EIP-AGRI Focus Group
Reducing emissions from cattle farming

FINAL REPORT
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1. Table of contents

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1. Summary

The Focus Group on reducing emissions from cattle farming explored possibilities for mitigating emissions of methane and ammonia from cattle – and their cost effectiveness. Its scope included both milk and meat cattle and all types of production intensities but was limited to mitigation measures at animal and animal housing level, including the handling of manure in storage facilities.

Before, during and after the two meetings of the 20 expert group, their discussions and group work aimed at: describing the current and up-coming mitigation measures, exploring their cost-effectiveness, identifying success and fail-factors for implementation of emission reducing measures and finding areas where research, development and knowledge-transfer is required.

Before the first Focus Group meeting, a starting paper was produced by the coordinating expert and the EIP-AGRI service team. As a result of the Focus Group work, seven mini-papers were written by the experts on selected topics.

This report summarises the findings of the mini-papers and the discussions during the two meetings of the group of experts, and it includes a description of the mitigation measures for ammonia and methane which were identified. These are divided into two overall groups. The first concerns measures which reduce emissions directly; including feeding, breeding and housing/manure storage measures. The second concerns tools and measures which facilitate emissions reduction, including farm models, precision livestock farming, measuring methods for emissions and synergies between different approaches.

In conclusion, there are possible solutions for reducing emissions of ammonia and methane from cattle and cattle housing– the cost-effectiveness of these solutions are however a major challenge and some require further research and development. Examples of measures and their associated challenges are:

- Farm management, this is widely regarded as one of the main factors affecting not only farm profitability but also farm livestock emissions.
- Feed additives, their methane emissions reducing capacity is under development, but cost will limit widespread application.
- Breeding, there is a potential in breeding for lower overall methane emissions per cow. The development of precise and accurate measurement methods for emissions from individual animals is needed.
- Breeding programmes and changes in feed composition can improve production efficiency. This will yield lower emissions of ammonia and methane per kg of milk or meat and can be an economic benefit for the farmer – but will not necessarily reduce overall emissions on a local or national scale. Precision livestock feeding can be a helpful tool for managing feed composition.
- Measurement of emissions of ammonia and methane from cattle is in general difficult and associated with large measurement errors, which makes it difficult to determine the actual effects of measures on emissions. The development of more accurate, more precise and cheaper measurement methods is therefore needed.
- Several housing technologies are available for ammonia reductions, but many are costly and require structural changes in animal housing facilities and are therefore not cost-efficient for the farmer.

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2. Introduction

Livestock production contributes significantly to ammonia and greenhouse gas (GHG) emissions. According to the European Environment Agency (EEA, 2016a) agriculture is responsible for 94 % of ammonia emissions in EU-28. Agriculture also accounts for approximately 10% of Europe's total GHG emissions when excluding emissions coming from Land Use, Land Use Change and Forestry (LULUCF). Out of these 10% of the total emissions of CO_2-equivalents (CO_2-eq), enteric fermentation accounts for 42% and manure management for 15% (Fernandez & Emele, 2015). The main livestock-related GHGs are methane (CH_4) from enteric fermentation and manure, and nitrous oxide (N_2O) from manure.

Ammonia, methane and N_2O are emitted to the air, where they can affect the climate, ecosystems and human health. Livestock production is also related to other environmental impacts like nutrient leaching to watercourses or nitrate leaching to ground water.

On the other hand, cattle also have positive impacts on society and environment. Livestock production constitutes the livelihood of many farmers across Europe and the rest of the world and is also an important source of export commodities and raw materials for the food industry. From an environmental perspective, cattle are able to transform types of biomass, which are inedible to humans, into nutritionally and economically valuable beef and dairy products, and can thereby contribute to the circular economy. Cattle also contribute to the conservation of certain ecosystems, where grazing is necessary to maintain biological balance.

Over recent decades, efforts have been made to reduce emissions from livestock. As a result, combined with reductions in livestock numbers, GHG emissions were reduced by 23% from 1990 to 2014 (EEA, 2016b) and ammonia emissions by 27% from 1990 to 2013 (EEA, 2016a). But more needs to be done to further improve air quality and combat global warming. Politically, the EU member states have committed to reducing both GHG and ammonia emissions further, which will require efforts by all sectors – including agriculture.

At the same time, the world demand for high quality food is increasing. A major challenge for the agricultural sector is therefore to increase production and at the same time decrease the environmental impact. This calls for cost-efficient methods of reducing emissions.

3. The work of the Focus Group

Aims of the Focus Group

The overall aim of this Focus Group was to identify methods to reduce cattle livestock emissions in a cost effective way for farmers.

More specifically, six main tasks were addressed:

- Make an inventory of competitive farm management practices and strategies related to animal, housing and feeding which are currently available to tackle emissions from cattle at farm level in the EU. Which working examples can be found in the EU? To delineate the work of the Focus Group input and output from the farm like feed, fertiliser, fuel, electricity and transport of products has not been included directly in the evaluation.
- Compare these different management practices and strategies, which reduce emissions from cattle, taking into account the cost-effectiveness, production efficiency and emission reduction efficiency. How can emission measuring methods contribute to this? This comparison has taken into account the importance of production system e.g. farm size, milk vs. beef production or intensive vs. extensive production.
- Explore solutions from livestock other than cattle, which could be beneficial for the reduction of emissions in cattle production systems.
- Identify success factors and fail factors that stimulate or limit the use of the identified management practices and strategies by farmers, and summarise how to address these factors and explore the role of innovation and knowledge transfer in addressing these fail factors.
- Identify needs from practice and possible gaps in knowledge on particular issues concerning emissions from cattle which may be solved by further research.
- Propose potential innovative actions to stimulate the knowledge and use of management practices and strategies in reducing emissions from cattle and to multiply positive effects within the agricultural sector.

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The process

The focal points of the work of the group were two face to face meetings for the group members. The first meeting in Copenhagen, Denmark 2-3 February 2016 and the second in Riga, Latvia 22-23 September 2016.

In preparation for the first meeting, a starting paper was prepared by the EIP-AGRI Service Point team, setting the scene for the coming work. A questionnaire was sent to the experts prior to the meeting to start the inventory.

The first meeting of the Focus Group was primarily concerned with the specific tasks of making an inventory of relevant mitigation measures and deciding how to compare them. Following these discussions, topics for mini-papers were decided and groups were formed for the selected topics. Between the first and the second meeting, the groups produced mini-papers on these topics.

At the second meeting, the preliminary mini-papers were presented and discussed by the whole Focus Group. Furthermore, the second meeting focused on identifying success and fail factors, the needs for research and ideas for Operational Groups, so these could be incorporated into the mini-papers. The second meeting also included a visit to a Latvian dairy farm, which was a great help in putting a practical implementation perspective on the Focus Group recommendations.

Following the second meeting, the experts continued their work on the mini-papers. The major points from the mini-papers and the discussions in the group are summarised in this final report.

This Focus Group has limited its scope to animal and farm initiatives. But the individual farm is part of a larger system and to grasp the full range of effects on emissions, a life cycle assessment (LCA) may be required. From a general sustainability point of view, there may be emission reductions which can be achieved by using agro-industrial by-products or the development of locally sourced proteins for feed. On the other hand, some of the available mitigation measures may also have a negative effect on e.g. climate gas emissions, if the consequences are evaluated in a larger perspective.

4. Measures for reducing emissions

The Focus Group discussed a range of different measures which can be applied in cattle production systems to reduce emissions. Overall, these measures can be divided into three groups of concrete measures, which can be applied to reduce emissions from cattle:

- Feeding measures
- Breeding measures
- Housing and manure storage measures

These measures are described in detail in separate mini-papers and summarised in this section.

Besides the direct measures, the Focus Group discussed a range of management tools, measures and scientific prerequisites which can facilitate implementation of emissions reductions. These tools and measures are described in chapter 5.

Within Europe, there are large differences in agricultural emissions, which are a reflection of different livestock production systems and the varying roles of livestock production in society as a whole. Emission levels, emission patterns and potential mitigation measures vary, depending on whether cattle farms are dairy or beef farms, whether they are large, medium or small and whether production is intensive or extensive. The Focus Group attempted to describe for which type of farms the different mitigation measures would be applicable.

The discussions focused on methane and ammonia emissions, and only briefly looked at nitrous oxide emissions. Methane and ammonia are major and relatively well-examined emissions. In many countries ammonia emissions are regulated and several mitigation measures are therefore already in practice. Methane emissions have been the centre of substantial research efforts in recent decades but mitigation options are not applied to the same extent as for ammonia.

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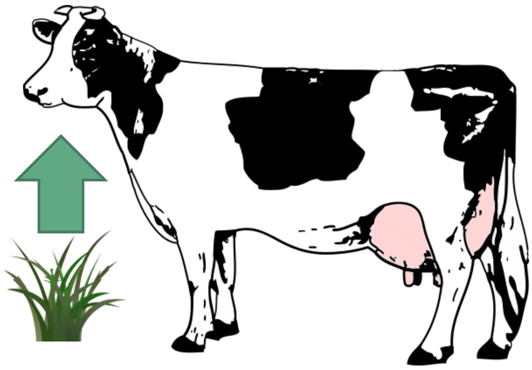
Feeding measures



The rumen microbiota and the host ruminant constitute a complex and interrelated biological system. By modulating the rumen or the rest of the digestive system, it is possible to reduce GHG emissions or lower the nitrogen (N) concentration in the manure. (Lower nitrogen content leads to lower emissions of ammonia and N_2O from the faeces and urine.) The Focus Group has identified 5 types of feeding measures, which can be used to reduce emissions:

- Forage quality
- Dietary ingredients
- Feed additives and plant compounds
- Precision protein feeding
- Rumen protected amino acids

Forage quality

An important feed characteristic that can impact enteric methane production is forage quality, specifically its digestibility. The higher the digestibility of a specific type of feed, the lower, the amount of methane produced per unit of feed consumed. Moreover, higher digestibility of feed decreases the amount of methane produced per unit of product (emission intensity) by diluting maintenance energy. Better digestibility also often leads to an increase in production, i.e. milk production or weight gain, making it a cost-efficient reduction measure. There is therefore an incentive for the farmer to use this mitigation measure. It must however be taken into consideration that even though the emissions per unit of product decrease, the overall emissions per animal may increase.

In general, methane reductions are correlated with greater nutrient quality and digestibility, which are two attributes for which forage type and maturity might be indicators. Increasing quality or digestibility of forages will increase production efficiency and this will likely result in decreased methane emissions per unit of product.

However, forages are almost always produced locally at the cattle farms and they are the feed ingredients with the largest variability in composition and have the largest impact on diet digestibility. Factors, such as plant species, variety, maturity at harvest and preservation can all affect forage quality and digestibility. It is therefore a parameter which requires a lot of information about locally produced feed ingredients and careful management by farmers if it is to be used for mitigating emissions. Good management practices can be applied on all types of dairy farms. For regulatory purposes a certain level of documentation will be needed, which is a fixed cost and hence poses a relatively larger burden on small farms, compared to larger farms.

Feed management is already practiced widely at different levels of sophistication depending on farm type. Precision livestock feeding can aid in managing the feed resources most efficiently as described in the mini-paper on this topic. There is however a need for tools and models for visualising (and documenting) the emission reductions at farm level, as discussed in the mini-paper on farm models/tools to help farmers reduce emissions.

Grazing and grass-based diets

Grazing can be used as a management tool to reduce ammonia emissions – when animals deposit manure directly on grassland, emissions are lower than when deposited in a barn. The interactions with emissions of other gases is, however, very complex. In some cases, grazing can lead to higher emissions of CH_4, N_2O and NO_3^-. Grassland soils also store large quantities of carbon and in many regions have the potential to sequester more carbon, while providing a range of other ecosystem services related to habitat and water quality. Improving management practices and breeding/adopting new species and cultivars can improve the quantity and quality of feed to animals and also, in some regions and systems, enhance soil carbon storage.

However, much more knowledge is needed about the interactions of various emission processes during grazing and about the potential for carbon sequestration and techniques for achieving it.

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By combining controlled rotational grazing with precision management of grassland and monitoring of animal parameters, it may also be possible to achieve a more productive and emission efficient cattle production in some regions.

Dietary ingredients

Concentrate feeds and starch generally provide more digestible nutrients than roughages. Including more concentrates generally increases the digestibility of feed and therefore has the same effects on animal productivity and methane emissions per unit of product as better forage quality.

Increased starch feeding is a possibility in some situations but not always. Intensive beef production in general already has a high content of starch in the feed. The main target production systems are therefore dairy farms, and these can in principle be of all sizes and intensities. The suitability and cost-efficiency of this approach for GHG mitigation depends on the access to and availability of starch feeds at the farm. Feed management must also be considered. Uneven feeding of high-starch feed can harm the cows.

There is also a large body of evidence showing that lipids reduce methane production. As for starch, supplementing animal diets with edible lipids for the sole purpose of reducing methane emissions is debatable from a resource efficiency perspective. However, lipids are usually added to the diet of lactating dairy cows to increase the energy concentration of the ration, especially in the early part of lactation. More recently, some marine or vegetable oils have also been introduced in the diet of dairy and beef cattle to increase unsaturated fatty acid content in beef and milk. In these cases, the reduction of methane emissions would be an additional benefit of lipid supplementation. Furthermore, high-oil by-products from the biofuel industries can naturally serve as a methane mitigating feed if included in the diet to decrease feed cost (Hales et al., 2013) and contribute to the circular economy.

In a larger perspective, the potential competition with direct human consumption of starch products must also be considered, as well as other environmental effects of increasing the number and size of intensive production systems. For instance confined intensive fattening feedlots have increased emissions of ammonia and larger problems with N leaching and runoff. Also, the potential losses of soil carbon and the loss of sequestration potential by feeding more starch., e.g. through cultivating arable crops (e.g. forage maize) instead of permanent grasslands, can be much larger than the GHG mitigation by CH_4 reduction (Vellinga and Hoving, 2011).

Feed additives, plant compounds

Some chemical compounds can have an inhibitory effect on methane-generating rumen micro-organisms, thereby lowering the overall methane production per animal. Laboratory experiments have shown methane reductions in vitro of up to 100%. Some substances have also been demonstrated to be effective in animal trials – in some cases resulting in an almost complete removal of methane emissions; however, these are not commercially viable due to animal health and food safety concerns or prohibitive costs. Research is currently focussed on examining natural or synthetic compounds that meet the requirements of long-term efficacy (including possible adaptation of the rumen microbial community), no negative effects on productivity, and food and animal safety.

While perhaps technically possible to achieve considerable (above 50%) reduction in methane emissions through the use of specific inhibitors, a number of practical issues need to be considered in beef and dairy farming:

- Nutrition: the combination of multiple additives, while potentially possible under experimental conditions, may prove impractical due to difficulties in formulation, including the inevitable dilution of nutritional value as additives account for an increasing share of the diet. Clearly there is a need for increased research into additives that are effective at low levels of dietary inclusion.
- Delivery: dietary additives may be applicable to housed ruminants but are far less applicable to extensively raised or grazing animals. Significant effort needs to be dedicated to delivery systems for extensively raised or grazing animals.
- Developing a convincing economic model: taken as a whole, current research suggests that measurable production responses to methane mitigation are unlikely to occur. Feed additives will therefore constitute an extra cost, without affecting production in any way. Thus, alternative methods need to be

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developed to incentivise the use of what are likely to be expensive additives to decrease ruminal methane production.

Precision protein feeding

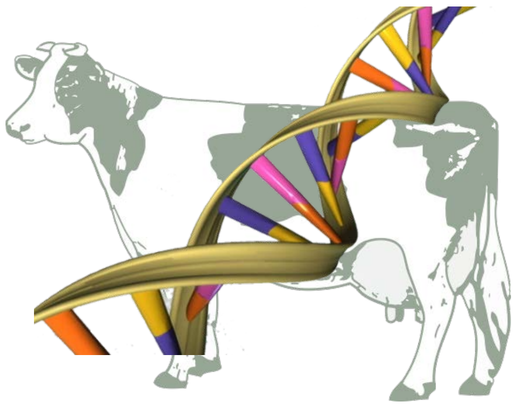
Two main aspects of ruminant nutrition can be related directly to ammonia emissions from cattle manure: (1) inefficient utilisation of feed nitrogen in the rumen; (2) inaccurate prediction of the animal protein requirements – both leading to overfeeding of dietary nitrogen which will result in excessive urinary nitrogen excretion and thereby excessive ammonia emissions. Urinary nitrogen losses by dairy cows decrease linearly with decreasing dietary crude protein levels. These reductions can sometimes be achieved with minimal or no effects on yield or composition of milk and milk protein. The important issue is to regulate the amount of specific amino acids, which are limiting for the utilization of all amino acids. By feeding a diet balanced in amino acid supply, better feed N use efficiency can be achieved.

Mitigation of ammonia emissions from cattle can therefore be achieved by better management of the protein and specific amino acids in the feed. This is a relatively cost-efficient measure for the farmer, as better feed utilisation means either the same production with decreased input or increased production with the same input.

In principle, this is applicable at all types and sizes of cattle farms, but good knowledge and management of the composition and digestibility of the feed is essential, including locally produced feeds. This poses a challenge in extensive production systems and in production systems based on grazing.

One way of achieving a better nitrogen utilisation in cattle is to use rumen protected amino acids. Animals do not actually have a requirement for protein. Instead, they require the specific amino acids that are the building blocks that make up proteins. In most situations, by selecting proper protein sources and judiciously using rumen protected (RP) amino acids, it should be theoretically possible to balance the amino acid needs of the cow while reducing crude protein (CP) intake. Broderick et al. (2008) published a study that demonstrated that a ration with 16.1% CP and added RP-Methionine (RP-Met) resulted in the same amount of milk as a 17.3% CP ration with less RP-Met, and both rations resulted in higher milk production than an 18.6% ration without RP-Met. There are current studies underway to further refine this relationship. Cost efficiency and applicability is therefore not yet known, but use of carefully designed feed compositions will require thorough feed management and thereby mostly be applicable to intensive farms.

Breeding measures



Many dairy cattle breeding goals aim at a simultaneous improvement of milk production and functional traits (health, fertility and longevity). Until now, selection strategies have ignored the effects of changing these traits on emissions. The only effect of breeding on emissions has therefore been the indirect effect of improved production efficiency i.e. reduced emissions per unit of product.

There is however a potential for improving both methane and ammonia emission efficiency through breeding measures. This is particularly relevant for dairy farms of many sizes and intensities, because dairy breeding is a highly developed business with world-wide trade of semen for artificial insemination. Dairy production is therefore a more obvious current target for the use of breeding to reduce emissions than beef production. On the longer-term, beef breeding programmes may be highly relevant, as the global impact of beef production on GHG emissions is large.

To include emissions more directly in the breeding goals, there are two strategies: (1) optimising the relative weights of currently available information on selection traits towards lower emissions; (2) adding information on traits that affect emissions but have not yet been considered when making selection decisions.

The first strategy is based on the fact that a lot of different traits are included in the current multi-trait selection indices. The relative weights of traits in the indices are often based on bio-economic models that simulate the

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effect of selection on farm profitability. Weights that result in maximum economic response or desired responses in one or more of the traits of interest are then used to construct the selection index.

Several options may be considered to also include the effect on emissions. A first option is to include emission costs in the optimisation model. A second option is to maximise economic response with a bio-economic model that also restricts emissions at farm level. A third option is to minimise emissions when producing a fixed amount of milk. Better quantification of the relationship between emissions and current selection traits is however needed. Longevity of dairy cows for instance reduces the emissions of methane per litre of milk because the emissions from the unproductive heifer period are diluted by a higher lifetime production per cow.

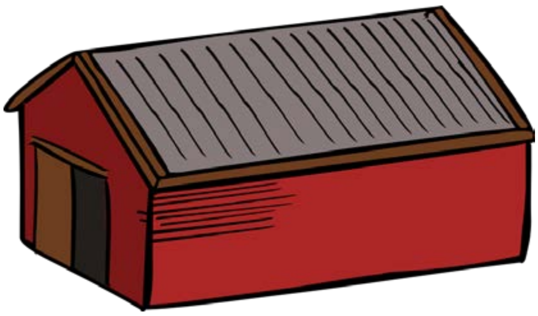
The second strategy is based on the possibility of adding a direct measure of emissions to the list of selection traits. This will also require more data in the form of accurate determination of emissions at individual animal level.

Although direct recording of especially methane emissions at individual animal level is technically feasible for example in respiration chambers, no large datasets are routinely available for breeding purposes due to practical challenges and high costs. There is therefore a need for new fast, easy and cheap methods of estimating emissions at individual animal level, either by measurement of emissions or by determination of proxy parameters.

During discussions it was suggested, that local adaptation of breeding objectives in dairy production could perhaps improve overall lifetime emission efficiency by taking more regional challenges into account. This could for instance be breeding towards coping better with heat stress in parts of the world where heat stress significantly affects productivity.

Challenges for including emissions in breeding programmes are that breeding is a long-term project and emission traits are invisible to the farmer. The costs for research and development of new indices will most likely be transferred to the farmers buying semen. To create incentives to push the development towards lower emissions, it is therefore essential to visualize the positive effects of the effort. Economic surplus for the farmer is a clear incentive, but having a “green” profile also contributes to the general good-will towards dairy and beef production.

Housing and manure storage measures



There are several mitigation techniques available, especially for dairy cattle. But there is still a big need for further optimisation of existing systems as well as research into and development of new ones. At different stages of development and implementation, the techniques can be grouped into the following types:

- Floor-based systems and related management techniques (e.g. scrapers and cleaning robots)
- Litter-based systems (use of alternative organic material)
- Slurry management techniques at pit level
- Indoor climate and ventilation control techniques
- End-of-pipe techniques (hybrid ventilation + air cleaning techniques)

Practically all existing emission mitigating housing techniques target ammonia and not methane. The primary target of this chapter on mitigation measures is therefore ammonia. A few methods also have an effect on methane. In the future, air scrubbers may also be equipped with options to oxidise methane.

Floor-based systems

Ammonia emissions can be reduced by separating urine and faeces or limiting air exchange with the pit. Both slatted and solid floor systems for cattle are generally adapted to do this. These adaptations mainly concern different profiling patterns in the floor creating built-in urine channels. These floor systems are also usually equipped with different types of manure scrapers or cleaning robots. Also, spraying systems can be installed to dilute and remove urine puddles and allow better manure scraping that enhances urine draining. Spraying systems may be combined with urease-inhibitors to reduce urea conversion to ammonia in the urine.

This approach is mainly used for dairy cattle in medium to large scale farms. It is well developed but its application has some limitations. The emission-reducing effect is highly dependent on proper maintenance of the entire system. It is therefore best suited for intensive production systems, where frequent supervision and rapid repairs can be expected. If the slats in a floor clog with manure this can lead to an increase in emissions. Scrapers and robots also must be completely adapted to the floor and interior of the housing; if not, the scrapers and robots may even be counterproductive, in smearing manure or high amounts of urine on the floor, which leads to higher ammonia emissions.

Installing scrapers and robots is most relevant when building new cattle barns, where they can be integrated in the design of the floor layout.

Litter-based systems

Litter-based systems are more common with beef cattle and typically consist of straw. Using a selection of alternative organic sources can reduce ammonia emissions through e.g. lowering pH, enhancing bacterial uptake of N or higher absorption of ammonium. The availability of practical options is currently very limited and performance and emission reduction efficiency is largely unknown. Furthermore, the risk of nitrous oxide formation in litter-based systems requires attention.

Slurry management techniques

Proper management of the slurry all the way from within the barn until it reaches the fields will reduce emissions. As this Focus Group is limited to initiatives at housing and animal level, only techniques at pit level and storage level will be discussed. There are however several well-established techniques which can reduce ammonia emissions during application in the field.

Several techniques can be applied at slurry pit level to limit the ammonia emission process. Additives may affect e.g. slurry pH (acidification), urease activity (inhibitors) and nitrification processes. Low rate intermittent slurry aeration can induce chemical reactions (e.g. oxidation) or biological activity. It can also 'break' the slurry crust prohibiting puddle formation at slurry pit level.

It is evident that fast removal of slurry from the barn will reduce ammonia emissions. Slurry removal can be carried out by e.g. a scraper system installed on a closed floor (walking floor or pit floor). After removal, the slurry can be moved to closed storage facilities or further processed on farm or off farm e.g. by anaerobic digestion. The latter can generate an added value for the farmer by producing biogas, and closed storage will always reduce emissions of both ammonia and methane compared to open storage.

If the slurry cannot rapidly be moved to a closed storage facility or anaerobic digestion, acidification of slurry can also reduce both methane and ammonia emissions. Unfortunately this also means that the slurry will not work well for biogas-production. The potential effects such as reduced possibilities for anaerobic digestion therefore have to be taken into account.

Technical challenges with additives are that in many cases they are of unknown composition which makes it difficult to identify emission reduction mechanisms. Except for acidification, performance and reduction efficiency are largely unknown.

Slurry storage techniques

There are also well developed options to reduce emissions during the storage of slurry.
One simple option is to cover the slurry storage either with a solid cover or by ensuring a formation of a thick natural crust on the slurry. Both types of cover reduce ammonia emissions. Solid cover gives the highest reduction but also has a much higher cost and more limited applicability, depending on the type of slurry storage facilities. Crust formation comes naturally in most cattle slurries due to the fibre residues in the slurry.

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Another option is to acidify the slurry in the slurry tank by adding strong sulphuric acid. This reduces both ammonia and methane emissions, but requires that the tank construction is suited for the lower pH of acidified slurry. As mentioned above, acidification may however limit the use of the slurry for biogas-production. The two types of measures can therefore not be used together.

Biogas production takes place in air tight biogas reactors. If the slurry is transported to the biogas facility rapidly after excretion it will reduce emissions of both ammonia and methane. Biogas facilities can be large plants using slurry and manure from many farms and other sources of organic material, or they can be smaller plants at individual farm level on large farms. All of them do however require a biogas infrastructure and substantial investments. Care must also be taken to implement ammonia mitigation measures after anaerobic digestion, as the digested slurry has an elevated pH and a higher ammonium content, which increases ammonia emissions.

Indoor climate control techniques

Lowering indoor temperature and air velocities near emitting surfaces can reduce ammonia emissions. This is a challenging task in naturally ventilated housing, but can be achieved by smart application of Automatically Controlled Natural Ventilation (ACNV). Also, roof insulation is expected to provide some effect. Indoor air treatment techniques such as fogging can also help reduce emissions.

The emission reduction potentials of these techniques are however not yet quantified.

ACNV is used in practice but current controlling algorithms are not aimed at reducing emissions. In general it is difficult to measure emissions from naturally ventilated barns which makes it hard to determine emissions from new systems and mitigation technologies and compare them to traditional systems. On one hand, applying ACNV may have the synergistic effect of reducing both direct ammonia evaporation and heat stress. On the other hand, an increased air-flow through the barn can increase total ammonia emissions.

Air exchange between head space of manure storage and barn air is also known as a potential strong driver of emissions. Its quantification and control is a technical challenge in naturally ventilated barns, which needs to be solved.

End-of-pipe techniques

End-of-pipe techniques are widely used in pig and poultry production and have a documented high removal potential for ammonia in mechanically ventilated housing. Some techniques also mitigate odour emissions. Air treatment can be obtained by chemical, biological or mixed scrubber systems. Implementation of these systems in cattle barns requires more closed (hybrid) ventilation systems in order to maximise the ratio of treated to untreated air. Such systems are still under development and are difficult to adapt to existing barns. The potential application is therefore primarily aimed at establishing entirely new housing facilities.

Combining different housing techniques

Most individual techniques, except for end-of-pipe techniques, can reduce emissions by 15-30%. Combining different techniques allows higher reduction efficiencies, e.g. combining feeding strategies, floor cleaning, smart ventilation etc. But care must be taken as some measures may not be synergistic but rather antagonistic when applied together.

One option under development and early implementation is to combine hybrid-ventilated barns with end-of-pipe treatment of the exhaust air. In this system, the naturally ventilated barn is also equipped with partial ventilation which ensures that most of the air from the headspace in slurry canals and manure storage is led through an air cleaning system before leaving the barn.

Low-emission application techniques for manure

The scope of this Focus Group does not include methods which can reduce emissions during the application of manure in the field. There is however a huge potential for reducing ammonia emissions with readily available methods. These methods include: trailing hose application, manure injection and various types of acidification of manure. The description of various techniques can be found in the UNECE Guidance Document on preventing

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and abating ammonia emissions (UNECE, 2014). Various methods approved for use in Denmark are described by the Danish Environmental Protection Agency: **http://eng.mst.dk/trade/agriculture/environmental-technologies-for-livestock-holdings/list-of-environmental-technologies/**

5. Tools and measures facilitating emission reductions

Besides the measures which can physically reduce emissions from cattle, there are a range of tools which can either facilitate implementation or help farmers, scientists or other decision makers choose the "right" measures – from an environmentally, socially and economically sustainable perspective.

Farm models

Farm management is widely regarded as one of the main factors affecting not only farm profitability but also farm livestock emissions. Weather and soil conditions also interact with farm management, and they therefore influence N (N_2O, NH_3, NO_x) and C (CH_4 and CO_2) emissions, the diffusion of pollution via N and P to water sources and the potential soil C sequestration capacity.

A number of tools at the farm level have been developed to estimate farm emissions and help reduce such emissions. Farm models are very useful for visualising emissions or nutrient flows that are otherwise invisible for farmers.

These tools have different scopes, scales and degrees of complexity both structurally and in terms of user-friendliness, which generally determine their specific purpose and required input data to run them.

The simplest: Farm nutrient accounting systems (e.g. nutrient budget methods) may be considered the simplest approach to estimate emissions. These generally consider only the elements (nutrients) entering and leaving the farm by the gate not taking any internal transformations into account.

The most complex: Whole-farm models are more sophisticated tools that incorporate most of the elements on a farm and try to represent some of the feedback nutrient loops amongst the different components of the system. All of the processes affecting emissions and farm productivity involve the cycle of C and N within the farm, most of which will be affected by weather and soil conditions, farm management and plant/animal genetics. For example, a measure to reduce GHG emissions at the animal level may reduce CP intake and this may have large effects on the different farm components as well as on the whole system (manure composition and emissions from manure storage and soil-plant emissions and productivity).

The more complex tools may be too difficult to parameterise at farm scale and therefore of little practical use.

Farmers and extension officers already use some models (e.g. feeding models) to improve farm performance both economically and environmentally. The value of these models is clear as they represent a strategic tool for the farmers and allow them to improve efficiency and reduce emissions at specific farm management stages. Improving on-farm efficiencies through better use of inputs strongly correlates with reduced production costs per kg of animal product leading to improved farm profitability.

Examples of various existing farm models can be found in the mini-paper on farm models/tools to help farmers reducing emissions.

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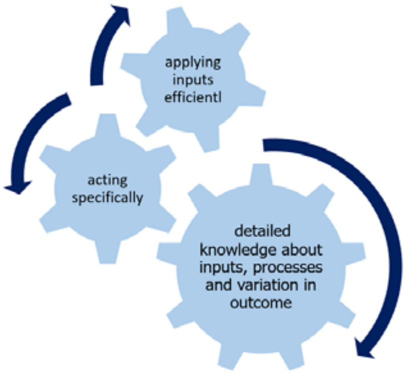
Precision livestock farming



Precision Farming (PF) uses new technologies to handle and manage farm information. The premise of PF is that this better use of information improves economic returns and reduces environmental impact. More information for PF with focus on data management, use of PF technologies for input and yield optimisation and the main barriers for the implementation of PF on European farms can be found in the recent **final report of the EIP-AGRI Focus Group on PF**.

Precision Livestock Farming (PLF) technologies enable continuous, automatic monitoring of animal welfare, health, production and environmental impact in real-time. Precision livestock farming can enable a farmer to monitor animals automatically and to create added value by helping to secure improved health, welfare, yields and environmental impact. Precision livestock farming caters for the individual animal's needs in bigger herds, integrating health, genetics, feed, social behaviour and resource use and availability, which can be supported by sensor technology integrated in monitoring systems. The PLF technologies can thus help farmers to increase livestock production and quality of production in a sustainable manner.

With several PLF technologies aimed at increasing the sustainability of livestock farms by looking at e.g. health, barn climate control, reproduction and quality control, precision livestock feeding is indicated by the Global Research Alliance (2013) as the most promising PLF technology for reducing ammonia and GHG emissions from livestock farms. Modifying animal feed composition can be a practical and efficient way to reduce emissions of livestock operations to the environment, as described in chapter 4 and the mini-paper on Feeding strategies. Precision feeding is about getting the right nutrient to the right animal at the right time, which will increase feed efficiency and productivity and consequently can improve farm profitability. A better use of resources lowers emission intensity. This can be done by controlling:

- individual feeding behaviour and individual feed intake
- the amount and composition of manure produced and the associated emissions from manure
- the enteric methane production

Monitoring feed intake is one of the main constraints both for precision feeding and for estimating methane emissions. Ideally this should be done on individual cow level and combined with information on e.g. milk yield and composition and body weight. On-line milk composition analysers that measure milk fat, protein, and lactose in real time at each milking with concurrent measurements of body weight are now available and might generate useful data to refine the feeding programme of dairy cows (Maltz et al., 2003)

Grasslands are an important source of low-cost and high-quality feed for ruminants in Europe. It is estimated that roughly half of the total dry matter intake by livestock at the global level comes from grass and other roughages, albeit with strong regional variations. Monitoring nutrient composition and feed intake for grazing cattle is however a challenge, but one where PLF technologies may be valuable.

As an example, customised balanced feeding programmes in grazing dairy cattle systems have shown to increase productivity and reduce enteric methane emission intensity (15-20%) and also N excretion (20-30%), which results in reduced emissions from manure. There is however in general a need for improved understanding of amino-acid utilisation in dairy cattle.

Measuring methods at barn and animal level

To monitor the effects of various emission mitigation measures, it is essential to have reliable and practical measurement methods for measuring emissions from cattle. Unfortunately, available information on emissions from cattle production and the effect of mitigation options is, compared to other livestock species, very limited. There are a number of reasons for this:

- Cattle are almost exclusively housed in naturally ventilated (NV) barns or grazing in the open. It has been widely acknowledged that the quantification of emissions from NV buildings is a more complicated and challenging task compared to mechanically ventilated buildings. Emissions are calculated as the product of the gas concentration in ventilated barn air and the air flow rate of the barn. There are substantial methodological difficulties to accurately determine airflow rates in NV barns.
- So far an undisputed reference field method for emission measurement cannot be identified from the variety of available methodological approaches. As a result, information on emissions from NV buildings is scarce and subject to discussion on measurement accuracy.
- Currently used research methods to determine air flow rates are mainly based on the mass balance principle (using tracer gases like CO_2/SF_6) and at a more experimental level on velocity measurements. Both approaches require a considerable effort in terms of measurement expertise, equipment and labour to yield reliable results.
- Scale and layout of NV cattle building vary considerably across Europe. This variability complicates the elaboration of standardised measurement protocols for emissions and the evaluation of mitigation options Europe wide.
- With the current state of art it is not possible for cattle farmers to routinely monitor at affordable costs the effects of mitigation options on barn emissions. This restricts the contribution of farmers' experience and expertise in developing mitigation options.

This lack of reliable and practical measurement methods for emissions from cattle has impeded the development and implementation of mitigation options. First results from measurement campaigns that comply with the setup of the VERA test protocols, which have been developed in cooperation between Denmark, the Netherlands and Germany (**http://www.vera-verification.eu/en/**), indicate that the ability to statistically distinguish emission factors (mean ammonia emission, per year and animal unit) between different cattle housing systems is limited to differences of at least 40% and more. This lack of distinctive power undermines the evaluation of many relevant mitigation options with reduction efficiencies below 40%.

There is therefore a need to improve measurement methods with particularly two aims:

1. Improvement of measurement methods to assign emission factors to mitigation options that can be used by regulators and policy makers, and accurate methods for research purposes to develop and optimise mitigation options.
2. The development of low-cost monitoring strategies that can be widely applied at farm level to support management decisions to lower emissions, and offer tools for verification of emission abatement.

Taking into account the rapid development of monitoring and climate control technologies, it is expected to see in the near future the use of intelligent PLF systems for emission reduction through optimised barn climate control and better air flow through smart ventilation systems.

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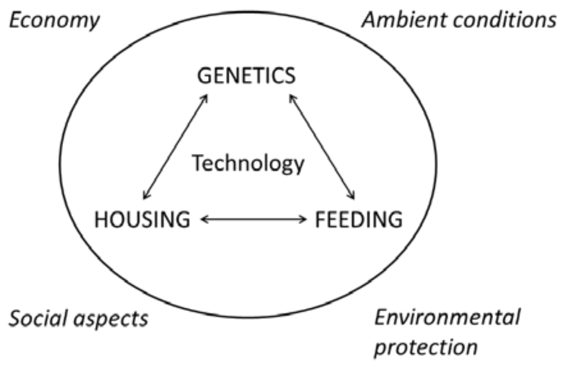
Synergies



In recent years, regulation pressure and efficiency needs have encouraged researchers and farmers to develop, test and apply different strategies to reduce emissions, as described in this report and in the various mini-papers of this Focus Group. The knowledge on how several of these different techniques can be applied on real farm conditions is however limited, and the aggregate potential of emission reduction is difficult to assess. Therefore, a question to be answered is how to integrate the different strategies to abate emissions in an effective and practical way, under farm conditions, at farm or regional scale. The mini-paper "Looking for synergies for a sustainable livestock production" addresses some potential synergies to be studied, including:

- Adaptation to suboptimal ambient conditions
- Adaptation to suboptimal feeding
- Integrating crop and livestock systems

The mini-paper also identifies some existing examples of projects, where synergies are being investigated. This includes the "feed a gene" project (http://www.feed-a-gene.eu/), the Cost Action LiveAge, and the Cost Action "Methagene" (http://www.methagene.eu/), which combine nutrition and genetic aspects, and includes precision farming. Combining different feeding and housing techniques is being studied as a regulatory option in the Netherlands and Flanders to reduce ammonia emissions. Establishing common efforts between nutrition and genetics may result in outstanding advances, particularly in cattle production. In addition, for ruminant systems, recent studies focus on how the microbiome of the rumen can be modified and how to reduce the impact of heat stress.

6. Success and fail factors

A wide range of measures can be applied at cattle farms to reduce emissions. There are also major challenges in implementing these measures. The challenge of reducing emissions from cattle can be solved at different stages in the production chain and with tools of varying complexity. The success and fail factors for implementing these tools are therefore also diverse. This was demonstrated during the Focus Group's general discussions, in the mini-papers and also during a separate session during the second meeting in Riga where success and fail factors for five specific mitigation measures were discussed.

One parameter, which was repeatedly mentioned as a major challenge for increased implementation of emission reducing measures, is the difficulty of showing the benefits to farmers. Emissions are invisible and many of the environmental effects are only visible over long time-spans and take place a long way from the source of the emissions. The emission reduction in itself is therefore not a good incentive for the farmer. In theory, several of the measures have benefits such as increased production efficiency which could be an incentive for the farmers. This must however be shown clearly during demonstration projects if the measures are to spread by themselves.

Another problem is that environmental production efficiency is not valued in environmental policies. On a national scale, reduction targets are absolute, little emphasis is put on how reductions are achieved. This leaves a gap between overall targets and the measures which can be used to achieve them. It also means that one of the few clear economic incentives for emission reductions – production efficiency – is not valued and accounted for by the political system.

In theory, it should also be possible to gain higher prices for agricultural products which are more environmentally sustainable due to lower emissions. This has however proven difficult and will require a highly credible certification/labelling effort. The complexity of the different environmental issues related to emissions makes it a challenge. While consumers generally know about GHG emissions and climate change, their knowledge of the problems associated with ammonia emissions is limited. There are also often trade-offs between different aspects of sustainability e.g. welfare and emissions, which makes it difficult for consumers to understand the meaning of a label or certificate.

More specific success and fail factors include the availability of sufficient data on the level of individual cows, so as to include emissions in breeding programmes; and better utilisation of all the data precision livestock farming can supply.

In all cases, a strong extension service which can advise farmers on how and when to implement various measures is essential. Many of the measures cannot be implemented immediately. Some require massive re-design of animal housing facilities and are only feasible in coordination with re-building projects or building new housing. Others will require dissemination of knowledge and training which may take years. A long-term strategy for implementation of emission reducing measures is therefore essential. This also requires in-depth investigations into the science-policy gap and ways to overcome it.

7. Ideas for research and Operational Groups

The Focus Group has also developed ideas for research and Operational Groups which can facilitate further the reduction of emissions from cattle farming. A summary can be found below

- A recurring recommendation was to test models, decision tools and precision livestock farming technologies and emission sensors under practical farm conditions.
- Demonstration projects can inspire other farmers and at the same time give valuable feed-back to the further development of these tools. Systems thinking could be developed by games from the farming models.
- Operational Groups could develop pilot projects about cattle housing construction
- Development and implementation of decision tools for improved N use efficiency and for new improved and cheap methane and ammonia measurement methods were also suggested.
- A related subject is the identification and practical implementation of proxy parameters for e.g. feed efficiency and methane production, which can facilitate quick and easy determination of emissions.
- With regards to breeding, there is a need for further research on estimating genomic breeding values for emissions. Work on testing tools and practices for collection of emission data on animals and farms, such as mentioned above will be helpful in this context.
- In the more complex part of the spectrum is the need for research into synergies of combining different measures – e.g. precision feeding and housing or precision feeding and breeding.
- More knowledge is also needed on emissions from naturally ventilated barns and during grazing – including methods for determining them.

8. Conclusions - what can be done to reduce future emissions?

Summarising the outcome of the Focus Group's work, there are possible solutions for reducing emissions of ammonia and methane from cattle farming – the cost-effectiveness of some of these solutions is however a challenge.

Farm management is widely regarded as one of the main factors affecting not only farm profitability but also farm livestock emissions. Weather and soil conditions also interact with farm management, and they therefore influence N (N_2O, NH_3, NO_x) and C (CH_4 and CO_2) emissions, the diffusion of pollution via N and P to water sources and the potential soil C sequestration capacity.

For both ammonia and methane emissions, changes in feed composition can improve production efficiency. This will yield fewer emissions per kg of milk or meat and can be an economic benefit for the farmer – but will not necessarily reduce overall emissions on a local or national scale. It will also require careful management of the feed for which development of improved precision livestock feeding and measurement systems are needed.

For methane reductions several different types of feed additives are under development. They still need to be thoroughly tested under production conditions – and so far the costs of these additives will limit widespread application.

Similarly targeted breeding programmes, focusing on improving production while decreasing emissions of ammonia and methane, can improve production efficiency – this is already happening. More milk per cow or per feed unit benefits the farmer and reduces emissions per kg of product. But again this will not necessarily reduce overall emissions on a local or national scale. On a larger scale, however, the environment will benefit from a more emission-efficient production. This discrepancy between local and global effects needs to be addressed when assessing future mitigation measures.

Breeding may also hold a key to the reduction of emissions. There appears to be a substantial genetic variation between individual cows in their methane emissions and thereby a potential for reducing overall methane emissions per cow by genetic selection. The major obstacle for using this knowledge for breeding towards lower overall emissions is the lack of precise and accurate measurement methods for emissions from individual animals.

Problems with measuring methane and ammonia emissions are also evident at other scales. Cows are mostly housed in naturally ventilated barns or graze outdoors, which makes it difficult to measure emissions. Therefore measurement errors are often large making it very difficult to determine whether a certain technique actually affects emissions. There is therefore a need to develop more accurate, precise and cheap measurement methods for determination of methane and ammonia emissions.

Housing technologies are a type of measure which is already available for ammonia reductions, but will mostly not be cost-efficient for farmers. Several of these measures also require structural changes in the animal housing. If such measures are to be implemented more broadly it is best done at the same time as re-building barns or building entirely new housing. A long-term implementation plan is therefore needed.

An inherent problem with emissions of methane and ammonia is also that both the emissions and their effects are invisible to the farmer and the consumer. Even the economic incentives for some measures can be difficult for the farmer to comprehend. In this context, farm models can be very helpful to illustrate e.g. how much a better nitrogen efficiency means for the whole farm nutrient balance and for the farm income. Demonstration projects can also be an effective tool to show other farmers the benefits.

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Annexes

Annex 1: List of members of the Focus Group

Mr/Ms	First name	Family name	Organisation	Country
Mr	Ole	Aaes	SEGES [DAFC] (Copa-Cogeca)	Denmark
Mr	Frank	Allen	Farmer	Ireland
Ms	Barbara	Amon	Leibniz Institute for Agricultural Engineering	Germany
Mr	Thomas	Bartzanas	Center For Research And Technology Hellas	Greece
Mr	Stijn	Bossin	Innovatiesteunpunt	Belgium
Mr	Andrew	Brewster	A Brewster and Son - Family Farm	United Kingdom
Mr	Salvador	Calvet Sanz	Universitat Politecnica de Valencia, Institute of Animal Science and Technology	Spain
Mr	Agustin	del Prado	BC3-Basque Centre for Climate Change	Spain
Mr	Peter	Demeyer	Institute for Agricultural and Fisheries Research (ILVO)	Belgium
Ms	Silvija	Dreijere	Latvian Ryral advisory and training center	Latvia
Ms	Iveta	Grudovska	Union Farmers Parliament	Latvia
Ms	Ceris	Jones	National Farmers Union	United Kingdom
Mr	Erwin	Koenen	CRV	Netherlands
Mr	Marcello	Mele	University of Pisa	Italy
Mr	Tom	Misselbrook	Rothamsted Research	United Kingdom
Mr	Diego	Morgavi	INRA	France
Mr	Nico	Ogink	Wageningen Livestock Research	Netherlands
Mr	Mateusz	Sękowski	Agricultural Advisory Center in Brwinów Branch Office in Radom	Poland
Mr	Claude	van Dongen	Farmer	Netherlands
Mr	David	Yanez-Ruiz	CSIC	Spain

Annex 2: Mini-papers on prioritised topics

Title of mini paper	Authors
Feeding strategies to reduce methane and ammonia emissions	David R. Yáñez-Ruiz, Diego Morgavi, Tom Misselbrook, Marcello Mele, Silvija Dreijere, Ole Aes, and Mateusz Sekowski
Housing techniques as mitigation options for emissions from cattle barns	Barbara Amon, Thomas Bartzanas, Stijn Bossin, Salva Calvet, Silvija Dreijere, Iveta Grudovska, Ceris Jones, Tom Misselbrook, Nico Ogink, Peter Demeyer
Precision Livestock Farming	Thomas Bartzanas, Barbara Amon, Salva Calvet, Marcello Mele, Diego Morgavi, Tomas Norton, David Yanez-Ruiz, Claude van Dongen
Looking for synergies for a sustainable livestock production	Salva Calvet, Agustín del Prado, Diego Morgavi, Barbara Amon, Peter Demeyer.
Farm models/tools to help farmers reducing emissions	Agustin Del Prado, Ole Aaes, Thomas Bartzanas, Stijn Bossin, Salva Calvet, Peter Demeyer, Iveta Grudovska, Tom Misselbrook, Claude Van Dongen
Measuring and monitoring methods to assess emissions from cattle barns and to evaluate and improve mitigation options	Nico Ogink, Barbara Amon, Salvador Calvet, Peter Demeyer, Erwin Koenen
Opportunities to reduce emissions in dairy cattle by animal breeding	Erwin Koenen, Salvador Calvet Sanz and Marcello Mele

All mini papers will soon be available on the EIP-AGRI website on the **Focus Group page**.

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AGRICULTURE & INNOVATION

The European Innovation Partnership 'Agricultural Productivity and Sustainability' (EIP-AGRI) is one of five EIPs launched by the European Commission in a bid to promote rapid modernisation by stepping up innovation efforts.

The **EIP-AGRI** aims to catalyse the innovation process in the **agricultural and forestry sectors** by bringing **research and practice closer together** – in research and innovation projects as well as *through* the EIP-AGRI network.

EIPs aim to streamline, simplify and better coordinate existing instruments and initiatives and complement them with actions where necessary. Two specific funding sources are particularly important for the EIP-AGRI:

- ✓ the EU Research and Innovation framework, Horizon 2020,
- ✓ the EU Rural Development Policy.

An EIP AGRI Focus Group* is one of several different building blocks of the EIP-AGRI network, which is funded under the EU Rural Development policy. Working on a narrowly defined issue, Focus Groups temporarily bring together around 20 experts (such as farmers, advisers, researchers, up- and downstream businesses and NGOs) to map and develop solutions within their field.

The concrete objectives of a Focus Group are:

- ✓ to take stock of the state of art of practice and research in its field, listing problems and opportunities;
- ✓ to identify needs from practice and propose directions for further research;
- ✓ to propose priorities for innovative actions by suggesting potential projects for Operational Groups working under Rural Development or other project formats to test solutions and opportunities, including ways to disseminate the practical knowledge gathered.

Results are normally published in a report within 12-18 months of the launch of a given Focus Group.

Experts are selected based on an open call for interest. Each expert is appointed based on his or her personal knowledge and experience in the particular field and therefore does not represent an organisation or a Member State.

*More details on EIP-AGRI Focus Group aims and process are given in its charter: http://ec.europa.eu/agriculture/eip/focus-groups/charter_en.pdf

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