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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_2O) 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-CO_2 and CO_2 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, ease of use, employment creation, a measurement of the ease of 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. subsides 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 (CO_2) emissions. Although the vast majority of GHG emissions from agriculture are non-CO_2 emissions, namely methane (CH_4) and nitrous oxide (N_2O), the ability to model CO_2 agricultural emissions/removals can improve the understanding on the abatement potential of different mitigation options. Moreover, including CO_2 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-CO_2 and CO_2 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 (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 21st 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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[1] Commission decision of 26 March 2013 on determining Member States' annual emission allocations for the period from 2013 to 2020 pursuant to Decision No 406/2009/EC of the European Parliament and of the Council (2013/162/EU). Official Journal of the European Union, L90, 106-110

[2] Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community’s greenhouse gas emission reduction commitments up to 2020. Official Journal of the European Union, L140, 136-148

[3] Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources; OJ L 375, 31.12.1991, p. 1–8

[4] Regulation (EU) No 1307/2013 of the European Parliament and of the Council of 17 December 2013 establishing rules for direct payments to farmers under support schemes within the framework of the common agricultural policy and repealing Council Regulation (EC) No 637/2008 and Council Regulation (EC) No 73/2009. Official Journal of the European Union, L347, 608-670

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[5].

The submission of the EU's INDC is based on the EU 2030 Climate and Energy Framework[6] , 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 CO_2 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 CO_2 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[7].

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

[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

croplands and grasslands). Flexibilities are also included in the proposal to meet the "no-debit" commitment. For example, when net CO_2 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 them[8].

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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[8] European Commission - Fact Sheet: Proposal to integrate the land use sector into the EU 2030 Climate and Energy Framework. Brussels, 20 July 2016. http://europa.eu/!gx39Yq

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_2O), methane (CH_4) and carbon dioxide (CO_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_2O)

Globally, agriculture contributes about 60% of the total anthropogenic N_2O emissions (Ciais et al., 2013). Diverse agricultural activities (e.g. fertilization) increase nitrogen availability in soils, which leads to an increase of N_2O emissions due to nitrification and denitrification processes. N_2O 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_2O 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_2O emissions from N-fertilizers production and use. **Nitrification inhibitors** temporarily suppress the microbial conversion of ammonium (NH_4+) to nitrite (NO_2-) in soil, decreasing direct N_2O 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 N_2O emissions are derived from applied mineral fertilisers and about 24% are indirect emissions from nitrate leaching and NH_3 volatilization. Nitrification inhibitors (NI) block or slow down the first step of the nitrification process where N_2O emissions are released from soil. NI are also capable to abate N_2O 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 N_2O emissions from agricultural soils (Ruser and Schulz, 2015) Abatements could be even larger when also considering N_2O 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 (CH_4)

CH_4 emissions represent 54.5% of total EU agriculture emissions (EEA, 2016). There are two main sources of agricultural CH_4 emissions in the EU: enteric fermentation in ruminants and manure management. Enteric fermentation is the largest source of CH_4 emissions, representing about 2% of total EU GHG emissions, 18% of total EU CH_4 emissions and 43% of total agricultural emissions. CH_4 emissions from manure management represent 0.5% of total GHG emissions, 4% of total EU CH_4 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 CH_4 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 practises 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 energy[9]) 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 KtCO$_2$eq 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).

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[9] Draft of final report submitted to DG Energy by Wageningen UR: Biogas beyond 2020 - Technical assessment study for biogas optimal use in the EU post-2020

3.3 Technological mitigation options for carbon dioxide (CO_2)

Carbon dioxide (CO_2) is the primary GHG emitted through human activities, mainly from transportation. While the agricultural sector is a major source of non-CO_2 emissions, its share in total CO_2 emissions is rather low. However, the agricultural sector has a large potential as a carbon sink to reduce GHG emissions. The implementation of CO_2 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 CO_2 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 CO_2 emitted when comparing with tillage operations (6.7 and 10.5 fold-increase by disc harrow and mouldboard application respectively; Life + Agricarbon[10] 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 CO_2 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.

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[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 CO_2 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 kitchengardens 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 e 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. Presumable, 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-CO_2 GHG emissions: 2010-2030

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

Non-CO_2 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 CH_4), waste (e.g. solid waste management releases CH_4, and wastewater CH_4 and N_2O), agriculture (CH_4, N_2O), and industrial processes (N_2O, PFCs, SF_6, HFCs). USEPA (2013) has reported that the total technically feasible global mitigation potential from non-CO_2 GHG gases for all these sectors is over 3,500 $MtCO_2e$ in 2030. The agriculture sector (cropland, livestock and rice) is estimated to be able to provide reductions of more than 500 $MtCO_2e$ at costs under \$30/tCO_2e.

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, N_2O and CH_4 emissions, and soil C stocks; ii) DNDC (Denitrification-Decomposition) Model for rice cultivation, a biophysical model used to simulate production, crop yields, CH_4, N_2O 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 CH_4 emissions from enteric fermentation (improved feed conversion, antibiotics, bST, propionate precursors, antimethanogen, intensive grazing) and 10 mitigation options for CH_4 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, 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 $MtCO_2e$ for cropland (4% of global non-CO_2 GHG emissions), 756 $MtCO_2e$ for rice cultivation (6% of global non-CO_2 GHG emissions) and 2,729 $MtCO_2e$ 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** from US Department of Agriculture

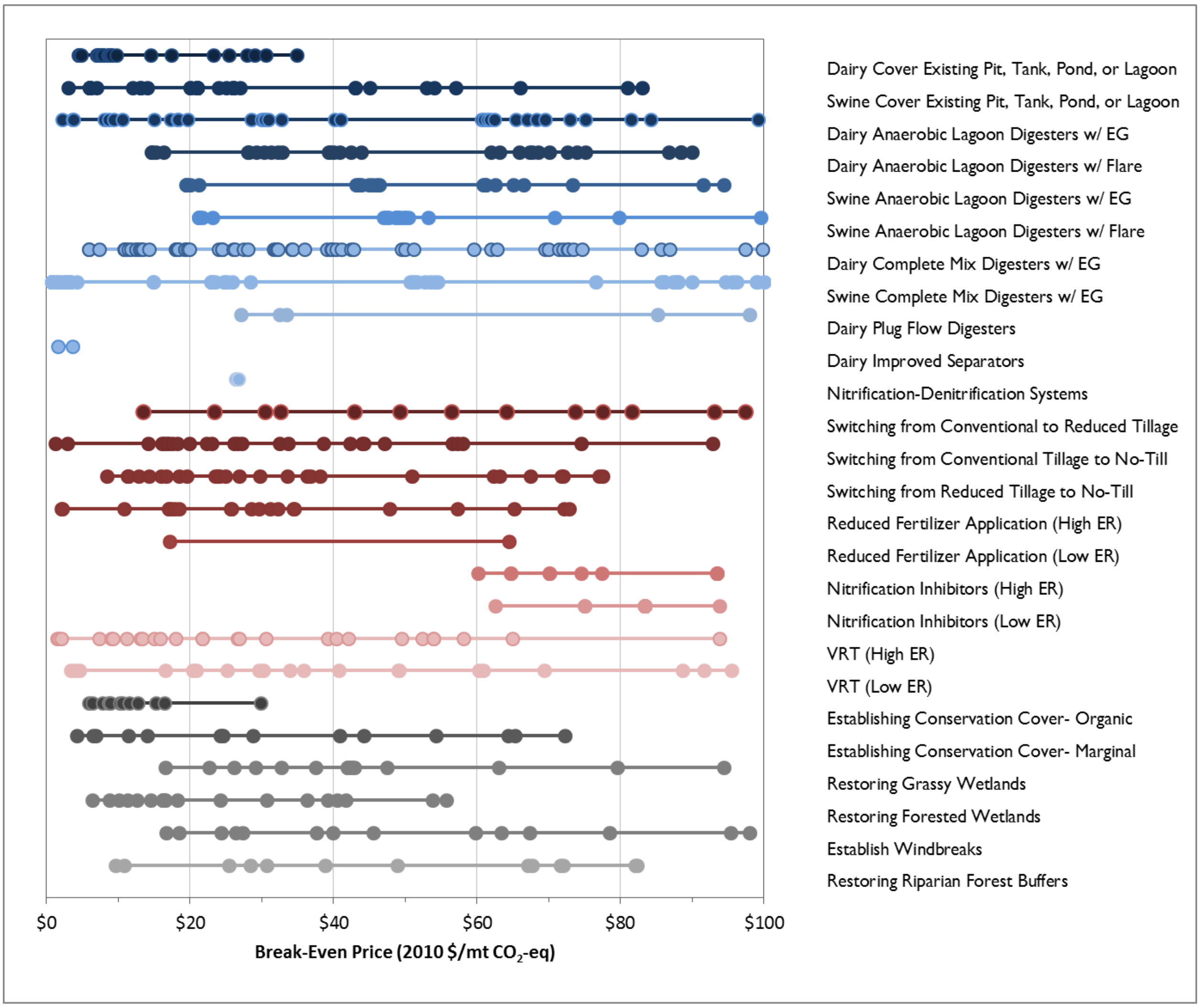
This presentation highlighted results of two reports jointly produced by USDA's Climate Change Program Office and ICF International. The overall goal of the two reports was to assess how agricultural producers might respond to incentives to adopt production and land management practices and technologies 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 CO_2 prices (below \$20 per mt CO_2e) and farms that would require a prohibitively high CO_2 price (above \$40 per mt CO_2e). Additionally, for a given CO_2 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 CO_2 prices ranging between \$0 and \$100 per mt CO_2e (the aggregate MACC for U.S. agriculture is shown in the presentation). The MACCs are developed by combining the CO_2 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 CO_2 prices increase, more mitigation options become economically rational to be adopted by farms. The MACC for U.S. agriculture shows that at a CO_2 price of \$100 per mt CO_2e, farms supply total GHG mitigation of about 120 Tg CO_2e. The MACC also indicates that the GHG mitigation potential from U.S. agriculture increases relatively gradually up to a CO_2 price of between \$30 and \$40 per mt CO_2e. At the \$40 price, U.S. farms supply mitigation of about 100 Tg CO_2e, which is already about 83% of the mitigation indicated at a price of \$100 per mt CO_2e. Above \$40 per mt CO_2e and 100 Tg CO_2e, 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 CO_2 fall in the range of \$30 to \$40 per mt CO_2. 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 CO_2costs. Above 100 Tg CO_2e, however, achieving additional mitigation in agriculture will probably be relatively expensive compared to mitigation options in other sectors. For a CO_2 price of \$20 per mt CO_2e, 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 CO_2e 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.

Figure 1: Summary of CO_2 break-even prices by GHG mitigation technology or practice



Abbreviations: **w/EG** means "with electricity generation"; **high ER** means local conditions result in relatively "high emission reductions"; **low ER** means local conditions result in relatively "low emission reductions"; **VRT** means "variable rate technology." Source: ICF (2013).

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, CO_2 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 $MtCO_2e$), nitrification inhibitors (2.5 to 9.8 $MtCO_2e$), fallowing of histosols (6.4 to 9 $MtCO_2e$), precision farming (4.9 to 16.6 $MtCO_2e$) and linseed as feed additive (2.3 to 7.4 $MtCO_2e$).

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 N_2O, NH_3, NO_X, CH_4, CO_2, 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 (NH_3 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 N_2O 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

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[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 CO_2 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.

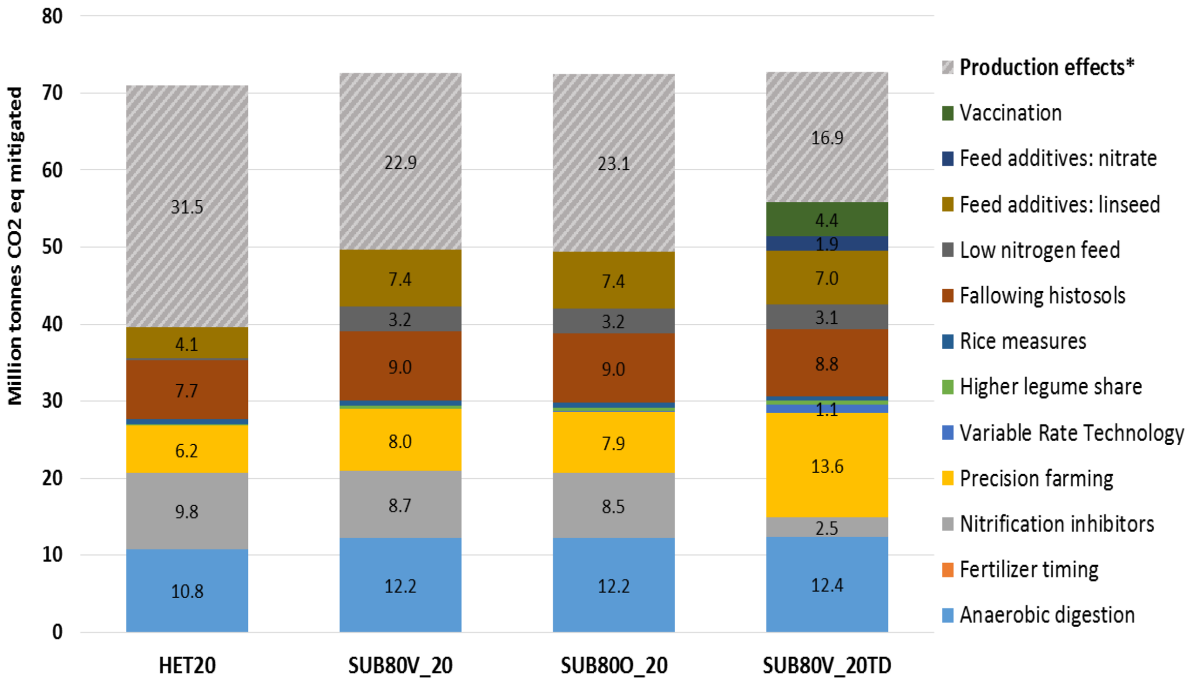
5 Priorities and road-map for dataset construction (Fourth Session)

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-CO_2 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-CO_2 and CO_2 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)



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

land related non-CO_2 technologies	**livestock related non-CO_2 technologies**	**CO_2 related technologies**
Fallowing histosols	Anaerobic digestion	Fallowing histosols
Nitrification inhibitors	Feed additives (linseed)	Grassland management*
Precision farming	Low nitrogen feed	Conservation agriculture*
Variable Rate Technology	Vaccination	
Higher legume share	Feed additives (nitrate)	
Rice measures		

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/ practises 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-CO_2 technological mitigation options or should technologies and practices reducing CO_2 emissions also be integrated?"

Participants agreed on the importance of including CO_2 emission mitigation in the datasets. Although the non-CO_2 emissions are the main GHG released from agriculture, technologies and practices reducing CO_2 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 manly 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_2 and CO_2 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.

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Annex I: Workshop Agenda

08:45 - 9:15	***Registration***	***All participants***
9:15 – 9:45	**Introduction to the workshop** **Chair: Giampiero Genovese (JRC-Seville)**	
9:15 - 9:25	Welcome and introduction to the workshop	Giampiero Genovese (JRC-Seville)
9:25 - 9:35	Overview of JRC research on Climate Change & Agriculture	Emilio Rodríguez-Cerezo (JRC-Seville)
9:35 - 9:45	Workshop objectives, structure and organization	Iria Soto-Embodas (JRC- Seville)
9:45 – 12:15	**Session 1: Examples of existing data (adoption, costs and mitigation potential) of technological mitigation options in the EU** **Chair: Thomas Fellmann (JRC- Seville)**	
9:45 - 10:15	Technological mitigation options for nitrous oxide (N_2O): Variable Rate Fertilization and nitrification inhibitors	Ulrich Adam (CEMA); Andreas Pacholski (EurochemAgro)
10:15 - 10:45	Technological mitigation options for methane(CH_4): On-farm anaerobic digesters and manure management	Philip Jones (Reading University); Jan Peter Lesschen (Wageningen UR)
10:45 – 11:15	***Coffee break***	
11:15- 11:45	Technological mitigation options for carbon dioxide (CO_2): Conservation agriculture and agroforestry systems	Emilio González (ECAF); Rosa Mosquera (EURAF)
11:45- 12:15	Discussion	All participants

12:15 – 16:00	**Session 2 : Existing datasets and models on mitigation technologies** **Chair: Ignacio Pérez-Domínguez (JRC- Seville)**	
12:15 - 12:35	Global Mitigation of Non-CO_2 GHG emissions	Shaun Ragnauth (EPA)
12:35 - 12:55	US GHG Mitigation Options and Costs for Agricultural Land and Animal production	Jan Lewandrowski (USDA)
12:55 - 13:15	Mitigation Options for the Agricultural Sector: The Spanish Roadmap	María Jose Alonso Moya (OECC)
13:15 – 14:15	***Lunch break***	
14:15 - 14:35	Economic assessment of EU mitigation policy options with the CAPRI model	Thomas Fellmann (JRC- Seville)
14: 35 - 14:55	MITERRA Model	Jan Peter Lesschen (Wageningen UR)
14:55 - 15:15	The Global Livestock Environmental Assessment Model	Anne Mottet (FAO)
15:15 - 16:00	Discussion	All participants
16:00– 16:30	***Coffee break***	
16:30 – 18:00	**Session 3: Priorities and road-map for dataset construction** **Chair: Manuel Gómez- Barbero (JRC- Seville)**	
16:30 - 17:00	Brainstorming session on dataset construction and assumptions	All participants
17:00 - 17:30	Setting up working road-map	All participants
17:30 - 18:00	Wrap-up and overall conclusions of the meeting, calendar for contributions and next steps	All participants
21:00	***Networking dinner***	

Annex II: List of participants

Participant/Speaker	Organization	E-mail
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Annex III: Presentations

All presentations can be downloaded at the following link.

Variable Rate Fertilization & Precision Agriculture. Ulrich Adam (CEMA)

Technological mitigation options for nitrous oxide (N_2O): Variable Rate Fertilization & Precision Agriculture

Ulrich Adam
14 June 2016

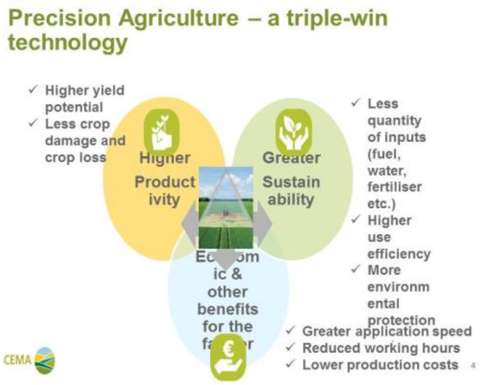
CEMA – the voice of the manufacturers of agricultural machinery in Europe (www.cema-agri.org)

1. **4,500 manufacturers**
2. **450 machine types**
3. **€26 billion annual turnover & 260,000 people employed**

European Agricultural Machinery: global leader in production + innovation

- → **World's largest producer of farm equipment** (31% of global production)
- → **2nd highest-ranking** European industry in terms of **innovativeness + competitive advantage**
- → **Over €10 Billion Investment in R & D Over The Last 5-6 Years**

Source: European Commission, 2013 Competitiveness Report



Precision Agriculture – a triple-win technology

- ✓ Higher yield potential
- ✓ Less crop damage and crop loss

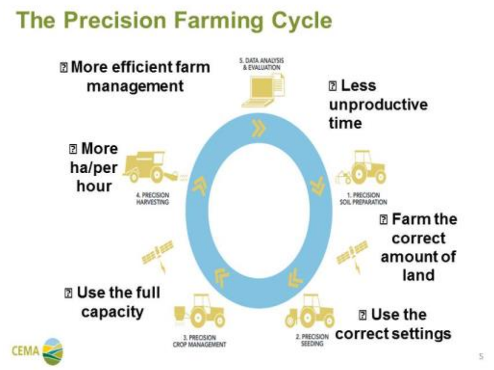
Higher Productivity

Greater Sustainability

Economic & other benefits for the farmer

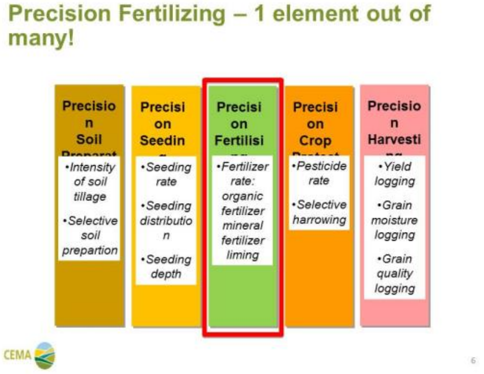
- ✓ Less quantity of inputs (fuel, water, fertiliser etc.)
- ✓ Higher use efficiency
- ✓ More environmental protection

- ✓ Greater application speed
- ✓ Reduced working hours
- ✓ Lower production costs



The Precision Farming Cycle

- ⍰ More efficient farm management
- ⍰ Less unproductive time
- ⍰ More ha/per hour
- ⍰ Farm the correct amount of land
- ⍰ Use the full capacity
- ⍰ Use the correct settings



Precision Fertilizing – 1 element out of many!

Precision Soil Preparat	Precision Seedin	Precision Fertilisi	Precision Crop Protect	Precision Harvesting
•Intensity of soil tillage •Selective soil prepartion	•Seeding rate •Seeding distribution •Seeding depth	•Fertilizer rate: organic fertilizer mineral fertilizer liming	•Pesticide rate •Selective harrowing	•Yield logging •Grain moisture logging •Grain quality logging

The Fertilization Challenge: how closely can we look at & treat plants?

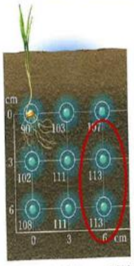
UK Trade & Invest

http://www.nue.okstate.edu/Small_scale_variability.htm

Management Challenges for Variable-Rate Fertilisation (VRF)

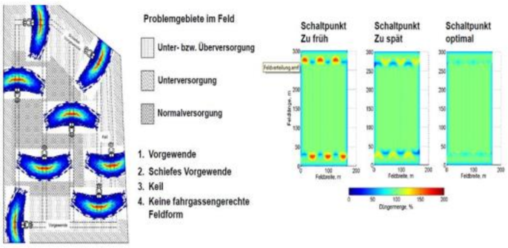
Conventional or traditional field management	Field *One rate*
Optimised management	Sub-Field *Variable rate*
Single plant management	Single plant *Individual rate*
Leaf scale management	Leaf *Leaf rate*

Precision Fertilization: in combined seeding, a difference of 3-6cm can mean a -10% decline or +13% increase in yield!



Research has shown that the yield increase is highest if the fertiliser is placed a few centimetres deeper and to the side of the seed (spring-sown crops).

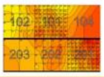
Variable Rate Fertilization (VRF): achieving the optimal spread



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
   - EM 38
   - yield maps

1. VRF: schematic overview



Ever more complex algorithms

- **Increasing agronomic intelligence per square meter…**

- **Ever more targeted VRT application!**

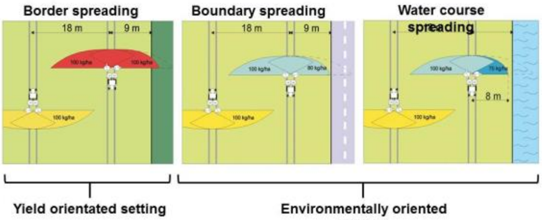
- Mapping & analysis of
  - Accurate soil data
  - Accurate nutrient/sensor data
  - application data
  - yield data

- Adopting inputs (intensity, amounts) to site-specific conditions within a field:
  - soil properties
  - water content
  - nutrient status
  - organic matter

1. VRF: advanced spreader technology

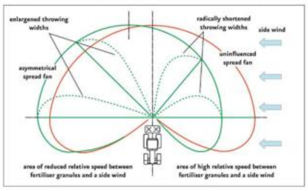
- Once it is clear what amount is to be spread per "square", the fertilizer spreader can dispense accordingly with automated techniques.
- **Smart spread:** the required mass flow for precise dosing leads to an accurate application "per square meter" if the spreader adjusts the spread depending on the 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 section control in order to avoid double fertilization. In the next few years, the **fully automatic self-adjusting spreader** will gain prominence.

1. VRF: achieving exact boundary spreading

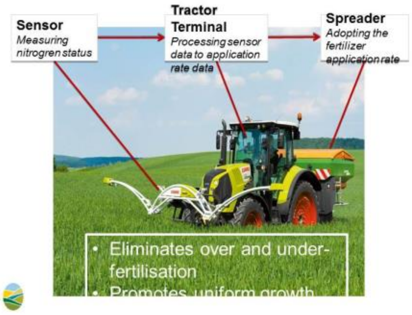


1. VRF: achieving exact boundary spreading even in windy conditions

- Weather station calculates spreading fan adjustment to correct wind drift

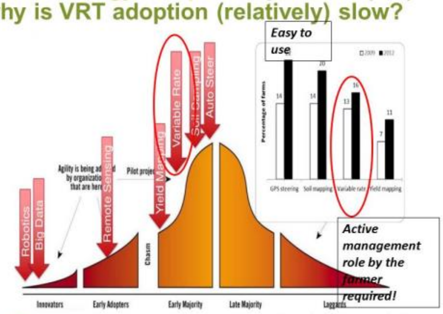


1. VRF: N-sensor



- Eliminates over and under-fertilisation
- Promotes uniform growth

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

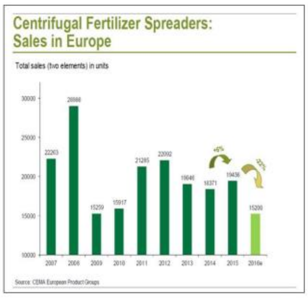


Easy to use

Active management role by the farmer required!

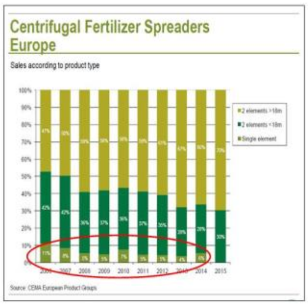
Source: *Clive Blacker, UK Trade & Investment, Based on: Defra 2013, Farm*

2. VRF uptake in Europe



2. VRF uptake in Europe

2. VRF uptake in Europe

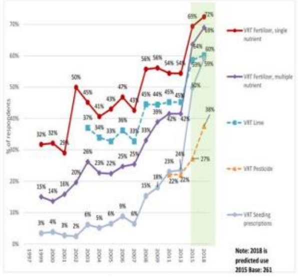


2. VRF uptake dynamics in Europe

- **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 liences 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!!!**

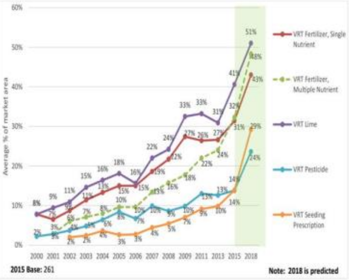
2. VRF uptake in the US – dealer service provision of VRF 1997-2015



Note: 2018 is predicted use
2015 Base: 261

Figure 14. Precision Ag Services Offered Over Time, Site-Specific Technologies.

2. VRF uptake in the US: arable area using VRF



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.

3. Costs of VRF technology – investment costs

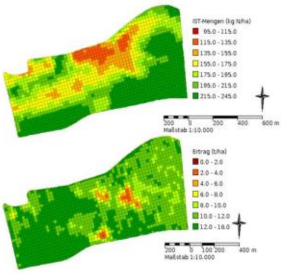
- Purely for VRF, cost savings may not justify initial investments in the equipment, yet several components (like satellite navigation, mapping costs and board computers) can be used in various PF applications.
- Other (non-agronomic/economic/environmental) benefits of VRF:
  - Evidence of compliance 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

Benefits of Precision Fertilizing

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

Cost-benefit case example 1

Site specific fertilising with costumary fertilized monitoring plots



<u>Site specific benefit:</u>
98 €/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

<u>Results:</u>

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

(Source: England Catchment Sensitive Farming Delivery Initiative)

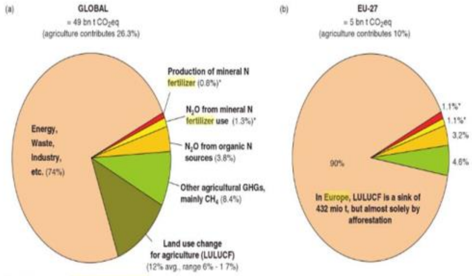


Figure 3.1 Estimated greenhouse gas emissions from production and use of mineral N fertilizers (in CO_2-equivalents) together with other agricultural activities and land use change for agriculture at (a) the global and (b) EU-27 scale (all 27 member states of the European Union as of 2007). Order of contributions in (b) the same as in (a). From Brentrup and Palliere (2008), based on IPCC (2007), Bellarby *et al.* (2008), UNFCCC (2008) and * author calculations.

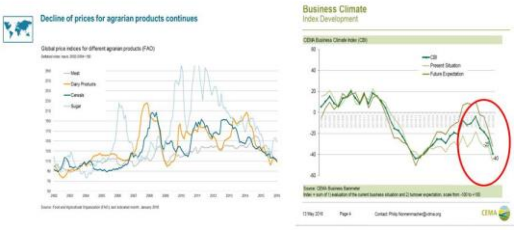
4. GHG emissions mitigation potential of VRF technologies

- Less energy use and less fertilizer use will contribute to less emission of greenhouse gasses, slowing down climate change and contributing to global objectives on this topic.
- Summary study by Diacono et al., 2013 on precision Nitrogen 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 saved N fertilizers, from 10 % to about 80 % less N, and reduced residual N in the soil by 30–50 %, without either reducing yields or influencing grain quality;
  - Precision N management based on real-time sensing and fertilization had the highest
  - profitability of about $5–$60 per ha compared to undifferentiated

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.a. (Cyclical) farm income situation/investment capacity of farmers



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

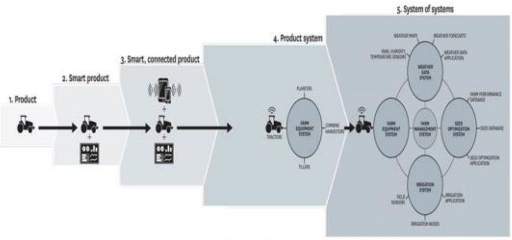
Cost:

- 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

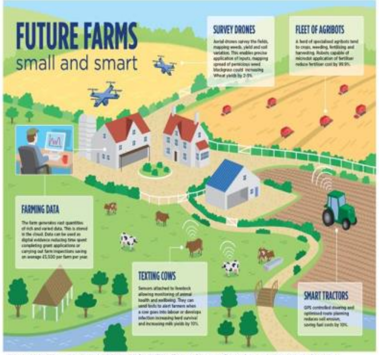
Digitisation: smart agricultural machinery & the Internet of Things (IoT)



Adapted from: Porter and Heppelmann: How Smart, Connected Products Are Transforming Competition, Harvard Business Review, 2014, https://hbr.org/2014/11/how-smart-connected-products-are-transforming-competition

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
  - **Int** aring & p s etc.
  - Bits it be really f ll sca



Source: http://www.nesta.org.uk/sites/default/files/future_farms_infographic_precision_agriculture.jpg

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 VRF/Precision Fertilising
  - No representative/aggregated data for regions/countries
  - Uptake barriers for different PA technologies
- CEMA study on CO2 reduction p machinery (3-year study, starts
- H2020 smartAKIS project (uptak

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)

Thank you!

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

CEMA web-portal on Precision Farming

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- Discover what smarter, more productive & sustainable farming is all about!

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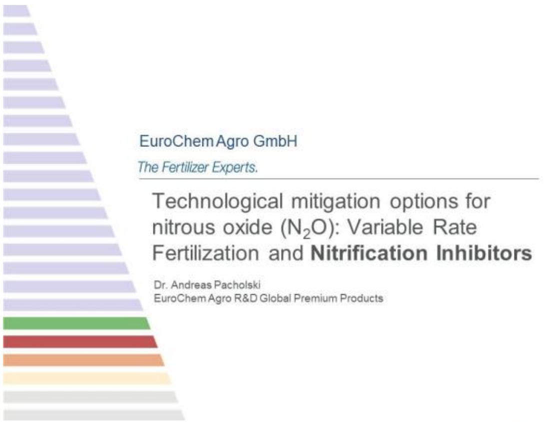
Variable Rate Fertilization and Nitrification Inhibitors. Andreas Pacholski (EuroChem Agro)

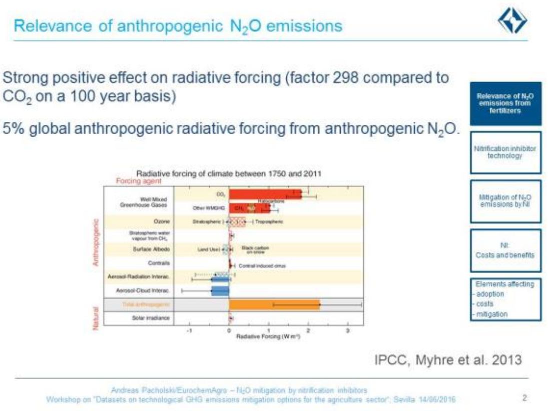


EuroChem Agro GmbH

The Fertilizer Experts.

Technological mitigation options for nitrous oxide (N_2O): Variable Rate Fertilization and **Nitrification Inhibitors**

Dr. Andreas Pacholski
EuroChem Agro R&D Global Premium Products



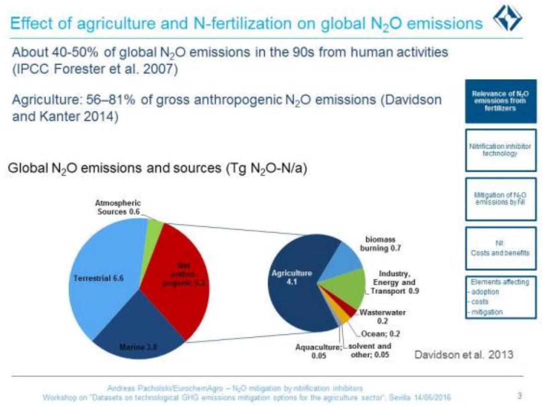
Relevance of anthropogenic N_2O emissions

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.

IPCC, Myhre et al. 2013

Andreas Pacholski/EurochemAgro – N_2O mitigation by nitrification inhibitors
Workshop on "Datasets on technological GHG emissions mitigation options for the agriculture sector"; Sevilla 14/06/2016 2



Effect of agriculture and N-fertilization on global N_2O emissions

About 40-50% of global N_2O emissions in the 90s from human activities (IPCC Forester et al. 2007)

Agriculture: 56–81% of gross anthropogenic N_2O emissions (Davidson and Kanter 2014)

Global N_2O emissions and sources (Tg N_2O-N/a)

Davidson et al. 2013

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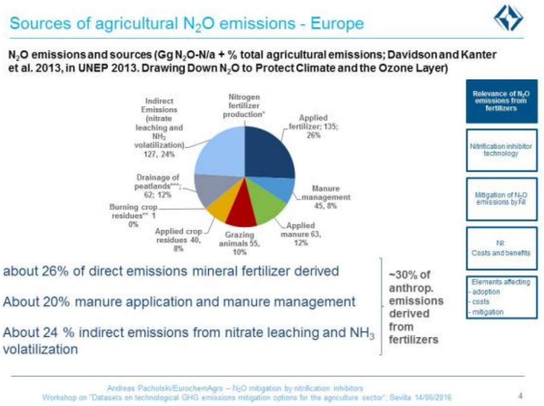

Sources of agricultural N_2O emissions - Europe

N_2O emissions and sources (Gg N_2O-N/a + % total agricultural emissions; Davidson and Kanter et al. 2013, in UNEP 2013. Drawing Down N_2O to Protect Climate and the Ozone Layer)

about 26% of direct emissions mineral fertilizer derived

About 20% manure application and manure management

About 24 % indirect emissions from nitrate leaching and NH_3 volatilization

~30% of anthrop. emissions derived from fertilizers

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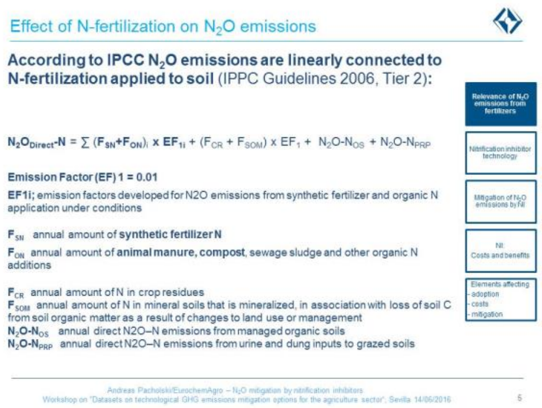

Effect of N-fertilization on N_2O emissions

According to IPCC N_2O emissions are linearly connected to N-fertilization applied to soil (IPPC Guidelines 2006, Tier 2):

$$N_2O_{Direct}\text{-}N = \sum (F_{SN}+F_{ON})_i \times EF_{1i} + (F_{CR} + F_{SOM}) \times EF_1 + N_2O\text{-}N_{OS} + N_2O\text{-}N_{PRP}$$

Emission Factor (EF) 1 = 0.01

EF1i; emission factors developed for N2O emissions from synthetic fertilizer and organic N application under conditions

F_{SN} annual amount of **synthetic fertilizer N**

F_{ON} annual amount of **animal manure, compost**, sewage sludge and other organic N additions

F_{CR} annual amount of N in crop residues
F_{SOM} annual amount of N in mineral soils that is mineralized, in association with loss of soil C from soil organic matter as a result of changes to land use or management
$N_2O\text{-}N_{OS}$ annual direct N2O–N emissions from managed organic soils
$N_2O\text{-}N_{PRP}$ annual direct N2O–N emissions from urine and dung inputs to grazed soils

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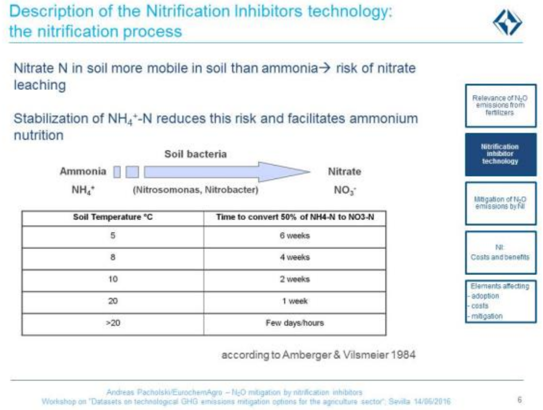

Description of the Nitrification Inhibitors technology: the nitrification process

Nitrate N in soil more mobile in soil than ammonia→ risk of nitrate leaching

Stabilization of NH_4^+-N reduces this risk and facilitates ammonium nutrition

Soil Temperature °C	Time to convert 50% of NH4-N to NO3-N
5	6 weeks
8	4 weeks
10	2 weeks
20	1 week
>20	Few days/hours

according to Amberger & Vilsmeier 1984

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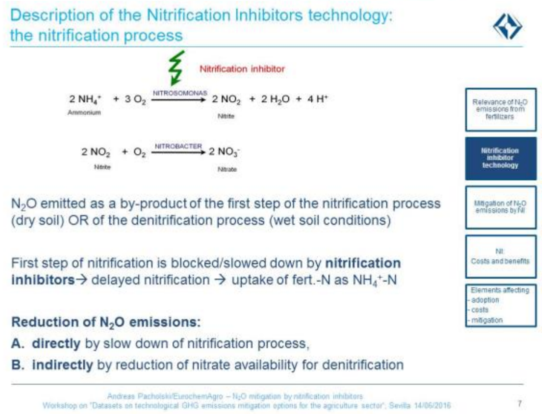


Description of the Nitrification Inhibitors technology: the nitrification process

$$2\,NH_4^+ + 3\,O_2 \xrightarrow{NITROSOMONAS} 2\,NO_2 + 2\,H_2O + 4\,H^+$$

$$2\,NO_2 + O_2 \xrightarrow{NITROBACTER} 2\,NO_3^-$$

N_2O emitted as a by-product of the first step of the nitrification process (dry soil) OR of the denitrification process (wet soil conditions)

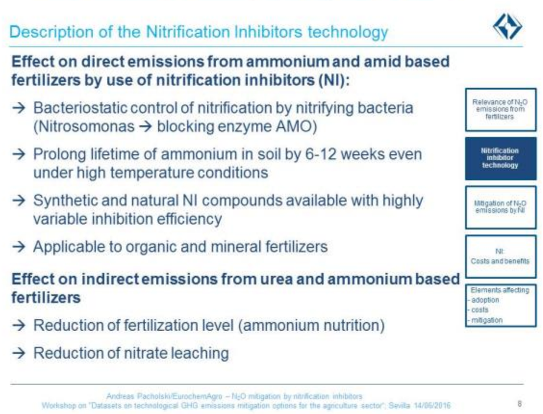
First step of nitrification is blocked/slowed down by **nitrification inhibitors**→ delayed nitrification → uptake of fert.-N as NH_4^+-N

Reduction of N_2O emissions:

A. directly by slow down of nitrification process,

B. indirectly by reduction of nitrate availability for denitrification

Andreas Pacholski/EurochemAgro – N_2O mitigation by nitrification inhibitors
Workshop on "Datasets on technological GHG emissions mitigation options for the agriculture sector"; Sevilla 14/06/2016 7



Description of the Nitrification Inhibitors technology

Effect on direct emissions from ammonium and amid based fertilizers by use of nitrification inhibitors (NI):

→ Bacteriostatic control of nitrification by nitrifying bacteria (Nitrosomonas → blocking enzyme AMO)

→ Prolong 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

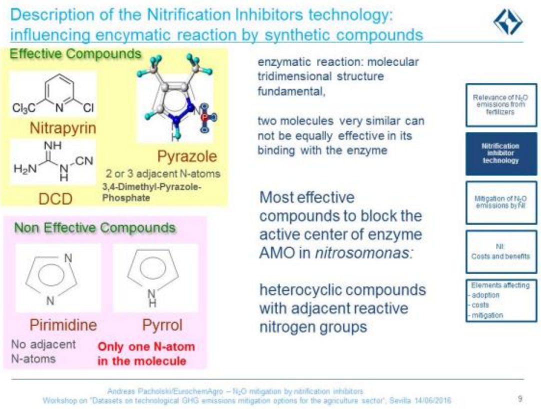
→ Applicable to organic and mineral fertilizers

Effect on indirect emissions from urea and ammonium based fertilizers

→ Reduction of fertilization level (ammonium nutrition)

→ Reduction of nitrate leaching

Andreas Pacholski/EurochemAgro – N_2O mitigation by nitrification inhibitors
Workshop on "Datasets on technological GHG emissions mitigation options for the agriculture sector"; Sevilla 14/06/2016 8



Description of the Nitrification Inhibitors technology: influencing encymatic reaction by synthetic compounds

Effective Compounds

Nitrapyrin

DCD

Pyrazole

2 or 3 adjacent N-atoms

3,4-Dimethyl-Pyrazole-Phosphate

Non Effective Compounds

Pirimidine

No adjacent N-atoms

Pyrrol

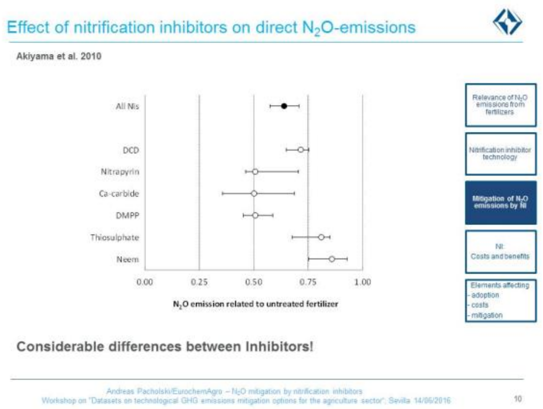
Only one N-atom in the molecule

enzymatic reaction: molecular tridimensional structure fundamental,

two molecules very similar can not be equally effective in its binding with the enzyme

Most effective compounds to block the active center of enzyme AMO in *nitrosomonas:*

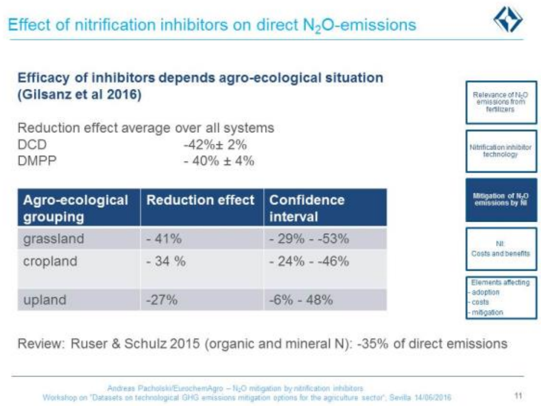
heterocyclic compounds with adjacent reactive nitrogen groups



Effect of nitrification inhibitors on direct N_2O-emissions

Akiyama et al. 2010

Considerable differences between Inhibitors!



Effect of nitrification inhibitors on direct N_2O-emissions

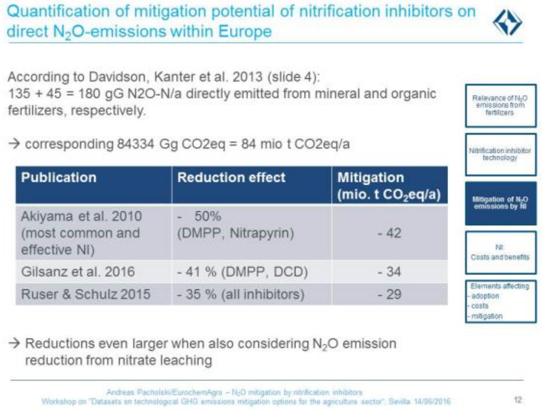
Efficacy of inhibitors depends agro-ecological situation (Gilsanz et al 2016)

Reduction effect average over all systems

DCD	-42%± 2%
DMPP	- 40% ± 4%

Agro-ecological grouping	Reduction effect	Confidence interval
grassland	- 41%	- 29% - -53%
cropland	- 34 %	- 24% - -46%
upland	-27%	-6% - 48%

Review: Ruser & Schulz 2015 (organic and mineral N): -35% of direct emissions



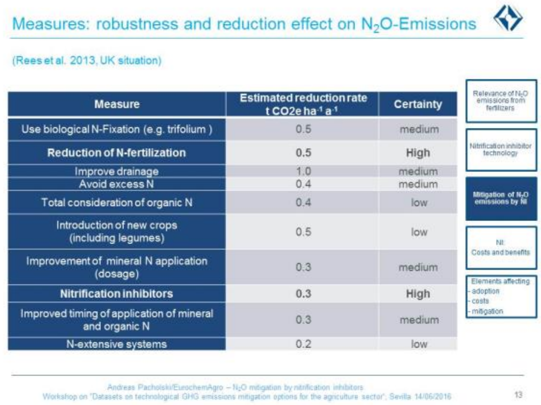
Quantification of mitigation potential of nitrification inhibitors on direct N_2O-emissions within Europe

According to Davidson, Kanter et al. 2013 (slide 4):
135 + 45 = 180 gG N2O-N/a directly emitted from mineral and organic fertilizers, respectively.

→ corresponding 84334 Gg CO2eq = 84 mio t CO2eq/a

Publication	Reduction effect	Mitigation (mio. t CO_2eq/a)
Akiyama et al. 2010 (most common and effective NI)	- 50% (DMPP, Nitrapyrin)	- 42
Gilsanz et al. 2016	- 41 % (DMPP, DCD)	- 34
Ruser & Schulz 2015	- 35 % (all inhibitors)	- 29

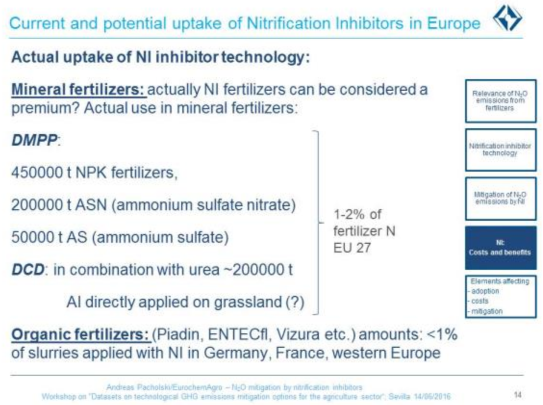
→ Reductions even larger when also considering N_2O emission reduction from nitrate leaching



Measures: robustness and reduction effect on N_2O-Emissions

(Rees et al. 2013, UK situation)

Measure	Estimated reduction rate t CO2e ha^{-1} a^{-1}	Certainty
Use biological N-Fixation (e.g. trifolium)	0.5	medium
Reduction of N-fertilization	**0.5**	**High**
Improve drainage	1.0	medium
Avoid excess N	0.4	medium
Total consideration of organic N	0.4	low
Introduction of new crops (including legumes)	0.5	low
Improvement of mineral N application (dosage)	0.3	medium
Nitrification inhibitors	**0.3**	**High**
Improved timing of application of mineral and organic N	0.3	medium
N-extensive systems	0.2	low



Current and potential uptake of Nitrification Inhibitors in Europe

Actual uptake of NI inhibitor technology:

Mineral fertilizers: actually NI fertilizers can be considered a premium? Actual use in mineral fertilizers:

***DMPP*:**

450000 t NPK fertilizers,

200000 t ASN (ammonium sulfate nitrate)

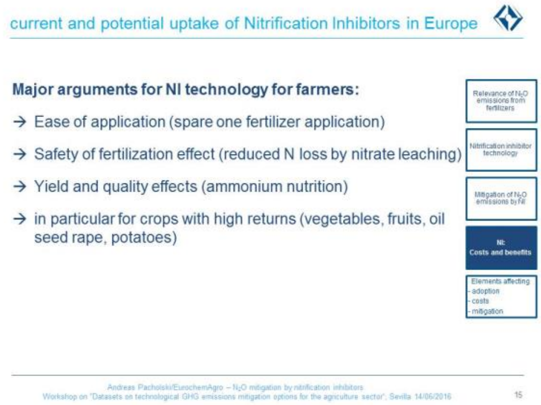
50000 t AS (ammonium sulfate)

***DCD*:** in combination with urea ~200000 t

AI directly applied on grassland (?)

1-2% of fertilizer N EU 27

Organic fertilizers: (Piadin, ENTECfl, Vizura etc.) amounts: <1% of slurries applied with NI in Germany, France, western Europe



current and potential uptake of Nitrification Inhibitors in Europe

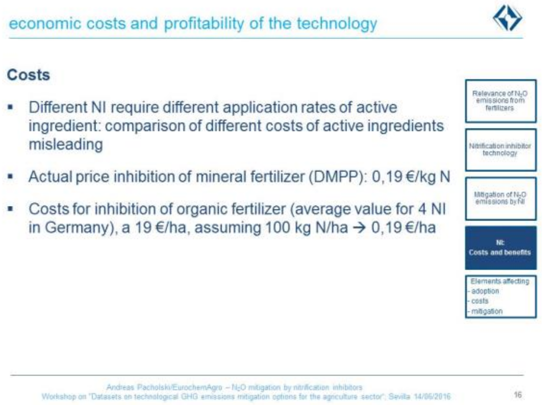
Major arguments for NI technology for farmers:

→ Ease of application (spare one fertilizer application)

→ Safety of fertilization effect (reduced N loss by nitrate leaching)

→ Yield and quality effects (ammonium nutrition)

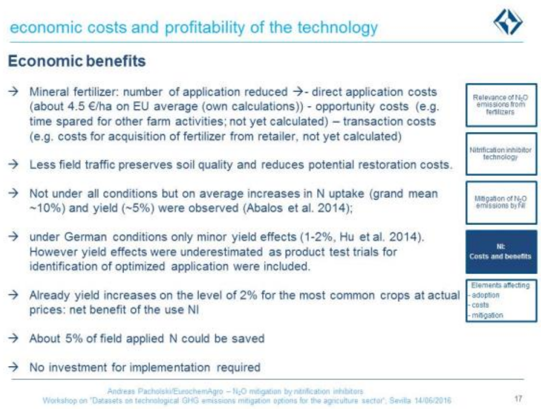
→ in particular for crops with high returns (vegetables, fruits, oil seed rape, potatoes)



economic costs and profitability of the technology

Costs

- Different NI require different application rates of active ingredient: comparison of different costs of active ingredients misleading
- Actual price inhibition of mineral fertilizer (DMPP): 0,19 €/kg N
- Costs for inhibition of organic fertilizer (average value for 4 NI in Germany), a 19 €/ha, assuming 100 kg N/ha → 0,19 €/ha

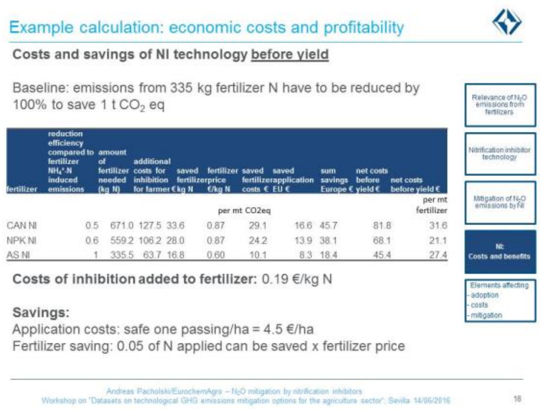


economic costs and profitability of the technology

Economic benefits

- Mineral fertilizer: number of application reduced →- direct application costs (about 4.5 €/ha on 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 (Abalos 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 prices: net benefit of the use NI
- About 5% of field applied N could be saved
- No investment for implementation required

Relevance of N_2O emissions from fertilizers
Nitrification inhibitor technology
Mitigation of N_2O emissions by NI
NI: Costs and benefits
Elements affecting
- adoption
- costs
- mitigation



Example calculation: economic costs and profitability

Costs and savings of NI technology before yield

Baseline: emissions from 335 kg fertilizer N have to be reduced by 100% to save 1 t CO_2 eq

fertilizer	reduction efficiency compared to fertilizer NH_4^+-N induced emissions	amount of fertilizer needed (kg N)	additional costs for inhibition for farmer €	saved fertilizer kg N	fertilizer price €/kg N	saved fertilizer costs €	saved application EU €	sum savings Europe €	net costs before yield €	net costs before yield €
					per mt CO2eq					per mt fertilizer
CAN NI	0.5	671.0	127.5	33.6	0.87	29.1	16.6	45.7	81.8	31.6
NPK NI	0.6	559.2	106.2	28.0	0.87	24.2	13.9	38.1	68.1	21.1
AS NI	1	335.5	63.7	16.8	0.60	10.1	8.3	18.4	45.4	27.4

Costs of inhibition added to fertilizer: 0.19 €/kg N

Savings:
Application costs: safe one passing/ha = 4.5 €/ha
Fertilizer saving: 0.05 of N applied can be saved x fertilizer price

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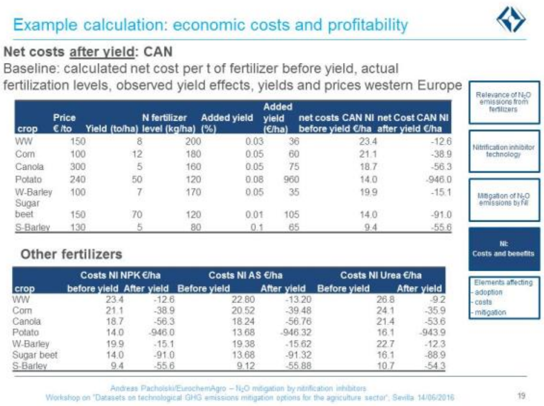

Example calculation: economic costs and profitability

Net costs after yield: CAN

Baseline: calculated net cost per t of fertilizer before yield, actual fertilization levels, observed yield effects, yields and prices western Europe

crop	Price € /to	Yield (to/ha)	N fertilizer level (kg/ha)	Added yield (%)	Added yield (€/ha)	net costs CAN NI before yield €/ha	net Cost CAN NI after yield €/ha
WW	150	8	200	0.03	36	23.4	-12.6
Corn	100	12	180	0.05	60	21.1	-38.9
Canola	300	5	160	0.05	75	18.7	-56.3
Potato	240	50	120	0.08	960	14.0	-946.0
W-Barley	100	7	170	0.05	35	19.9	-15.1
Sugar beet	150	70	120	0.01	105	14.0	-91.0
S-Barley	130	5	80	0.1	65	9.4	-55.6

Other fertilizers

	Costs NI NPK €/ha		Costs NI AS €/ha		Costs NI Urea €/ha	
crop	before yield	After yield	Before yield	After yield	Before yield	After yield
WW	23.4	-12.6	22.80	-13.20	26.8	-9.2
Corn	21.1	-38.9	20.52	-39.48	24.1	-35.9
Canola	18.7	-56.3	18.24	-56.76	21.4	-53.6
Potato	14.0	-946.0	13.68	-946.32	16.1	-943.9
W-Barley	19.9	-15.1	19.38	-15.62	22.7	-12.3
Sugar beet	14.0	-91.0	13.68	-91.32	16.1	-88.9
S-Barley	9.4	-55.6	9.12	-55.88	10.7	-54.3

Relevance of N_2O emissions from fertilizers
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current and potential uptake of Nitrification Inhibitors in Europe

Future uptake of NI technology:

High probability of increase due to increasing legislative demands with respect to NUE and N surplus in EU:

- dosage and timing of mineral fertilization have to be dealt with more accurately: NI provide a safeguard
- N from organic sources will be more critical for N-balances, in particular for organic N exported to arable farms → NI increase NUE and yield after organic fertilization
- Farm management highly more and more labor cost effective: NI provide an option for optimization
- Some active ingredients are limited with respect to production capacity → future inhibitors probably not limited

Relevance of N_2O emissions from fertilizers
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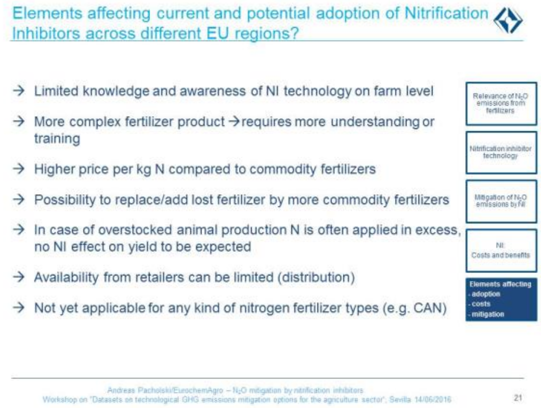

Elements affecting current and potential adoption of Nitrification Inhibitors across different EU regions?

- Limited knowledge and awareness of NI technology on farm level
- More complex fertilizer product →requires more understanding or training
- Higher price per kg N compared to commodity fertilizers
- Possibility to replace/add lost fertilizer by more commodity fertilizers
- In case of overstocked animal production N is often applied in excess, no NI effect on yield to be expected
- Availability from retailers can be limited (distribution)
- Not yet applicable for any kind of nitrogen fertilizer types (e.g. CAN)

Relevance of N_2O emissions from fertilizers
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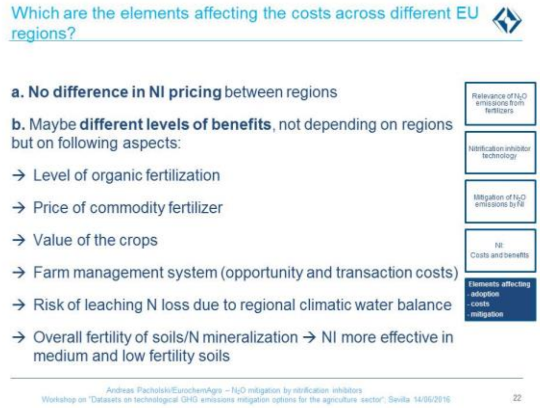

Which are the elements affecting the costs across different EU regions?

a. **No difference in NI pricing** between regions

b. Maybe **different levels of benefits**, not depending on regions but on following aspects:

- Level of organic fertilization
- Price of commodity fertilizer
- Value of the crops
- Farm management system (opportunity and transaction costs)
- Risk of leaching N loss due to regional climatic water balance
- Overall fertility of soils/N mineralization → NI more effective in medium and low fertility soils

Relevance of N_2O emissions from fertilizers
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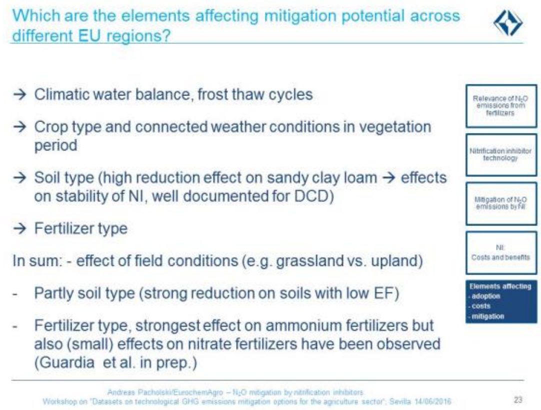

Which are the elements affecting mitigation potential across different EU regions?

- Climatic water balance, frost thaw cycles
- Crop type and connected weather conditions in vegetation period
- Soil type (high reduction effect on sandy clay loam → effects on stability of NI, well documented for DCD)
- Fertilizer type

In sum: - effect of field conditions (e.g. grassland vs. upland)

- Partly soil type (strong reduction on soils with low EF)
- Fertilizer type, strongest effect on ammonium fertilizers but also (small) effects on nitrate fertilizers have been observed (Guardia et al. in prep.)

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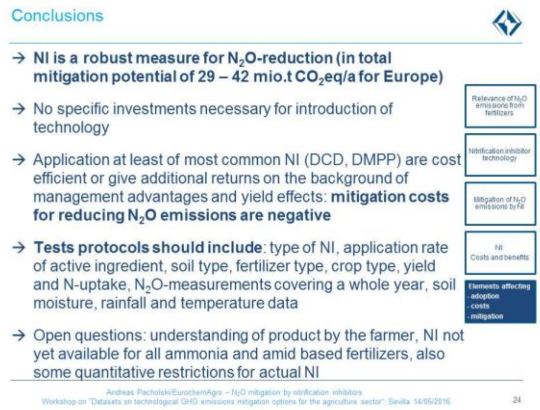

Conclusions

- **NI is a robust measure for N_2O-reduction (in total mitigation potential of 29 – 42 mio.t CO_2eq/a for Europe)**
- No specific investments necessary for introduction of technology
- Application at least of most common NI (DCD, DMPP) are cost efficient or give additional returns on the background of management advantages and yield effects: **mitigation costs for reducing N_2O emissions are negative**
- **Tests protocols should include**: type of NI, application rate of active ingredient, soil type, fertilizer type, crop type, yield and N-uptake, N_2O-measurements covering a whole year, soil moisture, rainfall and temperature data
- Open questions: understanding of product by the farmer, NI not yet available for all ammonia and amid based fertilizers, also some quantitative restrictions for actual NI

Relevance of N_2O emissions from fertilizers
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On-farm anaerobic digesters - an economic perspective. Philip Jones (Reading University)

Centre for Agricultural Strategy

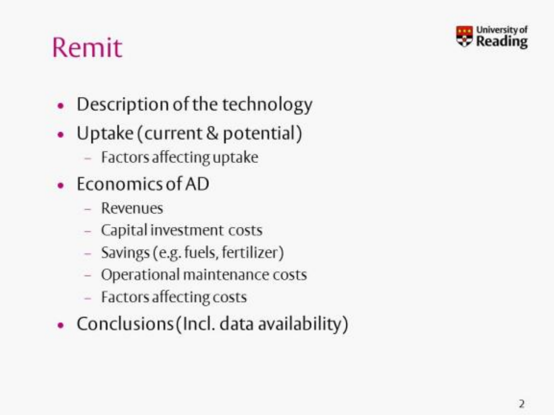
Workshop: Datasets for GHG mitigation technologies for agriculture

On-farm anaerobic digesters – an economic perspective

Philip Jones

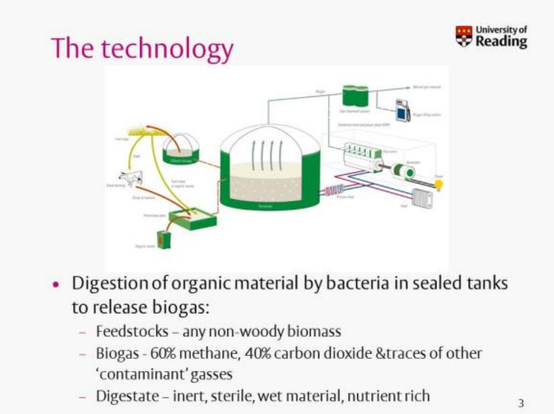
JRC, Seville, 05 October 2011

www.reading.ac.uk



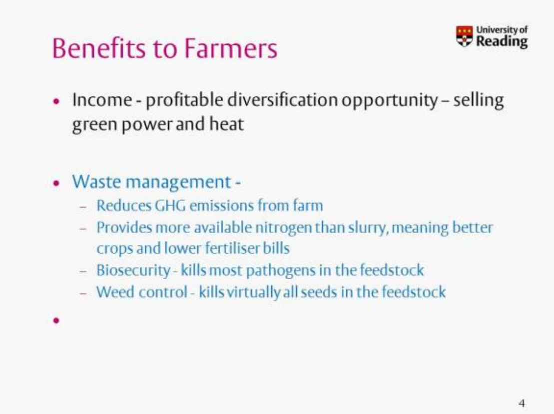
Remit

- 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)



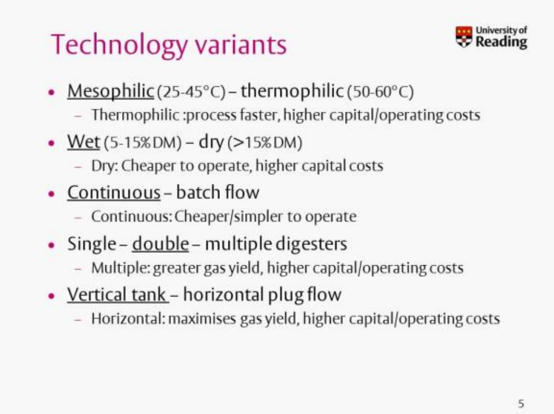
The technology

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



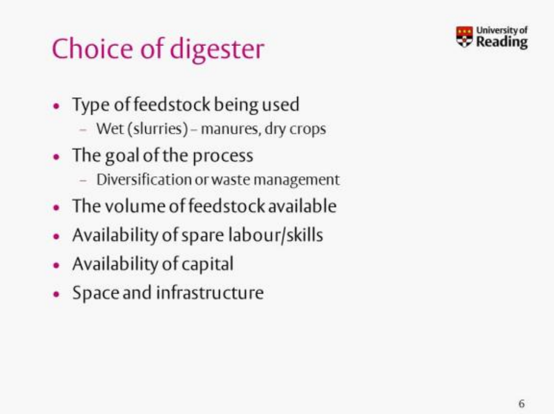
Benefits to Farmers

- 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 fertiliser bills
  - Biosecurity - kills most pathogens in the feedstock
  - Weed control - kills virtually all seeds in the feedstock
-



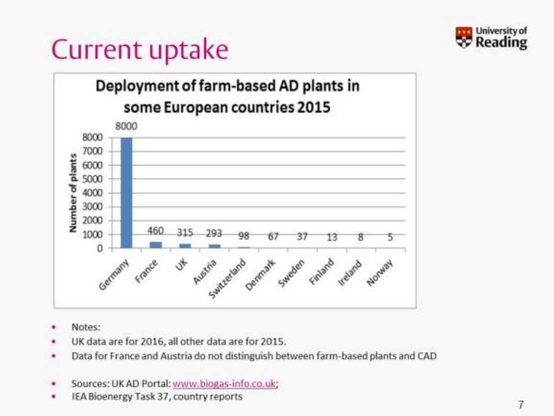
Technology variants

- Mesophilic (25-45°C) – thermophilic (50-60°C)
  - Thermophilic :process faster, higher capital/operating costs
- Wet (5-15% DM) – dry (>15% DM)
  - 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



Choice of digester

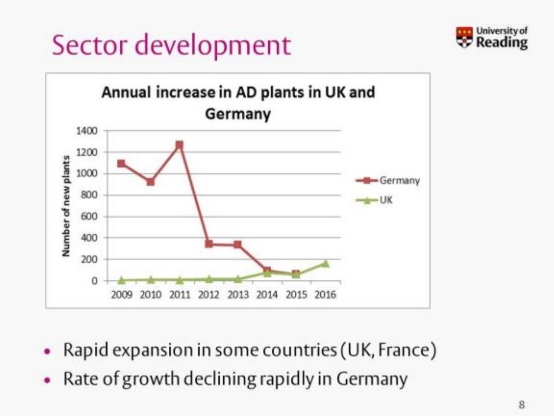
- Type of feedstock being used
  - Wet (slurries) – manures, dry crops
- The goal of the process
  - Diversification or waste management
- The volume of feedstock available
- Availability of spare labour/skills
- Availability of capital
- Space and infrastructure



Current uptake

- Notes:
- UK data are for 2016, all other data are for 2015.
- Data for France and Austria do not distinguish between farm-based plants and CAD

- Sources: UK AD Portal: www.biogas-info.co.uk;
- IEA Bioenergy Task 37, country reports



Sector development

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

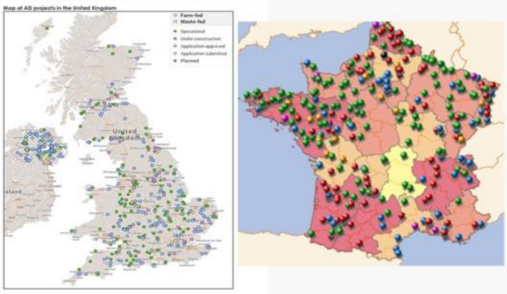
Data on uptake

Plant Name	Address	Postcode	Nation	EA classification	Type	Feedstock	Capacity of AD site [operational - built to take].	Technology provider [supplier]	Output process	Capacity [output] kwe	Year of operation
	Haughton, Oswestry, West Felton	SY11 4HF	England	Farm-fed	On-farm	Crops & farmyard manures	22,000			1,100	2012
	Green Lodge Farm, Forest Road, Huncote, Leicester	LE9 3LE	England	Waste-fed	Commercial	Pig Slurry and Food waste	86,000	Progen (Warrington)	CHP	2,000	2013
	Land 300m north west of East Denside Farm,Monikie ,Dundee	DD5 3QE	Scotland	Farm-fed	On-farm	Maize silage and manure	not known		CHP	249	2014
	Hillsborough	BT26 6DR	Northern Ireland	Farm-fed	Demonstration (R&D)	Dairy cow slurry, with capability of handling energy crops	5,000	BiogenGreenfinch		23	2008
	The Old Sawmills, Station Road, Llangadog, Carmarthenshire,	SA19 9LS	Wales	Waste-fed	Commercial	Municipal and business food waste	1,500	REACT	CHP	16	2011
	Land at Hollyhouse Farm,Horseway,,Chatteris	PE16 6XQ	England	Farm-fed	On-farm	Maize	11,550		CHP	500	2014

- Source: UK Official AD portal (http://biogas-info.co.uk)

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

Mapping AD uptake

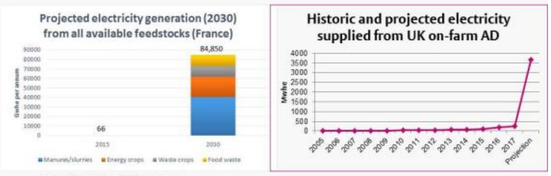


Uptake potential

- 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)

Example uptake projections

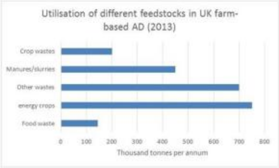


Note: 1 Gigawatt = 1000 Megawatts.

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

Feedstock utilisation

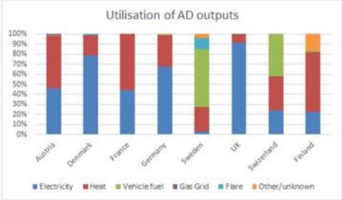
- Official data is unreliable
  - Only intended use of feedstocks is known (planning datasets)
  - Relative importance of each feedstock not known
  - Feedstock use may change
- More reliable data from ad hoc surveys (less coverage)



- Governments need this data for establishing sustainability criteria
  - Minimum use of wastes/slurries
  - Reduce use of food/feed crops
- Some Govt. data collected from farmers on end uses of crops

Source: NNFCC (2013) Anaerobic Digestion deployment in the United Kingdom.

End uses of generated energy



Note: All data are 2013/2014.
Source: National Reports, IEA Task 37, Berlin, 2015.

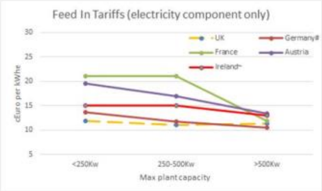
- Data collected by energy companies, regulators and departments of energy
- Used to monitor progress towards renewable energy targets

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 sources 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

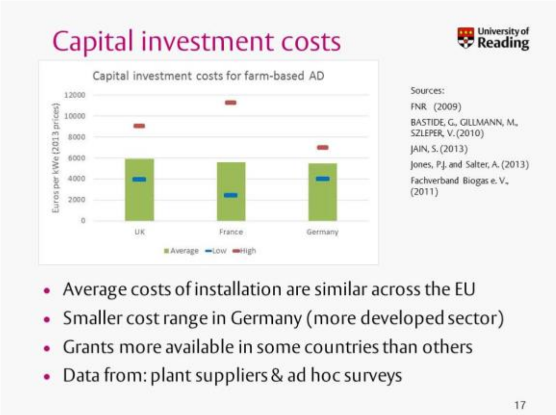
Feed In Tariffs



Notes:
~ Tariff for CHP (non-CHP tariff is lower)
# Values represent basic payment before supplements

Sources:
UK - https://www.ofgem.gov.uk/system/files/docs/2016/02/feed-in_tariff_generation_and_export_tables_08.02.2016_-_31.03.2016.pdf
Other countries: Country Reports IEA Bioenergy Task 37.

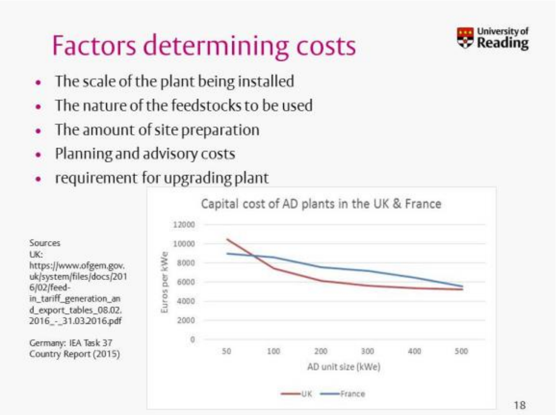
- FIT rates are scaled on the basis of installed electricity generation capacity
- variation in the support for small scale AD reflecting Government prioritisation of this type of deployment
  - France and Austria paying almost double rate in the UK.



Capital investment costs

Sources:
FNR (2009)
BASTIDE, G., GILLMANN, M., SZLEPER, V. (2010)
JAIN, S. (2013)
Jones, P.J. and Salter, A. (2013)
Fachverband Biogas e. V., (2011)

- 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

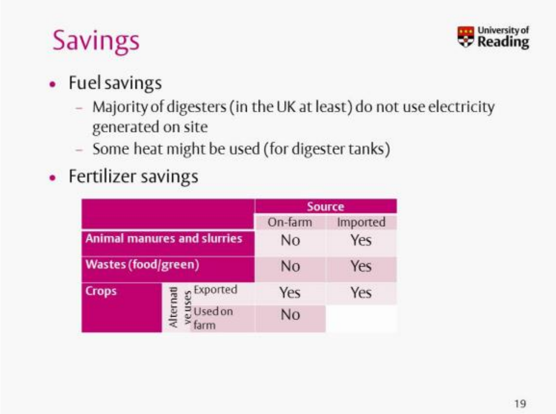


Factors determining costs

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

Sources
UK:
https://www.ofgem.gov.uk/system/files/docs/2016/02/feed-in_tariff_generation_and_export_tables_08.02.2016_-_31.03.2016.pdf

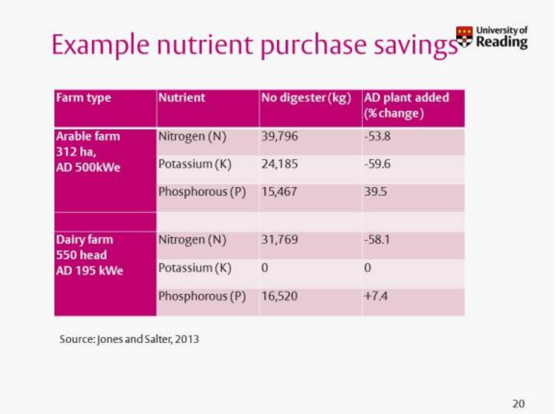
Germany: IEA Task 37 Country Report (2015)



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

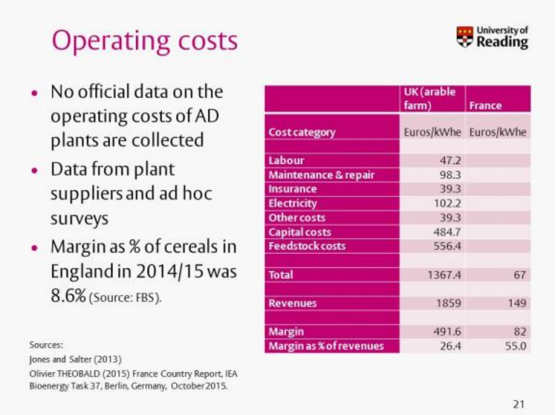
			Source	
			On-farm	Imported
Animal manures and slurries			No	Yes
Wastes (food/green)			No	Yes
Crops	Alternative uses	Exported	Yes	Yes
		Used on farm	No	



Example nutrient purchase savings

Farm type	Nutrient	No digester (kg)	AD plant added (% change)
Arable farm 312 ha, AD 500kWe	Nitrogen (N)	39,796	-53.8
	Potassium (K)	24,185	-59.6
	Phosphorous (P)	15,467	39.5
Dairy farm 550 head AD 195 kWe	Nitrogen (N)	31,769	-58.1
	Potassium (K)	0	0
	Phosphorous (P)	16,520	+7.4

Source: Jones and Salter, 2013

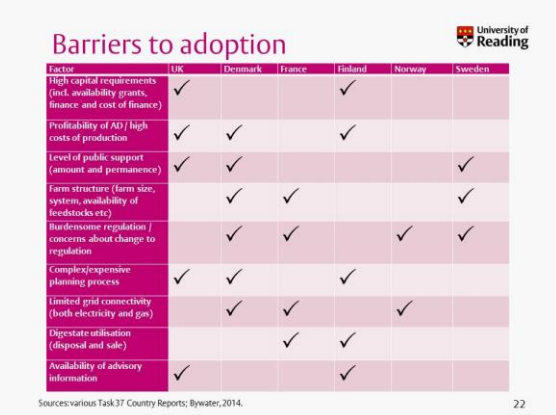


Operating costs

- 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 8.6% (Source: FBS).

	UK (arable farm)	France
Cost category	Euros/kWhe	Euros/kWhe
Labour	47.2	
Maintenance & repair	98.3	
Insurance	39.3	
Electricity	102.2	
Other costs	39.3	
Capital costs	484.7	
Feedstock costs	556.4	
Total	1367.4	67
Revenues	1859	149
Margin	491.6	82
Margin as % of revenues	26.4	55.0

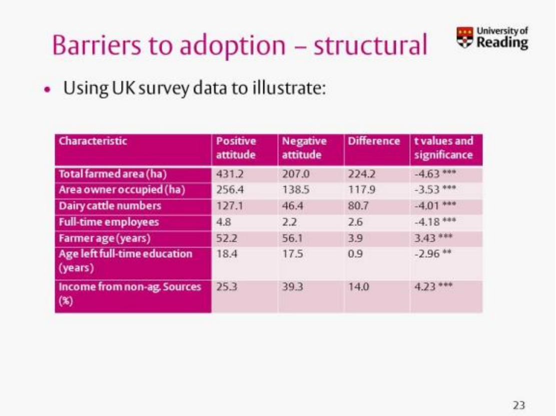
Sources:
Jones and Salter (2013)
Olivier THEOBALD (2015) France Country Report, IEA Bioenergy Task 37, Berlin, Germany, October 2015.



Barriers to adoption

Factor	UK	Denmark	France	Finland	Norway	Sweden
High capital requirements (incl. availability grants, finance and cost of finance)	✓			✓		
Profitability of AD / high costs of production	✓	✓		✓		
Level of public support (amount and permanence)	✓	✓				✓
Farm structure (farm size, system, availability of feedstocks etc)		✓	✓			✓
Burdensome regulation / concerns about change to regulation		✓	✓		✓	✓
Complex/expensive planning process	✓	✓		✓		
Limited grid connectivity (both electricity and gas)		✓	✓		✓	
Digestate utilisation (disposal and sale)			✓	✓		
Availability of advisory information	✓			✓		

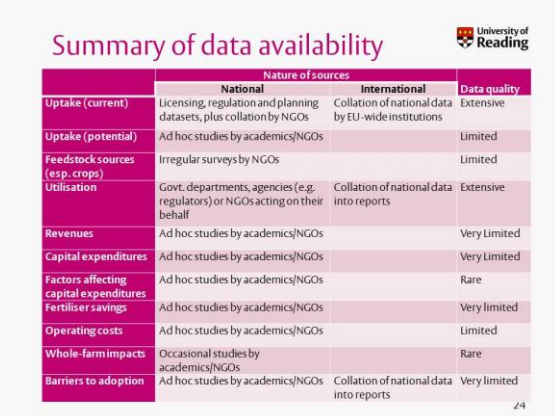
Sources: various Task 37 Country Reports; Bywater, 2014.



Barriers to adoption – structural

- Using UK survey data to illustrate:

Characteristic	Positive attitude	Negative attitude	Difference	t values and significance
Total farmed area (ha)	431.2	207.0	224.2	-4.63 ***
Area owner occupied (ha)	256.4	138.5	117.9	-3.53 ***
Dairy cattle numbers	127.1	46.4	80.7	-4.01 ***
Full-time employees	4.8	2.2	2.6	-4.18 ***
Farmer age (years)	52.2	56.1	3.9	3.43 ***
Age left full-time education (years)	18.4	17.5	0.9	-2.96 **
Income from non-ag. Sources (%)	25.3	39.3	14.0	4.23 ***



Summary of data availability

	Nature of sources		
	National	International	Data quality
Uptake (current)	Licensing, regulation and planning datasets, plus collation by NGOs	Collation of national data by EU-wide institutions	Extensive
Uptake (potential)	Ad hoc studies by academics/NGOs		Limited
Feedstock sources (esp. crops)	Irregular surveys by NGOs		Limited
Utilisation	Govt. departments, agencies (e.g. regulators) or NGOs acting on their behalf	Collation of national data into reports	Extensive
Revenues	Ad hoc studies by academics/NGOs		Very Limited
Capital expenditures	Ad hoc studies by academics/NGOs		Very Limited
Factors affecting capital expenditures	Ad hoc studies by academics/NGOs		Rare
Fertiliser savings	Ad hoc studies by academics/NGOs		Very limited
Operating costs	Ad hoc studies by academics/NGOs		Limited
Whole-farm impacts	Occasional studies by academics/NGOs		Rare
Barriers to adoption	Ad hoc studies by academics/NGOs	Collation of national data into reports	Very limited

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

Seville, 14 June 2016

Content

- Manure management in Europe
  - Manure processing
  - Review mitigation measures and emissions
  - Survey manure processing
- Anaerobic digestion
  - Introduction
  - Current uptake
  - Potential GHG savings
  - Issues related to anaerobic digestion
- Conclusions

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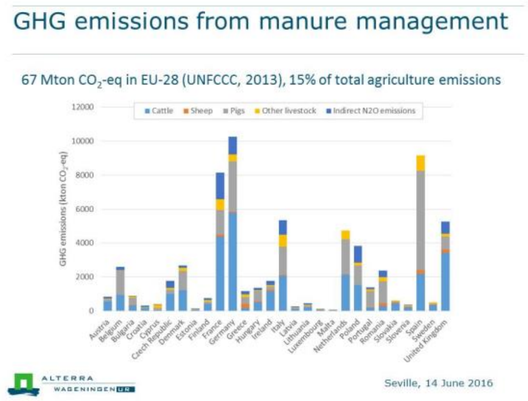

GHG emissions from manure management

67 Mton CO_2-eq in EU-28 (UNFCCC, 2013), 15% of total agriculture emissions

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Manure processing

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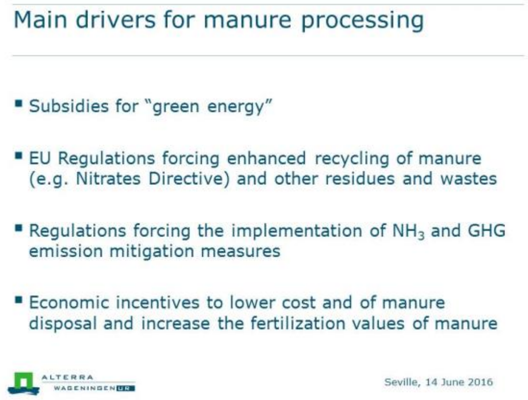

Main drivers for manure processing

- 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 NH_3 and GHG emission mitigation measures
- Economic incentives to lower cost and of manure disposal and increase the fertilization values of manure

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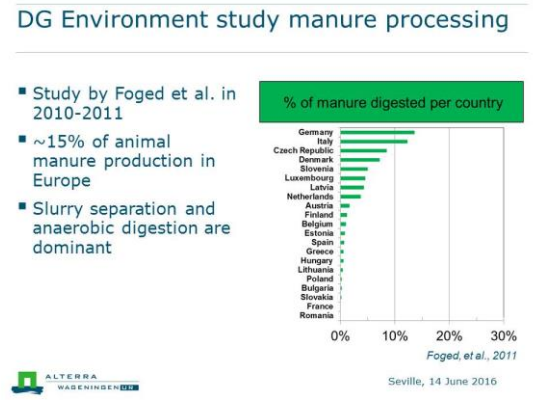

DG Environment study manure processing

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

Foged, et al., 2011

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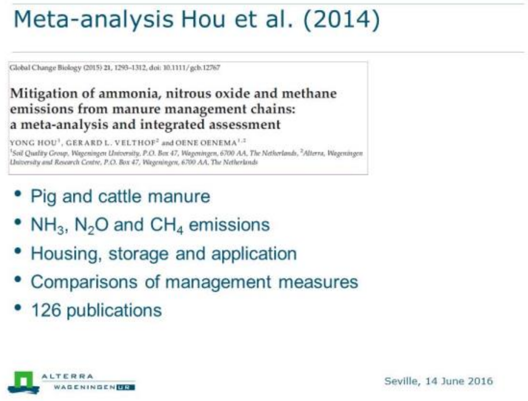

Meta-analysis Hou et al. (2014)

Global Change Biology (2015) 21, 1293–1312, doi: 10.1111/gcb.12767

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

YONG HOU[1], GERARD L. VELTHOF[2] and OENE OENEMA[1,2]

[1]*Soil Quality Group, Wageningen University, P.O. Box 47, Wageningen, 6700 AA, The Netherlands,* [2]*Alterra, Wageningen University and Research Centre, P.O. Box 47, Wageningen, 6700 AA, The Netherlands*

- Pig and cattle manure
- NH_3, N_2O and CH_4 emissions
- Housing, storage and application
- Comparisons of management measures
- 126 publications

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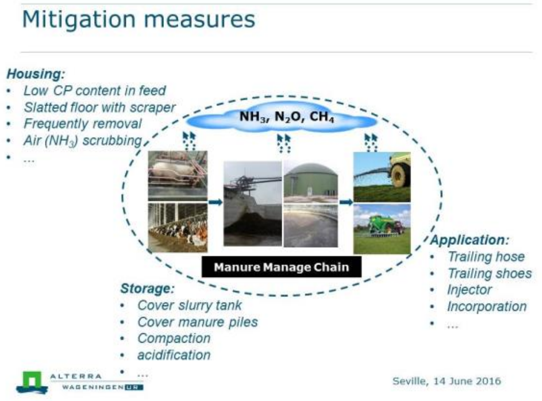

Mitigation measures

Housing:
- *Low CP content in feed*
- *Slatted floor with scraper*
- *Frequently removal*
- *Air (NH_3) scrubbing*
- *…*

Storage:
- *Cover slurry tank*
- *Cover manure piles*
- *Compaction*
- *acidification*
- *…*

Application:
- *Trailing hose*
- *Trailing shoes*
- *Injector*
- *Incorporation*
- *…*

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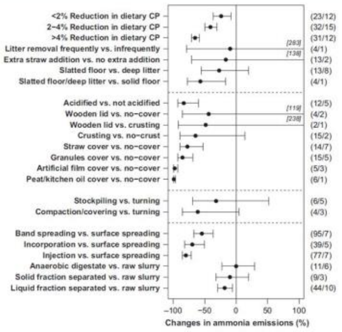
Effect on NH_3 emissions



Hou, et al., 2014. GCB.

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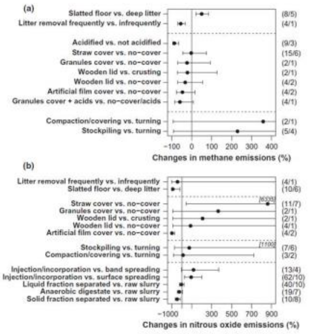
Effect on GHG emissions



Hou, et al., 2014. GCB.

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Manure acidification

- Use of H_2SO_4 to reduce pH of manure (>7 → 5.5)
- Can reduce both NH_3 and CH_4 emissions
- Currently mostly used during application → no effect on CH_4
- Savings of N → less fertilizer
- Risk on H_2S emissions

Photo: Lone E. Haargaard

Photo: Frank Bondgaard

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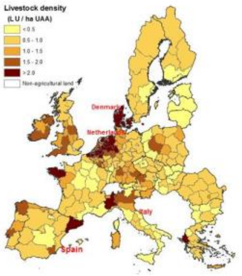
Stakeholder surveys manure treatment



Part of ReUseWaste project

Stakeholder groups:

- Livestock farmers
- Farmers' organizations
- Agricultural advisors
- Clean-tech. developers
- Policy makers
- Researchers

Hou, et al., under review

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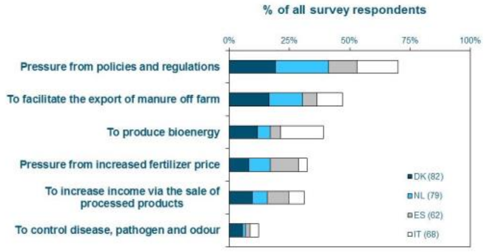
Factors stimulating adoption



Hou, et al., under review

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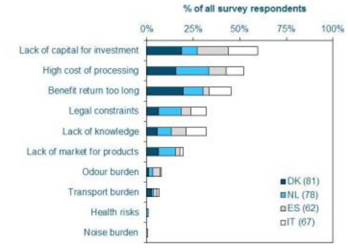
Constraints and barriers



Hou, et al., under review

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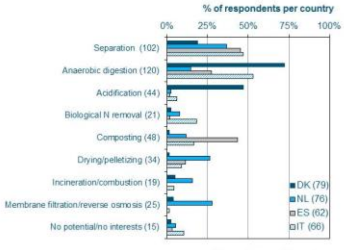
Technology preference in next decade



Hou, et al., under review

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Anaerobic digestion

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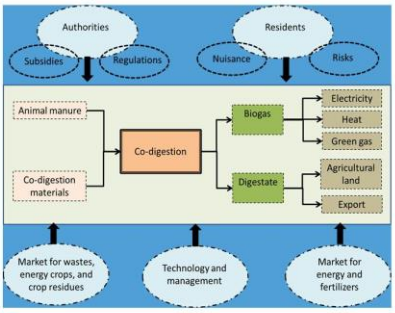
Factors influencing (co-)digestion

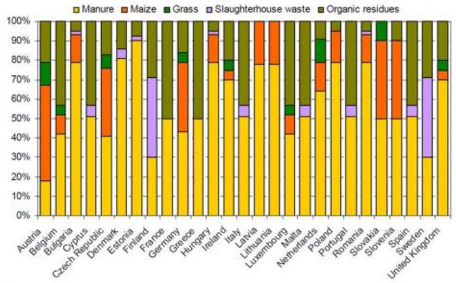


Current biogas production EU-28

- Data based on study for DG Energy (ENER/C1/2015-438)

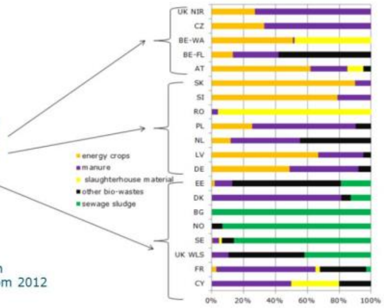
- Biogas production in 2014 about 625 PJ (Source: Eurostat)
- Biogas is 7.6% of total RE primary production
- 4 fold increase in biogas production since 2005
- 50% of all biogas is produced in Germany, followed by Italy and United Kingdom
- 18% from landfill, 9% from sewage sludge and 72% from other (mainly farm based plants)

Current feedstock use (source: Alterra, 2011)



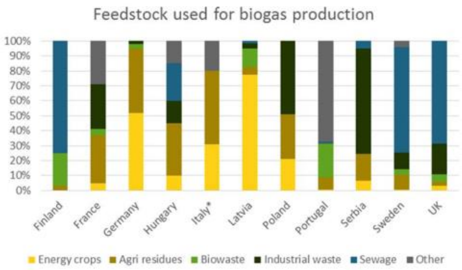
Current feedstock use (source: DG Env. study)

Sewage sludge
1.not included
2.not specified
3.included

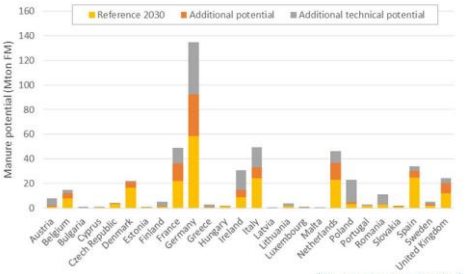


Data are based on questionnaires from 2012

Current feedstock use (source: EBA, 2015)

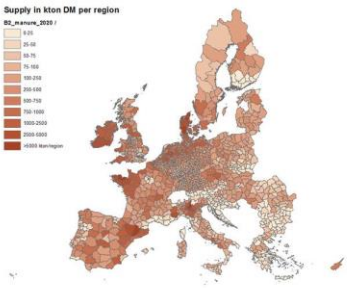


Liquid manure potential in 2030



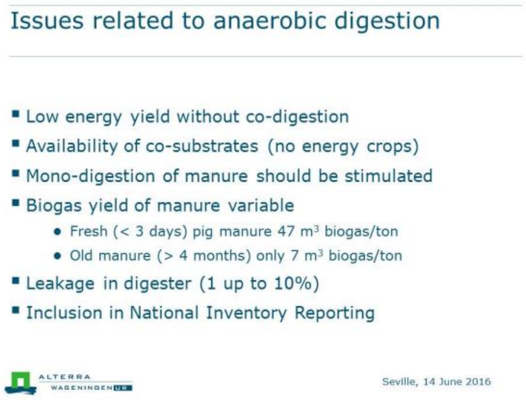
(Source: Biomass Policies)

Manure potentials (Source: BiomassPolicies)



GHG emissions savings (in kton CO_2-eq for 2008)

Main countries	Avoided GHG emission from manure storage	Avoided GHG emission fossil fuels for electricity	Avoided GHG emission fossil fuels for heating	GHG emissions from biogas production	Net avoided GHG emissions
Austria	24	295		63	256
Czech Republic	8	62	17	9	78
Denmark	238	194	27	3	457
Germany	571	3417		626	3363
Netherlands	119	173	10	99	204
Spain	44	62	5	1	110
United Kingdom	124	225		24	325
EU-27	1179	4507	117	836	4967

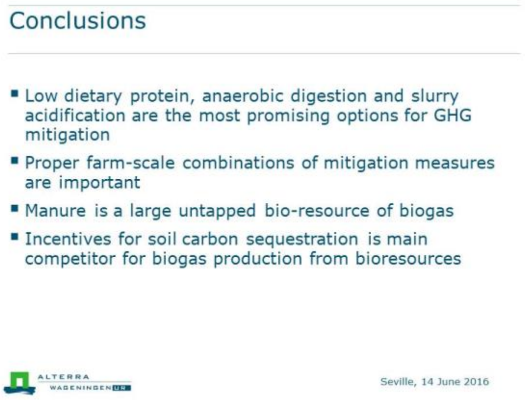


Issues related to anaerobic digestion

- 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 m^3 biogas/ton
  - Old manure (> 4 months) only 7 m^3 biogas/ton
- Leakage in digester (1 up to 10%)
- Inclusion in National Inventory Reporting

ALTERRA WAGENINGEN UR

Seville, 14 June 2016



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

ALTERRA WAGENINGEN UR

Seville, 14 June 2016

Conservation agriculture. Emilio Gonzalez-Sanchez (ECAF/Cordoba University)


ECAF
European Conservation Agriculture Federation
UNIVERSIDAD D CORDOBA

TECHNOLOGICAL MITIGATION OPTIONS FOR CARBON DIOXIDE: CONSERVATION AGRICULTURE

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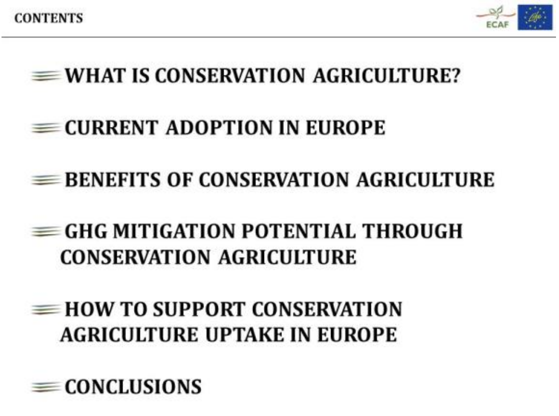
EUROPEAN CONSERVATION AGRICULTURE FEDERATION
UNIVERSITY OF CORDOBA (SPAIN)
egonzalez@ecaf.org – www.ecaf.org
IPTS, SEVILLE, JUNE 14TH 2016

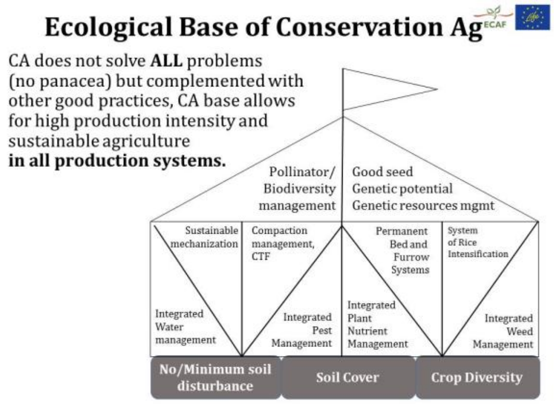

CONTENTS

- WHAT IS CONSERVATION AGRICULTURE?
- CURRENT ADOPTION IN EUROPE
- BENEFITS OF CONSERVATION AGRICULTURE
- GHG MITIGATION POTENTIAL THROUGH CONSERVATION AGRICULTURE
- HOW TO SUPPORT CONSERVATION AGRICULTURE UPTAKE IN EUROPE
- CONCLUSIONS


What is Conservation Agriculture – Principles of ecological sustainability

- **No or minimum mechanical soil disturbance by** – seeding or planting directly into untilled 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

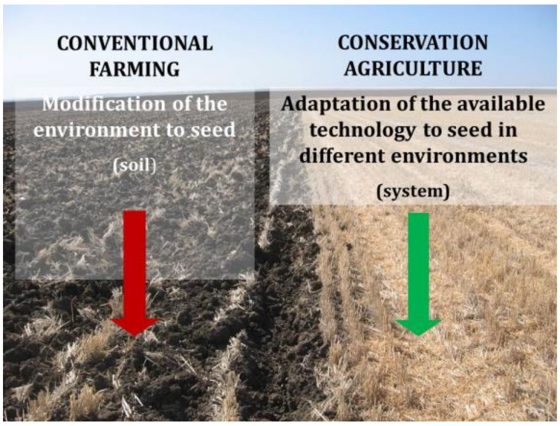
*Key element: **Conservation Agriculture** is a combination of several resource conserving practices **simultaneously** creating **synergies** between them for optimization & sustainability.*


Ecological Base of Conservation Ag

CA does not solve **ALL** problems (no panacea) but complemented with other good practices, CA base allows for high production intensity and sustainable agriculture **in all production systems.**


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

No/Minimum soil disturbance | Soil Cover | Crop Diversity

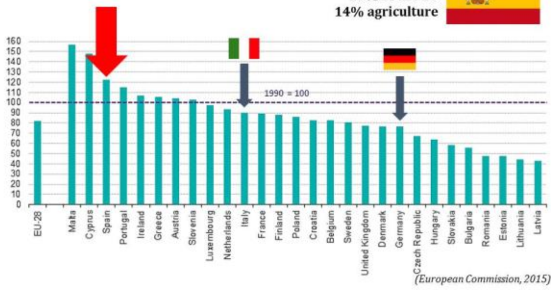

CONVENTIONAL FARMING	CONSERVATION AGRICULTURE
Modification of the environment to seed (soil)	Adaptation of the available technology to seed in different environments (system)


Picture: A. Trapero

INTRODUCTION AND JUSTIFICATION

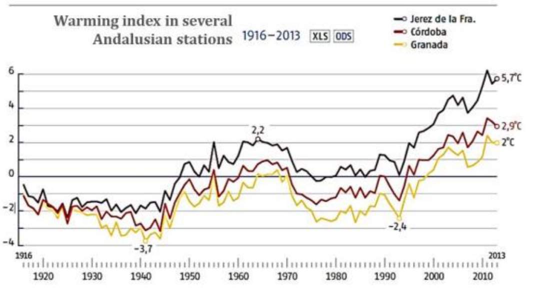
GHG emissions: 4,678.8 M Mg CO_2-eq.
10% of the world
9% agriculture

GHG emissions: 319.6 M Mg CO_2-eq.
15% of the EU
14% agriculture



(European Commission, 2015)

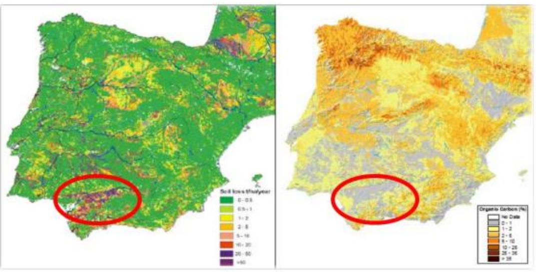
INTRODUCTION AND JUSTIFICATION



(Report about the environment in Andalusia 2014, 2015)

INTRODUCTION AND JUSTIFICATION

Carbon in soil is related to other major environmental threaths



Maps of risk of soil erosion and organic carbon contents in Spain

JRC – European Commission (2003, 2004)

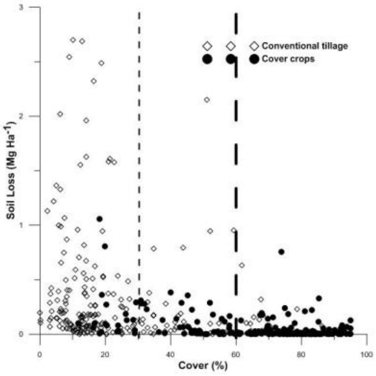
Soil degradation processes are very expensive -unaffordable- for Society

SOIL DEGRADATION	ANNUAL COSTS
Erosion	€0.7 – 14.0 billion
Organic matter decline	€3.4 – 5.6 billion
Compaction	Cannot be estimated
Salinisation	€158 – 321 million
Landslides	Up to €1.2 billion per event
Contamination	€2.4 – 17.3 billion
Biodiversity decline	Cannot be estimated

(European Commission, Soil Thematic Strategy, 2006)

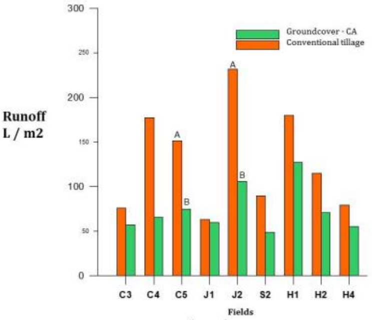
The total costs of degradation would be up to **€38 billion annually for EU.**

Erosion control with Conservation Agriculture



(Márquez-Garcia et al., 2013)

Runoff control with Conservation Agriculture

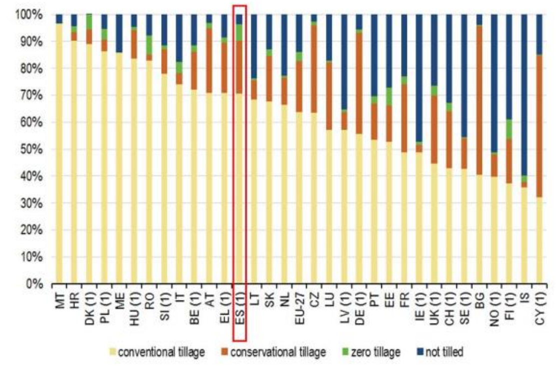


(Márquez-Garcia et al., 2013)

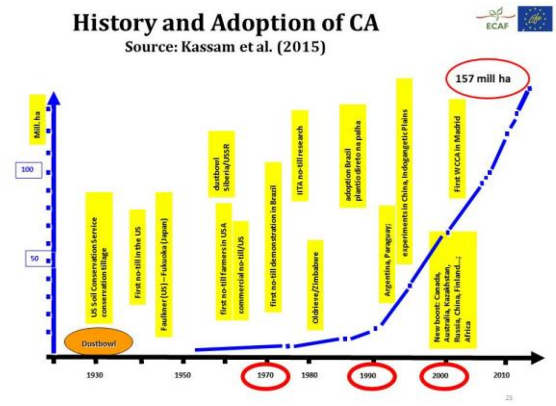
BENEFITS OF CONSERVATION AGRICULTURE

Conservation Agriculture has a positive effect on the mitigation of climate change, by both increasing soil organic carbon, and by reducing the emissions of CO_2 into the atmosphere.

TYPE OF CROP	TECHNIQUE	SYNONYM	CA	COMMENTS
ANNUAL	No-tillage	No till; Zero tillage; Zero till; Direct drilling; Direct seeding; Direct sowing	Yes	If combined with permanent soil cover and crop rotations.
	Reduced tillage	Minimum tillage; Minimum till; Reduced till	No	Generally, the preparation of soil for planting needs 2-3 tillage operations. Less than 30% of soil is covered after seeding.
	Mulch tillage	Mulch till	No	The mulch is buried through tillage operations. Less than 30% of soil is covered after seeding.
	Strip tillage	Strip till	?	The equipment must be used accurately in order to qualify as CA. Generally, there is excessive soil or residue disturbance, so less than 30% of soil is covered after seeding.
	Ridge tillage	Ridge till	No	Building the ridge involves soil tillage in most of the surface. Less than 30% of soil is covered after seeding.
	Slot tillage	Slot till; Slot planting	?	The equipment must be used accurately in order to qualify as CA. Generally, there is excessive soil or residue disturbance, so less than 30% of soil is covered after seeding.
	Row tillage	Row till	No	Generally, excessive soil or residue disturbance. Less than 30% of soil is covered after seeding.
PERMANENT	Groundcovers		Yes	If combined with permanent soil cover.

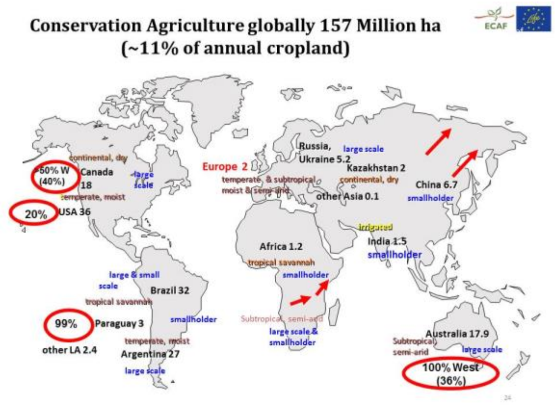


(1) Data extrapolated from SAPM sample.



History and Adoption of CA

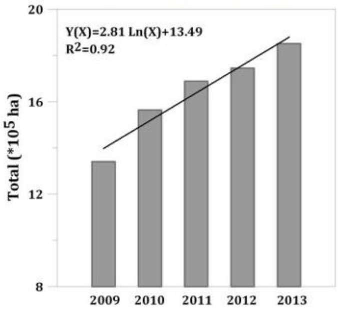
Source: Kassam et al. (2015)



Conservation Agriculture globally 157 Million ha (~11% of annual cropland)

Evolution of Conservation Agriculture in Spain

(annual and perennial crops)



Sources: MAGRAMA, 2010; MAGRAMA, 2011a; MAGRAMA, 2012; MAGRAMA, 2013; MAGRAMA, 2014c.

GHG MITIGATION THROUGH CONSERVATION AGRICULTURE

Meta-analysis on atmospheric carbon capture in Spain through the use of conservation agriculture

González-Sánchez, E.J., Ordóñez-Fernández, R., Carbonell-Bojollo, R., Veroz-González, O., Gil-Ribes, J.A.

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

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

Region	Province	Soil classification	Soil Management System
Andalusia	Seville	Xerofluvent	MT vs. TT
	Seville	Chromic Haploxerept	NT vs. TT MT vs. TT
	Cordoba	Calcic Haploxerept	CC vs. TT
	Cordoba	Ruptic-Lhitic Xerorthent	CC vs. TT
	Cordoba	Calcic Haploxerept	CC vs. TT
	Huelva	Typic Haploxerept	CC vs. TT
	Seville	Typic Calcexerept	CC vs. TT
	Jaen	Calcic Haploxerept	CC vs. TT
	Jaen	Calcic Haploxerept	CC vs. TT
	Cordoba	Vertisol	CC vs. TT
	Jaen	Anthropic Xerortent	CC vs. TT
Extremadura	Caceres	Ultic Haploxeralf	NT vs. TT
Castille-La Mancha	Toledo	Calcic Haploxeralf	NT vs. TT MT vs. TT
Madrid	Madrid	Vertic Haploxeralf	NT vs. TT MT vs. TT
	Madrid	Calcic Haploxeralf	NT vs. TT MT vs. TT
Castille and Leon	Burgos	Typic Calcixerols	NT vs. TT MT vs. TT
Aragon	Zaragoza	Xerollic Calciorthid	NT vs. TT MT vs. TT
Catalonia	Lerida	Typic Xerofluvent	NT vs. TT MT vs. TT
	Lerida	Fluventic Xerocrept	NT vs. TT MT vs. TT
Navarra	Navarra	Calcic Haploxerept	NT vs. TT

GHG MITIGATION THROUGH CONSERVATION AGRICULTURE

$$OC_i(kg/ha) = OC_i(kg_{OC}/100\,kg_{soil}) \times \rho_i(kg_{soil}/m^3) \times D_i(m) \times 10^4\,m^2/ha$$

$$OC_i(Mg/ha) = 10^{-3} OC_i(kg/ha)$$

$$OC_{Dt}TT(Mg/ha) = \sum_1^n OC_i TT$$

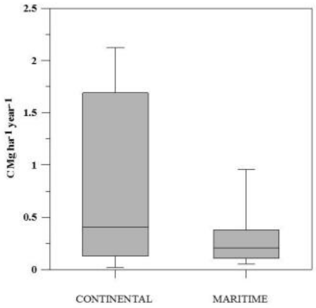
$$OC_{Dt}CA(Mg/ha) = \sum_1^n OC_i CA$$

$$\Delta OC_{Dtj}(Mg/ha\ year) = \left(\mathrm{OC_{Dtj}\ CA(Mg/ha)} - \mathrm{OC_{Dtj}\ TT(Mg/ha)}\right)/Y_j$$

$$\boxed{FC(Mg/ha\ year) = \sum_{j=1}^{j=S} \Delta OC_{Dtj} x\left(D_{tj}/D_{t\max}\right) \Big/ S}$$

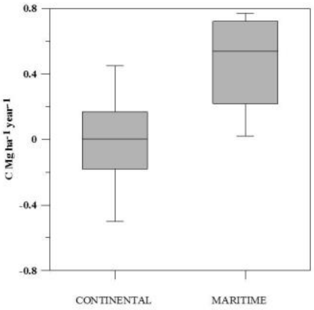
GHG MITIGATION THROUGH CONSERVATION AGRICULTURE

C fixation in no tillage in maritime and continental Mediterranean climates



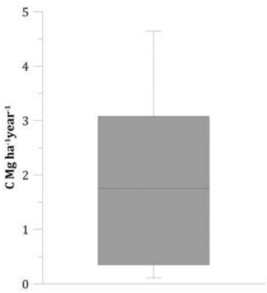
GHG MITIGATION THROUGH CONSERVATION AGRICULTURE

C fixation in minimum tillage in maritime and continental Mediterranean climates



GHG MITIGATION THROUGH CONSERVATION AGRICULTURE

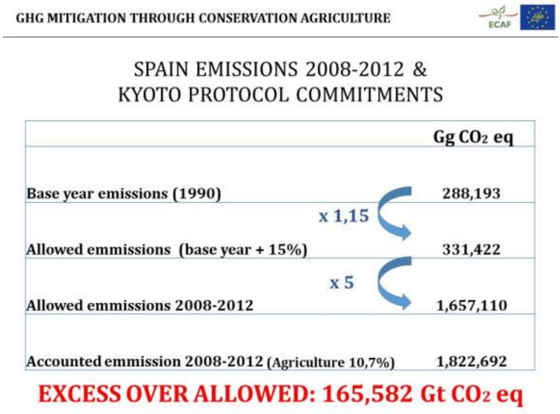
C fixation in groundcovers in Mediterranean climate



GHG MITIGATION THROUGH CONSERVATION AGRICULTURE

Carbon fixation coefficients of Conservation Agriculture over conventional farming

Agricultural Practice	C coefficient of fixation (Mg ha-1 year-1)	Period
No-tillage	0.85	<10 years
	0.16-0.40	>10 years
Minimum tillage	-0.16	<10 years
	0.03-0.30	>10 years
Groundcovers	1.54	<10 years
	0.35	>10 years

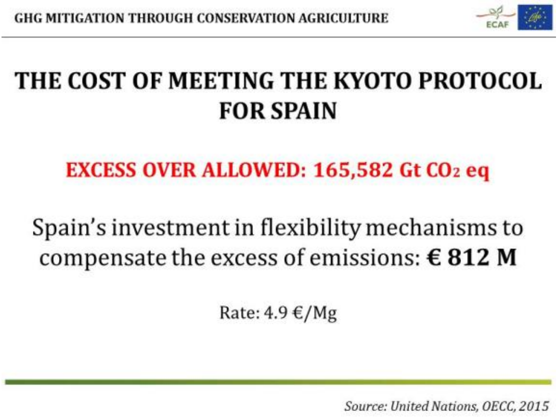


GHG MITIGATION THROUGH CONSERVATION AGRICULTURE

SPAIN EMISSIONS 2008-2012 &
KYOTO PROTOCOL COMMITMENTS

	Gg CO_2 eq
Base year emissions (1990)	288,193
Allowed emmissions (base year + 15%)	331,422
Allowed emmissions 2008-2012	1,657,110
Accounted emmission 2008-2012 (Agriculture 10,7%)	1,822,692

EXCESS OVER ALLOWED: 165,582 Gt CO_2 eq



GHG MITIGATION THROUGH CONSERVATION AGRICULTURE

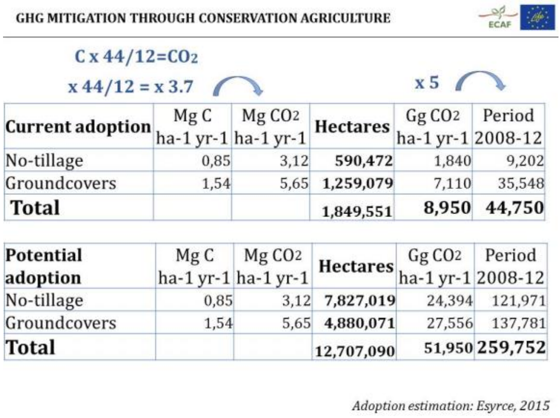
THE COST OF MEETING THE KYOTO PROTOCOL FOR SPAIN

EXCESS OVER ALLOWED: 165,582 Gt CO_2 eq

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

Rate: 4.9 €/Mg

Source: United Nations, OECC, 2015



GHG MITIGATION THROUGH CONSERVATION AGRICULTURE

$C \times 44/12 = CO_2$

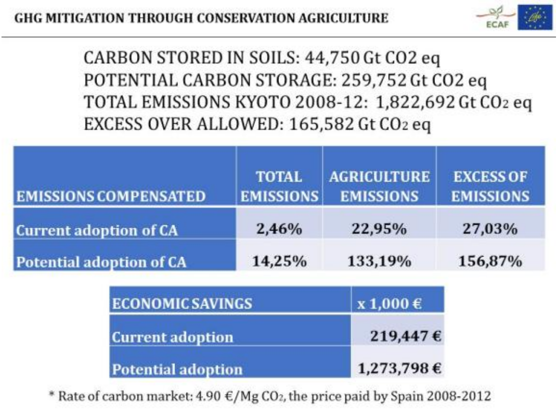
$\times 44/12 = \times 3.7$

x 5

Current adoption	Mg C ha-1 yr-1	Mg CO_2 ha-1 yr-1	**Hectares**	Gg CO_2 ha-1 yr-1	Period 2008-12
No-tillage	0,85	3,12	**590,472**	1,840	9,202
Groundcovers	1,54	5,65	**1,259,079**	7,110	35,548
Total			**1,849,551**	**8,950**	**44,750**

Potential adoption	Mg C ha-1 yr-1	Mg CO_2 ha-1 yr-1	**Hectares**	Gg CO_2 ha-1 yr-1	Period 2008-12
No-tillage	0,85	3,12	**7,827,019**	24,394	121,971
Groundcovers	1,54	5,65	**4,880,071**	27,556	137,781
Total			**12,707,090**	**51,950**	**259,752**

Adoption estimation: Esyrce, 2015



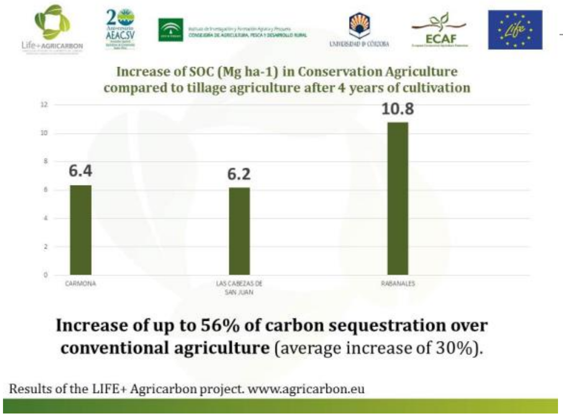
GHG MITIGATION THROUGH CONSERVATION AGRICULTURE

CARBON STORED IN SOILS: 44,750 Gt CO2 eq
POTENTIAL CARBON STORAGE: 259,752 Gt CO2 eq
TOTAL EMISSIONS KYOTO 2008-12: 1,822,692 Gt CO_2 eq
EXCESS OVER ALLOWED: 165,582 Gt CO_2 eq

EMISSIONS COMPENSATED	TOTAL EMISSIONS	AGRICULTURE EMISSIONS	EXCESS OF EMISSIONS
Current adoption of CA	2,46%	22,95%	27,03%
Potential adoption of CA	14,25%	133,19%	156,87%

ECONOMIC SAVINGS	x 1,000 €
Current adoption	219,447 €
Potential adoption	1,273,798 €

* Rate of carbon market: 4.90 €/Mg CO_2, the price paid by Spain 2008-2012



Increase of SOC (Mg ha-1) in Conservation Agriculture compared to tillage agriculture after 4 years of cultivation

Increase of up to 56% of carbon sequestration over conventional agriculture (average increase of 30%).

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

GHG MITIGATION THROUGH CONSERVATION AGRICULTURE

Soil management systems and short term CO_2 emissions in a clayey soil in southern Spain

Authors: Carbonell-Bojollo, R., González-Sánchez, E.J., Veróz-González, O., Ordóñez-Fernández, R.

Journal: Science of the Total Environment (2011), 409 (15), pp. 2929-2935.

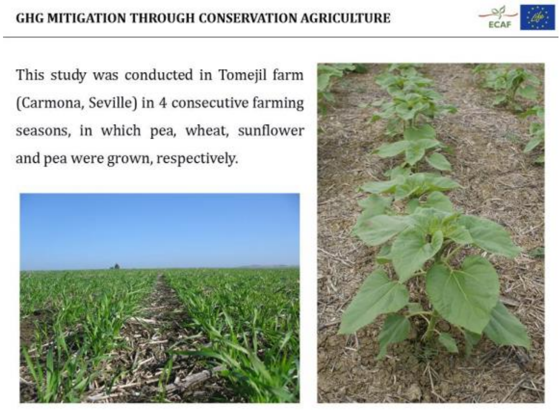
Indexed at: Journal Citation Reports (JCR)
Category: ENVIRONMENTAL SCIENCES.

In 2011, Science of the Total Environment had an impact factor of 3,286

Ranking: 29/205 (Q1)

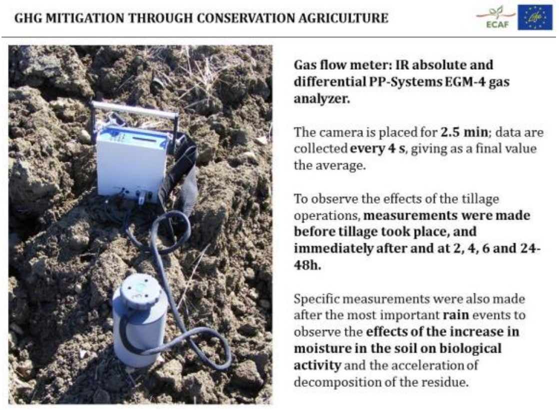
Article citations: 11 times

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



GHG MITIGATION THROUGH CONSERVATION AGRICULTURE

This study was conducted in Tomejil farm (Carmona, Seville) in 4 consecutive farming seasons, in which pea, wheat, sunflower and pea were grown, respectively.



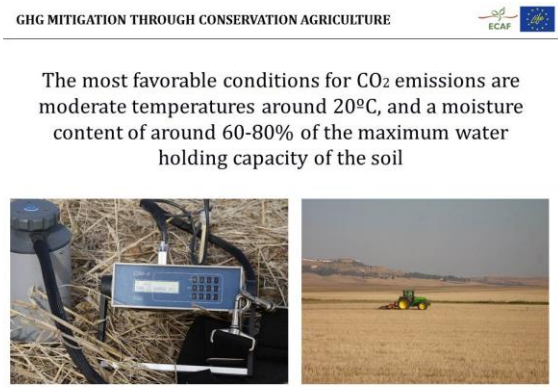
GHG MITIGATION THROUGH CONSERVATION AGRICULTURE

Gas flow meter: IR absolute and differential PP-Systems EGM-4 gas analyzer.

The camera is placed for **2.5 min**; data are collected **every 4 s**, giving as a final value the average.

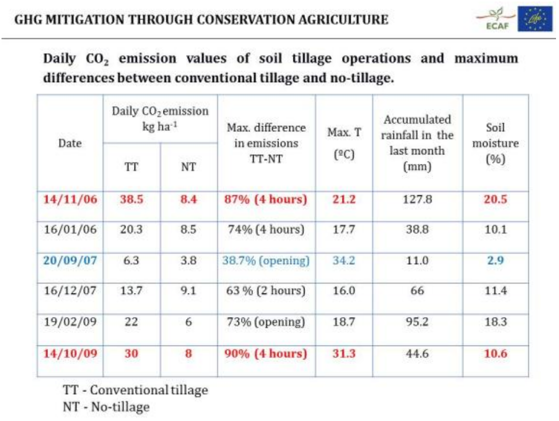
To observe the effects of the tillage operations, **measurements were made before tillage took place, and immediately after and at 2, 4, 6 and 24-48h.**

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 residue.



GHG MITIGATION THROUGH CONSERVATION AGRICULTURE

The most favorable conditions for CO2 emissions are moderate temperatures around 20ºC, and a moisture content of around 60-80% of the maximum water holding capacity of the soil

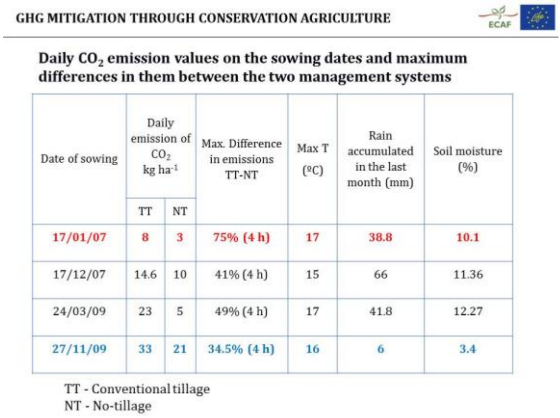


GHG MITIGATION THROUGH CONSERVATION AGRICULTURE

Daily CO_2 emission values of soil tillage operations and maximum differences between conventional tillage and no-tillage.

Date	Daily CO_2 emission kg ha^{-1}		Max. difference in emissions TT-NT	Max. T (ºC)	Accumulated rainfall in the last month (mm)	Soil moisture (%)
	TT	NT				
14/11/06	**38.5**	**8.4**	**87% (4 hours)**	**21.2**	127.8	**20.5**
16/01/06	20.3	8.5	74% (4 hours)	17.7	38.8	10.1
20/09/07	6.3	3.8	38.7% (opening)	34.2	11.0	**2.9**
16/12/07	13.7	9.1	63 % (2 hours)	16.0	66	11.4
19/02/09	22	6	73% (opening)	18.7	95.2	18.3
14/10/09	**30**	**8**	**90% (4 hours)**	**31.3**	44.6	**10.6**

TT - Conventional tillage
NT - No-tillage

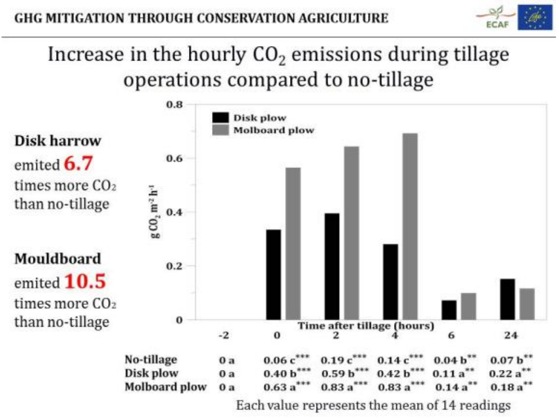


GHG MITIGATION THROUGH CONSERVATION AGRICULTURE

Daily CO_2 emission values on the sowing dates and maximum differences in them between the two management systems

Date of sowing	Daily emission of CO_2 kg ha^{-1}		Max. Difference in emissions TT-NT	Max T (ºC)	Rain accumulated in the last month (mm)	Soil moisture (%)
	TT	NT				
17/01/07	**8**	**3**	**75% (4 h)**	**17**	**38.8**	**10.1**
17/12/07	14.6	10	41% (4 h)	15	66	11.36
24/03/09	23	5	49% (4 h)	17	41.8	12.27
27/11/09	**33**	**21**	**34.5% (4 h)**	**16**	**6**	**3.4**

TT - Conventional tillage
NT - No-tillage



GHG MITIGATION THROUGH CONSERVATION AGRICULTURE

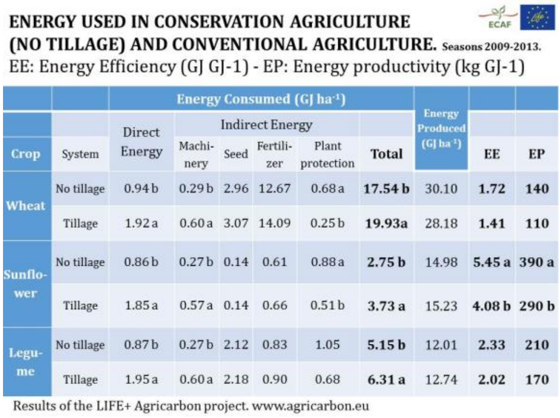
Increase in the hourly CO_2 emissions during tillage operations compared to no-tillage

Disk harrow
emited **6.7**
times more CO2
than no-tillage

Mouldboard
emited **10.5**
times more CO2
than no-tillage

	-2	0	2	4	6	24
No-tillage	0 a	0.06 c***	0.19 c***	0.14 c***	0.04 b**	0.07 b**
Disk plow	0 a	0.40 b***	0.59 b***	0.42 b***	0.11 a**	0.22 a**
Molboard plow	0 a	0.63 a***	0.83 a***	0.83 a***	0.14 a**	0.18 a**

Each value represents the mean of 14 readings

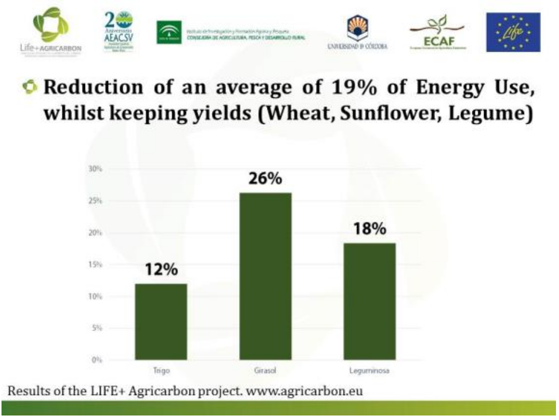


ENERGY USED IN CONSERVATION AGRICULTURE (NO TILLAGE) AND CONVENTIONAL AGRICULTURE. Seasons 2009-2013.

EE: Energy Efficiency (GJ GJ-1) - EP: Energy productivity (kg GJ-1)

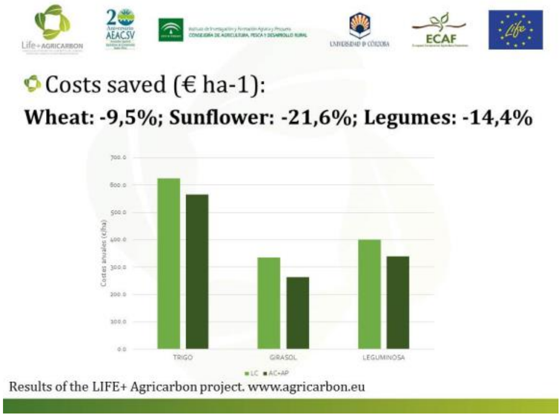
		Energy Consumed (GJ ha^{-1})						Energy Produced (GJ ha^{-1})		
		Direct Energy	Indirect Energy							
Crop	System		Machinery	Seed	Fertilizer	Plant protection	Total		EE	EP
Wheat	No tillage	0.94 b	0.29 b	2.96	12.67	0.68 a	**17.54 b**	30.10	**1.72**	**140**
	Tillage	1.92 a	0.60 a	3.07	14.09	0.25 b	**19.93a**	28.18	**1.41**	**110**
Sunflower	No tillage	0.86 b	0.27 b	0.14	0.61	0.88 a	**2.75 b**	14.98	**5.45 a**	**390 a**
	Tillage	1.85 a	0.57 a	0.14	0.66	0.51 b	**3.73 a**	15.23	**4.08 b**	**290 b**
Legume	No tillage	0.87 b	0.27 b	2.12	0.83	1.05	**5.15 b**	12.01	**2.33**	**210**
	Tillage	1.95 a	0.60 a	2.18	0.90	0.68	**6.31 a**	12.74	**2.02**	**170**

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



Reduction of an average of 19% of Energy Use, whilst keeping yields (Wheat, Sunflower, Legume)

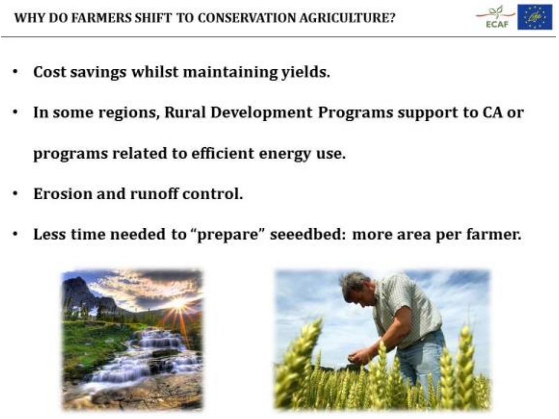
Results of the LIFE+ Agricarbon project. www.agricarbon.eu



Costs saved (€ ha-1):

Wheat: -9,5%; Sunflower: -21,6%; Legumes: -14,4%

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



WHY DO FARMERS SHIFT TO CONSERVATION AGRICULTURE?

- **Cost savings whilst maintaining yields.**
- **In some regions, Rural Development Programs support to CA or programs related to efficient energy use.**
- **Erosion and runoff control.**
- **Less time needed to "prepare" seeedbed: more area per farmer.**

HOW TO SUPPORT THE UPTAKE OF CA IN EUROPE

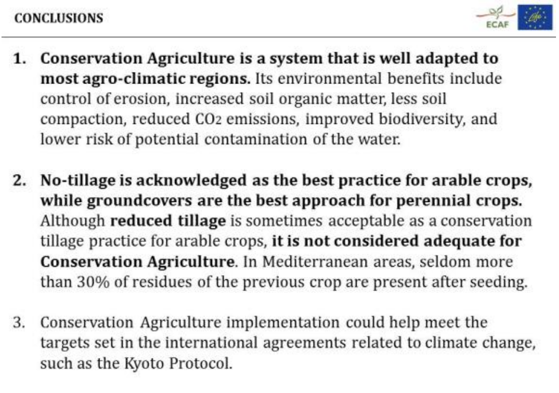
SUPPORTING TRAINING FOR FARMERS - MINDSET

HOW TO SUPPORT THE UPTAKE OF CA IN EUROPE

INCENTIVES FOR INVESTMENT IN MACHINERY

HOW TO SUPPORT THE UPTAKE OF CA IN EUROPE

NEW AND BETTER POLICIES:
THE EU IS STILL SUPPORTING OLD AGRICULTURAL MODELS

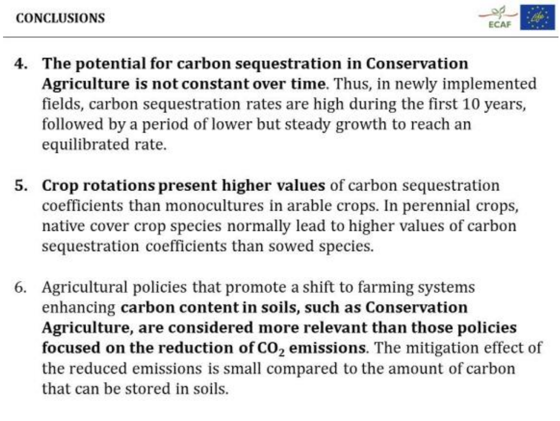


CONCLUSIONS

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 CO_2 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.



CONCLUSIONS

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 sowed 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 CO_2 emissions**. The mitigation effect of the reduced emissions is small compared to the amount of carbon that can be stored in soils.

¡GRACIAS!
Q&A time

Prof. Dr. Emilio J González-Sánchez
EUROPEAN CONSERVATION AGRICULTURE FEDERATION
UNIVERSITY OF CORDOBA (SPAIN)
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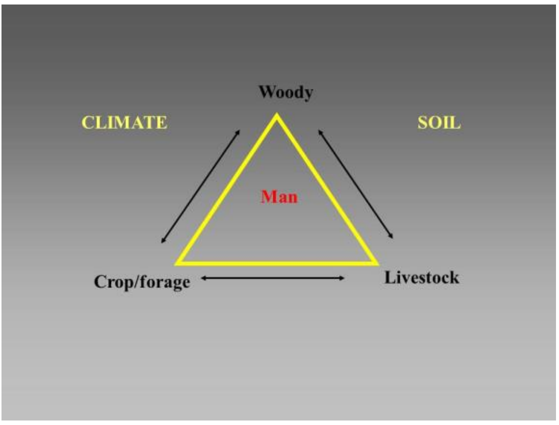
Agroforestry systems. Maria Rosa Mosquera-Losada (EURAF/University of Santiago de Compostela)

Technological mitigation options for carbon dioxide (CO2): Agroforestry

María Rosa Mosquera-Losada

Crop Production Department
University of Santiago de Compostela



Woody

CLIMATE

SOIL

Man

Crop/forage

Livestock

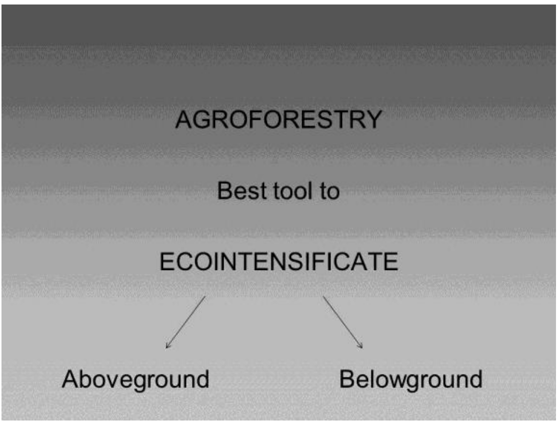
Europe agriculture goal

Increase food production in a sustainable way

FAO

Improvement efficiency in the use of resources

ECOINTENSIFICATION



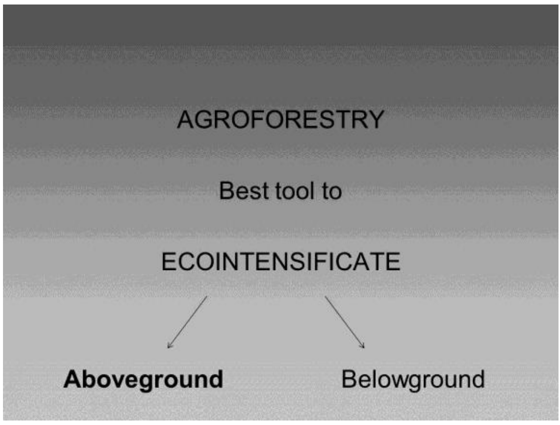
AGROFORESTRY

Best tool to

ECOINTENSIFICATE

Aboveground

Belowground



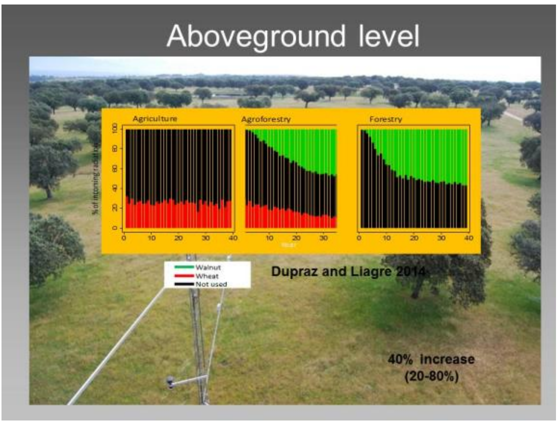
AGROFORESTRY

Best tool to

ECOINTENSIFICATE

Aboveground

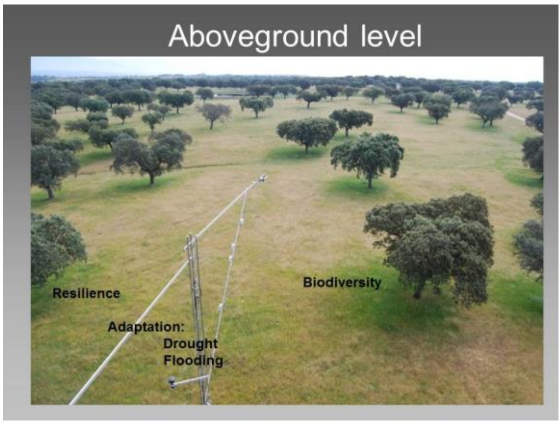
Belowground



Aboveground level

Dupraz and Liagre 2014

40% increase
(20-80%)

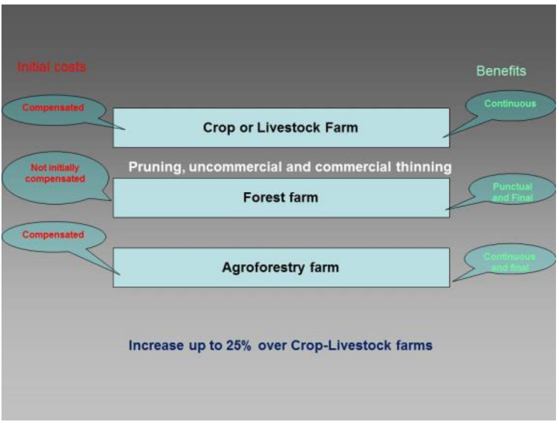


Aboveground level

Resilience

Biodiversity

Adaptation:
Drought
Flooding



Initial costs

Benefits

Compensated

Crop or Livestock Farm

Continuous

Pruning, uncommercial and commercial thinning

Not initially compensated

Forest farm

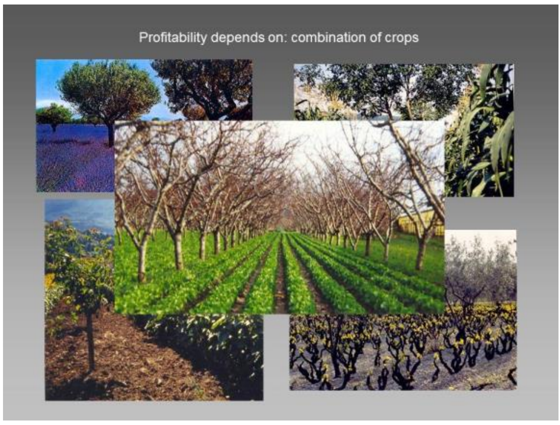
Punctual and Final

Compensated

Agroforestry farm

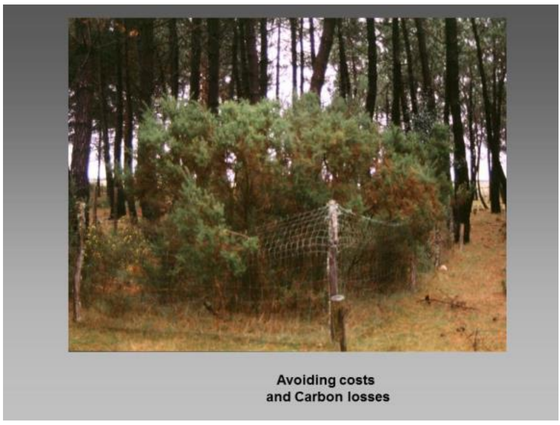
Continuous and final

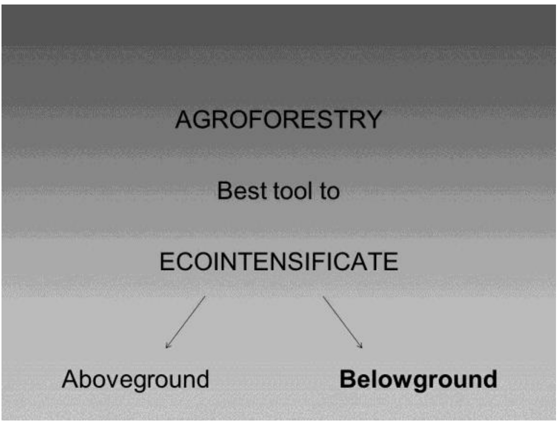
Increase up to 25% over Crop-Livestock farms


Profitability depends on: combination of crops


Tree lines

20% increasing crop production

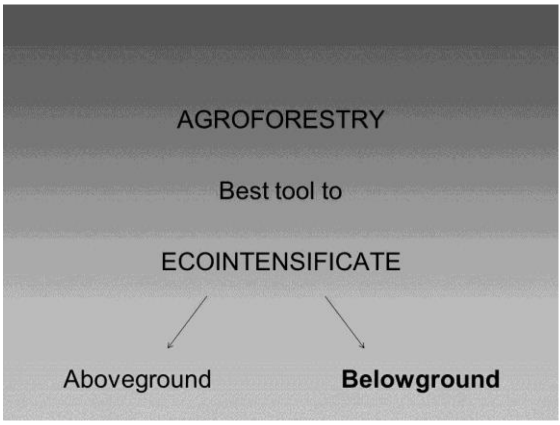

Avoiding costs and Carbon losses


AGROFORESTRY

Best tool to

ECOINTENSIFICATE

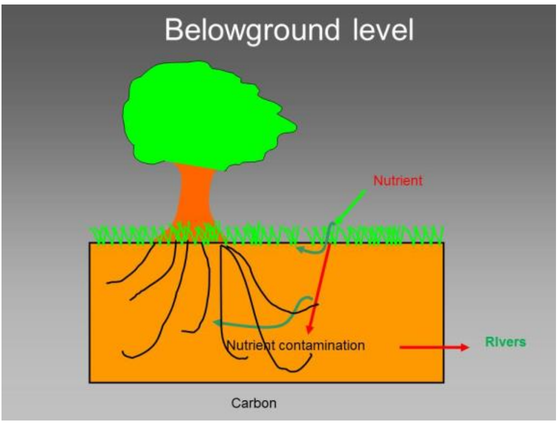
Aboveground **Belowground**

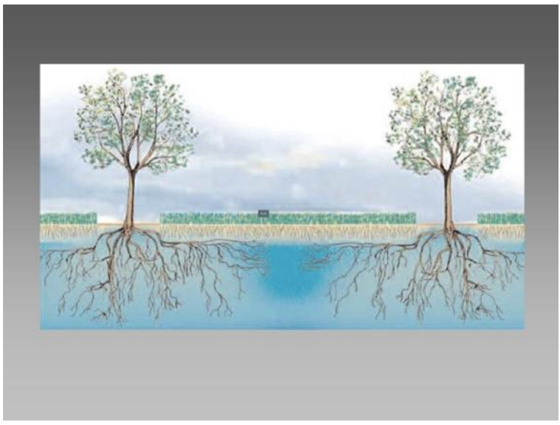

AGROFORESTRY

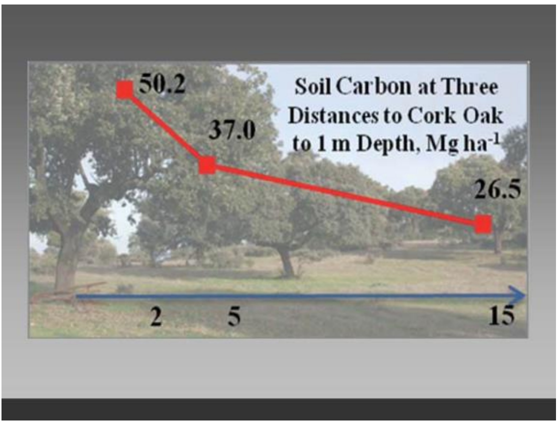
Best tool to

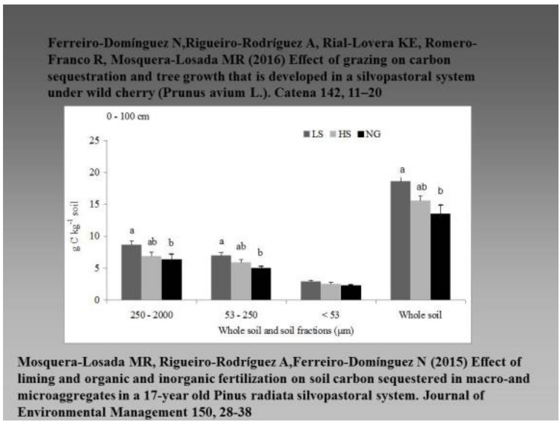
ECOINTENSIFICATE

Aboveground **Belowground**


Belowground level

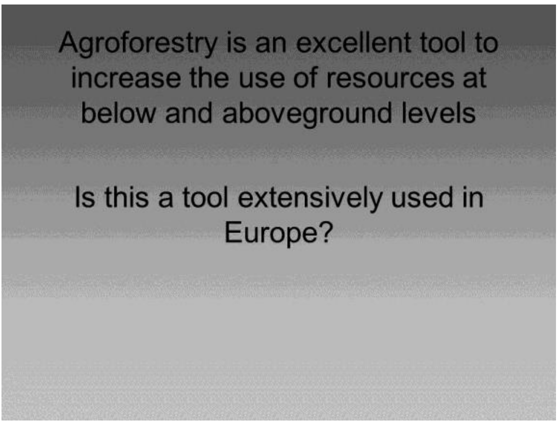



Soil Carbon at Three Distances to Cork Oak to 1 m Depth, Mg ha^{-1}



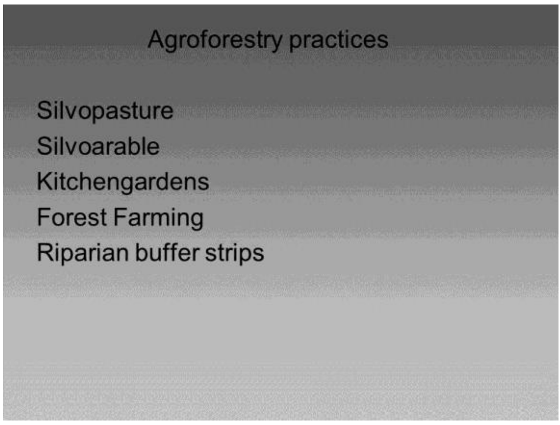
Ferreiro-Domínguez N,Rigueiro-Rodríguez A, Rial-Lovera KE, Romero-Franco R, Mosquera-Losada MR (2016) Effect of grazing on carbon sequestration and tree growth that is developed in a silvopastoral system under wild cherry (Prunus avium L.). Catena 142, 11–20

Mosquera-Losada MR, Rigueiro-Rodríguez A,Ferreiro-Domínguez N (2015) Effect of liming and organic and inorganic fertilization on soil carbon sequestered in macro-and microaggregates in a 17-year old Pinus radiata silvopastoral system. Journal of Environmental Management 150, 28-38



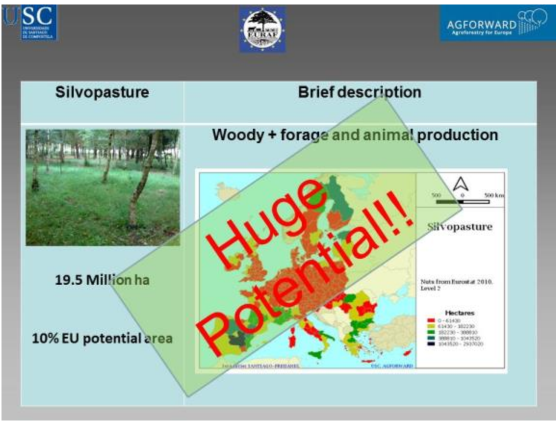
Agroforestry is an excellent tool to increase the use of resources at below and aboveground levels

Is this a tool extensively used in Europe?

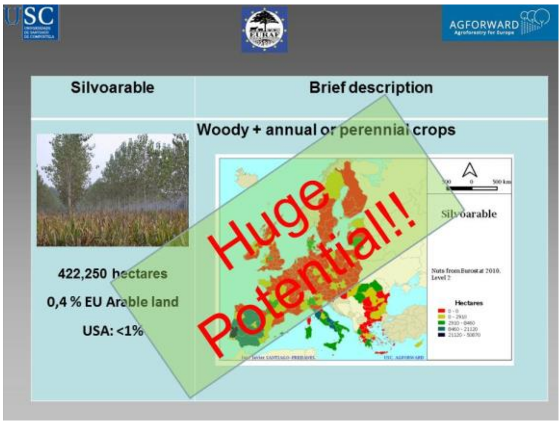


Agroforestry practices

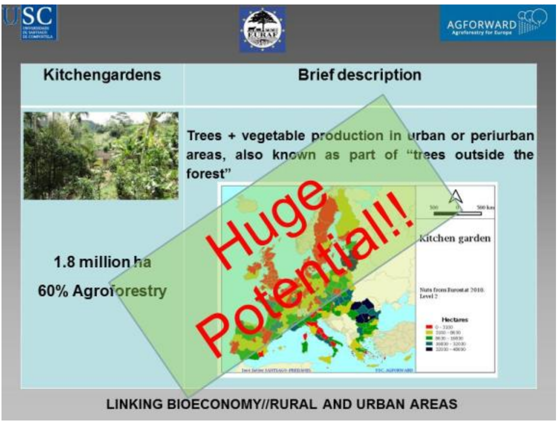
Silvopasture
Silvoarable
Kitchengardens
Forest Farming
Riparian buffer strips



Silvopasture	Brief description
19.5 Million ha 10% EU potential area	Woody + forage and animal production

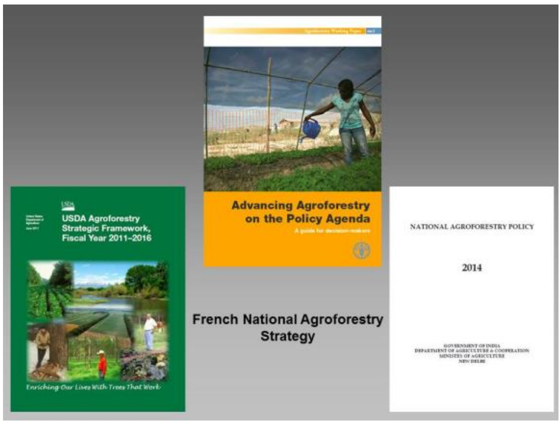


Silvoarable	Brief description
422,250 hectares 0,4 % EU Arable land USA: <1%	Woody + annual or perennial crops



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

LINKING BIOECONOMY//RURAL AND URBAN AREAS

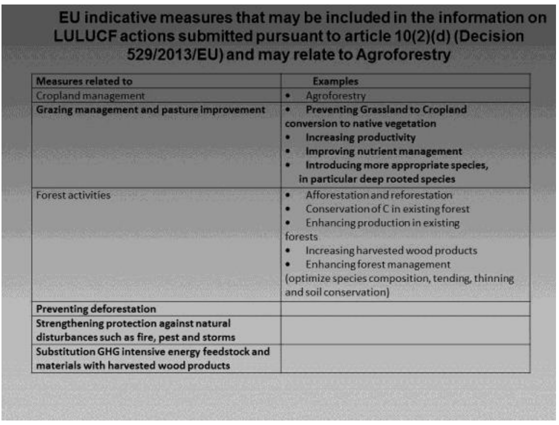


French National Agroforestry Strategy

NATIONAL AGROFORESTRY POLICY

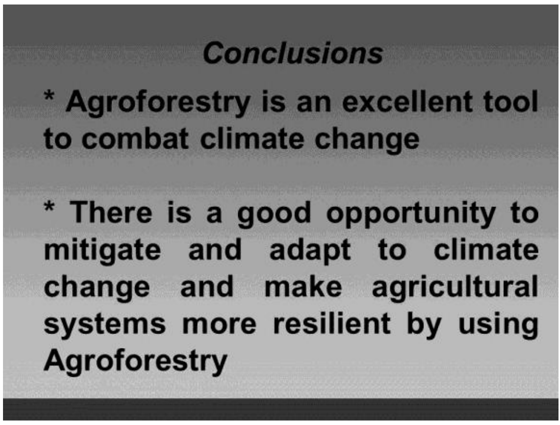
2014

GOVERNMENT OF INDIA
DEPARTMENT OF AGRICULTURE & COOPERATION
MINISTRY OF AGRICULTURE
NEW DELHI



EU indicative measures that may be included in the information on LULUCF actions submitted pursuant to article 10(2)(d) (Decision 529/2013/EU) and may relate to Agroforestry

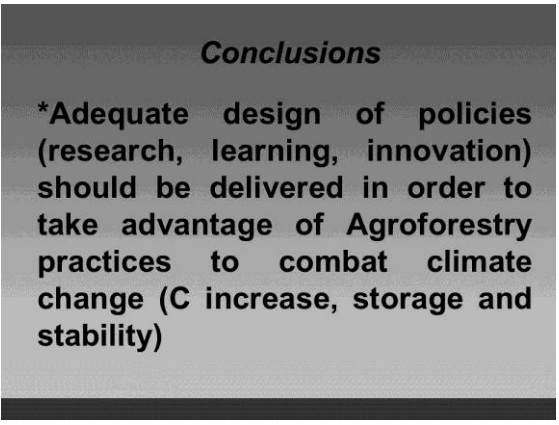
Measures related to	Examples
Cropland management	• Agroforestry
Grazing management and pasture improvement	• **Preventing Grassland to Cropland conversion to native vegetation** • **Increasing productivity** • **Improving nutrient management** • **Introducing more appropriate species, in particular deep rooted species**
Forest activities	• Afforestation and reforestation • Conservation of C in existing forest • Enhancing production in existing forests • Increasing harvested wood products • Enhancing forest management (optimize species composition, tending, thinning and soil conservation)
Preventing deforestation	
Strengthening protection against natural disturbances such as fire, pest and storms	
Substitution GHG intensive energy feedstock and materials with harvested wood products	



Conclusions

* Agroforestry is an excellent tool to combat climate change

* There is a good opportunity to mitigate and adapt to climate change and make agricultural systems more resilient by using Agroforestry



Conclusions

*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)

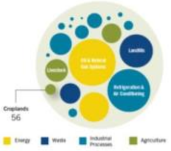
Global Mitigation of Non-CO2 GHG: 2010-2030. Shaun Ragnauth (USEPA)

United States Environmental Protection Agency

Global Mitigation of Non-CO_2 Greenhouse Gases: 2010 - 2030

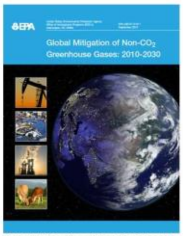
Shaun Ragnauth – U.S. EPA | Climate Change Division

Workshop on "Datasets on GHG emissions mitigation technologies for the agriculture sector"
Seville, June 14, 2016



Non-CO_2 Global Mitigation Report: 2010-2030 Background

- USEPA has developed a comprehensive global mitigation analysis for non-CO_2 GHGs, covering:
  - All non-CO_2 greenhouse gases (methane, nitrous oxide, high GWP gases)
  - All emitting sectors (energy, waste, agriculture, and industrial processes)
    - Coal mining (CH_4)
    - Oil and natural gas systems (CH_4)
    - Solid waste management (CH_4)
    - Wastewater (CH_4, N_2O)
    - Specialized industrial processes (N_2O, PFCs, SF_6, HFCs)
    - Agriculture (CH_4, N_2O).
  - Global coverage – disaggregated at the country level
  - 2010 – 2030
- Coupled with baseline emission projections from EPA's non-CO_2 projections report
- Has undergone an external peer review process
- Builds on work started in 1999
  - 2001 & 1999 EPA reports on CH_4 and N_2O domestic mitigation potential
  - Stanford Energy Modeling Forum – EMF-21
  - 2006 Global Mitigation of Non-CO_2 Greenhouse Gases
- Provides improved data to better understand the costs and opportunities for reducing non-CO_2 greenhouse gas emissions.

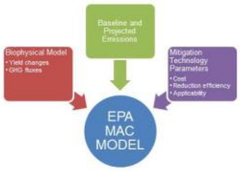


Global Mitigation of Non-CO_2 Greenhouse Gases
(USEPA, 2013)

Methodology

MACs provide information on the amount and cost of emissions reductions that can be achieved in a given sector

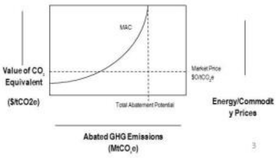
- Abatement options are represented through bottom-up engineering cost analysis
- Costs, benefits, and potential mitigation is assessed for each option
- For each sector and region the MAC curve is determined by the series of breakeven price calculations for the suite of available options
- Each point reflects the average price and reduction potential for a given abatement option


Baseline and Projected Emissions

Biophysical Model
- Yield changes
- GHG fluxes

Mitigation Technology Parameters
- Cost
- Reduction efficiency
- Applicability

EPA MAC MODEL

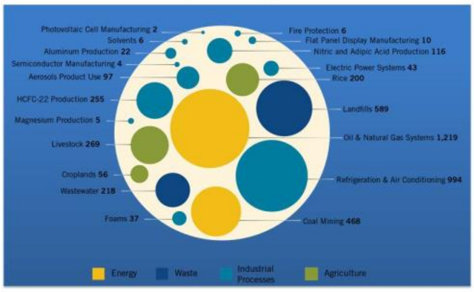


Data Sources and Models

- Data sources
  - Emissions baseline:
    - Domestic - U.S. Inventory of Greenhouse Gases and Sinks
    - International regions - Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990-2030
  - Emissions projections:
    - Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990-2030 (EPA 430-D-11-003)
    - Sector specific models and data for agriculture sources
      - DayCent
      - IMPACT
      - DNDC
      - FAOSTAT
  - Labor, energy and commodity prices:
    - Labor - U.S. BLS
    - Energy - EIA – AEO 2010, International Energy Statistics
    - Materials – UNCTAD Statistical Database
  - Mitigation and cost estimates:
    - Sector specific engineering and cost studies
    - Industry reported and supplied data
    - U.S. EPA Clean Watersheds Needs Survey
- Models
  - MAC model (EPA)
    - GAMS based model allows for fast updates to MACs based on new projections, cost, mitigation data, or other updated parameters
  - DNDC Model (Applied Geosolutions/UNH)
    - Rice mitigation
  - DayCent Model (University of Colorado)
    - Croplands
  - IMPACT Model (IFPRI)
  - Vintaging Model (EPA)

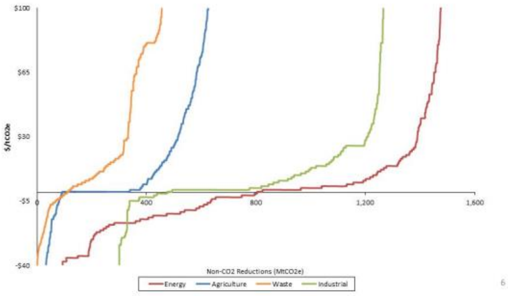
Key Findings

- Total technically feasible global mitigation from non-CO_2 GHG sources in 2030 is over 3,500 $MtCO_2e$



Aggregate Results – MACs by Sector (2030)

Globally, over 500 $MtCO_2e$ of reductions from the agriculture sector are available under $30/$tCO_2e$.



Croplands – Models and Data Sources

- Models:
  - DAYCENT ecosystem model
    - Biophysical model to estimate crop yields, N_2O and CH_4 emissions, and soil C stocks at 0.5° 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 (IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade)
    - Projected acreage changes to meet future demand reflecting socio-economic drivers (population growth, technology change, etc.)
  - US EPA Marginal Abatement Cost (MAC) Model
    - Assimilates abatement measure technology costs, yield changes, expected benefits, and emission reductions
      - Computes abatement cost for each option
      - Calculates break-even prices for each option for 195 countries to construct MAC curves
- Data sources:
  - Weather data – North American Carbon Program
  - Soil data – FAO Digitized Soil Map of the World
  - Cropland areas – global cropland map developed by Ramankutty et al. (2008)

Croplands - Methodology

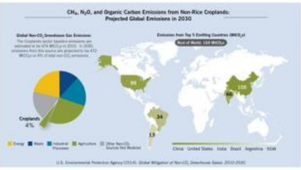
- Methodology
  - Crops modeled for irrigated and non-irrigated systems:
    - Maize
    - Wheat
    - Barley
    - Soybean
    - Sorghum
  - Established baseline scenario for each crop production system assuming business as usual practices
  - Used IMPACT model to develop projected baseline emissions and crop production
  - Analyzed seven mitigation scenarios:
    - No-till
    - Optimal N fertilization (precision agriculture)
    - Split N fertilization
    - 100% residue incorporation
    - Nitrification inhibitors
    - Reduced fertilization
    - Increased fertilization
  - Total harvested area scaled to match country scale data on harvested areas reported in FAOSTAT
    - Including analogous crops and matching FAOSTAT harvested areas, the DAYCENT simulated area was about 61% of global non-rice cropland areas reported in FAOSTAT
  - DAYCENT data pulled in to MAC model to generate break-even prices and MAC curves

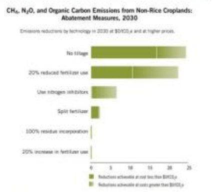
Croplands Mitigation Technologies

Mitigation Technology	Applicability	Economic Applicability and Cost	Additional Factors
No-Till Adoption	All regions/All time periods	Reductions in labor costs assciated with reduction in field preparation. May require additional equipment for direct planting, but may be offset by traditional tillage equipment costs	Where yields change as a result, production is valued at the market price.
Reduced Ferilization (20% reduction)	All regions/All time periods with non-zero ferilizer application rates	Reduces operation costs by the value of fertilizer withheld	Where yields change as a result, production is valued at the market price.
Increased Fertilization (20% increase)	All regions/All time periods with non-zero ferilizer application rates	Increases operation costs by the value of additional fertilizer used	Where yields change as a result, production is valued at the market price.
Split N Fertilization (Spread over three separate and equal applications)	All regions/All time periods with non-zero ferilizer application rates	Assumed to require 14% more labor to account for additional passes over fields to apply fertilizer multiple times	Where yields change as a result, production is valued at the market price.
Nitrification Inhibitors	All regions/All time periods with non-zero ferilizer application rates	Assumed cost to be $20 per hectare for the United States and scaled to other regions	Where yields change as a result, production is valued at the market price.
100% Residue Incorporation	All regions/All time periods	No cost associated with this option	Where yields change as a result, production is valued at the market price.

- Data Gaps
  - Capital costs not widely available for mitigation technologies
    - Lack of regional specific cost estimates of emerging management practices and mitigation measures
  - All costs in MAC model are around changes in yield and fertilization utilization
  - Limited data on the adoption of new technology in the agriculture sector

Croplands Results





CH$_4$, N$_2$O, and Organic Carbon Emissions from Non-Rice Croplands: Emissions Reduction Potential, 2030

It would be cost-effective to reduce emissions by 5.4%, compared to baseline, in 2030. An additional 6.4% reduction is available using technologies with increasingly higher costs.

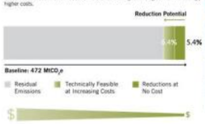


Table 1-2: DAYCENT Base Mean Yields, and Differences from Mean Yield for Mitigation Strategies, by Year (Metric tons of Grain per Hectare)

	2010	2015	2020	2025	2030
Maize					
Base Yield	3.64	3.64	3.64	3.59	3.6
No-Till	0	-0.25	-0.17	-0.12	-0.07
Optimal N fertilization*	0	2.9	3.05	3.1	3.08
Split N Fertilization	0	0.16	0.17	0.19	0.18
100% Residue Inc.	0.22	0.23	0.24	0.24	0.24
Nitrification Inhibitors	0	-0.01	-0.01	-0.01	-0.01
Reduced Fertilization	-0.05	-0.36	-0.39	-0.4	-0.4
Increased Fertilization	0.04	0.28	0.29	0.31	0.31

Rice Cultivation – Models and Data Sources

- Models:
  - DNDC (Denitrification-Decomposition)
    - Biophysical model used to simulate production, crop yields and GHG fluxes under BAU and mitigation scenarios
    - DNDC predicts daily CH$_4$, N$_2$O and soil carbon fluxes from rice paddies through the growing and fallow seasons as fields remain flooded or move between flooded and drained conditions during the season
  - US EPA Marginal Abatement Cost (MAC) Model
    - Assimilates abatement measure technology costs, yield changes, expected benefits, and emission reductions
      - Computes abatement cost for each option
      - Calculates break-even prices for each option for 195 countries to construct MAC curves
- Data Sources:
  - FAO country-level statistics (FAOSTAT 2010) were used to establish harvested area for rice
  - Global meteorological data from NOAA's National Centers for Environmental Prediction were used to establish climate data in the model
  - N fertilizer application rates were based on DNDC fertilizer use data, derived from global data sources
  - IFPRI IMPACT model used for projected acreage of production systems

Rice Cultivation - Methodology

- Methodology:
  - Baseline scenarios established for each country reflecting assumptions on water management, fertilizer application, residue management, and tillage practices
  - Simulated rice yields and GHG fluxes for each grid cell and aggregated at the country level
  - Analyzed 26 mitigation scenarios using DNDC
    - Address management techniques in various combinations
      - Water management
      - Residue management
      - Tillage
      - Fertilizer management alternatives
  - Compared mitigation options to portions of the baseline to which they could potentially be applied
  - In DNDC rice production areas were held constant at the 2010 level to obtain the biophysical effects of management practice changes on crop yields and GHG fluxes
  - DNDC data pulled in to MAC model to generate break-even prices and MAC curves

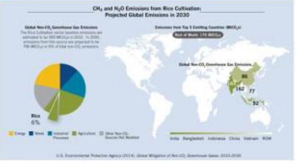
Rice Cultivation – Management Techniques

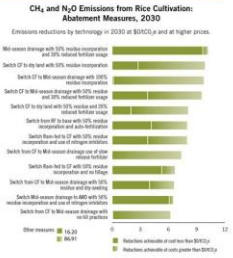
Management Technique	Description
Rice flooding	
Continuous Flooding (CF)	rice paddy is flooded on planting date and drained 10 days prior to harvest date - applies to both irrigated and rainfed rice
Mid-season drainage (MD)	rice paddy is drained twice during growing season for 8 days - final drainage is 10 days prior to harvest date - applies only to irrigated rice
Alternate wetting and drying (AWD)	rice paddy is initially flooded to 10 cm – water level is reduced at rate of -0.5 cm/day till to -5cm and then reflooded at rate of 0.5 cm/day till to 10 cm - applies only to irrigated rice
Dryland rice	all irrigated and rainfed rice are swapped for dryland rice - no flooding occurs
Rice seeding	
Direct seeding (DS)	rice paddy is flooded 40 days after planting date and drained 10 days prior to harvest date - applies to both irrigated and rainfed rice
Residue incorporation	
50%	50% of above-ground crop residue is removed - remaining residue is incorporated at next tillage
100%	all residue remains in place and is incorporated at next tillage
Tillage	
Conventional	prior to first crop in rotation tillage to 20cm depth; subsequent tillages (following each crop in rotation) to 10cm depth
No-till	tillage only mulches residue
Fertilizer	
Conventional	fertilizer N applied as urea on plant date using a crop-specific rate
Ammonium sulfate	fertilizer N applied as ammonium sulfate on plant date using a crop-specific rate
Nitrification inhibitor	nitrification inhibitor is used with urea; reduced conversion of NH4 to NO3 is simulated with 60% efficiency over 120 days
Slow-release	slow-release urea applied on planting date – N is released over 90 days at a linear rate
10% reduced	Crop-specified baseline fertilizer N rate is reduced by 10% (applied as urea)
20% reduced	Crop-specified baseline fertilizer N rate is reduced by 20% (applied as urea)
30% reduced	Crop-specified baseline fertilizer N rate is reduced by 30% (applied as urea)
auto fertilization	Fertilizer N is applied at the rate that maximizes crop yield

- **Capital Cost:** None of the options were assumed to have any capital cost.
- **Annual Operation and Maintenance (O&M) Cost:** Changes in labor, fertilizer, and other inputs associated with each option.
- **Annual Benefits:** Calculated based on changes in production associated with changes in yield, valued at market prices.
- **Applicability:** All options applicable for a given cropping pattern were assumed available to all acres in all countries. Water management options are only applicable to irrigated systems. No water management options are available for rain fed, deep-water, or upland rice
- **Technical Efficiency:** Determined by the DNDC Model for each country, production type, and water management combination for each mitigation option.
- **Technical Lifetime:** Indefinite

- **Data Gaps and Limitations**
  - Consistent data on management practices is not available for all countries or regions
  - Assumes mitigation techniques can be applied with no lead time

Rice Cultivation - Results





CH$_4$ and N$_2$O Emissions from Rice Cultivation: Emissions Reduction Potential, 2030

It would be cost-effective to reduce emissions by 8%, compared to baseline, in 2030. An additional 18% reduction is available using technologies with increasingly higher costs.

Livestock – Models and Data Sources

- Models:
  - US EPA Marginal Abatement Cost (MAC) Model
    - Assimilates abatement measure technology costs, yield changes, expected benefits, and emission reductions
      - Computes abatement cost for each option
      - Calculates break-even prices for each option for 195 countries to construct MAC curves
  - IFPRI IMPACT Model
- Data Sources:
  - Baseline – USEPA Global Projections Report
  - Mitigation data – various literature, including UNFCCC

Livestock - Methodology

- Methodology:
  - Baseline and projections
    - Uses 2005 country-level livestock population data from the EPA Report, "Global Anthropogenic Non-CO$_2$ Emissions"
    - For the period 2010-2030 an alternate business-as-usual forecast was constructed using livestock production and market price projections generated by IMPACT
      - IMPACT model projections provide a set of prices and global production patterns consistent with their livestock population and productivity assumptions.
  - Evaluates six mitigation options for enteric fermentation CH$_4$ emissions
  - Evaluates ten mitigation options for manure management CH$_4$ emissions
  - EPA MAC model evaluates mitigation options, costs, and associated reductions to generate break-even prices and MAC curves

Livestock Enteric Fermentation – Mitigation options

Abatement Option	Total Installed Capital Cost (2010 USD)	Annual O&M Cost (2010 USD)	Capital Lifetime (Years)	Reduction Efficiency (change in emissions per head)	Benefits (Changes in Livestock or Energy Revenue)
Improved Feed Conversion	0	25–295 per head	NA	CH_4: –39.4% to +39.6%	0–79% increase in animal yield
Antibiotics	0	4–9 per head	NA	CH_4: –0.4% to –6%	5% increase in animal yield
bST	0	123–300 per head	NA	CH_4: –0.2% to +10.3%	12.5% increase in animal yield
Propionate Precursors	0	40–120 per head	NA	CH_4: –10% beef cattle and sheep; –25% dairy animals	5% increase in animal yield
Antimethanogen	0	9–33 per head	NA	CH_4: –10%	5% increase in animal yield
Intensive Grazing	0	–180 to +1 per head	NA	CH_4: –13.3% beef cattle; –15.5% dairy cattle	–11.2% reduction in dairy cattle yield

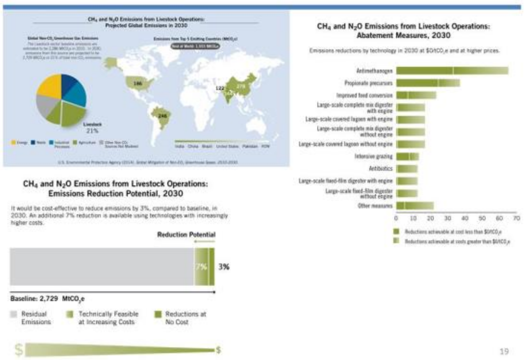
- Data gaps and limitations
  - Limited and inconsistent data for enteric fermentation on estimated magnitude of emissions reductions
  - Abatement options including bST and antibiotics are controversial and have animal and human health concerns
  - Some options will not be commercially available until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

Livestock Manure Management – Mitigation Options

Mitigation Option	Capital Cost	Annual O&M	Annual Benefits	Applicability	Technical Efficiency	Lifetime
Complete-mix Digester with and without engine	$61/$100 per head (swine), $588/$958 per head (cattle) depending on optional engine	Estimated $0.07--$0.11 per head (swine), $2.06/3.35 (cattle)	$8 per head (swine), $65 per head (cattle) if equipped with an engine and used to displace purchased power	Swine and cattle managed in intensive production systems in developed regions	85%	20 years
Plug-flow Digester with and without engine	$790/$1288 per head	Estimated $2.30 -- $8.90 per head	$65 per head if equipped with an engine and used to displace purchased power	Dairy cattle in developed regions	85%	20 years
Fixed-film Digester with and without engine	$102/$128 per head	Estimated $0.06 -- $0.13 per head	$8 per head if equipped with an engine and used to displace purchased power	Swine managed in intensive production systems in developed regions	85%	20 years
Large-scale Covered Lagoon with and without engine	$25/$43 per head (swine), $773/$1,182 (cattle)	Estimated $0.06/$0.13 per head (swine), $2.01/$3.43 (cattle)	$8 per head (swine), $65 per head (cattle) if equipped with an engine and used to displace purchased power	Swine and dairy cattle managed in intensive production systems in developed regions	85%	20 years
Small-scale Dome Digester	$50 per 1,000 lbs liveweight	Estimated $1.25 per 1,000 lbs liveweight	$7 per head (swine), $48 per head (cattle	Swine and dairy cattle in developing regions	50%	10 years
Centralized Digester	$163 per head (swine) , $1,007 per head (cattle)	Estimated $0.07 per head (swine), $2.06 per head (cattle)	$8 per head (swine), $65 per head (cattle) if equipped with an engine and used to displace purchased power	Swine and dairy cattle in intensively managed production systems in EU-27 regions	85%	20 years

- Data Gaps and Limitations
  - Often reflect anecdotal experience reported in a specific country, region or livestock production system
  - Measures focus on CH_4 flaring or use for energy production
  - Limited options for reducing N_2O

Livestock - Results



Limitations and Future Data Needs

- Limitations and Future Data Needs
  - Availability and quality of data to represent the highly complex and heterogeneous cropland, rice and livestock production systems of the world
  - Biophysical 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-CO_2 sources with mitigation options that are available today
- Despite potential for project level cost savings and environmental benefits, barriers to mitigating non-CO_2 emissions (particularly CH_4) continue to exist:
  - Traditional practices
  - Regulatory and legal issues
- MACs and mitigation data set can feed in to 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

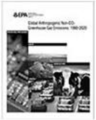
More Information

- Mitigation Report available on the web at:

https://www3.epa.gov/climatechange/EPAactivities/economics/nonco2mitigation/execsumm/index.html#

- Projections Report available on the web at:

http://www.epa.gov/climatechange/EPAactivities/economics/nonco2projections.html



- Contact:

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US GHG Mitigation Options and Costs for Agricultural Land and Animal production. Jan Lewandrowsky (USDA)

GHG Mitigation Options and Costs for Agricultural Land and Animal Production within the United States

Jan Lewandrowski (USDA)

Datasets on GHG emissions mitigation technologies for the agricultural sector

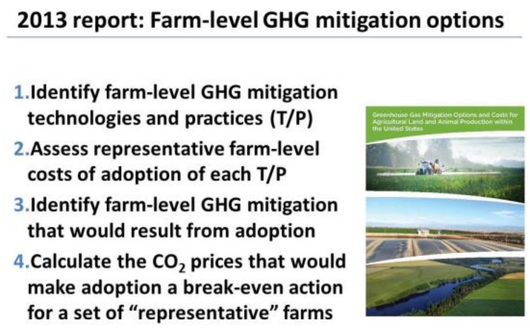
June 14, 2016

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

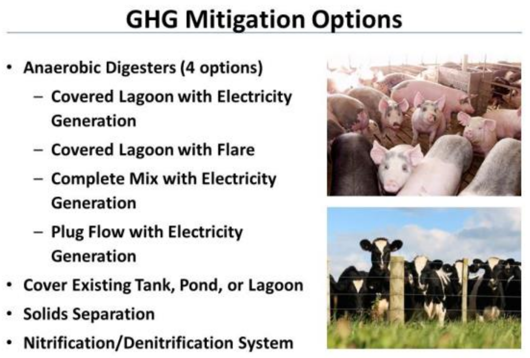


2013 report: Farm-level GHG mitigation options

1. **Identify farm-level GHG mitigation technologies and practices (T/P)**
2. **Assess representative farm-level costs of adoption of each T/P**
3. **Identify farm-level GHG mitigation that would result from adoption**
4. **Calculate the CO_2 prices that would make adoption a break-even action for a set of "representative" farms**

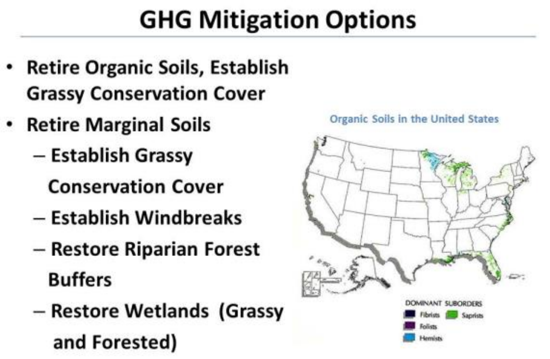
GHG Mitigation Options

- **Reduce Application of N Fertilizers (10%)**
- **Nitrogen Inhibitors**
- **Fall to Spring N Applications**
- **Variable Rate N Applications**
- **Reduced tillage (3 options)**
  - **Conventional to No-till**
  - **Conventional to Reduced**
  - **Reduced to No-till**



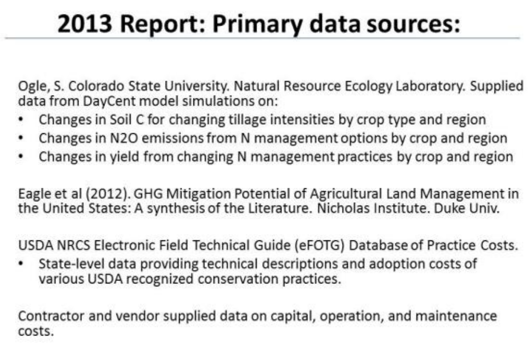
GHG Mitigation Options

- **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)**



2013 Report: Primary data sources:

Ogle, S. Colorado State University. Natural Resource Ecology Laboratory. Supplied data from DayCent model simulations on:

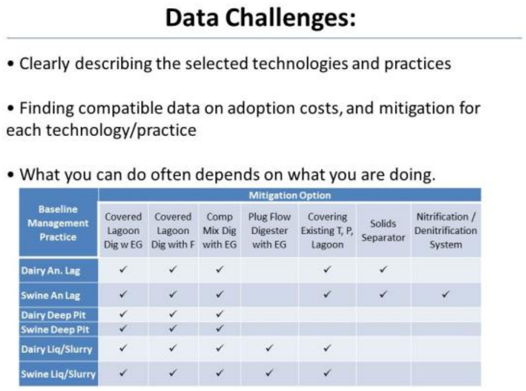
- Changes in Soil C for changing tillage intensities by crop type and region
- Changes in N2O emissions from N management options by crop and region
- Changes in yield from changing N management practices by crop and region

Eagle et al (2012). GHG Mitigation Potential of Agricultural Land Management in the United States: A synthesis of the Literature. Nicholas Institute. Duke Univ.

USDA NRCS Electronic Field Technical Guide (eFOTG) 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.



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.

Baseline Management Practice	Mitigation Option						
	Covered Lagoon Dig w EG	Covered Lagoon Dig with F	Comp Mix Dig with EG	Plug Flow Digester with EG	Covering Existing T, P, Lagoon	Solids Separator	Nitrification / Denitrification System
Dairy An. Lag	✓	✓	✓		✓	✓	
Swine An Lag	✓	✓	✓		✓	✓	✓
Dairy Deep Pit	✓	✓	✓				
Swine Deep Pit	✓	✓	✓				
Dairy Liq/Slurry	✓	✓	✓	✓	✓		
Swine Liq/Slurry	✓	✓	✓	✓	✓		

Final Outcomes

Technology	Baseline Practice	Farm Size	Region	Animal /Crop	BE Price
Covering Existing Lag	Anaer Lag	> 5000	PA	Swine	$3.48
Improved Separators	Anaer Lag	1,000 - 2,499	AP	Dairy	$3.63
Covering Existing Lag	Anaer Lag	2,500+	PA	Dairy	$4.53
VRT Nitrogen Sensor	N Manag	NA	AP	Corn	$4.56
Covering Existing Lag	Anaer Lag	2,500+	MN	Dairy	$4.83
Covering Existing Lag	Anaer Lag	2,500 - 4,999	PA	Swine	$5.57
Retire Org Soils-L	Cult Org Soil	NA	SE	NA	$5.83

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 CO_2 price

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 MACCs showing total agriculture sector GHG mitigation at CO_2 prices between $0 and $100 per mt CO_2 e**

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**

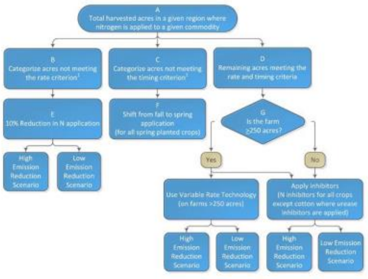
Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010
- **CH4 emissions by Manure Management System by region**
- **Acres of organic soils in cultivation**

2016 Report: Other data sources

- Ribaudo, M., J. Delgado, L. Hansen, M. Livingston, et al. 2011. *Nitrogen in Agricultural Systems; Implications for Convervation Policy*. Washington D.C.: USDA.
- USDA FSA. 2010. *Conservation Reserve Program: Annual Summary and Enrollment Statistics*: U.S. Department of Agriculture, Farm Service Agency.
- USDA NRCS. 2013a. *2007 National Resources Inventory: Wetlands*. Washington, DC: USDA, Natural Resources Conservation Service.
- USDA NRCS. 2013b. *Summary Report: 2010 National Resources Inventory*. Washington, DC and Ames, IA: USDA, Natural Resources Conservation Service and Iowa State University, Center for Survey Statistics and Methodology. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1167354.pdf.
- WRP. 2013. *Wetlands Reserve Program (WRP): 2008 Farm Bill Report (FY 2009 through FY 2012)*: USDA, Natural Resources Conservation Service, WRP. www.nrcs.usda.gov/Internet/NRCS_RCA/reports/fb08_cp_wrp.html.
- EPA. 2009c. *National Water Quality Inventory: Report to Congress: 2004 Reporting Cycle*. Washington, DC: U.S. Environmental Protection Agency.

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.



A
Total harvested acres in a given region where nitrogen is applied to a given commodity

B
Categorize acres not meeting the rate criterion[1]

C
Categorize acres not meeting the timing criterion[1]

D
Remaining acres meeting the rate and timing criteria

E
10% Reduction in N application

F
Shift from fall to spring application
(for all spring planted crops)

G
Is the farm >250 acres?

Yes

No

High Emission Reduction Scenario

Low Emission Reduction Scenario

Use Variable Rate Technology (on farms >250 acres)

Apply inhibitors
(N inhibitors for all crops except cotton where urease inhibitors are applied)

High Emission Reduction Scenario

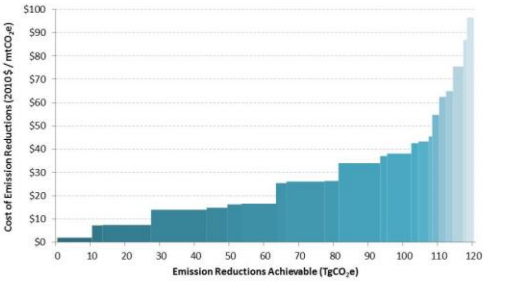
Low Emission Reduction Scenario

High Emission Reduction Scenario

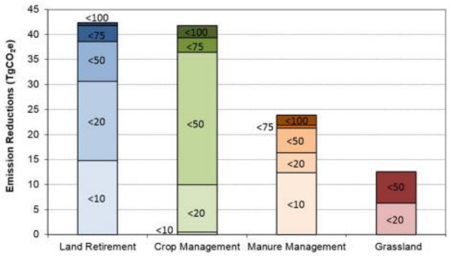
Low Emission Reduction Scenario

[1] Based on Ribaudo et al. 2011 criteria.

National MACC for all Mitigation Options (< $100 per mt CO_2e)



Mitigation by Source and CO_2 Price ($ per mt CO_2e)



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ICF

Diana Pape, Vice President
ICF International
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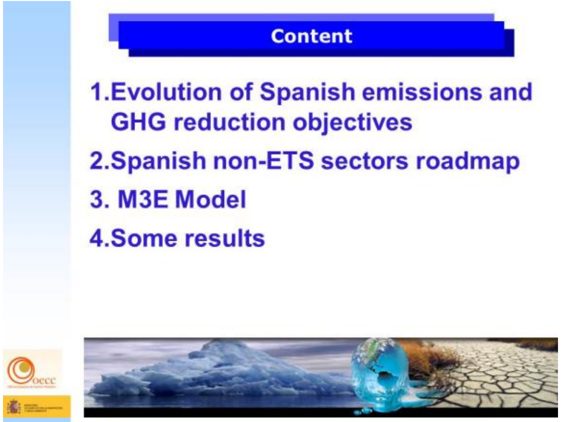
Mitigation Options for the Agricultural Sector: The Spanish Roadmap. Maria José Alonso Moya (OECC)

Mitigation Options for the Agricultural Sector: The Spanish Roadmap

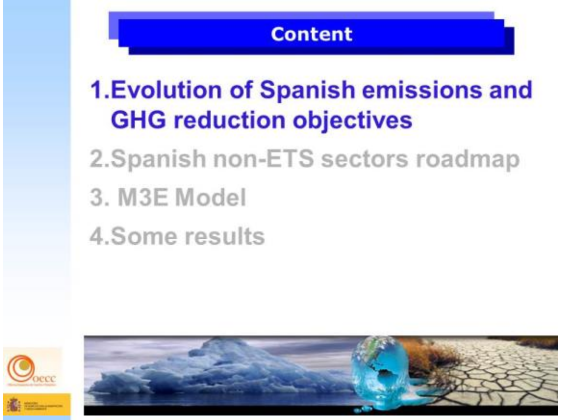
Workshop on "Datasets on technological GHG emissions mitigation options for the agriculture sector"

María José Alonso Moya
Oficina Española de Cambio Climático
JRC, Sevilla, 14th June 2016



Content

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



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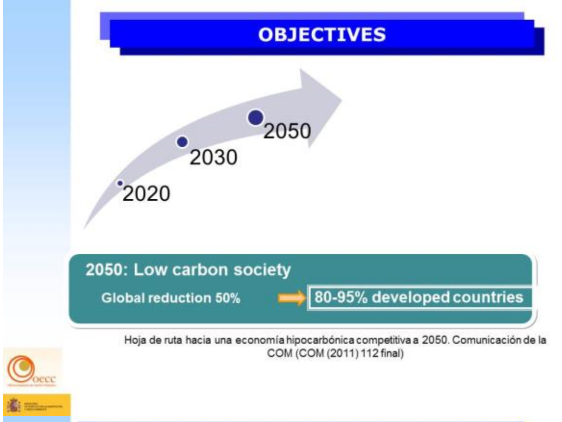
Evolución emisiones GEI España

Evolución del índice de emisiones GEI sobre el año base PK

Índice de evolución anual (año base = 100)

1990	1995	2000	2005	2006	2007	2008
100,0	113,9	134,7	153,3	150,8	153,9	143,0

2009	2010	2011	2012	2013	2014
129,9	126,2	126,0	124,3	114,5	115,0

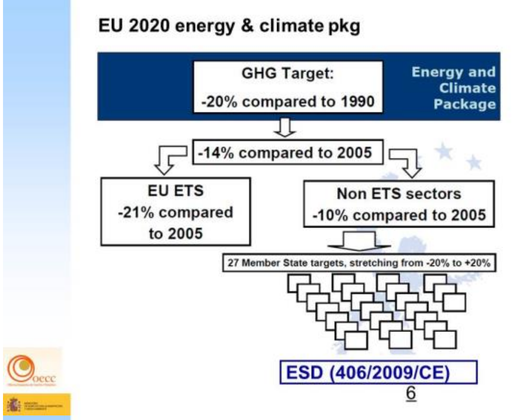


OBJECTIVES

2050: Low carbon society

Global reduction 50% → 80-95% developed countries

Hoja de ruta hacia una economía hipocarbónica competitiva a 2050. Comunicación de la COM (COM (2011) 112 final)



EU 2020 energy & climate pkg

Energy and Climate Package

GHG Target:
-20% compared to 1990

-14% compared to 2005

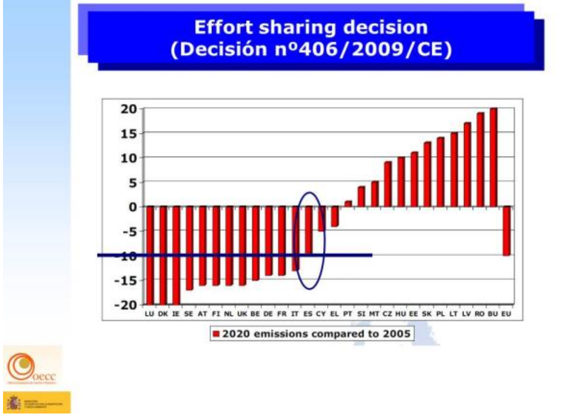
EU ETS
-21% compared to 2005

Non ETS sectors
-10% compared to 2005

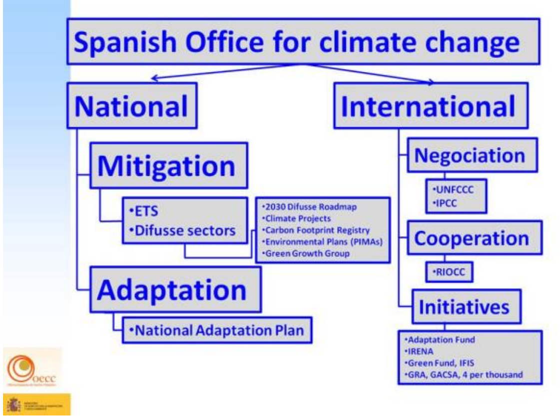
27 Member State targets, stretching from -20% to +20%

ESD (406/2009/CE)

6

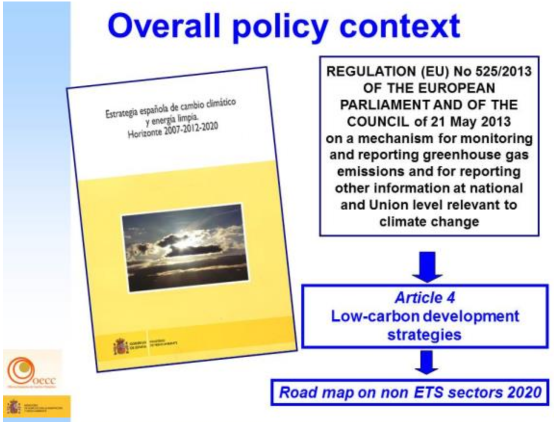


Effort sharing decision
(Decisión nº406/2009/CE)



Spanish Office for climate change

- National
  - Mitigation
    - •ETS
    - •Difusse sectors
      - •2030 Difusse Roadmap
      - •Climate Projects
      - •Carbon Footprint Registry
      - •Environmental Plans (PIMAs)
      - •Green Growth Group
  - Adaptation
    - •National Adaptation Plan
- International
  - Negociation
    - •UNFCCC
    - •IPCC
  - Cooperation
    - •RIOCC
  - Initiatives
    - •Adaptation Fund
    - •IRENA
    - •Green Fund, IFIS
    - •GRA, GACSA, 4 per thousand



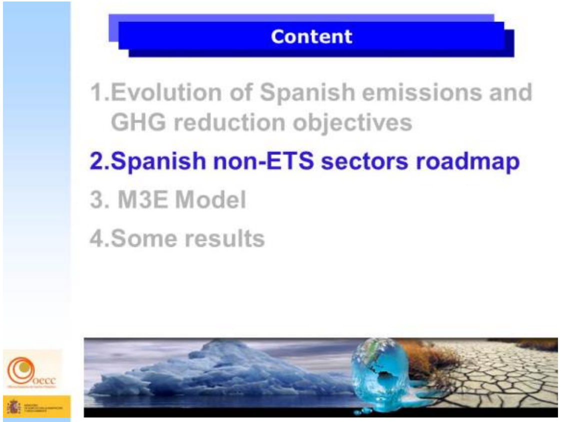
Overall policy context

Estrategia española de cambio climático y energía limpia. Horizonte 2007-2012-2020

REGULATION (EU) No 525/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2013 on a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information at national and Union level relevant to climate change

Article 4
Low-carbon development strategies

Road map on non ETS sectors 2020



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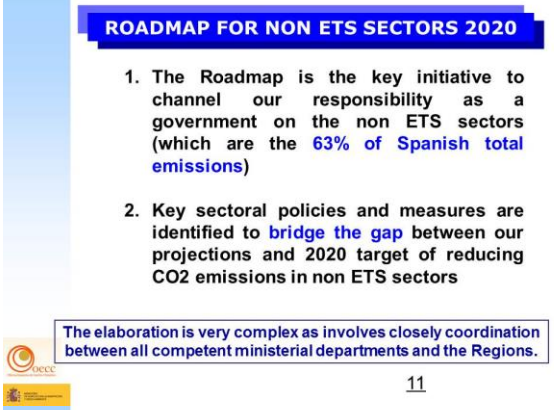
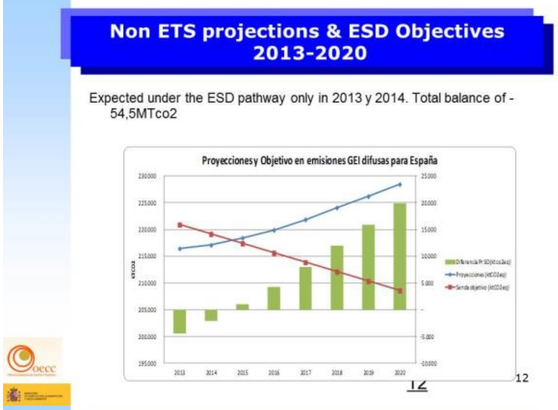


ROADMAP FOR NON ETS SECTORS 2020

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**

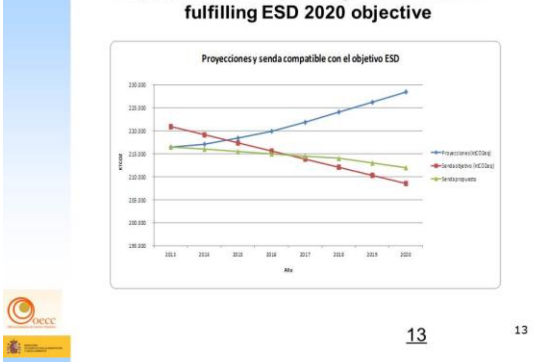
The elaboration is very complex as involves closely coordination between all competent ministerial departments and the Regions.



Non ETS projections & ESD Objectives 2013-2020

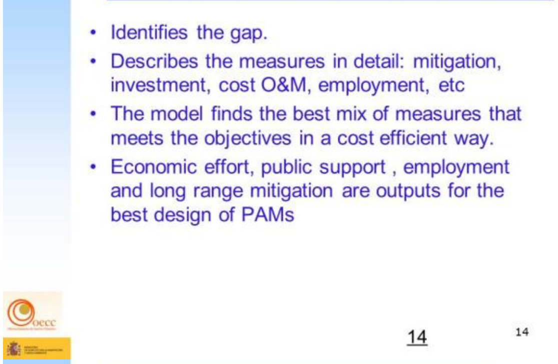
Expected under the ESD pathway only in 2013 y 2014. Total balance of -54,5MTco2

Proyecciones y Objetivo en emisiones GEI difusas para España



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

Proyecciones y senda compatible con el objetivo ESD



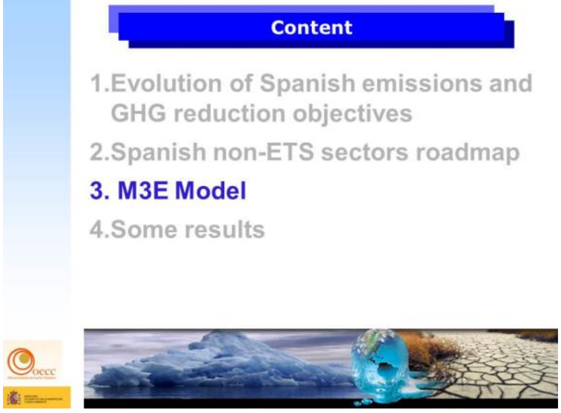
Key elements of the ESD Roadmap 2020

- 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

43 measures

Non ETS sectors:

- Building
- Transport
- **Agriculture**
- Waste
- F-Gases
- Non ETS Industry



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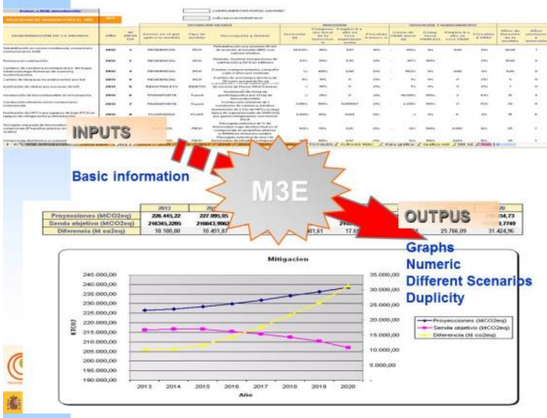
M3E

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

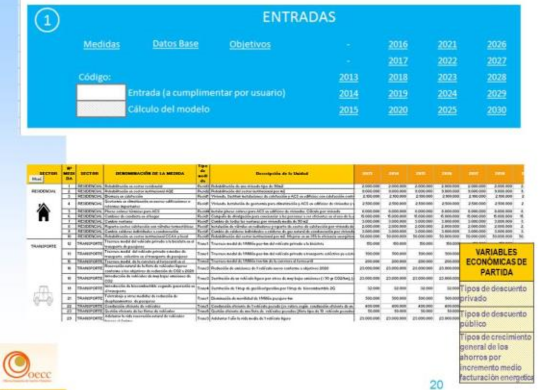
EXCEL file
Easy to use- Solver

Main charateristics

- ❑ **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**
- ❑ **Lineal optimicer**: best solution for given conditions.
- ❑ Identifies duplicities



Graphs
Numeric
Different Scenarios
Duplicity



VARIABLES ECONÓMICAS DE PARTIDA
- Tipos de descuento privado
- Tipos de descuento público
- Tipos de crecimiento general de los ahorros por incremento medio facturación energética

INPUTS

Investment Costs	Operating and mantenance costs	Time	Emissions	Level of applicability
- Cost - Local component - Employment - Taxes		- Lenght - Years previous	- Mitigation CO2 - Eª saving	- Universe - Potential

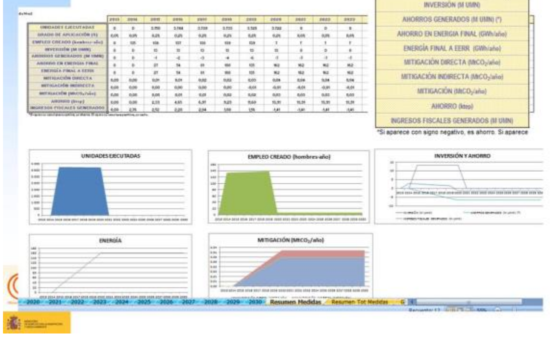
OUTPUTS

M3E Model **optimizes how measures interact for given objectives using Solver**

	Sector en el que aplica la medida	Grado Aplicación	Grado Aplicación
1	RESIDENCIAL	0,00%	16,60%
2	RESIDENCIAL	67,05%	0,00%
3	RESIDENCIAL	100,00%	0,00%
4	RESIDENCIAL	100,00%	0,00%
5	INDUSTRIA ETS	0,00%	0,00%
6	TRANSPORTE	0,00%	0,00%
7	TRANSPORTE	100,00%	0,00%
8	FLUORADOS	0,00%	0,00%
9	RESIDUOS	100,00%	0,00%
10	RESIDUOS	100,00%	0,00%
11	RESIDUOS	0,00%	0,00%
12	AGRÍCOLA	0,00%	0,00%
13	AGRÍCOLA	0,00%	0,00%
14	INDUSTRIA NO ETS	0,00%	0,00%

OUTPUTS

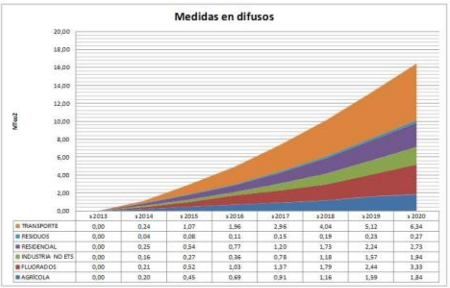
For each measure evaluated



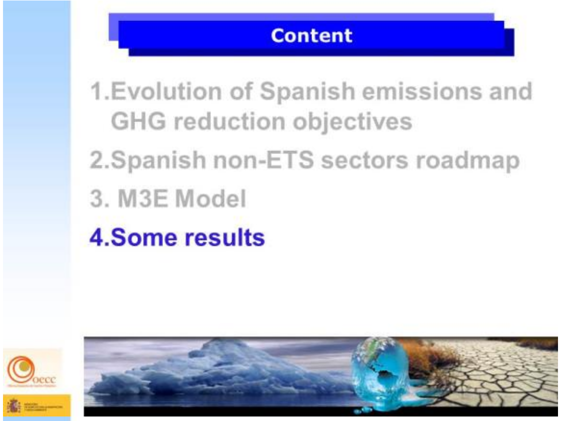
UNIDADES EJECUTADAS
GRADO DE APLICACIÓN (%)
EMPLEO CREADO (hombres-año)
INVERSIÓN (M UMN)
AHORROS GENERADOS (M UMN) (*)
AHORRO EN ENERGIA FINAL (GWh/año)
ENERGÍA FINAL A EERR (GWh/año)
MITIGACIÓN DIRECTA (MtCO$_2$/año)
MITIGACIÓN INDIRECTA (MtCO$_2$/año)
MITIGACIÓN (MtCO$_2$/año)
AHORRO (ktep)
INGRESOS FISCALES GENERADOS (M UMN)

*Si aparece con signo negativo, es ahorro. Si aparece

How each sector contributes to the objective?

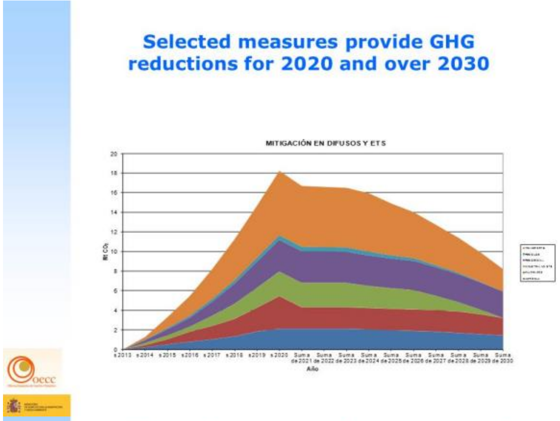


	s 2013	s 2014	s 2015	s 2016	s 2017	s 2018	s 2019	s 2020
TRANSPORTE	0,00	0,24	1,07	1,96	2,96	4,04	5,12	6,34
RESIDUOS	0,00	0,04	0,08	0,11	0,15	0,19	0,23	0,27
RESIDENCIAL	0,00	0,25	0,54	0,77	1,20	1,73	2,24	2,73
INDUSTRIA NO ETS	0,00	0,16	0,27	0,36	0,78	1,18	1,57	1,94
FLUORADOS	0,00	0,21	0,52	1,03	1,37	1,79	2,44	3,33
AGRÍCOLA	0,00	0,20	0,45	0,69	0,91	1,16	1,59	1,84

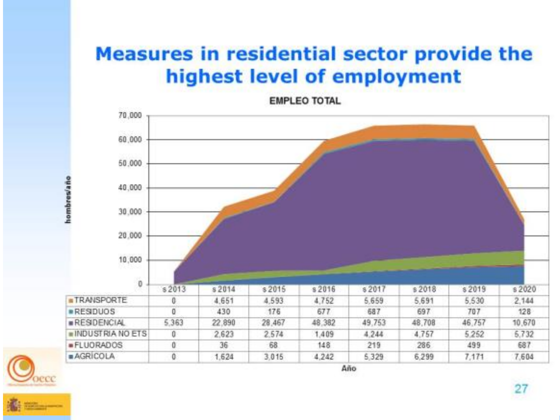


Content

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

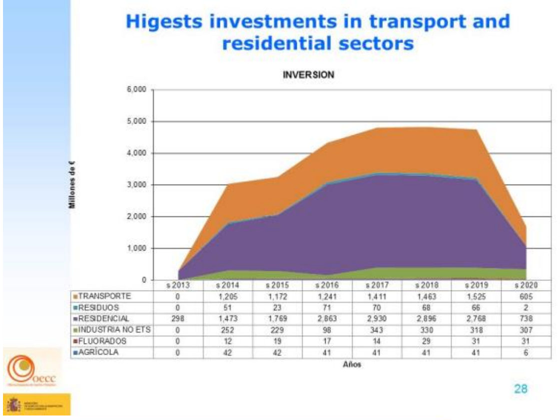


Selected measures provide GHG reductions for 2020 and over 2030



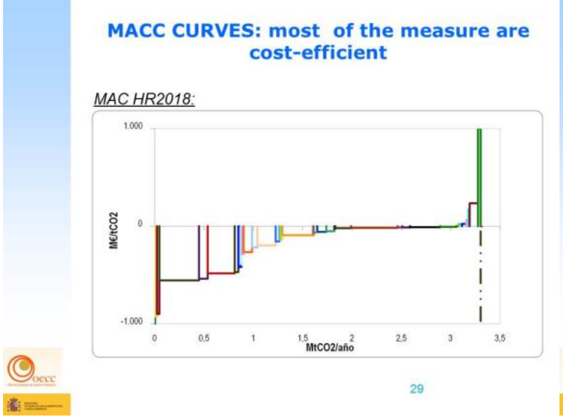
Measures in residential sector provide the highest level of employment

	s 2013	s 2014	s 2015	s 2016	s 2017	s 2018	s 2019	s 2020
TRANSPORTE	0	4,651	4,593	4,752	5,659	5,691	5,530	2,144
RESIDUOS	0	430	176	677	687	697	707	128
RESIDENCIAL	5,363	22,890	28,467	48,382	49,753	48,708	46,757	10,670
INDUSTRIA NO ETS	0	2,623	2,574	1,409	4,244	4,757	5,252	5,732
FLUORADOS	0	36	68	148	219	286	499	687
AGRÍCOLA	0	1,624	3,015	4,242	5,329	6,299	7,171	7,604



Higests investments in transport and residential sectors

	s 2013	s 2014	s 2015	s 2016	s 2017	s 2018	s 2019	s 2020
TRANSPORTE	0	1,205	1,172	1,241	1,411	1,463	1,525	605
RESIDUOS	0	51	23	71	70	68	66	2
RESIDENCIAL	298	1,473	1,769	2,863	2,930	2,896	2,768	738
INDUSTRIA NO ETS	0	252	229	98	343	330	318	307
FLUORADOS	0	12	19	17	14	29	31	31
AGRÍCOLA	0	42	42	41	41	41	41	6



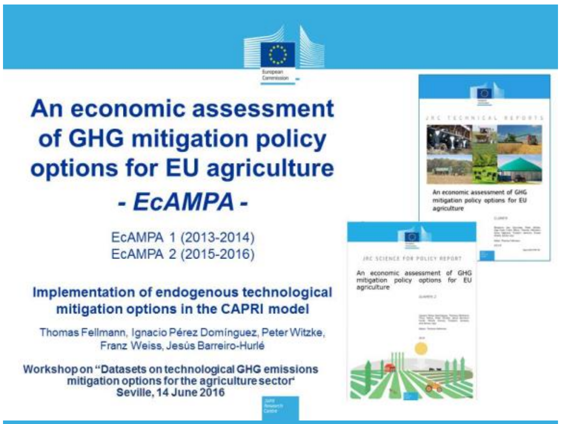
MACC CURVES: most of the measure are cost-efficient

MAC HR2018:

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)

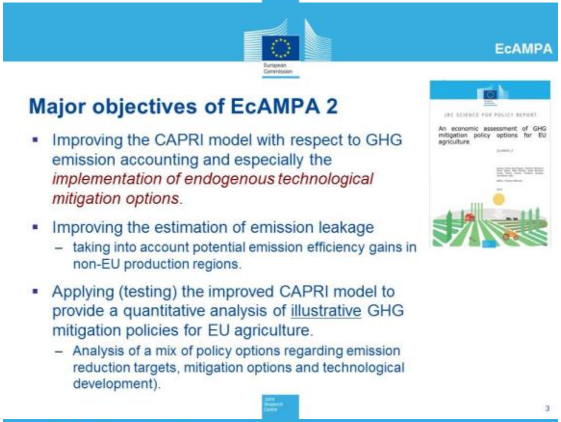
Implementation of endogenous technological mitigation options in the CAPRI model

Thomas Fellmann, Ignacio Pérez Domínguez, Peter Witzke, Franz Weiss, Jesús Barreiro-Hurlé

Workshop on "Datasets on technological GHG emissions mitigation options for the agriculture sector"
Seville, 14 June 2016

EcAMPA

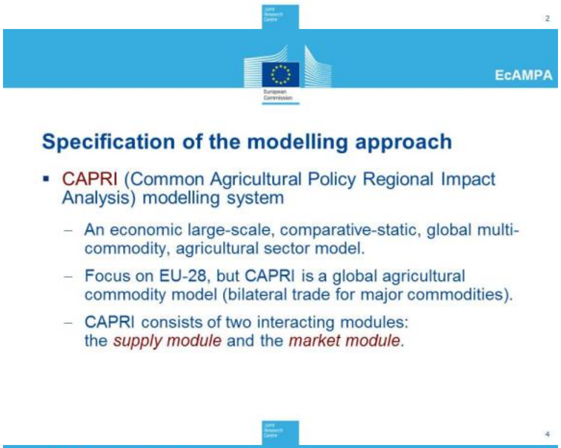
Background of EcAMPA 2



EcAMPA

Major objectives of EcAMPA 2

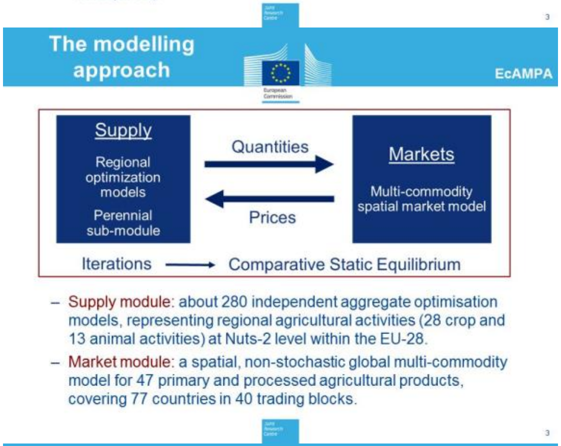
- Improving the CAPRI model with respect to GHG emission accounting and especially the *implementation of endogenous technological mitigation options*.
- Improving the estimation of emission leakage
  - taking into account potential emission efficiency gains in non-EU production regions.
- Applying (testing) 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).



EcAMPA

Specification of the modelling approach

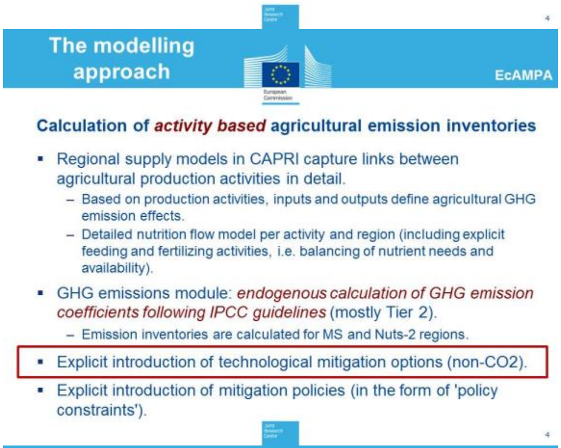
- CAPRI (Common Agricultural Policy Regional Impact Analysis) modelling system
  - An economic large-scale, comparative-static, global multi-commodity, agricultural sector model.
  - Focus on EU-28, but CAPRI is a global agricultural commodity model (bilateral trade for major commodities).
  - CAPRI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



The modelling approach

EcAMPA

- Supply module: about 280 independent aggregate optimisation models, representing regional agricultural activities (28 crop and 13 animal activities) at Nuts-2 level within the EU-28.
- Market module: a spatial, non-stochastic global multi-commodity model for 47 primary and processed agricultural products, covering 77 countries in 40 trading blocks.

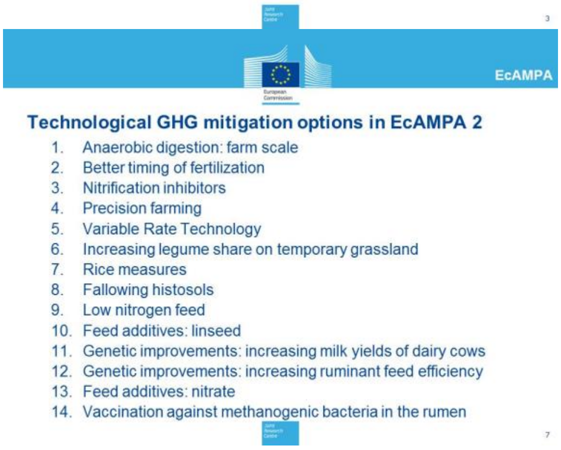


The modelling approach

EcAMPA

Calculation of *activity based* agricultural emission inventories

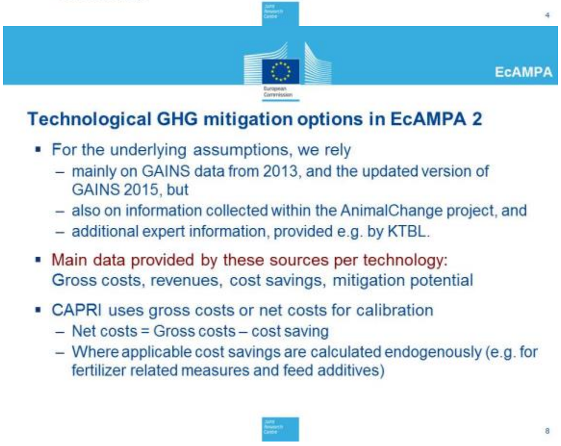
- Regional supply models in CAPRI capture links between agricultural production activities in detail.
  - Based on production activities, inputs and outputs define agricultural GHG emission effects.
  - Detailed nutrition flow model per activity and region (including explicit feeding and fertilizing 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 MS and Nuts-2 regions.
- Explicit introduction of technological mitigation options (non-CO2).
- Explicit introduction of mitigation policies (in the form of 'policy constraints').



EcAMPA

Technological GHG mitigation options in EcAMPA 2

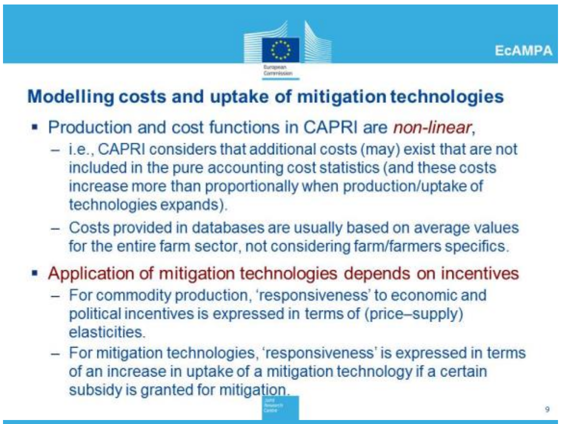
1. Anaerobic digestion: farm scale
2. Better timing of fertilization
3. Nitrification inhibitors
4. Precision farming
5. Variable Rate Technology
6. Increasing legume share on temporary grassland
7. Rice measures
8. Fallowing histosols
9. Low nitrogen feed
10. Feed additives: linseed
11. Genetic improvements: 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



EcAMPA

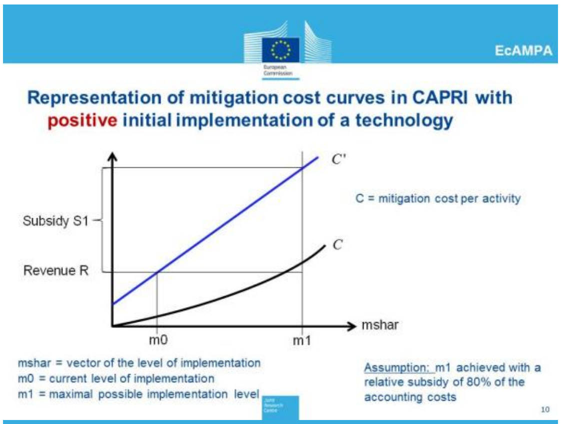
Technological GHG mitigation options in EcAMPA 2

- 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 farm/farmers 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.

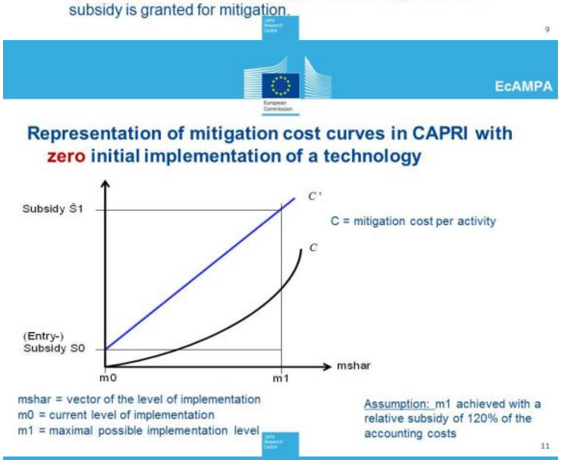


Representation of mitigation cost curves in CAPRI with **positive** initial implementation of a technology

C = mitigation cost per activity

mshar = vector of the level of implementation
m0 = current level of implementation
m1 = maximal possible implementation level

Assumption: m1 achieved with a relative subsidy of 80% of the accounting costs

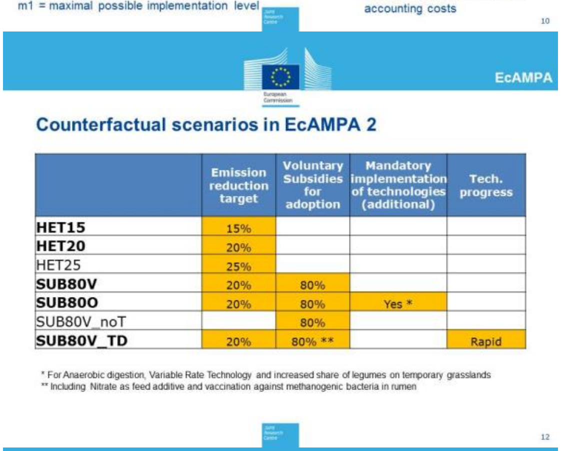


Representation of mitigation cost curves in CAPRI with **zero** initial implementation of a technology

C = mitigation cost per activity

mshar = vector of the level of implementation
m0 = current level of implementation
m1 = maximal possible implementation level

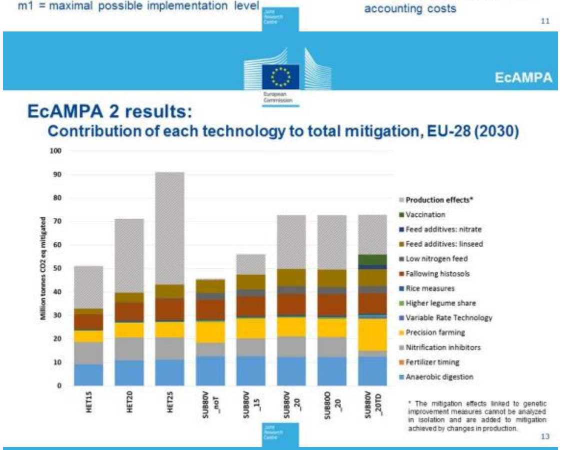
Assumption: m1 achieved with a relative subsidy of 120% of the accounting costs



Counterfactual scenarios in EcAMPA 2

	Emission reduction target	Voluntary Subsidies for adoption	Mandatory implementation of technologies (additional)	Tech. progress
HET15	15%			
HET20	20%			
HET25	25%			
SUB80V	20%	80%		
SUB80O	20%	80%	Yes *	
SUB80V_noT		80%		
SUB80V_TD	20%	80% **		Rapid

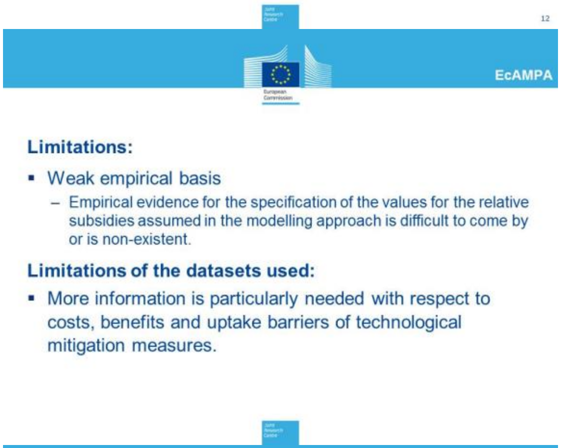
* For Anaerobic digestion, Variable Rate Technology and increased share of legumes on temporary grasslands
** Including Nitrate as feed additive and vaccination against methanogenic bacteria in rumen



EcAMPA 2 results:

Contribution of each technology to total mitigation, EU-28 (2030)

* The mitigation effects linked to genetic improvement measures cannot be analyzed in isolation and are added to mitigation achieved by changes in production.



Limitations:

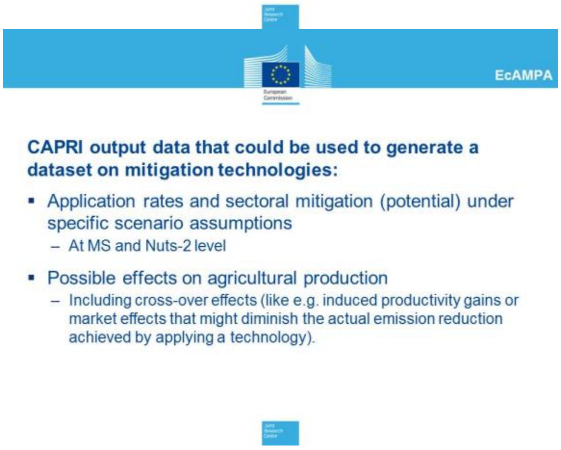
- Weak empirical basis
  - Empirical evidence for the specification of the values for the relative subsidies assumed in the modelling approach is difficult to come by or is non-existent.

Limitations of the datasets used:

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

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, applying it, know-how, 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.)?



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. induced productivity gains or market effects that might diminish the actual emission reduction achieved by applying a technology).

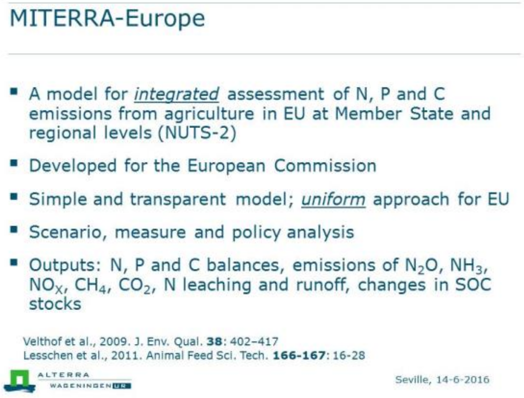
MITERRA Model. Jan Peter Lesschen (Alterra - Wageningen UR)

MITERRA-Europe
Assessment of mitigation technologies

Jan Peter Lesschen, Igor Staritsky, Gerard Velthof,
Peter Kuikman and Oene Oenema

Alterra, Wageningen University and Research, The Netherlands

Seville, 14-6-2016

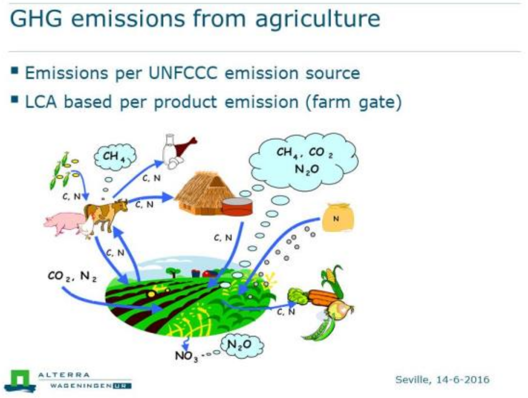


MITERRA-Europe

- 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_2O, NH_3, NO_X, CH_4, CO_2, N leaching and runoff, changes in SOC stocks

Velthof et al., 2009. J. Env. Qual. **38**: 402–417
Lesschen et al., 2011. Animal Feed Sci. Tech. **166-167**: 16-28

Seville, 14-6-2016



GHG emissions from agriculture

- Emissions per UNFCCC emission source
- LCA based per product emission (farm gate)

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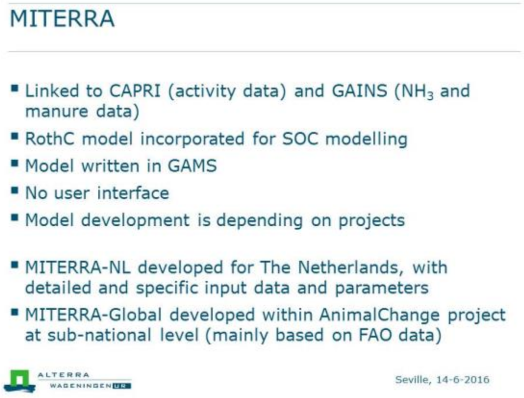

MITERRA

- Linked to CAPRI (activity data) and GAINS (NH_3 and manure data)
- RothC model incorporated for SOC modelling
- Model written in GAMS
- No user interface
- Model development is depending on projects

- MITERRA-NL developed for The Netherlands, with detailed and specific input data and parameters
- MITERRA-Global developed within AnimalChange project at sub-national level (mainly based on FAO data)

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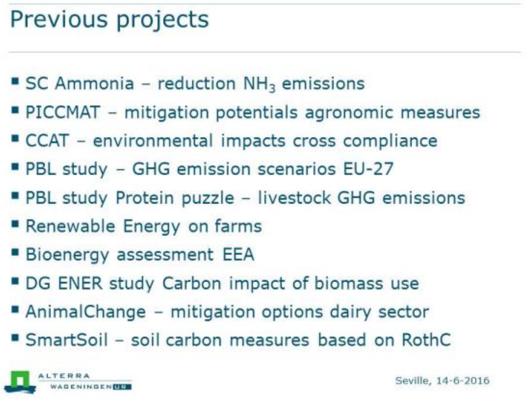

Previous projects

- 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

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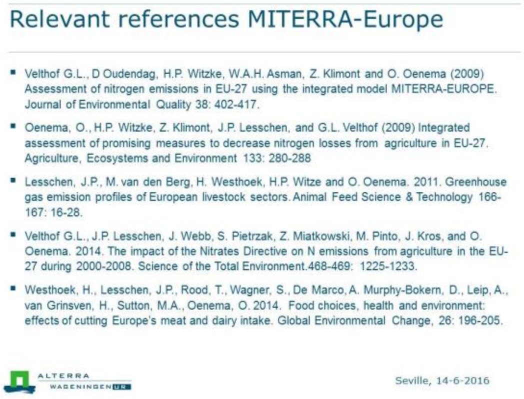

Relevant references MITERRA-Europe

- Velthof G.L., D Oudendag, H.P. Witzke, W.A.H. Asman, Z. Klimont and O. Oenema (2009) Assessment of nitrogen emissions in EU-27 using the integrated model MITERRA-EUROPE. Journal of Environmental Quality 38: 402-417.
- Oenema, O., H.P. Witzke, Z. Klimont, J.P. Lesschen, and G.L. Velthof (2009) Integrated assessment of promising measures to decrease nitrogen losses from agriculture in EU-27. Agriculture, Ecosystems and Environment 133: 280-288
- Lesschen, J.P., M. van den Berg, H. Westhoek, H.P. Witze and O. Oenema. 2011. Greenhouse gas emission profiles of European livestock sectors. Animal Feed Science & Technology 166-167: 16-28.
- Velthof G.L., J.P. Lesschen, J. Webb, S. Pietrzak, Z. Miatkowski, M. Pinto, J. Kros, and O. Oenema. 2014. The impact of the Nitrates Directive on N emissions from agriculture in the EU-27 during 2000-2008. Science of the Total Environment.468-469: 1225-1233.
- Westhoek, H., Lesschen, J.P., Rood, T., Wagner, S., De Marco, A. Murphy-Bokern, D., Leip, A., van Grinsven, H., Sutton, M.A., Oenema, O. 2014. Food choices, health and environment: effects of cutting Europe's meat and dairy intake. Global Environmental Change, 26: 196-205.

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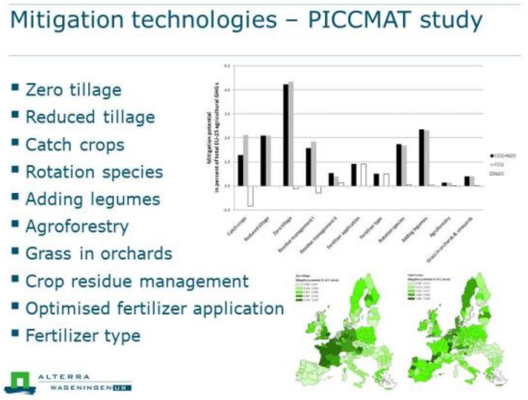
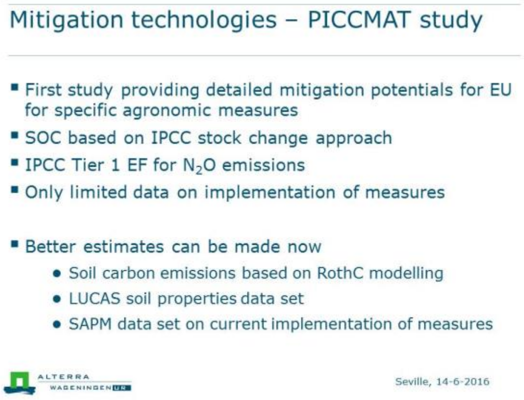


Mitigation technologies – PICCMAT study

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



Mitigation technologies – PICCMAT study

- 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_2O 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

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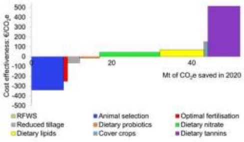
Mitigation technologies for dairy MACC

- Optimal N fertilisation
- Reduced tillage
- Cover crops
- Reduced fertilisation during winter period
- Animal breeding for reduced enteric CH_4
- Dietary lipids
- Dietary nitrate
- Dietary tannin
- Dietary probiotics



PhD study Frank Koslowski (SRUC)

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Other mitigation technologies

- NH_3 and NO_3 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 (S2BIOM 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

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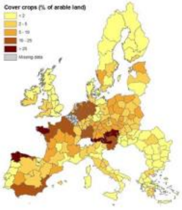
Relevant data sets

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



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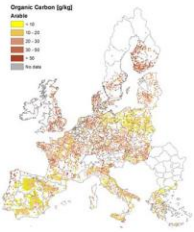
Relevant data sets

- GIS data
  - Environmental zones
  - ESDB (soil data)
  - Climate data
- LUCAS soil data
  - 22000 sample locations
  - All EU countries
  - Linked to land use
  - Sampled in 2009 and currently resampled
  - Less useful for management data
- Cool Farm tool?



ALTERRA WAGENINGEN UR

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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)

ALTERRA WAGENINGEN UR

Seville, 14-6-2016

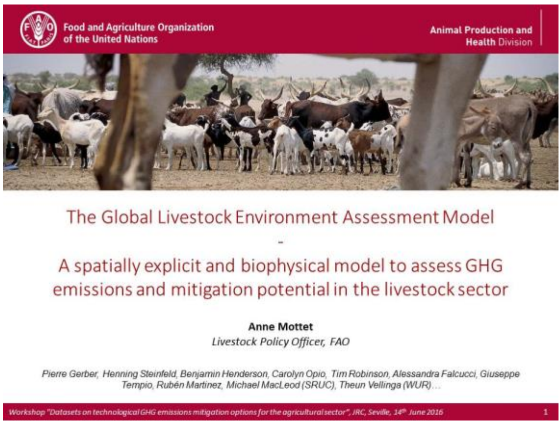
Questions?

Janpeter.Lesschen@wur.nl

ALTERRA WAGENINGEN UR

Seville, 14-6-2016

The Global Livestock Environmental Assessment Model. Anne Mottet (FAO)



The Global Livestock Environment Assessment Model

-

A spatially explicit and biophysical model to assess GHG emissions and mitigation potential in the livestock sector

Anne Mottet
Livestock Policy Officer, FAO

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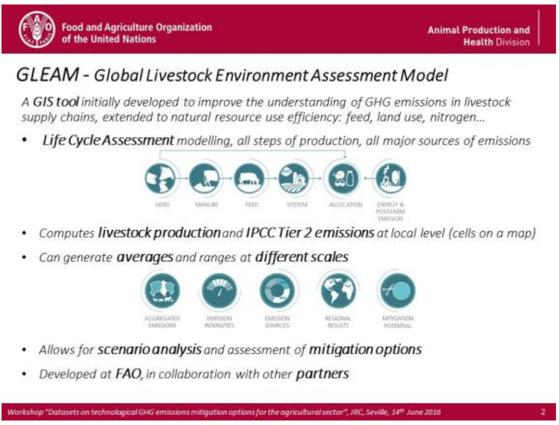


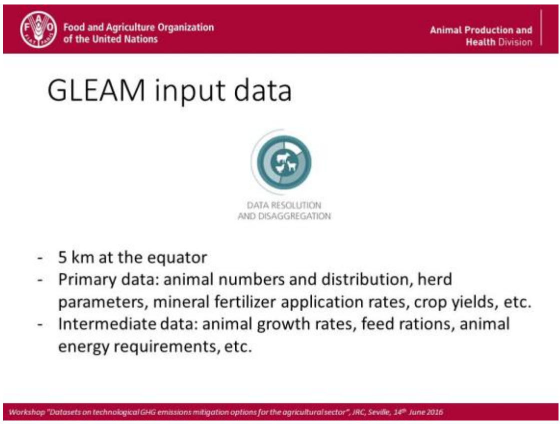
GLEAM - Global Livestock Environment Assessment Model

*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*

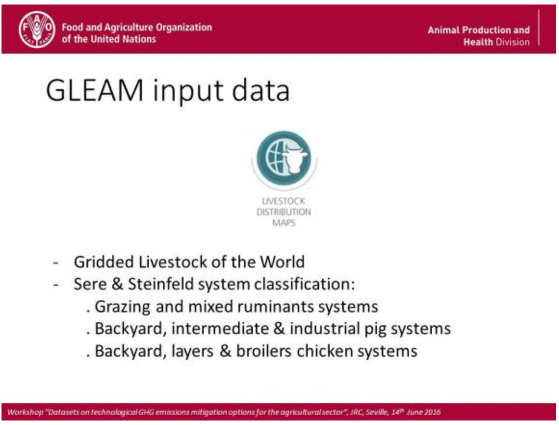
- *Computes **livestock production** and **IPCC Tier 2 emissions** at local level (cells on a map)*
- *Can generate **averages** and ranges at **different scales***

- *Allows for **scenario analysis** and assessment of **mitigation options***
- *Developed at **FAO**, in collaboration with other **partners***



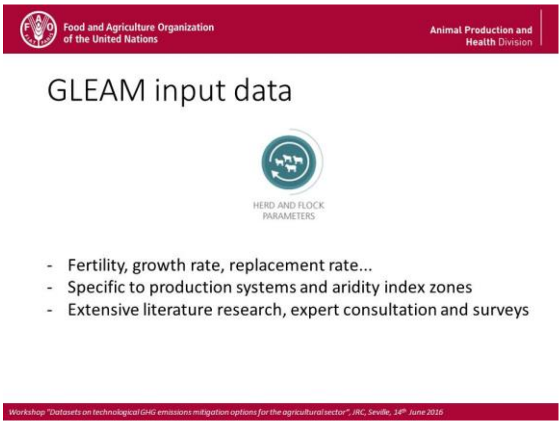
GLEAM input data

- 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.



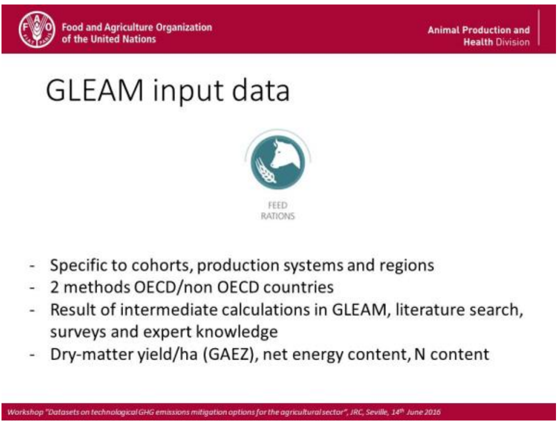
GLEAM input data

- Gridded Livestock of the World
- Sere & Steinfeld system classification:
  - . Grazing and mixed ruminants systems
  - . Backyard, intermediate & industrial pig systems
  - . Backyard, layers & broilers chicken systems



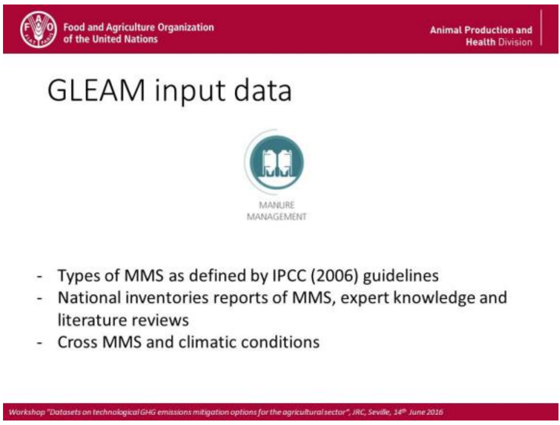
GLEAM input data

- Fertility, growth rate, replacement rate…
- Specific to production systems and aridity index zones
- Extensive literature research, expert consultation and surveys



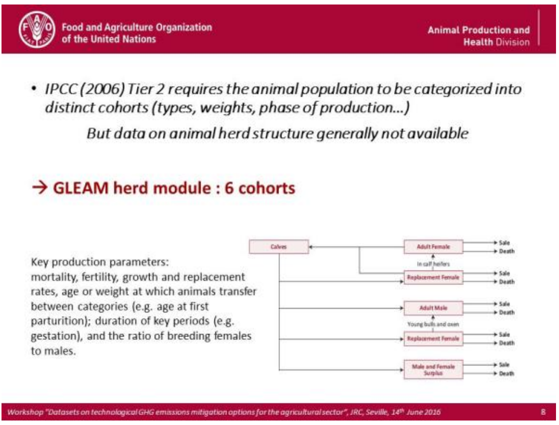
GLEAM input data

- 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

- Types of MMS as defined by IPCC (2006) guidelines
- National inventories reports of MMS, expert knowledge and literature reviews
- Cross MMS and climatic conditions



- *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. age at first parturition); duration of key periods (e.g. gestation), and the ratio of breeding females to males.

- ***Calculation of animal energy requirement for each cohort (Tier 2)***

IPCC (2006) Tier 2: Equations 10.3 to 10.13

Gross energy requirement = maintenance + lactation and pregnancy + animal activity + weight gain and production.

No IPCC equations for calculating energy requirement of pigs or poultry

→derived from NRC (1998) for pigs and Sakomura (2004) 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

- ***Calculation of CH4 emissions arising enteric fermentation (Tier 2)***

IPCC (2006) provides default enteric methane conversion factor, Y_m (% of gross energy converted to methane)

GLEAM has specific Ym to reflect the wide range of diets and feed characteristics :

$$Y_{m\,Cattle} = 9.75 - 0.05 \cdot DE$$
$$Y_{m\,mature\,sheep} = 9.75 - 0.05 \cdot DE$$
$$Y_{m\,lamb<1\,year} = 7.75 - 0.05 \cdot DE$$

where DE = feed digestibility of the ration

CH_4 emission factor:

$$EFCH_4 = (365 \cdot GE \cdot (Y_m|100)|55.65)$$

- ***CH4 emissions arising during manure management (Tier 2)***

Volatile solids excretion rates: Equation 10.24 IPCC (2006)

Proportion of the volatile solids converted to CH_4 during manure management: Equation 10.23 IPCC (2006)

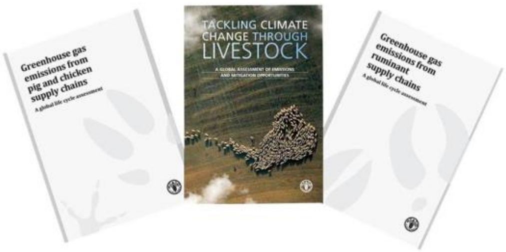
CH_4 conversion factor: IPCC (2006, Table 10A-7)

Proportion of manure managed in each system: official statistics (such as the Annex 1 countries' National Inventory Reports to the UNFCC), other literature sources and expert judgement. IPCC systems challenging.

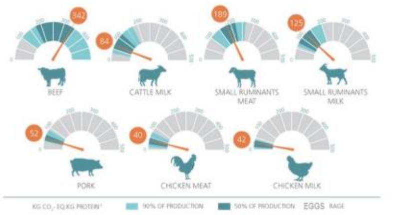
- ***N2O emissions arising during manure management (Tier 2)***

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 N_2O: IPCC (2006) default emission factors for direct N_2O (Table 10.21, IPCC 2006) and indirect via volatilization (Table 10.22, IPCC 2006) + variable leaching rates, depending on the AEZ



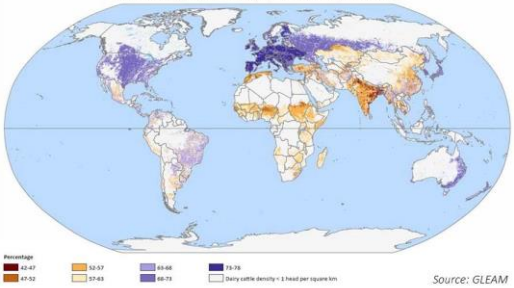
*Diversity in livestock production systems is a **challenge** for GHG emissions reporting and an **opportunity** for mitigation*



Global emission intensities by commodity. All commodities are expressed in a per protein basis. Averages are calculated at global scale and represent an aggregated value across different production systems and agro-ecological zones.

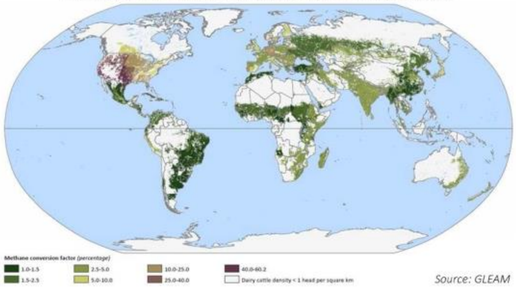
Gerber et al., 2013

Feed digestibility for dairy cattle



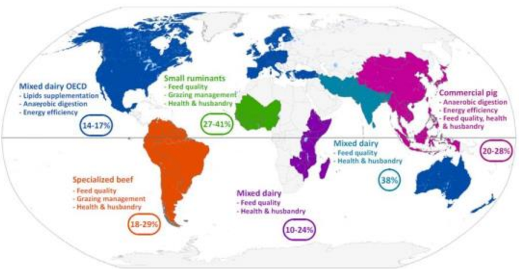
Source: GLEAM

Methane conversion factor for dairy cattle



Source: GLEAM

Case studies: mitigation POTENTIAL



Mottet et al., 2016, REEC

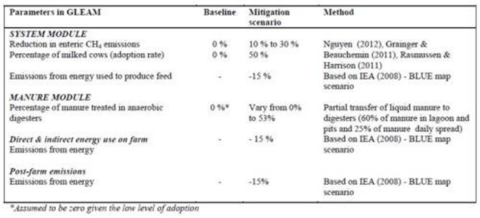


Table 8. GLEAM parameters to evaluate mitigation potential in mixed dairy production in OECD countries

Parameters in GLEAM	Baseline	Mitigation scenario	Method
SYSTEM MODULE			
Reduction in enteric CH_4 emissions	0 %	10 % to 30 %	Nguyen (2012), Grainger &
Percentage of milked cows (adoption rate)	0 %	50 %	Beauchemin (2011), Rasmussen & Harrison (2011)
Emissions from energy used to produce feed	-	-15 %	Based on IEA (2008) - BLUE map scenario
MANURE MODULE			
Percentage of manure treated in anaerobic digesters	0 %*	Vary from 0% to 53%	Partial transfer of liquid manure to digesters (60% of manure in lagoon and pits and 25% of manure daily spread)
Direct & indirect energy use on farm			
Emissions from energy	-	- 15 %	Based on IEA (2008) - BLUE map scenario
Post-farm emissions			
Emissions from energy	-	-15%	Based on IEA (2008) - BLUE map scenario

**Assumed to be zero given the low level of adoption*

Mottet et al., 2016, REEC

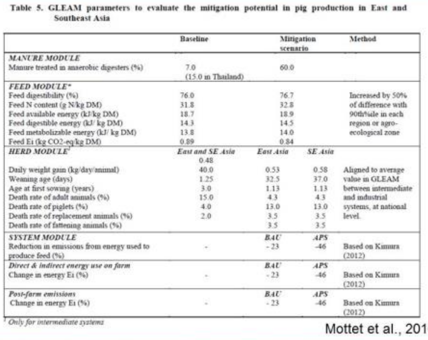


Table 5. GLEAM parameters to evaluate the mitigation potential in pig production in East and Southeast Asia

	Baseline	Mitigation scenario		Method
MANURE MODULE				
Manure treated in anaerobic digesters (%)	7.0 (15.0 in Thailand)	60.0		
*FEED MODULE**				
Feed digestibility (%)	76.0	76.7		Increased by 50%
Feed N content (g N/kg DM)	31.8	32.8		of difference with
Feed available energy (kJ/kg DM)	18.7	18.9		90th%ile in each
Feed digestible energy (kJ/ kg DM)	14.3	14.5		region or agro-
Feed metabolizable energy (kJ/ kg DM)	13.8	14.0		ecological zone
Feed Ei (kg CO2-eq/kg DM)	0.89	0.84		
HERD MODULE[1]	*East and SE Asia*	*East Asia*	*SE Asia*	
	0.48			
Daily weight gain (kg/day/animal)	40.0	0.53	0.58	Aligned to average
Weaning age (days)	1.25	32.5	37.0	value in GLEAM
Age at first sowing (years)	3.0	1.13	1.13	between intermediate
Death rate of adult animals (%)	15.0	4.3	4.3	and industrial
Death rate of piglets (%)	4.0	13.0	13.0	systems, at national
Death rate of replacement animals (%)	2.0	3.5	3.5	level.
Death rate of fattening animals (%)		3.5	3.5	
SYSTEM MODULE		*BAU*	*APS*	
Reduction in emissions from energy used to produce feed (%)	-	- 23	-46	Based on Kimura (2012)
Direct & indirect energy use on farm		*BAU*	*APS*	
Change in energy Ei (%)	-	- 23	-46	Based on Kimura (2012)
Post-farm emissions		*BAU*	*APS*	
Change in energy Ei (%)	-	- 23	-46	Based on Kimura (2012)

[1] *Only for intermediate systems*

Mottet et al., 2016, REEC

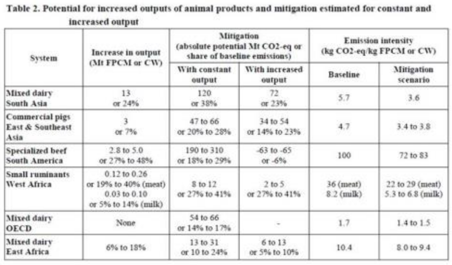
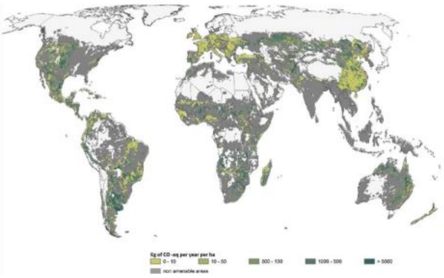


Table 2. Potential for increased outputs of animal products and mitigation estimated for constant and increased output

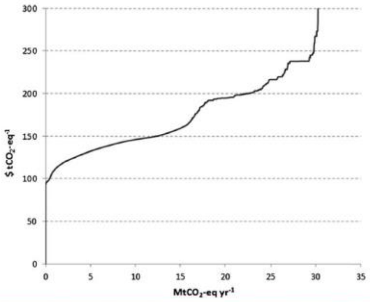
System	Increase in output (Mt FPCM or CW)	Mitigation (absolute potential Mt CO2-eq or share of baseline emissions)		Emission intensity (kg CO2-eq/kg FPCM or CW)	
		With constant output	With increased output	Baseline	Mitigation scenario
Mixed dairy South Asia	13 or 24%	120 or 38%	72 or 23%	5.7	3.6
Commercial pigs East & Southeast Asia	3 or 7%	47 to 66 or 20% to 28%	34 to 54 or 14% to 23%	4.7	3.4 to 3.8
Specialized beef South America	2.8 to 5.0 or 27% to 48%	190 to 310 or 18% to 29%	-63 to -65 or -6%	100	72 to 83
Small ruminants West Africa	0.12 to 0.26 or 19% to 40% (meat) 0.03 to 0.10 or 5% to 14% (milk)	8 to 12 or 27% to 41%	2 to 5 or 27% to 41%	36 (meat) 8.2 (milk)	22 to 29 (meat) 5.3 to 6.8 (milk)
Mixed dairy OECD	None	54 to 66 or 14% to 17%	-	1.7	1.4 to 1.5
Mixed dairy East Africa	6% to 18%	13 to 31 or 10 to 24%	6 to 13 or 5% to 10%	10.4	8.0 to 9.4

Mottet et al., 2016, REEC

Global distribution of soil C sequestration potential, from improved grazing management in the world's grazing lands (Henderson et al., 2015 AGEE)



Global MAC curve displaying the incremental increases in the cost of abating each unit of GHG emissions with the nitrates feeding practice (Henderson et al., 2015, Mitig Adapt Strateg Glob Change)



GLEAM – future developments for mitigation assessments

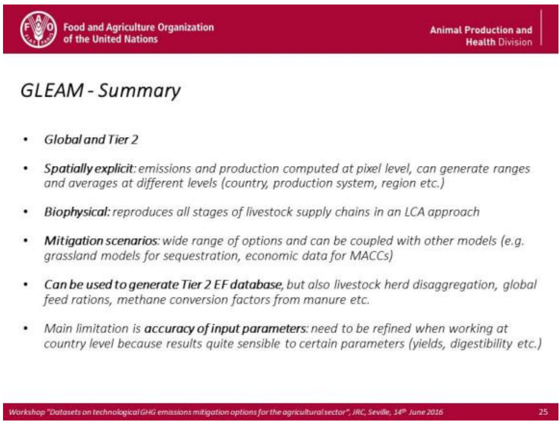
- *Carbon sequestration module (work with INRA)*
- *Seasonality in feed rations (pilot in West Africa, work with WUR and CIRAD)*
- *Direct impact of feed quality on animal performances (weight gains and yields)*
- *Continuous refinement of parameters and production systems from working at country level*

GLEAM - Applications

- *Calculate **emissions** from **livestock supply chains** at national, regional, global levels and by species and type of production systems*
- ***Ex-ante assessment** of technical interventions in the livestock sector (e.g. vaccination campaigns, feed quality improvements etc.)*
- *Support the design of **Nationally Appropriate Mitigation Actions** (e.g. productivity gains in dairy production in Kenya)*
- *Support the formulation of **investment proposals** for CSA (e.g. Ecuador, Niger, Zambia, Malawi, with GCF formulation)*
- *Cost-benefit assessment of mitigation options: **Mitigation Abatements Cost Curves** (spatially explicit)*

GLEAM-i (interactive)

- *Publicly available, user-friendly tool for calculating emissions using IPCC Tier 2 methods in a single Excel file*
- *Designed to support governments, project planners and civil society organizations*
- *Can be used in the preparation of national inventories and in ex-ante evaluation of projects with interventions in livestock*



Food and Agriculture Organization of the United Nations

Animal Production and Health Division

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 sequestration, economic data for MACCs)*
- ***Can be used to generate Tier 2 EF database**, but also livestock herd disaggregation, global feed rations, methane conversion factors from manure etc.*
- *Main limitation is **accuracy of input parameters**: need to be refined when working at country level because results quite sensible to certain parameters (yields, digestibility etc.)*

Workshop "Datasets on technological GHG emissions mitigation options for the agricultural sector", JRC, Seville, 14th June 2016 25

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Thank you
www.fao.org/gleam

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