3.2 Agroforestry systems

Presentation given by **Maria Rosa Mosquera-Losada** from European Agroforestry Federation (EURAF) and University of Santiago de Compostela (Spain).

Agroforestry (AF) is defined as the integration of woody vegetation (trees and shrubs as first component) in at least two vertical layers on land, with the bottom layer providing an agricultural product such as crops or forage/pasture (second component) which may be consumed by animals (third component). Agroforestry is a tool for eco-intensification (i.e. improvement of soil, nutrient and radiation resource use efficiency) in both above and belowground level increasing biomass production. AF also favours C storage at deeper soil layers and fine particles, as the lack of disturbances like ploughing prevents CO₂ release and improve C stability, respectively.

The application of agroforestry can help to increase storage and stabilize soil organic carbon, and in turn reinforce the agricultural system to be more climate change resilient, besides increasing biodiversity at plot, farm and landscape level (Torralba et al., 2016, Mosquera-Losada et al., 2016a), nutrient recycling (i.e. reducing fertilizer Needs), increasing water and food safety and security, and profitability when compared with exclusively forest or agricultural land use (Buttoud, 2013; Mosquera-Losada et al., 2016a and 2016b). Moreover, agroforestry can help to reduce forest fire risk, therefore contributing to avoid GHG emissions. The area of agroforestry is seen as an indicator of the Climate Smart Agriculture adoption in farms (Buttoud, 2013), as it protects and sustains agricultural production capacity, ensures food diversity and seasonal nutritional security, diversifies rural incomes, strengthen resilience to climatic fluctuations, and also perpetuates local knowledge and social and cultural values.

Agroforestry can be applied by a set of different practices including i) silvopasture, i.e. woody plus sward/forage and animal production; ii) silvoarable, i.e. woody plus annual or perennial crops; iii) home gardens or kitchen gardens i.e. trees plus vegetable production in urban or peri-urban areas; iv) forest farming; and v) riparian buffer strips. Mosquera et al. (2016b) described that total agroforestry practices roughly occupies 19.7 million hectares in Europe, including silvopasture, silvoarable, and home gardens. Silvopasture occupies about 17.7 Mha in Europe, while silvoarable is only located in 0.36 Mha, of which over 60% combines annual species cropping with permanent crops (mainly identified as fruit trees). Thus silvoarable practices represent less than 0.08% of total European area; this figure is similar to those found in other developed countries like e.g. the USA (USDA 2013). Home gardens are placed in 1.8 Mha in Europe, with a huge potential to be expanded in urban and peri-urban areas. The estimation for the current Riparian buffer strips associated with agroforestry practices is about 362,000 ha in Europe. These figures indicate that there is a large agroforestry adoption potential in Europe and the use of models may help to provide information on adoption potential. For example, the Yield-SAFE model is able to evaluate the productivity of crops, trees, shrubs and livestock when they are growing alone or combined in AF systems; soil carbon sequestered is also considered. Farm-SAFE is able to use Yield-SAFE data to provide scenarios under different farm socioeconomic conditions, including policy constrains or promotion.

According to a recent FAO report (Buttoud, 2013), the major barriers for the adoption of agroforestry are: i) delayed return on investment and under-developed markets; ii) emphasis on commercial agriculture not considering ecosystem services; iii) ignorance of the advantages of agroforestry, mainly linked to the limited experience and low capacity among some national extension services; iv) unclear status of land and tree resources, adverse regulations and lack of coordination among sectors.
3.4 Open discussion on data availability

During the discussion, participants agreed that precise data on adoption and costs of management practises and technologies that could mitigate GHG emissions from the agriculture sector is lacking globally and specifically for the EU context. The mitigation potential of the technologies has been largely studied, but it is site and location specific and the upscaling of data and aggregation is difficult to undertake.

In the EU, estimating technology adoption is a difficult task, both ex ante and ex post. On the one hand, systematic farm surveys which can provide primary data are necessary to assess actual farmers’ management practices, but so far such surveys are very scarce and this situation does not seem likely to change in the coming years. On the other hand, the different approaches for technology uptake complicate the analysis. For example, Variable Rate Fertilization technology can be either used by farmers as machinery owners or supplied as a service by companies or farm machinery cooperatives. In addition, not even the technology manufacturers are able to say if farmers are really using the technology, because a farmer may, for example, buy licences but in the end may not use the related equipment. A further complication for gathering data on adoption rates is that most manufacturers are not very keen in sharing sales data. To overcome previous limitations, participants suggested to first gathering data available from earlier research projects and surveys that include benefits for both the public and private sector.

Participants identified key elements affecting the adoption of the presented technological mitigation options that should be considered when building datasets: the price evolution of agricultural products, farmers’ investment capacity, farmers’ education and skills which may affect farmers’ ease of technology use as well as regulations and policy (e.g. compliance, subsidies, tax benefits). Behavioural and social factors were considered as key elements that may help to properly understand uptake of mitigation technologies by farmers.

An important element raised during the discussion was that mitigation technologies are constantly evolving, which might represent an opportunity to substantially increase uptake. It is likely that an evolving technology (e.g. improved VRF technology over time through continuous data use/collection, AF or CA adoption) might increase the efficiency of the technology, thus reducing the investment cost and increasing uptake. However, technology evolution might complicate the assumptions that need to be included for modelling environmental and economic impacts of technological mitigation options.

Different issues on the assessment of costs of specific technological GHG mitigation options were discussed during this session. Variable Rate Fertilization cost savings for the use of fertilizers, man labour and fuel do not currently cover initial investments in the equipment, yet several components (like satellite navigation, mapping and board computers) can be used in other precision farming applications such as precision seeding. Additionally, this technology could support the evidence of compliance with legislation through automated documentation (e.g. a digital farm book which contains data on timing, quantity of fertilizer/pesticide inputs, etc.). NI costs are variable depending on the efficiency of this technology and its application rate. Different crop types, environmental conditions and active compound types affect NI efficiency. Presumably, future NI active ingredients might be cheaper and more competition between companies is expected, which might result in price reductions for NI. The effect of NI on yields is an important element determining the costs-effectiveness of this mitigation measure that still needs to be further investigated.

The costs and GHG emissions reduction from the adoption of AD can substantially differ according to plant size, operating processes, type of digester, or type of feedstock among others. In general, investment costs are expensive and official data regarding operating costs is lacking. Cost-effectiveness of AD is linked to country specific elements such as the electricity price, the national subsidies provided and final use of the digestate (e.g. fertilizer). Agroforestry systems profitability is highly dependent on the
system (combination of crops, trees and livestock management) used. In turn, the appropriateness of each system is highly dependent on the specific conditions of each region. From a management point of view, special attention should be given to develop understory herbaceous varieties to perform better under shading conditions but also to develop tools for a better understanding of what is the best distribution of the trees within the plots (copses, hedgerows, trees in line surrounding plots) to deliver higher productivity and a high level of ecosystem services.

Participants highlighted the importance of including in the dataset not only data to assess directly the costs of the technologies, but also data linked to co-benefits that could increase their uptake and use (e.g. the reduction of erosion through the use of conservation agriculture, soil carbon sequestered by trees on land while growing up, grazing period extension while woody perennials are present in different layouts, or the waste management through AD use).

The session finished with a debate on whether the generation of datasets should be based on average information and/or on benchmark estimates. Some participants considered appropriate to define a representative system for the different technologies that could be used to generalize the data of interest (i.e. adoption, costs and GHG emission reduction). However, other participants raised concerns against this approach, as the huge variability linked to mitigation technologies (e.g. differences in the financial performance of AD can be big, NI efficiency is highly dependent on crops and regions) might not allow generating valid representative systems.
4 Models and datasets on technological mitigation options for the agricultural sector in the EU (Third Session)

Section 3 assessed existing datasets and models integrating data on technological mitigation options for the agriculture sector. The workshop covered models and datasets applied both at global and European scale. Each participant included a description of the model and its potential application. In particular, the participants provided information on the data sources used for model input, and the model output and findings that could be embedded into dataset construction. The main questions addressed in this session were:

- Which are the data sources used in the model?
- How can the output data generated with the model fit the dataset on mitigation technologies?
- Which are the main limitations of the data sources the model uses?
- Which methodological approaches could be used to overcome these data gaps?

4.1 Global mitigation of non-CO₂ GHG emissions: 2010-2030

Presentation given by Shaun Ragnauth from US Environmental Protection Agency (USEPA)

Non-CO₂ GHG gases (methane, nitrous oxide, high GWP gases) are released from different sectors, including energy (e.g. coal mining, and oil and natural gas systems release CH₄), waste (e.g. solid waste management releases CH₄ and wastewater CH₄ and N₂O), agriculture (CH₄, N₂O), and industrial processes (N₂O, PFCs, SF₆, HFCs). USEPA (2013) has reported that the total technically feasible global mitigation potential from non-CO₂ GHG gases for all these sectors is over 3,500 MtCO₂e in 2030. The agriculture sector (cropland, livestock and rice) is estimated to be able to provide reductions of more than 500 MtCO₂e at costs under $30/tCO₂e.

A set of different simulation models were used to estimate the mitigation potential of agriculture, including: i) DAYCENT Model for cropland technologies, an ecosystem model to estimate crop yields, N₂O and CH₄ emissions, and soil C stocks; ii) DNDC (Denitrification-Decomposition) Model for rice cultivation, a biophysical model used to simulate production, crop yields, CH₄, N₂O and soil carbon fluxes from rice paddies under BAU and mitigation scenarios; iii) IFPRI IMPACT Model (IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade) for cropland and livestock technologies, a model to develop projected baseline emissions and crop/livestock production reflecting socio-economic drivers (e.g. population growth, technology change); and iv) US EPA Marginal Abatement Cost (MAC) Model for cropland, rice cultivation and livestock production, a model that incorporates outputs from the simulation models above along with mitigation technology technical and cost information to calculate break-even prices and illustrate abatement cost for each option (technology costs, yield changes, expected benefits, and emission reductions).

The models used different scenarios and technologies to estimate the mitigation potential for cropland, rice cultivation and livestock production. Seven mitigation scenarios were used for cropland simulations by including no-till, optimal N fertilization (precision agriculture), split N fertilization, 100% residue incorporation, nitrification inhibitors, reduced and increased fertilization (20%). The DNDC model for rice cultivation included 26 mitigation scenarios by addressing different combinations of 4 management techniques (water management, residue management, tillage, and fertilizer management alternatives). The livestock models included 6 mitigation options for CH₄ emissions from enteric fermentation (improved feed conversion, antibiotics, bST, propionate precursors, antimethanogen, intensive grazing) and 10 mitigation options for CH₄ emissions from manure management (complete-mix digester with and without engine, plug-flow digester with and without engine, fixed-film digester with and without engine, plug-flow digester with and without engine, fixed-film digester with and without engine).
engine, large-scale covered lagoon with and without engine, small-scale dome digester, and centralized digester).

Different data sources were also necessary according to the simulation type. Cropland simulations included weather data (North American Carbon Program), soil data (FAO Digitized Soil Map of the World) and cropland areas (Ramankutty et al., 2008). Rice cultivation simulations included harvested area for rice (FAOSTAT 2010), climate data (NOAA’s National Centers for Environmental Prediction), fertilizer use data (based on DNDC model), and production area data (based on IFPRI IMPACT model). Livestock simulations included livestock population data (EPA report), and mitigation data (UNFCCC and other literature). There is limited information of regional/national data on cost and adoption rates of cropland and rice cultivation, magnitude of emission reduction and long term costs for enteric fermentation options, and some concerns on human health implications of other options (e.g. bST, antibiotics).

The sector baseline emissions in 2030 were projected to be 472 MtCO$_2$e for cropland (4% of global non-CO$_2$ GHG emissions), 756 MtCO$_2$e for rice cultivation (6% of global non-CO$_2$ GHG emissions) and 2,729 MtCO$_2$e for livestock (21% of global non-CO$_2$ GHG emissions). From these baselines, 5.4% of emissions could be reduced by using cost-effective cropland technologies, 8% by rice cultivation technologies and 3% by livestock technologies (plus an additional reduction of 6.4%, 18% and 7% by using technologies with increasingly higher cost).

In summary, significant cost-effective abatements could be achieved by existing mitigation options. However, despite potential cost savings and environmental benefits, the adoption of mitigation technologies is still limited due to strong traditions and regulatory and legal issues. There is a lack of mitigation measure data and information on capital and annual costs, reduction efficiencies, new measures not captured, scientific understanding of mitigation impacts and technology adoption rates and interactions. Further assessment of mitigation technologies would enhance the marginal abatement cost analyses.

### 4.2 US GHG Mitigation options and costs for agricultural land and animal production

Presentation given by [Jan Lewandrowsky](https://www.usda.gov) from US Department of Agriculture

This presentation highlighted results of two reports jointly produced by USDA’s Climate Change Program Office and ICF International. The overall goal of the two reports was to assess how agricultural producers might respond to incentives to adopt production and land management practices and technologies that mitigate GHG emissions. The first report, titled *Greenhouse Gas Mitigation Options and Costs for Agricultural Land and Animal Production within the United States* (ICF, 2013), identifies 20 specific technologies and practices (see presentation) that individual farm operations could adopt in their crop and livestock production systems and in their land management decisions that would result in GHG mitigation. For each option, the report contains: i) a detailed technical description of the technology or practice; ii) estimates of farm-level adoption costs for the technology or practice for a set of typical farms; iii) estimates of the farm-level GHG mitigation potential associated with adoption; and iv) estimates of CO$_2$ prices that would make adoption a break-even investment for various farms. Where possible and appropriate, the adoption costs and GHG mitigation potential for each practice or technology are further distinguished by farm size, commodity produced, and region of the country.

Figure 1 summarizes the set of CO$_2$ break-even prices for each mitigation technology across the set of representative farms considered. In the figure, each dot represents a CO$_2$ break-even price for the technology or practice displayed to its right for a specific representative farm defined by a unique combination of region, farm size, and/or commodity produced (CO$_2$ break-even prices above $100 per mt CO$_2$e are not shown, but are available in the report). The figure shows that no single GHG mitigation option is
uniquely the best option for all regions, farm sizes, or commodities. For each mitigation option in this analysis, there are farms that could economically adopt the technology at relatively low CO₂ prices (below $20 per mt CO₂e) and farms that would require a prohibitively high CO₂ price (above $40 per mt CO₂e). Additionally, for a given CO₂ price, almost any policy framework will increase the mitigation potential, as the number of mitigation options increases. Thus, from a policy perspective the goal should be to allow farms as much flexibility as possible in identifying and adopting the most cost-effective mitigation options for their circumstances.

The second report titled Managing Agricultural Land within the United States (Pape, 2016), develops Marginal Abatement Cost Curves (MACCs), showing how much GHG mitigation the various parts of the U.S. farm sector would supply across a schedule of CO₂ prices ranging between $0 and $100 per mt CO₂e (the aggregate MACC for U.S. agriculture is shown in the presentation). The MACCs are developed by combining the CO₂ break-even prices and the associated GHG mitigation levels of the technologies and practices described in the first report with estimated distributions of current farm production and land management practices (constructed from data sources identified in the presentation). As CO₂ prices increase, more mitigation options become economically rational to be adopted by farms. The MACC for U.S. agriculture shows that at a CO₂ price of $100 per mt CO₂e, farms supply total GHG mitigation of about 120 Tg CO₂e. The MACC also indicates that the GHG mitigation potential from U.S. agriculture increases relatively gradually up to a CO₂ price of between $30 and $40 per mt CO₂e. At the $40 price, U.S. farms supply mitigation of about 100 Tg CO₂e, which is already about 83% of the mitigation indicated at a price of $100 per mt CO₂e. Above $40 per mt CO₂e and 100 Tg CO₂e, the MACC turns sharply upwards, implying rapidly increasing costs of achieving additional mitigation in the farm sector.

Low-end U.S. government estimates of the social cost of CO₂ fall in the range of $30 to $40 per mt CO₂. The aggregate MACC then suggests that incentivizing farms to mitigate GHG emissions may be cost effective up to the low-end estimates of the social CO₂ costs. Above 100 Tg CO₂e, however, achieving additional mitigation in agriculture will probably be relatively expensive compared to mitigation options in other sectors. For a CO₂ price of $20 per mt CO₂e, U.S. farms supply mitigation of about 63 Tg CO₂e. The implied total cost would be about $1.26 billion. In the context of comparing the relative value of pursuing alternative mitigation strategies in different economic sectors, the 63 Tg CO₂e can be viewed as a ballpark estimate of the marginal GHG benefits of the next $1 billion spent incentivizing the adoption of GHG mitigating technologies in the U.S. agriculture sector.
4.3 Mitigation options for the agricultural sector: The Spanish Roadmap

Presentation given by Maria José Alonso Moya from Spanish Office of Climate Change

In the policy context, all Member States share a collective target to reduce GHG emissions by 20% compared to their 1990 levels by 2020. There are different individual targets depending on the emission levels of each country as enacted in the Energy and Climate Package of the EU 2020 Horizon. Further, the ETS sectors (European Trading Scheme to regulate emissions) and the non-ETS sectors (i.e., transport, buildings, small industry, agriculture and waste) share a target to reduce GHG emissions by 21% and 10% respectively compared to their 2005 levels. The non-ETS reductions are regulated by the Effort Sharing Decision (ESD; 406/2009/CE). The Spanish Office of Climate Change (OECC) is responsible of the climate change policy and commitments at national (mitigation and adaptation) and international (UNFCCC, IPCC negotiations, cooperation and initiatives) level.

The Spanish roadmap for non-ESD sectors is the key initiative to channel the Spanish commitments regarding the non-ETS sector emissions (which represent 63% of total Spanish emissions) and aims at identifying potential policies and a cost-efficient set of
measures to meet the emission reduction targets. Measures are evaluated with the modelling tool M3E (Modelización de medidas para la mitigación en España) according to their investment and operating costs, savings (monetary and energy), employment generated, level of applicability, CO₂ abatements and VAT parameters. The M3E tool is an Excel based linear optimization model, optimizes how measures interact for a given objective. The tool is easy to use and adaptable with respect to user needs. It covers the 2013 to 2030 horizon and up to 65 mitigation measures per year can be included. The highlighted mitigation measures for agriculture included in the ESD Roadmap 2020 are: manure management through anaerobic digestion, education and training to improve fertilizing efficiency, no-tillage, legumes on managed and fertilized grasslands, training for efficient tractor driving, woody crops pruning waste re-use as biomass or soil incorporation, and seeded legume-cover on irrigated woody crops.

4.4 Economic assessment of EU mitigation policy options with the CAPRI model

Presentation given by Thomas Fellmann from the Joint Research Centre of the European Commission

The JRC designed the project "Economic Assessment of GHG mitigation policy options for EU agriculture (EcAMPA 1 and 2) to assess some of the aspects of a potential inclusion of the agricultural sector into the EU 2030 policy framework for climate and energy (Van Doorslaer et al., 2015; Pérez Domínguez et al., 2016). The EcAMPA 2 study involved three major goals. First, improve the GHG emission accounting of the CAPRI (Common Agricultural Policy Regional Impact Analysis) modelling system, particularly regarding the implementation of endogenous technological mitigation options. Second, improve emissions leakage estimates by including potential emission efficiency gains in non-EU production regions. Third, provide a quantitative policy analysis based on reduction targets and technological mitigation options. The CAPRI model has two modules interacting between them, a supply module that assesses agricultural production activities (regional optimization models at Nuts2 level within EU28) and a market module that assesses prices and trade (global spatial multi-commodity model). GHG emission coefficients are endogenously calculated for Member States and Nuts 2 regions, following the IPCC guidelines (mostly Tier 2) in the GHG emissions module.

The EcAMPA 2 study included 14 technological GHG mitigation options. For the underlying assumptions of costs, revenues, cost savings and mitigation potential, the study relied on different data sources: GAINS dataset (2013, 2015), information gathered from the AnimalChange project, and additional expert information. The CAPRI model considers that production costs are non-linear, acknowledging that additional costs (may) exist that are not included in the pure accounting cost statistics and such costs may increase more than proportionally when production or the adoption of mitigation technologies expands. The application of mitigation technologies is determined by economic and political incentives (e.g. subsidies), and the responsiveness to such incentives is expressed in an increase in uptake of a mitigation technology. The policy scenarios in EcAMPA 2 were built according to different criteria on reduction targets, subsidies for mitigation technologies, type of implementation (voluntary or mandatory) and technological progress. The findings showed the mitigation contribution of each technology individually and in combination for EU-28 in 2030. Depending on the scenario, the largest mitigation contributions to total EU-28 emission reduction were reported for anaerobic digestion (9.1 to 12.5 MtCO₂e), nitrification inhibitors (2.5 to 9.8 MtCO₂e), fallowing of histosols (6.4 to 9 MtCO₂e), precision farming (4.9 to 16.6 MtCO₂e) and linseed as feed additive (2.3 to 7.4 MtCO₂e).

One of the major limitations of the EcAMPA 2 study is the relatively weak empirical basis for the specification of the values for the relative subsidies assumed in the modelling approach for the uptake of mitigation technologies. Therefore, in particular more information is needed with regarding to costs, benefits and uptake barriers of technological mitigation measures. In general, more information and data is needed on
i) how applying the mitigation technology leads to lower emissions, ii) how much the technology is able to reduce emissions, iii) which are the possible positive or negative cross-over effects, iv) which costs (regarding e.g. the technology itself, know how, etc.) and benefits (e.g. yield increase) are comprised in the application of the technology, and v) for which farmers are the technological options relevant (e.g. size of farms, technical requirements that must be met, etc.).

4.5 MITERRA Model

Presentation given by Jan Peter Lesschen from Alterra (Wageningen University)

MITERRA-Europe is a model developed for integrated assessment of N, P and C emissions from agriculture in the EU at Member State and regional level (Nuts 2). It is a simple and transparent model that can conduct scenario, measure and policy analysis providing outputs on N, P and C balances, emissions of N₂O, NH₃, NOₓ, CH₄, CO₂, N leaching and runoff, and changes in soil organic carbon (SOC) stock. The MITERRA-Europe model is linked to CAPRI (activity data on crops and livestock) and GAINS (NH₃ and manure data), and lastly the RothC model has been incorporated for SOC modelling. The MITERRA model does not include the socio-economic dimension. At worldwide level, the MITERRA-GLOBAL model was developed within the AnimalChange project at sub-national level (mainly based on FAO data).

Several EU project outputs related to agricultural GHG emissions and abatement are based on MITERRA modelling. For example in the EU PICCMAT project, the MITERRA model provided the first EU estimations on the mitigation potential of specific agricultural technologies (SOC was based on the IPCC carbon stock change approach and N₂O emissions were based on IPCC Tier 1 emission factors). Better estimates were provided in successive projects (e.g. SmartSOIL, AnimalChange) by using RothC modelling to estimate SOC emissions or input from more complete datasets (LUCAS for soil properties, SAPM Survey on Agricultural Production Methods for current technology adoption, and GIS data sources).

4.6 The Global Livestock Environmental Assessment Model

Presentation given by Anne Mottet from FAO

GLEAM (Global Livestock Environment Assessment Model) is a GIS tool developed at FAO in collaboration with other partners. GLEAM can be used to calculate emissions from livestock supply chains at national, regional and global levels, and by species and type of production systems. Additionally, GLEAM can be used in the preparation of national inventories, supports the design of Nationally Appropriate Mitigation Actions, and ex-ante evaluation of projects with interventions in livestock (e.g. vaccination campaigns, feed quality improvements).

The model uses a Life Cycle Assessment (LCA) approach including all steps of production (feed production and transport, on farm and processing and transport of animal products) and all major sources of emissions (including emissions for feed production and direct and indirect energy on farm as well as post-farm emissions). GHG emissions are calculated following the IPCC Tier 2 guidelines. The mitigation scenarios cover a wide range of options, including improvements in feed quality, feed supplementation, animal husbandry, animal health and manure management. The model allows for the assessment of the mitigation potential from gains in efficiency and productivity. GLEAM can be coupled with other models to include impacts of grazing management on carbon sequestration (e.g. grassland models for carbon sequestration) or a cost benefits analysis (economic data for MACCs). Results are quite sensible to certain parameters (livestock yields, feed digestibility). When used at country level, GLEAM input parameters are refined to best describe production systems. Additional, the GLEAM-i is an open access and user-friendly tool for calculating emissions using IPCC Tier 2 methods at country level in a single Excel file to support governments, project planners and civil society organizations.
The mitigation potential of different case study regions was evaluated according to the livestock system (e.g. mixed dairy farms, pig production, specialised beef, and small ruminants) by using GLEAM (Mottet et al., 2016). The estimates show significant mitigation potential in all regions and systems and higher values in regions of South Asia and East Africa.

4.7 Open discussion on existing datasets and models on mitigation technologies

A diversity of models and associated datasets were presented both to be globally and regionally applied. A set of the models presented are capable to assess the environmental impact of the different technological GHG mitigation options (e.g. DAYCENT model for cropland technologies; DNDC – Denitrification Decomposition Model for rice cultivation; MITERRA model; GLEAM - Global Livestock Environment Assessment Model), and others (e.g. IFPRI’s IMPACT - International Model for Policy Analysis of Agricultural Commodities and Trade for cropland and livestock technologies; US EPA Marginal Abatement Cost - MAC model for cropland, rice cultivation and livestock production; M3E model; CAPRI - Common Agricultural Policy Regional Impact Analysis) assess the socio-economic impacts along with estimating the GHG mitigation potential.

The participants of the workshop agreed that one of the most important limitations of all models is the often weak data regarding the adoption rates assumed for the technological GHG mitigation options. This parameter is essential to determine the impacts of the different technologies and management practices. Imprecise assumptions can lead to poor impact estimates. Moreover, specific data on barriers and incentives for adoption, regional cost data, and specific information on technological mitigation options for livestock are often missing, but are key determinants for improving the model assessment of technological mitigation options.

A further relevant issue raised during the discussion is the need to properly understand the applicability of the different technological GHG mitigation options. Better information on the potential applicability of the technologies and mitigation practices at country or regional level will generate appropriate baselines and enhance the modelling analysis.

An important element that needs to be considered when modelling mitigation technologies used by farmers is how good or bad they are at using the technology. Otherwise, the GHG mitigation impacts will not be properly estimated.

Participants outlined that the main data sources of the different models currently are expert judgement and knowledge, literature reviews, and previous research projects (like e.g. FutureFarm 11 or AnimalChange 12). Expert groups’ consultations were also mentioned as important data sources for certain models. For instance, the GLEAM model uses the feed database of the Livestock Environmental Assessment and Performance (LEAP) partnership for emissions associated to feed crops production, including application of fertilizers and manure. LEAP is a multi-stakeholder partnership on benchmarking and monitoring of the environmental performance of the livestock sector.

Participants discussed that, according to existing data, the application of some technologies implies a negative cost, i.e. farmers would be better off (increase their income) when applying these technologies. Apparently, this is contrary to what can be observed in reality, i.e. the existing data does not explain the low actual adoption rates of the respective technologies. Therefore, experts concluded that some factors related to farmers’ behaviour or decision making processes are missing or are not being considered in many assessments on the adoption potential (e.g. risk aversion, cost of

11 The FutureFarm Project funded by the Seventh Research Framework Programme of the European Union (EU-FP7) under the Grant Agreement No 212117. www.futurefarm.eu
12 The AnimalChange Project funded by the EU-FP7 of the European Union under the Grant Agreement No 266018. www.animalchange.eu
technology learning, high investment cost/linked with irreversibility of the adopted technology). The existence of presumed negative costs also complicates the assessment of possible incentives needed to increase the uptake of technological GHG mitigation options. Thus, information and analysis of non-economic adoption barriers (e.g. awareness, strong traditions, education) is needed in order to enhance adoption rates and improve respective modelling exercises.

Participants agreed that models should generally treat technologies and practises dedicated to mitigate CO₂ emissions with caution. Some studies (e.g. the DEFRA study on the UK) concluded that the only agricultural mitigation technology that reduces agricultural emissions in a reliable manner is “manure management”. Other mitigation management practises, such as zero-tillage, should be considered with caution since farmers can use them and reduce the emissions but for example adopt full tillage every few years to deal with pan or weed problems, thereby releasing all the carbon that had been stored in the soil through conservation tillage.

Overall, participants emphasized the need for a better understanding of what is really happening on the farm, i.e. what farmers are actually doing and what is the impact of their current behaviour when it comes to GHG mitigation practices. This understanding will help building much more accurate baselines for all the models as well as future scenarios. In addition, getting to know directly from farmers the most appropriate incentives to boost the adoption of cost-effective technological GHG mitigation options seems to be fundamental for proper assessments.
5 Priorities and road-map for dataset construction (Fourth Session)

In the fourth session the main elements to be considered when generating a dataset on technological mitigation options for the agricultural sector at EU level were discussed. Experts provided recommendations and guidelines on the approach to follow based on their own experience. Specific questions were used to guide and animate the open discussion.

“Q1. Which are the main technological GHG mitigation options that should be prioritized to reduce GHG emissions in the medium to long term (i.e. 2030 and 2050)?”

The JRC science and policy report “Economic assessment of GHG mitigation policy options for EU agriculture (EcAMPA 2)” includes different technological mitigation options that were considered by experts to be among the most promising for reducing non-CO₂ GHG emission and at the same time were possible to be included in the agro-economic modelling framework of the analysis (Figure 2; Pérez Domínguez et al., 2016). Based on this report, a set of potentially cost-effective technological non-CO₂ and CO₂ mitigation options were compiled. Table 1 presents the list of these potentially cost-effective technological GHG mitigation options ordered by their mitigation capacity.

Figure 2: Contribution of technological mitigation option to total mitigation (EU-28)

![Figure 2: Contribution of technological mitigation option to total mitigation (EU-28)](image)

Note: The columns represent scenarios with a mitigation target of 20% for EU agriculture, without (HET20) and with subsidies for the uptake of mitigation technologies (different scenario variants). Source: Pérez Domínguez et al. (2016).
Table 1: List of potentially cost-effective technological GHG mitigation options ordered by mitigation capacity

<table>
<thead>
<tr>
<th>land related non-CO₂ technologies</th>
<th>livestock related non-CO₂ technologies</th>
<th>CO₂ related technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fallowing histosols</td>
<td>Anaerobic digestion</td>
<td>Fallowing histosols</td>
</tr>
<tr>
<td>Nitrification inhibitors</td>
<td>Feed additives (linseed)</td>
<td>Grassland management*</td>
</tr>
<tr>
<td>Precision farming</td>
<td>Low nitrogen feed</td>
<td>Conservation agriculture*</td>
</tr>
<tr>
<td>Variable Rate Technology</td>
<td>Vaccination</td>
<td></td>
</tr>
<tr>
<td>Higher legume share</td>
<td>Feed additives (nitrate)</td>
<td></td>
</tr>
<tr>
<td>Rice measures</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: *Technological mitigation options not included in EcAMPA 2. Upper rows indicate more mitigation capacity.

The comprehensiveness of Table 1 was discussed with the participants.

In the discussion it was recommended that the following potentially cost-effective technological mitigation options should also be included into the list: i) agroforestry; ii) land retirement; iii) increased animal and crops productivity; iv) cover crops, v) use of residues on soil (e.g. leaving pruning residues in the soil), and vi) low carbon animal diet. Due to their importance in the EU context, these additional options should also be considered when building datasets on technological GHG mitigation options.

With regard to livestock related technological mitigation options, it was highlighted that vaccination has so far not been proved to be very effective in GHG emission reduction. It was suggested that, instead, technologies aiming at increasing the productivity at herd level (e.g. through animal husbandry management, changing the herd age composition) should be considered as they have proven to be cost-effective due to high mitigation potential and reduced implementation cost.

"Q2. Which are the main indicators (apart from costs, mitigation potential and adoption rates) that need to be included in the dataset in order to generate realistic and precise estimates to be used in current models?"

The JRC proposed a dataset approach that foresees information on the following indicators as most important: i) behavioural data on the current use and potential uptake of technological mitigation options; ii) costs and savings linked to the mitigation technologies/ practices used; and iii) GHG mitigation potential associated with the implementation of the technologies and management practices.

The participants agreed on these indicators, but also proposed a set of additional important variables that could be included in the datasets:

- Structural data of farm holdings (e.g. size, yield, woody vegetation presence).
- Productivity increase due to the technology use (i.e. impact on productivity).
- Ease of use (as a risk associated with its adoption).
- Responsiveness of adoption to farm size, and other adoption factors.
- Bioregional differences.
- Employment creation.
Furthermore, it was highlighted that the datasets should also assess the uncertainties linked to each of those indicators and variables.

"Q3. What are the main limitations for the generalization of those data?"

There was a consensus that the most important limitation is the lack of accurate baseline information (see previous section), i.e. it is often unknown to which extend and how farmers are currently using the respective technological mitigation options. Such baseline information is essential to understand farmer’s behaviour towards the technologies, and can then be used to identify and assess which practices may be adopted by farmers under different conditions and scenarios. It was suggested that, even when the baseline cannot be set from a quantitative point of view, it would be helpful to conduct a qualitative assessment to identify and understand the practices farmers are currently using.

Another identified limitation for data generalisation is the great data variability that often exists for the same technology type, as for example, nitrification inhibitors can have different mitigation potentials depending on various factors such as the fertilizer used, the brand, the provider or the environmental conditions.

"Q4. Which is the missing data that needs to be gathered for assessing the potential application of the different technological GHG mitigation options for the agricultural sector at EU level?"

Participants emphasized again that the most relevant data missing is linked to current and potential adoption rates of the technologies. There is a need to assess this potential for each EU region and/or member state. It was considered that estimates on potential adoption rates need to be related to expected policy support measures (e.g. potential CAP subsidies).

"Q5. Which is the best approach to gather missing information?"

Different data gathering methods were proposed and discussed among participants.

**Massive and systematic literature review** is the first approach proposed to start with for gathering (missing) information. However an important drawback of this approach is that most literature studies are based on experimental data which is not applicable for all local farm conditions and difficult to generalize. Thus, attention should be given whether the data provided corresponds with experimental settings or real farm conditions.

**Expert consultations** by bringing together specialists on specific topics of the different technological mitigation options can be complementary to the literature review. This can provide a quick overview of the existing data and information on controversial issues and data gaps.

**Modelling** was also proposed as an alternative methodology for generating missing data, however some participants considered the utility of purely model based data as limited for this purpose: Models can provide a good range of estimates but absolute values should be taken with caution due to the uncertainties related to model assumptions.

**EU datasets** (such as Eurostat and FADN) currently provide some data on technological GHG mitigation practices (e.g. uptake of zero-tillage); participants suggest the inclusion of other technological GHG mitigation practices of interest. However, budgetary constraints might not allow doing so.

**Focus groups discussions (with farmers and extension agents) and stakeholder consultations** were proposed as a qualitative methodology for gathering information on the current use of the technologies. This approach can also provide information on the
side benefits and drawbacks of the technology adoption. However, it might not provide information on the technological mitigation potential. Already existing EIP-Agri Focus groups and the operational groups developed under the Rural Development Programs can contribute to this purpose.

**Interviews with farmers** can provide the necessary information to illustrate the actual situation and specific issues at local level. Moreover, such interviews can be useful to reflect socio-economic or other behavioural determinants affecting the adoption (i.e. information that is often missing or difficult to find in the literature). In addition, the interviews can be useful for comparing and validating information provided by previous studies or models.

**Surveys of the industry** were also proposed as an approach to gather information regarding current and potential adoption of the different technological mitigation options. Participants highlighted the effectiveness of dealers’ surveys based on their own experiences. The only drawback associated with this survey type is the difficulty of gathering information on technology and service prices due to commercial confidentiality.

Lastly, the **European Innovation Partnerships (EIP)** was also proposed as an instrument to gather missing information. EIP is a new approach to EU research and innovation in which a group of stakeholders “i) step up research and development efforts; ii) coordinate investments in demonstration and pilots; iii) anticipate and fast-track any necessary regulation and standards; and iv) mobilise ‘demand’ in particular through better coordinated public procurement to ensure that any breakthroughs are quickly brought to market” (EU Innovation Union, 2015).

"Q6. Shall emission leakage be accounted for in the dataset (as a trade-off of EU production and consumption patterns)?”

GHG emissions are a global concern, and restricting the mitigation of emissions to just EU region does not give the full picture of the mitigation effects of specific technological mitigation options. Participants agreed on the importance of identifying and addressing emission leakage when assessing the mitigation capacity of the EU’s agricultural sector. However, current methodologies and tools (e.g. life cycle assessment) do usually not yet account for it. Moreover, participants considered that emission leakage does not have to be part of a dataset, but should be rather an outcome of model based scenario analysis since leakage can vary depending on the different scenario assumptions.

"Q7. Shall the dataset focus on broad categories (e.g. fertilization management techniques) or specific technologies (e.g. Variable Rate Fertilization, Nitrification Inhibitors)?”

Participants agreed on the importance of being technology-specific rather than focussing on broad mitigation techniques. It is important to clearly define the technology, establishing an applicability framework and clearly identify the technology’s costs, ease to implement, short-, medium- and long-term efficiency, local adaptation and GHG mitigation capacity. Once this information is gathered, specific technologies can be merged into broader categories when required.

"Q8. Shall the dataset focus on non-CO₂ technological mitigation options or should technologies and practices reducing CO₂ emissions also be integrated?”

Participants agreed on the importance of including CO₂ emission mitigation in the datasets. Although the non-CO₂ emissions are the main GHG released from agriculture, technologies and practices reducing CO₂ emissions have also great potential to contribute to the global mitigation of GHG emissions. Additionally, it was highlighted that
some of these technologies can be applied in a very cost-effective way. However, linked to the previous discussion point, there is a need to clearly define which technologies might have and might not have a direct impact on GHG emission reduction (e.g. reduced tillage versus zero tillage).

“Q9. How to deal with technologies that can have a “double counting” impact on GHG emission reduction? How to assess this inconsistency in the dataset?”

Participants considered that one means to avoid cross-over effect, i.e. not considering the effect that the use of one technology can have on the mitigation potential of a second technology is to assess the different technological mitigation options in an integrated manner. Special care should be taken in identifying the interaction of effects of each technology, bearing in mind that emission reduction should not be double counted. It was proposed to establish a clear “applicability of the mitigation technology” index, establishing different penetration indexes for the technologies that share applicability and target the same emission source (e.g. in the case of different technologies targeting emissions related to fertilizer use).
6 Conclusion

The present report concludes that although valuable information was reported in the workshop for the selected mitigation technologies (i.e. Variable Rate Fertilization, Nitrification Inhibitors, on-farm Anaerobic Digester, Manure Management, Conservation Agriculture, and Agroforestry Systems), there is a clear lack of primary data regarding the mitigation potential, current and potential uptake, and cost-effectiveness globally and for the EU context. Particularly, current adoption rates were found to be still far too little known and limited to build an accurate baseline scenario for modelling mitigation policy options. Some figures were shown on adoption rates for nitrification inhibitors, which accounts for about 1-2% of nitrogen fertilizer, and for anaerobic digesters, which are mainly deployed in Germany. However, for most of the mitigation technologies there is a clear lack of empirical and official data on adoption rates or related information (e.g. feedstock utilisation) and costs. In some cases already existing data were recognised to not be available free of charge or open access (e.g. sales data on specific machinery or other agricultural inputs such as seeds or fertilizers among others).

Limitations were also found for adoption assessments of mitigation technologies due to difficult ex post and ex ante measurement and monitoring, different potential approaches for uptake (e.g. farmers can be machinery owners or use services for operations), and heterogeneity when calculating investment and operating costs.

A major conclusion of the workshop is that there is certainly a need to build consistent datasets per agricultural GHG mitigation option. Workshop participants agreed and ranked a list of the following main technological mitigation options that should be covered by improved datasets (including both non-CO<sub>2</sub> and CO<sub>2</sub> emissions): fallowing histosols, nitrification inhibitors, precision farming-variable rate technology, higher legume share, rice measures, anaerobic digestion, low nitrogen feed, vaccination (not proved to be very effective), feed additives (nitrate), grassland management, conservation agriculture, agroforestry, land retirement, increase animal and crops productivity, cover crops, use of residues on soil and low carbon animal diet. Participants also agreed which elements should be included in the adoption dataset. However there was no consensus with regard to using average figures or benchmark estimates. The elements of the datasets should be technology and site specific including adoption rates, costs, mitigation potential, structural data of farm holdings, productivity increase due to the technology use, employment creation, measurement of the ease of use, adoption drivers and barriers and bioregional differences. Furthermore, participants indicated that the datasets should be built using massive and systematic literature reviews, already existing databases and research projects, expert consultations and focus group discussions, and interviews and surveys with the farming community (farmers, agricultural advisers, policy makers, related agro industries or enterprises).

It therefore follows that is fundamental to collect more secondary and primary data on the EU adoption rates, costs and mitigation potential to understand what is currently happening at farm level and assessing how this may evolve in the future. Even though the task of building consistent and comprehensive datasets would likely imply costly and time consuming efforts, such datasets seem to be imperative for the proper analysis of agriculture's GHG mitigation potential.
References


UNFCCC (2008) Challenges and opportunities for mitigation in the agricultural sector: technical paper. United Nation Framework Convention on Climate Change. Available at:


## Annex I: Workshop Agenda

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Chair</th>
<th>Participants</th>
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<tbody>
<tr>
<td><strong>08:45 - 9:15</strong></td>
<td><strong>Registration</strong></td>
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<tr>
<td><strong>9:15 – 9:45</strong></td>
<td><strong>Introduction to the workshop</strong></td>
<td>Chair: Giampiero Genovese (JRC-Seville)</td>
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<tr>
<td>9:15 - 9:25</td>
<td>Welcome and introduction to the workshop</td>
<td>Giampiero Genovese (JRC-Seville)</td>
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<tr>
<td>9:25 - 9:35</td>
<td>Overview of JRC research on Climate Change &amp; Agriculture</td>
<td>Emilio Rodríguez-Cerezo (JRC-Seville)</td>
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<tr>
<td>9:35 - 9:45</td>
<td>Workshop objectives, structure and organization</td>
<td>Iria Soto-Embodas (JRC-Seville)</td>
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<tr>
<td><strong>9:45 – 12:15</strong></td>
<td><strong>Session 1: Examples of existing data (adoption, costs and mitigation potential) of technological mitigation options in the EU</strong></td>
<td>Chair: Thomas Fellmann (JRC-Seville)</td>
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<tr>
<td>9:45 - 10:15</td>
<td>Technological mitigation options for nitrous oxide (N\textsubscript{2}O): Variable Rate Fertilization and nitrification inhibitors</td>
<td>Ulrich Adam (CEMA); Andreas Pacholski (EurochemAgro)</td>
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<tr>
<td>10:15 - 10:45</td>
<td>Technological mitigation options for methane(CH\textsubscript{4}): On-farm anaerobic digesters and manure management</td>
<td>Philip Jones (Reading University); Jan Peter Lesschen (Wageningen UR)</td>
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<td><strong>10:45 – 11:15</strong></td>
<td><strong>Coffee break</strong></td>
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<td>11:15 - 11:45</td>
<td>Technological mitigation options for carbon dioxide (CO\textsubscript{2}): Conservation agriculture and agroforestry systems</td>
<td>Emilio González (ECAF); Rosa Mosquera (EURAF)</td>
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<tr>
<td>11:45 - 12:15</td>
<td>Discussion</td>
<td>All participants</td>
<td></td>
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<tr>
<td>Time</td>
<td>Session 2: Existing datasets and models on mitigation technologies</td>
<td>Chair: Ignacio Pérez-Domínguez (JRC- Seville)</td>
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<tr>
<td>12:15 - 12:35</td>
<td>Global Mitigation of Non-CO₂ GHG emissions</td>
<td>Shaun Ragnauth (EPA)</td>
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<tr>
<td>12:35 - 12:55</td>
<td>US GHG Mitigation Options and Costs for Agricultural Land and Animal production</td>
<td>Jan Lewandrowski (USDA)</td>
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<tr>
<td>12:55 - 13:15</td>
<td>Mitigation Options for the Agricultural Sector: The Spanish Roadmap</td>
<td>María Jose Alonso Moya (OECC)</td>
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<tr>
<td>13:15 – 14:15</td>
<td>Lunch break</td>
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<tr>
<td>14:15 - 14:35</td>
<td>Economic assessment of EU mitigation policy options with the CAPRI model</td>
<td>Thomas Fellmann (JRC- Seville)</td>
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<tr>
<td>14:35 - 14:55</td>
<td>MITERRA Model</td>
<td>Jan Peter Lesschen (Wageningen UR)</td>
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<tr>
<td>14:55 - 15:15</td>
<td>The Global Livestock Environmental Assessment Model</td>
<td>Anne Mottet (FAO)</td>
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<tr>
<td>15:15 - 16:00</td>
<td>Discussion</td>
<td>All participants</td>
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<tr>
<td>16:00– 16:30</td>
<td>Coffee break</td>
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<tr>
<td>16:30 – 18:00</td>
<td>Session 3: Priorities and road-map for dataset construction</td>
<td>Chair: Manuel Gómez-Barbero (JRC- Seville)</td>
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<tr>
<td>16:30 - 17:00</td>
<td>Brainstorming session on dataset construction and assumptions</td>
<td>All participants</td>
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<tr>
<td>17:00 - 17:30</td>
<td>Setting up working road-map</td>
<td>All participants</td>
<td></td>
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<tr>
<td>17:30 - 18:00</td>
<td>Wrap-up and overall conclusions of the meeting, calendar for contributions and next steps</td>
<td>All participants</td>
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<tr>
<td>21:00</td>
<td>Networking dinner</td>
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</tbody>
</table>
Annex II: List of participants

<table>
<thead>
<tr>
<th>Participant/Speaker</th>
<th>Organization</th>
<th>E-mail</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Jesús</td>
<td>Barreiro-Hurle</td>
<td>JRC Seville (Economics of Agriculture Unit)</td>
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<td>Thomas</td>
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<td>Iria</td>
<td>Soto-Embodas</td>
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Annex III: Presentations
All presentations can be downloaded at the following link.

Variable Rate Fertilization & Precision Agriculture. Ulrich Adam (CEMA)
1. VRT for fertilizers: a quantum leap in technology evolution in the last 10 years

1. Overarching objective: how much mineral fertilizer should ideally be spread in each “square-metre” of a field?
2. Required technology: a precise, regular & accurate soil and nutrient analysis.
3. Solution: sensor technology to examine the state of the plant helpful but in itself insufficient to establish yield potential of a particular “square-metre” in a field. To do this, several supplementary techniques are helpful:
   - Satellite/drone observations
   - Soil samples
   - Yield maps

1. VRF: advanced spreader technology

- Once it is clear what amount is to be spread per “square”, the fertilizer spreader can dispense accordingly with automated techniques.
- Smart spread: the required mass flow for precise dosing leads to an accurate application “per square meter” if the spreader adjusts the spread depending on the field form, the working width, the tramline system, field boundaries, etc. Currently, the full automation of the dosage of the current fertilizer mass flow is almost standard technology.
- Next steps: fully automatic self-adjusting spreader will gain prominence.

1. VRF: achieving exact boundary spreading

- Increasing agronomic intelligence per square meter...
- Mapping & analysis of:
  - Accurate soil data
  - Accurate nutrient/sensor data
  - Application data
  - Yield data
- Even more complex algorithms
- Ever more targeted VRF application
- Adopting inputs (intensity, amounts) to site-specific conditions within a field:
  - Soil properties
  - Water content
  - Nutrient status
  - Organic matter

Management Challenges for Variable-Rate Fertilisation (VRF)

Variable Rate Fertilization (VRF): achieving the optimal spread

1. VRF: schematic overview

Border spreading
Boundary spreading
Water course spreading

Yield orientated setting
Environmentally oriented setting
1. VRF: achieving exact boundary spreading even in windy conditions

- Weather station calculates spreading fan adjustment to correct wind drift

2. Technology Adoption dynamics (UK): why is VRT adoption (relatively) slow?

- Source: Clive Walker, UK Trade & Investment. Based on: BiBo 2013, Farsi

2. VRF uptake in Europe

- Centrifugal Fertilizer Spreaders: Sales in Europe

2. VRF uptake dynamics in Europe

- VRF: 40% of spreaders sold are VRF/section control-enabled
- Section Control: 10% of new spreaders are sold together with SC licences
- Section Control: 25-30% of all newly sold spreaders are actually run with SC (share is higher, as licences can be bought later or other licences can be used)
- Automatic Documentation: 20% of newly sold spreaders can automatically document process-related data
- N-sensor: only around 5% of total German arable land fertilized using N-sensors

**STILL A LOT OF UPTAKE POTENTIAL!!!**

2. VRF uptake in the US – dealer service provision of VRF 1997-2015

- Image: Provides insight into service times for specific technologies
2. VRF uptake in the US: arable area using VRF

3. Costs of VRF technology – investment costs

- Purely for VRF, cost savings may not justify initial investments in the equipment, yet several components (like satellite navigation, mapping costs and board computers) can be used in various PF applications.
- Other (non-agronomic/economic/environmental) benefits of VRF:
  - Evidence of compliance with legislation through automated documentation
  - The recording and geo location of activities performed in each parcel (Digital farm book: date or timing, quantity of fertilizer/pesticide inputs, etc.) could be used by farmers as evidence of the respect to cross compliance

Cost-benefit case example 1

Site specific fertilising with costumary fertilized monitoring plots

Site specific benefit: 98 €/ha

3. Investment costs for VRF technology

- Used (non-VRF) spreader: EUR 400-4,000
- New VRF spreaders: EUR 15,000 PLUS costs for sensor & further PF technology
- Cost of N-sensor + support technology: EUR 19,000-40,000
- Link to farm size: N-sensor costing 26.100 Euro costs:
  - EUR 23 Euro/ha when used on 250 ha p.a.
  - EUR 11.50/ha on 500 ha p.a.

Benefits of Precision Fertilizing

- Higher yield potential (+5% or more)
- Greater application speed
- Reduced working hours
- Automatic documentation
- Reducing fertiliser use by 5-30%, up to 32% (apple orchards)
- Economic benefit: €10-€100/ha

Cost-benefit case example 1

- UK farmer: 1,250 hectare arable crops on fen/clay soils
- Mapped soil nutrient content: maps showed variable indices – some high P areas
- Data sent to calibrate variable rate spreader to match fertiliser in right places to crop needs

Results:
- Reduced fertiliser input: 15-20t/year
- Fertiliser savings: GBP 14/hectare

4. GHG emissions mitigation potential of VRF technologies

- Less energy use and less fertilizer use will contribute to lower emission of greenhouse gases, slowing down climate change and contributing to global objectives on this topic.
- Summary study by Diacono et al., 2013 on precision N management of wheat (treatment maps, in season nitrogen management decisions, sensor based N rate recommendations):
  - Sensor-based N management systems when compared with common farmer practices showed high increases in the N use efficiency of up to 368 %
  - These systems also reduced N fertilizers, from 10 % to about 80 % less N, and reduced residual N in the soil by 20-50 %, without either reducing yields or influencing grain quality.
- Precision N management based on real-time sensing and fertilization had the highest potential to cut budgets (e.g., 20% CO2 emissions).
5.a. Key elements affecting uptake

• (Cyclical) farm income situation/investment capacity of farmers
• Farm size
• Education/skills & ease of use
• Regulation & public policy (compliance, subsidies, tax brakes)

5.b. & c. Key elements affecting cost & mitigation potential

Cost:
• Operational cost: farm size (again)
• Initial investment: technology maturity, uptake & pricing mechanisms (greater uptake triggering falling prices like in the case of GPS receivers...)

Mitigation potential:
• Speed of uptake
• Further technology evolution, particularly robotics & big data

PRESENT & FUTURE: Big data & Internet of Things

• Opportunities:
  • Ever more data & connectivity: harmonization of data transfer & direct transfers from machine to farm and from farm to application in the cloud + more integrated systems with multiple vehicle/sensor data over the entire process to optimise inputs and maximize outputs.
  • Data refinement: making sense of data turning it into intelligence & advice
  • Internet & big data providing & processing
  • Bit: creating & providing

6. Conclusions

• Great potential to increase use efficiency and minimize environmental impact of fertiliser use with the help of VRF & precision technology
• GHG savings potential, environmental benefits and ROI of Precision Fertilising are immense, particularly when soil variability is high
• Still a lot of untapped potential:
  • Constantly evolving technology: smart systems that refine and improve algorithms over time through continuous data use/collection (e.g. yield/soil maps)
  • Uptake by farmers: promote farmers’ ability to invest in PF technologies through financial incentives and support (e.g. Saxony, France)

6. VRF: tackle key uptake barriers!

• Strengthen farmers’ investment capacity:
  • Mechanisms needed to ensure farmers at all scales can access PF technology (or corresponding contractual services)
  • As certain systems still only profitable as of a certain farm size (e.g. auto-guidance as of 100-300ha)
• Promote training & skills:
  • Farm operator education to focus on e.g. farm management acumen, necessary technical/IT know-how
  • Supportive efforts by industry: promote ease of use, reduce complexity of VRF technology, ensure compatibility of machines and systems
6. Improve the evidence base (datasets & models)

- Still not systematically assessed:
  - how much GHG savings potential (and other environmental benefits) Precision Agriculture offers
  - No comprehensive clear-cut methodology and data on savings potential for specific PA technologies, like VR/Precision Fertilising
  - No representative/aggregated data for regions/countries
  - Uptake barriers for different PA technologies
- CEMA study on CO2 reduction in machinery (3-year study, starts H2020 smartAKIS project (upta)[...]

6. The case for stronger EU policy support

- Align EU policies to promote more effectively PA in agriculture
- A new strategic agenda for the CAP post-2020:
  - Make the CAP a forward-looking tool focused on enhancing sustainable farm productivity (TFP) & to support farm investment capacity in desirable innovations (such as Precision Farming)
  - New support mechanisms to be considered: productivity 'bonus', crop yield insurance schemes, shifting 15% of CAP to R&D...
- Accelerate research through dedicated support for industrial R&D in the most promising areas of Precision/Digital/Smart Farming:
  - Drive up research funding (H2020, EIP-AGRI, AIOTI)

All the news & updates on: www.cema-agri.org

CEMA web-portal on Precision Farming

- www.cema-agri.org/page/precision-farming
- Discover what smarter, more productive & sustainable farming is all about!

CEMA: join the debate!

✔ Sign up to CEMA’s monthly Newsletter www.cema-agri.org/newsletters
✔ Follow us on Twitter
✔ Like us on Facebook
✔ Join the our group on LinkedIn
✔ Watch our videos on YouTube
Variable Rate Fertilization and Nitrification Inhibitors. Andreas Pacholski (EuroChem Agro)

Effect of agriculture and N-fertilization on global \( N_2O \) emissions

About 40-60\% of global \( N_2O \) emissions in the last 60 years from human activities (IPCC: 2006).

Agriculture: 60-80\% of gross anthropogenic \( N_2O \) emissions (Davidson and Kanem, 2014).

Global \( N_2O \) emissions and sources (Tg \( N_2O-N\))

Sources of agricultural \( N_2O \) emissions - Europe

About 26\% of direct emissions: manure fertilizer derived
About 20\%: manure application and manure management
About 24\%: indirect emissions from nitrate leaching and \( NH_3 \) volatilization

Relevance of anthropogenic \( N_2O \) emissions

Strong positive effect on radiative forcing (factor 298 compared to \( CO_2 \) on a 100 year basis).

5\% global anthropogenic radiative forcing from anthropogenic \( N_2O \).

Description of the Nitrification Inhibitors technology: the nitrification process

Nitrates in soil more mobile in soil than ammonium → risk of nitrate leaching

Stabilization of \( NH_4^+ \)/\( NH_3 \) reduces this risk and facilitates ammonium nutrition

Effect of direct emissions from ammonium and amid based fertilizers by use of nitrification inhibitors (NI): → Bacterial/chemical control of nitrification by inhibiting bacteria (Nitrosomonas → blocking enzyme AMO) → Proximal lifetime of ammonium in soil by 6-12 weeks even under high temperature conditions → Synthetic and natural NI compounds available with highly variable inhibition efficiency → Applicable to organic and mineral fertilizers

Effect on indirect emissions from urea and ammonium based fertilizers → Reduction of fertilization level (ammonium nutrition) → Reduction of nitrate leaching
economic costs and profitability of the technology

Economic benefits

- Mineral fertilizer: number of applications reduced → direct application costs (around 1.5-4 ha and EU average own calculations) + opportunity costs (e.g. time spared for other farm activities, not yet calculated) = transaction costs (e.g. costs for acquisition of fertilizer from retailer, not yet calculated).
- Less field traffic preserves soil quality and reduces potential restoration costs.
- Not under all conditions but on average increases in N uptake (grand mean = +10%) and yield (<5%) were observed (Askew et al. 2014).
- Under German conditions only minor yield effects (1-2%, Hu et al. 2014). However, yield effects were underestimated as product test trials for identification of optimized application were included.
- Already yield increases on the level of 2% for the most common crops at actual price net benefit of the use of N.
- About 5% of field applied N could be saved.
- No investment for implementation required.

Example calculation: economic costs and profitability

Net costs after yield: CAN

<table>
<thead>
<tr>
<th></th>
<th>100% N</th>
<th>50% N</th>
<th>0% N</th>
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<tr>
<td>Costs</td>
<td>195.4</td>
<td>144.2</td>
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<tr>
<td>Net cost</td>
<td>213.5</td>
<td>213.5</td>
<td>213.5</td>
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<tr>
<td>Savings</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
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<tr>
<td>Other fertilizers</td>
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</tr>
<tr>
<td>Costs</td>
<td>195.4</td>
<td>144.2</td>
<td>144.2</td>
</tr>
<tr>
<td>Net cost</td>
<td>213.5</td>
<td>213.5</td>
<td>213.5</td>
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<tr>
<td>Savings</td>
<td>0.5</td>
<td>0.5</td>
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On-farm anaerobic digesters - an economic perspective. Philip Jones (Reading University)

Workshop: Datasets for GHG mitigation technologies for agriculture

On-farm anaerobic digesters – an economic perspective
Philip Jones

The technology

- Digestion of organic material by bacteria in sealed tanks to release biogas:
  - Feedstocks - any non-toxic biomass
  - Biogas - 60% methane, 40% carbon dioxide & traces of other 'contaminant' gases
  - Digestate - inert, sterile, wet material, nutrient rich

Technology variants

- Mesophilic (25-45°C) - thermophilic (50-60°C)
  - Thermophilic: process faster, higher capital/operating costs
- Wet (5-15% OM) – dry (>15% OM)
  - Dry: Cheaper to operate, higher capital costs
- Continuous – batch flow
  - Continuous: Cheaper, simpler to operate
- Single – double – multiple digesters
  - Multiple: greater gas yield, higher capital/operating costs
- Vertical tank – horizontal plug flow
  - Horizontal: maximises gas yield, higher capital/operating costs

Current uptake

Deployment of farm-based AD plants in some European countries 2015

Remit

- Description of the technology
- Uptake (current & potential)
  - Factors affecting uptake
- Economics of AD
  - Revenues
  - Capital investment costs
  - Savings (e.g. fuels, fertilizer)
  - Operational maintenance costs
  - Factors affecting costs
- Conclusions (incl. data availability)

Benefits to Farmers

- Income - profitable diversification opportunity – selling green power and heat
- Waste management -
  - Reduces GHG emissions from farm
  - Provides more available nitrogen than slurry, meaning better crops and lower fertilizer bills
  - Biosecurity: kills most pathogens in the feedstock
  - Weed control: kills virtually all seeds in the feedstock

Choice of digester

- Type of feedstock being used
  - Wet (skirries) - manures, dry crops
- The goal of the process
  - Diversification or waste management
- The volume of feedstock available
- Availability of spare labour/skills
- Availability of capital
- Space and infrastructure

Sector development

- Rapid expansion in some countries (UK, France)
- Rate of growth declining rapidly in Germany
Data on uptake

<table>
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<tr>
<td>Biomass</td>
<td>27,000</td>
<td>12</td>
<td>£1,200,000</td>
<td>£3,100,000</td>
<td>£4,300,000</td>
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<tr>
<td>Wind</td>
<td>8,000</td>
<td>20</td>
<td>£1,500,000</td>
<td>£3,000,000</td>
<td>£4,500,000</td>
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<tr>
<td>Solar</td>
<td>5,000</td>
<td>50</td>
<td>£1,000,000</td>
<td>£2,000,000</td>
<td>£3,000,000</td>
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Source: UK Official AD Portal [http://www.digasinfo.co.uk]

Data on the uptake of AD plants is readily available
- Governments, regulators, industry associations

Uptake potential
- Three different approaches to estimating this:
  - Availability of feedstocks (high end estimates)
  - Surveys of farmer intention/attitudes (medium range estimates)
  - Trends in current uptake of farm-based AD plants (low end estimates)

Feedstock utilisation
- Official data is unreliable
  - Only intended use of feedstocks is known (planning datasets)
  - Relative importance of each feedstock not known
  - Feedstock use may change
- More reliable data from ad hoc surveys (less coverage)

AD revenues
- Basic FITs for electricity generated or supplied to grid (ROCS being phased out in 2017)
- Enhancements to FIT (based on efficiency, use of certain feedstocks etc.)
- RHI (in some countries)
- Gate fees (for taking in imported wastes)
- Accessibility of each revenue source varies according to the type output being generated
- Majority of AD plants generate electricity by CHP units
  - FITs are the most important source of revenue

Mapping AD uptake

Example uptake projections
- Feedstock availability est. - 1,285-fold increase on present
- Farmer intentions - 18-fold increase on present
- Historic trends - short-term development potential

End uses of generated energy
- Data collected by energy companies, regulators and departments of energy
- Used to monitor progress towards renewable energy targets

Feed In Tariffs
- FIT rates are set on the basis of installed electricity generation capacity
- Variation in the support for small scale AD reflecting Government prioritisation of this type of deployment
  - France and Austria paying almost double rate in the UK

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### Capital investment costs

- Average costs of installation are similar across the EU
- Smaller cost range in Germany (more developed sector)
- Grants more available in some countries than others
- Data from: plant suppliers & ad hoc surveys

### Savings

- Fuel savings
  - Majority of digesters (in the UK at least) do not use electricity generated on site
  - Some heat might be used (for digester tanks)
- Fertilizer savings

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<th>Source</th>
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<tr>
<td>Animal residues and slurry</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Waste (Road grit)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Costs</td>
<td>Exported</td>
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### Factors determining costs

- The scale of the plant being installed
- The nature of the feedstocks to be used
- The amount of site preparation
- Planting and advisory costs
- Requirement for upgrading plant

### Example nutrient purchase savings

<table>
<thead>
<tr>
<th>Farm type</th>
<th>Nutrient</th>
<th>AD plant added (kg ha⁻¹)</th>
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</thead>
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<tr>
<td>Anaerobic digesters (AD) 10 000 t AD</td>
<td>Nitrogen (N)</td>
<td>39,796</td>
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<tr>
<td></td>
<td>Phosphorus (P)</td>
<td>35,946</td>
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<td>Truly anaerobic digesters (AD) 195 t AD</td>
<td>Nitrogen (N)</td>
<td>23,130</td>
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<tr>
<td></td>
<td>Phosphorus (P)</td>
<td>16,520</td>
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</table>

Source: Jones and Salter (2013)

### Operating costs

- No official data on the operating costs of AD plants are collected
- Data from plant suppliers and ad hoc surveys
- Margin as % of cereals in England in 2014/15 was 8.0% (source: IFA)

### Barriers to adoption

- Using UK survey data to illustrate:

<table>
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<th>Characteristics</th>
<th>Problem faced</th>
<th>Percentage of responses</th>
<th>Difference in response</th>
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<td>Total annual income (£)</td>
<td>236.4</td>
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<td>Energy costs (£)</td>
<td>117.3</td>
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<tr>
<td>Capital costs (£)</td>
<td>173.1</td>
<td>173.1</td>
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<tr>
<td>Total expenses (£)</td>
<td>558.6</td>
<td>558.6</td>
<td>558.6</td>
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<tr>
<td>Margin (£)</td>
<td>1516</td>
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### Summary of data availability

- Data availability
  - National: Complete data collected from national data sources and institutions
  - International: Data collected from international data sources and institutions

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<th>International</th>
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<td>Summary</td>
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On-farm anaerobic digesters and manure management. Jan Peter Lesschen (Alterra, Wageningen University)

On-farm anaerobic digesters and manure management

Jan Peter Lesschen, Yong Hou, Oene Oenema
Alterra, Wageningen University & Research, The Netherlands

GHG emissions from manure management

67 Mton CO₂-eq in EU-28 (UNFCCC, 2013), 15% of total agriculture emissions

Main drivers for manure processing

- Subsidies for "green energy"
- EU Regulations forcing enhanced recycling of manure (e.g. Nitrates Directive) and other residues and wastes
- Regulations forcing the implementation of NH₃ and GHG emission mitigation measures
- Economic incentives to lower cost and of manure disposal and increase the fertilization values of manure

DG Environment study manure processing

- Study by Foged et al. in 2010-2011
- ~15% of animal manure production in Europe
- Slurry separation and anaerobic digestion are dominant

Meta-analysis Hou et al. (2014)

Mitigation of ammonia, nitrous oxide and methane emissions from manure management chains: a meta-analysis and integrated assessment

- Pig and cattle manure
- NH₃, N₂O and CH₄ emissions
- Housing, storage and application
- Comparisons of management measures
  - 126 publications

Mitigation measures

Housing:
- Lower CP content in feed
- Stalled floor with scraper
- Frequent removal
- Air (NH₃) scrubber

Storage:
- Cover slurry tank
- Cover manure piles
- Compaction
- Aeration

Application:
- Trailing hose
- Trailing shoe
- Injector
- Incorporation

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Effect on NH₃ emissions

- Use of H₂SO₄ to reduce pH of manure (7 → 5.5)
- Can reduce both NH₃ and CH₄ emissions
- Currently mostly used during application → no effect on CH₄
- Savings of N → less fertilizer
- Risk on H₂S emissions

Manure acidification

Factors stimulating adoption

- Pressure from policies and regulations
- To facilitate the export of manure off farm
- To produce bioenergy
- Pressure from increased fertilizer price
- To increase income via the sale of processed products
- To control disease, pathogens and colour

Stakeholder surveys manure treatment

Part of RelievWaste project

- Stakeholder groups:
  - Livestock farmers
  - Farmers’ organizations
  - Agricultural advisors
  - Clean-tech developers
  - Policy makers
  - Researchers

Constraints and barriers

Technology preference in next decade

Anaerobic digestion
Factors influencing (co-)digestion

Current biogas production EU-28
- Data based on study for DG Energy (ENER/C1/2015-438)
- Biogas production in 2014 about 625 PJ (Source: Eurostat)
- Biogas is 7.6% of total RE primary production
- 4 fold increase in biogas production since 2005
- 50% of all biogas is produced in Germany, followed by Italy and United Kingdom
- 18% from landfill, 9% from sewage sludge and 72% from other (mainly farm based plants)

Current feedstock use (source: Alterra, 2011)

Current feedstock use (source: DG Env. study)
- Sewage sludge 1. not included 2. not specified 3. included
- Data are based on questionnaires from 2012

Current feedstock use (source: EBA, 2015)

Liquid manure potential in 2030

Manure potentials (Source: Biomass Policies)

GHG emissions savings (in kton CO2-eq for 2008)

- Table

<table>
<thead>
<tr>
<th>Main countries</th>
<th>Avoided GHG emission from manure storage</th>
<th>Avoided GHG emission fossil fuels for electricity</th>
<th>Avoided GHG emission fossil fuels for heating</th>
<th>GHG emissions from biogas production</th>
<th>Net avoided GHG emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>24</td>
<td>295</td>
<td>63</td>
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<tr>
<td>Czech Republic</td>
<td>8</td>
<td>62</td>
<td>17</td>
<td>9</td>
<td>78</td>
</tr>
<tr>
<td>Germany</td>
<td>238</td>
<td>264</td>
<td>27</td>
<td>3</td>
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<tr>
<td>Germany</td>
<td>373</td>
<td>3417</td>
<td>626</td>
<td>266</td>
<td>3363</td>
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<tr>
<td>Netherlands</td>
<td>118</td>
<td>173</td>
<td>10</td>
<td>99</td>
<td>204</td>
</tr>
<tr>
<td>Spain</td>
<td>44</td>
<td>82</td>
<td>3</td>
<td>1</td>
<td>110</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>124</td>
<td>225</td>
<td>24</td>
<td>24</td>
<td>325</td>
</tr>
<tr>
<td>EU-27</td>
<td>1178</td>
<td>4957</td>
<td>117</td>
<td>236</td>
<td>4897</td>
</tr>
</tbody>
</table>
Issues related to anaerobic digestion

- Low energy yield without co-digestion
- Availability of co-substrates (no energy crops)
- Mono-digestion of manure should be stimulated
- Biogas yield of manure variable
  - Fresh (< 3 days) pig manure 47 m³ biogas/ton
  - Old manure (> 4 months) only 7 m³ biogas/ton
- Leakage in digester (1 up to 10%)
- Inclusion in National Inventory Reporting

Conclusions

- Low dietary protein, anaerobic digestion and slurry acidification are the most promising options for GHG mitigation
- Proper farm-scale combinations of mitigation measures are important
- Manure is a large untapped bio-resource of biogas
- Incentives for soil carbon sequestration is main competitor for biogas production from bioresources
Conservation agriculture. Emilio Gonzalez-Sanchez (ECAF/Cordoba University)

What is Conservation Agriculture – Principles of ecological sustainability

- No or minimum mechanical soil disturbance by - seeding or planting directly into undisturbed soil
- Enhance and maintain organic matter cover on the soil surface - using crop residues and cover crops to protect & feed soil life
- Diversification of species -- both annuals and perennials - in associations, sequences and rotations

Key element: Conservation Agriculture is a combination of several resource conserving practices simultaneously creating synergies between them for optimization & sustainability.

Ecological foundation for sustainable agriculture production is provided by application of Conservation Agriculture principles

CONVENTIONAL FARMING
Modification of the environment to seed (soil)

CONSERVATION AGRICULTURE
Adaptation of the available technology to seed in different environments (system)
Soil degradation processes are very expensive - unaffordable - for Society

<table>
<thead>
<tr>
<th>SOIL DEGRADATION</th>
<th>ANNUAL COSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erosion</td>
<td>€0.7 – 14.0 billion</td>
</tr>
<tr>
<td>Organic matter decline</td>
<td>€3.4 – 5.6 billion</td>
</tr>
<tr>
<td>Compaction</td>
<td>Cannot be estimated</td>
</tr>
<tr>
<td>Salinisation</td>
<td>€158 – 321 million</td>
</tr>
<tr>
<td>Landslides</td>
<td>Up to €1.2 billion per event</td>
</tr>
<tr>
<td>Contamination</td>
<td>€2.4 – 17.3 billion</td>
</tr>
<tr>
<td>Biodiversity decline</td>
<td>Cannot be estimated</td>
</tr>
</tbody>
</table>

The total costs of degradation would be up to €30 billion annually for EU.

Runoff control with Conservation Agriculture

Conservation Agriculture has a positive effect on the mitigation of climate change, by both increasing soil organic carbon, and by reducing the emissions of CO₂ into the atmosphere.
### Meta-analysis on atmospheric carbon capture in Spain through the use of conservation agriculture


Journal: Soil & Tillage Research (2012), 122, pp. 52-60.

http://dx.doi.org/10.1016/j.still.2014.10.016

### Evolution of Conservation Agriculture in Spain

#### (annual and perennial crops)

<table>
<thead>
<tr>
<th>Year</th>
<th>Total (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>8</td>
</tr>
<tr>
<td>2010</td>
<td>12</td>
</tr>
<tr>
<td>2011</td>
<td>16</td>
</tr>
<tr>
<td>2012</td>
<td>20</td>
</tr>
<tr>
<td>2013</td>
<td>24</td>
</tr>
</tbody>
</table>

\[
Y = 2.11 Ln(X) + 13.49 \quad R^2 = 0.92
\]

### C fixation in no tillage in maritime and continental Mediterranean climates

![C fixation in no tillage in maritime and continental Mediterranean climates](image1)

### C fixation in minimum tillage in maritime and continental Mediterranean climates

![C fixation in minimum tillage in maritime and continental Mediterranean climates](image2)

### C fixation in groundcovers in Mediterranean climate

![C fixation in groundcovers in Mediterranean climate](image3)

### Carbon fixation coefficients of Conservation Agriculture over conventional farming

<table>
<thead>
<tr>
<th>Agricultural Practice</th>
<th>C coefficient of fixation (Mg ha⁻¹ year⁻¹)</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-tillage</td>
<td>0.85</td>
<td>&lt;10 years</td>
</tr>
<tr>
<td>Minimum tillage</td>
<td>0.16</td>
<td>&gt;10 years</td>
</tr>
<tr>
<td>Groundcovers</td>
<td>1.54</td>
<td>&lt;10 years</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>&gt;10 years</td>
</tr>
</tbody>
</table>

\[
OC_{(Mg/ha)} = \frac{OC_{(kg/m^2)} \times 10^3}{D} \times \rho \times (kg_{m^2}/m^2) \times D \times m^{-2}/ha \\
OC_{(Mg/ha)} = \sum OC_{X}\sum TT \\
OC_{(Mg/ha)} = \frac{\sum OC_{X} \cdot CA}{\sum C_{A}} \\
\Delta OC_{(Mg/ha/year)} = \left( OC_{(Mg/ha)} - OC_{(Mg/ha)} \right) / \gamma \\
FC(Mg/ha/year) = \sum \frac{\Delta OC_{X} \times (D/D_{max})}{S}
\]
THE COST OF MEETING THE KYOTO PROTOCOL FOR SPAIN

EXCESS OVER ALLOWED: 165,582 Gt CO\textsubscript{2} eq

Spain’s investment in flexibility mechanisms to compensate the excess of emissions: € 812 M

Rate: 4.9 €/Mg

Source: United Nations, OREC, 2015

CARBON STORED IN SOILS: 44,750 Gt CO\textsubscript{2} eq
POTENTIAL CARBON STORAGE: 259,752 Gt CO\textsubscript{2} eq
TOTAL EMISSIONS KYOTO 2008-12: 1,822,692 Gt CO\textsubscript{2} eq
EXCESS OVER ALLOWED: 165,582 Gt CO\textsubscript{2} eq

EMISSIONS COMPENSATED

<table>
<thead>
<tr>
<th>Total Emissions</th>
<th>Agriculture Emissions</th>
<th>Excess of Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current adoption of CA</td>
<td>2.46%</td>
<td>22.95%</td>
</tr>
<tr>
<td>Potential adoption of CA</td>
<td>14.25%</td>
<td>133.19%</td>
</tr>
</tbody>
</table>

ECONOMIC SAVINGS: € 1,000

Current adoption: € 219,447

Potential adoption: € 1,273,790

* Rate of carbon market: 4.90 €/Mg CO\textsubscript{2}, the price paid by Spain 2008-2012

SOIL MANAGEMENT SYSTEMS AND SHORT TERM CO\textsubscript{2} EMISSIONS IN A CLAYEY SOIL IN SOUTHERN SPAIN

Authors: Carbonell-Buxó, R., González-Sánchez, E., Yermo-González, O., Ordóñez-Fernández, R.


Indexed in: Journal Citation Reports (ICR), Category: ENVIRONMENTAL SCIENCES.

In 2011, Science of the Total Environment had an Impact Factor of 3.296

Ranking: 29/205 (Q1)

Article citations: 11 times

http://dx.doi.org/10.1016/j.scitotenv.2011.09.016

GION MITIGATION THROUGH CONSERVATION AGRICULTURE

Gas flow meter IR absolute and differential PP Systems ECM 4 gas analyser.

The camera is placed for 2.5 min; data are collected every 2 s giving a final value of the average.

To observe the effects of the tillage operations, measurements were made before tillage took place, and immediately after and at 2, 4, 6 and 24-48 h.

Specific measurements were also made after the most important rain events to observe the effects of the increase in moisture in the soil on biological activity and the acceleration of decomposition of the residues.
The most favorable conditions for CO₂ emissions are moderate temperatures around 20°C, and a moisture content of around 60-80% of the maximum water holding capacity of the soil.

Daily CO₂ emission values of soil tillage operations and maximum difference between conventional tillage and no-tillage.

<table>
<thead>
<tr>
<th>Date</th>
<th>Daily CO₂ emission kg ha⁻¹</th>
<th>Max. difference tillage TT-NT</th>
<th>Max. T (°C)</th>
<th>% accumulated rainfall in the last month</th>
<th>Soil moisture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14/11/96</td>
<td>30.5</td>
<td>8.4</td>
<td>21.2</td>
<td>122%</td>
<td>20.0</td>
</tr>
<tr>
<td>16/01/96</td>
<td>23.8</td>
<td>9.5</td>
<td>17.7</td>
<td>28.0</td>
<td>10.1</td>
</tr>
<tr>
<td>18/09/97</td>
<td>6.3</td>
<td>3.8</td>
<td>31.7</td>
<td>11.0</td>
<td>11.4</td>
</tr>
<tr>
<td>14/12/97</td>
<td>13.9</td>
<td>4.3</td>
<td>18.0</td>
<td>66</td>
<td>11.4</td>
</tr>
<tr>
<td>18/10/99</td>
<td>8</td>
<td>3.8</td>
<td>23.5</td>
<td>44.0</td>
<td>16.0</td>
</tr>
</tbody>
</table>

TT - Conventional tillage
NT - No-tillage

Increase in the hourly CO₂ emissions during tillage operations compared to no-tillage.

- Disk harrow emitted 6.7 times more CO₂ than no-tillage
- mouldboard emitted 3.5 times more CO₂ than no-tillage

ENERGY USED IN CONSERVATION AGRICULTURE (NO TILLAGE) AND CONVENTIONAL AGRICULTURE.

<table>
<thead>
<tr>
<th>Crop</th>
<th>System</th>
<th>Direct Energy (Wh ha⁻¹)</th>
<th>Indirect Energy (Wh ha⁻¹)</th>
<th>Total (Wh ha⁻¹)</th>
<th>EE (Wh L⁻¹)</th>
<th>EP (Wh L⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>No-till</td>
<td>0.24a</td>
<td>0.29a</td>
<td>0.53a</td>
<td>14.0a</td>
<td>1.72a</td>
</tr>
<tr>
<td></td>
<td>TT</td>
<td>1.92a</td>
<td>1.05a</td>
<td>2.97a</td>
<td>28.1a</td>
<td>3.14a</td>
</tr>
<tr>
<td>Sunflower</td>
<td>No-till</td>
<td>0.86b</td>
<td>0.27b</td>
<td>1.13b</td>
<td>21.5a</td>
<td>3.30a</td>
</tr>
<tr>
<td></td>
<td>TT</td>
<td>1.85a</td>
<td>1.05a</td>
<td>2.90a</td>
<td>26.0a</td>
<td>3.51a</td>
</tr>
<tr>
<td>Legume</td>
<td>No-till</td>
<td>0.81b</td>
<td>0.27b</td>
<td>1.08b</td>
<td>12.8a</td>
<td>2.03a</td>
</tr>
<tr>
<td></td>
<td>TT</td>
<td>1.85a</td>
<td>1.05a</td>
<td>2.90a</td>
<td>26.0a</td>
<td>3.51a</td>
</tr>
</tbody>
</table>

Results of the LIFE+ Agricarbon project: www.agricarbon.eu

Costs saved (€ ha⁻¹):
- Wheat: -9.5%; Sunflower: -21.6%; Legumes: -14.4%

Reduction of an average of 19% of Energy Use, whilst keeping yields (Wheat, Sunflower, Legume)
1. Conservation Agriculture is a system that is well adapted to most agro-climatic regions. Its environmental benefits include control of erosion, increased soil organic matter, less soil compaction, reduced CO₂ emissions, improved biodiversity, and lower risk of potential contamination of the water.

2. No-tillage is acknowledged as the best practice for arable crops, while groundcovers are the best approach for perennial crops. Although reduced tillage is sometimes acceptable as a conservation tillage practice for arable crops, it is not considered adequate for Conservation Agriculture. In Mediterranean areas, seldom more than 30% of residues of the previous crop are present after seeding.

3. Conservation Agriculture implementation could help meet the targets set in the international agreements related to climate change, such as the Kyoto Protocol.

4. The potential for carbon sequestration in Conservation Agriculture is not constant over time. Thus, in newly implemented fields, carbon sequestration rates are high during the first 10 years, followed by a period of lower but steady growth to reach an equilibrated rate.

5. Crop rotations present higher values of carbon sequestration coefficients than monocultures in arable crops. In perennial crops, native cover crop species normally lead to higher values of carbon sequestration coefficients than sowned species.

6. Agricultural policies that promote a shift to farming systems enhancing carbon content in soils, such as Conservation Agriculture, are considered more relevant than those policies focused on the reduction of CO₂ emissions. The mitigation effect of the reduced emissions is small compared to the amount of carbon that can be stored in soils.
Agroforestry systems. Maria Rosa Mosquera-Losada (EURAF/University of Santiago de Compostela)

Technological mitigation options for carbon dioxide (CO2): Agroforestry

Maria Rosa Mosquera-Losada
Crop Production Department
University of Santiago de Compostela

Europe agriculture goal
Increase food production in a sustainable way

AGROFORESTY
Best tool to

ECOINTENSIFICATE
Aboveground
Belowground

Aboveground level

AGROFORESTY
Best tool to

ECOINTENSIFICATE
Aboveground
Belowground

Benefits

Crop or Livestock Farm
Pruning, uncommercial and commercial thinning
Forest farm
Agroforestry farm

Increase up to 25% over Crop-Livestock farms
Profitability depends on combination of crops.

AGROFORESTRY
Best tool to
ECOINTENSIFICATE

Aboveground
Belowground

Belowground level

Soil Carbon at Three Distances to Cork Oak to 1 m Depth, Mg ha⁻¹:

- 2: 50.2
- 5: 37.0
- 15: 26.5
Agroforestry is an excellent tool to increase the use of resources at below and aboveground levels

Is this a tool extensively used in Europe?

**Agroforestry practices**
- Silvopasture
- Silvoarable
- Kitchengardens
- Forest Farming
- Riparian buffer strips

**Silvoarable**
- Woody + annual or perennial crops
  - 422,250 hectares
  - 0.4% EU Arable land
  - USA: <1%

**Kitchengardens**
- Trees + vegetable production in urban or periurban areas, also known as part of "trees outside the forest"
  - 1.8 million hectares
  - 60% Agroforestry

**Silvopasture**
- Woody + forage and animal production
  - 19.5 Miliion hectares
  - 10% EU potential area

**EU indicative measures that may be included in the information on LULUCF actions submitted pursuant to article 19(2)(d) (Decision 528/2013/EU) and may relate to Agroforestry**

<table>
<thead>
<tr>
<th>Measure related to</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agroforestry</td>
<td>- Improving Greenland s-Copeland assessment for mixed species&lt;br&gt;- Improving productivity&lt;br&gt;- Improving silvicultural management&lt;br&gt;- Introducing more appropriate species, in particular deep rooted species.</td>
</tr>
<tr>
<td>Agroforestry</td>
<td>- Afforestation and reforestation&lt;br&gt;- Conservation of existing forest&lt;br&gt;- Enhancing agroforestry existing forests&lt;br&gt;- Increasing biomass and产值&lt;br&gt;- Enhancing forest management&lt;br&gt;- Enhancing forest protection, including prevention of illegal deforestation and forest degradation.</td>
</tr>
<tr>
<td>Agroforestry</td>
<td>- Strengthening protection against natural hazards&lt;br&gt;- Strengthening landscape protection and enhancing, inter alia, the capacity for carbon sequestration and materials with harvested wood products.</td>
</tr>
</tbody>
</table>

---

French National Agroforestry Strategy
<table>
<thead>
<tr>
<th>Conclusions</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Agroforestry is an excellent tool to combat climate change</td>
<td></td>
</tr>
<tr>
<td>* There is a good opportunity to mitigate and adapt to climate change and make agricultural systems more resilient by using Agroforestry</td>
<td></td>
</tr>
<tr>
<td>* Adequate design of policies (research, learning, innovation) should be delivered in order to take advantage of Agroforestry practices to combat climate change (C increase, storage and stability)</td>
<td></td>
</tr>
</tbody>
</table>
Global Mitigation of Non-CO₂ GHG: 2010-2030. Shaun Ragnauth (USEPA)

Methodology

MACs provide information on the amount and cost of emissions reductions that can be achieved in a given sector:
- Abatement options are represented through bottom-up engineering cost analysis.
- Costs, benefits, and potential mitigation is assessed for each option.
- For each sector and region the MAC curve is determined by the series of breakeven price calculations for the suite of available options.
- Each point reflects the average price and reduction potential for a given abatement option.

Key Findings

- Total technically feasible global mitigation from non-CO₂ GHG sources in 2030 is over 3,500 MTCO₂e.

Croplands – Models and Data Sources

- Models:
  - DAYCENT (ecosystem model)
  - Biophysical model to estimate crop yields, N2O and CH4 emissions, and soil C stocks at a 0.05 grid resolution.
  - Simulates C and N fluxes between atmosphere, vegetation, and soil through representation of influence of environmental conditions (soil, weather patterns, crop and forage qualities, and management).
  - IMPACT (IPCC’s International Model for Policy Analysis of Agricultural Commodities and Trade)
  - Agro-economic model that drives land use to meet future demand reflecting socio-economic drivers (population growth, technology change, etc.).
- US EPA Marginal Abatement Cost (MAC) model
  - Assembles abatement measures for technology costs, yield changes, expected stabilities, etc.
  - Computes abatement cost for each option.
  - Calculates breakeven prices for each option for 195 countries to construct MAC curves.

- Data sources:
  - Weather data – North American Carbon Program
  - Soil data – FAO Digital Soil Map of the World
  - Cropland areas – global cropland map developed by Ramankutty et al. (2008)

Non-CO₂ Global Mitigation Report: 2010-2030 Background

- USEPA has developed a comprehensive global mitigation analysis for non-CO₂ GHG sources.
- All non-CO₂ greenhouse gases (methane, nitrous oxide, N₂O; SF₆; PFCs; HFCs).
- All emitting sectors (energy, waste, agriculture, and industrial processing).
- Global coverage – disaggregated at the country level.
- 2010 – 2030.

- Countries evaluated at the national level.
- Global coverage – disaggregated at the country level.
- Baseline energy projections from USEPA’s non-CO₂ projections report.
- Has undergone an external peer review process.
- 2010 – 2030.

- USEPA’s projections for 2010 and 2030.
- Provides improved data to better understand the costs and opportunities for reducing non-CO₂ greenhouse gas emissions.

Data Sources and Models

- Data sources:
  - IMPACT (IPCC’s International Model for Policy Analysis of Agricultural Commodities and Trade)
  - Agro-economic model that drives land use to meet future demand reflecting socio-economic drivers (population growth, technology change, etc.).
- MAC model
  - Agro-economic model that drives land use to meet future demand reflecting socio-economic drivers (population growth, technology change, etc.).
- IMPACT (IPCC’s International Model for Policy Analysis of Agricultural Commodities and Trade)
- Agro-economic model that drives land use to meet future demand reflecting socio-economic drivers (population growth, technology change, etc.).

Aggregate Results – MACs by Sector (2030)

Globally, over 500 MTCO₂e of reductions from the agriculture sector are available under $50CO₂e/ton.
Croplands Mitigation Technologies

- Technologies: }
- Methodology: }
- Data Sources: }

Rice Cultivation – Models and Data Sources

- Models: }
- Data Sources: }

Livestock – Models and Data Sources

- Models: }
- Data Sources: }

Croplands Results

- Methodology: }
- Data Sources: }

Rice Cultivation – Results

- Methodology: }
- Data Sources: }

Livestock - Methodology

- Methodology: }
- Data Sources: }

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Livestock Enteric Fermentation – Mitigation options

- Data gaps and limitations
  - Limited and inconsistent data for enteric fermentation on estimated magnitude of emissions reductions
  - Abatement options including B1ST and antibiotics are controversial and have animal and human health concerns
  - Some options will not be commercially available until at least 2020
  - Uncertain costs, especially under long-term use

Livestock Manure Management – Mitigation Options

Limitations and Future Data Needs

- Limitations and Future Data Needs
  - Availability and quality of data to represent the highly complex and heterogeneous crop, rangeland, and livestock production systems of the world
  - Biodiversity modeling uncertainties, in particular with respect to soil organic carbon simulations
  - Availability of mitigation measure data
    - Capital and annual costs
    - Reduction efficiencies
    - New measures not captured
    - Scientific understanding of mitigation impacts
  - Technology adoption rates
  - Assumptions may be optimistic
  - Potential interactions of multiple mitigation measures are not fully addressed in this analysis

Summary

- Significant cost-effective mitigation exists from agricultural non-CO2 sources with mitigation options that are available today
- Despite potential for project level cost savings and environmental benefits, barriers to mitigating non-CO2 emissions (particularly CH4) continue to exist:
  - Traditional practices
  - Regulatory and legal issues
  - MACs and mitigation data set can feed into a number of climate analytical needs
  - CGE modeling
  - Analysis of cost and availability of mitigation opportunities
  - Climate policy analysis
  - Potential for future analysis and assessment of mitigation technologies to enhance marginal abatement cost analyses

More Information

- Contact:
  - Shaun Ragnauth
  - US EPA – Climate Change Division
  - 1-202-243-9142
  - ragnauth.shaun@epa.gov
US GHG Mitigation Options and Costs for Agricultural Land and Animal production. Jan Lewandrowsky (USDA)

Purpose of the Research
Facilitate a better understanding of how agriculture producers could respond to incentives to adopt specific GHG mitigating production and land management practices and technologies.

Effort has two parts
- 2013 report: Greenhouse Gas Mitigation Options and Costs for Agricultural Land and Animal Production within the United States
- 2016 report: Managing Agricultural land for Greenhouse Gas Mitigation within the United States

2013 report: Farm-level GHG mitigation options

1. Identify farm-level GHG mitigation technologies and practices (Y/P)
2. Assess representative farm-level costs of adoption of each Y/P
3. Identify farm-level GHG mitigation that would result from adoption
4. Calculate the CO₂ prices that would make adoption a break-even action for a set of “representative” farms

GHG Mitigation Options

- Anaerobic Digesters (4 options)
  - Covered Lagoon with Electricity Generation
  - Covered Lagoon with Flare
  - Complete Mix with Electricity Generation
  - Plug Flow with Electricity Generation
- Cover Existing Tank, Pond, or Lagoon
- Solids Separation
- Nitrification/Denitrification System

GHG Mitigation Options

- Retire Organic Soils, Establish Grassy Conservation Cover
- Retire Marginal Soils
  - Establish Grassy Conservation Cover
  - Establish Windbreaks
  - Restore Riparian Forest Buffers
  - Restore Wetlands (Grassy and Forested)

Data Challenges:

- Clearly describing the selected technologies and practices
- Finding compatible data on adoption costs, and mitigation for each technology/practice
- What you can do often depends on what you are doing.

2013 Report: Primary data sources:

- Ogle, S. Colorado State University, Natural Resource Ecology Laboratory. Suiplied data from DSSAT model simulations:
  - Changes in Soil C for changing tillage intensities by crop type and region
  - Changes in N2O emissions from N management options by crop and region
  - Changes in yield from changing N management practices by crop and region

USDA-NRCS Electronic Field Technical Guide (eFOTGS) Database of Practice Costs.
- State-level data providing technical descriptions and adoption costs of various USDA-recognized conservation practices.
- Contractor and vendor supplied data on capital, operation, and maintenance costs.

Table: Basic Management Practice

<table>
<thead>
<tr>
<th>Practice Management</th>
<th>Covered Lagoon</th>
<th>Covered Lagoon</th>
<th>Complete Mix</th>
<th>Plug Flow</th>
<th>Existing L, P, Lagoon</th>
<th>Solids Separation</th>
<th>Nitrification / Denitrification System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy Arid</td>
<td>✓</td>
<td>✓</td>
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<td>✓</td>
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<td>✓</td>
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<tr>
<td>Dairy Arid</td>
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<tr>
<td>Dairy Arid</td>
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<td>✓</td>
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Final Outcomes

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<thead>
<tr>
<th>Technology</th>
<th>Baseline Practice</th>
<th>Farm Size</th>
<th>Region</th>
<th>Animal</th>
<th>CE Price</th>
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<tbody>
<tr>
<td>Covering Existing Lag</td>
<td>Amherst Lag</td>
<td>&gt; 1000</td>
<td>RA</td>
<td>Swine</td>
<td>$5.48</td>
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<tr>
<td>Improved Separators</td>
<td>Amherst Lag</td>
<td>&gt; 1000</td>
<td>AP</td>
<td>Dairy</td>
<td>$5.55</td>
</tr>
<tr>
<td>Covering Existing Lag</td>
<td>Amherst Lag</td>
<td>&gt; 1000</td>
<td>RA</td>
<td>Dairy</td>
<td>$5.55</td>
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<tr>
<td>VRT Nitrogen Sensor</td>
<td>Northport NA</td>
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<td>AP</td>
<td>Corn</td>
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<td>Reline Organosol-L</td>
<td>Cult Org Soil</td>
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<td>SE</td>
<td>NA</td>
<td>$0.83</td>
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</table>

Ability to clearly compare the relative costs of various mitigation options

Can identify all mitigation options that are cost effective for farms to adopt at a given CO2 price

2016 Report: Primary data sources

USDA Agricultural Resource Management Survey (ARMS) Data:
- U.S. Livestock Management Practices by Farm Size and Production Region
- U.S. Crop Management Practices by Farm Size and Production Region, 2009-2012

2007 USDA Census of Agriculture
- Harvested acres by region, commodity, and farm size
- Number of head (dairy cattle and swine) by region and farm size

Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010
- CH4 emissions by Manure Management System by region
- Acres of organic soils in cultivation

Assessing the Applicability of N Management Options

- Starting Point:  
  Acres where N is applied.
- Omit farms smaller than 100 acres.
- Assume acres not meeting the timing criteria meet the rate criteria and visa versa.

Mitigation by Source and CO2 Price ($ per mt CO2e)

2016 report: Marginal Abatement Cost Curve Analysis

1. Assess the potential adoption of each T/P by USDA production region, commodity, and farm size
2. Develop a methodology indicates when potential adopters of each T/P decide to adopt
3. Aggregate the adoption decisions into MACC's showing total agriculture sector GHG mitigation at CO2 prices between $0 and $100 per mt CO2 e

2016 Report: Other data sources


National MACC for all Mitigation Options (< $100 per mt CO2e)

Contact Information

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ICF International
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Mitigation Options for the Agricultural Sector: The Spanish Roadmap
Maria José Alonso Moya (OECC)

Mitigation Options for the Agricultural Sector: The Spanish Roadmap

Content
1. Evolution of Spanish emissions and GHG reduction objectives
2. Spanish non-ETS sectors roadmap
3. M3E Model
4. Some results

OBJECTIVES
2050: Low carbon society
Global reduction 60%
80-95% developed countries

Effort sharing decision (Decisión n°406/2009/CE)
2030 emissions compared to 2020

EU 2020 energy & climate pkg

Spanish Office for climate change

Negotiation
UNFCCC
Cooperation
Initiatives

Mitigation
-ETS
Diffuse sectors
1890/90 ETS Roadmap
Climate Proactive Framework (FPI)
National Adaptation Plan
Overall policy context

ROADMAP FOR NON ETS SECTORS 2020

1. The Roadmap is the key initiative to channel our responsibility as a government on the non ETS sectors (which are the 63% of Spanish total emissions)

2. Key sectoral policies and measures are identified to bridge the gap between our projections and 2020 target of reducing CO2 emissions in non ETS sectors

The elaboration is very complex as involves closely coordination between all competent ministerial departments and the Regions.

Proposed non ETS pathway with the aim of fulfilling ESD 2020 objective

43 measures

Non ETS sectors:
• Building
• Transport
• Agriculture
• Waste
• F-Gases
• Non ETS Industry

Content

1. Evolution of Spanish emissions and GHG reduction objectives
2. Spanish non-ETS sectors roadmap
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Non ETS projections & ESD Objectives 2013–2020

Expected under the ESD pathway only in 2013 y 2014. Total balance of - 54.9 MtCO2

Key elements of the ESD Roadmap 2020

• Identifies the gap.
• Describes the measures in detail: mitigation, investment, cost O&M, employment, etc
• The model finds the best mix of measures that meets the objectives in a cost efficient way.
• Economic effort, public support, employment and long range mitigation are outputs for the best design of PAMs

Content

1. Evolution of Spanish emissions and GHG reduction objectives
2. Spanish non-ETS sectors roadmap
3. M3E Model
4. Some results
M3E

- Tool that serves to quantify measures for planning low carbon strategy
- Model that optimizes considering cost-efficient parameters
- Takes into account: investments, savings (monetary and energy), employment, VAT parameters.

Main characteristics

- Easy: can be adapted to user needs.
- Costs/savings, employment, CO2 (ETS and non-ETS), ingresos fiscales.
- From 2013 to 2030
- Up to 65 measures/year can be included
- Linear optimizer: best solution for given conditions.
- Identifies duplicates

INPUTS

- Investment Costs
- Operating and maintenance costs
- Time
- Emissions
- Level of applicability
- Cost
- Local component
- Employment
- Taxes
- Length
- Years previous
- Universe
- Potential

OUTPUTS

- For each measure evaluated
- M3E Model optimizes how measures interact for given objectives using Solver

How each sector contributes to the objective?
Content

1. Evolution of Spanish emissions and GHG reduction objectives
2. Spanish non-ETS sectors roadmap
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4. Some results

Selected measures provide GHG reductions for 2020 and over 2030

Higests investments in transport and residential sectors

2020 Roadmap for agriculture

1. Manure Management through Anaerobic Digestion
2. Education and Training to improve fertilizing efficiency
3. No-tillage
4. Legumes on managed and fertilized grasslands
5. Training for Efficient Tractor Driving
6. Woody Crops pruning Waste re-use as biomass or soil incorporation
7. Seeded Legume-cover on Irrigated woody crops
Economic assessment of EU mitigation policy options with the CAPRI model. Thomas Fellmann (EC JRC Seville)

An economic assessment of GHG mitigation policy options for EU agriculture

- EcAMPA -
  EcAMPA 1 (2013-2014)
  EcAMPA 2 (2015-2016)

Implementation of endogenous technological mitigation options in the CAPRI model

Thomas Fellmann, Agnieszka Damrogstad, Peter Aidt, Francisco Maroto, Jesus Barrenechea
Workshop on “Denmark on technological GHG emissions mitigation options for the EU agriculture sector”
Seville, 16 June 2015

Major objectives of EcAMPA 2

- Improving the CAPRI model with respect to GHG emission accounting and especially the implementation of endogenous technological mitigation options.
- Improving the estimation of emission leakage:
  - taking into account potential emission efficiency gains in non-EU production regions.
- Applying (testing) the improved CAPRI model to provide a quantitative analysis of illustrative GHG mitigation policies for EU agriculture:
  - Analysis of a mix of policy options regarding emission reduction targets, mitigation options and technological development.

The modelling approach

Supply
Regional optimisation models
Passes in sub-model

Quantities

Comparative Static Equilibrium

Market
Multi-commodity spatial market model

Prices

Calculations of activity based agricultural emission inventories

- Regional supply models in CAPRI capture links between agricultural production activities in detail.
- Based on production activities, inputs and outputs defining agricultural GHG emission factors.
- Detailed nutrient flow model per activity and region (including explicit feeding and fertilising activities, i.e. balancing of nutrient needs and availability).
- GHG emissions module: endogenous calculation of GHG emission coefficients following IPCC guidelines (mostly Tier 2).
- Emission inventories are calculated for Nuts 1 and Nuts 2 regions.

- Explicit introduction of technological mitigation options (non-CO2).
- Explicit introduction of mitigation policies (in the form of “policy constraints”).

Technological GHG mitigation options in EcAMPA 2

1. Anaerobic digestion: farm scale
2. Better timing of fertilization
3. Nitrification inhibitors
4. Precision farming
5. Variable Rate Technology
6. Increasing legume share on temporary grassland
7. Rice measures
8. Following harvest
9. Low nitrogen feed
10. Feed additives: Inseed
11. Genetic improvements: increasing milk yields of dairy cows
12. Genetic improvements: increasing ruminant feed efficiency
13. Feed additives: nitrate
14. Vaccination against methanogenic bacteria in the rumen

Background of EcAMPA 2

- CAPRI (Common Agricultural Policy Regional Impact Analysis) modelling system:
  - An economic large-scale, comparative-static, global multi-commodity, agricultural sector model.
  - Focus on EU-28, but CAPRI is a global agricultural commodity model (bilateral trade for major commodities).
  - CAPRI consists of two interacting modules: the supply module and the market module.

The modelling approach

Technological GHG mitigation options in EcAMPA 2

- For the underlying assumptions, we rely:
  - mainly on GAINS data from 2013, and the updated version of GAINS 2015, but
  - also on information collected within the AnimalChange project, and
  - additional expert information, provided e.g. by KTBL.
- Main data provided by these sources per technology:
  - Gross costs, revenues, cost savings, mitigation potential
- CAPRI uses gross costs or net costs for calibration
  - Net costs = Gross costs – cost saving
  - Where applicable cost savings are calculated endogenously (e.g. for fertilizer related measures and feed additives).
Modelling costs and uptake of mitigation technologies

- Production and cost functions in CAPRI are non-linear.
  - i.e., CAPRI considers that additional costs (may) exist that are not included in the pure accounting cost statistics (and these costs increase more than proportionally when production/uptake of technologies expands).
  - Costs provided in databases are usually based on average values for the entire farm sector, not considering farms/farmer specifics.

- Application of mitigation technologies depends on incentives
  - For commodity production, “responsiveness” to economic and political incentives is expressed in terms of (price-supply) elasticities.
  - For mitigation technologies, “responsiveness” is expressed in terms of an increase in uptake of a mitigation technology if a certain subsidy is granted for mitigation.

Representation of mitigation cost curves in CAPRI with zero initial implementation of a technology

EcAMPA 2 results:
Contribution of each technology to total mitigation, EU-28 (2030)

More information/data needed for each technological mitigation option:

- How? How does applying the mitigation option lead to lower GHG emissions?
- How much? Quantification of the reduction (potential) of the technology.
- Cross-over effects? Positive and/or negative cross-over effects that need to be considered (are they quantified regarding emissions)?
- Costs and benefits? Which costs (e.g., for the technology itself, application, etc.) and possible benefits (e.g., yield increases) are comprised?
- Who? For which farmers are the technological options relevant (e.g., does it require a certain farm size, etc.)?

Representation of mitigation cost curves in CAPRI with positive initial implementation of a technology

Counterfactual scenarios in EcAMPA 2

Limitations:

- Weak empirical basis
  - Empirical evidence for the specification of the values for the relative subsidies assumed in the modeling approach is difficult to come by or is non-existent.

Limitations of the datasets used:

- More information is particularly needed with respect to costs, benefits and uptake barriers of technological mitigation measures.

CAPRI output data that could be used to generate a dataset on mitigation technologies:

- Application rates and sectoral mitigation (potential) under specific scenario assumptions
  - At MS and Nuts-2 level
- Possible effects on agricultural production
  - Including cross-over effects (like e.g., reduced productivity gains or market effects that might diminish the actual emission reduction achieved by applying a technology).
MITERRA Model. Jan Peter Lesschen (Alterra - Wageningen UR)

**MITERRA-Europe**

Assessment of mitigation technologies

Jan Peter Lesschen, Igor Staritsky, GerardVelthof, Peter Kulkman and Gene Oenema

Alterra, Wageningen University and Research, The Netherlands

A model for integrated assessment of N, P and C emissions from agriculture in EU at Member State and regional levels (NUTS-2)

Developed for the European Commission

Simple and transparent model; uniform approach for EU

Scenario, measure and policy analysis

Outputs: N, P and C balances, emissions of N$_2$O, NH$_3$, NO$_x$, CH$_4$, CO$_2$, N leaching and runoff, changes in SOC stocks

Velthof et al., 2009. J. Envi. Qual. 38: 402-417

Lesschen et al., 2013. Annu. Rev. Plant. 64: 157-171

Previous projects

- SC Ammonia – reduction NH$_3$ emissions
- PICCMAT – mitigation potentials agronomic measures
- CCAT – environmental impacts cross compliance
- PBL study – GHG emission scenarios EU-27
- PBL study Protein puzzle – livestock GHG emissions
- Renewable Energy on farms
- Bioenergy assessment EEA
- DG ENER study Carbon impact of biomass use
- AnimalChange – mitigation options dairy sector
- SmartSoil – soil carbon measures based on RothC

Relevant references MITERRA-Europe


Mitigation technologies – PICCMAT study

- Zero tillage
- Reduced tillage
- Catch crops
- Rotation species
- Adding legumes
- Agroforestry
- Grass in orchards
- Crop residue management
- Optimised fertilizer application
- Fertilizer type

First study providing detailed mitigation potentials for EU for specific agronomic measures

SOC based on IPCC stock change approach

IPCC Tier 1 EF for N$_2$O emissions

Only limited data on implementation of measures

Better estimates can be made now
- Soil carbon emissions based on RothC modelling
- LUCAS soil properties data set
- SAPM data set on current implementation of measures
Mitigation technologies for dairy MACC

- Optimal N fertilisation
- Reduced tillage
- Cover crops
- Reduced fertilisation during winter period
- Animal breeding for reduced enteric CH₄
- Dietary lipids
- Dietary nitrate
- Dietary tannin
- Dietary probiotics

Relevant data sets

- CAPRI on activity data for crops and livestock (especially projections)
- Survey on Agricultural Production Methods (SA/MM)
  - Included in 2010 FFS
  - Information on tillage practices, soil cover, crop rotations, irrigation and manure management
- Farming systems data (SEAMLESS project)

Conclusions

- MITERRA is well developed to assess environmental impacts of mitigation technologies at EU and national scale
- A wide range of measures can be assessed and implementation of new measures is relatively simple
- Economic / cost dimension is not assessed
- Depending on other models for projected activity data
- Data collection should focus on current management data (crop, livestock and soil)

Other mitigation technologies

- NH₃ and NOₓ leaching abatement options
- Based on Hou et al. (2016) feed options can be assessed (not completely implemented yet)
- Grass legume mixtures on temporary pastures
- Detailed crop residue management for straw crops and perennials (S2BICOM project)
- Anaerobic digestion (RE on Farm study, 2011)
  - Will be updated now based on the DG Energy Biogas study
- Other measures (e.g. nitrification inhibitors) can be relatively simple added

Relevant data sets

- GIS data
  - Environmental zones
  - ES26 (soil data)
  - Climate data
- LUCAS soil data
  - 32000 sample locations
  - All EU countries
  - Linked to land use
  - Sampled in 2009 and currently resampled
  - Less useful for management data
- Cool Farm tool?

Questions?

Janpeter.Lesschen@wur.nl
The Global Livestock Environmental Assessment Model. Anne Mottet (FAO)

GLEAM - Global Livestock Environment Assessment Model
A GIS tool initially developed to improve the understanding of GHG emissions in livestock supply chains, extended to natural resource use efficiency: feed, land use, nitrogen.
- Life Cycle Assessment modelling, all steps of production, all major sources of emissions
- Computes livestock production and IPCC Tier 2 emissions at various levels (fields on a map)
- Can generate average and ranges at different scales
- Allows for scenario analysis and assessment of mitigation options
- Developed at FAO, in collaboration with other partners

GLEAM input data
- 5 km at the equator
- Primary data: animal numbers and distribution, herd parameters, mineral fertilizer application rates, crop yields, etc.
- Intermediate data: animal growth rates, feed rations, animal energy requirements, etc.

GLEAM input data
- Gridded Livestock of the World
- Sere & Steinfield system classification:
  - Grazing and mixed ruminant systems
  - Backyard, intermediate & industrial pig systems
  - Backyard, layers & broilers chicken systems

GLEAM input data
- Fertility, growth rate, replacement rate...
- Specific to production systems and animal index zones
- Extensive literature research, expert consultation and surveys
- Specific to cohorts, production systems and regions
- 2 methods OECD/non OECD countries
- Result of intermediate calculations in GLEAM, literature search, surveys and expert knowledge
- Dry matter yield/ha (GAEZ), net energy content, N content

GLEAM input data
- IPCC (2006) Tier 2 requires the animal population to be categorized into distinct cohorts (types, weights, phase of production...)
  But data on animal herd structure generally not available

GLEAM herd module: 6 cohorts
- Key production parameters: mortality, fertility, growth and replacement rates, age or weight at which animals transfer between categories (e.g. legal weight partitioning), duration of key periods (e.g. gestation), and the rate of breeding transitions to male.
• Calculation of animal energy requirement for each cohort (Tier 2)
  Gross energy requirement = maintenance + lactation and pregnancy + animal activity + weight gain and production.
  No IPCC equation for calculating energy requirement of pigs or poultry
  Derived from IPCC (1996) for pigs and FAO (2001) for chickens

• Calculation of feed intake, total feed emissions and land use (Tier 2)
  Feed intake of each animal category (in kg DM/day), animal’s energy requirement / average energy content of the ration

• CH4 emissions arising during manure management (Tier 2)
  Proportion of volatile solids converted to CH4 during manure management: Equation 10.23 IPCC (2006)
  CH4 conversion factor: IPCC (2006, Table 10A-7)
  Proportion of manure managed in each system: official statistics (such as the Annex 1 countries’ National Inventory Reports to the UNFCCC), other literature sources and expert judgement. IPCC systems challenging.

• N2O emissions arising during manure management (Tier 2)
  N excretion: Equation 10.31 IPCC (2006) as the difference between intake and retention.
  N intake depends on the feed: dry matter intake and the N content per kg of feed.
  Rate of conversion of excreted N to N2O IPCC (2006): default emission factors for direct N2O (Table 10.21, IPCC 2006) and indirect via denitrification (Table 10.22, IPCC 2006) + variable leaching rate, depending on the ACC

Diversity in livestock production systems is a challenge for GHG emissions reporting and an opportunity for mitigation

Feed digestibility for dairy cattle

Methane conversion factor for dairy cattle

Case studies: mitigation POTENTIAL

Source: GLAM

Mottet et al., 2016, REEC
GLEAM - Summary

- Global and Tier 2
- Spatially explicit: emissions and production computed at pixel level, can generate ranges and averages at different levels (country, production system, region etc.)
- Biophysical: reproduces all stages of livestock supply chains in an LCA approach
- Mitigation scenarios: wide range of options and can be coupled with other models (e.g. grassland models for excretion, economic data for NMRIC)
- Can be used to generate Tier 2 EF databases but also livestock herd disaggregation, global food ratios, methane conversion factors from manure etc.
- Main limitation: accuracy of input parameters need to be refined when working at country level because results quite sensible to certain parameters (yields, digestibility etc.)

Thank you

www.fao.org/gleam
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