European Cooperation in the field of Scientific and Technical Research - COST -

Brussels, 24 May 2013

COST 016/13

MEMORANDUM OF UNDERSTANDING

Subject :	Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action FA1302: Large-scale methane measurements on individual ruminants for genetic evaluations

Delegations will find attached the Memorandum of Understanding for COST Action FA1302 as approved by the COST Committee of Senior Officials (CSO) at its 187th meeting on 15-16 May 2013.

MEMORANDUM OF UNDERSTANDING
For the implementation of a European Concerted Research Action designated as

COST Action FA1302
LARGE-SCALE METHANE MEASUREMENTS ON INDIVIDUAL RUMINANTS FOR GENETIC EVALUATIONS

The Parties to this Memorandum of Understanding, declaring their common intention to participate in the concerted Action referred to above and described in the technical Annex to the Memorandum, have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of document COST 4154/11 “Rules and Procedures for Implementing COST Actions”, or in any new document amending or replacing it, the contents of which the Parties are fully aware of.

2. The main objective of the Action is to reduce environmental footprints of animal-derived food using methane mitigation strategies through animal breeding. The Action aims at harmonising large-scale methane measurements using different techniques; agreeing on identified easy to record proxies for methane emissions for genetic evaluations; and on approaches for incorporating methane emissions in breeding strategies.

3. The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 68 million in 2013 prices.

4. The Memorandum of Understanding will take effect on being accepted by at least five Parties.

5. The Memorandum of Understanding will remain in force for a period of 4 years, calculated from the date of the first meeting of the Management Committee, unless the duration of the Action is modified according to the provisions of Chapter IV of the document referred to in Point 1 above.

A. ABSTRACT AND KEYWORDS

Methane is a greenhouse gas (GHG) that contributes to climate change. The livestock sector, particularly ruminants, is estimated to contribute up to 18% of total global anthropogenic GHG emissions. Preliminary data suggest that genetic selection to reduce methane emissions is possible. However, successful breeding programs require large datasets of individual animal measurements which cannot be generated by any EU country working alone. Smaller datasets of methane measurements are being generated by individual countries across the EU, which could be combined if agreement could be reached on how best to harmonise the data. Discussing harmonisation and protocols for future collection of such data is the focus of this METHAGENE network. METHAGENE aims to discuss and agree on 1) protocols to harmonise large-scale methane measurements using different techniques; 2) easy to record and inexpensive proxies for methane emissions to be used for genetic evaluations; and 3) approaches for incorporating methane emissions into national breeding strategies. METHAGENE will co-ordinate and strengthen EU scientific and technical research through improved cooperation and interactions, which is essential for breeding ruminants with lower environmental footprints resulting in less contribution to global warming.

Keywords: enteric methane emissions, measuring techniques, protocols, large dataset, breeding programs

B. BACKGROUND

B.1 General background

Climate change is a growing international concern and it is well established that the release of greenhouse gases (GHG) is a contributing factor. The European Union has committed itself to reduce its GHG emissions by 20% by the year 2020 relative to 1990 levels. The global livestock sector, particularly ruminants, contributes approximately 18% of total anthropogenic GHG emissions (Steinfeld et al., 2006). In the EU, the livestock sector accounts for about 13% of total GHG emissions (Leip et al., 2010). Of the various GHG produced by ruminants, enteric methane (CH_4) is the most important contributor, with a global warming potential 25 times that of carbon dioxide (CO_2).

Technical solutions to reduce enteric methane emissions have been, and continue to be, extensively researched. Animal breeding that exploits natural animal variation in methane emissions is an additional mitigation strategy that is cost-effective, permanent, and cumulative. Nonetheless, within animal production, there is little or no concerted EU-wide effort on long-term breeding strategies to mitigate against GHG from ruminants. There have been several, largely nationally funded, studies that have taken place (or are underway), but are too small in size to draw definitive conclusions and also are of insufficient size to make any meaningful contribution to national, EU-wide, or international mitigation strategies through breeding. This is because successful animal breeding strategies require measurements on a large population of animals. With the recent successful incorporation of genomic information into breeding schemes the reliance on very large populations of phenotyped animals is relaxed. However, a reference population of several thousand animals is still required to estimate the contribution of each genomic region to expression of the phenotype under investigation (Calus et al., 2013). Therefore, a dataset of several thousand animals with similarly defined phenotype for methane output would be sufficient for accurate genetic evaluation of the trait.

The current ‘gold standard’ for measuring methane emissions is respiration chambers, but these are expensive and impractical for large-scale data collection. The sulphur hexafluoride (SF_6) technique can be used for field-scale data collection, but requires insertion of rumen boluses, daily animal handling and laboratory measurement of gases (McGinn et al., 2006). In recent years researchers, including those involved in METHAGENE, have developed many innovative non-invasive techniques, either by infrared (Garnsworthy et al., 2012b; Lassen et al., 2012) or photo acoustic (Negussie et al., 2012) gas analysers, or by using a laser methane detector (Chagunda et al., 2009). Partners are applying these techniques in different projects, for example in the Netherlands, Denmark, UK, Finland, and in the EU FP7 *RuminOmics* project.

Calus et al. (2013) showed that records on at least 10,000 cows are required to generate accurate genomic predictions. This is certainly not achievable within a single country or even a small group of countries. Therefore, to facilitate genetic selection for reduced methane as a mitigation strategy, it would be highly desirable to combine individual national datasets to produce an EU-wide database. However, data are collected using different protocols and combining these data but requires intensive consultation among contributing scientists across a range of disciplines. More importantly however, scientists planning to undertake future studies in methane currently have no agreed protocols on how to proceed with the collection of such data in the future to ensure their use in breeding strategies.

METHAGENE aims to develop consensus on protocols for the collection of methane output data using a multi-disciplinary approach to facilitate existing and future data from different countries and collection methods to be harmonised and combined. Discussions amongst experts will also help to identify possible predictor traits of methane emissions (e.g., biomarkers in milk) that could easily be exploited. Furthermore, methane emissions are currently not directly included in any national cattle breeding objective worldwide. This is due to not only a lack of sizable data on which to make selection decisions, but it is also due to a lack of consensus on how to optimally include methane emissions in a breeding objective. Lastly, METHAGENE aims to develop standards on ways to express methane emissions, with consideration of advantages and disadvantages of expressing methane per unit (digestible) feed and per unit of consumable product (i.e., milk and/or meat), also considering the time horizon of the emission in a life cycle assessment and the need to ensure that selection for low emissions does not compromise production efficiency. Achieving these goals of METHAGENE will position the EU as the global leader in the field of methane mitigation strategies.

B.2 Current state of knowledge

Methane-determining factors

The rumen is the major site of methane production in which anaerobic archaeal microorganisms convert H_2 and CO_2 to CH_4. In ruminants, methane is a natural by-product of anaerobic respiration, produced predominantly in the rumen (~90%), and to a small extent in the large intestine (~10%) (Ellis et al., 2008). The contribution of methane released by flatulence is only marginally, while eructation and air from the lungs accounts for the majority of total methane produced by a ruminant. The major factors that determine methane production include the amount of feed consumed by the ruminant, and the digestion of that feed. As more feed is ingested, more methane is produced, but the portion of methane per kg dry matter intake (DMI) decreases with increasing feed intake (Jentsch et al., 2007). Conversion of feed material to methane in the rumen involves the integrated activities of several different microbial species, the final step being carried out by methanogenic archaea. Methane production serves as the principal electron sink within the rumen. On the other hand, propionate, largely produced with fermentation of non-structural carbohydrates, serves as a competitive pathway for electron use in the rumen and is accompanied by a decrease in overall methane production.

Differences between animals being identified as high- or low efficient feed utilizers, or high- or low methane emitters, have also been reported. Individual methane production may vary by 100% during the day. For example, Van Zijderveld et al. (2010) showed with sheep in respiration chambers that methane production varied by much more than 100% during the day. This might have an effect on the measurements, when they are only performed for a short period during the day; i.e., during milking.

In addition to the amount of DMI, diet composition (e.g., dietary fat) has an important influence in methane emissions (Hegarty, 2009). The amount and quality of the carbohydrate fraction affects methane production. For example, a greater portion of starch reduces methane production, while greater fibre content increases methane production. Feeding supplements capable of scavenging H_2, such as unsaturated fatty acids (Martin et al., 2008) or nitrate (Hulshof et al., 2012), but also antibiotics and immunization (Buddle et al., 2011), may help to reduce ruminal methane production albeit they may also have negative effects on feed intake and milk production. Hence, taking cognisance of feed intake and milk production or growth rate is essential in selection for animals with lower methane production potential.

Residual feed intake (RFI) is a measure of feed efficiency where negative values imply improved feed efficiency, and is calculated as the difference between the actual and expected feed intake. Beef cattle selected for high and low RFI differed in methane production by 28% (Nkrumah et al., 2006). By comparing methane emissions of Angus steers chosen from breeding lines divergently selected for RFI, Hegarty et al. (2007) found also that the most efficient animals (low RFI) had a lower methane production rate. Selection for low RFI may also have a favourable effect on the total amount of manure produced (15% to 20% less than those selected for high RFI) and also on the potential quantity of nitrous oxide liberated from these manures. This potential effect on nitrous oxide can be due to a reduction in total N intake and a greater efficiency of capturing dietary N (Hegarty et al., 2007).

A significant sire effect was found in an analysis of methane emissions during milking in 215 cows (Garnsworthy et al., 2012b), which suggests that there is a genetic component. Estimated heritabilities in dairy cattle were 0.35 for predicted methane production and 0.40 for RFI, and a positive genetic correlation between the two suggests that selection on RFI may be one strategy to reduce methane emissions from ruminants (de Haas et al., 2011). Accounting for just one of these components might, however, result in undesirable genetic changes. Particular consideration must be given to a general involvement of RFI in selection strategies of dairy cows because in early lactation, dairy cows ingest insufficient feed to meet energy requirements for milk production and thus enter into a negative energy balance (Negussie et al., 2013). Severe and prolonged negative energy balance is associated with infertility in dairy cows, which increases methane emissions at the herd level through increased animal numbers (Garnsworthy, 2004). Furthermore, during early lactation dairy cows exhibit a low RFI, but high feed intake is a prerequisite to minimize the incidence of metabolic disorders such as fatty liver (Schaff et al., 2012).

Feed intake, diet quality and composition, body weight, activity, circadian rhythm, stage of lactation and inter-individual differences are major factors influencing methane production. Because of these considerable variations, it is difficult but very important to get reliable estimates from single methane measurements reflecting entire daily methane production. This obstacle calls for establishing relationships between snapshot methane concentrations determined once or twice a day and total daily methane production. One possible way to overcome this problem may be to measure the ratio between CH_4 and CO_2 (Madsen et al., 2010). This ratio provides a relative measure and is independent of methane concentration. Another issue is how to relate methane production level to production efficiencies. An often suggested trait is methane per kg milk per day, but this trait has been already more than halved during the last 45 years (Capper et al., 2009). CH_4/kg DMI, CH_4/(kg milk * body weight) or CH_4/kg milk produced during lifetime may be further valuable traits (Yan et al., 2010; Lassen et al., 2012). In conclusion, selection on methane emissions must rely on validated methane measurements and should be fine-tuned with physiological and production traits of dairy cows.

Comparison and calibration of measurements

Compared with respiration chambers, the main advantage of the SF_6 measuring technique is that it can be used on a larger number of individuals that can be kept under near-normal conditions. As a consequence, this technique is especially useful for grazing animals. The accuracy of the technique has been validated against different chamber techniques (Johnson et al., 1994; Boadi et al., 2002; McGinn et al., 2006; Grainger et al., 2007). Nevertheless, the literature reports significant bias linked to the measuring system itself. The technique is based on the use of SF_6 as a tracer gas emitted by a permeation tube placed into the rumen of monitored animals, and methane emission is calculated from CH_4:SF_6 ratios and SF_6 permeation rate (PR). The PR is assessed gravimetrically prior to placement of a permeation tube into the rumen. After placement, it is not possible to check or correct the PR unless by recovering permeation tubes which implies having fistulated animals or slaughtering them. Main biases of the SF_6 technique reported in the literature are linked to an unclear influence of the rumen environment on the PR (Swainson et al., 2011) and an unexplained empirical direct relationship observed between PR and calculated methane emission (Vlaming, 2008).

A laser methane detector system (LMD) to estimate methane concentration in dairy cows was initially suggested in an experimental study by Chagunda et al. (2009). In that study, they demonstrated that the use of a LMD was feasible in dairy cows and the data produced made biological sense. The LMD is a non-invasive and non-contact technique which entails directing a laser beam at the methane point source, in this case a cow’s nostrils to perform highly sensitive infrared absorption measurements (Iseki and Miyaji, 2003; Chagunda et al., 2009). This remote way

of enteric methane detection is useful because it enables measurements to be taken without disturbing the animals from exhibiting their normal behaviour (Chagunda et al., 2009). In a study with dairy cattle, Chagunda and Yan (2011) demonstrated that the LMD had a strong level of agreement with methane concentrations in a respiration chamber (r=8, P<0.001). Further assessment using dairy cattle and sheep in metabolic chambers gave values of sensitivity of 95.4 and 93.4% and specificity of 96.5 and 78.7% for cows and sheep, respectively (Chagunda et al., 2012). This meant that the LMD was able to detect periods of high methane concentration (sensitivity) at least 93% of the time and was able to avoid misclassifying periods of low methane concentration as high concentrations (specificity) at least 79% of the time. The main disadvantage of the LMD system is that the equipment has to be hand-held to take measurements from an animal.
Several researchers have recently investigated use of infrared gas analysers to measure enteric methane, sometimes in combination with CO_2, released during milking or feeding. Lassen et al. (2012) measured CH_4 and CO_2 concentrations at intervals of 20 seconds during milking over a 3-d period in 93 cows. Repeatability between visits in ratio of mean CH_4:CO_2 ratio was up to 0.4 using this method. Garnsworthy et al. (2012a) measured methane concentrations at 1-second intervals during milking and calculated mass flux of methane released by eructation. For 12 cows, methane emission rate recorded during milking on farm showed a linear relationship (r =0.89, P<0.001) with daily methane output by the same cows when housed subsequently in respiration chambers. For 42 cows, methane emission rate during milking was greater on a high methane diet, and the increase compared with a control diet was similar to that observed for cows in respiration chambers (Garnsworthy et al., 2012a). In a larger study, Garnsworthy et al. (2012b) measured methane emissions during milking over a 5-month period in 215 cows and found that measurements were highly repeatable for individual cows from one month to the next (r =0.72 to 0.80; P<0.001) and showed good agreement (concordance =0.63; P<0.05) with predicted daily methane emissions.
The GreenFeed system (C-Lock Inc, Rapid City, USA) uses a tracer (propane) to calculate volumetric flux of air (L/min) to measure CH_4 and CO_2 during feeding in cattle visiting a “baiting” station. In a New Zealand evaluation, mean methane emission estimates by the GreenFeed system were higher and more variable than those derived from the respiration chamber and the SF_6 tracer technique, but herd-average emissions derived from GreenFeed measurements correlated well over 24-hour periods with those derived from respiration chambers (Pinares and Waghorn, 2012).
A feature of all systems that measure methane “in line” during milking or feeding is that measurements are highly variable. But because several hundred measurements can be generated in a very short time period, individual cow means can be established that are repeatable and related to true emissions. The overwhelming advantage of online techniques, compared with SF_6 and LMD, is

the negligible labour requirement facilitated by automation.

Methane indicators

Mid-infrared (MIR). Mid-infrared spectra of milk samples are generated routinely by national and commercial laboratories for prediction of milk composition during milk recording. Therefore, any approach that utilizes this information can immediately be implemented but also applied retrospectively to already analysed samples with the spectral data stored. In vivo experiments performed using the SF_6 method showed that it is possible to estimate methane emissions of lactating dairy cows from MIR spectra of milk samples (Dehareng et al., 2012). A possible delay between a variation in methane emission and an onset in milk response was mentioned by these authors. These preliminary results suggest the possibility to predict individual methane emissions, allowing at least inventory type of assessments at a farm level or at a regional scale. With more collaboration and additional data, an improved equation could be generated. Predictions could then become robust enough to use MIR spectra to identify individually low-methane-emitting cows and to develop selection and management tools to reduce methane emissions.

Fatty acids (FA). Various FA in milk may be used as markers of microbial activity, and some have strong relationships with molar proportions of individual volatile fatty acids in the rumen (Vlaeminck et al., 2006), which in turn are related to methane production. Some milk FA were moderately related to methane production in dairy cattle (Chilliard et al., 2009; Dijkstra et al., 2011), but more data on wider ranges of diets and animals are required to further elucidate the accuracy of prediction of methane production based on milk FA profiles.

Microbial profiles. Because methane is produced by archaea, which are associated with protozoa and cellulolytic bacteria, the microbial profile of the rumen can give an indication of potential methane production by individual animals. Classic microbial culture methods cannot replicate the diversity of rumen microorganisms and their interactions, therefore attention is now being focussed on the rumen microbiome (Ross et al., 2012). The EU FP7 project *RuminOmics* is investigating links between the rumen microbiome and the host genome in order to improve understanding of the mechanisms involved in control of methane emissions. Microbial profiling, although an excellent research tool is considered too expensive for application to the large populations required for selective breeding.

Benefit for producers

Methane emissions represent a loss of between 2 and 12% of the ingested energy by an animal (Czerkawski, 1969), so reducing methane whilst maintaining or improving production levels and feed efficiency provides a direct economic benefit to producers.

Genetic improvement of livestock is a particularly cost-effective technology, producing permanent and cumulative changes in performance. However, methods to quantify the potential value of genetic improvement to reduce GHG emissions across production and functional traits are limited. One of the major limitations to the wider inclusion of GHG emissions in farm management and breeding programmes is the lack of available measurements, which this Action is expected to address. Firstly, by collecting detailed measures of methane emissions (and feed intake) on animals with wider production and fitness (i.e., health, fertility, longevity) data, the major knowledge gap on the true relationships between methane emissions and production, efficiency and fitness traits will be filled. Large datasets are required to generate these estimates with sufficiently low standard errors of estimates. Furthermore, these relationships could vary by environment (i.e., country). By dissecting the genetic components of the traits related to the environmental impact of animals and their farming systems, the contribution of traits to improvement of the environmental impact of livestock farming can be estimated as well as estimating the trade-offs between those traits. This information will help to develop tools for collection of genetic and/or phenotypic data which will allow inclusion of methane and other GHG emission traits into breeding objectives by breeding organisations, thereby further enhancing the reduction in GHG emissions at a relatively small economic cost. Through this, farmers will benefit indirectly via the improved genetic material coming from the breeding organisations resulting in animals that use their energy intake more efficient.

Many studies have shown that genetic improvement has been successful at improving energetic efficiency of production and increases farm profitability (Amer et al., 2007). Moreover, on-going improvements in efficiency have been shown to contribute to GHG mitigation from livestock agriculture (Moran et al., 2008). These studies have shown that most changes in profitability and environmental efficiency are largely due to a change in the overall efficiency of the individual animal and escalating to the wider system. Furthermore, reducing methane emissions by selecting animals with low methane emissions and/or RFI will also contribute to savings in feed cost and ensure sustainable natural resource utilisation.

Although the focus of this Action is the farm animal and the farming system, the outputs will help inform the wider food chain and policy makers. The reduction of the environmental footprint of food production is a priority as the political drive to reduce GHG emissions strengthens. There are global and local (e.g., regional, national) targets for GHG reductions across economic activities which are being addressed by a range of strategies, and agriculture is not exempt from this. For example, UK agriculture has established a voluntary GHG Action Plan (http://www.nfuonline.com/ghgap/) ahead on any potential national/international legislative forces coming into place. Knowledge of breeding potential for reduced methane emissions would therefore be valuable for producers, industry and policy makers in helping to meet national or international emission targets.

B.3 Reasons for the Action

Breeding for reduced methane emissions requires access to a large dataset of animals with methane measures or correlated measures. No single country or even a small group of countries can generate such data. Therefore, METHAGENE aims to produce freely available protocols to collect, harmonise, compare, calibrate and store large-scale methane measurements from different techniques with the end goal of facilitating the establishment of a large European database suitable for genetic evaluations in the long term. Its major benefit to society is provision of a necessary component of a permanent and cumulative mitigation strategy to help reduce EU and global GHG emissions. Although animal breeding is thought of as being a relatively slow process, milk production in most dairy cattle populations has increased by 50% in the past 25 years, half of which was due to genetic improvement. This increase in genetic gain, primarily in the last 15 years, was achieved through international sharing of milk production data. Our hypothesis, substantiated by limited available data, is that reducing methane emissions through animal breeding is possible without necessarily compromising milk output and animal health, fertility and welfare. Achieving both objectives is necessary to feed a growing world population without simultaneously increasing the environmental footprint.

Being able to combine methane measurements generated by many research centres employing different, yet related, techniques will provide the critical mass required for genetic selection as a mitigation strategy. Combining measurements also offers opportunities for powerful meta-analysis to provide more reliable estimates of actual European methane emissions. Putting in place freely available and easy to understand guidelines for collection of methane data will ensure that future experiments collecting methane data will be provided with sufficient details to ensure that such data can subsequently be used also in breeding programs. Combining current national efforts will thus provide added value, promote synergy, reduce research efforts, and save costs and resources.

Although METHAGENE focuses primarily on methane emissions and particularly dairy cows, the procedures developed as well as the trust within the collaborative group can expand the efforts to other traits and other species.

The necessary knowledge and highly skilled personnel is in short supply across EU research and animal breeding centres, especially among the EU new member states in Eastern Europe. METHAGENE will generate knowledge, protocols and tools of substantial value to EU food and agriculture sector. METHAGENE, through the direct involvement of especially new entrant countries, will also facilitate exchange of knowledge and staff between laboratories and enable young European researchers to receive cross-disciplinary training as an investment in the European intellectual capital and knowledge based bio-economy. Results from METHAGENE will be disseminated to industry, EU scientists and policy makers who will be informed through scientific publications and workshops, newsletters, public information and briefing papers.

B.4 Complementarity with other research programmes

METHAGENE will create an immediate synergy with related scientific networks such as ASGGN (Animal Selection, Genetics and Genomics Network) of the Global Research Alliance (http://www.asggn.org/), and FNN (Network and Database on Feed and Nutrition in Relation to Greenhouse Gas Emissions). Several members of METHAGENE already participate in these networks.

No other current or planned research programme exists which has the same objectives and benefits as this COST Action.

In addition, this COST Action is complementary to the on-going EU Framework projects:

- *RuminOmics:* A collaborative FP7-project that aims to integrate expertise and technologies to investigate links between the rumen microbiome, the host genome, digestive efficiency, methane emissions and nitrogen excretion in order to increase rumen efficiency and decrease the environmental footprint of ruminant production (http://www.ruminomics.eu/).

- *AnimalChange:* A collaborative FP7-project that aims to provide a vision of the future of the integrate mitigation and adaptation options for sustainable livestock production under climate change. The particular linkages to this COST Action are in the development of cutting-edge technologies for mitigation (http://www.animalchange.eu/).

- *GreenHouseMilk:* A Marie Curie Initial Training Network providing training and facilitating research to develop genetic tools to mitigate the environmental impact of dairy systems (http://www.sruc.ac.uk/greenhousemilk/).

- *OptiMir:* An INTERREG project primarily based on putting into practice the results emanating from on-going research projects with particular relevance to milk MIR analyses (http://www.optimir.eu/).

The present COST Action supports the European Technology Platform on Food for Life (http://etp.ciaa.eu) and the Sustainable Farm Animal Breeding and Reproduction Technology Platform (FABRE-TP; www.fabretp.info) with input for their Strategic Research Agenda). Furthermore, this COST Action will complement many on-going national research programmes (e.g., UK Agricultural Greenhouse Gas Research Platform (http://www.ghgplatform.org.uk/), Scotland's ClimateXChange (http://www.climatexchange.org.uk/)). A full inventory will be made by each WG at the start of the Action.

C. OBJECTIVES AND BENEFITS

C.1 Aim

The main objective of the Action is to discuss and agree on protocols to harmonise large-scale methane measurements using different techniques; easy to record and inexpensive proxies for methane emissions to be used for genetic evaluations; and approaches for incorporating methane emissions into national breeding strategies.

C.2 Objectives

The aim of METHAGENE is to contribute to establishment of the European Research Area as being the global expert in methane mitigation strategies through animal breeding by creating a dynamic network of motivated researchers and industry partners who will discuss, agree and subsequently clearly disseminate:

1. Animal- and herd-level factors contributing to variation among animals in methane production, distinguishing between true influences and those attributable to methodology; appropriate units of measurements (e.g., grams per unit output or per unit input) and the use of common units that allow data and interpretation of the data to be compatible within and between populations

2. Established protocols for calibration, comparison, harmonisation and merging large-scale methane measurement using from different techniques and measuring strategies for individual animal methane emissions

3. Identified easy to record and inexpensive indicator traits for methane emissions from ruminants (e.g., milk fatty acid profiles, mid-infrared spectra of milk samples, and others), without sacrificing accuracy, to be used for genetic evaluations

4. Approaches, necessary information and tools for EU countries for incorporating methane emissions in national breeding strategies while simultaneously taking cognisance of other animal performance characteristics

METHAGENE focuses also on secondary objectives with high priority to:

1. Stimulate research, education, exchange of knowledge and experience, and train Early Stage Researchers at training schools

2. Communicate and discuss relevant research in this field by organising 3 workshops, of which at least 1 will be open for EU members and other international groups outside the consortium

3. Knowledge management and exchange (KME) with/to the scientific community, policy makers, primary producers, animal breeding organisations, and sensor technology industries. This COST Action will pursue a dissemination strategy targeted to bridge the gap between specialised research forums and non-specialised people, to more closely connect science to general public on this crucial issue

C.3 How networking within the Action will yield the objectives?

This COST Action will yield an efficient network of European experts, who are working on strategies to quantify and mitigate methane emissions from ruminants and who are funded by national research programmes. The Action will thus bring together a critical mass of experts from a range of disciplines to create an effective network of knowledge and expertise. Because methane is influenced by so many factors, success will only be achieved if all of the interested disciplines are represented. Key features to achieve the objectives will be:

1. Developing a collaborative community of multidisciplinary researchers

2. Jointly developing a detailed action plan and a common research and innovation agenda

3. Organising meetings and workshops focussed on the distinct but inter-related topics for the Working Groups of this COST Action

4. Financing a number of Short Term Scientific Missions (STSM) for exchange of technologies and training between labs in different member states, with preference given to Early Stage Researchers. On demand, but at least yearly a competitive call for STSMs supported by the Action will be held. The applications for the STSMs will be sent to the Chair of the Evaluation Committee. The approval process is subject to the COST rules and guidelines, and dependent on the budgetary possibilities

5. Running Technical Training Schools by the leading institutes of the Action at which basic and advanced methodologies will be taught, especially for Early Stage Researchers

C.4 Potential impact of the Action

The COST Action, whose benefits are described in B3, will lead to:

1. Common units and descriptors for large-scale methane emissions and other traits in individual methane measurements in ruminants

2. Established protocols for calibration, comparison and merging data from different techniques and measurement strategies which can be used beyond this Action in optimally designing future experiments

3. Identified indicator traits for methane emissions from ruminants to facilitate cost-effective inclusion of environmental traits in national and EU breeding strategies, and

4. The necessary information and tools for EU countries to include methane emissions in their national breeding strategies

A major benefit to society from the Action will be the impact on the farm animal breeding industry, the feeding industry, the sensor technology industry, and the primary industry. The Action generates the necessary information and resources to monitor methane emissions on a farm scale and to identify biomarkers reflecting the methane production level; data generated will also be useful in subsequent activities on the exploitation of genomic predictions of methane emissions. Establishing this COST Action will support a cohort of highly experienced and qualified scientists at the forefront of knowledge with a career in academia, agriculture and environmental technology industries.

The major goal defined in the Kyoto protocol is to reduce GHG emissions in the long term, with specific targets set for 2020, in order to reduce predicted global warming. The outcome of this COST Action will critically contribute to this objective and reduce environmental footprints of animal-derived food. Level of annual reductions in methane emissions can be integrated into or used for refinement of climate models and weather forecasts.

The EU will benefit upon dissemination of data to the FAO and establish Europe as one of the major players in the field of GHG mitigation from livestock production.

The procedures and logistics put in place in METHAGENE, although developed for genetic evaluation of methane emissions in dairy cows, can easily be expanded in subsequent projects to include other traits (e.g., feed intake, animal health) in other breeds (e.g., beef cattle) or species (e.g., sheep). Moreover, the trust and friendship generated in METHAGENE will be crucial in fostering a strong collaborative effort in future projects among interested parties. The benefits and impact of METHAGENE will persist for a long time after its official conclusion.

C.5 Target groups/end users

The target groups and end users are the following:

1. **Researchers:** animal breeders, animal nutritionists, animal physiologists, rumen microbiologists, bio-informaticians, system biologists, statisticians, gas analysis experts and environmental engineers. The Action will generate new standardized procedures, guidelines, integrative approaches, and genome-based selection strategies available to all.

2. **Advisors** from animal breeding organisations will get easy access to new knowledge and innovative tools, and can take a role in dissemination towards dairy producers.

3. **Policy makers/governments** from national and international bodies, and bodies from industry who are seeking information for policy development

4. **Industry:** breeding organisations, feed industries and farmers will obtain perspectives and knowledge for future decisions on production strategies

All groups will be directly involved in this Action. They have already been invited to take part as experts and to comment on the proposal.

D. SCIENTIFIC PROGRAMME

D.1 Scientific focus

In this COST Action will the following questions will be addressed:

1: How to measure methane?

Enteric methane emissions vary quantitatively within and between days, and within and between animals. A number of factors influence the amount of methane that is eructed. In this COST Action knowledge will be shared of how methane can be measured and how different factors such as time of day, stage of lactation, eating and drinking behaviour, feed intake and feed conversion ratio can influence the recordings, and provide tools for interpreting obtained large scale measurements.

2: How to compare methods and monitoring strategies, and harmonise methane measurements across countries?

A number of approaches have been used to generate individual measurements of methane from ruminants. In some cases, the trait methane output is defined differently and different techniques are used for its evaluation across countries. Therefore, one of our most important tasks in this COST

Action will be to develop systems and methodologies by which trait definitions and evaluation models are harmonised in order to make use of the large and diverse data sources for international genetic and nutritional evaluations but also to compare performance in different populations.

3: Are indicators available that can help prediction of methane emissions?

Obtaining accurate and repeatable measurements of methane from dairy cows is complex. Therefore, a supplementary approach could be to use indirect indicator traits related to methane production. Several studies are being conducted in this area, based on different approaches. For example, based on the rumen microbiota, which are responsible for methane eructed by ruminants, or by estimating feed efficiency of cows under the hypothesis that if a cow eats less for the same milk production, it will eruct less methane, or to use changes in milk composition. Methanogenesis has indirect links with the production of fatty acids in milk and thus milk composition. Currently, all of these indicators are being developed independently and at small scale, and no discussion and studies are being conducted to evaluate the similarity of conclusions generated by all of these indicators. In this COST Action knowledge will be shared of indicator traits for methane emissions from ruminants to facilitate cost-effective inclusion of environmental traits in national and EU breeding strategies.

4: How can the farmer use the findings?

Farmers benefit indirectly via the improved genetic material coming from the breeding organisations giving animals that use their energy intake more efficient. However, it is important that methane emissions are not reduced as a result of decreased digestibility, performance or health and fertility. In this COST Action the focus will be on the importance of methane emission relative to other traits and come up with suggestions on how to include the information in the breeding goal in order to lower the environmental impact of ruminant production systems without adverse effects on production and efficiency. This way, the farmers can make optimal use of the results generated in thisAction (and subsequent data collected using the guidelines produced in this Action) on direct methane measurements and correlated indicator traits.

D.2 Scientific work plan methods and means

The scientific programme of the COST Action concentrates on five different but interrelated areas. FiveWorking Groups (WG) align with the scientific programme. The experts that have already expressed their interest in the consortium of this COST Action have collected methane data on at least 5,000 cows, since the late ‘80’s. This will provide a unique database to enable addressing the issues raised in each of the WGs. Each WG will discuss recent developments in a specific area of

this rapidly-advancing field to facilitate concerted progress. The discussion areas in the 5 WG are:
WG1. Methane-determining factors: to compile a) an inventory and discuss possible factors associated with variation in methane production b) standardized definitions for methane measurements, and (c) combined and integrated data into novel genetic models.
The following further tasks have been identified for WG1:

- To establish a network of nutritionists, physiologists and geneticists, animal breeders, and microbiologists working in the field of methane production from ruminants

- To establish a beneficial interaction between researchers working on environmental and genetic factors determining methane production

- To provide the most specific and sensitive means of assessing methane production of animal origin and to recommend the use of standardized protocols and units

- To exchange experience and knowledge, protocols, experimental design and data analysis with other WGs especially with Early Stage Researchers in an international forum

- To communicate what environmental factors should be considered in calibrating techniques, validating methane indicators and integrated into genetic selection strategies

- To collaborate with the other WGs of this COST Action

- To exploit data already available to be integrated into novel genetic models

WG2. Comparison and calibration of measurements: to generate, discuss and develop protocols for collection, harmonisation, comparison, calibration and storage of methane emission measurements on individual animals made using different techniques and measurement strategies. In this WG some important issues are addressed. The main issue is that, at the moment, the trait ‘methane output’ cannot be assumed as the same trait across countries or studies, so correlations

between estimates of the trait are not unity. The main reasons for these discrepancies are that the trait is not measured in the same way across countries, and that different statistical and evaluation models are used across countries. Therefore, trait and model harmonization are needed.
The following further tasks have been identified for WG2:

- To standardize methane measurements across countries and establish equivalence of different methodology. The intention is not to restrict research to one technique, which would entail discarding valuable data, but to produce conversion factors for use when fitting a joint evaluation model

- To harmonise trait definitions across countries. For instance, defining methane output as output per unit of body weight, feed intake or milk production across countries

- To harmonise models used for evaluation of methane output across countries. Models used currently are different due to environmental components such as the herd structure, recording systems and breeds. Considerable discussions, interactions and research are required to develop a unified model for the traits of interest.

- To establish correlations when traits are measured, defined, and modelled in the same way. The hypothesis is that environments and production systems are sufficiently different across countries that the traits expressed to some extent depend on a different combination of genes in the different countries. This leads to consideration of a genotype by environment interaction (GxE)

WG3. Proxies for methane emission: to brainstorm and (in)validate easy to measure, inexpensive indicators of methane that are closely related to enteric, and examine their relationships with methane emissions
Enteric methane from ruminants is an important but often difficult source to quantify on an individual basis and on a large scale. As a result, scientists in many research institutes are currently working on simple, fast and reliable techniques. Simultaneously, researchers have identified several traits that are directly or indirectly associated with methane output. However, more needs to be done on identifying traits or combinations of traits that have a high correlation with methane output and that could easily be recorded. To achieve this, concerted efforts will be made to compile, test

and develop least-cost indicators of methane output that could be routinely recorded on a large scale. This is an essential prerequisite in developing strategies for estimation of breeding values with respect to relevant environmental impact traits.
The following further tasks have been identified for WG3:

- To collate and distillate all available information/knowledge regarding the relationship between methane output and other production, functional or compositional traits that could contribute to reliable prediction of methane output. This involves reviews of published, unpublished or grey literature related to potential indicators of methane output in ruminants and their documentation

- To merge experimental results and data from designed experiments, surveys and monitoring studies and on-station or laboratory analyses to conduct a large scale association analysis fitting appropriate statistical and analytical models

- To collate milk MIR data and methane data and refine the prediction equations already developed by members of this Action team but most importantly evaluate the robustness of these prediction equations across different breeds, environments and production systems

- To collate milk fatty acid data and methane emissions and 1) (in)validate the prediction equations already published in the scientific literature to predict methane emission from milk fatty acid and 2) develop new prediction equations that are robust across many different environmental conditions including breed, stage of lactation, feeding system

- To generate data on new possible proxies for methane emissions heretofore not considered but identified through intense discussions amongst world leading experts as part of the WG

- To identify the most promising traits or trait combinations that are highly associated with methane output in ruminants and which are low-cost and could easily be recorded routinely on a large scale

WG4. Benefit for producers: to quantify the importance of methane emissions (or indicators) relative to other performance traits in breeding goals (e.g., milk or meat yield, fertility), and indicate the benefit for producers when methane emissions is included in breeding goals within EU dairy cow populations.

In this WG information will be gathered from preceding WGs and expertise in the Action to estimate the importance of methane emissions traits, including potential proxies, on the performance of the animal and of the livestock system. This will allow us to develop recommendations and suggest approaches (e.g., economic weights, restricted selection indexes, desired gains indexes) for the inclusion of methane into breeding goals.

The following further tasks have been identified for WG4:

- To collate information, where available, on the (genetic and phenotypic) relationships between defined methane and proxy traits and other production and fitness traits in breeding goals. This information will highlight which of the broad spectrum of production and fitness traits are favourably, unfavourably or not at all correlated to genetic improvement for methane emissions and as such highlight the potential co-benefits and trade-offs of selecting for reduced methane

- To establish how different traits contribute to the environmental impact of livestock systems and therefore highlight which traits to target via genetic improvement. Ruminant genetic improvement, although enacted on an individual animal basis, will impact on the GHG emissions from the entire system. To this end it is important to consider genetic improvement for reducing GHG emissions in terms of the holistic system rather than the individual animal alone

- To quantify the impact of genetic improvement for methane emissions on other system outputs (e.g., welfare, health, income). Genetic selection goals that reduce overall system GHG emissions are likely to have correlated effects on other production (total output, quality etc.), functional (welfare, health fertility etc.) and financial (income, input levels etc.) outputs/indicators. Understanding the trade-offs and win-wins with different ruminant selection policies will help to guide and develop breeding goals that consider a broader range of system outputs

- To produce recommendations on how methane emissions could be included in selection objectives for ruminant livestock in the EU. This will allow the Action to explore the impact of genetic improvement (and different routes for genetic improvement) of individual animal biological traits on the environmental impact of the system. At the same time insights will be provided into understanding trade-offs, or win-wins, with other system outputs such as economic performance and animal health and welfare

WG5. Knowledge and management exchange (KME): to support KME of innovations to methane sensor, breeding, dairy, and meat industries. In order to increase the potential application of the results, two international stakeholders are involved in METHAGENE.
The goals of this Action will be realised by the following methods: organised and specialised workshops and meetings, Short Term Scientific Missions, dissemination and sharing of information via share points, social media, conferences, scientific papers and articles for the industry.
The following further tasks have been identified for WG5:

- Stimulate research, education, exchange of knowledge, technical experience, and mobility among scientists and PhD-students

- Manage and exchange knowledge with/to the scientific community, policy makers, primary producers, animal breeding organisations, etc.

- Communicate and discuss recent relevant research in this field and the results of METHAGENE

The work within the Action will be guided by a detailed work description, which will include yearly meetings of the network members, Short Term Scientific Missions (STSM), workshops, scientific conferences and outreach activities for knowledge technology transfer. METHAGENE will cover all costs for the activities within this network, e.g. management, coordination and meeting costs.

The research programme itself will be carried out by the member laboratories and is funded by national and international research funds.

E. ORGANISATION

E.1 Coordination and organisation

Participants of METHAGENE have internationally recognised experience in using various innovative measuring, calibration and breeding techniques in research for at least 10 years. Most partners are applied scientists with close links to industry and are well recognised as following their research all the way through to implementation and extension.
METHAGENE will be led by a Management Committee (MC), comprising a chairperson, a, and leaders of each of the 5 WG, of which one will represent the industry and farmer's cooperatives. Exchange of personnel, small equipment and skills sets in data handling techniques between labs will provide direct comparisons of methods, leading to a matrix of equivalence.
The MC will contact through Skype or Video-conferencing at least 4 times per year to discuss the progress in the Action by monitoring and evaluating the achievement of objectives in each WG. Meetings of the WGs will be organised on a yearly basis as two- or three-day meetings at different partner locations. These frequent gatherings are scheduled in order to have an optimal exchange of ideas, to discuss progress, to build upon acquired knowledge and to plan future activities. Joint WG meetings will enhance integration of activities from different fields, and promote interface between WGs.
Four workshops will provide cross-Working Group sessions to promote synergy. These workshops will be well advertised in advance and METHAGENE will provide an open and flexible framework, allowing further partners to join. All partners however will be encouraged to actively participate in METHAGENE, if not with data then with ideas. Innovations will be initiated through exchange of expertise between scientists and industry experts from different areas, leading to novel tools and ideas.
1) The 1st workshop will be held in month 6 and focuses on WG1 and WG2. Animal physiologists, nutritionists, breeders and environmental engineers will discuss current knowledge and experience. This workshop will identify knowledge gaps and generate a strategy, including a plan for specific bilateral/multilateral site visits. It will be the responsibility of the WG leaders to retain momentum and dialog within the WG but also to ensure other WGs are aware of progress and when results are expected
2) The 2nd workshop will be held in month 18 and focuses on WG3. A similar audience to the first

workshop will be invited to discuss, based on the pertinent methane trait defined in the first workshop, what likely proxy traits could be used as predictors of methane. Such developments are currently only in their very early stages of examination but preliminary results will be presented, discussed, and possible refinements suggested with a view of re-examination in the following months and reporting back via the WG3 leader
3) The 3rd workshop will be held in month 30 and will focus on WG4. Industry representatives will be strongly encouraged to attend since the suggestions made in WG4 will likely be implemented by industry and therefore they must understand the rationale for coming to such a conclusion
4) The final meeting will be held in month 44, and wraps up the results of all WGs. This meeting will be open for everybody, and will therefore be widely advertised and all targeted audience will be strongly encouraged to attend. This symposium might be held as a satellite to a larger conference
Although a main focus is provided for each workshop, they will not be exclusive and each WG will participate in every workshop. Thus, for example, preliminary ideas for WG3-5 will be presented in the 1st workshop, and progress reports for WG1-2 will be presented at the 3rd workshop. In all workshops there will be an open opportunity for presentation of posters. Students and Early Stage Researchers will be particularly encouraged to present their on-going research and receive feedback and engage in possible collaboration. A one-page summary of the research will also be distributed. Posters will be displayed for the duration of the workshop but a dedicated time-slot will be given for the presentation and discussion of posters. Money will be allocated for young scientists primarily post docs for STSMs visiting seniors from the COST Action.
There will be a METHAGENE share-point, and video/phone conferences upon request to facilitate information flow and discussions in smaller specialist groups to work on specific areas, between the WG-meetings and workshops.

The responsibility of the MC will also be to:
- Monitor, review and assess the activities of the Action
- Receive reports made by the WGs
- Prepare annual reports for the EU
- Establish and coordinate training schools
- Promote and approve Short Term Scientific Missions

E.2 Working Groups

The structure of the COST Action is based on five WGs:

1. WG1: Methane-determining factors

2. WG2: Comparison and calibration of measurements

3. WG3: Methane indicators

4. WG4: Benefit for producers

5. WG5: Knowledge and management transfer

MC members based on their speciality and interest will take part in the different WGs. Each WG will have a leader and a deputy leader to guide the scientific progress in their WG. WG leaders will report progress on WG objectives and deliverables to the MC.

E.3 Liaison and interaction with other research programmes

In B4 the complementarity with EU projects (e.g., *RuminOmics* and *AnimalChange*) is given. Also it is described that the participants operate in many national and international networks. The advantage of this programme is the liaison and interaction with many other national research programmes and networks.

METHAGENE has contact with Genetics and Genomic Network (www.asggn.org) of the Global Research Alliance which will facilitate interactions with researchers in Australasia and North and South America. Reducing the environmental impact of ruminants is a world-wide issue, and Brazil has already shown interest to learn from this network. Although METHAGENE is organised in the Domain *Food & Agriculture*, it promotes also cross-cutting linkages with *Environment,* bringing together stakeholders from different fields. The Action will greatly enhance on-going and future research and ensure maximum exploitation of the novel data generated through its networking activities.

E.4 Gender balance and involvement of early-stage researchers

This COST Action will respect an appropriate gender balance in all its activities and the Management Committee will place this as a standard item on all its MC agendas. The Action will

also be committed to considerably involve Early Stage Researchers. This item will also be placed as a standard item on all MC agendas.
Involvement of Early Stage Researchers will be established by supporting visits of ESRs to high-profile labs and groups with great expertise in the area of interest of this Action. One member of the MC will be specifically assigned to the task of involving ESRs.

F. TIMETABLE

The COST Action will run for a total of four years. The timetable and milestones are given in Table F. The Action will be initiated at the first MC meeting in the beginning of Year 1. The WGs will be formed and WG Coordinators elected.

Table F: Timetable, Milestones (M) and Deliverables (D) for the METHAGENE Action

	Description	Year 1		Year 2		Year 3		Year 4	
		1	2	1	2	1	2	1	2
D1	Kick of meeting	X							
D2	Official webpage operational	X							
D3	Webpage operational	X							
D4	Open mail group operational	X							
D5	Mail group operational	X							
D6	Management Committee meeting held	X	X						
D7	Working Group meetings held	X	X						
D8	Competitive call STSMs held		X						
D9	Workshop 1 held		X						
D10	Training school 1 held		X						
M1	***Possible factors associated with variation in methane production identified***		X						
M2	***Definitions for methane measurements standardized***		X						
D11	Management Committee meeting held			X	X				
D12	Working Group meetings held			X	X				
D13	Competitive call STSMs held				X				
D14	Workshop 2 held				X				
D15	Training school 2 held				X				
M3	***First description of protocols for collection, harmonisation, comparison, calibration and storage of methane emission measurements***				X				
M4	***First indicators of methane identified and validated***				X				
D16	Management Committee meeting held					X	X		
D17	Working Group meetings held					X	X		
D18	Competitive call STSMs held						X		
D19	Workshop 3 held						X		
D20	Training school 3 held						X		
M5	***Importance of methane emissions (or***						X		

	indicators) relative to other performance traits in breeding goals quantified								
D21	Final Management Committee meeting held							X	X
D22	Final Working Group meetings held							X	X
D23	Final competitive call STSMs held								X
D24	Final workshop held								X
D25	Training school 4 held								X
M6	***Benefit for producers when methane emissions is included in breeding goals within EU dairy cow populations described and quantified***							X	
D26	Special issue scientific journal submitted								X
D27	Final report published								X

G. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: AT, BE, CH, CZ, DE, DK, ES, FI, FR, IE, IT, NL, NO, PL, SE, SI, UK. On the basis of national estimates, the economic dimension of the activities to be carried out under the Action has been estimated at 68 Million € for the total duration of the Action. This estimate is valid under the assumption that all the countries mentioned above but no other countries will participate in the Action. Any departure from this will change the total cost accordingly.

H. DISSEMINATION PLAN

H.1 Who?

The targeted audiences of this COST Action can be categorised as:

- Partners in the COST Action

- International researchers (e.g., animal breeders, animal nutritionists, system biologists, environmental engineers, etc.) working on methane emissions from ruminants and mitigation strategies

- Early Stage Researchers working on methane emissions from ruminants and mitigation strategies

- Technology Platforms: ETP Food for Life and FABRE-TP

- Advisors working for farmers to improve farm management and genetics

- Policy makers that have an interest in reducing the environmental impact from ruminants

- Industry that will have incentive to incorporate mitigation strategies to actively participate in lowering methane output from ruminants

- The general public will be targeted to raise public awareness of reducing the environmental impact of ruminants

H.2 What?

The COST Action will use the following tools for dissemination:

- For the partners in the COST Action there will be conferences, events, organised and specialised workshops and meetings, e-mail networks, share-point, and reports with on-going work in the COST Action

- For other researchers, ETPs Food for Life and the industry there will be a website, where scientific and popular publications, international conferences, events and reports will be available

- For policy makers and advisors there will be a website and publications in terms of flyers and abstracts describing the work done in the COST Action

- For the general public there will be a webpage with updated information on the activity and impact of the work generated in the COST Action

- Social media (e.g., Twitter) will be used for all targeted audiences to put attention on the disseminated results

H.3 How?

The Management Committee will be responsible for ensuring appropriate running of the COST Action and dissemination of results, checking the progress of the Action at each of its meetings, and to update the dissemination plan during the course of the Action. They will set up an Action specific website, while the WG leaders will be responsible for keeping it updated. The Management Committee will receive proposals for the use of funding and select annual activities, decide subjects of training courses, and compile annual COST reports.

Two webpages will be established – one that is password protected for members of the COST Action. Here on-going work and files will be stored and exchanged, as well as data will be put up that undergraduate students could analyse. Another webpage will be openly accessible to the public. Here activities, events and publications will be described, and advisors, non-participating researchers and the general public can subscribe to the homepage. Also open positions in the COST Action network will be presented here; e.g., PhD fellowships or post doc positions.

Two email-lists will be generated. One email list for members of the COST Action and another email list for people or organizations that subscribe to webpage updates and newsletters.

The COST Action will establish 3 workshops. These workshops will be announced well ahead and be open to anyone who would like to participate. The last workshop will be held in relation to other scientific conferences to attract as many people as possible. This could be at the annual meeting of the European Association of Animal Production (EAAP), at the Greenhouse Gas and Animal Agriculture conference (GGAA), or at one of the annual INTERBULL meetings.

Up to 8 STSMs per year will be supported by METHAGENE. These will be used as a tool for internal dissemination, and seminars will have to be given during these short visits. Everybody in the consortium can apply for these travel grants, by sharing their idea and aim with the MC. The MC will then decide on whether or not the visit will be financially supported with at travel grant.

Training Schools: one Training School per year will be organized for Early Stage Researchers. The topics of the Training Schools will be 1) methane-determining factors, 2) combining/comparing measurements from different equipment, 3) proxies for methane (e.g., fatty acid profiles, and mid-infrared spectra of milk samples), and 4) breeding strategies for reduced methane output of ruminant, including LCA-approaches to establish how different traits contribute to the environmental impact of livestock systems.

The work done in this COST Action will be submitted for publication in a special issue of a peer reviewed journal (e.g., Advances in Animal Biosciences) that will highlight the major findings of the network during the Action period.