DOCTOR OF PHILOSOPHY

# Improving Farm Practices and Evaluating Livestock Farmers’ Attitudes to Greenhouse Gas Emission Mitigation

Burbi, Sara

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By

**Sara Burbi**

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**By**

**Sara Burbi**

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# ABSTRACT

## Improving farm practices and evaluating livestock farmers' attitudes to greenhouse gas emission mitigation

In recent years the farming sector has been under growing pressure. Markets influence demand and prices, challenging farmers to improve production, business competitiveness and reduce environmental impact. Agriculture accounts for 9% of the total greenhouse gas emissions in the United Kingdom. Quantitative scientific literature provides useful strategies to reduce methane and nitrous oxide emissions from livestock farms. Their adoption may depend on their effectiveness and the influence of farmers' perceptions of climate change on their decision-making. Adopting concepts of translational research and participatory action research, the study builds social capital among 14 livestock farmers in the South West and West Midlands, and evaluates the potential for adoption of emission mitigation strategies. The Rapid Farm Practices Appraisal (RFPA) tool was created to assess farm practices based on their mitigation potential. Practices were assessed twice over 6-9 months. Semi-structured interviews were used to assess barriers and opportunities to farmer engagement and on-farm innovation. Farmers were invited to a focus group meeting to network with other farmers and engage with researchers. All farmers participated in the 2 farm assessments. Only half the farmers adopted changes in farm management. The main difficulties related to the storage and treatment of manures due to the financial investments necessary. All farmers appreciated the RFPA tool, the clearness of the information provided and the focus of the tool on practices directly. All farmers accepted to be interviewed during the second farm visit; however, 2 farmers were unable to participate in the focus group meeting. Farmers' main obstacles to innovation were limited financial capital, lack of trust in government action and confusion over the effectiveness of farm advice on mitigation. The lack of long-term flexibility of agricultural policies greatly influenced farmers' decision-making. Farmers preferred practical solutions obtained through consistent, clear and transparent advisory services. The source of information greatly influenced their acceptance of advice. Farmers preferred peer-to-peer knowledge sharing and participatory activities in order to access knowledge on mitigation directly from scientists. Results provide positive grounds for the expansion of the RFPA tool to include economic assessment of farm practices and the engagement of a larger pool of farmers. Further research is needed in order to better understand how the source of information influences farmers' acceptance of climate change science. Further studies should include a comparison between different farming systems i.e. organic v conventional, small-scale v large-scale.

**Key words:** greenhouse gases, participatory action research, translational research, farmer engagement, sustainable farming systems

# DECLARATION

The work within this thesis is based on the author's independent research at the Royal Agricultural University, Cirencester under the supervision of Dr John S. Conway and Dr Richard N. Baines. The author is responsible for the model and tool development, field testing and application, interpretation of results and the conclusion reached within this thesis. All assistance and advice from colleagues have been acknowledged.



Sara Burbi

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# ACKNOWLEDGMENTS


*"It would be nice if all of the data which sociologists require could be enumerated because then we could run them through IBM machines and draw charts as the economists do. However, not everything that can be counted counts, and not everything that counts can be counted."*

William Bruce Cameron
"Informal Sociology: A Casual Introduction to Sociological Thinking" (1963)

After starting the PhD some friends said that I must be very committed to choose to work on the same thing for 3 years. Commitment certainly helped enjoy the highs and overcome the lows that every project is made of, but this study wouldn't have been possible without the support and encouragement from my supervisors, Dr Richard N Baines and Dr John S Conway. They encouraged me to develop my ideas and provided guidance and support in engaging with other researchers and professionals in the UK and Europe.

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I would like to thank the Principal, Prof Chris Gaskell, for his continuing interest and support of the study. It is my hope that the now Royal Agricultural University will continue to support students interested in translational research, fostering sustainable innovation in the agricultural sector.

A big thank you goes to Peter Brooks, Theano Manoli and the Library staff, who have been a valuable help all throughout the study, as well as the Print Room staff, for printing all the farm reports, posters and material needed during the 3 years.

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# Table of Contents

# List of Tables

# List of Figures

# Chapter 1

# Introduction

**1.1 The climate change debate**

**1.2 Problem statement and study aim**

**1.3 Study objectives**

**1.4 Outline of methodology**

**1.5 Thesis outline**

# 1 Introduction

## 1.1 The climate change debate

The impact of livestock on the environment and farmers' livelihood has gained increasing visibility in the past two decades. The term *"livestock revolution"* was first introduced by Delgado et al. (1999) to address the possible impacts of the increase in meat consumption, in particular in developing countries. The effects included negative repercussions on world food prices, due to the competition between the production of animal feed and that of produce destined to human consumption. While an increase in livestock production was predicted to bring benefits in terms of improved diets and income generation, it became quite obvious that such a production could have a negative impact in terms of environmental sustainability (i.e. pollution, deforestation and over-consumption) and on public health (i.e. animal-borne diseases, pesticides, antibiotics, food safety and diet).

In fact, negative environmental impacts from livestock farming increased over time (FAO, 2006), resulting in water pollution, biodiversity loss and 70% of grazing land in dry areas being the subject of degradation due to overgrazing, compaction and erosion. Moreover, greenhouse gas (GHG) emissions from livestock systems were estimated to amount to 18% of global emissions. Livestock are responsible for 37% of methane ($CH_4$) emissions, originating predominantly from ruminant enteric fermentation processes and for 65% of nitrous oxide ($N_2O$) emissions originating from manures and fertilisers use (ibid). However, with an estimated 1.7 billion animals, livestock production represents an important sector of societies, generating 40% of the global agricultural domestic product, employing around 1.3 billion people, occupying ¼ of the Earth land surface area and utilising ⅓ of the total available arable land to produce animal feed (FAO, 2010). It is thus reasonable to assume that any action that attempts to tackle the issue of GHG emissions from livestock will have repercussions not only on production and therefore on local, national and international markets, but also on farmers' livelihoods and income generation as well.

In the United Kingdom, the Climate Change Act of 2008 set the target of reducing the overall greenhouse gas (GHG) emissions by 80% by 2050 (United Kingdom Parliament, 2008). The Act is the result of the ratification of the Kyoto Protocol in 1998 (United Nations, 1998). The target applies to every sector of society and the initial phases of the GHG Action Plan for the Agricultural Sector (NFU, 2011) involved updating gases inventories and reviewing implementation strategies to mitigate emissions. By identifying the sources of GHG emissions, mitigation strategies aim to reduce emissions by adopting farm practices with a reduced environmental impact but which will still ensure a cost-effective livestock production. Science-based evidence on emissions covers a wide range of mitigation options. However, measurements and system boundaries for Life Cycle Analysis (LCA) models needed for carbon accounting are not always standardised or uniformly defined. The debate is even hotter in the agricultural sector, where farms vary greatly in size and type of management, resulting in greater challenges to provide standardised carbon footprinting methodologies.

## 1.2 Problem statement and study aim

The lack of uniformity in quantifying data on GHG emissions due to the large body of evidence from studies under a wide range of conditions, coupled with the lack of consistency in carbon accounting estimates, may result in scepticism over the impacts of GHG emission mitigation, widening the gap between scientific research and its practical application. Farmers are under multiple pressures: production, market competitiveness, environmental conservation and, more recently, GHG emissions. However, when investigating GHG emission mitigation it is important to consider farmers' livelihoods, and the impact mitigation strategies may have at economic, environmental and social levels. Therefore, the study of farmers' behaviour becomes a key element in predicting the success in the adoption of mitigation strategies.

This study aimed to support the Action Plan by developing a practical approach to GHG emission mitigation, considering scientific data and social implications. It provides valuable information on livestock farmers' perception of mitigation strategies, the sustainability, strengths and limitations of such strategies and therefore the possible implications for policy-makers.

## 1.3 Study objectives

The study represented an example of translational research where a selected group of livestock farmers act as co-researchers. The purpose of the study was three-fold: on the one hand it critically evaluated scientific evidence on GHG mitigation; on the other hand it provided support to farmers on the implementation of on-farm innovation to mitigate GHG emissions while at the same time, it assessed the extent to which farmers' attitudes and perceptions of GHG emission mitigation influenced their behaviour and their subsequent adoption of mitigation strategies.

The study addressed the following objectives; to:-

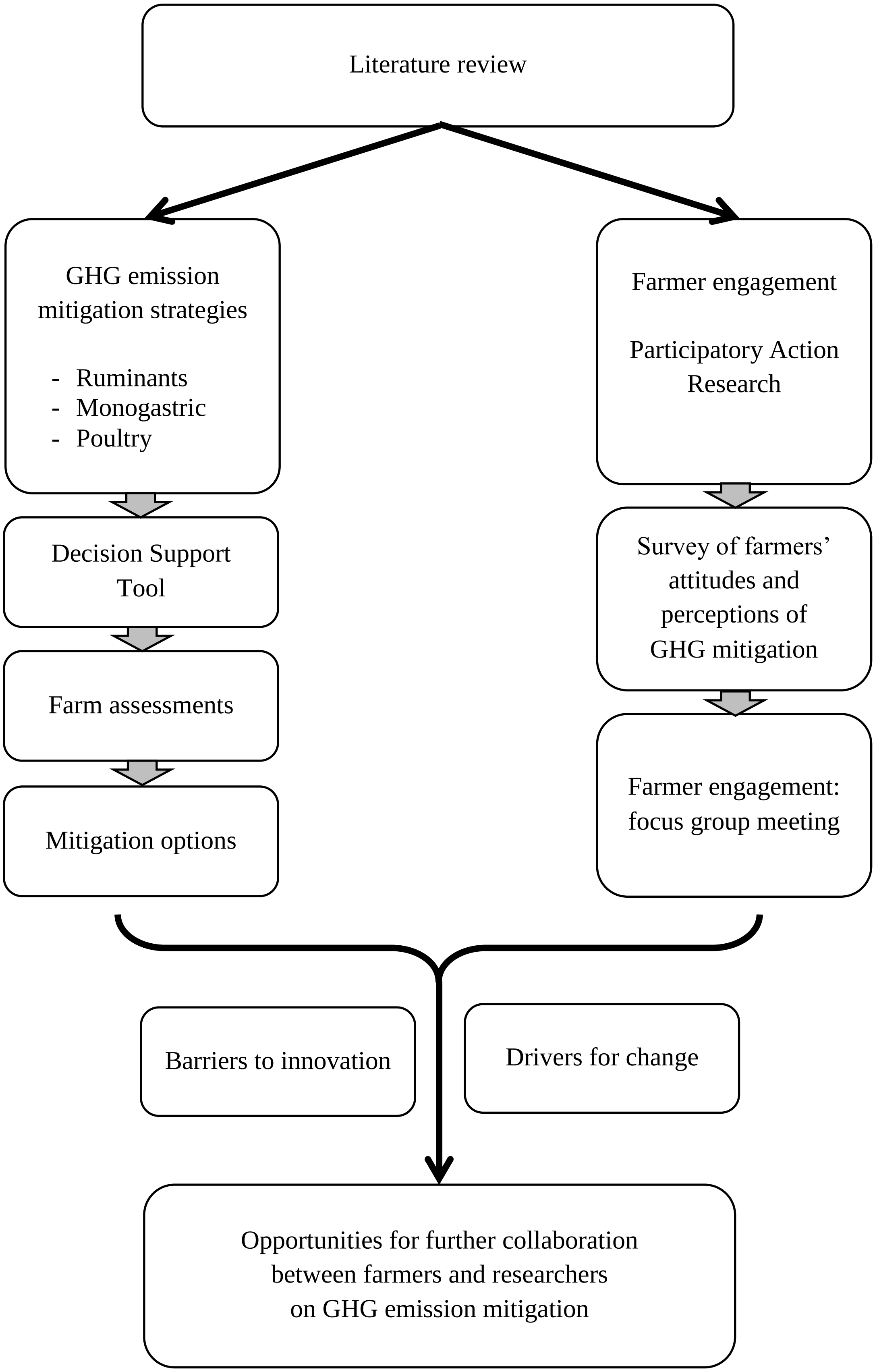
1. Provide more accurate estimates of GHG emissions and a review of carbon calculators currently available in the UK;
2. Assess the feasibility of practical application of mitigation strategies;
3. Provide a free and easy-to-use decision support tool for farmers and land managers, in the form of a decision tree;
4. Propose mitigation options to farmers and land managers based not only on environmental impacts, but also considering their socio-economic impact on businesses;
5. Evaluate farmers' responses and attitudes to mitigation strategies and the barriers to on-farm GHG emission mitigation;
6. Evaluate the potential to overcome these barriers and the influence of farmer engagement with researchers by adopting a multidisciplinary participatory action research methodology.

## 1.4 Outline of methodology

The initial phase was to critically review current literature on livestock and GHG emission mitigation. The objective was to identify quantitative evidence on the degree of mitigation possible. The evidence was then used to standardise the improvement realisable based on current evidence. The review also allowed the mitigation data and units of measures to be standardised.

The second phase focused on farmer engagement. A set of farmers was selected in the South West and West Midlands regions for a pilot study. Farms were extensive livestock farms with primarily pasture-based systems. The following illustrates the methodology stages (Figure 1.1), which are described in more detail in chapter 5.

Figure 1.1 Outline of methodology.



## 1.5 Thesis structure

*Chapter 1. Introduction.* This chapter provides a brief overview of the topics addressed by the study and outlines the methodology adopted.

*Chapter 2. Challenges facing the agricultural sector in the England.* This chapter provides a review of the greatest challenges facing agricultural production in the England. It illustrates the potential obstacles to carbon accounting and how these may undermine the accuracy of carbon accounting tools, citing free on-line carbon footprint calculators such as CALM Carbon Accounting for Land Managers (CLA, 2011) and the Climate Friendly Food Calculator (Smith, 2011). This section also highlights challenges related to the lack of universal definition of the system boundaries needed in order to apply Life Cycle Analysis and obtain carbon footprint estimates.

*Chapter 3. Greenhouse gas emissions and potential for mitigation in the livestock sector.* This chapter illustrates the sources of greenhouse gas emissions on farm, with particular interest on the methane ($CH_4$) and nitrous oxide ($N_2O$) emissions and a specific focus on emissions from manure, providing a review of the most acknowledged mitigation options currently available at the farm level.

*Chapter 4. Farmer engagement.* This section features a review of farmer engagement strategies that can be adopted to promote sustainable on-farm innovation by fostering researcher-farmer collaboration and knowledge sharing.

*Chapter 5. Case Study Research.* This section illustrates the methodology adopted in the study providing detailed information on its stages and expected outcomes. The stages consisted of the formulation of a model for a decision support tool designed for livestock farmers; followed by the test of the model on 14 farms across the South West and West Midlands regions; and finally the evaluation of farmers' attitudes and perceptions of GHG emission mitigation using semi-structured interviews and a farmer focus group meeting.

*Chapter 6. Results and Discussion.* After reporting the results obtained from pilot testing of the decision support tool on farm and from farmer engaging activities, these are critically evaluated in order to provide valuable information on farmers' attitudes and perceptions of GHG emission mitigation. The discussion addresses the greatest obstacles and barriers to on-farm innovation found in the study and ends on a positive note by discussion opportunities and drivers for change, by highlighting the importance of farmer engagement.

*Chapter 7. Conclusion.* Finally, this chapter briefly summarises the methodology adopted in the study, illustrates the strengths and limitations of the methodology adopted and the possibilities for further development of projects addressing farmer engagement on GHG emission mitigation at the farm level.

# Chapter 2

# Challenges facing the agricultural sector in England

# 2 Challenges facing the agricultural sector in England

Even though the impulse on growth has long shifted from the agricultural sector to the industrial and then the services sectors, agriculture still represents an important part of British society. In recent times agri-businesses have seen an increased pressure on producing food in a sustainable way. The complexity of the challenge can refer to the concept of multiple exposures described in the works of Belliveau et al. (2006) and O'Brien et al. (2004). The authors suggest that, while climate change can present both risks and opportunities for producers, the vulnerability of agricultural systems is linked to the presence of multiple internal and external influences. Farmers may have different perceptions of risk associated with climate change and innovation, which can influence greatly their behaviour and their relationships with other stakeholders i.e. researchers, extension agents, policy-makers (Tam and McDaniels, 2013). The concept of "boundary work" described by Clark et al. (2011) in the context of sustainable development is meant to facilitate meaningful interaction between stakeholders that may have different views and understandings of a problem and emphasizes the importance of establishing collaborative action between stakeholders across the boundary.

These considerations highlight the importance of the adoption of integrated approaches in agricultural research i.e. the need for studies oriented to problem-solving and which take into account not only the economic and environmental factors influencing sustainable development, but also consider the impact of knowledge sharing and the attitudes and needs of the various actors involved in the development process leading to changes in agricultural practices (Hirsch Hadorn et al., 2006). Integrated methodologies that include quantitative and qualitative approaches and the use of case studies should also provide greater insight on possible solutions to complex context-dependent problems (Scholz et al., 2006). The relevance of case study research will be further discussed in section 4.3.4.

Therefore, in order to promote the effective implementation of changes and on-farm innovation, it is important to understand that the agricultural sector is exposed to multiple pressures that go beyond the technical aspects of production processes and include the influence of local and global markets and infrastructure; the influence of activities that promote environmental conservation and protection; and the social implications of change linked to the need to ensure the sustainability of the livelihoods of the people involved at different levels of the production chain.

As a result, it is reasonable to expect that the problem of greenhouse gas (GHG) mitigation may not be a priority for producers. Agricultural restructuring needs to address issues that may have varying degrees of priority, depending on the specific aims of rural development and innovation programmes. Immediate and short-term concerns could be the compliance to Common Agricultural Policy (CAP) regulations and the possibility of subscribing to Environmental Stewardship Schemes in order to ensure competitiveness and environmental sustainability of agri-businesses. Market pressures on prices, as well as the pressure on using resources sustainably, could also be considered short-term concerns. However, this study did not focus on the economic analysis of GHG emission mitigation. With a specific focus on the impact of climate change on agriculture and GHG emission mitigation as an example of on-farm innovation, this chapter provides an overview of the challenges facing the agricultural sector in England, in particular regarding effective policy making, the impact of agricultural research and the importance of successful engagement with the farming community. The challenges related to farmer engagement will be further discussed in chapter 4.

## 2.1 Climate change and agriculture in England

This section provides an overview of the impact of climate change on agriculture and the issues related to policy making for the agricultural sector.

### 2.1.1 Impact of climate change on the agricultural sector

The agricultural sector is perhaps one of the most multifaceted and versatile sectors of society. While its association with food production is fairly straight forward, agriculture is considered both a provider and a recipient of ecosystem services (Swinton et al., 2007). In fact, agriculture is responsible for a series of important ecosystem services. Therefore, farm and landscape management can have a positive influence on ecosystems or, conversely, they can lead to ecosystem disservices (Power, 2010), illustrated in table 2.1.

Table 2.1 Agricultural ecosystem services and disservices linked to land use change and human intervention (Adapted from Swinton et al., 2007 and Power, 2010).

| | **Agriculture** | **Farm management** | **Landscape management** |
|---|---|---|---|
| **Ecosystem Services** | Provisioning:<br>- Nutrient cycling<br>- Water<br>- Biodiversity<br>- Pollination<br><br>Regulating:<br>- Pest control<br>- Nutrient recycling<br>- Soil conservation<br>- Carbon sequestration<br><br>Cultural:<br>- Aesthetics<br>- Recreational services | Provision of:<br>- Food<br>- Timber<br>- Bioenergy | Windbreaks<br>Hedgerows<br>Natural habitats |
| **Ecosystem disservices** | | Loss of biodiversity<br>Nutrient runoff<br>Soil and water pollution<br>Pesticide poisoning<br>Greenhouse gas emissions | |

Human interventions such as land use changes have multiple effects on ecosystems. The conversion of wild landscape to agricultural land can provide food, animal feed or fuel. However, landscape management can also result in loss of natural habitats, loss of biodiversity, pollution, poisoning and greenhouse gas emissions. The latter are linked to one of the most debated topics in the past two decades: climate change and its impact on agriculture is a controversial topic, since a great deal of uncertainty still surrounds the validity and reliability of the models used to evaluate the impact of climate change in the agricultural sector. The fact that agriculture is constantly under pressure for increased yields, market competitiveness and environmental conservation, doesn't make the task of policy makers any easier. In fact, a recent study evaluating Dutch policies directly related to the implementation of EU directives has revealed that policy makers tend to focus their efforts on high level governance issues, rather than on agricultural ecosystem services (Schouten et al., 2012). This is because ecosystem services are more difficult to evaluate using standardised criteria, and they are often linked to the concept of resilience described by Carpenter et al. (2001, p.766) and defined by Walker et al. (2004, p.2) as *"the capacity of a system to absorb disturbance, undergo change, and retain the same essential functions, structure, identity and feedbacks".* Therefore, policy making that promotes resilience requires a complex web of activities which include ecosystem evaluation, socio-economic research and public engagement (Schouten et al., 2012). Initially, it is important to understand the likely impacts of climate change on the agricultural sector and what issues the policy makers need to understand in order to enable the sector to cope with future changes.

In the United Kingdom, the Department for Environmental, Food and Rural Affairs has recently carried out the UK Climate Change Risk Assessment exercise for 2012 and the report highlights both risks and opportunities for the agricultural sector in the next 50 years (Table 2.2). The agricultural sector is expected to be affected significantly by the increase in temperatures, the increase in frequency of extreme weather events resulting in higher risk of flooding and drought, changes in rainfall patterns and in the concentration of atmospheric $CO_2$. Although these changes represent a threat to the viability of current UK agriculture and to the provision of sustainable food production, they could present opportunities, such as:-

- an extended grazing season for livestock;
- an increase in yields for crops and fodder;
- warmer winters can result in shorter housing of livestock and therefore lower costs of feed, bedding and housing maintenance.

Table 2.2 summarises the range of opportunities and threats that could be brought to the agricultural sector by future climate change scenarios and the level of confidence the UK Government attributes to each forecast (DEFRA, 2012b). One of the most likely effects of climate change will be the greater risk of flooding and drought. Therefore, opportunities that may arise from future climate scenarios will depend primarily on the adequate provision of water and nutrients to crops and livestock. From the point of view of farmers, provided yields and livestock production will not be adversely affected by greater climate variability, the challenge will also include maintaining market competitiveness, at local, national and international levels, and adapt not only to climate, but also to the ever changing demands of consumers (Cheshire and Woods, 2013).

Table 2.2 Opportunities and threats from climate change (DEFRA, 2012b).

| **Impacts of climate change** | | **2020s** | **2050s** | **2080s** | **Confidence** |
|---|---|---|---|---|---|
| **Opportunities** | Changes in potato yield (due to combined climate effects and $CO_2$) | + | + | + | Low |
| | Changes in grassland productivity | + | ++ | ++ | Medium |
| | Changes in sugar beet yield (due to warmer conditions) | + | ++ | +++ | Medium |
| | Opportunities to grow new crops | + | ++ | +++ | High |
| | Changes in wheat yield (due to warmer conditions) | ++ | ++ | +++ | Medium |
| **Threats** | Reduction in milk production due to heat stress | - | - | - | Low |
| | Reduction in dairy herd fertility due to heat stress | - | - | - | Low |
| | Increased duration of heat stress in dairy cows | - | - | - | High |
| | Number of unsustainable water abstractions (agriculture) | - | -- | -- | Medium |
| | Flood risk to high quality agricultural land | - | -- | --- | High |
| | Drier soils (due to warmer and drier summer conditions) | -- | -- | -- | Medium |
| | Increases in water demand for irrigation of crops | -- | -- | -- | Medium |

Therefore, the role of researchers and policy makers is growing in importance. The former needs to ensure that research is targeting the needs of the farming community, such as an increased productivity combined with environmental sustainability and conservation, by engaging with farmers in activities that will provide them support with coping with the challenges they are facing i.e. knowledge transfer, collaboration and capacity building (Larsen et al., 2011; Peer and Stoeglehner, 2013). The latter needs to integrate the latest scientific evidence into policies which promote environmental protection and conservation, sustainable use of agricultural resources and business competitiveness at market level. The challenge lies in the diversity of the topics that the agricultural sector entails and in ensuring that compartmentalised legislation does not result in conflicting policies that may create confusion among landowners and land managers (Beilin et al., 2012).

### 2.1.2 Policy making and agriculture

Assessing the environmental impact of the agricultural sector is a complex task, since the size, type and management of farm holdings can vary greatly. It is difficult to generalise an intervention or a policy that was designed in a specific context, and it is important to take into account that the agricultural sector is subject to policies that address apparently unrelated issues, but that in fact are interconnected i.e. food production and retail, environmental conservation, animal welfare, pollution and waste management (OECD, 2010).

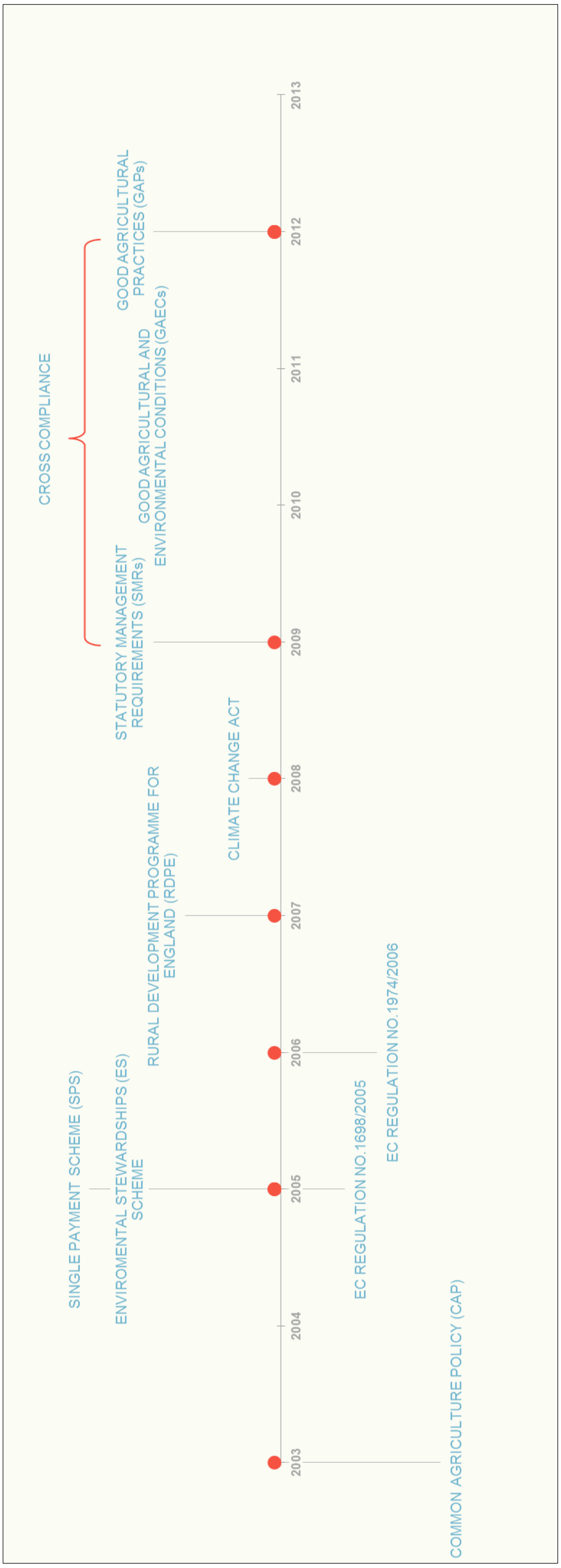
The impact of the agricultural sector in the United Kingdom in terms of greenhouse gas (GHG) emissions has been recently evaluated by the Department of Environment, Food and Rural Affairs (DEFRA, 2012b). It is estimated that agriculture accounts for about 9% of the total GHG. The breakdown of this figure attributes 32% of the emissions to methane

($CH_4$), 61% to nitrous oxide ($N_2O$) and less than 10% to carbon dioxide ($CO_2$). As a result of the implementation of the Climate Change Act of 2008, a series of measures have been put into place by the UK Government in order to improve agricultural practices, improve businesses' competitiveness and promote environmental conservation (DEFRA, 2007; Natural England, 2011). The Greenhouse Gas Action Plan of 2009 addressed the issue of emissions from the agricultural sector with an initial update on the gases inventories and a review of the GHG mitigation strategies available (NFU, 2011).

In England, the government provides a series of measures to incentivise farmers to safeguard the environment and at the same time improve farm practices. Rural grants are made available to farmers under the Rural Development Programme for England (RDPE) (DEFRA, 2007). The programme was created to implement the European Council (EC) Regulations No.1698/2005 and EC No.1974/2006 that provide support for rural development in each member state (European Union, 2005; European Union, 2006).

Under the Common Agricultural Policy, the Single Payment Scheme (SPS) provides economic support to farmers (European Union, 2003). Farmers under SPS have to ensure Cross Compliance with Statutory Management Requirements (SMRs) and Good Agricultural and Environmental Conditions (GAECs) (Figure 2.1). Moreover, the British Government adopted measures to promote competitiveness of the agricultural sector combined with environmental protection that include economic instruments, such as Environmental Stewardship Schemes at entry level and higher level (Natural England, 2011). A series of handbooks and manuals are available for farmers to test their practices against the various stewardships schemes' regulations and ensure compliance to the Good Agricultural Practices (GAPs) and GAECs (RPA, 2009; RPA, 2011; RPA, 2012).

Figure 2.1 Legislative timeline for the agricultural sector.



Therefore, farmers can find a wide range of guidance and suggestions regarding the impact of farm management practices that they can decide to adopt depending on the needs of their agribusiness.

However, the growing interest in the environmental impact of greenhouse gases from the agricultural sector and in particular in the practices that effectively mitigate GHG emissions, has raised the issue of proofing these practices against the policy instruments that promote agricultural competitiveness and sustainability both in terms of economic and environmental benefits. Therefore, it is important to understand that the agricultural sector is under great pressure at the moment because of its fragile economic situation. Agricultural businesses have to find equilibrium between productivity and viability and farmers choosing sustainable agricultural practices have to take into account available options based on their practical application, labour intensiveness and cost-effectiveness.
Given the economic constraints all sectors are currently subject to, it is essential to identify which are the greatest challenges that could influence the decision making process at the farm level. Greenhouse gas emission mitigation strategies which are difficult to implement could be strategies advising a change in animal diet. Farms either produce feed or part of the feed on farm (i.e. arable crops), or have contracts with feed suppliers. A change in crops cultivated on farm or a change in feed from specific suppliers may not be a practical option for many farmers, as the benefits from the change in management could only be evaluated in the long run. Another point that needs to be taken into account is the labour intensiveness of a given mitigation option. Finally, policy makers need to ensure that the policies that promote environmental conservation, good agricultural practices and aim at supporting farmers in reducing their carbon footprint do not provide conflicting advice to

farmers on improving productivity, competitiveness and environmental sustainability (Beilin et al., 2012).

## 2.2 Challenges facing climate change impact assessment

### 2.2.1 Life Cycle Analysis

Life Cycle Analysis (LCA) is a methodology that requires identifying all stages of a production cycle and the definition of the system boundaries of a given product, in order to assess its impact in terms of greenhouse gas emissions. There are two types of LCA: attributional and consequential. *Attributional LCA* allows describing the environmental properties of a life cycle, whilst *consequential LCA* aims at assessing the impact of changes in practices (Ekvall and Weidema, 2004). The latter is the most appropriate methodology used in carbon calculators and it is widely used in LCA exercises in North America (Beauchemin et al., 2010; Pelletier et al., 2010) and Europe (Lopez-Ridaura et al., 2009; Nemecek et al., 2011; Thomassen et al., 2008) to support policy making (Hamelin et al., 2010; Wesnæs et al., 2009). The methodology is essential to every carbon footprint calculator, as it breaks down the various stages of production and allows calculation of their impact. However, LCA presents some limitations. The results are heavily dependent on the system boundaries (Schmidt, 2004). In fact, a carbon footprint model may include or exclude certain stages of production (Rotz et al., 2010); therefore, results may vary not only depending on the farm, but also on the type of calculator used to assess the farm impact (Schils et al., 2007). For instance, results from land use changes and especially the competition for land destined to produce food for human consumption or feed for animal consumption, are not included in LCA models currently used to evaluate the environmental impact of a given product (de Vries and de Boer, 2010).

Moreover, $CO_2$-eq conversion rates are standardised for all greenhouse gases identified in the Kyoto Protocol and mentioned in the IPCC Guidelines (IPCC, 2006). However, carbon accounting tools do not always consider all greenhouse gases and may just focus on $CO_2$, $CH_4$ and $N_2O$, grouping all other gases (Gillenwater, 2008), and they may also need country-specific adapted calculations (Havlikova et al., 2008; Rodhe et al., 2009), in particular considering the constant updating of scientific data inventories, the uncertainties that still surround some areas of investigation i.e. land management (Misselbrook et al., 2011) and the possible changes in governments' budgets allocated to GHG inventories and footprint accounting (Kitzes et al., 2009).

### 2.2.2 Carbon footprint calculators

The Greenhouse Gas Protocol standard is commonly used to categorise an organisation's emissions into 3 groups or scopes (Russell, 2011). In the agricultural sector, scopes can be described as follows:-

- *Scope 1. Direct emissions:* these emissions originate from activities that are directly under the farmers' control i.e. on-farm activities related to animals, crops, soils, fuels.
- *Scope 2. Indirect emissions:* these emissions originate from energy (i.e. electricity) used on-farm but produced elsewhere and therefore they are not under the farmers' control.
- *Scope 3. Indirect emissions:* these emissions are not under farmers' control at any rate. Examples include the emissions from the transportation of labour and waste to and from the farm, and the emissions from the production of fertilisers, feed, machineries and, more generally, farm inputs.

Under the Greenhouse Gas Protocol, an organisation must include scope 1 and 2 emissions within its carbon footprint. However, there is broad discretion about which scope 3 emissions should be included in a business carbon footprint - for example, organisations often include waste disposed to landfill and employee business travel from scope 3 (Russell, 2011).

There is a plethora of carbon footprint calculators available for the agricultural sector, the reason being the peculiarity of farming systems and the purpose of the calculator. Using IPCC guidelines, BSI Standards and LCA modelling, different carbon footprint calculators can provide different estimates of a particular product. A number of institutions have developed calculators that can be used in agriculture, but some are proprietary or do not have an online version providing user-friendly access (Little and Smith, 2010). Two calculators that have free online access are the Country Land & Business Association (CLA) Carbon Accounting for Land managers (CALM) calculator (CLA, 2009) and the Carbon Friendly Food (CFF) calculator (Smith, 2010). Both calculators require the user to register an account, free of charge, with the possibility of creating a farm profile. Farmers can access the account at later stages and therefore they can monitor their agri-business footprint over the years.

#### *2.2.2.1 Publicly Available Specification 2050*

The Publicly Available Specification 2050 (PAS 2050) is a tool developed by the British Standards Institution (BSI), sponsored by the Carbon Trust and DEFRA, to assess GHG emissions based on their life cycle. Virtually any product or any business can be evaluated by running a Life Cycle Analysis (LCA) and identifying key stages of production. PAS 2050 was not specifically built for the agricultural sector and it is not interactive, but it is rather a tool promoting consensus building by consultation at business level and at business-to-consumer level.

PAS 2050 is a consultative document that takes into account the 6 gases identified in the Kyoto Protocol. Emissions are calculated in Carbon Equivalents. Data are gathered from various sources: stakeholders, research groups, governmental panels and nongovernmental organisations. The assessment of each greenhouse gas emission is based on a “hybrid LCA” methodology, combining the guidelines suggested by the Carbon Trust (2010) for LCA, with an input-output supply chain analysis and ISO-14040 compliance (ISO, 2006). This wider approach is meant to provide more accuracy and a comprehensive coverage of GHG emissions sources. The official PAS 2050 document was first published in October 2008 by the British Standards Institution (BSI, 2008). A detailed report on the PAS 2050 methodology is available on the DEFRA website (DEFRA, 2008). The document is simply a consultative tool; therefore, farmers and land managers cannot use it interactively, but may only refer to it to estimate the impact of their business or the impact of a given product along the supply chain. Updated versions are constantly under review, using data provided by the Carbon Trust, in order to provide a reference tool that features the latest up-to-date scientific knowledge on GHG emission factors and calculations.

#### *2.2.2.2 CLA CALM calculator*

The CALM carbon footprint calculator was developed by CLA using IPCC guidelines and formulas (IPCC, 2006), integrated with the UK GHG inventory report 1990-2008 (DECC, 2008). It is regularly updated and features calculations and emission factors reported in the National Inventory Report of 2011 (UNFCC, 2011). The inventories follow the directives of the UNFCCC on reporting emissions; therefore, the data available may overlap between the various documents and they are sometimes merged for the purpose of the CALM.

The tool measures emissions of $CO_2$, $CH_4$ and $N_2O$ from land-based businesses. The emissions taken into account are from energy use, livestock, agricultural activities (cultivation, land-use change and fertiliser use). The figures are then balanced against the carbon stored in soil and vegetation. The tool does not measure the carbon sequestration directly, but rather the change in the emission rates if Environmental Stewardship options are adopted. This approach provides an estimate of the carbon balance of the assessed business.

The CALM calculator takes into account scope 1, scope 2 and certain scope 3 emissions (i.e. emissions from processing and distribution of inputs such as feed and fertilisers). Even though collecting data for Scope 3 emissions is seldom easily done by the farmer, figures for these emissions are recommended to be added to the calculator whenever available. For nitrogen fertilisers in particular, CALM can provide guidance in assessing emissions.

The calculator is oriented toward a practice-based calculation, rather than a product-based calculation. However, it does not take into account organic farm management practices and it only partially considers carbon sequestration (Little and Smith, 2010). Other challenges facing accurate calculations are emissions derived from land use changes. In fact, soil types are a very important variable in calculations; however, the type of data from national inventories and IPCC guidelines present discrepancies in results produced and challenges the purpose of the calculator, which is to *"show the contribution of the farm to the national inventory"* (Ward, 2011). In fact, as the calculator follows GHG Protocol Standard (Russell, 2011), auditing results issued by CALM should be comparable with figures provided by the UK National Inventory, making it easier for businesses to assess their consistency with national reports and possible reduction in GHG emissions.

#### *2.2.2.3 CFF calculator*

The Climate Friendly Food (CFF) calculator was developed in 2009 by organic farmer Jonathan Smith and researchers Mukti Mitchell, Rupert Hawley and Jenny Hall. Similarly to CALM, the CFF calculator was developed following the IPCC Guidelines (IPPC, 2006) and is regularly updated using UK national inventories, data from DEFRA made available to the public and other reputed sources such as Rothamsted Research Institute and acknowledged scientific journals. The tool takes in to account scope 1 and scope 2 emissions; it partially takes into account scope 3 emissions (i.e. organic fertiliser, feed) and *"it covers soil organic processes and carbon sequestration, which are omitted from most other agricultural calculators yet can be the greatest contributors to net carbon emissions or sequestration"* (Smith, 2009, official website). The tool has a similar online interface to CALM, albeit more visually appealing, as the latest update introduced the possibility of generating graphs from the footprinting results. Users can create an account and track changes in footprint over time. The tool is now part of a toolkit available online for farmers to add a climate friendly certification to their produce.

### 2.2.3 The footprint dilemma: to off-set or to reduce?

Life Cycle Analysis and carbon footprint calculators represent useful tools to attempt to quantify GHG emissions. However, farming systems are complex and a broader approach may be needed in order to consider aspects of agricultural production that are not currently accounted for by the acknowledged LCA models, as proposed by Garnett (2009), who suggests the formulation of a model that includes scope 3 emissions, cost-benefit scenarios and the controversial topic of the quantification of ecosystem services, in terms of actual needs of a service instead of its surplus provision.

Moreover, a change in farm practices may result in an improvement in GHG emission mitigation, but it may also have a negative effect on other aspects of farming e.g. transportation, socio-economic constraints. Based on a thorough analysis of the most recent GHG mitigation studies, de Boer et al. (2011, p.424) suggest that *"the full potential of a mitigation option to achieve a net reduction of GHGs or its trade-offs with other aspects of sustainability (e.g. animal welfare) are not generally addressed in the literature."* Important trade-offs to consider when changing a farm practice are animal welfare, practical feasibility, farm livelihood, waste management costs, transportation, labour and added energy costs, both direct (i.e. fuel needed for on-farm machinery use) and indirect (i.e. fertiliser used to increase crop production), animal and human health, public perception and acceptance (i.e. grain-fed livestock vs pasture-fed livestock) and the sustainable use of soil and water resources (de Boer et al., 2011). Even though, as part of its Green Growth Strategy, the Organisation for Economic Co-operation and Development recognised that trade-offs should be included in policy design that addresses environmental issues (OECD, 2010), these are difficult to assess in terms of socio-economic impact. Moreover, although the feasibility and effectiveness of certain mitigation options are not considered context-dependent (e.g. lower livestock replacement rate), farmers' perceptions of GHG mitigation options, such as improved feed conversion efficiency and production per unit of livestock, in terms of cost-effectiveness and possible trade-offs, may vary greatly depending on the size and type of farm, as well as on the current national economic situation i.e. cost of inputs (Vellinga et al., 2011).

Therefore, farmers are not only facing the challenge of producing food in a cost-effective system that ensures that sustainable use of environmental resources, but they also have to find the balance between possible trade-offs and obligations to comply with current national policies that may not consider "the whole picture" of agricultural production.

## 2.3 The way forward

### 2.3.1 Policy making under climate change challenges

Governments are continuously facing the challenge of promoting sustainable agricultural practices, in particular under the latest revision of the Common Agricultural Policy (CAP). A recent report on the targets of CAP 2020 highlighted the importance of sustainable conservation agriculture as a strategy to both adapt and mitigate the impacts of climate change (Basch et al., 2012). Among the steps to take, the authors cite activities that foster social capital, promote knowledge exchange and knowledge transfer in order to integrate researchers' scientific knowledge with farmers' practical experience. Governments should also promote stakeholders' engagement and adopt strategies that incentivise farmers to join environmental stewardship schemes. The British Government, through Natural England, reaches out to the public by illustrating the benefits of signing Environmental Stewardship (ES) schemes (Natural England, 2012). Information is given on ecosystem services received or provided by farming and on how sustainable management options suggested in the schemes can benefit ecosystem services. The Government incentivises the sustainable use of soil and water resources, nutrient cycling, carbon sequestration, waste management, and the management of livestock and crop production in order to reduce the negative environmental impacts of agri-businesses and promote sustainable food production and environmental conservation in thriving rural communities.

Although all European member states have adopted National Adaptation Strategies to cope with the impacts of climate change, the implementation of such strategies can provide mixed results. This is the case of the United Kingdom which, like Denmark, has developed a National Adaptation Strategy that addresses a variety of sectors, including agriculture, but still faces a number of challenges linked to the uncertainty surrounding scientific knowledge about the effectiveness and reliability of GHG mitigation strategies, the involvement of multi-level actors (i.e. government agencies, local agencies, private sector) and the development of a transparent knowledge network infrastructure (Biesbroek et al., 2010). A further obstacle is the design and implementation of an effective methodology to evaluate the impact of climate change action on farming. As illustrated in previous paragraphs, the evaluation of a farming system presents challenges related to the size and financial viability of the business. It is possible that farmers are linked to local social networks and involved in community-based knowledge sharing activities. Therefore, field studies and extension work including surveys and data collection on farmers' attitudes to climate change are an effective, yet potentially expensive and time-consuming strategy in order to assess the socio-economic impact of climate change in different farming contexts where, as an example, models designed for the large-scale farming sector do not apply to small-scale farming systems (Claessens et al., 2012). It then becomes necessary to design a strategy that can combine the benefits of extension services i.e. promoting two-way communication between farmers, researchers and/or government agencies, with the reliability of farm management practices assessment based on the most recent scientific knowledge on GHG mitigation options.

### 2.3.2 Effective communication

In order to illustrate the focus of supra-national action on climate change, Hofmann et al. (2011) have analysed the topics of the studies from European countries, including the United Kingdom, that were used by the Intergovernmental Panel on Climate Change in its review of climate change impacts (IPCC, 2007b). It is interesting to note that, while the authors found that most studies considered by the IPCC related to climate change being the *"driver for change"*, they also found that the majority of the studies focus on climate change impact projections but do not consistently use the same vocabulary and they do not adopt an integrative approach to climate change issues. Therefore, the general conclusion of the study was that fragmentation of climate change studies and knowledge transfer (i.e. communication without using technical jargon) remain major barriers to the formulation of a widely accepted model to address the impacts of climate change and engage with the public on mitigation strategies (Hofmann et al., 2011). In particular, the challenge of formulating socio-economic scenarios is linked to the difficulty in obtaining reliable long-term climate change scenarios on which to base mitigation strategies, which are not influenced by short-term political and/or economic constraints (Kriegler et al., 2012).

Experiences in Finland and in Italy have shown that the greatest obstacles to the implementation of effective climate change strategies at national level lie in the communication between the various actors involved and in the interaction between governmental agencies and extra-governmental groups or institutions (Juhola and Westerhoff, 2011). Part of the reasons lie in the lack of common language between the various stakeholders (i.e. policy makers, researchers and the farming community), which can result in a lack of integration of the sectors involved (Tol, 2005). In fact, farmers' perception of a lack of clear agency and long-term strategy from the British Government, funded on transparent information tailored for the agricultural sector, may result in people's reaction to climate change to depend on personal and often socio-economic reasons, rather than relying on a wider acknowledgement that the impact of climate change needs a common strategy (Lorenzoni et al., 2007). The divergence in goals between the researchers' community and the farmers' community, the former aiming at publishing high impact research studies, whilst the latter is looking for practical advice based on sound scientific knowledge, is highlighting the challenges in achieving successful on-farm innovation for the benefit of both researchers and farmers (Brookfield and Gyasi, 2009). On the other hand, there is also the risk of considering that the continuous publishing of new research, whether its results are accessible to the public or not, will lead to an improvement in the sustainable use of agricultural and environmental resources and therefore research always leads to benefits for society via policy making (Robards et al., 2011).

### 2.3.3 Successful farmer engagement on GHG mitigation

This chapter has introduced the challenges facing the successful design and implementation of GHG mitigation strategies. The findings show that there is a need for a long-term strategy which addresses the problem of on-farm GHG mitigation using a comprehensive approach. This approach should include on the one hand, hard science on GHG mitigation and on the other hand, successful methodologies for farmer engagement which promote knowledge transfer (i.e. researcher-to-farmer-to-researcher), knowledge sharing (i.e. farmer-to-farmer) and facilitate change by putting science to use in on-farm innovation in order to reduce GHG emissions. A schematic representation of the relationships between farmers, researchers and policy makers is proposed in figure 2.2a and refined in figure 2.2b to show farmers as co-researchers, in the case of small-scale or extensive low-input farming systems. The subject will be addressed in more detail in chapters 4 and 5.

Figure 2.2a. Interaction gaps between small-scale farmers, researchers and policy makers.

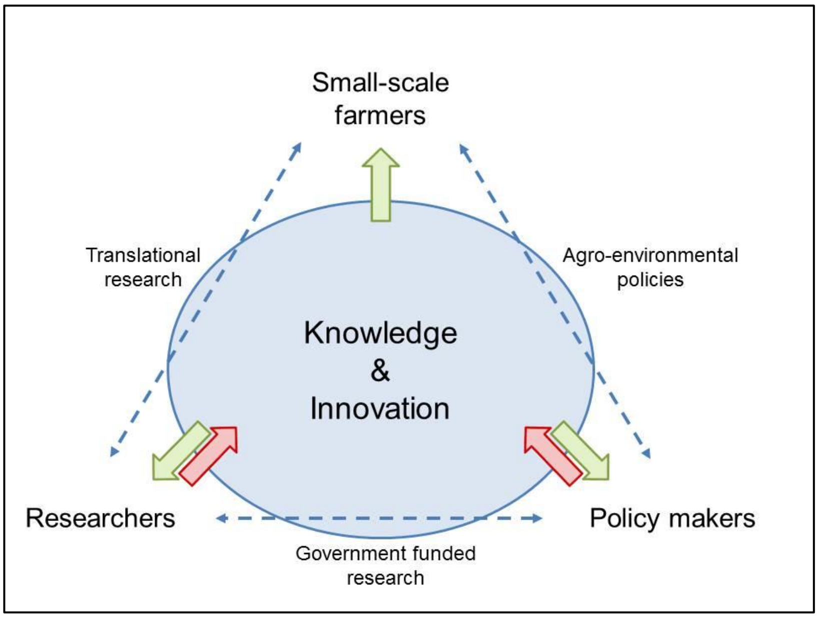
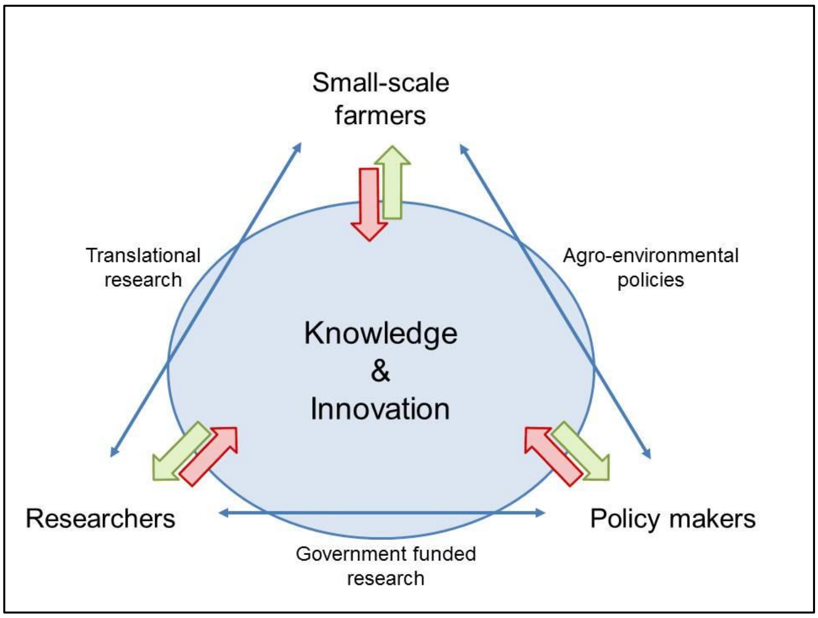
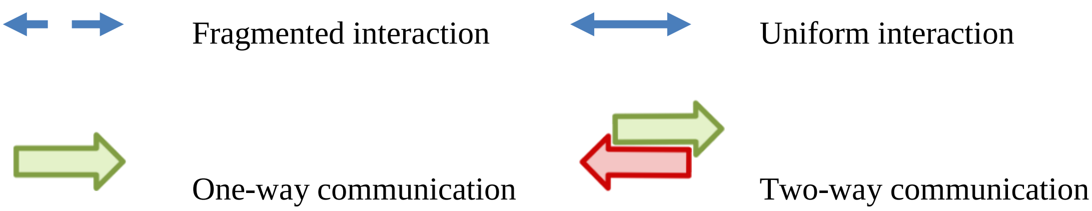



Figure 2.2b. Proposed improvement of integrated climate change action to promote small-scale farmers engagement




Keys:



Finally, by adopting the approach found in translational research, this study combines qualitative and quantitative research methodologies in order to design a framework for successful engagement with livestock farmers. The following chapters present a review of the most acknowledged scientific data on on-farm mitigation strategies, followed by a review of the most effective approaches used to engage with farming communities, and finally the formulation and test of a decision support tool with the aim of helping farmers identify possible changes in practices to reduce GHG emissions. The study provides valuable information to support the GHG Action Plan for the agricultural sector (Burbi et al., 2011) and it includes activities to promote the establishment of a two-way communication flow between researchers and farmers, where researchers act as extension officers, giving advice to farmers on solutions derived from scientific knowledge that may not be accessible to them, whilst farmers will act as co-researchers, providing valuable feedback to researchers on real and perceived barriers to GHG mitigation in livestock farming systems.

# Chapter 3

# Greenhouse gas emission mitigation from livestock farms

# 3 Greenhouse gas emission mitigation from livestock farms

This chapter reviews the quantitative evidence regarding the mitigation of greenhouse gas emissions at the farm level. It then provides a series of mitigation options available to farmers who aim at reducing the carbon footprint of their agri-businesses.

## 3.1 Introduction

The role of greenhouse gases (GHG) and their contribution to climate change has been subject of many studies in the past two decades. GHG emissions can be naturally occurring emissions and man-made emissions. The study focuses on the former, divided into carbon dioxide ($CO_2$) and non-$CO_2$ gases, the two main ones being methane ($CH_4$) and nitrous oxide ($N_2O$) (IPCC, 2001). The Global Warming Potential (GWP) has been officially adopted to assess the actual effect of a given greenhouse gas on global warming and events related to climate change, where $CO_2$ is taken as reference and its GWP is 1 i.e. *"the ratio of the time integrated radiative forcing from the instantaneous release of 1 kilogram (kg) of a trace substance relative to that of 1 kg of a reference gas"* (IPCC, 2001). The Intergovernmental Panel on Climate Change estimates the GWP of methane at 25 and 298 for nitrous oxide (IPCC, 2007c).

The latest report issued by the Department of Energy & Climate Change (DECC, 2013) refers to greenhouse gases inventories up to the year 2011. It reports an overall reduction of greenhouse gases by 29.2% from the 1990 baseline and the impact of the agricultural sector accounts for 9.2% of the total emissions in the United Kingdom. In order to follow the progress of emission reduction results over the years, the Greenhouse Gas Action Plan for the agricultural sector was released in 2009. A panel of independent bodies and national agencies contributed to its outline and implementation. The initial phase of the GHG Action plan includes an update of the greenhouse gases inventories for the agricultural sector and a review of the implementation strategies currently available in order to mitigate emissions. A review has been published to monitor progress and achievements (NFU, 2011). The breakdown of the sources and impact of the 3 main greenhouse gases according to DEFRA (2012a) is summarised below:

Table 3.1 Sources and impact of greenhouse gas emissions from the agricultural sector (source: DEFRA, 2012a).

| **Gaseous emission** | **Source** | **Impact** |
|---|---|---|
| Carbon dioxide ($CO_2$) | Energy used for fuel and heating | Less than 10% |
| Methane ($CH_4$) | Ruminant digestion processes<br>Production and use of manure and slurry | 32% |
| Nitrous oxide ($N_2O$) | Synthetic and organic fertilizers | 61% |

## 3.2 Review criteria

It is important to understand the difference between mitigation and adaptation to climate change. The Intergovernmental Panel on Climate Change stated that mitigation is *"an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases"* (IPCC, 2007a, 878); whilst adaptation is the *"adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities"* (IPCC, 2007a, p. 869).

For the purpose of this review, mitigation strategies related to agricultural activities were considered, with a specific focus on livestock farming practices. Science-based evidence on agricultural GHG emissions currently found in the literature covers a wide range of mitigation options that support the development of targeted strategies for different livestock farming systems in England. However, the measurements used are not standardised. System boundaries for Life Cycle Assessment (LCA) models are also not always uniformly defined. Therefore, it is difficult to compare results and assess which findings better reflect the actual conditions on farms. Moreover, the most commonly used free carbon calculators use science-based evidence but provide different estimates, relying on proxy measures and estimates, and they need constant revision and improvement so as not to risk missing key areas on GHG emissions (CLA, 2011; Smith, 2011). However, the review focused on quantitative evidence only and sought to standardise findings by reporting the most acknowledged mitigation strategies cited in scientific literature that are under farmers' control, illustrating their importance in terms of application at the farm level. Estimates' ranges vary accordingly to the evidence found in literature.

## 3.3 Mitigation – Quantitative evidence

The two most important greenhouse gases originating from livestock farming practices are methane and nitrous oxide. There is a substantial amount of literature addressing various mitigation options to reduce these emissions. Literature reporting qualitative studies was not included in this review. The reason for such choice stands in the fact that in order to provide information that can be easily accepted by farmers as useful, recommendations should be based on studies quantifying greenhouse gases mitigation. By focusing on the practices that give clear estimates of the most probable outcomes in terms of emissions reduction, farmers could then be presented with practical solutions that could be assessed against the benefits in terms of cost, increased productivity and better waste management. Literature providing quantitative measures of greenhouse gas mitigation was compared with previous publications, in order to increase confidence in the references, and to detect any recent innovations. Given the large amount of literature available, the following paragraphs will only provide an overview of the current options available at the farm level in order to mitigate methane and nitrous oxide emissions, including nitrate leaching remarks where necessary. The key areas of intervention are summarised:

Table 3.2 Summary of key areas of practical intervention based on mitigation.

| | **Practices that influence nitrogen losses** | **Practices that influence carbon losses** |
|---|---|---|
| **Dietary management** | Crude Protein (CP) intake<br>Additional forage : concentrate ratio | Low forage / high concentrate |
| **Housing** | Deep litter<br>Slatted floors<br>Flushing floors | Frequency of removal of manure |
| **Manure storage and treatment** | Straw addition<br>Cover, compaction<br>Separation solid / liquid fraction | Aeration, composting<br>Slurry crust<br>Anaerobic digestion<br>Temperature (summer, cooling) |
| **Grazing and pasture management** | Rotations<br>Avoid compaction | Legumes on pasture<br>Grazing younger pasture<br>Avoid compaction |
| **Manure application to soil** | Manure type, soil type, temperature, soil moisture, application methods | Manure type, soil type, temperature, soil moisture, application methods |

Mitigation strategies to reduce methane emissions include dietary management and rumen manipulation (Arriaga et al., 2010a; Arriaga et al., 2010b; Eckard et al., 2010), improved housing management and increased efficiency of farming systems by adopting breeds with improved productivity and feed conversion efficiency (Chadwick et al., 2011; Hamelin et al., 2010; Lachance et al., 2005; Misselbrook et al., 2006; Philippe et al., 2006). Mitigation strategies to reduce nitrous oxide emissions include not only dietary management, housing management and improved productivity, but more importantly manure storage, treatment and application to soil, and practices related to soil management and grazing and pasture management (Chadwick et al., 2011). The following summarises the key literature on practices related to dietary management (Table 3.3), livestock housing (Table 3.4), manure storage and treatment (Table 3.5), grazing and pasture management (Table 3.6) and manure application to field (Table 3.7).

Table 3.3 Key literature on mitigation strategies related to dietary management.

| **Animal** | **Practice** | **Expected emission reduction** | | | | **Reference** |
|---|---|---|---|---|---|---|
| | | **$CH_4$** | **$N_2O$** | **$NH_3$** | **Other losses** | |
| **ruminants** | Use legumes as forage | -15% $CH_4$ (white clover) | | | | Hammond, K. J., personal communication. Cited by: Buddle et al., 2010 |
| **ruminants** | Replace high fibre dried grains with maize- or wheat-based concentrate feed | -12% $CH_4$ | | | | Benchaar et al., 2001 |
| | | | -22% $N_2O$ / kg of milk produced | | | Luo et al., 2010 |
| | | | | | -8.9% total N excreted | Arriaga et al., 2010a |
| | | | | -36.5% $NH_3$ | | Arriaga et al., 2010b |
| | | | | | -30% total N<br>-45% urinary N<br>-44% faecal N | Misselbrook et al., 2005b |
| **ruminants** | Replace with maize-, wheat- or barley-based concentrate feed | | | | -54% N | Klevenhusen et al., 2010 |
| **pigs** | Reduce crude protein | | | | -24.1% total N excreted | Philippe et al., 2006 |
| **pigs**<br>**poultry** | Grinding and pelleting | | | | -22-30% manure N | Rotz, 2004 |
| **ruminants** | Combine legumes with cereal grains | -15% $CH_4$ | | | | Hammond, K. J., personal communication. Cited by: Buddle et al., 2010 |
| **ruminants** | Combine forage (non legumes) with oilseed meals | -13% $CH_4$ (g/day) | | | | Beauchemin et al., 2008 |
| **ruminants** | Tannins | -13-33% $CH_4$ | | | -45-59% urine N<br>+18-21% faecal N | Animut et al., 2008<br>Patra and Saxena, 2010 |
| | Saponins (yucca, corn, potato starch, corn hay, wild rye concentrate, hay concentrate) | -2-28.3% $CH_4$ | | | | Patra and Saxena, 2010 |

(Continued)

| Animal | Practice | Expected emission reduction | | | | Reference |
|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | $NH_3$ | Other losses | |
| **ruminants** | Oils (fatty acids):<br>sunflower oil<br>canola oil<br>flaxseed | (g/kg DMI)<br>-10% enteric $CH_4$<br>-18% enteric $CH_4$<br>-16% enteric $CH_4$ | | | | Beauchemin et al., 2008 |
| **ruminants** | whole cottonseed | -2.9% $CH_4$ per 1% added fat | | | | Granger et al., 2010 |
| **ruminants** | coconut oil, sunflower seeds<br>rapeseeds | -27% $CH_4$ | | | | Machmüller et al., 2006 |
| **ruminants** | Fat supplementation | | | | -14% manure N | Machmüller et al., 2006 |
| **ruminants** | Salt* | | | | -5-10% urine N | Eckard et al., 2010 |
| **ruminants** | Total Mixed Ration (TMR)<br>Use a software to formulate the ration | Balanced diet | | | | Basely and Hayton, 2007 |
| **ruminants** | Closely check the supplementation limits | Balanced diet | | | | Garnett, 2009<br>Graux et al., 2011<br>Jacob et al., 2011 |

Table 3.4 Key literature on mitigation strategies related to livestock housing.

| **Animal** | **Practice** | **Expected emission reduction** | | | | **Reference** |
|---|---|---|---|---|---|---|
| | | **$CH_4$** | **$N_2O$** | **$NH_3$** | **Other losses** | |
| **ruminants** | Use slurry based systems with slatted floors or hard standing areas | | Little to no $N_2O$ emissions | | | Jungbluth et al., 2001<br>Thorman et al., 2003 |
| **pigs** | Use slurry based systems or fully slatted floors | | Little to no $N_2O$ emissions | | | Jungbluth et al., 2001<br>Thorman et al., 2003<br>Groenestein and van Fassen, 1996 |
| | | $CH_4$ vary based on production cycle | | | | Costa and Guarino, 2009<br>Sommer et al., 2009 |
| **any** | Increase frequency of complete manure removal | -40% $CH_4$ | | <br>-46% $NH_3$<br>-23-80% $NH_3$ | | Haeussermann et al., 2006<br>Lachance et al., 2005<br>Hamelin et al., 2010 |
| **any** | Adopt straw-flow systems | -50% $CH_4$ | | | | Philippe et al., 2007 |
| **any** | Avoid mechanical mixing of deep litter | | Increase in $N_2O$ may vary | | | Groenestein et al., 1993 |
| **any** | Replace grid floor with hard standing area, or clean regularly | | Little to no $N_2O$ emissions | | | Ellis et al., 2001<br>Misselbrook et al., 2001 |
| **any** | Flush with water<br>Flush with water and formalin | | -15% $NH_3$<br>-50% $NH_3$ | | | Misselbrook et al., 2006 |

(Continued)

| Animal | Practice | Expected emission reduction | | | | Reference |
|---|---|---|---|---|---|---|
| | | **$CH_4$** | **$N_2O$** | **$NH_3$** | **Other losses** | |
| **poultry** | Adopt rotations system Yarding with other animals (Grassland recovery) | | -18% $N_2O$ | | | Hobson, 2007<br>Luo et al., 2010 |
| | Provide outdoor run | Emissions dispersed | | | | Hobson, 2007<br>Jacob et al., 2011 |
| | Chicken coop with bedding (sawdust, straw, woodchips) | | Ca. -23% $N_2O$ | | | Dekker et al., 2011<br>Hobson, 2007 |
| | Litter management | | -23% $N_2O$ (varies greatly) | -50-80% $NH_3$ | | Webb et al., 2011<br>Aarnink et al., 2006 |
| | Use straw bedding or straw and zeolite bedding | -25% moisture of litter | | | | Garcia et al., 2008 |
| | Plant trees nearby | Emissions trade-off | | | | Baines, 2011 |
| | Install ventilation units: heat recovery ventilators, destratification fans | | | $NH_3$ dispersed | | Manning, 2011 |

Table 3.5 Key literature on mitigation strategies related to the storage and treatment of solid and liquid manures.

| **Practice** | **Expected outcomes** | | | | **Reference** |
|---|---|---|---|---|---|
| | **$CH_4$** | **$N_2O$** | **$NH_3$** | **Other losses** | |
| Use liquid fraction for anaerobic digestion | | Lower $N_2O$ | Increased $NH_3$ | | Fangueiro et al., 2008<br>Berg et al., 2006<br>Misselbrook et al., 2005a |
| | -75% $CH_4$ | | | | Turnbull and Kamthunzi, 2004 |
| Liquid fraction aeration | AD yield<br>+2-14.6% $CH_4$ | | | | Kaparaju et al., 2008 |
| Addition of glycerol to liquid fraction | AD yield<br>+200% $CH_4$ | | | | Wohlgemut, 2010 |
| Prevent encrustation | | Little to no $N_2O$ emissions | | | Berg et al., 2006<br>van der Zaag et al., 2009 |
| Leave natural crust | -38% $CH_4$ | | -50% $NH_3$ | | Bicudo et al., 2003<br>Misselbrook et al., 2005a |
| Addition of water | | | | | Abd El Kader et al., 2007 |
| Addition of phosphogypsum | | | | -54% GHG<br>Composition:<br>traces of $N_2O$<br>14% $CH_4$ | Hao et al., 2005 |
| Compacting | Lower $CH_4$ in colder months | -30% $N_2O$ | -90% $NH_3$ | | Chadwick, 2005 |
| | | -30-70% $N_2O$ | -30-70% $NH_3$ | | Abd El Kader et al., 2007 |
| Static composting solid fraction | | | -60% $NH_3$ | | Brito et al., 2008<br>Szanto et al., 2007 |
| Monthly turning | -89.8% $CH_4$ | -46% $N_2O$ | +66% $NH_3$ | | Szanto et al., 2007<br>Brito et al., 2008<br>Shen et al., 2011 |
| Addition of straw | | -32% $N_2O$ | | | Yamulki, 2006 |

(Continued)

| Practice | Expected outcomes | | | | Reference |
|---|---|---|---|---|---|
| | $CH_4$ | $N_2O$ | $NH_3$ | Other losses | |
| Use permeable cover, i.e. straw | | +200% $N_2O$ | -60-90% $NH_3$ | | Thorman et al., 2007 |
| Use impermeable cover, i.e. tarpaulin, plastic | | | -60-90% $NH_3$ | | Stenglein et al., 2011<br>Thorman et al., 2006<br>Funk et al., 2004a; 2004b |
| Ensure cover is airtight<br>Use ventilation hoses | -54% $CH_4$ | | | | Hansen et al., 2006<br>Stenglein et al., 2011<br>Rodhe et al., 2009 |
| Use additives, i.e. lactic acid, saccharose | | | -43% $NH_3$ | | van der Stelt et al., 2007 |
| Reduce pH | -40% $CH_4$ | | | | Berg et al., 2006 |
| Reduce T° (shades, pipes) | N.A. (lower $CH_4$) | Little to no $N_2O$ emissions | | | Sommer et al., 2007<br>Rodhe et al., 2009<br>Massé et al., 2008<br>van der Zaag et al., 2010<br>Dinuccio et al., 2008<br>Rodhe et al., 2009 |

Table 3.6 Key literature on mitigation strategies related to grazing and pasture management.

| Sector | Practice | Expected emission reduction | | | | Reference |
|---|---|---|---|---|---|---|
| | | **$CH_4$** | **$N_2O$** | **$NH_3$** | **Other losses** | |
| **livestock** | Avoid grazing in colder, wetter months (Autumn, Winter) | | -7-11% $N_2O$ (IPCC)<br>-40% $N_2O$ and $NO_3$ | | | IPCC, 2006<br>de Klein et al., 2006 |
| | Use of stand-off / feed pads in colder, wetter months | | -60% $N_2O$ | | | Luo et al., 2010 |
| | Adopt rotational grazing management to reduce grazing time, e.g.: move animals every 1-2 days (intensive grazing, frequent rotations) | -22% $CH_4$ | -10% $N_2O$ | | | DeRamus et al., 2003<br>Schils et al., 2006 |
| | Reduce grazing density, stocking rate | | -25% $N_2O$<br>-17% $N_2O$<br>$N_2O$ decreases proportionally (sheep) | | | Flechard et al., 2007<br>Luo et al., 2010<br>Saggar et al., 2007 |
| | | -55% $N_2O$ and $CH_4$ | | | | Allard et al., 2007 |
| | Adopt Whole Farm Management (WFM) approach | | | | -3.46% GHG | Lovett et al., 2008 |
| **pasture** | Graze on younger pasture, e.g. Spring, rather than Summer | Spring grazing:<br>5% GE lost in $CH_4$<br>Summer grazing:<br>6-7% of GE lost in $CH_4$ | | | | Robertson and Waghorn, 2002 |
| | Legumes on pasture, e.g. white clover | -15% $CH_4$ | | | | Hammond, 2010 |

(Continued)

| Sector | Practice | Expected emission reduction | | | | Reference |
|---|---|---|---|---|---|---|
| | | $CH_4$ | $N_2O$ | $NH_3$ | Other losses | |
| **soil** | Install drainage system<br>Use strip grazing system with daily rotations (minimise poaching)<br>Avoid grazing on slopes (minimise runoff and animal treading) | | -27% $N_2O$ | | | Luo et al., 2010<br>Menneer et al., 2005 |
| | Avoid compaction, in particular of heavy soils, i.e. clay, clay loam. | Indicatively, compaction leads to:<br>+30-90% $CH_4$ +20-200% $N_2O$ | | | | Mosquera et al., 2007<br>Snyder et al., 2009 |
| | Apply nitrification inhibitors (experimental) | | -70% $N_2O$ | | | Di et al., 2007<br>Eckard et al., 2010 |

Table 3.7 Key literature on mitigation strategies related to the application of manure to field.

| **Practice** | **Expected outcomes** | | | | **Reference** |
|---|---|---|---|---|---|
| | **$CH_4$** | **$N_2O$** | **$NH_3$** | **Other losses** | |
| Application mixed with green waste | | -64% $N_2O$ | | | Dalal et al., 2010 |
| Set up manure analysis system | | -18% $N_2O$ | | | Luo et al., 2010 |
| Split applications | | -30% $N_2O$ | | | Saggar et al., 2007 |
| Avoid application to soil with high moisture content, i.e. Water Filled Pore Space (WFPS) %<br>Avoid autumn applications | | $N_2O$ x10 when WFPS increases from 60% to 70% | | | Akiyama et al., 2004<br>Bateman and Baggs, 2005<br>Petersen et al., 2008<br>Snyder et al., 2009 |
| Injection | | +6.09% $N_2O$ | -20-75% $NH_3$ cattle | | Carew, 2010<br>Chadwick et al., 2011<br>Misselbrook et al., 2002<br>Rodhe et al., 2006 |
| Incorporation | | | -60-80% $NH_3$ pigs | | |
| Spreading | | | -80-90% $NH_3$ cattle/pigs<br>-26-57% $NH_3$ cattle/pigs | | |
| Surface deposition | | +1.69% $N_2O$ | | | |
| Shallow injection | | $N_2O$ (% of N applied):<br>0.4% cattle (grassland)<br>0.9% cattle (maize)<br>3.6% pig (maize) | | | Velthof and Mosquera, 2011 |
| Surface application | | $N_2O$ (% of N applied):<br>0.1% cattle (grassland)<br>0.4% cattle (maize)<br>0.9% pig (maize) | | | |
| Ensure regular maintenance of machinery | Optimum fertiliser management | | | | DEFRA, 2009 |

### 3.3.1 Mitigation of methane emissions

#### *3.3.1.1 Livestock husbandry*

Improving livestock productivity reduces feed and energy losses. Higher productivity can be achieved by improving nutrition and by reducing the number of unproductive animals. For example, improving pasture quality can lead up to a 50% reduction in enteric $CH_4$ losses per unit of weight gain in lambs (Waghorn and Hegarty, 2011). Similarly, prolonged lactations in dairy systems and reduced finishing times in beef cattle systems can reduce emissions per animal, as cows calve less frequently and slaughter weight is reached at a younger age (Smith et al., 2007).

Livestock housing management practices influence greatly both methane and nitrous oxide emissions. Methane emissions vary based on production cycles i.e. emissions from farrowing houses are usually lower than those from fattening houses because they are cleaned on average every 27 days, instead of 90-100 days for the fattening houses (Costa and Guarino, 2009; Sommer et al., 2009). However, the complete cleaning of slurry based systems after each fattening cycle reduces $CH_4$ emissions by 40% according to Haeussermann et al. (2006). In straw-flow systems, higher temperatures can be registered, due to a better aeration of the litter. This can lead to higher methane losses. However, adopting a daily scraping routine can reduce $CH_4$ emissions by up to 50% (Philippe et al., 2007). Other mitigation strategies combine reduction of methane emissions and nitrous oxide emissions as well. These will be summarised in the section addressing nitrous oxide emissions (section 3.3.2).

### *3.3.1.2 Dietary management manipulation*

Providing a balanced diet has been proven to be related to an increase in productivity, which is associated with lower GHG emissions when units of produce are considered i.e. live weight gain, milk production, egg laying rates (Garnett, 2009; Graux et al., 2011; Jacob et al., 2011). The adoption of the Total Mixed Ration (TMR) system or of a software in order to formulate the ration is useful to improve nutrient management, to reduce excess N in the diet and to balance energy requirements for groups of animals, especially monogastrics, at different production stages (Basely and Hayton, 2007).

The biological control of ruminal fermentations is essential to mitigate emissions by modifying the equilibrium of the production of Volatile Fatty Acids (VFA) in the rumen. The Acetate : Propionate : Butyrate ratio can be influenced by the fibre content in the diet. Notably, higher fibre content leads to higher acetate production and therefore higher methane emissions. The combination of addition of grain to forage based diet and the use of forages with lower fibre content increases starch and reduces fibre intake. This reduces the rumen pH and favours the production of propionate rather than acetate in the rumen, therefore reducing methane losses.

Legumes have high water soluble carbohydrates content, low fibre content and a low total carbohydrate : protein ratio, compared to normal grasses. They are more nutritious than grasses; they have high digestibility and increase Dry Matter Intake (DMI), reducing $CH_4$ emissions. According to Hammond et al. (2009), plant breeding seems to influence just about 19% of the methane emission rate, feeding legume forages such as white clover reduces $CH_4$ emissions by 15% compared to animals fed with perennial ryegrass (Hammond, K. J., personal communication. Cited by: Buddle et al., 2011). In pasture-fed systems, grazing on younger pastures, in particular with legumes mixes and grasses with lower fibre content, reduces the passage rate and consequently the production of $CH_4$ (Robertson and Waghorn, 2002). Legumes influence methane yield as well as nitrogen losses. Legumes have a high crude protein (CP) content, while cereal grains have a lower CP compared to other types of concentrate feed (e.g. oilseed meals). Combining legumes and cereal grains to keep the ration CP below 16% DMI prevents feeding excess nitrogen, which would be otherwise excreted in the urine, increasing ammonia ($NH_3$) losses, as well as in the manure, increasing nitrous oxide ($N_2O$) losses.

The use of concentrates in the ration has proven to be effective in reducing methane emissions i.e. Forage : Concentrate ratio of 1:1. Replacing high fibre dried grains with maize- or wheat-based concentrate feed reduces $CH_4$ emissions by 12% according to Benchaar et al. (2001). In fact, feeding rations with low fibre and high energy contents influence enteric fermentations, but if pushed too far the economic benefits of rumination would be lost. Concentrates reduce ruminal pH and consequently reduce $CH_4$ emissions. High fibre dried grains i.e. barley have more fibre compared to maize and wheat; hence their potential to reduce ruminal pH and $CH_4$ emissions is lower, but they cost less.
Dietary supplements can also be used to influence the ruminal pH and the activity of the rumen methanogenic population. Oils, fatty acids and various seeds directly inhibit some rumen methanogens. Sunflower oil reduces enteric $CH_4$ by 10% g/kg DMI, canola oil by 18% and flaxseed by 16% (Beauchemin et al., 2008). Granger et al. (2010) observed a reduction of methane losses by 2.9% per 1% of added fat in ruminants. Coconut oil, sunflower seeds and rapeseeds reduce methane losses by up to 27% (Machmüller et al., 2006).

Plant secondary compounds such as tannins and saponins influence the acetate-propionate balance, reducing methanogenesis, ruminal pH and hydrogen ($H^+$) availability for ruminal bacteria and protozoa, increasing the overall efficiency of low forage / high concentrate diets. Tannins reduce methane losses by 13-33% according to Animut et al. (2008), while toxic effect of saponins found in yucca, corn, potato starch, corn hay, wild rye concentrate and hay concentrate have on methanogens can reduce enteric methane production by 2-28.3% enteric $CH_4$ (Patra and Saxena, 2010).

At a lower pH, hydrogen ($H^+$) is less available to produce $CH_4$ (Hegarty et al., 1999; Joblin, 1999). Certain ionophores, such as the antibiotic monensin, produced by *Streptomyces cinnamonensis,* reduce the acetate-propionate ratio by inhibiting the activity of ruminal protozoa, therefore reducing $CH_4$ production by up to 9-10% (Castro-Montoya et al., 2012; McGinn et al., 2004; van Vugt et al., 2005; Waghorn et al., 2008; Weimer et al., 2011). Guan et al. (2006) estimated the reduction at up to 30% and Eckard et al. (2010) suggested a dose-dependency interaction. Moreover, studies in the past have shown that ionophores have a transient effect of approximately 2 weeks (Wang at al., 1998) and the use of ionophores is tightly regulated within the European Union (Lovett et al., 2006), not making it an attractive option for GHG mitigation. There may, however, be some benefits in rotating rations containing ionophores to prevent methanogen adaption.

### 3.3.2 Mitigation of nitrous oxide emissions

#### *3.3.2.1 Livestock husbandry*

In the study of gaseous nitrogen losses from livestock housing, it is important to remember that even though ammonia is not a greenhouse gas, its concentration influences the environmental performance of farms and the issues related to pollution. Following naturally occurring nitrification and denitrification reactions, ammonia leads to the emission of $N_2O$. In pig housing, the use of fully slatted floors reduces ammonia ($NH_3$) losses by 46% (Lachance et al., 2005) and the use of various types of concretes can reduce $NH_3$ losses by 23 to 80% (Hamelin et al., 2010). Regularly flushing hard standing areas with water and water with the addition of formalin also decreases $NH_3$ emissions by 15% and 50% respectively (Misselbrook et al., 2006). These results are related to the fact that such systems are easier to clean; therefore they provide less substrate for the reactions that transform ammonia and nitrates in nitrous oxide and they support results from studies on slurry based systems with slatted floors or hard standing areas in ruminant and pig housing, where the $N_2O$ emissions registered from livestock housing were close to zero (Ellis et al., 2001; Jungbluth et al., 2001; Misselbrook et al., 2001; Thorman et al., 2003).

#### *3.3.2.2 Dietary management*

Grinding and pelleting feed, especially in pigs and poultry, increases feed digestibility, therefore it maximizes feed conversion efficiency and reduces N excretion in manure by 22-30% (Rotz, 2004).

Plant chemical composition also influences nitrogen losses. Tannins increase the efficiency of amino-acids digestion, reducing urine N excretion by 45-59% and increasing faecal N excretion by 18-21%. However, the overall $N_2O$ emissions can be reduced by 5-10%, even though the degradation of urine on soil is faster than that of faeces (Patra and Saxena, 2010). In ruminants, fat supplementation influences not only methane emissions but also reduces by 14% $NH_3$ emissions from fresh manures (Machmülller et al., 2006), even though this is not a GHG, it is important from a plant fertility and pollution perspective.

The use of concentrates can effectively mitigate nitrogen losses, as concentrates reduce ruminal pH and influence ruminal activity. Maize and wheat-based concentrate feeds register a reduction by 54% of N excretion from slurry, compared to slurry from barley diet (Klevenhusen et al., 2010). In lactating cows, Luo et al. (2010) observed a reduction by 22% of $N_2O$ / kg of milk produced. They attributed the result to the lower protein content found in maize-based concentrate feed, which reduces the risk of feeding excess N in the ratio, especially to animals on pasture. The total N excreted can be reduced by 8.9% and ammonia losses can be reduced by 36.5% (Arriaga et al., 2010a; Arriaga et al., 2010b). Misselbrook et al. (2005b) analysed N losses in dairy cows with a CP reduced from 19.4 to 13.6% of DMI. They observed a reduction of total N losses by 30% and reductions of urinary N and faecal N by up to 45% and 44% respectively.

Lowering the protein intake of cattle can be used to reduce nitrogen losses. However, in order to maintain an appropriate intake of at least 14% DMI, oilseed meals can be used to balance the total CP intake in case legumes are not used in the ration as forage (Beauchemin et al., 2008).

Balancing the protein intake and energy intake ratio is particularly important in pig nutrition. For example, a reduction of CP intake can reduce the total N excreted by 24.1% when CP in fattening pigs is reduced from 17.64% to 14.37% (Philippe et al., 2006). In ruminants, increasing the salt intake leads to an increase in water intake from the animal, with consequent dilution of urine. Although an absolute reduction in N excretion isn’t observed, the concentration of nitrogen in urine can be reduced by up to of 5-10% (Eckard et al., 2010).

#### *3.3.2.3 Manure storage and treatment*

A significant amount of literature addresses various issues related to the storage and treatment of manure and slurries. It is generally advised to adopt dry manure systems (Karakut et al., 2012) and separate the solid and liquid fractions for better storage management. A series of practices help reduce emissions from both fractions and the following summarises the most effective ones in the treatment of solid manure and liquid fractions from ruminant and monogastric livestock systems. Treatments of the solid fraction include composting, compacting, mixing with straw, the control of pH and temperature of the compost pile and the use of a series of additives.

Composting can be static or involve monthly turning of the compost pile. There are significant differences between the two treatments. Static composting of the solid fraction, without turning or a cover, increases its dry matter (DM) content, consequently reducing $NH_3$ losses by 60% $NH_3$ (Brito et al., 2008; Szanto et al., 2007). On the other hand, the monthly turning of the compost bed increases aeration, influencing the porosity and the structure of the compost pile. It also helps maintain a more homogeneous temperature. Gaseous emissions due to anaerobic processes are reduced, with reduction of nitrous oxide and methane emissions by 46% and 89.8% respectively; however, nitrate leaching can increase by up to 66% (Brito et al., 2008; Shen et al., 2011; Szanto et al., 2007).

It is important to remember that gaseous losses from manure can only be effective by controlling the temperature of the compost pile and the balance between aerobic and anaerobic conditions. Compacting can reduce $NH_3$ by up to 90% and to a certain extent $N_2O$ (up to 30% reduction); $CH_4$ emissions are reduced in colder months, but may significantly increase in warmer months (Chadwick, 2005). The addition of water can reduce the free air space by 20-60%. These conditions do not favour the reactions that produce nitrous oxide, resulting in a reduction of $N_2O$ emissions by 30-70% (Abd El Kader et al., 2007). Mixing solid manure with straw on a 1 : 1 ratio can increase the Dry Matter content of the compost pile, influencing the Carbon : Nitrogen ratio and therefore reducing $N_2O$ emissions by up to 32% (Yamulki, 2006).

Covers can be used to reduce ammonia volatilisation, nitrous oxide and methane emissions. The work of Thorman et al. (2007) summarises results indicating that permeable covers (i.e. straw) have a dual effect on nitrogen losses. The addition of straw effectively reduces $NH_3$ losses from FYM heaps by 60 to 90%; however, $N_2O$ losses more than double. In the case of straw-based storage systems, it is advised to apply FYM directly to field and reduce the storage period to a minimum, as storage accounts for ca. 85% of $N_2O$ emissions.

Impermeable covers provide the anaerobic conditions necessary to prevent $NH_3$ losses. The mitigation effect varies from 60 to 90% reduction in $NH_3$ volatilisation. Impermeable covers such as tarpaulin or plastic are more expensive than other types of covers, but they have several advantages: they are durable and can be used to effectively capture methane produced by the manure storage units (e.g. heap, lagoons) to take it to combustion plants such as anaerobic digesters (Funk et al., 2004a; Funk et al., 2004b; Stenglein et al., 2011; Thorman et al., 2006).

Airtight covers do not provide favourable conditions for the facultative aerobic microorganisms responsible for the production of some $CH_4$. Methane emissions can be reduced by up to 54%. However, when impermeable covers are used, it is necessary to make sure the cover is airtight to avoid gas leaks. Ideally, pipes or hoses should be used to redirect emissions to ventilation units. During storage of liquid manure, peaks of emissions can be registered when the pit is covered by a thick crust and cracks occur under pressure from gases underneath the surface (Hansen et al., 2006; Rodhe et al., 2009; Stenglein et al., 2011).

Emissions can be mitigated by ensuring optimum pH and temperature of the manure heap. Methane emissions are significantly reduced when slurry is uncovered and has a pH below 4.5-5. The reduction can be of up to 40% but the effect of acidification of slurry can vary: pH < 6.0 reduces $CH_4$ and $N_2O$; pH < 5.0 reduces ammonia losses as well (Berg et al., 2006). Temperature of storage can be reduced using shades or piping systems. Very little $N_2O$ emissions are registered at temperatures in the range of 5-25°C e.g. when a surface crust if formed. However, higher $NH_3$ losses are registered at 25°C (Dinuccio et al., 2008; Rodhe et al., 2009). $CH_4$ emissions from slurry stored below 15- 20°C are lower than at 24°C. For instance, $CH_4$ emissions during the summer are about 20% higher than the annual average. This could be explained by the fact that in a cold month, a surface crust can form and prevent the release of $CH_4$ and other gases (Massé et al., 2008; Rodhe et al., 2009; Sommer et al., 2007; van der Zaag et al., 2010). Moreover, the use of additives such as lactic acid, saccharose combined with temperatures of 4°C reduces $NH_3$ volatilisation by 43% according to van der Stelt et al. (2007). The addition of phosphogypsum reduces the total greenhouse gas losses by 54%; emissions register a composition of 14% methane and little to no $N_2O$. Phosphogypsum is a by-product of the fertiliser industry. It influences the pH of the compost pile and its sulphur content. The majority of gaseous losses are as in the form of carbon dioxide emissions, which have a lower Global Warming Potential compared to methane and nitrous oxide. One of the advantages of such treatment is that the end product of the composting phase has potentially higher value as fertiliser depending on its use, registering unchanged nitrogen content when compared to untreated compost piles, but higher sulphur content (Hao et al., 2005).

The separation of the liquid fraction from the solid fraction has numerous advantages in terms of management of storing conditions. Storing fractions separately allows a better control over factors influencing emissions: temperature, water content, aeration, cover. In addition, separation may increase slurry storage capacity and fractions may have a higher nutrient content. This is an advantage if slurry is used as fertiliser. However, slurry separation can only effectively reduce ammonia and methane emissions, in particular from the solid fraction, when combined with lower temperatures and solid cover solutions. Dinuccio et al. (2008; 2011) and Fangueiro et al. (2008) have reported limited benefits in terms of emission mitigation when the two fractions remain untreated. Storage of liquid fraction in anaerobic conditions does not promote nitrification of ammonia ($NH_3$) to nitrates ($NO_3^-$) and therefore, denitrification reactions that produce nitrous oxide ($N_2O$) are also reduced to a minimum (Fangueiro et al., 2008).

After separation, the liquid fraction can be stored or used in anaerobic digesters and the solid fraction can be composted. Factors such as crust, cover, temperature and aeration modify emissions greatly. The effect of encrustation of the surface of slurry or its cover is twofold: it increases $N_2O$ emissions but lowers $NH_3$ emissions. To effectively reduce $N_2O$ emissions, a cover and additives can be used. Storage of liquid fraction in anaerobic conditions does not promote nitrification ($NH_3$ to $NO_3^-$) and, therefore, denitrification rates are also reduced to a minimum. Nitrous oxide emissions are only registered in slurry with a dry encrusted surface, in particular when containing straw. This is caused by the lack of oxygen and by the higher temperatures and pH developing during storage (Berg et al., 2006; van der Zaag et al., 2009). Natural crusts prevent the proliferation of aerobic microorganisms that produce methane. Methane emissions can be reduced by 34% and nitrate leaching can also be halved. However, the effectiveness of a natural crust can vary greatly depending on its thickness, which influences N losses and durability. Therefore it is generally not advised to let a natural crust form (Bicudo et al., 2003; Misselbrook et al., 2005a).

The use of anaerobic digesters to treat the liquid fraction has a positive impact on methane emissions from manure, significantly lowering their impact on the farm emissions balance by up to 75% (Turnbull and Kamthunzi, 2004). In the case of the liquid fraction being used in anaerobic digesters, aeration is advised before the slurry is used in a digestate. Aeration usually involves mixing, without the formation of a crust. This practice creates aerobic conditions, having multiple effects on emissions: (i) increased $CH_4$ yields from digestate by 2-14.6%; (ii) increased $NH_3$ emissions, which are usually reduced in anaerobic conditions; (iii) lower $N_2O$ emissions (Berg et al., 2006; Fangueiro et al., 2008; Misselbrook et al., 2005a). These effects are due to intermittent mixing, which increases biogas production yields by maintaining an optimum level of aeration and particles distribution. Crust layers are less likely to consolidate and the overall yield of the biogas plant increases, at virtually very little or no cost (Kaparaju et al., 2008). Methane yield from the digestate can double by adding 1% of glycerol (Wohlgemut, 2010), where the process remains stable, the quality of the end products does not vary and the yield is significantly increased, offsetting other sources of emissions at the farm level.

#### *3.3.2.4 Soil and pasture management*

Grazing animals, particularly those on legume pastures, have a higher rate of ruminal ammonia ($NH_3$) excreted as urea in the urine (Arelovich et al., 2003). Ruminal ammonia is the result of digestive processes involving non-protein nitrogen. The nitrogen contained in urine applied to soils during grazing is converted into nitrates ($NO_3^-$) by nitrification, which can subsequently produce nitrous oxide ($N_2O$) by denitrification reactions, hence the relation between urine from grazing ruminants and $N_2O$ emissions. Furthermore, as nitrous oxide emissions are higher in wet conditions, they can be reduced by 7-11% according to the IPCC (2006) and by up to 40% (de Klein at al., 2006) by avoiding grazing in colder and wetter months.

A series of practices can improve soil management and reduce $N_2O$ emissions. Grazing systems should aim at minimizing poaching by using strip and paddock grazing systems where animals are moved to a new pasture every day; and minimize runoff and animal treading i.e. avoid grazing on slopes (Menneer et al., 2005). Soil compaction reduces aeration, negatively affecting water content, drainage, plant growth and soil composition. Indicatively, compaction can lead to an increase of methane emissions up to 30-90% and nitrous oxide emissions by up to 20-200% depending on the type of soil, and should therefore be avoided, in particular on heavy soils i.e. clay, clay loam, as it has greater negative impact than on lighter soils i.e. sandy loam, loam (Mosquera et al., 2007; Snyder et al., 2009). Waterlogged soils present lower soil aeration, which promotes denitrification of nitrates, therefore increasing $N_2O$ emissions. By ensuring appropriate soil drainage, nitrous oxide emissions can be reduced by up to 27% (Luo et al., 2010). The use of stand-off or feed pads in colder, wetter months restricts grazing and reduces the amount the effluent deposited on the soil. Removal of manure from the areas surrounding the feed pads can reduce nitrous oxide emissions by up to 60% according to Luo et al. (2010).

The adoption of rotational grazing influences both grazing time and grazing density. In particular, moving animals every 1-2 days can have a great impact on both methane and nitrous oxide emissions. Reducing grazing time has multiple advantages: it increases the chances that animals graze on younger pasture, which has lower fibre content, therefore reducing $CH_4$ emissions by up to 22%; and when combined with reduced fertilizer use, it decreases the N-availability on pasture, therefore reducing by up to 10% nitrous oxide emissions (DeRamus et al., 2003; Schils et al., 2006). Reducing grazing density will avoid overgrazing and soil compaction. This will lead to lower nitrous oxide emissions, especially on heavy soils. Nitrous oxide emissions can be reduced by 25% according to Flechard et al. (2007); however, the reduction is proportional to the livestock production stage and the overall reduction of methane and nitrous oxide emissions can reach up to 55% (Allard et al., 2007; Saggar et al., 2007).

Ensuring the correct rate and timing of fertiliser application reduces the risk of applying excess nitrogen and therefore reduces nitrous oxide emissions from soils. The application of nitrification-inhibitor-coated fertilisers can reduce nitrous oxide emissions by up to 70-80%. This experimental strategy has been tested on different soil types and managements and it has been observed that the use of a fine-particle suspension nitrification inhibitor (i.e. dicyandiamide, DCD) reduces the rate of ammonium ($NH_4^+$) converted into nitrate ($NO_3^-$), which then is converted into nitrous oxide ($N_2O$) by denitrification. Therefore the use of DCD reduces nitrate leaching and gaseous losses as $N_2O$ (Di et al., 2007; Eckard et al., 2010). However, this strategy is still not economically viable for farmers, as it is an experimental product and its effectiveness varies greatly depending on weather and soil conditions (Monaghan et al., 2009).

## 3.4 Next steps

This review highlighted the key areas for intervention in order to mitigate methane and nitrous oxide losses at the farm level. Practices taken into account can be divided in 5 areas: dietary management, livestock housing, manure storage and treatment, grazing and pasture management and manure application to soil. Only literature providing quantifying measures of emissions reduction in relation to practices that are under farmers' control was considered. This approach ensured that farmers could see a direct link between the good agricultural practices and the potential for GHG mitigation in various livestock systems. In spite of the uncertainty regarding the effectiveness of certain practices, the review showed that a great number of options are available to the farmer. In particular, it showed that some practices have multiple benefits, reducing methane and nitrous oxide losses, as well as limiting waste management or improving animal productivity. However, results from other practices need further assessment, especially in relation to their cost-effectiveness and compliance with GAPs, GAECs and Environmental Stewardship Schemes.

Therefore, this review of literature quantifying GHG emission mitigation from livestock farming systems showed that there is sufficient scientific knowledge of the topic to achieve successful on-farm mitigation. It is now necessary to analyse the possible barriers to farmer engagement, notably considering farmers' perceptions of the issue of GHG emissions and on-farm mitigation. What is the best way to engage with farmers to drive change and promote on-farm innovation? Researchers need to acknowledge the effectiveness of knowledge transfer techniques, the importance of social capital and how networks of influence within the agricultural sector can represent a strength rather than a barrier to change.

The following chapter illustrates the fundamental theories behind successful farmer engagement, as a foundation for a framework that creates opportunities for effective communication and partnership with the livestock farming sector.

# Chapter 4

# Farmer engagement

# 4 Farmer engagement

Successful farmer engagement can play an important role in providing constructive advice to farmers and promoting on-farm innovation on the one hand, while providing valuable information to future policy-makers on the other hand. As illustrated in section 2, farmers can be exposed to multiple pressures linked to production processes, the influence of agri-environmental policies, market forces and the need to ensure the sustainable use of environmental resources. Therefore, the issue of GHG emission mitigation may not be a priority for farmers, as from their point of view the benefits from the adoption of mitigation strategies may not be clearly defined. This chapter addresses the challenges facing farmer engagement, farmers' drivers for innovation and the opportunities to overcome current barriers to the adoption of innovative agricultural practices, such as in this case practices promoting GHG emission mitigation.

## 4.1 Introduction

In order to reduce emissions at the farm level, it is essential to consider farm practices that are directly under farmers' control. However, it is also important to consider the current challenges that farmers are facing and how farmers' attitudes to climate change are affecting their decisions. This is particularly vital in order to better understand the dynamics within the farming sector, where decisions may not be taken solely on financial grounds. The previous chapter explored the issues related to greenhouse gas (GHG) emission mitigation. In spite of uncertainty regarding mitigation strategies and the disconnection between farmers, researchers and policy makers, successful farmer engagement can be achieved by adopting the principles of Participatory Action Research (PAR) to complement the current knowledge of farmer drivers for innovation.

## 4.2 Practical challenges

### 4.2.1 Greenhouse gas emission mitigation

Farmers face a number of challenges in considering how to reduce greenhouse gas (GHG) emissions. These include knowledge of mitigation, the level of support and advice available and the attitudes of farmers per se. In spite of the residual uncertainty surrounding the validity of results from carbon calculators available from the agricultural sector, a substantial scientific literature provides useful options for farmers who want to reduce their carbon footprint by mitigating methane and nitrous oxide losses. These were addressed in chapter 3, and include:-

- Increased concentrates and use of legumes as forage;
- Reduction of the Crude Protein content in the ration of ruminant and especially monogastric livestock;
- Improved feed conversion efficiency;
- Frequency of manure removal from housing units, type of litter, type of floor and regular flushing and cleaning on livestock housing;
- Treatment of solid and liquid manures e.g. low temperatures, aeration, composting, straw addition, the use of covers;
- Anaerobic digestion can be used to benefit from methane emissions as a source of energy;
- Use of legumes on pasture, shorter rotational grazing patterns and attention to soil management (i.e. avoiding waterlogging and compaction);
- Timing of manure application to soils, type of application, application rate.

However, it is important to consider farmers' attitudes and perceptions of mitigation strategies. In order to do so, the study needs to address GHG emission mitigation from a perspective which includes social dynamics and interactions between farmers and researchers as change agents.

### 4.2.2 Influences on decision making

Farmers' perceptions of GHG mitigation strategies are a key element to understand the potential for adoption of new policies to incentivise emission reduction. Farmers tend to be more concerned about the practicality of some changes, in particular the ones involving capital investment or an increase in labour, while some mitigation options can be difficult to implement due to the size of the farm and/or its adoption of Environmental Stewardship schemes. In fact, a recent survey of experts and farmers on GHG mitigation strategies evaluated a series of mitigation options in terms of effectiveness according to experts and in terms of practicality according to farmers (Jones et al., 2013). The results showed that only 6 out of 26 strategies were considered both effective and practical, indicating that the adoption of mitigation strategies may vary significantly based on advice and support given to farmers and that *"flexible policies are needed to enable farmers to select the mitigation measures that are most suited to their own situation"* (Jones et al., 2013, p.9). Government policies have multiple influences on farmers' attitudes and decision making. Policies that incentivise conservation actions and help accessing financial support are considered beneficial to improve farm practices (Deressa et al., 2009). On the contrary, the lack of information and the lack of social capital have a negative effect on farmers' scepticism around issues related to climate change. Activities that promote social capital are farmer-to-farmer knowledge sharing and government extension or advisory system (Islam et al., 2013).

Networks of influence play an important role in promoting innovation among farmers. They foster farmer-to-farmer knowledge sharing and complement scientific research carried out by academia, independent research institutions or government agencies. In this respect, it is important to understand the value of farmers' knowledge and experience, and their contribution to the successful application of scientific research in order to promote effective communication and capacity building (Virji et al., 2012). There is a historical difference between scientific knowledge and local knowledge. The latter is based on practical experience and anecdotal knowledge, therefore it is usually not considered to have a real value in formal scientific research. However, in the agricultural sector, social interactions, networks and behaviours are influenced by individuals' knowledge and experiences, and the gap in communication between researchers and farmers can affect the successful implementation of innovating strategies (Castellanos et al., 2013). Researchers are seen as distant entities that focus on one particular aspect that interests them, without considering other factors that might affect farmers' perceptions and attitudes to climate change. Therefore, farmers generally tend to rely more on peers' experiences and knowledge, rather than on advice given by scientists. Indeed, influential individuals within farmers' groups may have a much greater impact than scientific advisors. This suggests that successful farmer-driven innovation can be achieved through activities that generate knowledge and network interactions, such as farmer groups (McKenzie, 2011). While being willing to pay for independent advice when needed, farmers also appreciate flexibility in recommendations regarding their farming systems. This approach is essential to gain credibility and trust from farmers and it will help researchers focus on practical problems, rather than proposing solutions based on theoretical models. Fostering the generation, sharing and transfer of knowledge and the interactions between farmers networks and groups of interest is the way forward in order to engage with farmers on innovation and more generally, on agri-businesses sustainability (Raymond et al., 2010).

### 4.2.3 Agricultural extension services

Farmers' attitudes and perceptions of climate change are greatly influenced by the contact with other farmers and individuals within farmers' networks of influence. External influences are represented by a range of actions from the media and extension officers to pressure groups and consumers per se. However, one of the greatest challenges is that over the past 30 years government funding for extension and advisory work in the UK as well as in other European countries has been gradually reduced (Swanson and Rajalahti, 2010). Extension services now vary in efficiency and impact, relying mostly on privatised, and therefore fragmented, action (Oreszczyn et al., 2010). The issues related to agricultural research in the UK were already highlighted more than a decade ago by Buhler (2002), who illustrated how the government's interest, and therefore funding, moved away from research including farmers' participation to embrace a model based on private funding and therefore limiting the government agricultural extension services in the UK. In fact, drawing from experiences in the developing world, Islam et al. (2013) suggest that farmers' reluctance to embrace change or adopt on-farm innovation could be dealt with by using a long-term, broader approach to extension that includes formal and non-formal education, rather than relying solely on narrower approaches based on purely technical advice that doesn't take into consideration social implications of change. In spite of the need for substantial government investment, this strategy presents multiple advantages as it generates knowledge transfer activities, promoting advances and innovation in the agricultural sector, ensuring transparency and knowledge sharing. Farmers appreciate being presented with possible innovative solutions not only from a technical or environmental point of view, but also from an economic point of view that considers cost-effectiveness of each strategy, to allow them to choose the best option for their system (Islam et al., 2013; McKenzie, 2011). A broader approach to extension also fosters two-way communication between farmers and researchers. These links enable researchers and policy makers to reach a better understanding of the underlying factors that influence farmers' decision making (Kings and Ilbery, 2010). Therefore, it helps building both social capital and it promotes successful communication between farmers, researchers and policy makers by addressing practical problems without neglecting environmental and socio-economic implications. Promoting farmers, researchers and government agency has obvious benefits in terms of policy making, facilitating the implementation of future policies addressing natural resource management and Good Agricultural Practices (GAP) (Islam et al., 2013; Röckmann et al., 2012).

Finally, effective innovation is highly dependent on successful communication between all parties involved: farmers, researchers and policy makers. Innovation needs to overcome the barriers created by on the one hand scepticism over climate change and how the UK government is addressing the issue in the agricultural sector, and on the other hand the dichotomy in goals and objectives between farmers and researchers.

## 4.3 Theoretical background

### 4.3.1 Social capital

Section 4.2.1 has shown that social relationships have a great influence on the way farmers, researchers and government interact. In particular, these interactions play a key role in farmers' attitudes and perceptions to issues related with climate change and, therefore, in the adoption of on-farm innovation. These findings suggest that approaches that promote social capital building activities are likely to have positive outcomes in terms of farmer engagement and adoption of innovation. But what is exactly social capital and how do the concepts behind social capital theory apply to the agricultural sector?

The definition of social capital most widely acknowledged nowadays is the one reported by the World Bank: *"Social capital is defined as the norms and social relations embedded in the social structures of societies that enable people to co-ordinate action to achieve desired goals"* (Narayan, 1999, p.6). This broad definition has been widely accepted by the Organisation for Economic Co-operation and Development (OECD) (Keely, 2007) and in the United Kingdom by the Office for National Statistics (ONS, no date). Both accept the description that identifies three main types of social capital:

- *Bonding Social Capital*: It is represented by the links between people that share common values and a common identity. These bonds create strong connections between individuals with homogeneous characteristics.

- *Bridging Social Capital*: This type of social capital is represented by the links and networks between individuals and groups external to the closest circle of relationships. It can include business relationships and more heterogeneous links to individuals and groups that can share interests but do not necessarily share a common identity.

- *Linking Social Capital*: It is represented by the network of relationships with individual or groups in a different position of power within the social hierarchy; for instance, government agencies, national institutions.

As in other sectors of society, the benefits of enhancing social capital are multiple in the agricultural sector. Trust and the acknowledgement of the value of individual and collective knowledge can be considered as essential components of social capital (Burton and Paragahawewa, 2011). The authors suggest that the relationships between farmers, policy makers and intermediaries can benefit from a higher level of trust; therefore, farmers can be more likely to embrace change and innovation. It can then de argued that trust can play a key role in influencing farmers' attitudes to on-farm innovation, in particular in the case of advice given to promote less tangible benefits such as ecosystem services and environmental conservation (i.e. agri-environmental schemes), as well as the assessment of the economic impact of agri-businesses. Furthermore, a strong social capital may also result in less effort needed from policy makers in promoting environmental schemes, as farmers will be more inclined to join on their own accord (Burton and Paragahawewa, 2011). A cohesive social capital is more likely to result in improving the effectiveness of common-pool resource management; in fact, people will take on the monitoring and enforcement of environmental regulations, actually converting regulatory acts in social acts (Ostrom, 2000).

However, in spite of the recognised importance of social capital to improve relationships at various levels between individuals and groups, leading to increased farmer participation, there are few studies on the influence of trust and its impact on issues related to agriculture and environmental conservation (Mariola, 2012). However, Hall and Pretty (2008) found that social capital, and in particular linking social capital, have a great influence on farmers' attitudes and consequently on farm management. Moreover, a recent study undertaken in the South West region, on the relationship between farmers and government advisors on bovine tuberculosis, highlighted the importance of social capital within the sector and suggested that lack of linking social capital, represented by consistent contact with extension officers or government advisors, has multiple negative impacts: lower level of trust in government officials and more generally, in government actions, lower level of credibility of the information and advice given to farmers (Fisher, 2013).

Finally, fostering social capital and building relationships based on trust have the potential to promote effective two-way communication between the various actors involved: researchers, farmers and government agents. Therefore, by acknowledging the importance of social capital, researchers need to adopt methodologies that ensure effective knowledge transfer to farmers, while at the same time build a strong linking social capital that will promote farmer participation and improve their attitudes to change and on-farm innovation.

### 4.3.2 Participatory Action Research (PAR)

The societal divide between researchers and farming communities is affected by a tangible difference in the goals and in the means and language used to communicate their knowledge. In the case of greenhouse gas (GHG) emission mitigation, translational research can achieve good results in term of farmer engagement and innovation adoption, provided it is oriented toward practical problem-solving activities and listens to farmers' opinions. Therefore, the difficulties in communication can be overcome by adopting a pragmatic approach to research. PAR represents one of the most effective strategies. It is described as *"a reflective process of progressive problem-solving led by individuals working with others to improve the way they address issues and solve problems"* (German et al., 2012, p.16), where different actors engage at various levels, building social capital in order to find collective solutions (Pretty and Buck, 2002). This approach is in stark contrast with the one used in conventional research. The main differences between PAR, action research (AR) and conventional research are summarised (Table 4.1). It is important to analyse these methodologies in the context of agricultural research. Participatory Rural Appraisal (PRA), a methodology within PAR, is often used to provide farmers with tools to obtain information on their environment. This approach has limited advantages, addressing the problems from the primarily technical point of view of the researcher. Conversely, PAR aims at listening to and empowering farmers in promoting innovation. It then monitors change, reflects on achievements and failures, and proposes new actions to drive change (German et al., 2012). Moreover, although PAR and AR can sometimes seem to overlap, given the lack of a context-independent definition of what is "action" and what is "research", PAR has been successfully adopted in a number of studies to promote rural development, and it is argued that this is due to stakeholder engagement (Mapfumo et al., 2013; Oliver et al., 2012; Phillipson et al., 2012; Shortall, 2008). By translating current scientific knowledge and by promoting farmer-to-farmer knowledge sharing, it is argued that PAR provides support to farming communities and has a greater influence on farmers' attitudes to scientific and technological innovation.

According to a recent study on the benefits and issues related to PAR in the agricultural sector in the European Union, one of the key characteristics of successful two-way communication between the parties involved is transparency and respectful listening (Röckmann et al., 2012). The main advantage in this approach is that collaboration between scientists and stakeholders will help understand how best to deal with uncertainties, in particular regarding the effects of mitigation strategies on farm incomes, profitability and environmental impact. Therefore, scientists should focus on practical problems, rather than theoretical modelling alone, according to Le Gal et al. (2011).

Table 4.1 Characteristics of different learning approaches (adapted from German and Stroud, 2007).

| Characteristics | Participatory Action Research | Action Research | Conventional (Empirical) Research |
|---|---|---|---|
| 1. Purpose | Solve localized problems | Derive lessons for the global community on how to solve certain types of problems | Characterize past and current situations and use trends to predict future |
| 2. Tools | Interactive[1] (facilitation, negotiation, participatory monitoring and evaluation) | Extractive (monitoring the performance of scientific indicators, impact assessment, process documentation) and Interactive (some PAR methods) | Extractive (a large body of methods derived from diverse social and biophysical sciences) |
| 3. Carried out by whom? | Actors in a change process (farmers, leaders of organizational change, policymakers, urban residents) and researchers as facilitators | Researchers with an interest in “process” (how transformation occurs); change agents interested in deriving generalizable lessons, who bring stakeholders along with them | Researchers. At times, change agents will also turn to conventional research either for inputs (i.e. technologies) or to evaluate the impact of change processes they have facilitated |

[1] PAR is not just a set of tools, but a philosophy and broad approach to knowledge generation and societal engagement.

In agricultural research on GHG emission mitigation, it is important to consider that there is a great deal of uncertainty. On the one hand there is a range of estimates in mitigation potential, due to the variety of physical factors affecting the results, and on the other hand the socio-economic impacts of mitigation strategies at the farm level are affected by farmers' and researchers' attitudes. Uncertainties do not play in favour of successful communication based on trust; therefore, successful farmer engagement is needed in order to fill the gap between scientists and farmers. Frustration over lack of clear government action on issues related to greenhouse gas emissions from farms is widespread among certain types of farmers, in particular small-scale and organic farmers. Farming communities may have different goals and objectives, but all share concerns over the lack of effective communication from the government, which results in scepticism and general mistrust in interventions by actors outside of the farmers' relatively limited networks of influence (Kings and Ilbery, 2010). From a land use policy point of view, collaborative agri-environmental schemes are proven to have a positive influence on farmer engagement on environmental issues. However, barriers to collaboration between researchers, government and farmers are argued to primarily be the lack of communication among parties and the lack of long-term flexibility of environmental schemes (Emery and Franks, 2012).

The agricultural sector seems to be facing a paradox where farmers who are naturally inclined to adapt to changing circumstances, such as weather, labour and market demands, in order to ensure long-term sustainability and competitiveness of their businesses, are now reluctant to subscribe to schemes that they see as fixing their decision-making and thus affecting the very long-term environmental and socio-economic sustainability the schemes should be promoting. These arguments lead one to conclude that the agricultural sector is in need of participatory action and engagement with farming communities in order to break free from the pre-concepts about theoretical science and the mistrust of government. Farmers' knowledge and experiences need to have a value in agricultural research that supports the policy making process. Only by undertaking in-depth studies of context-based problems, can researchers help overcome the barriers surrounding farmer engagement and foster social capital that provide farmers with the necessary knowledge to face the challenges related to environmental impact e.g. conservation, greenhouse gas emissions, ecosystem services; and the socio-economic implications of policy actions at the farm level.

### 4.3.4 Case Study Research

In order to achieve successful PAR, case studies can be used to analyse in more depth the drivers for change among livestock farmers in England. In this context, the initial challenge consists not only in combining quantitative scientific studies with qualitative research relying on a selected group of case studies, but most importantly in justifying the use of case studies rather than the design of a broader, replicable, quantitative research strategy such as a farmer survey.

In support of case studies, Flyvbjerg (2006) identifies five misunderstandings often associated with case study research. These are also analysed by Tihanyi et al. (2011) in the context of farmers and agri-businesses in South Africa. Following Flyvbjerg's and Tihany's arguments, the following illustrate why case study research is an appropriate methodology to engage with farmers on GHG emission mitigation strategies.

*"Misunderstanding no. 1. General, theoretical (context-independent) knowledge is more valuable than concrete, practical (context-dependent) knowledge."*

The very scope of the study was to analyse context-dependent changes at the farm level. In fact, PAR seeks to engage with individuals and communities in order to understand processes, challenges and drivers for change. Human beings are naturally inclined to better understand a situation when immersed into it or when presented with a series of similar situations from which to draw greater insight of a given problem.

*"Misunderstanding no. 2. One cannot generalize on the basis of an individual case; therefore, the case study cannot contribute to scientific development."*

Case studies provide an analysis of a given situation in given conditions. Therefore, they are not meant to be generalised in order to explain what happens in broader contexts. In fact, in the agricultural sector, factors to be considered in development studies include not only soil, water, climate, crops and livestock, but also include economic factors such as productivity, competitiveness and access to markets, as well as broader socio-ecological factors such as biodiversity, environmental conservation and social capital, with a particular focus on rural livelihoods and farmers' attitudes and perceptions of climate change. Therefore, scientific development in agriculture is highly context-dependent, in particular of socio-economic factors that may affect the adoption of newer, better strategies to mitigate the impact of agricultural practices on the environment.

*"Misunderstanding no. 3. The case study is most useful for generating hypotheses, that is, in the first stage of a total research process, while other methods are more suitable for hypotheses testing and theory-building."*

One can argue that an experiment can be successfully replicated in vitro and a hypothesis can be developed from such consistent results. However, this cannot be used as guarantee that the same experiment replicated in vivo will give the same results, as have been found with a number of mitigation strategies. Similarly, case studies represent a valuable methodology that gives in-depth analysis in contexts in which relationships and dynamics within the society or within a specific sector of society may play a role in the decision making process, such as in this case the agricultural sector. Case study research does not aim at building a theory.

*"Misunderstanding no. 4. The case study contains a bias towards verification, that is, a tendency to confirm the researcher's preconceived notions."*

Bias is an important factor to consider when operating on case studies. However, various methodologies are available that can prevent bias to influence the selection of case studies. Case studies can be selected using different sampling methodologies, such as randomised sampling or cluster sampling. For the purpose of the present study, the criteria for selection were the type of farm (i.e. livestock), the type of production (i.e. extensive, low-input) and the location (i.e. South West region and West Midlands region).

*"Misunderstanding no. 5. It is often difficult to summarize and develop general propositions and theories on the basis of specific case studies."*

As it was already explained, case studies are meant to provide in depth analysis of a context-dependent situation, as opposed to a general in-depth summary. In fact, if the ultimate purpose of case study research was to summarise an in-depth analysis, then the analysis would lose its value.

Finally, Case Study Research presents a series of strengths and limitations. However, quantitative and qualitative social studies should complement one another, rather than ignore one another (Flyvbjerg, 2006). On the one hand, quantitative studies are needed to obtain information on a large scale that can provide valuable support for policy-makers. On the other hand, in-depth analysis of context-dependent situations is also needed to better understand the drivers for change within the farming community. By analysing the underlying barriers to farmer engagement, it is possible to reach a greater understanding of farmers' attitudes and perceptions of the impact of climate change at the farm level. This information is equally valuable for policy-makers in order to improve agricultural legislation and its implementation. The following study was developed to evaluate the potential for successful communication between academic researchers and farmers in the South West of England.

The role of social networks in natural resources management is the focus of extensive research in recent years. The current challenges facing researchers aiming at studying complex socio-ecological systems are highlighted in studies undertaking context-dependent research in both the developed and the developing world (Bodin and Crona, 2009; Bodin and Tengö, 2010; Bodin et al, 2006; Cornell et al., 2013; Ekins et al, 2003; Folke, 2006; Janssen et al., 2006; Österblom et al., 2010; Plummer and Armitage, 2007; Vignola et al., 2010). The understanding of complex socio-environmental dynamics ensures a more effective management of environmental resources and fosters cohesive, productive and sustainable rural communities. It is important to consider the locality of the issues to be addressed. Therefore, the methodology proposed in this study presents multiple advantages:

i. the potential for development of effective interdisciplinary research;
ii. a framework for successful long-term farmer engagement;
iii. it promotes knowledge sharing and interaction between researchers and farmers on the topic of GHG mitigation.

## 4.4 Multidisciplinarity

Farmer attitudes and perceptions of climate change are influenced by a complex web of factors. These range from economic pressure, to environmental conservation, to the social implication in terms of long-term sustainability of rural livelihood (Mills et al., 2013). Farmers' concerns may range from cross compliance and meeting Environmental Stewardship Schemes requirements to the cost of production and market pressures on prices and standards. Therefore, GHG emission mitigation may not be a priority for farmers. Moreover, the peculiarity of the agricultural sector lies in the fact that each agri-business is unique in its impact on the environment and the community as a whole. Research aiming at improving livestock farms practices to reduce the impact of GHG emissions needs to take into account the multi-faceted characteristics of rural livelihood and acknowledge that the one-model-fits-all approach cannot apply (Fischer and Glenk, 2011). Integrative methodologies should be adopted (Feola and Binder, 2010). In fact, with respect to the implications of human interactions on natural resource management, it is important to remember that *"knowledge integration, the blending of concepts from two or more disciplines to create innovative new worldviews, is a key process in attempts to increase the sustainability of human activities on Earth"* (Newell et al., 2005, p.299). Studies suggest that research addressing current environmental problems needs to embrace multidisciplinarity as a way to establish collaborative action between farmers, researchers, the private sector and government, in order to address practical issues facing the agricultural sector (Hicks et al. 2010; Jolibert and Wasselink, 2012; Sutherland et al., 2012; van Rijnsoever and Hessels, 2011; Weichselgartner and Kasperson, 2010).

A multidisciplinary approach can be considered appropriate in order to obtain an integrated assessment of the environmental impact of livestock farm practices in terms of greenhouse gas emissions. The peculiar modularity of the approach allows the researchers to address multiple challenges:-

- Initially, practices directly under farmers' control are critically assessed against current scientific knowledge and the farmers are provided with a choice of practical solutions to mitigate emissions;

- Subsequently, the more complex dynamics behind farmers' attitudes to climate change and their drivers for innovation can be analysed in depth to give evidence-based evaluation of the greater barriers that need to be addressed to promote the adoption of climate-friendly or climate smart farm practices.

At the same time, by acknowledging that research is only one of the aspects of innovation in the agricultural sector (Klerkx et al., 2012), the framework aims at promoting farmer-to-farmer interaction and knowledge sharing, as well as farmer-driven research. Quantitative and qualitative research methodologies are combined in order to engage with farmers by establishing a two-way communication between researchers and farmers and, therefore, providing practical solutions to farmers and socio-economical information which is of great value to policy makers.

## 4.5 Drivers for farmer engagement

Researchers should be encouraged to investigate the existing knowledge farmers have of GHG mitigation. Understanding farmers' knowledge and perceptions is the first necessary step towards the integration of local or experiential based and scientific knowledge, therefore ensuring successful environmental management (Oenema et al., 2011; Raymond et al., 2010). This critical step represents the strength and the weakness of any engagement methodology.

Integrating farmers' knowledge with scientific research is the foundation for Participatory Action Research that aims at improving existing situations and adopting the best agricultural practices based on specific environmental, social and economic contexts. On the other hand, the individuality of each farm shows that in order to be successful, science has to be problem-focused, instead of relying on categorisation of solutions. Decision support tools that allow farmers to specify in great detail the factors affecting GHG emission mitigation may eventually become highly complex and therefore at risk of becoming less appealing to farmers as end users. This aspect has a particular influence on extensive farming systems, where low-input management is more likely to affect future decisions, especially those requiring greater capital investments. Therefore, advisory services should give practical advice based on context-dependent circumstances.

### 4.6 Knowledge sharing

However, studies have shown that farmers' drivers for innovation and engagement with the research community may not be solely financial (Cocklin et al., 2007; McKenzie, 2011; Mills et al., 2013). Farmers are more inclined to accept knowledge shared within farmer-to-farmer groups or within other interests groups where knowledge is drawn not only from scientific research, but more importantly from experience. Unlike in the industry sector, where the process of categorisation and standardisation of best practices is easier to implement, in the agricultural sector the impact of innovation has greater inconsistency due to the variability in the size, type and geographic context of agri-businesses. Categorisation and standardisation have obvious limitations, which reflect in the disconnection between science-driven agricultural research and its practical application at farm level. Therefore, researchers need to gain credibility with farmers in order to overcome this social divide and achieve successful participatory research. Extension agents need to engage with individuals within the farmers' groups who might have greater influence on other members; they need to ensure that advice is context-dependent and they need to establish a consistent and transparent communication channel with farmers (Matouš et al., 2010; Oreszczyn et al., 2010). Therefore, the process requires time and resources that research institutions may not have. Greater investments from the government in supporting public-funded extension services would ensure consistency in advisory outcomes. Furthermore, these can be justified and reduced GHG emissions can be argued to be a public good. This would also address the barrier to engagement represented by farmers' frustration and lack of trust over unclear government agency.

## 4.7 Conclusion

Successful greenhouse gas emission mitigation needs to consider farm practices that are directly under farmers' control. This approach will ensure that farmers accept advice that is feasible and practical at the same time. Farmers' perceptions and attitudes to climate change have a great influence on the adoption of innovations. Extension agents need to understand the factors affecting farmer decision making. In particular, promoting linking social capital and establishing relationships based on transparency and trust greatly improve interactions between farmers and researchers or government agents. Researchers need to acknowledge the multidisciplinary aspect of the challenges facing livestock farmers. Therefore, a unique approach needs to be adopted, oriented to practical problem solving but at the same time valuing farmers' contribution to the knowledge pool. Such an approach will ensure that the barriers created by the lack of trust in individuals external to farmers' networks of influence are addressed and it will create opportunities for on-farm innovation based on successful participatory action and translational research. It is for these reasons that participatory case studies were chosen for the field study, as described in the next chapter.

# Chapter 5

# Case Study Research

# 5 Case Study Research

This chapter illustrates the methodology adopted in the study and provides a description of its stages, starting from the sample selection and continuing with details of the model used within the research framework.

## 5.1 Introduction

Greenhouse gas emission mitigation at the farm level faces two main challenges. On the one hand, the economic and logistic feasibility of mitigation strategies needs to be a priority of researchers who aim at advising farmers and agri-businesses. On the other hand, researchers and advisory services need to adopt appropriate, successful approaches to farmer engagement which are more likely to ensure long-term, two-way communications with farmers and embedded behavioural changes.

The key steps towards the establishment of successful collaboration between researchers and farmers are:

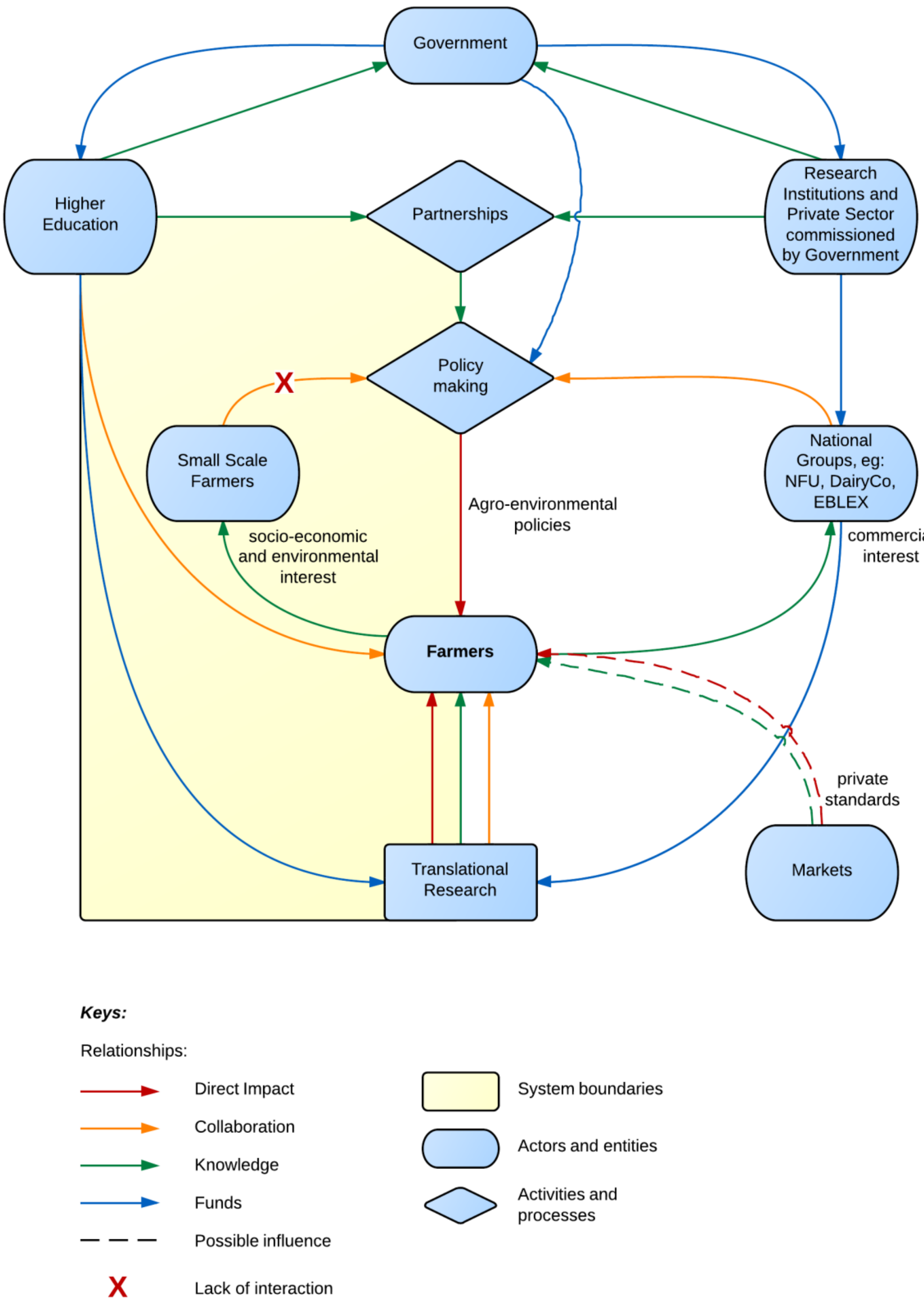
i. The understanding of farmers' knowledge and perceptions of the problems related to on-farm greenhouse gas (GHG) emissions;
ii. The provision of transparent knowledge transfer from scientists, in a language that is understandable by farmers (translational research) and
iii. The fostering of farmer-to-farmer networks to promote knowledge sharing and build cultural and social capital within the agricultural sector.

## 5.2 Methodological approach

When addressing livestock farmer engagement on GHG emission mitigation, the first step towards the formulation of a model is the identification of the system in which the study operates, in order to ensure that the research efforts are directed toward the intended target. Figure 5.1 provides an overview of the relationships between groups of farmers, academic institutions, interest groups and the government, and the possible influence of markets, based on recent studies addressing issues related to farmer engagement and the socio-economic interactions internal and external to the farming community. A key finding is the disconnection between farms producing on a smaller scale and institutions involved in the policy making process and between these smaller scale and extensive farms and markets. Hence the importance of promoting farmer engagement in order to increase the opportunities for collaboration, adopting translational research methodologies and fostering knowledge sharing activities.

The previous chapter highlighted the importance of adopting case study research in order to obtain in-depth knowledge of a specific situation. In this case of farmer engagement, case study research represents the research method that is more likely to succeed in identifying context-based barriers to engagement and possible solutions to overcome these barriers or minimise their negative impact on relationships between farmers and researchers. The aim of the study was to integrate impact assessment of on-farm GHG emissions with farmer engagement activities. As a pilot study set in the South West and West Midlands regions, it was based on a framework developed to include research methodologies that guarantee valuable results in short-term studies such as this one. The principles taken into consideration were illustrated in section 4.3.3.

Figure 5.1 Societal system boundaries.



These ensured that the model designed to evaluate on-farm impact assessment of farm management practices provided effective support to the translational research approach adopted, but within the timeframe assigned to the study.

### 5.2.1 Sample selection

The sampling technique adopted to select the farmers was chosen based on the resources available (i.e. time, financial support). Pilot studies adopt non-probability sampling technique such as *convenience sampling* as a cost-effective way for researchers to obtain a pilot sample under time constraints, by including individuals that are *“readily available”* (Özdemir et al., 2011). Convenience sampling of farmers has obvious limitations, linked to its non-probabilistic nature. Farmers that are listed in local or national databases are easier to contact and therefore they are more likely to be overexposed to surveys. This may lead to a higher non-response rate and lack of interest in participating in yet another survey or research study. Conversely, farmers who accept to participate in research studies are showing an interest in the topic of the study, in this case being livestock farmers’ perceptions of climate change and on-farm management of GHG emission mitigation. This may lead to a higher number of participants giving positive responses to the research questions and therefore the results may not be representative of the wider livestock farming community. However, this study was set up to pilot a methodology for farmer engagement that can be adopted on wider scales at a later stage. Therefore, the purpose of the sample in this study was to provide a sufficient number of case studies to support the methodology and to receive farmers’ feedback on future actions to tackle the issue of on-farm livestock GHG emission mitigation for their farms.

The criteria for the selection of farmers for this study were:-

- Location: South West and West Midlands regions, as they represent strongholds of livestock farming:
- Sector: livestock i.e. dairy, beef, pig, poultry, mixed livestock-arable (i.e. fodder);
- Type of production: extensive farming systems. For the purpose of this study farms were identified as small to medium-scale and practicing low-input extensive methods, some of which were organic.

During spring 2011, a total of 60 farmers were contacted at farming conferences in the South West and by telephone or email, using business directories. Farmers were asked the type of production their farming system adopted and they were then invited to participate in the study. Fourteen (14) farmers accepted the invitation: 11 certified organic farms and 3 conventional farms following organic principles, identified as uncertified organic. Table 5.1 summarizes the profiles of the farms included in the study.

For the purpose of the study, each farm was identified by a letter i.e. from A to N, in order to guarantee the anonymity of the results presented in this section. The following characteristics are included:-

- Farm location, i.e. county
- Farm type, i.e. organic, conventional, uncertified organic
- Type of livestock
- Location in an Nitrates Vulnerable Zone (NVZ)
- Environmental Stewardship Schemes (ESS)
- Farm size – land surface area, in hectares (ha)
- Farm size – number of animals

Table 5.1 Farm profiles at the time of first visit (early spring 2012).

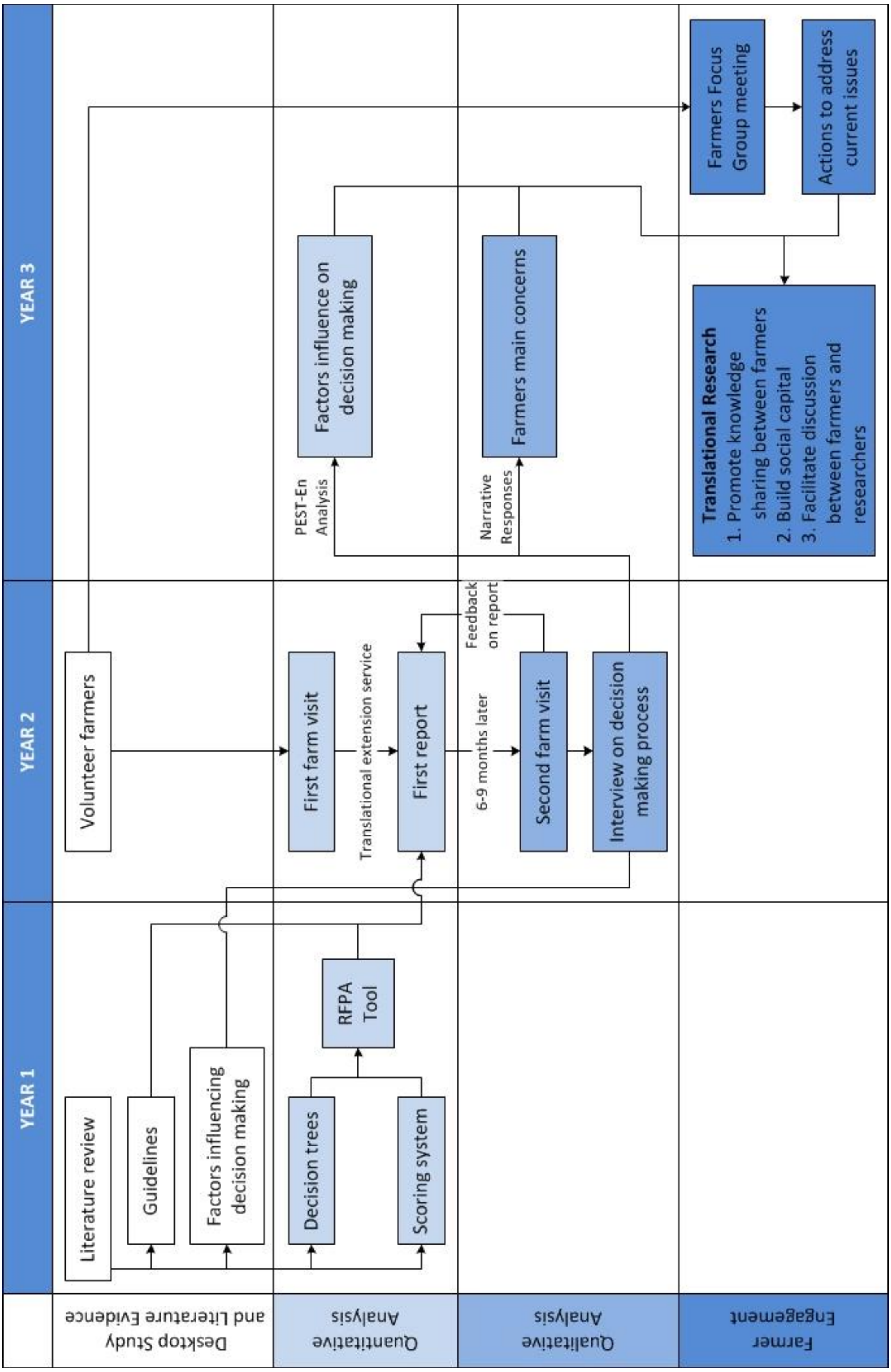
| Farm | County | Type | Livestock | NVZ | ESS | Size - Land | Size - Animals |
|---|---|---|---|---|---|---|---|
| A | Herefordshire | Conventional* | beef* | Yes | HLS | 56 ha. pasture, 126 ha. arable | 37 beef cows (21 cows + followers) |
| B | Herefordshire | Conventional* | sheep*, poultry C | Yes | - | 242 ha. pasture | 1,650 ewes, 55,000 boilers |
| C | Gloucestershire | Conventional* | dairy* | Yes | HLS | 360 ha. (180 pasture, 180 arable) | 350 dairy cows |
| D | Gloucestershire | Organic | dairy, sheep | No | ELS, HLS | 530 ha. | 150 dairy cows, 300 ewes |
| E | Bristol | Organic | dairy | No | - | 350 ha. pasture, 50 ha. arable | 250 dairy cows, 130 young stocks |
| F | Gloucestershire | Organic | beef, sheep, pigs | No | ELS, HLS | 73.4 ha. (of which 15.61 ha. arable) | 12 ewes, 122 lambs, 2 beef |
| G | Cornwall | Organic | beef, sheep, veg | No | ELS, HLS | 137.59 ha. (80.94 ha. pasture, 56.66 ha. temporary with 16.19 ha. veg. rotation) | 60 suckler cows, 10 followers, 200 ewes |
| H | Cornwall | Organic | beef, sheep, pigs | Yes | OELS | 68.80 ha. | 28 suckler cows, 10 followers, 22 calves, 14 sheep, 8 pigs |
| I | Oxfordshire | Organic | dairy | No | HLS | 485.62 ha.+ 80.94 ha. non-organic arable | 300 dairy cows (100-110 dairy cows + followers) |
| J | Cornwall | Organic | beef, sheep, poultry | No | OELS | 28.33 ha. | 61 beef, 48 ewes, 15 geese, 15 chicken |
| K | Devon | Organic | beef | No | OELS | 50 ha. | 30 suckler cows, 60 young stocks |
| L | Wiltshire | Organic | dairy, beef, sheep, pigs | Yes | OELS | 550 ha. (340 pasture + 185 arable) | 250 pigs, 170 dairy, 100 beef, 21 ewes, 1 ram |
| M | Herefordshire | Organic | beef, sheep, poultry, pigs C | No | HLS | 350 ha. | 110 suckler cows, 140 young stocks, 350 ewes, 6 sows, 40 piglets, 250 laying hens |
| N | Herefordshire | Organic | Dairy | Yes | HLS | 169.97 ha. | 270 cows, 90 young stocks, 100 calves, 50 cattle rebulled |

**Keys:** *: uncertified organic; C: conventional farming system.

## 5.3 Field research framework and data collection

The following framework combines a science-based farm management assessment with qualitative research in order to provide practical advice on reducing farm emissions on the one hand, whilst on the other hand gaining in-depth knowledge of the current problems livestock farmers are facing when dealing with greenhouse gas (GHG) emission mitigation, along with the drivers and obstacles to innovation at the farm level. The framework was developed in order to establish successful communication channels with a pilot set of volunteer farmers. This approach initially provided each farmer with an assessment of their current farm practices against GHG mitigation strategies. It then continues with the analysis of farmers’ knowledge of the topic of climate change and GHG mitigation, their interest in it or lack thereof, and the main obstacles to GHG mitigation on their farm. The framework can be divided in 3 main activities; appraisal of farm practices is done by scoring in relation to GHG emission mitigation potential, while decision trees are used to identify options. The timeline is further summarised (Figure 5.2).

Figure 5.2. Timeline of methodology.



### 5.3.1 Rapid Farm Practices Appraisal tool

The Rapid Farm Practices Appraisal (RFPA) tool consisted of decision trees, scoring tables and a booklet containing recommendations for farmers based on qualitative evidence, in order to reduce emissions. The initial phase involved the review of the scientific literature citing in vivo studies that quantify GHG emission mitigation. The review allowed for the identification of key areas for intervention. Livestock farm practices were therefore divided into 5 areas: dietary management, livestock housing, manure storage and treatment, grazing and pasture management, and manure application to field. Each section was then analysed using:-

- *Scoring tables*: Each practice was evaluated against its GHG mitigation potential. Each practice was assigned a Farm Management Score (FMS) based on the practice application, and a Likert-scale based Mitigation Potential Score (MPS). A sample scoring table used in this study is illustrated in Table 5.2.

- *Decision trees*: Practices implementation was assessed using section-specific decision trees that provide with a reference linked to the booklet containing specific guidelines and recommendations to mitigate emissions on farm. A sample decision tree used in this study is illustrated in Figure 5.3.

- *Guidelines booklet*: The review of scientific literature illustrated in chapter 3 was used as foundation to provide targeted recommendations to the farmer, based on farm-specific contexts. A sample section of the booklet used in this study can be found in Appendix I. Each recommendation included the practice, the expected outcome in terms of GHG emissions reduction and a brief explanation of the reasons for such an outcome, avoiding technical jargon whenever a simpler vocabulary could be used.

This tool was created in order to be easily understood by farmers. The decision trees and the guidelines booklet provided a straight forward analysis of farm practices management by linking each practice to recommendations specifically tailored for the farm. This approach ensured that farmers could appreciate the validity of the recommendations given, which did not rely on general farm profiles with varying degrees of similarities with the actual farm being assessed. Consequently, the scoring tables gave an overview of the specific potential impact of the agri-business in terms of emissions. The simplified scoring system was based on the most acknowledged scientific findings on GHG mitigation and it allowed the monitoring of the farm impact over time in the case of a change in farm practices management. Therefore it could also be used to forecast possible variations in the farm impact based on changes in farm practices.

Table 5.2 Scoring sheet for the assessment of practices related to on-farm storage and treatment of manure.

## Livestock farm practices scoring sheet

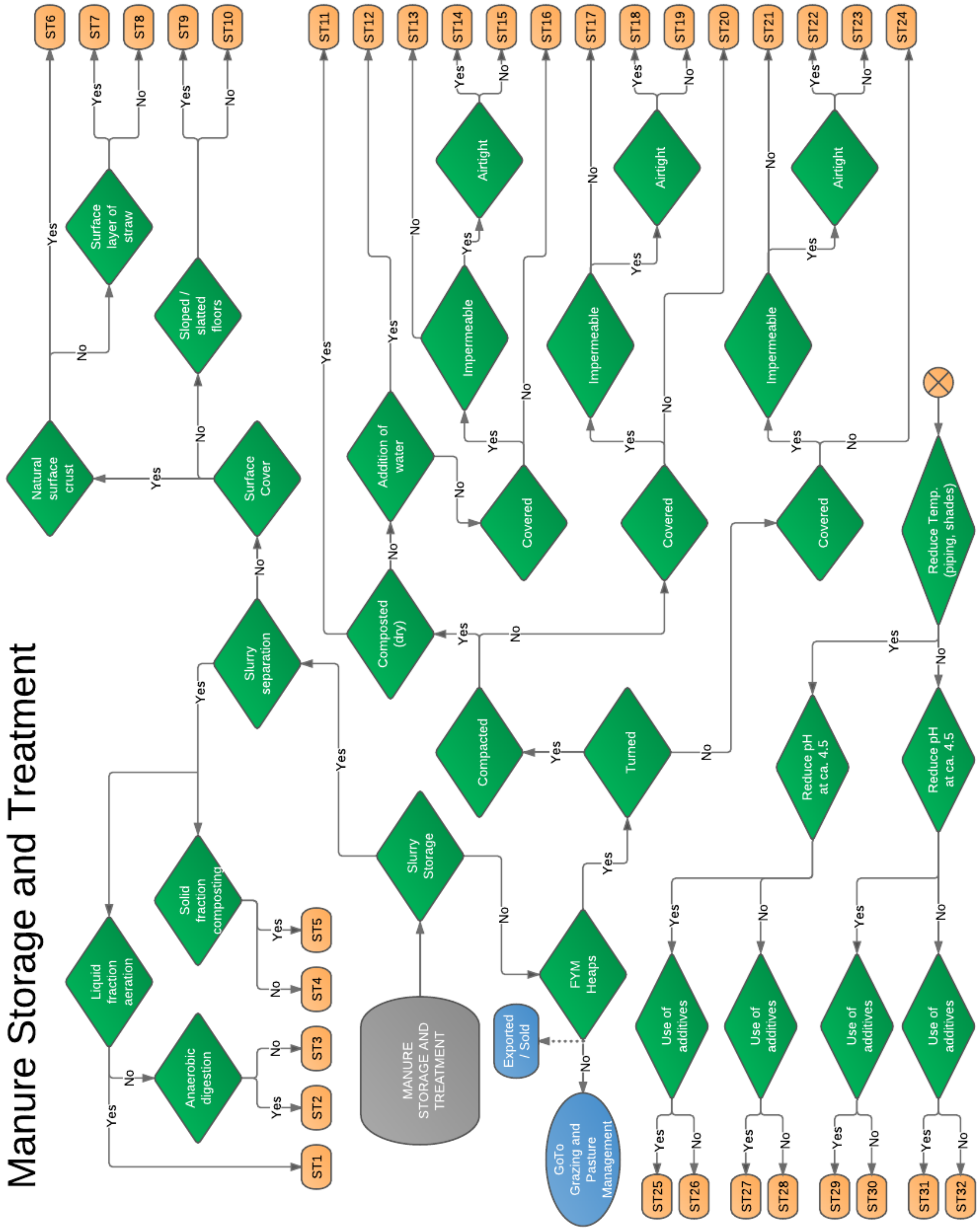
| | |
|---|---|
| Farm Management Score | +: practice is adopted, -: practice is not adopted, 0: N/A |
| Mitigation Potential Score | 1: <10%, 2: 10-30%, 3: >30% |

### Section 3. Manure Storage and Treatment

| | |
|---|---|
| 1. Slurry storage | |
| a. Slurry separation | -3 0 +3 |
| i. Use of liquid fraction in anaerobic digestion | -1 0 +1 |
| 1. Aeration | -1 0 +1 |
| 2. Addition of glycerol | -3 0 +3 |
| ii. Solid fraction composted | -3 0 +3 |
| b. Surface cover | |
| i. No cover, crust | -3 0 +3 |
| ii. Surface layer of straw | -3 0 +3 |
| iii. Fixed cover (e.g. wood, plastic, rubber) | -3 0 +3 |
| c. Sloped or slatted floors | -3 0 +3 |
| 2. Farm Yard Manure (FYM) heaps | |
| a. Turned regularly / at least once in 2-3 months (short storage) | -3 0 +3 |
| b. Compacted | -3 0 +3 |
| c. Composted | -3 0 +3 |
| d. Addition of straw (not from bedding) | -3 0 +3 |
| e. Addition of water (not rain) | -3 0 +3 |
| f. Covered | |
| i. In livestock pens (e.g. straw over manure) / from overwintering, not covered | -3 0 +3 |
| ii. Impermeable cover | -3 0 +3 |
| iii. Airtight cover | -3 0 +3 |
| iv. Straw cover or other permeable cover | -3 0 +3 |
| g. Piping system or shades to reduce temperature | -3 0 +3 |
| h. Use of additives to reduce pH | -3 0 +3 |
| i. Use of other additives (e.g. saccharose) | -3 0 +3 |

Section score: _______________

Figure 5.3 Decision tree for practices related to manure storage and treatment.



### 5.3.2 Farm visits

The second phase consisted of inviting a pilot set of farmers to participate in the study. Each farm was visited twice and semi-structured interviews are used on both occasions. During the first visit, the farmers were interviewed on their current farm management. The Rapid Farm Practices Appraisal tool allowed obtaining a detailed report for each farm, containing an assessment of the estimated impact of farm practices in terms of GHG emissions and a series of recommendations with the aim of mitigating emissions. The results of this first assessment were then included in a report presented to the farmer, promoting discussion on the topics touched in the report. The aim of this exercise was to provide the farmers with suggestions and recommendations based on the latest scientific evidence on GHG mitigation and on the most recent reports published by DEFRA and various scientific bodies, while at the same allow the researchers to gather valuable feedback on farm management practices, as well as on the structure and content of the farm assessment reports. The key strength of this approach is that the information given is tailored to each farm’s specific management.

Subsequently, a second visit was organised after 6-9 months to monitor changes in farm management. After reviewing changes and running the RFPA tool again to update the both scores and recommendations, farmers were also interviewed on how they take decisions on farm. A total of 17 factors were selected based on literature review of recent studies on farmers and stakeholder engagement in the agricultural sector (Table 5.3). Farmers were asked whether they take into account the factors or they don’t, during the decision making process. The sample questionnaire can be found in Appendix II. The questionnaire was used during the second round of visits. In 2 cases the farmers agreed to be sent the questionnaire by post, to reduce researchers’ travel costs. They were mailed a pre-stamped envelope along with the questionnaire and a return deadline was agreed over the phone. Phone follow ups were also agreed to discuss the responses given in the questionnaire.

The purpose of the second visit was two-fold: on the one hand, it assessed changes in farm management and farmers acceptance of recommendations based on scientific knowledge of GHG mitigation from a practical point of view; on the other hand, the second interview assesses farmers' perceptions of GHG mitigation and their relationships with factors internal and external to their farm systems. The second assessment was done using a PEST analysis model, including environmental factors. The model was named PEST-En and included Political (P), Economic (E), Social (S), Technical (T) and Environmental (En) factors that may be taken into account by farmers when making decisions on farm. The analysis was integrated by narrative responses given by farmers during the interview. Narrative responses were analysed using a simple taxonomy system: by identifying key words (e.g. trust, experience, influence, support, problem, risk) in order to group similar narratives provided greater insight on the motivations behind each answer, as different motivations can be given for the same answer.

### 5.3.3 Farmer focus group meeting

The last phase of the study included a farmer focus group meeting. All participants were invited to present their views on the study and its methodology, and to discuss opportunities for action at the community level and for further research and partnerships between academia and farmers. The event was open to farmers that did not participate in the study, in order to engage on a wider scale. The first part of the meeting consisted in sharing the results of the study to date and in farmers presenting their experiences of the study. Participants were then split into groups, each group discussing issues related to a topic of concern. Topics selected during the meeting were livestock feeding, grassland and pasture management, manure storage and treatment. Participants were encouraged to voice their concerns over issues related to GHG emissions and to propose actions to tackle them. The meeting served as an opportunity to network with other farmers, share experiences and discuss possible solutions.

Table 5.3 Factors influencing decision making at the farm level, grouped according to the PEST-En analysis model.

| **Type of factor** | **Reference** | **Description** |
|---|---|---|
| Political | P1 | Trust in official reports<br>i.e. government (DEFRA, Environment Agency) |
| | P2 | Trust in source of recommendations (institution)<br>i.e. research centres, universities, associations |
| | P3 | Support in integrating Environmental Stewardship schemes (i.e. ELS, OELS, HLS) and GHG emissions reduction |
| | P4 | The level of bureaucracy linked to obtaining grants |
| Economic | E1 | Financial constraints i.e. limited budget |
| | E2 | Current management is profitable already |
| | E3 | External support for budget and farm management matters |
| | E4 | Cost of agricultural consultants |
| | E5 | Labour force availability |
| Social | S1 | Trust in source of recommendations (individual)<br>i.e. the person conducting the study |
| | S2 | Community support |
| | S3 | Previous bad experiences<br>i.e. consultants, community actions, interest groups |
| Technological | T1 | Trust in scientific basis of GHG emissions reduction strategies |
| | T2 | Trust in assessment tools currently available<br>i.e. carbon accounting tools |
| | T3 | User-friendliness of assessment tools |
| Environmental | En1 | Interest in conservation and environmental matters |
| | En2 | Renewable energy more important greenhouse gas emissions reduction |

## 5.4 Data analysis

Results obtained from the study were quantitative data regarding the implementation of practices that mitigate greenhouse gas emissions and qualitative data on farmers' attitudes to climate change, in particular the barriers and opportunities for the adoption of GHG emission mitigation options.

Quantitative data obtained using the RFPA tool was reported as number of changes in farm practices over the total number of possible changes. Percentages of estimated GHG emission mitigation were provided for each farm following the farm practices scoring system described in section 5.3.1.

Qualitative data was obtained using semi-structured interviews using the PEST-En analysis model described in section 5.3.3. Percentages were provided for positive, negative and neutral responses over the total number of farmers interviewed. Analysis of individual case studies was used to highlight circumstances that were considered to have a possible influence on specific farmers' responses. Narrative responses were analysed by coding concepts such as trust, knowledge, risk, experience. E.g. words such as confidence, certainty, reliance and belief were associated to the concept of trust; words such as uncertainty and danger were associated to the concept of risk (e.g. financial, legal, reputational).

## 5.5 Further considerations

The framework set to create a model for integrated socio-environmental farm assessment; therefore, it is important to understand the boundaries of the study's approach. Even though the study was initially set as a quantitative scientific study, at a second stage it incorporated concepts and methodologies that are used in qualitative research, such as social studies. The farm assessment tool provided the basis for the engagement of farmers on the topic of on-farm innovation in GHG emissions reduction, initially at individual level, and subsequently during a farmer focus group meeting.

Finally, by engaging with farmers on GHG emission mitigation, this approach adopts principles of translational research that aims at translating scientific knowledge into practical advice. By using a farmer-friendly model to assess a series of farm activities from a practical point of view, rather than simply providing a figure from a carbon footprint calculator, the framework aims at creating a network of farmers and at building long-term relationships between farmers and researchers, fostering knowledge transfer and knowledge sharing to promote innovation at the farm level.

The methodology presented here can be used by researchers and extension practitioners in order to obtain data on the impact of smaller scale livestock farms in terms of GHG emissions and on the barriers as well as the drivers for innovation in mitigating emissions at the farm level. The method can also be scaled up to embrace larger farms and networks. The data collected will provide valuable information to policy makers, ensuring the continuity and effectiveness of agricultural policy in England.

The following chapter illustrates the outcomes of the exercise, providing a critical review of the results and arguments to support further development of the methodology.

# Chapter 6

# Results and discussion

# 6. Results and discussion

This section illustrates the results of the study, after providing a brief overview of the characteristics of the farms that were assessed. Initially, results are presented regarding the adoption of changes in farm management practices, followed by a detailed analysis of the practices separated by sector. Subsequently, results from the farmer engagement exercises are discussed: firstly, the acceptance of the RFPA tool is evaluated, followed by the researcher-to-farmer engagement activities, and lastly the farmer knowledge sharing activity is discussed (i.e. farmer focus group). Finally, the chapter discusses the obstacles and barriers to change highlighted by the study and, to conclude on a positive note, discusses the opportunities and drivers for change that were shown by the interaction between the researcher as knowledge broker and change agent and farmers as co-researchers.

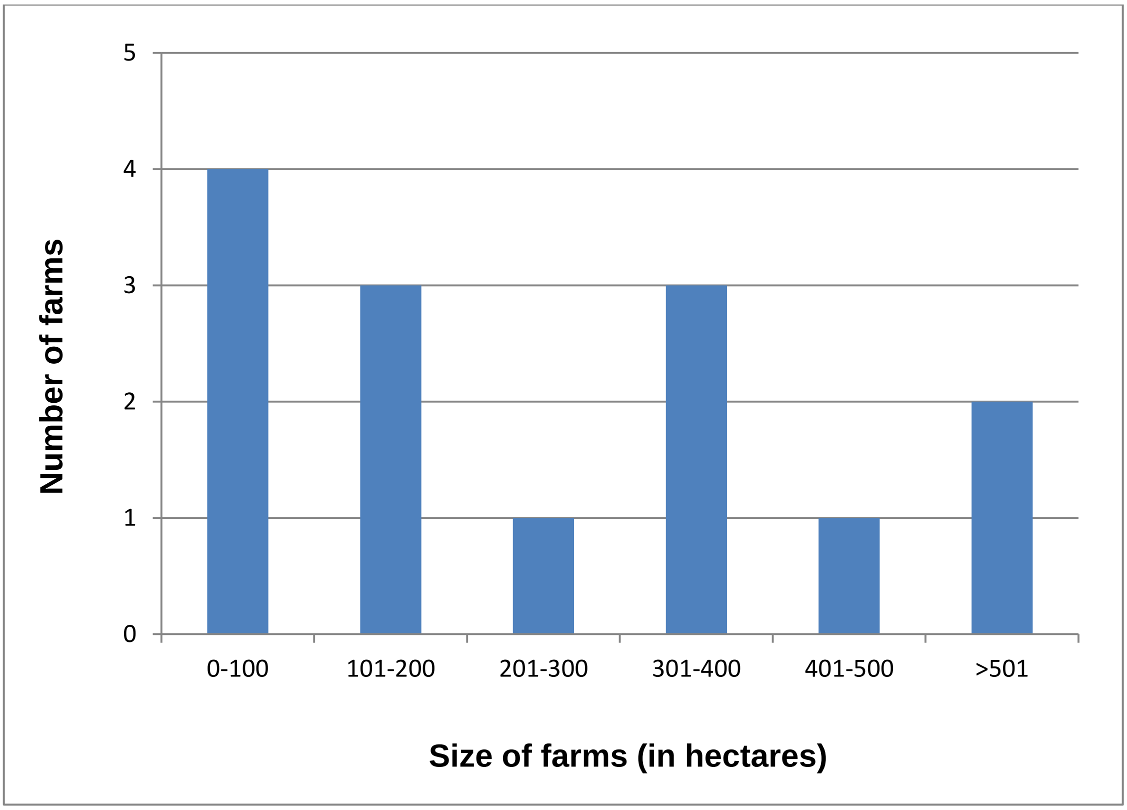
The study did not aim at representing the whole of the British livestock farming sector and thus convenience sampling was adopted to contact farmers. Criteria for selection were illustrated in section 5.2.1. A pilot set of 60 livestock farmers were invited to participate in the study. Farms were located in England, in the South West and West Midlands regions. Farms selected were livestock and mixed arable-livestock farms, where arable production was solely destined to animal feed. Fourteen farmers showed interest in matters relating to greenhouse gas (GHG) emission mitigation and agreed to participate (Table 6.1). The range in farm size was quite wide (between 28 and 550 hectares) because half the farms had arable production. However, only 3 farms had a size above 400 hectares, with maximum size of 550 hectares (Figure 6.1). Six farms were located within a Nitrate Vulnerable Zone (NVZ) and only 2 farms were not part of any Environmental Stewardship Scheme, while 7 farms were under either Entry Level

Schemes (ELS) or Organic Entry Level Schemes (OELS) and 8 farms were also under Higher Level Schemes (HLS).

Table 6.1 Summary of farm profiles.

| | **Farm characteristics** |
|---|---|
| **Number** | 14 |
| **Location** | South West (10):<br>- Gloucestershire (3)<br>- Oxfordshire (1)<br>- Bristol (1)<br>- Wiltshire (1)<br>- Devon (1)<br>- Cornwall (3)<br>West Midlands: Herefordshire (4) |
| **Location within a Nitrate Vulnerable Zone (NVZ)** | Yes (6)<br>No (8) |
| **Size (range)** | Min. 28.33 hectares<br>Max. 550 hectares |
| **Type** | Livestock and Mixed livestock (7)<br>Mixed arable / livestock (7) |
| **Livestock** | Beef (8) 60-300 animals<br>Dairy (7) 150-350 animals<br>Sheep (7) 50-1650 animals<br>Pig (3) 50-250 animals<br>Poultry (3) 30-55,000 animals |
| **Type of farm** | Certified organic (11)<br>Uncertified organic (3) |
| **Environmental Stewardship Schemes** | No ESS (2)<br>ELS / OELS (7)<br>HLS (8) |

Figure 6.1 Size of farms that participated in the study.



## 6.1 Adoption of change at the farm level

The RFPA tool described in chapter 5 was used to assess farm management practices in terms of GHG mitigation potential and their on-farm implementation. All 14 farms were assessed twice over 6-9 months between early spring 2012 and autumn 2012. Further information on farmers' attitudes to climate change and their actual and perceived barriers to GHG mitigation were based on the results from a semi-structured interview conducted in autumn 2012. No farmer withdrew from the study at this stage. However, the success of 100% engagement at this stage was accompanied by mixed results regarding the farms' management performance. The following analyses changes adopted in terms of farm management practices and the obstacles presented by farmers in implementing GHG mitigation strategies.

Farmers responded well to the recommendations proposed in the farm assessment reports. In fact, the study presented the farmers with the opportunity of filling the knowledge gap on GHG emissions. Practices that showed multiple benefits including GHG mitigation were more easily adopted within 1 year from the first farm assessment. In total, half of the farmers implemented changes in farm practices within the 6-9 months between the first and the second farm assessment (Figure 6.2). Farmers showed interest in practices that presented low economic risk but clear benefits in terms of productivity and GHG emission mitigation. In contrast, limited financial capital and labour force availability were the main reasons given for the lack of change in farm management and for the difficulties in implementing on-farm innovation in order to reduce GHG emissions. Changes in practices related to grazing and pasture management, manure application to field, manure storage and treatment and dietary management were observed in at least 2 farms per each sector. One farm also improved practices related to livestock housing and 2 farms implemented changes in more than one sector (Table 6.2). However, even though half the farmers changed their farm practices as a result of the first assessment carried out using the RFPA tool, it has to be noted that when considering practices divided by sector, the results vary because of the relative importance of each practice within the single farming system. For instance, Farm F was a completely pasture-based system; therefore, the sectors of dietary management and livestock housing were not included in the farm assessment. This approach provided a balanced assessment tailored to the specific farming system of each farm. As a result, the overall percentage of practices that were changed has relative importance due to the peculiarity of each farming system analysed. Conversely, it is important to consider each farm separately in order to analyse the results from changes in practices. The RFPA tool helped identify the sections in which improvements in GHG emission mitigation were registered over time (Figure 6.3). In fact, all farms that implemented changes registered an improvement in the second assessment. Fewer farms scored negatively in 2 sections and in 3 sections; 3 farms scoring positively in all sections at the second visit, as opposed to just 1 farm scoring positively in all sections at the beginning of the study (Figure 6.4).

Therefore, in order to acquire further understanding of the links between farm management change and GHG emission mitigation, the following sections will address in more detail the changes registered in each of the 5 sectors assessed.

Figure 6.2 Percentage of adoption of changes in farm practices and breakdown of changes by practice sector (n = 14).

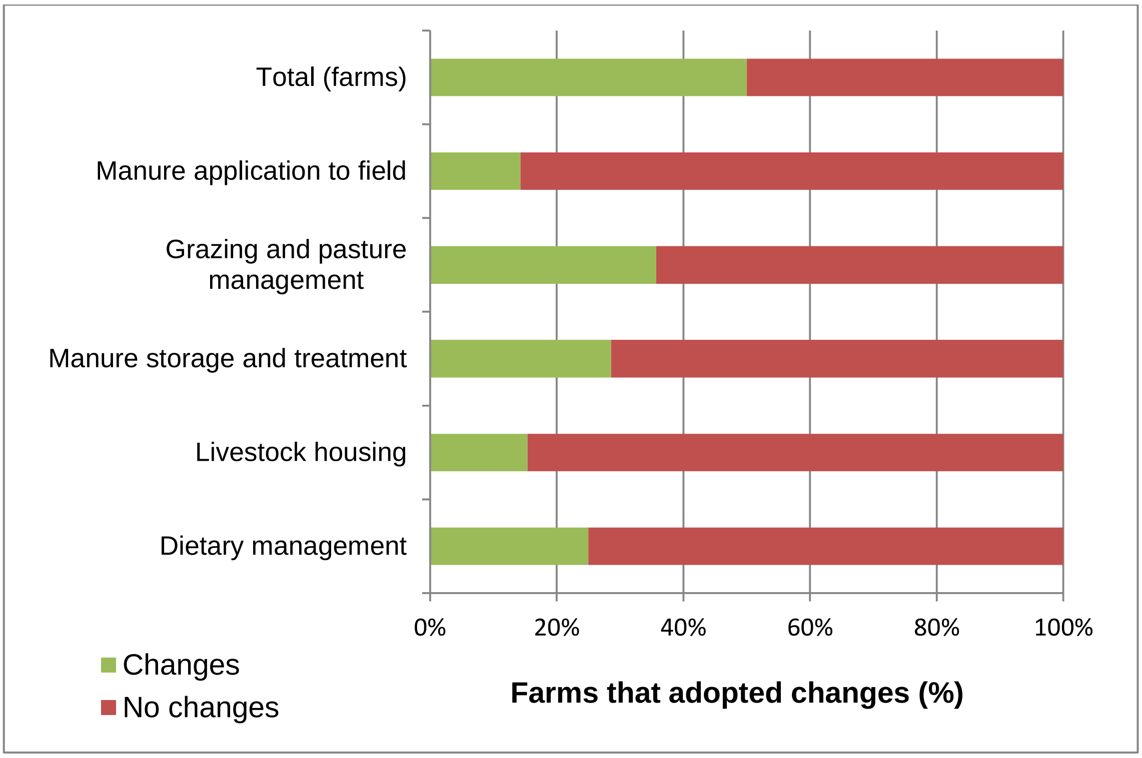


Table 6.2 Changes in farm practices.

| **Farm** | **Changes made** |
|---|---|
| A | Manure application to field |
| B | - |
| C | Manure storage and treatment<br>Manure application to field |
| D | Dietary management |
| E | - |
| F | Dietary management<br>Grazing and pasture management |
| G | - |
| H | - |
| I | - |
| J | Grazing and pasture management |
| K | - |
| L | - |
| M | Manure storage and treatment |
| N | Livestock housing |

Figure 6.3 Results of two farm assessments in spring 2012 (1) and autumn 2012 (2) carried out using the RFPA tool.

(Note: the arrows indicate farms and elements changed)

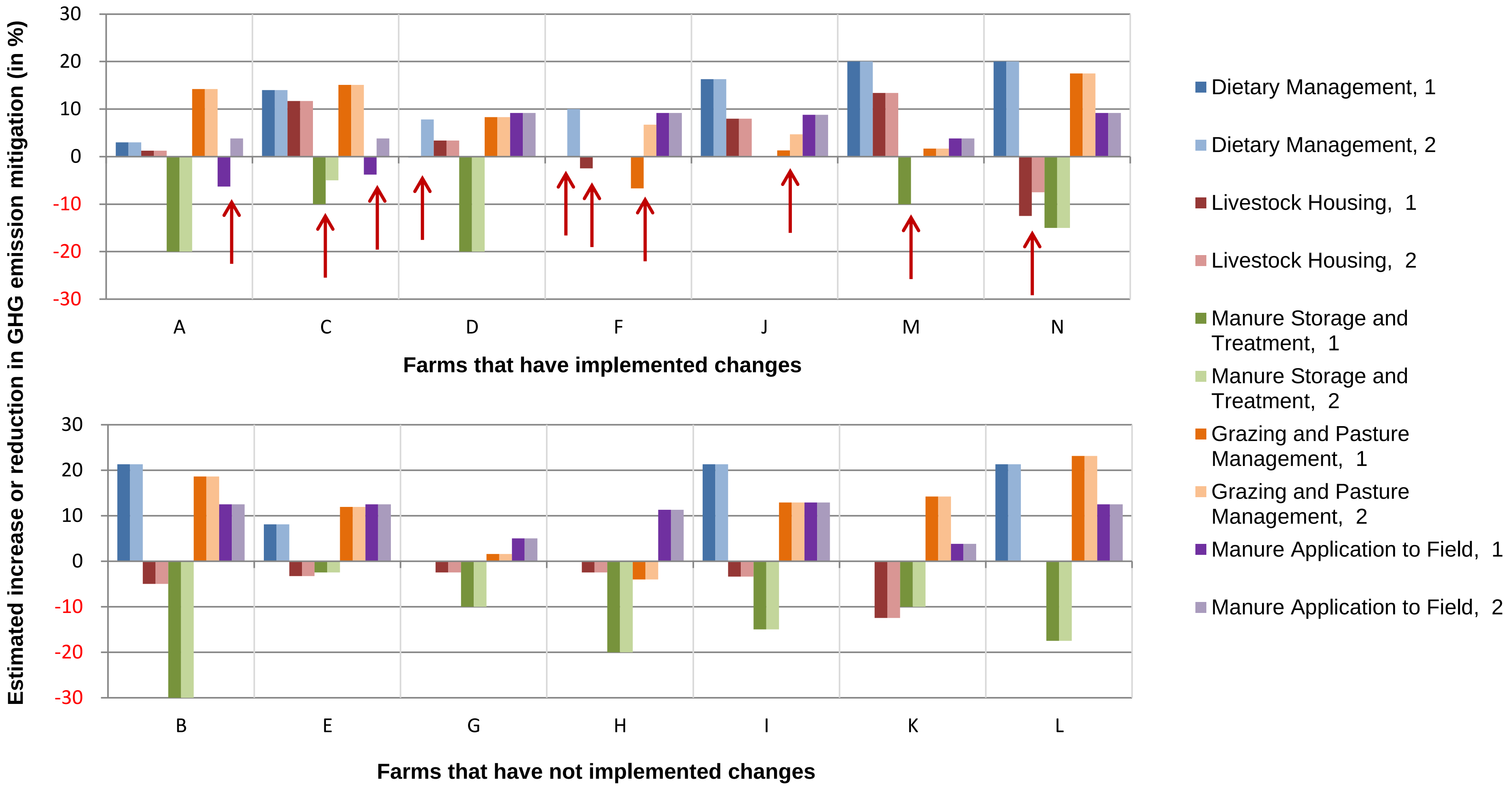
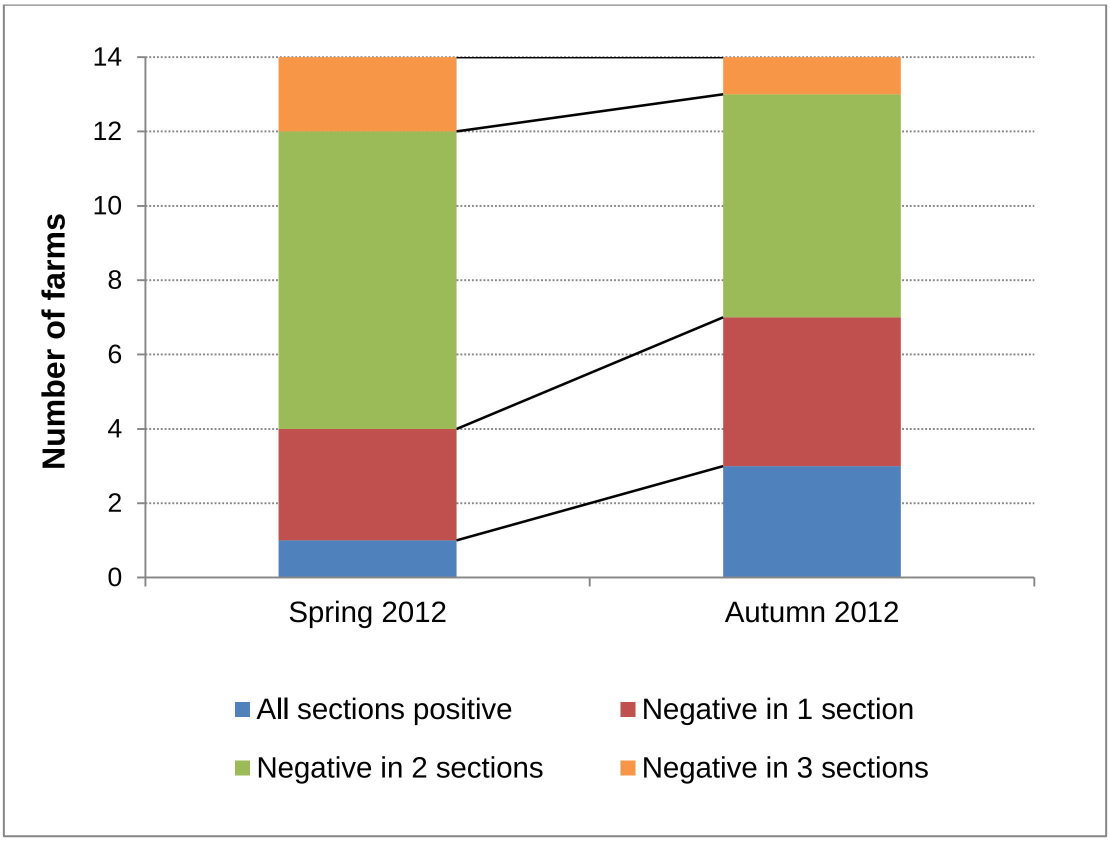


Figure 6.4 Comparison of RFPA tool results between the first and second farm assessment.



## 6.2 Improvement of farm management practices

This section analyses in detail the results obtained during the assessment of management practices carried out using the RFPA tool. Practices are separated by group, as described in section 5.3.1.

### 6.2.1 Dietary management

It is reasonable to think that diet is a crucial part of any livestock agri-business. An optimum diet is reflected in good animal health and welfare and therefore it increases the overall productivity of the farm (Waghorn and Clark, 2004). Farm practices that mitigate GHG emissions, such as feeding forages with higher protein content, also ensure good dietary standards for optimum production (Hersom, 2008). Dietary management influences GHG emissions, in particular methane emissions from ruminant enteric fermentation and, to a lesser extent, emissions from hindguts fermentations in monogastric animals, such as pigs (chapter 3). Given the type of farm visited (i.e. extensive, pasture-based), concentrates were not considered within the farming system and farmers preferred not to introduce concentrates in the livestock diet. In fact, introducing concentrates would have represented an additional input cost, not reflecting the type of farm management embraced by the farmers.

The majority of farms scored positively at the first assessment (Table 6.3). This result indicates that most farms already adopted best practices that would fit within their farming system. These same practices are also beneficial in order to reduce GHG emissions from enteric and/or hindguts fermentation in ruminant and monogastric livestock.

Table 6.3 Estimated (+) or reduction (-) in GHG emission mitigation (in %) and impact of changes in dietary management.

| Farm | Spring 2012 | Change in practices | Autumn 2012 |
|---|---|---|---|
| A | 3.00 | no | 3.00 |
| B | 21.30 | no | 21.30 |
| C | 14.00 | no | 14.00 |
| D | -0.15 | yes | 7.80 |
| E | 8.10 | no | 8.10 |
| F | 0.00 | yes | 10.00 |
| G | 0.00 | no | 0.00 |
| H | 0.00 | no | 0.00 |
| I | 21.30 | no | 21.30 |
| J | 16.30 | no | 16.30 |
| K | 0.00 | no | 0.00 |
| L | 21.30 | no | 21.30 |
| M | 20.00 | no | 20.00 |
| N | 20.00 | no | 20.00 |

***Keys:***

Green: improvement of on-farm GHG mitigation potential

Red: lack of improvement of on-farm GHG mitigation potential, starting from a negative mitigation potential score

In particular, 12 out of 14 farms included legumes in the livestock diet and the 2 remaining farms introduced legumes during the 1 year assessment. The use of legumes in the diet and in crop rotations has multiple benefits i.e. reduced environmental impact in terms of energy efficiency in cultivation, reduced application of Nitrogen-fertilisers and reduced GHG emissions from crop cultivation (Nemecek et al., 2008) and increased dietary protein in livestock ration, leading to reduced methane emissions from ruminant's enteric fermentation (Philippe et al., 2006).

Four farms out of 14 registered a neutral impact in terms of GHG emissions. One of them (Farm F) adopted changes that were expected to mitigate emissions (i.e. higher percentage of legumes on pasture), and therefore scored positively at the second farm assessment. The only farm where a negative impact was registered during the first visit (Farm D) improved its dietary management practices; notably it introduced legumes in the diet, therefore reducing emissions from ruminant enteric fermentation (i.e. methane). Interestingly, both farms were under ELS and HLS. The fact that both farmers were tenants did not seem to influence their actions, as both were interested in expanding their knowledge on GHG mitigation. Farmer F had the support of a family member with previous work experience as environmental consultant and Farmer D had the support of a family member working as land manager elsewhere, but able to help in providing information regarding possible economic benefits of introducing legumes in the diet in terms of land management and livestock productivity. As shown in Box 6.1, the diversity of the profiles of these two farms may suggest that the main driver for innovation could have been knowledge rather than the circumstances in which the farmers operate, as both farmers had relatively easy access to information on environmental issues via family members.

Box 6.1 Influence of farm background on change

Farmers D and F adopted changes in dietary management in order to mitigate GHG emissions. Their profiles and their farms profiles are very different, with the only common points in tenancy, environmental schemes and a relatively easy access to information to help them adopt environmentally friendly farm practices.

| | Farm D | Farm F |
|---|---|---|
| Size | 530 ha. | 73.4 ha. |
| Type | Organic | Organic |
| Tenancy / Ownership | Tenant | Tenant |
| Environmental Schemes | ELS, HLS | ELS, HLS |
| Livestock | Dairy<br>Ewes, lambs | Ewes, lambs<br>Beef, pigs |
| Arable (for animal feed) | Yes | Yes |
| Source of knowledge | LEAF*<br>Family<br>(land manager) | Family<br>(environmental consultant)<br>Farmers' group** |

*LEAF: Linking Farming And Environment; **PFLA, Pasture-Fed Livestock Association

Among the farms which did not implement any changes, 9 were already adopting best practices to mitigate GHG emission within the limits of their systems, but 3 farms (Farms G, H and K) registered a neutral impact and, therefore, they could have improved their practices in order to mitigate emissions. A closer look into the profiles of these farms did not seem to highlight key characteristics in relation to the farmers' willingness to change. Seven (7) farmers out of 12 were tenants and 5 owned the farms. Half the farms were under HLS, 2 under no scheme and 4 under ELS/OELS only. Farms G, H and K were all under environmental schemes, with Farm G being the only one of the 3 under HLS, and their primary production was organic, pasture-fed beef. One farmer was a tenant (Farmer G) and the other 2 (Farmers H and K) owned the farms. One interesting characteristic is perhaps that these 2 out of these 3 farms (Farms H and K) were among the 4 smallest farms in the study in terms of total land surface area, whether land was used as pasture or for arable/fodder production (i.e. Farm F, H, J and K. Farm H extended over 68.80 ha. and Farm K 50 ha. The third farm, Farm G, had a size of 137.59 ha. but only 80.94 ha. were used as pasture, there rest was used as temporary ley and vegetable production.

All 4 smallest farms and the slightly bigger Farm G were family-run and only relied on external labour occasionally. All farmers were able to interact with local farmers' groups, which they primarily relied upon to obtain information and knowledge about innovation in farming via peer-to-peer interaction with other farmers in the area. Three (3) of them (Farms G, H and K) did not improve their mitigation potential, 1 (Farm F) adopted changes which reflected in the mitigation of GHG emissions from dietary management practices and 1 (Farm J) was already adopting all effective mitigation strategies concerning livestock diets.

It may be reasonable to expect that rather than the size of the farms alone, the combination of labour force availability and type of production (i.e. pasture-based) could result in greater financial pressure and uncertainty regarding the level of production needed to ensure the viability of the business. Under such circumstances, farmers may be effectively prevented from adopting changes and implementing innovation due to the difficulty in re-establishing a balance in their production system after the application of changes in dietary management practices.

Indeed, it is important to take into consideration the fact that changes in livestock diet may be difficult to implement due to a series of practical, logistic or financial obstacles. In particular, feed can be produced on-farm, when the farmer decides to allocate part of the land surface to arable crop production. In this case, a change in diet would mean a change in arable production, which has to follow seasons, crop rotations and contracts with seed suppliers.

Feed can also be bought when not produced on-farm, either to supplement pasture or to provide necessary dietary requirements during overwintering. However, contracts with feed suppliers may not be changed over short periods of time (i.e. 6 months) because of financial implications, such as change in costs that may affect negatively the annual farm budget.

The following describes in more detail which practices were more successfully adopted by farmers and which, in turn, presented the greatest difficulties in being adopted.

*Concentrates:* Only 6 farms out of 14 included concentrates in the ration during the overwintering period, therefore limiting the benefits of concentrates in the diet to 2-5 months over the year. The choice of not including concentrates in the ration was based on the type of farming system, which relied on forage and grazing (i.e. pasture-fed). However, it is important to remember that the study did not aim at forcing farmers to change their farming system. The RFPA tool was designed specifically to provide recommendations and suggestions to farmers tailored to their farming system. The lack of use of concentrates was registered only on farms in which concentrates were not part of the system and, therefore, it was not considered a negative result *per se*.

*Supplementation:* A total of 6 farms out of 14 included some form of supplementation to the livestock diet i.e. oil seeds and meals, potato starch, brewers' spent grains. Four of these farms included oilseed meals in the ration. Six farms out of 14 had dairy production, either exclusively or within a mixed livestock system; five of these farms included supplementation in the diet. Only 1 pasture-based farm did not include any supplementation, not even during overwintering, and only 1 farm with beef cattle production (Farm A) included limited amounts of potato starch during the short overwintering period (i.e. 6-8 weeks). Like in the case of concentrates, supplementation was not considered a possible mitigation for 8 farmers, because it did not fit within the farm profile and farming system.

*Legumes:* During the first visit, only one farm (Farm D) did not include legumes in the ration and another farm (Farm F) with a pasture-based system had a limited percentage of legumes in the grass mixes applied on a small portion of land surface area. The latter was due to HLS restrictions. Both farms improved their practices by introducing legumes in the diet (Farm D) and by working with the seed supplier in order to find the most appropriate seed mix allowed under the HLS agreement and by re-seeding a greater land surface area (Farm F).

Considering the size of the farms included in the study, it is reasonable to expect the following behaviours from farmers:

- Carefully designed livestock diets in order to fulfil all nutritional requirements, improve productivity and increase profit margins.
- Given the limited budget and small margins to play with, diets relying on cheapest feed option that has the best cost-quality balance.
- Reluctance to change diets without careful economic impact assessment of a change in feed, as feed directly affects outputs, productivity and farm income.
- Good diets, and therefore a good productivity, ensuring farmer livelihoods and those of their families, whether the farmers own the business or are tenant-farmers.

The results of the assessment of the practices related to dietary management show that, in spite of restrictions encountered in one case (Farm F), all farmers adopted good farming practices that not only ensured good levels of productivity, but were compliant with Environmental Schemes' (ES) regulations, where applicable, and mitigated GHG emissions. The motivations behind farmers' decision making related to ES, governmental advice and livestock dietary management are addressed in detail in section 6.4.2. No clear differences emerged from the comparison between farmers who adopted change and those who did not. Size and type of farm did not seem to influence the choice of farmers to adopt changes in farm practices. However, 3 out of the 4 smallest farms within the study had a neutral impact in terms of emissions from dietary management practices. Nevertheless, those 3 farmers did not adopt any on-farm improvement in order to try to mitigate emissions; while the fourth farm adopted changes to positively reduce emissions. This result could suggest that size and the financial limitations linked to running small pasture-based systems tend to have a negative influence on farmers' uptake of innovative practices to mitigate GHG emissions, but other characteristics may have a greater influence.

For instance, all farms in the study, except Farm E and Farm L, had some interaction with their peers in the form of local farmers' groups. Therefore, all the 4 smallest farms (Farm F, H, J and K) could rely on local farmers' groups and networks to access knowledge. The one who adopted changes (Farm F) had a relatively easier access to knowledge via a family member. However, Farm H was in a similar situation, but preferred not to adopt any changes. Interestingly, Farmer H was a very proactive member of his local farmers' group and, as it will be discussed later in section 6.2.5, interested in innovative approaches such as mob grazing and carbon sequestration. The main reason given for not changing dietary management practices was the financial implications. This seems to indicate a rather polarised approach to innovation, where practices that were more likely to have a potential economic return (i.e. better soil and pasture management and the possibility of being paid based carbon credits) were prioritised over other forms of innovation with a more uncertain outcome, such as dietary changes.

### 6.2.2 Livestock housing management

During the first visit in spring 2012, half the farms registered a negative score for practices related to livestock housing (Table 6.4). However, at the time of the second assessment in autumn 2012 only 1 farm (Farm N) implemented changes, while another farm (Farm F) had converted to a completely pasture-based system; therefore, livestock housing couldn’t be re-assessed. But the emissions can be transferred to grazing and pasture management (section 6.2.5), where the farmer adopted practices that resulted in a mitigation of GHG emissions from grazing animals.

Mitigation options for livestock housing management practices included increasing the frequency of complete manure removals from housing units, flushing floors and the management of bedded areas.

All farmers were aware of the multiple benefits from implementing good housing management practices, in particular regarding animal health. However, the absence of straw bedding could be considered a controversial option because even though the practice would reduce GHG emissions from bedded areas and make it easier to clean floors, animal welfare has to be taken into account. Therefore, none of the farmers introduced bare concrete floors housing and the emphasis was placed on regular cleaning and provision of fresh straw for bedding.

Table 6.4 Estimated increase (+) or reduction (-) in GHG emission mitigation (in %) and impact of changes in livestock housing management.

| Farm | Spring 2012 | Change in practices | Autumn 2012 |
|---|---|---|---|
| A | 1.25 | no | 1.25 |
| B | -5.00 | no | -5.00 |
| C | 11.70 | no | 11.70 |
| D | 3.40 | no | 3.40 |
| E | -3.30 | no | -3.30 |
| F | -2.50 | yes | n/a |
| G | -2.50 | no | -2.50 |
| H | -2.50 | no | -2.50 |
| I | -3.40 | no | -3.40 |
| J | 8.00 | no | 8.00 |
| K | -12.50 | no | -12.50 |
| L | 0.00 | no | 0.00 |
| M | 13.40 | no | 13.40 |
| N | -12.50 | yes | -7.50 |

***Keys:***

Green: improvement of on-farm GHG mitigation potential

Red: lack of improvement of on-farm GHG mitigation potential, starting from a negative mitigation potential score

n/a: farm converted to entirely pasture-based system

Recommendations to increase the frequency of complete manure removal from livestock housing were well received by farmers. However, they cited a series of difficulties in implementing this practice on a regular basis. Barriers cited were:-

*Lack of labour force availability,* cited by 4 farmers: Farmers A, I, J and N. Two of them (A and J) scored well during the assessment, but were still interested in potential improvement. It can be argued that as smaller farms are more likely to rely on the work of 1 or 2 people (i.e. farm owner or tenant famer), they may experience difficulties in adopting GHG mitigation strategies that require additional labour. In this case, farm characteristics were extremely different.

Farm A was an uncertified organic pasture-fed beef cattle farm with 56 ha. of pastures and additional 126 ha. of arable production for fodder. Cattle were housed for a maximum of 6-8 weeks during the winter, depending on weather. Farmer A was the farm manager and, while running the business under HLS agreement, he aimed at obtaining organic certification in the near future.

Farm I was a 485.62 ha. certified organic dairy farm, also under HLS agreement, housing the stock for up to 4 months during the colder season. Farmer I had been a tenant on the farm for the past 25 years and he had a great interest in renewable energies and on-farm innovation to promote environmental sustainability, but had been working with limited labour force, which resulted in a number of solutions adopted in the past to try to overcome this obstacle, such as installing a scraper in the housing unit in order to be able to clean the bedded areas regularly. Without this solution, a high frequency of cleaning of livestock housing would have been impossible. However, the system adopted to separate the liquid part of what was scraped from the barns resulted in the storage of manures as Farm Yard Manure (FYM) and slurry in an open-air lagoon. While the former was regularly turned, the latter was not monitored, which has a negative impact on the estimated GHG emissions from manure storage, as illustrated in section 3.3.2.

Farm J was the smallest farm in the study, with just 28.33 ha. of pasture for mixed livestock that included local rare breed beef, ewes, geese and chicken. Farmer J had bought the farm in 2005 and converted it from a conventional dairy farm to a certified organic, family-run mixed livestock farm under OELS agreement. Labour force was cited as a major factor in determining what could be done on the farm.

Farm N was a 170 ha. organic dairy farm with pasture-fed production, under HLS agreement. Like Farm A, stock was housed for a very limited time and like Farm J, this was a family-run farm. In this case, however, Farmer N was the third generation owner of the farm and showed great attachment to his business, which reflected in his statement concerning labour force:

*"When you pay people, you want return on it."(Farmer N)*

The characteristics of these 4 farms could suggest that regardless of size, type of livestock or farmers' background, labour force availability can become an obstacle to the implementation of practices such as increasing the frequency of manure removal from housing units, even if the stock is housed for limited periods of time. However, Farm A and J scored well in the assessment, Farm I and N did not score well but only Farm N adopted changes and reduced the impact of the emissions from housing facilities. Moreover, Farmers B, E, G, H and K also scored negatively in the section related to housing management and Farms G, H and K were all family-run with effectively just the farmer working on the farm, but they did not cite labour force as a problem. Three (3) of them were tenant farmers and 2 owned the farm. Farm B and E were not under any environmental scheme and only Farm G was under HLS. Therefore, based on these results, it is not possible to identify common characteristics among these farms and their tenant farmers or owners which could illustrate why farmers may cite labour force availability as a positive or negative influence on farmers' uptake of innovation.

*Limited space available for manure storage,* cited by 6 farmers: Farmers A, C, G, J, K and N. Increasing the frequency of manure removal results in the need for adequate manure storage on farm. Section 6.2.3 addresses in more detail the difficulties of farmers may encounter in building facilities dedicated to manure storage and treatment. What can be interesting in this case is that all of the farmers who cited labour force availability as a problem (Farmers A, J and N), except Farmer I, also cited limited space for manure storage to be an obstacle. These conditions affected the frequency of turning of FYM because even if there was sufficient space to manoeuvre the machinery, the facilities did not provide enough floor space with adequate surfacing where to turn the manure heap.

The characteristics of Farms C, G and K were also rather different in terms of size and production, ranging from Farm C with 360 ha. farmed half as arable (fodder) and half as pasture, under HLS agreement; to Farm G with 137.59 ha. of pasture for organic beef cattle, of which approx. 16 ha. on rotation with vegetable production, under both OELS and HLS agreements and Farm K with 50 ha. beef cattle farm under OELS (Table 6.5). Therefore, at this stage, no common farm characteristic seems to emerge as possible influence on the adoption of change.

Table 6.5 Profiles of farmers who cited problems linked to limited space available for manure storage.

| Farm | Size Category (ha)[a] | Livestock | Organic Certification | Ownership | ESS | Mitigation | Change |
|---|---|---|---|---|---|---|---|
| A | 101-200 | beef | No | Manager | HLS | Yes | No |
| C | 301-400 | dairy | No | Owner | HLS | Yes | No |
| G | 101-200 | beef, sheep, vegetables | Yes | Tenant | ELS, HLS | No | No |
| J | <100 | beef, sheep, poultry | Yes | Owner | OELS | Yes | No |
| K | <100 | beef | Yes | Owner | OELS | No | No |
| N | 101-200 | dairy | Yes | Owner | HLS | No | Yes |

**Keys:** [a] Including arable land for fodder; ESS: Environmental Stewardship Schemes.

*Limited financial capital* available to make improvements and changes in livestock housing facilities was cited by 10 farmers, which is not uncommon, considering that 11 farms out of 14 overwintered livestock for a short period of time (i.e. 6 weeks to 3 months).

Results show that the farmers who cited limited financial capital as a reason for not always being able to adopt improvements in their housing management, worked on farms varying greatly in size and type of livestock (Table 6.6). However, many of these farmers shared common values regarding farming. Farmers C, F, G, H, J, K and N all relied on farming to support their families and had no other form of income than the one from their farms. While a change in housing management was not recommended to Farmers C and J because they were already adopting best practices to reduce GHG emissions from housing units, Farmers F, G, H, K and N were recommended to improve their housing management, but only F and N implemented changes. In particular, Farmer F decided to adopt a completely pasture-based system with no housing at all, effectively transferring emissions from housing units to practices related to grazing and pasture management and reducing the amount of labour required to manage livestock housing efficiently; while Farmer N increased the frequency of manure removal from housing units, even though he cited labour force availability, limited space for manure storage and limited financial capital as possible obstacles to his adoption of changes in housing management. Box 6.2 illustrates possible similarities between Farmer F and Farmer N.

Table 6.6 Profiles of farmers who cited problems linked to limited financial capital.

| Farm | Size Category (ha)[a] | Livestock | Organic Certification | Ownership | ESS | Mitigation | Change |
|---|---|---|---|---|---|---|---|
| A | 101-200 | beef | No | Manager | HLS | Yes | No |
| C | 301-400 | dairy | No | Owner | HLS | Yes | No |
| D | >501 | dairy, sheep | Yes | Manager | ELS, HLS | Yes | No |
| E | 301-400 | dairy | Yes | Tenant | - | No | No |
| F | <100 | sheep, beef, pigs | Yes | Tenant | ELS, HLS | No | Yes |
| G | 101-200 | beef, sheep, vegetables | Yes | Tenant | ELS, HLS | No | No |
| H | <100 | beef, sheep, pigs | Yes | Owner | OELS | No | No |
| I | 401-500 | dairy | Yes | Tenant | HLS | No | No |
| J | <100 | beef, sheep, poultry | Yes | Owner | OELS | Yes | No |
| K | <100 | beef | Yes | Owner | OELS | No | No |
| L | >501 | dairy, beef, pigs, sheep | Yes | Manager | OELS | Yes | No |
| N | 101-200 | dairy | Yes | Owner | HLS | No | Yes |

**Keys:**: [a] Including arable land for fodder; ESS: Environmental Stewardship Schemes.

Box 6.2 Farm ownership and tenancy. Does it matter?

Farm F is a mixed livestock farm situated in Gloucestershire. It obtained full organic certification in 2011. At the time of the study, livestock included 12 ewes that were housed just for lambing, a couple of free range pigs and beef cattle was being introduced. Farmer F had taken on the tenancy of the farm, owned by the National Trust, 10 years prior to the study and he was very passionate about converting the production to an entirely pasture-fed system, as well as expanding the sheep and beef stock. In addition to the ELS agreement the farm was under since 2004, the farmer had recently signed the HLS agreement in 2012 with the purpose of managing the land to the best possible standards in order to promote environmental conservation and sustainable use of agricultural land.

Farm N is a medium sized dairy farm in the West Midlands. The business is family-run and farmer N is the third generation owner of the farm. He is very proud of his family history and values, which reflect in the full organic certification obtained in 2006 from the Organic Farmers and Growers Ltd. and the subscription to the HLS agreement in 2010. Farmer N adopts pasture-fed farming practices, housing his 270 cows only for a limited time during the colder and wetter months. Farmer N showed similar interest in adopting environmental conservation practices and sustainable use of resources. The fact that both farmers had personal attachment to their businesses and lifestyles could suggest that ownership of the farm may not necessarily lead to greater motivation in overcoming possible financial obstacles in adopting on-farm innovation.

Given the small sample of farmers, it is not possible at this stage to identify any of the 3 reasons cited above as the main influence behind farmers' behaviour because farmers who provided similar responses and cited similar problems reacted in different ways to the proposed changes. It is reasonable to expect that small family-run farms can be more susceptible to financial limitations, but results showed that farmers working on larger farms like Farm A, E or I, that were not run as family businesses (i.e. the farmer was the manager and no other member of the family was working on the farm) were also concerned with financial limitations. This aspect will be addressed in more detail in section 6.4.1, illustrating results not limited to practices related to housing management.

### 6.2.3 Manure storage and treatment

The RFPA tool highlighted a series of problems in the storage and treatment of manures on farm. The barriers encountered are similar to those in the case of livestock housing practices, as described in section 6.2.2. In spring 2012, only 2 farms out of 14 registered a neutral impact. All other 12 farms registered a negative impact i.e. lack of mitigation of GHG emissions (Table 6.7). Two farms with a negative impact adopted changes. Farm C and Farm M increased the frequency of manure removal and improved their score in the second assessment in autumn 2012: one reduced the negativity of its GHG impact and one reached a neutral impact score. The impact of all other farms remained unchanged over the 6-9 months in between the two assessments. By analysing each farm's circumstances, the study aimed to identify common characteristics which may suggest possible influences on farmers' uptake of recommendations to mitigate GHG emissions from manure storage and treatment.

Practices that were already fully or partially adopted by the farms in question included:-

*Composting:* It is important to consider that organic farms can obtain their certifications from various bodies (e.g. Soil Association Ltd., Organic Farmers and Growers Ltd.) and that the requirements for the composting of manures, although similar, may result in differences in their practical implementation, with a minimum composting time of 6 months before application (Environment Agency, 2012; Soil Association, 2012), that in some cases is extended for up to 2 years (Farm E) following Soil Association recommendations. None of the uncertified organic farms composted manure before using it as fertiliser. The majority of the certified organic farms composted manure, with the exception of Farms D, H, I and L. It is interesting to note that Farm D, I and L were the 3 largest farms to participate in the study, with sizes between 480 ha. and 550 ha.

including arable production for fodder. Even though Farm D and L had a mixed livestock production, all 3 farms had a dairy production accounting between 100 and 170 cows annually, including the followers. All 3 farmers were tenants, as opposed to the situation of Farmer H, owner of a 68.8 ha. family-run mixed livestock farm. The fact that these farms did not compost manures could be linked to the possibility that adequate space and facilities are not available on-site. However, none of these 4 farmers cited lack of space to store manure among the problems encountered on farm (Section 6.2.2), but they all cited financial limitations instead, and Farmer I cited labour force availability as well. Specific reasons for not composting manures were not provided by these farmers, which could suggest that financial limitations were often used as a more general reason for not implementing innovation or adopting changes in farm management, regardless of the size of the farm and the possible benefits from practices that reduce the environmental impact of farms. Results also suggest that individual responses from farmers do not seem to be related to specific farm characteristics that would identify the presence or absence of obstacles such as storage space, highlighting differences that are likely to exist between farmers' perceptions of an obstacle and actual presence of the obstacle (i.e. lack of storage space). Further analysis on this subject will be carried out in section 6.4 covering the wider range of farm practices and farmers' attitudes addressed by the study.

Table 6.7 Estimated increase (+) or reduction (-) in GHG emission mitigation (in %) and impact of changes in manure storage and treatment.

| Farm | Spring 2012 | Change in practices | Autumn 2012 |
|---|---|---|---|
| A | -20.00 | no | -20.00 |
| B | -30.00 | no | -30.00 |
| C | -10.00 | yes | -5.00 |
| D | -20.00 | no | -20.00 |
| E | -2.50 | no | -2.50 |
| F | 0.00 | no | 0.00 |
| G | -10.00 | no | -10.00 |
| H | -20.00 | no | -20.00 |
| I | -15.00 | no | -15.00 |
| J | 0.00 | no | 0.00 |
| K | -10.00 | no | -10.00 |
| L | -17.50 | no | -17.50 |
| M | -10.00 | yes | 0.00 |
| N | -15.00 | no | -15.00 |

***Keys:***

Green: improvement of on-farm GHG mitigation potential

Red: lack of improvement of on-farm GHG mitigation potential, starting from a negative mitigation potential score

*Addition of water, addition of straw:* These practices were considered important by all farmers. However, addition of water and/or straw was not consistent in time, due to lack of cover on some Farm Yard Manure (FYM) heaps and weather fluctuations (i.e. rainfall), and the high content of straw from the bedding. Results did not show any specific relationship between the adoption of these practices and farms' characteristics. At the time of the first farm assessment, the 2 farmers who did not implement either of the practices were Farmer I and Farmer J, whose farms differ greatly in size (485 ha. and 28.3 ha. respectively), livestock (dairy and beef, sheep, poultry respectively) and subscription to environmental schemes (HLS and OELS respectively); Farmer I was a tenant farmer while Farmer J owned the farm. Conversely, the only farmer adopting both practices was Farmer F, whose profile has been discussed in previous paragraphs (Box 6.2). All these 3 farmers were interested in interacting with other farmers and local farmers groups. However, the same can be said of other farmers in the study who did already implement at least one of these two practices, as well as of Farmer M who was the only one who adopted changes and introduced additional straw following the recommendation issued as a result of the first farm assessment. The contents of water and straw can vary greatly depending on the amount of straw from the bedding and practices related to housing management, such as complete removal of bedding and floors cleaning. In particular, it is not unreasonable to expect that farmers could show scepticism regarding the exact quantity of straw to be added to FYM heaps because of different percentages of straw already being present at the moment of storing manure mixed with bedding collected from housing units. However, the RFPA tool used to assess farms in this study did not aimed to provide such detailed recommendations, but rather to identify problematic practices and raise awareness among farmers of the GHG emission mitigation strategies that could help them reduce their farms' impact in the future. Therefore, during the study emphasis was put on ensuring that fresh straw was added regularly to housing units in order to have reasonable amounts of straw in the FYM heaps.

*Turning:* Farmers expressed difficulties in turning FYM heaps because of lack of adjacent space to manoeuver the machinery (Farms A, H and J), while others (Farms C and N) followed the recommendation of turning the heaps monthly before application to field. Interestingly, both uncertified organic farms A and C were not turning their FYM heaps. The other uncertified organic farm, Farm B, had no FYM heaps because ewes were kept on pasture all year long. As illustrated in Table 6.6 the only common characteristic between Farms A and C is that they were both under HLS agreement, which requires farmers to adopt a manure management plan to ensure the correct use of manures. Both farms had a manure management plan and both had cited limited space for manure storage as possible obstacles. Nevertheless, only Farm C adopted the practice of turning FYM heaps monthly before application to field, as recommend after the first farm assessment. Farmer A is a young farm manager, while Farmer C is a second generation farmer over 80 years of age. Both are well linked to local farmers groups and showed great passion about farming using the most environmentally friendly practices in order to produce good quality food. However, their reaction to the proposed change in FYM heaps turning was different. The owner of Farm C even expressed interest in installing pipes under the manure storage system to generate electricity from the heat produced by the storage system. However, the financial investment necessary is currently preventing the farmer from implementing this solution.

These results show that even though both farmers were facing similar obstacles logistically and financially, it could be reasonable to suggest that in this situation Farmer A decided to adopt changes that he may have perceived as having a more valuable long-term return in terms of efficiency of production. In particular, taking into account practices related to the application of manure to field (Section 6.2.5), Farmer A decided to introduce regular manure analysis in order to ensure efficient manure and nutrient management, and he did not try to adopt monthly turning of FYM even though the amount of manure produced by his 37 beef cattle herd during overwintering was not to be considered large and unmanageable. Farmer C, however, who like Farmer A was also recommended to analyse manure regularly, did not adopt such practice. His experience is described in Box 6.3.

Such results once again show that individuals placed in similar circumstances and presented with similar options may choose one route instead of another. In this case, a possible explanation could be that the cost of manure analysis is easily quantifiable and can be added to the farm annual budget. The actual cost of turning the manure on a monthly basis or the addition of water and/or straw to the FYM heaps can perceived as less quantifiable or perhaps their cost is not perceived as easy to single out and budget for (i.e. cost of fuel for the machinery and cost of labour). When facing financial limitations and logistic problems, Farmer C showed an approach that could perhaps be described as holistic in terms of farm management, including an additional task i.e. monthly turning of FYM heaps, within the activities carried out regularly on farm; while Farm A showed a more managerial approach by preferring to invest in manure analysis first and plan changes in the future, but not necessarily implementing them straight away.

Box 6.3 A conventional farm with a proactive old farmer.

Farm C is a conventional dairy farm in Gloucestershire, run by the current owner, a second generation farmer of more than 80 years of age. The farm is managed following organic principles, although the farm does not hold organic certification. The farm is situated within a Nitrate Vulnerable Zone (NVZ) and it has taken part in the Higher Level Stewardship scheme. The size of the farm is 360 ha., of which 180 ha. are used as pasture, with long term ley and permanent grass, while the remaining 180 ha. is arable land for the production of fodder. The size of the herd is around 350 animals. Animals are separated by age, with varying housing times depending on the stage of production. Young stocks are kept on pasture all year long, 20 animals during the winter and 40-60 during the summer. Male calves are reared for beef on pasture, following grazing rotational patterns.

In spite of his age, Farmer C is a very hands-on farmer. He supervises every single operation on farm and he is helped with the farm activities by 2 labourers: one helps running the milk and yogurt processing unit adjacent the main farm buildings; the other one is a part-time worker. Additional labour is contracted during the year depending on necessity (i.e. harvesting, calving season) and financial availability.

Farm C is a family-run business and Farmer C is passionate about producing good quality produce for the community. Farm C produces fresh milk and yogurt which, along with a small amount of beef, are sold locally at farmers' markets in the area by Farmer C's wife and children. Farmer C is very conscious about the importance of optimum dietary management for his business and he follows a textbook with dairy cattle nutritional guidelines. Great attention is given to grazing rotations to ensure animals graze on good pastures and do not damage the soil excessively.

Financial limitations have been an obstacle in recent years, but housing management has remained efficient thanks to previous investments in a scraping system when the business was run as an intensive dairy farm without animals on pasture. The scraping system considerably facilitated the cleaning of the bedded areas and reduced labour hours, even after the intensive production was replaced by a pasture-based one. However, during the first farm assessment, the storage of FYM was found to be simply a heap in a small area with concrete flooring. The heap was not turned monthly and manure was not treated in any way before application to field at least 6 months later. Improvements in manure storage and the introduction of regular manure analyses were recommended to Farmer C, who initially cited finances and labour as his major concerns, as well as the fact that the area with concrete floor available for storage was limited. However, at the second farm assessment, Farmer C agreed that improvements in manure storage were much needed. He explained that he considered manure analysis a cost he could not afford at that time and preferred to manoeuver machinery more frequently on-site in order to turn the FYM monthly. Financial limitations were still a great concern for Farmer C, as potentially, any change in practices could have resulted in additional costs in terms of fuel, labour and time. But after reading the first farm assessment and the recommendations given to him, he managed to slot in some improvements, like turning the FYM heap monthly, in the farm's routine activities. This farmer's experience shows that there can be scope for improvements in farm management and small steps can be taken by farmers even when the lack of financial capital and/or labour could be perceived by them as obstacles too difficult to overcome.

When considering the organic farms in the study, Farms J, L and M were already turning the manure heaps regularly. Of all the other farms, only Farm N decided to adopt this practice following recommendation after the first farm assessment, even though he pointed out storage space and labour as possible obstacles, but he agreed that he could overcome these problems by managing more efficiently the scraping of the housing units and the location of the FYM heap, so as to insert a monthly turn of the heap within the daily scraping routines. A common characteristic between Farms J, L and M was the mixed livestock farming system, but their sizes varied greatly, Farm J being the smallest farm in the study (28.33 ha.), Farm L being the largest (340 ha. of pasture and 185 ha. of arable land) and Farm M expanding over a combined 350 ha. of pasture and arable land. Farm M was under HLS agreement, while Farms J and L were under OELS agreement. Interestingly, Farmer J did cite labour force, storage space and financial limitations during the farm visit, but he was able to turn the manure heaps on a monthly basis with careful time planning and manoeuvring of the machinery.

Results do not seem to highlight a common denominator between the organic farms who did not adopt this practice even after recommendation. Available space was cited by Farmers G and K, and labour force was cited by Farmer I. No specific obstacles were cited by other the farmers other than a general reference to financial limitations.

Finally, in the case of monthly turning of manure heaps, results did not highlight significant similarities among all farms who responded by adopting change. Therefore, it can be reasonable to believe that individual circumstances may play a significant role in farmers' decision making process.

Practices that registered the greatest barriers to adoption were:-

*Slurry separation:* Only 4 farms out of 14 (Farms E, I, J and K) had a slurry separation system in place. Farm E is part of a larger holding. The slurry separation tank was installed as part of the company investment; therefore, as opposed to Farm C, which is a small family-run dairy farm, the move wouldn't have been possible if Farm E was not part of a larger business.

Farm I had a grid system at one end of the dairy housing unit. During overwintering, bedding mixed with manure was collected using a scraper and liquid manure separated from the solids. The latter was stored in uncovered FYM heaps; the former stored in an open-air lagoon until spreading on field.

Farm J converted from small-scale dairy production to small-scale mixed livestock without any dairy cattle. One of the 2 small housing units retained an under-floor slurry tank that collected slurry during overwintering and was emptied by the farmer twice a year.

Farm K had a small concrete tank where manure scraped from the overwintering housing unit was collected and liquid waste drained into a smaller tank via a piping system. The farm produced very limited amounts of manure and no further investment was made to improve the collection system.

All other farms considered slurry separation a costly practice that may affect their budgets. As an example, the manager of Farm D considered the option and sought advice from experienced consultants, who considered it not viable.

*Use of covers:* This practice can be difficult to implement in extensive low-input systems when additional investments are required. FYM heaps also did not have covers on any of the farms in the study. The heaps were left on field or on a concrete surfaced area near the housing units. The owner of Farm N had attempted to use a system of tarpaulin and tyres to cover the FYM heap, but the farm is located in a windy valley; therefore the system was abandoned.

As shown in chapter 3, airtight covers provide the most effective mitigation results as they allow the collection of gases from the manure stores, which can be then used to provide energy and heating. However, airtight covers are likely to be more expensive and adequate piping and ventilation systems would be required. Four farmers out of 14 had a slurry collection system, but no airtight covers were installed. In 2 cases (Farms E and J), the slurry tank was covered by a roof, while in the other 2 cases (Farms I and K) the tank had no cover of any kind. Interestingly, Farms J and K were the 2 smallest farms in the study, both under OELS and both farmers owned their farms. Instead, Farms E and I were both dairy farms, their size differed had (i.e between 100-110 dairy cows with followers on Farm I, and 250 dairy cows with followers on Farm E). Both farmers were managers, but no other common characteristics were found between the two. In the case of the two small farms (Farms J and K), the slurry was collected from overwintered beef cattle and the structure of the housing units allowed the collection of slurry without additional labour for the farmers, who were both the sole workers on site. No additional structure was present on Farm K to provide a roof or any other type of cover to the slurry tank, as Farmer K preferred not to invest in these facilities. The same reaction was shown by Farmer I: the slurry lagoon did not have a cover when he took over the tenancy of the farm and he preferred not to invest in one. The facilities at Farm E were such that the slurry tank was covered by a roof.

There does not seem to be a specific obstacle to adoption of covers on slurry tanks other than the possible financial implications of having to build additional facilities. However, studies using a larger sample of farms with similar characteristics would be needed to further investigate the potential for adoption of such practice.

Finally, these results lead to some important considerations. Farm buildings had limited space available for manure stores (i.e. composting before application to field) with concrete floors, appropriate drainage and sewage system, storage for liquid leaks collected from manure pits and appropriate cover of both solid and liquid storage systems. However, the provision of adequate facilities did not always depend on the size of the farm, but rather on the type of management adopted i.e. half the farms in this study had less than 150 cows, overwintered for 6-8 weeks. It can be reasonable to expect that the small size of these farms could not offer much margin within the annual farm budgets for improvement of the facilities destined to manure storage and treatment. In order to build storage facilities, provide cover to manure heaps and slurry tanks, install drainage and collection systems, a capital investment is needed. However, some farmers on farms with smaller stocks, as well as others working with larger stocks, were reluctant to invest capital in additional facilities because of the labour that their maintenance would have involved and the limited space some farms could allocate to the collection and treatment of waste.

The results show that farmers may find it difficult to see the connection between investment in manure storage and treatment and increased productivity. Contrary to what happens with mitigation options related to dietary management, which match good practices that ensure optimum balance between nutritional inputs and productivity, in the case of manure storage and treatment, the impact on farm productivity is indirect. For instance, composting manure produces organic fertiliser that will benefit the pastures and / or the crop production, where present. The farms visited compost manure following organic regulations, where applicable. However, as it has been mentioned earlier, in the case of farms where livestock is entirely pasture-fed or it is overwintered for a limited length of time (i.e. 6-8 weeks) depending on weather conditions, the amount of manure produced only influences productivity in terms of the amount of organic fertiliser available for field application. In some cases i.e. Farms A, E and K, the amount of manure collected in FYM heaps during the overwintering period is not sufficient to fertilise the whole of the farm land surface area. Farm H had as little as 30 suckler cows overwintered for up to 2 months. In these conditions, it is not unreasonable to expect that farmers may be reluctant to invest or to apply for grants, in order to build small capacity manure storage systems that may provide limited cost-effectiveness. Such obstacles and financial limitations which may affect farmers' uptake of on-farm innovation will be addressed in more detail in section 6.4.

### 6.2.4 Grazing and pasture management

Grazing and pasture management mitigation options are directly affecting productivity of farms with livestock grazing for most of the year, as pasture represents the primary source of feed. Therefore, it is reasonable to expect that, as has been discussed previously in section 6.2.1, farmers pay close attention to pasture management. Overall, farms implemented good agricultural practices related to grazing and pasture management (Table 6.8). Mitigation options proposed to farmers included monitoring of stocking rates, grazing times (i.e. weather conditions), rotational grazing and the use of feed pads on pasture; optimal pasture management with legumes on pasture and frequent rotations to allow livestock to graze on younger pasture; and soil management practices to avoid compaction, waterlogging, run off and poaching, such as the installation of drainage systems and fences to adopt strip grazing systems. Overall, stocking rates were closely monitored by farmers, rotational systems were adopted and legumes included in seed mixes.

Table 6.8 Estimated increase (+) or reduction (-) in GHG emission mitigation (in %) and impact of changes in grazing and pasture management.

| Farm | Spring 2012 | Change in practices | Autumn 2012 |
|---|---|---|---|
| A | 14.20 | no | 14.20 |
| B | 18.60 | no | 18.60 |
| C | 15.10 | no | 15.10 |
| D | 8.30 | no | 8.30 |
| E | 11.90 | no | 11.90 |
| F | -6.70 | yes | 6.70 |
| G | 1.60 | no | 1.60 |
| H | -4.00 | no | -4.00 |
| I | 12.90 | no | 12.90 |
| J | 1.30 | yes | 4.70 |
| K | 14.20 | no | 14.20 |
| L | 23.10 | no | 23.10 |
| M | 1.70 | no | 1.70 |
| N | 17.50 | no | 17.50 |

***Keys:***

Green: improvement of on-farm GHG mitigation potential

Red: lack of improvement of on-farm GHG mitigation potential, starting from a negative mitigation potential score

A total of 10 farms out of 14 scored positively at the first farm assessment. Only 2 farms scored negatively, Farm F and Farm H. They both had a similar approach to soil management, with the advantage of a flat land surface area in the case of Farm F.

In terms of pasture and livestock management, the greatest problem encountered by Farm F was the very limited amount of legumes on pasture, while other practices did not constitute a problem, especially because of the very low stocking rate on the farm. The farm converted to an entirely pasture-based system and re-seeded pasture with mixes containing higher percentage of legumes, therefore improving the farm's mitigation score during the second assessment in autumn 2012

Conversely, Farm H had problems regarding the management of a higher stocking rate on rotation on sloped fields and the impossibility of reducing the stocking rate or increasing the frequency of rotations due to lack of labour force. The farm obtained a negative assessment score at the first visit but no changes were implemented to improve the score. The farmer agreed on the need for improvement and he showed great interest in strip grazing and the "mob grazing" technique (Savory, 1991), where daily rotations of livestock in smaller paddocks result in areas being grazed intensively for short periods of time, at 120 days intervals. However, the farmer encountered obstacles related to the amount of labour required to install adequate fencing and move the herd daily. Moreover, the farm being located in a rainy area in Cornwall, with heavy soils and sloped pastures, strip grazing couldn't always be adopted. Therefore, the farmer closely monitored the stocking rate to ensure optimum grazing density and soil management.

Interestingly, both farms had similar size (i.e. 73.4 ha. Farm F and 68.8 ha. Farm H) and both businesses were family-run, with just the farmer working on-site. Farm F was under ELS and HLS, while Farm H was under OELS. Farmer H occasionally organised farm visits for local schools and both farmers showed interest in issues regarding environmental conservation and carbon sequestration within the range of services agriculture can provide to society. Moreover, both Farmer F and H participated in the activities of their local farmers' groups and showed interest in peer-to-peer knowledge exchange. However, on the one hand, Farmer F managed to adopt some changes, which required him to work with a seed supplier to find the most appropriate legume-rich seed mix to use under his HLS agreement; on the other hand, in spite of showing interest in innovation, Farmer H did not adopt any changes to his farm management. The recommendation given to Farmer H required additional labour. Therefore, it is reasonable to suggest that in the case of small farms with similar characteristics, like Farm F and H, labour could have a great influence on farmers' decision-making.

Farms E and J were advised to install a drainage system in order to improve soil management. Farm E, being part of a larger holding, agreed to introduce the matter to the higher management and, in the meantime, work towards improving soil conditions by installing additional fencing and adopting strip grazing with an increased frequency of rotations. Farm J was family-run, pasture-based, organic mixed livestock farm, like Farm H, with greater problems with drainage in one field in particular, but could not afford installing a drainage system. The interesting result is that Farm J had already obtained a positive score at the first assessment of its practices relating to grazing and pasture management; therefore, changes in this section of farm management were not recommended, but rather advised to further improve the overall score. Nevertheless, Farmer J decided to adopt some changes to compensate the lack of a drainage system, such as strict control of the stocking rate and increasing the frequency of rotations to minimize poaching. Both Farmer H and J owned their mixed-livestock farms, both were interested in wider environmental issues related to agriculture and farming, and both participated in knowledge exchange activities via their local farmers groups. The only difference between the two cases was the size of the farm i.e. Farm H was a little more than twice the size of Farm J, hence the likelihood of labour force being a greater issue for Farm H than for Farm J. Therefore, a larger sample of small farms with similar characteristics to those of Farm H and J would need to be analysed in order to obtain a better understanding of the opportunities for GHG emission mitigation from grazing and pasture management.

All farmers in the study stated that good care of pastures and soils in the long-run reflects on productivity and animal health and welfare. Moreover, half the farmers interviewed showed interest in carbon sequestration as a possible way to ensure good long-term soil health and nutrient management. Among these farmers no prevalence was found of either owners rather than tenant farmers, or of farmers working on smaller rather larger farms. Indeed, it is also not unreasonable to believe that some farmers might be interested in soil sequestration as a potential source of income in terms of farm subsidies, although this particular topic was not investigated during the study.

Even though the majority of farmers adopted good grazing and pasture management practices, most of the scepticism showed by farmers was related to the uncertainty regarding the actual benefits in terms of GHG emissions reduction and how a change in practices is reflected in a carbon footprint report. Emissions from soils are more difficult to measure, due to obvious practical reasons and the multitude of variables affecting the accuracy of model predictions (Asseng et al., 2013; Rötter et al., 2013). Farmers’ interest and trust in the scientific basis behind GHG emission mitigation will be addressed in more detail in section 6.4.3.

### 6.2.5 Manure application to field

The majority of the farms which participated in the study obtained a positive mitigation score at the visit assessment (Table 6.9), which shows that, regardless of farm characteristics such as size, type of farm, environmental schemes, tenancy or ownership of the business, farmers apply good agricultural practices, such as avoiding manure application in autumn or to soils with high moisture content. Manure spreading and injection were also adopted; while split applications and application of manure mixed with green waste had limited implementation because some farmers did not have access to green waste or the amount of manure to be applied on field was very limited. However, it is important to remember that the RFPA used to assess the farms was designed so that farm scores were only negatively affected when a practice considered applicable within the farming system was not adopted.

Table 6.9 Estimated increase (+) or reduction (-) in GHG emission mitigation (in %) and impact of changes in manure application to field.

| **Farm** | **Spring 2012** | **Change in practices** | **Autumn 2012** |
|---|---|---|---|
| A | -6.30 | yes | 3.80 |
| B | 12.50 | no | 12.50 |
| C | -3.80 | yes | 3.80 |
| D | 9.20 | no | 9.20 |
| E | 12.50 | no | 12.50 |
| F | 9.20 | no | 9.20 |
| G | 5.00 | no | 5.00 |
| H | 11.30 | no | 11.30 |
| I | 12.90 | no | 12.90 |
| J | 8.80 | no | 8.80 |
| K | 3.80 | no | 3.80 |
| L | 12.50 | no | 12.50 |
| M | 3.80 | no | 3.80 |
| N | 9.20 | no | 9.20 |

***Keys:***

Green: improvement of on-farm GHG mitigation potential

Red: lack of improvement of on-farm GHG mitigation potential, starting from a negative mitigation potential score

The only 2 farms that scored negatively during the first assessment were Farm A and Farm C. Both were uncertified organic farms under HLS agreement, but farmers followed organic principles. They were quite different in size and type of livestock. At the time of the first assessment, Farm A included 56 ha. of pasture for a total of 37 beef cows and follower, and 126 ha. of arable production for fodder; Farm C had 180 ha. of pasture for 350 dairy cows and further 180 ha. for arable production for fodder. Both stocks were housed for a limited time during the winter months, as farmers preferred pasture-based farming principles. Differences were also found in the farmers' characteristics. Farmer A was the farm manager, while Farmer C was a second generation owner of the business. Nevertheless, as a result of the recommendations proposed to them in order to improve their management of manure application to soil, both farmers implemented changes that led to a positive score during the second farm assessment in autumn 2012. Farm A had recently approved a manure management plan and, by the time of the second assessment, manure analysis and forage analysis had been carried out to ensure optimum nutrient management. Even though application of manure in autumn could not be avoided for reasons linked to crop cultivation, the farmer ensured that manure was not to be applied on soils during wetter days. Conversely, Farm C avoided the application of manure during the colder and wetter months, therefore scoring positively at the second assessment.

These results lead to some important considerations. Machinery necessary to apply slurry may represent a barrier to adopt the optimum type of application (i.e. injection), as the deeper the manure is applied to soil, the fewer emissions are registered (Eckard et al., 2010). However, adequate machinery may not be available to the farmer. As an example, the manager of Farm E had a good relationship with the contractor that provided farm machinery for the larger holding Farm E is part of and, therefore, he could replace slurry spreading with injection to ensure optimum depth of application. This situation may not be possible in other contexts, based on the amounts of slurry produced, such as in the case of the 8 family-run farms that participated in the study.

Furthermore, it is important to remember that NVZ restrictions and organic legislation influence some agricultural practices related to the application of manure. The results of the farm assessments did not show a direct relationship between mitigation strategies related to manure application to field and farms being located within a NVZ. However, it is reasonable to expect that good agricultural practices and restrictions under NVZ regulation match with practices that are estimated to reduce emissions. Therefore, further detailed investigation is advised on this subject.

It has been mentioned in section 6.2.3 that manure has to be composted prior to application. Therefore, the timing of collection and the duration of composting influence the timing of application. The application mixed with green waste may also be less feasible in reality, as 13 farms out of 14 did not have access to green waste material that could be added to the compost pile.

Another important factor to take into account is weather conditions. Although it is advised to avoid manure application in autumn to reduce N losses from cold and wet conditions, spring may not have better weather conditions, as weather can be unpredictable and unstable for a length of time. Moreover, farms with arable production such as winter crops may need to apply manure in the autumn.

Furthermore, when comparing the characteristics of the farms that scored negatively and whose farmers were recommended to adopted changes, with the characteristics of the other farmers in the study, results show that all 11 organic farms scored positively and did not implement changes, but only 1 (Farm B) out of 3 uncertified organic farms scored positively and the other 2 farms (Farms A and C) scoring negatively, but they both adopted changes following recommendations. This could suggest that the management of manure application to field is more effective in mitigating emissions on farms that strictly follow organic principles. However, the small sample size of this study does not allow for generalisation of these results and a greater sample representative of the characteristics of both farms and farmers (i.e. size, farming system, type of livestock, tenancy or ownership, labour force, farmers' age or education) is needed to compare organic and conventional farming systems in terms feasibility of GHG emission mitigation strategies.

Finally, the greater obstacles encountered to the improvement of farm practices in this section can be ascribed to the use of contractors to apply manure to field. This factor influences the type of application based on pre-existing contracts and on the possible additional costs farmers may encounter if changing application method. However, it has to be noted that the farmers interviewed do not produce large amounts of manure or slurry, as explained in section 6.2.3. In the majority of farms, the amount of manure collected during the overwintering was not sufficient to fertilise the entire farm land surface area, without additional organic fertiliser brought in and the manure being applied primarily to arable land.

The changes observed between early spring and autumn 2012 showed that farms can have a certain margin for improvement in management practices in spite of practical obstacles related to the infrastructure available, possible lack of space for additional manure storage facilities and the use of contractors, in particular to apply manure on field.  However, no common farms' or farmers' characteristics were highlighted as possible obstacles or incentives to the adoption of on-farm innovation. The next part of the study set to identify other possible obstacles that may be related to farmer's attitudes and perception of GHG mitigation. The following illustrates the results of farmer engagement activities.

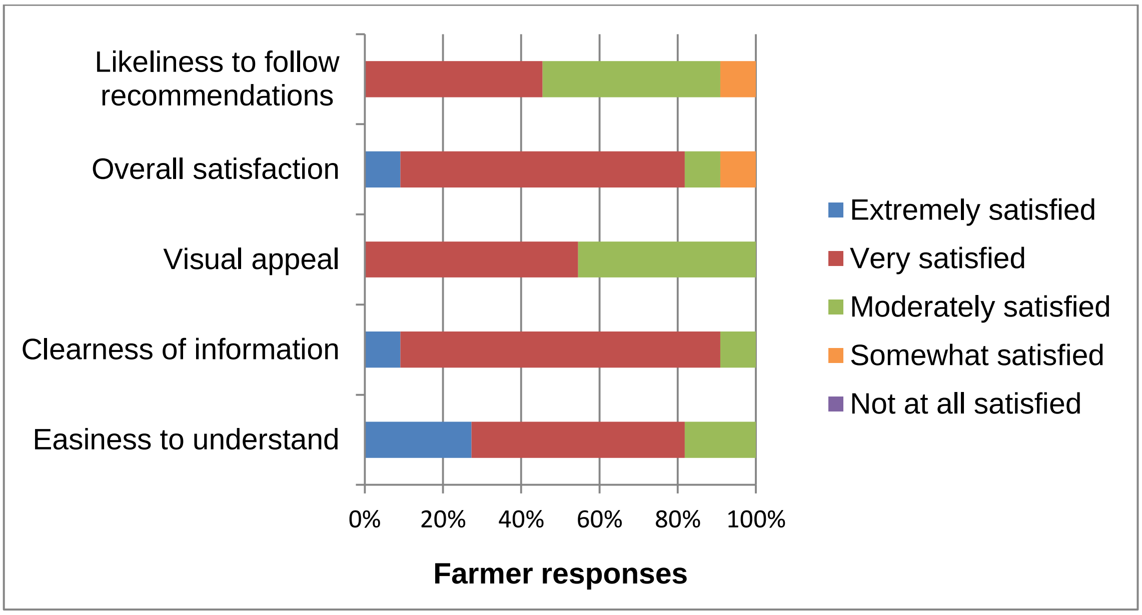
## 6.3 Farmer engagement

This section illustrates the results of farmer engagement at different stages during the study. Initially, feedback is given on the methodology used and the application of the RFPA tool. Then farmers' attitudes and perceptions of GHG emission mitigation are evaluated, followed by the results from the focus group meeting organised in February 2013 as final stage of the study.

### 6.3.1 Rapid Farm Practices Assessment tool

All farmers were asked to provide their feedback on the Rapid Farm Practices Assessment (RFPA) tool described in section 5.3.1, by filling out a feedback form enclosed with the farm assessment report submitted to them after the first visit in spring 2012. Although only 11 farmers provided formal feedback, overall the RFPA tool was well received (Figure 6.5) and farmers showed interest in the methodology used.

Figure 6.5 First visit report feedback survey. Farmers were asked to give a score to each survey question, ranging from "not at all satisfied" to "extremely satisfied" (n = 11).



During the interviews in autumn 2012, eight out of 14 farmers (Farmers B, C, G, J, K, L, M and N) expressed scepticism over carbon footprinting tools for agri-businesses. Among the reasons provided, farmers included *"grey areas of carbon accounting"* (Farmer H), in particular the uncertainty regarding calculations of emissions originating from pasture and grazing. Even though 2 farmers openly stated they did not trust current carbon footprinting tools as they did not believe the tools reflect the real situation on their farms (J and K), 9 out of 14 farmers (Farmers A, F, G, H, I, J, K, M and N) expressed interest in opportunities for improving carbon sequestration on their pasture. These farmers were not sure that the current free carbon calculators are accurate and valuable tools to help them assess carbon sequestration and therefore obtain a balanced footprint which takes into account not only emissions, but sequestration as well. The following paragraph will further discuss farmers' attitudes to climate change, including their perceptions and opinions of current carbon footprint calculators.

It is important to consider that the tool created for the purpose of this study focuses on specific farm practices, providing an estimate of the emission mitigation for each practice, which could be a reason for its appeal to all the farmers interviewed. The dislike of carbon footprinting tools may be related to the fact that carbon calculators require farmers to look for and input relatively large amounts of data regarding their farm inputs, outputs and livestock. Conversely, the farmers interviewed considered the approach taken by the RFPA tool to be more useful in providing practical alternatives to practices that generate the greatest GHG emissions, rather than a series of figures to represent the sources of emissions. Eleven farmers responded to a feedback survey on the report they received. The results showed that 9 out of 11 farmers found the farm assessment reports easy to understand and 10 out of 11 farmers considered the information provided to be extremely or very clear, in particular the short descriptions that included scientific information regarding the reasons why a given practice was considered beneficial for mitigating on-farm GHG emissions. In his feedback, one farmer stated that the report contained *"some interesting material that I was not previously conscious of"* (Farmer N).

The study showed that the methodology was also well accepted by farmers, mostly because of its practical approach to GHG emission mitigation and the clearness of the information provided to the farmers. The results support what was found by Islam et al. (2013) and Llewellyn (2007) regarding the likeliness of farmers accepting advice being dependent on the transparency and clearness of communication of agricultural extension officers and/or researchers. Moreover, the RFPA tool represents a Decision Support System (DSS) that does not function as proxy for farmers, but rather as an actual tool that translates science-based information into valuable practical recommendations, and therefore it is more likely to be accepted by farmers (McCown, 2002).

Finally, the results showed that the RFPA tool has the potential for engagement with farmers on a wider scale, by using a relatively simple approach that translates complex scientific knowledge into practical farm advice; in other words, a practical example of translational research.

### 6.3.2 Farmers' attitudes and perceptions of GHG mitigation

During the second farm visit in autumn 2012, semi-structured interviews were carried out to gather data on farmer decision-making process, as described in section 5.3.2 (Table 5.1). Factor evaluation was based on the percentage of farmers citing a factor as a positive, negative or neutral in influencing the way they take decisions (Figure 6.6). Results show that the factors with the greatest positive influence are the trust in the advisor and the interest in environmental matters; while the factors most negatively affecting farmers are represented by financial limitations and the lack of trust in government action (Table 6.10). The results seem to be in line with what discussed in chapter 4 regarding Participatory Action Research and the interaction between extension officers and farmers, although the observation should be treated with caution due to the low sample size. Further discussion on the greatest obstacles and opportunities found in the survey follows in sections 6.4 and 6.5.

Figure 6.6 Impact of factors influencing farmer decision-making (n = 17). Note: refer to Table 5.1 for factors description.

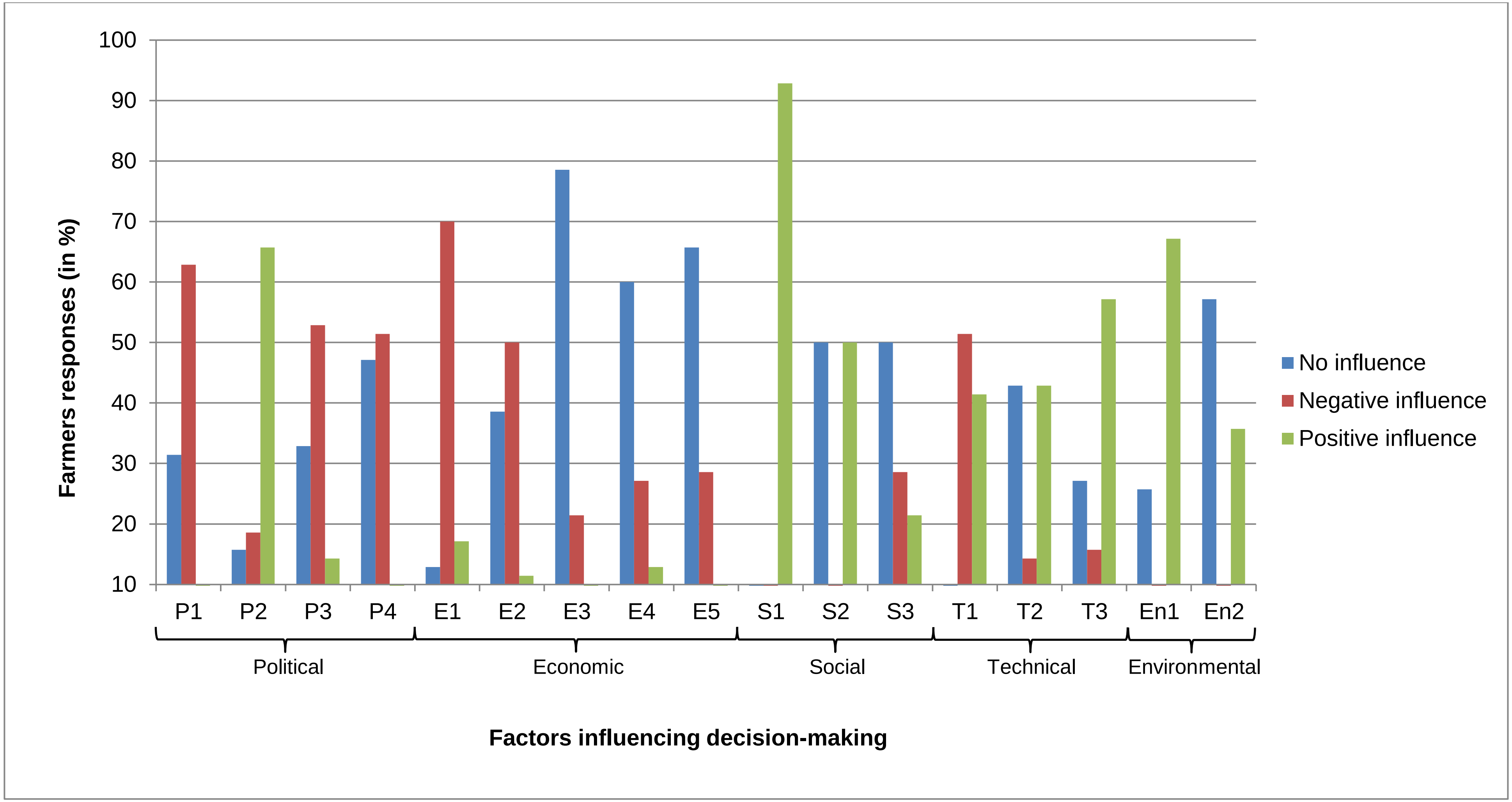


Table 6.10 Factors with the greatest impact on farmer decision-making, based on the percentage of responses (n=17).

| **Impact** | **Factor** | **Percentage (%)** |
|---|---|---|
| Positive | S1. Trust in source of recommendations (individual) | 92.9 |
| | En1. Interest in conservation and environmental matters | 67.1 |
| | P2.Trust in source of recommendations (institution) | 65.7 |
| | T3. User-friendliness of assessment tools | 57.1 |
| | S2. Community support and/or engagement | 50 |
| Negative | E1. Financial constraints (limited budget) | 70 |
| | P1. Trust in official reports, government | 62.9 |
| | P3. Support in integrating environmental schemes and GHG emissions reduction | 52.9 |
| | P4. Bureaucracy linked to obtaining grants | 51.4 |
| | T1. Trust in scientific basis | 51.4 |
| | E2. Reluctance to change (current management is viable) | 50 |
| Neutral | E3. Budget management support (farm accounting) | 78.6 |
| | E5. Labour force availability | 65.7 |
| | E4. Cost of agricultural consultants | 60 |
| | En2. Interest in renewable energies | 57.1 |

**Categories of factors**: P: Political; E: Economic; S: Social; T: Technological; En: Environmental.

#### *6.3.2.1 Political factors*

Political factors assessed by the survey included trust in official reports i.e. government (DEFRA, Environment Agency); trust in source of recommendations (institution) i.e. research centres, universities, associations; support in integrating Environmental Stewardship schemes (i.e. ELS, OELS, HLS) and GHG emissions reduction; and the level of bureaucracy linked to obtaining grants.

Most farmers, including 2 working on uncertified organic farms (Farmers B, C, E, F, G, J, K, M and N), stated that they do not trust in government action and this has a negative impact on their acceptance of recommendations from government bodies. Therefore, it is reasonable to expect that farmers' uptake of innovation leading to changes in farm practices could be affected. However, Farmers A, D, I and L stated that this particular factor had no influence on their decisions. None of these farmers works on a family-run farm. Conversely, all but Farms E and M are family-run businesses. This could suggest that farmers running family businesses, whether as owners or tenants, could have a different attitude to government and policies, perhaps showing more scepticism over changes that could damage the long-term sustainability of their families' livelihood. On the other hand, it is also reasonable to expect that long-term sustainability may require adaptation to changing environments and market pressures in order to ensure the viability of a business. However, the reasons given by these farmers included the fact that they perceive the recommendations offered by the government as not matching with their type of farm and their beliefs. Farmer K runs a small 50 ha. beef cattle farm with his wife. He stated that *"most [recommendations] are not relevant to our type of farm, low input organic and most reports are tailored for maximum production" (Farmer K).* Others, like Farmers M and N, citied lobbying and politicisation as reasons for their low level of trust in government policies. Farms M and

N are different in size and livestock, the former being a mixed livestock farm spread over 350 ha. of land; the latter being a dairy farm on 170 ha. owned by Farmer N. However, both are pasture-fed certified organic businesses and both are under HLS schemes. The fact that they are under environmental schemes could suggest that in spite of their lack of trust in government policies, certain types of legislation can be accepted when farmers see benefits for their businesses, perhaps not only from a financial point of view. Further analysis of this matter is discussed in sections 6.4.1 and 6.4.2.

An interesting finding from the survey is that the negative impact of the lack of trust in government action did not prevent Farmers C, F, J, M and N from adopting changes in farm practices as a result from the farm assessments carried out during the field study, suggesting that other factors may play more important roles in shaping farmers' decisions. The responses given by the farmers with similar farms may differ greatly, as illustrated in Box 6.4. Not all farmers who cited a lack of trust in governmental action also considered the bureaucracy linked to obtaining grants and the lack of support in integrating environmental schemes and GHG emission mitigation as negative influences on their decision-making. Moreover, the majority of farmers (Farmers A, B, C, D, E, G, I, J, M and N) stated that the trust in the source of recommendations (i.e. institution) has a positive influence on their adoption of changes, in particular the trust in institutions which hold a good reputation at national and/or international level, such as, for instance, the Soil Association or specific divisions of the Agriculture and Horticulture Development Board (AHDB) e.g. EBLEX or HGCA. The fact that such institutions may carry out research utilising government funding does not seem to be reflected in farmers' responses, suggesting that farmers' attitudes to change and innovation are greatly influenced by their perception of government action and, perhaps, the politicisation of it, pushing farmers to look for what they perceive as reputable information independent from the government, even though in reality that might not be the case.

Box 6.4 Trust in the source of recommendations. A nebulous political business?

Farmers F and H run similar businesses; the former is in Gloucestershire, the latter in Cornwall. Both farms are organic, pasture-fed, mixed livestock farms and they also have similar size (73.4 ha. farm F and 68.8 ha. Farm H). A limited amount of land is destined to arable production to complement livestock feed during the winter months. Livestock includes beef and sheep. Farmer F has been a tenant on the farm since 2004, while Farmer H is running the family farm. Both farmers utilise very limited labour on farm and both farms are run as family businesses.

During the study, Farmers F and H showed similar attitudes to farming, embracing a simple lifestyle focused on producing good quality food following the most environmentally sustainable practices. Farm F is farmed under ELS and HLS; while Farm H is just under OELS agreement. They are both active members of their local farmers' groups and they showed great interest in innovation and progress in terms of agricultural sustainability, within the farming system of their choice, notably low input extensive organic farming.

However, their responses to the farmers' attitudes survey were very different, in particular regarding the political factors that may exercise an influence on the decisions they take for their businesses. While both farmers considered the lack of support in integrating environmental schemes with GHG emission mitigation to be a negative influence, citing as biggest obstacle the practicability of conflicting advice from subsequent environmental policies, Farmer H also considered the level of bureaucracy in obtaining grants to have a negative impact on his farm, but Farmer F did not consider this aspect to have an influence at all in his case, although he acknowledged that it may become an issue in the future. The most interesting result is that while Farmer F's response seems to align itself to that of the other family-run business in the study, by citing the lack of trust in government action to have a negative impact on his farm, Farmer H stated this factor actually has a positive impact and he stated he *"will follow legislation"*. The key to such discording results may reside in the fact that both farmers stated that they do not always trust in the source of recommendations (i.e. institution) regarding GHG emission mitigation and may follow reports and advice from reputable research institutions only in the case such advice matches with their farm profile and their belief in low input organic farming.

Therefore, it could be possible that both farmers value the source of recommendations greatly and their scepticism is reflected in different attitudes towards the government as a result of their own perceptions of the impact government action is having on their businesses. One farmer seemed more affected by bureaucracy (Farmer H) while the other seemed more affected by the contents of official reports and handbooks provided by the government. However, Farmer F did implement some changes on his farm, overcoming possible bureaucratic obstacles, but Farmer H did not implement any changes on his farm.

#### *6.3.2.2 Economic factors*

Among the economic factors assessed by the survey, limited budgets was considered a negative influence on farmers' decision-making by all farmers, except by Farmer M, who stated this factor has no influence on his decisions, and by Farmers B, G and K, who, instead, stated that financial limitations have actually a rather positive influence because they push them to create and adopt annual financial plans in order to avoid greater investments. Interestingly, these 3 farms are all family-run businesses but their size and production vary greatly, from a 242 ha. uncertified organic sheep farm under no environmental schemes (Farm B), to a 137.6 ha. organic beef, sheep and vegetables farm under ELS and HLS (Farm G), to a 50 ha. organic beef farm under OELS (Farm K). None of these farms implemented any changes in farm practices within the timeframe assigned to the study. However, other family-run farms (i.e. Farms C, F, J and N) of varying sizes could adopt changes, even though financial limitations were cited by their farmers among the greatest obstacles.

Farmers who considered limited budgets a negative influence on their decisions provided similar explanations to the ones who, instead, stated it had a positive influence. Both groups mentioned yearly plans and generally showed *"entrepreneurial attitude"* (Farmer I), but some perceived this as a positive influence (Farmer B, G and K), while the others considered it a negative influence on their decisions. The terminology they used to express similar concepts was also different. The group with a positive attitude used phrases such as *"small investments"* (Farmer G and K) and *"avoid borrowing money"* (Farmer K), which could suggest an attitude oriented to small positive actions or changes. The group with a negative attitude used instead phrases such as *"prioritise actions"* (Farmer A), *"buy"* (Farmers J and N), *"profits"* and *"no support from banks"* (Farmer C), which, instead, could suggest a harsher managerial approach to financial planning. Two of them also referred to *"this year"*

(Farmers C and D), which suggests that their attitude was strongly influenced by the bad season they were experiencing in 2012.

Therefore, it could be reasonable to expect that limited financial capital alone may not be the most important factor in shaping farmers' decisions regarding the adoption of change, but rather specific obstacles linked to the financial aspects of running an agri-business. The majority of farmers dismissed external support for farm budgeting and accounting as not influential and only Farms A, C and H expressed their wish to have access to some form of support in this respect, even though Farms A and C managed to implement changes. Likewise, the cost of agricultural consultants was seen by the majority of farmers as irrelevant to their decision-making process, but Farmer A stated that the cost is *"money well spent"* when the benefits from the service are considered, while Farmers C, F, I and N, instead, considered agricultural consultants too expensive. Nevertheless, these obstacles did not prevent Farmers A, D, F and N to adopt changes during the study. One possible reason could be the influence of labour cost availability, discussed previously in section 6.2.2, but another reason can perhaps be found in the farmers' responses to the influence of the current profitability of their businesses. Half of them (Farmers A, C, E, F, H, K and L) stated that this has a negative influence on them, fuelling more scepticism regarding the possible impact of changes in farm management: even though Farmers A, C and F adopted some changes, Farmers C, F and H cited the very word *"scepticism"* and Farmer K simply said that he is *"happy with the current system"*, which suggests that it is not unreasonable to expect farmers to express doubts over changes and innovation in the case of uncertain impacts of GHG emission mitigation strategies on farms' viability. Conversely, Farmers E, G and M showed interest in getting more information on how to improve their businesses and it seemed that current profitability was seen by them as an incentive to do even better;

however, only Farm M adopted some of the recommendations given during the study. Similarly, the current profitability of their farms was considered to have no influence on the decisions of Farmers D, I, J and N; but only Farmers D, J and N were among those who adopted changes in farm management.

Results seem to suggest that great variability in farmers' attitudes and responses to financial pressures can be found among the farmers in this study. Not only they provided similar reasons for opposite reactions, but their responses also seem to suggest that what may be considered an obstacle in theory, may not be one in practice, as some of them did adopt changes as a result of the farm assessments. This subject will be further discussed in section 6.4.

#### *6.3.2.3 Social factors*

The social factors assessed in the survey had the purpose to evaluate to what extent farmers' interactions with peers and extension agents could influence their decision-making and whether such influence would promote change and the adoption of on-farm innovation or rather hinder the acceptance of GHG emission mitigation strategies.

Farmers' responses showed an interesting variety of attitudes towards social interactions. All farmers but Farmer L stated that trust in the individual carrying out extension work is a very important aspect of providing farm advisory services. Farmer L, instead, stated that he does not take into account this aspect when making decisions regarding farm management changes. Other farmers appreciated the importance of *"personal contact"* (Farmer A) to establish good relationships with extension agents and quite a few farmers elaborated on the reasons for trusting extension agents and other advisors, including scientists: Farmers F, M and N referred to the *"level of knowledge"* shown by the individual, their *"background and motivations"* and their possible links to institutions, which could reflect in higher credibility of the individual and in a lower likelihood of farmers doubting about possible hidden agendas or marketing influence on farm advice.

Such concerns were also highlighted by the question on the influence of previous bad experiences with consultants or community and interest groups. While 7 farmers (Farmers B, D, E, F, I, K and M) stated that these have no influence on their decisions, citing a sort of *move on* attitude in which one learns from experiences, whether good or bad, and tries to do better in the future, a similar attitude was cited by Farmers A, G and J, who instead considered previous bad experiences a positive influence. As an example, Farmers A and D used the expressions *"openness"* and *"open attitude"* in their responses and both Farmers A and M used the expression *"do better next time"*. All 3 farmers adopted changes in farm management as a result of recommendations issued during the study, but Farmer A considers previous bad experiences a positive influence, while Farmers D and M considered previous bad experiences to be of no influence on their decisions.

Moreover, farmers' responses to the influence that community support and engagement may have on their decisions were rather polarised. Half the farmers (Farmers C, E, G, H, K, L and M) stated that links with the community had no influence on their decisions, citing a *"go ahead and do it"* attitude (Farmer E) and the lack of interest in what their neighbours do (Farmers C, K, L and H). All other farmers instead considered community engagement to be a positive influence. In particular, they put emphasis on the value of interactions with other farmers as they consider them a way of learning and acquiring valuable information (Farmers B, F, J and N), as well as a possibility to see *"the bigger picture"*, referring to the agricultural sector, rather than isolate themselves focusing on farming only (Farmer A). In spite of the great variability in farms' characteristics, an interesting observation could be that among farmers that adopted changes during the study, only 2 considered community interactions of no influence (Farmers C and M), but all others (Farmers A, D, F, J and N) stated that community engagement positively influenced their decisions, with Farmers A and D pointing out the fact that the learning process works both ways between their peers.

These results seem to suggest that on the one hand farmers' perceptions of a factor's influence on their behaviour may be different, but these perceptions could lead to similar attitudes to change. However, on the other hand, farmers' responses regarding the impact that community engagement can have on their behaviour relate to the importance of social capital and in particular to the impact that strengthening farmers' bonding social capital can have on their attitudes to innovation and learning. Possible opportunities to promote change and innovation linked to social interactions and knowledge sharing are further discussed in section 6.5.2.

#### *6.3.2.4 Technological factors*

Factors assessed in this section of the survey aimed to evaluate the relationship farmers had with scientific knowledge and the tools available to facilitate the reduction of farms' carbon footprints. Results of the survey show that trust in the science was not necessarily associated with trust in the tools as well, and farmers' responses varied greatly from case to case.

Five farmers (i.e. Farms C, D, K, M and N) considered the use of carbon footprinting tools a tedious process, especially because the figure provided at the end of the process does not necessarily highlight the options available to the farmer who wishes to reduce the agri-business' carbon footprint. The profiles of these farms vary greatly in size, ownership and adoption of environmental agreements, and no common characteristic seems to explain their responses. Moreover, Farmers C, D, M and N did adopt some of the recommendations issued during the study. Therefore, it is reasonable to believe that their views of the carbon footprinting process as a hindrance, rather than a useful exercise, may not have a great influence on their attitude toward the adoption of on-farm innovation, provided the benefits of innovation are visible and understood by the farmers.

Farmer H, who farms a family-run small organic mixed livestock farm, stated that he has an interest in carbon footprinting tools; he cited comparisons between the results obtained using the CLA CALM tool and the Climate-Friendly Food tool and he appeared to be knowledgeable on the subject, even stating that tools are getting better recently and are more user-friendly. However, he expressed confusion regarding the scientific basis of GHG emission mitigation, which led to scepticism about the subject and a negative influence on his decisions due to his lack of trust in scientific knowledge. A similar attitude was shown by Farmer A, who farmed a small uncertified organic beef farm and who showed scepticism over scientific evidence, mostly in relation to the way it is presented (i.e. statistics), but great interest in carbon accounting tools and the recent improvements in their degree of detail and user-friendliness.

Conversely, Farmers B and C, who farm larger family-run uncertified organic sheep and dairy farms, had exactly opposite views: complete trust in science, but marked lack of interest in carbon accounting tools (Farmer B) or the solution of having external carbon audits to take care of the matter (Farmer C).

Results seem to suggest that there is no clear distinction between the opposite attitudes of the farmers in this study and that their trust in scientific evidence of GHG emission mitigation and carbon accounting tools may depend on other factors, such as the source of knowledge and the way knowledge is presented to them. These will be addressed in section 6.4.3.

### *6.3.2.5 Environmental factors*

When analysing farmers' responses to the influence that the interest in environmental matters, such as conservation, sustainability, carbon sequestration, or in renewable energies can have on their decisions do adopt innovation, it is important to remember that, while farmers invited to the study were not selected based on the type of farming principles (i.e. organic or conventional), but rather on the type of production (i.e. extensive, low-input), the majority of farmers who responded to the invitation farmed organically and the only 3 farms that were not certified organic followed organic principles nevertheless. Ten farmers (Farmers C, D, E, F, G, H, I, L, M and N) responded that their interest in environmental matters has a positive influence on their decisions, motivating them to adopt a proactive behaviour towards the acquisition of knowledge that could bring on-farm innovation and sustainability. The profiles of these 10 farms are quite varied, ranging from a family-run mixed organic livestock farm with 28 suckler cows, 14 sheep and 8 pigs on a land surface area of 68.80 ha., to larger size organic farms with mixed livestock, and they include the 4 largest farms in the study, one of which, Farm C, was not certified organic. Two of these 10 farmers (Farmers M and N) cited that the fact that their businesses were under HLS was a clear evidence of their interest and concern for environmental matters. The only other instance in which HLS was cited was by Farmer A in explaining that his biggest concern was the farm's profitability and that in his case he considered the HLS agreement was *"forced"* on the business that he was managing. As a result, environmental matters were of no influence for him. Moreover, even though Farmer F cited environmental conservation as a priority on his farm, which is under ELS and HLS, he did not mention environmental schemes specifically and no other farmer did in their responses to the survey. These results seem to suggest that a general interest in environmental matters is present, but farmers in this study did not necessarily associated it with environmental schemes and preferred to use more general terminology in their responses without citing specific examples or proofs of their interest in environment matters.

Farmer E was the only farmer who mentioned that one should also *“take into account people’s feelings”* when referring to the way land and livestock should be farmed and the importance of public’s perception of farming in terms of its environmental impact. This concept was also pointed out by Farmer G during the farmers’ focus group organised later in the study (Section 6.3.3), although using a more business-oriented perspective, citing the importance of knowing whether the consumer really cares about carbon-friendly products, therefore making it worth investing in innovation to reduce the carbon footprint of the farm, otherwise the farmer would lose on the investment if sales returns do not match with market demands. Indeed, it is reasonable to expect that, especially in the recent economic situation, farmers with limited financial capital may remain sceptical over investing in innovation without clear signals of a market demand for specific carbon-friendly products. Such products can have lower environmental costs, but they are likely to be sold at a premium price and the revenue from their sales could represent a great uncertainty for farmers depending on their market links and infrastructure of distribution channels.

Two farmers out of 14 considered environmental matters and conservation issues a negative influence on their decisions. Farmer K expressed a general feeling of uncertainty when taking decisions regarding environmental conservation, primarily related to his acquisition of knowledge other than that from peers within local farmers’ groups; while Farmer B stated that he was interested in environmental matters, but added *“I don’t always agree with environmental experts”*. The two farm profiles are very different: at the time of the assessment, Farm B was a sheep farm with about 1,600 ewes on 242 ha. of land, with no organic certification; whilst Farm K was a small organic beef system with 30 suckler cows and 60 young stocks on 50 ha. of land. Moreover, Farm B was not under any environmental scheme, while Farm K was under OELS, but had no interest in entering HLS in the future. However, both businesses were pasture-based and family-run: Farmer B was a third generation tenant and his children were all working on the farm; Farmer K had recently taken over the business from his father.

Even though these results are obviously not representative of the sector, it is interesting to observe that once again, uncertainty and lack of confidence in experts' advice, combined with different perceptions of the importance and impact of environmental schemes on farming practices are cited among reasons for not adopting change such as innovative practices that could benefit the farm by reducing its environmental impact in terms of GHG emissions.

When asked if renewable energy was a more important topic than the reduction of GHG emissions, Farmers A, C, G, I and J stated that renewable energy was part of their business strategy, whether by already adopting renewable energy solutions (i.e. Farm J was equipped with solar panels and machinery was run using recycled cooking oil), by having recently invested in them (i.e. Farm A had a wind turbine on pasture) or by planning to invest in them in the near future (i.e. Farmer C was interested in installing solar panels on farm buildings; Farmer I was interested in the possibility of installing solar panels on pasture). However, Farmer K stated that renewable energy production was not more important than reducing GHG emissions from his livestock and all other 8 farmers in the study expressed various concerns over the actual benefits of investing in renewable energies, all resulting in a general disregard of the topic of renewable energies. Farmer D approached the matter from a financial point of view and deemed it not practical and not efficient at the moment. Farmer B openly stated he is more interested in reducing GHG emissions first, although he did not implement any of the recommendations to do so, and Farmer M had a very cynical attitude and considered the issue of renewable energy a political and marketing issue *“pushed too much, just to boost sales”.* Farmers H and N, instead, stated that the two issues of renewable energy and GHG emissions go hand in hand and the business should be considered as a whole. A similar attitude towards possible business trade-offs was expressed by Farmers A and J, but they instead considered the interest in the renewable energy a positive influence rather than a neutral one like in the case of Farmers H and N.

These results show that farmers’ attitudes to environmental issues can vary greatly and that, once again, attitudes that can be considered similar lead to discording results in farmers’ behaviours or farm management. It could be reasonable to consider that farmers’ perception of the influence of certain factors is a complex subject that needs more detailed analysis; in particular, narratives obtained during this study using the semi-structured interviews show the importance of the use of similar expressions and arguments to describe different perceptions which may result in similar attitudes. In order to obtain further evidence on farmers’ attitudes and perception of GHG emission mitigation, a farmers’ focus group was organised to allow farmers to interact and express themselves not only with the researcher, but in an environment shared with other farmers.

### 6.3.3 Knowledge sharing

The last phase of the study involved a focus group meeting with the farmers who participated in the project. Farmers external to the study were also invited, in order to promote knowledge sharing and attract the interest of a wider group of livestock farmers in the region. Farmers who could not attend the meeting were invited to share topics that concerned them the most, so as to enable the facilitators to cover all aspects of sustainable farming and GHG emission mitigation during the interactive workshops organised for the farmers.

Seven farmers could not attend the meeting but contacted the organiser by phone or email to communicate their topics of interest. Seven farmers attended (Farmers A, D, H, I, J, K and N), along with 2 other farmers external to the project.

These results show that physical distance has a relative impact on farmer engagement. However, Farmer G who was distant from the meeting location could not attend. The majority of farmers who could not attend had problems in finding replacements to ensure regular farm activities during their absence. Five of the 7 farmers (Farmers C, E, F, G and M) who could not attend established contact with the researcher in order to make sure they would receive an account of the meeting and that the topics they were most interested in would be addressed during the event.

Only 2 farmers (Farmers B and L) showed lack of interest in meeting with other farmers. These two farms are located in Herefordshire and Wiltshire and do not share common characteristics, nor do the farmers. The farmers did not provide further explanation on the motivations behind their decision. Therefore, it was not possible to identify which underlying reasons may have influenced their decision not to participate in the farmers' focus group. Conversely, farmers from Devon, Cornwall and other farmers from Herefordshire showed a marked proactive attitude and acted as delegates of their local farmers group, actively participating in the meeting and taking notes to report to their respective local groups. The latter had the potential of information reaching an estimate of further 80 farmers across England.

The meeting agenda was outlined in section 5.3.3. The event served as an opportunity for farmers to share their views and experiences with the project. It also presented them with a chance for networking with other farmers across the region in a friendly and informal setting. Farmers were given the opportunity to choose the topics for discussion. It has to be noted that the discussion groups organised during the afternoon saw farmers so passionate about the topics addressed that the meeting lasted longer than originally planned and organisers had to eventually bring the discussions to an end, as some farmers would have had difficulties returning to their farms should the event have been extended for much longer. The group was also joined by 8 African extensionists as rapporteurs; however, that did lead to wider discussions and comparisons with their systems. The following is an excerpt of the meeting minutes distributed to all participants in the study.

***"Afternoon session***

*Attendees were split in 2 groups. One group jointly discussed issues related to livestock feeding and grassland and pasture management. The second group discussed issues related to manure management.*

***Group 1. Livestock feeding and grassland and pasture management***

*The group discussed issues related to influence of livestock feeding and the impacts of various grazing systems. One of the points raised was whether simple dietary changes have an overall improvement on carbon footprints e.g. the use of garlic affects flora and fauna in the digestive system but the effect is only transient.*

*The group highlighted the importance of clearly understanding how the carbon cycle, methane cycle and nitrogen cycle work. A resilient grazing system might then be more useful in the long run. The equilibrium between the various cycles is a key issue to address. An imbalance in the diet could lead to an imbalance in livestock growth or in manure composition. It is vital to identify which imbalances need to be managed.*

*Differences in grazing systems also play an important role in identifying sources of emissions and key issues. Parameters applied in grazing systems in the UK do not apply in Africa for example, where manure has different uses. Types of rotational grazing systems may vary from a climatic zone to another. In Uganda nomadic pastoralism and 3 months rotations are predominant, while in New Zealand mob stocking is preferred.*

*The discussion continued on issues regarding carbon sequestration and whether a 150 days grazing cycle based on a high fibre, low protein diet was the best option to reduce methane emissions. Mob grazing may not give best performance of stock, but maximises carbon sequestration. Finally, a few suggestions were made to reduce the carbon footprint of grazing farming systems: systems need to be climatically resilient, to sequester more carbon, to slow down the carbon cycle and to offset more carbon, especially if a system can't reduce emissions any further and needs therefore to find a grazing solution that maximises offsets.*

***Group 2. Manure storage and treatment***

*A number of points were discussed by the group. It was very clear from the beginning that mitigation options related to manure management encounter a series of obstacles. In fact, while it is important to maintain good nitrogen levels in the manure, as this is then applied to field, it is also vital to identify which practices are practicable for each farm as farm systems are very diverse. Furthermore, economic and logistic problems were identified as obstacles to change.*

*Other concerns regarded the importance of communication between researchers and farmers in order to give confidence in findings and stimulate changes in practices. A number of solutions were discussed (i.e. composting, covering of manure stores, turning, sealing of manure stores), as well as problems related to the applicability of such practices (i.e. diesel costs, lack of space, investment in infrastructure and materials). The group concluded that it is very difficult to obtain detailed advice on specific practices related to manure management. This is linked to the difficulty in assessing manure emissions with an adequate degree of certainty. In fact, emissions depend on a large number of factors and calculations can vary significantly from farm to farm, making it difficult to find standardised solutions.*

*The group also highlighted the challenges related to changing practices and investing in new materials and facilities, not having enough certainty of their economic viability. Therefore, until regulated, it is difficult to incentivise change because it is not clear if there's a financial gain on the investment. Finally, it was suggested that off-*setting *emissions within the farm system could be a more practical solution to allow each farm to reduce the carbon footprint as a whole.*

***Topics for future discussions***

*Delegates who could not attend the meeting, but who had a specific interest in certain topics, had communicated the topics prior to the meeting. Some topics could be discussed, but due to lack of time to continue the discussions further, a list was compiled to highlight specific issues to be addressed by future meetings. Issues revolve around 3 main areas of concern:-*

*Farming systems:*

- *Differences in emissions of grazing systems e.g. set stocking, rotational grazing system, taking into account differences in sequestration of carbon in soil;*
- *Carbon sequestration options;*
- *Uncertainty regarding suggestions from eg. Aberystwyth University on crops and grazing pasture mixes: do they actually match with my soil and weather?*

*Carbon accounting and energy:*

- *Carbon sequestration included in carbon accounting tools;*
- *Emissions embedded in cereals for indoor cattle feed;*
- *Offsetting emissions within the farming system;*
- *Whole farm approach to sustainability and resilience;*
- *Biofuels and land competition;*
- *Impact of policy;*

*Farm profitability, markets and consumers' perception:*

- *Consumers' interest in climate change, the added value of climate friendly products;*
- *Opportunities to reduce emissions and increase profits at the same time;*
- *How to farm without fossil fuels / products and sell;*
- *How to make farming profitable;*
- *Nutrients go to town but don't come back to the farm."*

Results from the focus group show that farmers appreciated the opportunity to interact with researchers and other farmers in a relaxed environment. They proactively participated in proposing action to tackle issues related to GHG emission mitigation that were highlighted during the study, integrating their own experience with that of other farmers. The topics that the farmers consider should be addressed in future studies show that the participant to the focus group had a wider understanding of the challenges facing agricultural production, not only focusing on specific issues related to GHG emission mitigation but including them in a wider range of issues that touch farming practices directly, carbon accounting, as well as market forces that influence agricultural production.

Finally, the results of the study showed 100% farmer engagement in researcher-farmer interaction with no farmer dropping out of the study after the first farm assessment in spring 2012. This led to 50% of participants changing practices, with an estimated 100% improvement in on-farm GHG emission mitigation when recommended changes were adopted. Subsequently, the study showed 85.7% engagement in farmer-to-farmer interaction in its final stage. Although qualitative, this can be described as a good result; in particular, considering that the large amount of information collected during the 2 farm assessments, the feedback survey, the survey on farmers' attitudes and perceptions on GHG emission mitigation and finally the focus group meeting. These activities provided interesting insights on the barriers to innovation perceived by farmers, as well as activities that could be considered opportunities for farmer interaction with researchers in order to improve on-farm GHG emission mitigation.

## 6.4 Obstacles and barriers to change

The results showed that the farmers interviewed had an interest in GHG mitigation. However, a series of barriers were presented to the implementation of GHG mitigation strategies. These can be summarised as follows.

### 6.4.1 Financial constraints

It is important to remember that the study targeted extensive livestock farms in order to explore barriers and opportunities for GHG emission mitigation. While it is not unreasonable to expect that such farms may have financial difficulties throughout the years, the farmer behaviour survey revealed that more than half of the farmers considered 3 of the 5 financial factors assessed not to have any influence on their decisions (Table 6.10). These factors were either considered as *"part of the game"* (i.e. agricultural consultants) or the farmers had relevant experience. For instance, 10 out of 14 farmers did not use external accountants but only 2 of them stated that they are negatively affected and would appreciate some support with accounting issues. The remainder of them accepted their limitation due to the size of their farms. Interestingly, the cost of agricultural consultants led to similar considerations by farmers. During the interviews, 8 out of 14 farmers stated that the cost of consultants was not affecting their decisions in any of the sectors assessed i.e. *"they are not unduly expensive*" (Farmer H);

however, 5 out of 14 farmers cited local farmers' groups they joined in order to obtain support, free advice and opportunities to share experiences with other farmers. This specific point can be considered a favourable condition to drive change and innovation; therefore, it will be addressed in detail in section 6.5.

Five farmers acknowledged that agricultural consultants provide valuable information and support; therefore, the farmers were ready to pay for the service. However, 6 out of 14 farmers interviewed remained sceptical over advice that can be given by consultants. One of the reasons provided was:

> *"How can I be sure that the consultant is recommending this seed mix for its actual benefits (emissions, soil etc.) rather than just to sell his product?"* (Farmer N)

Limited finance was considered among the greatest barriers to on-farm innovation, with 10 out of 14 farmers identifying it as a negative influence on their decisions (Table 6.10). In particular, farmers cited problems related to the lack of support from banks and the need to adopt an entrepreneurial attitude and take risks. The year 2012 was very tough on farmers due to weather events that affected production. However, even though the need *to "prioritise yearly actions"* was cited among the negative effects of having to produce efficiently and sustainably on limited budgets, 1 farmer attributed a positive influence to financial limitations and adopted *"a rolling programme year on year of small investments to avoid borrowing money" (Farmer G)*. These results highlight the importance of in-depth studies of farmers' attitudes and perceptions to on-farm innovation, as one condition can be seen as a hindrance by some or an opportunity for improvement by others. In others words, to go beyond the 'what do you do/not do' question to 'why'.

The study showed that difficulties in implementing on-farm innovation can be linked to financial pressure, as supported by the work of Barnes et al. (2010) on the motivations to GHG mitigation in a wide range of agri-businesses (i.e. arable, dairy, beef). The authors found that the main driver for change was economic, followed by improving management practices and market pressure. This is in line with the results of the study, showing that financial pressures are perceived as a great influence on farmers' decisions, either promoting change, when financial capital is available, or preventing on-farm innovation to be adopted, when budgets are limited.

Therefore, it is important to consider the type of farm and the motivations of farmers who run extensive low-input livestock farms. In this study, farms were almost exclusively organic pasture-based systems, with only very short overwintering based on climatic conditions. Moreover, 8 out of 14 farms were family-run businesses. The choice of pasture-based systems could be linked to reduced running costs (i.e. labour, housing, inputs), but it could be ascribed to lifestyle choices. On the one hand, the organic livestock farmers interviewed saw financial limitations as obvious barriers to improvement in farm management practices; on the other hand, organic farmers tend to rely on government subsidies for their business to remain sustainable but are often critical of government action (Kings and Ilbery, 2010). These results suggest that farmer decision-making is a complex field in which a wide range of factors can lead to an equally wide range of reactions from farmers.

### 6.4.2 Trust in government action

A good number of farmers i.e. 9 out of 14, expressed confusion and mistrust regarding the support provided by the government and 4 farmers stated a lack of time and interest in Government initiatives. Twelve farms were under Environmental Stewardship schemes, with 8 farms under HLS agreement, while 4 farms were under OELS agreement. Although interested in improving farm practices in order to reduce GHG emissions, they did not find that advice given under ELS and/or HLS always matched with practices that are recommended to mitigate emissions. Moreover, 10 out of 14 farmers highlighted the fact that the issue of integrating ES and GHG emission mitigation is not taken seriously by the Government, with such statements as *"emissions don't fit anywhere [in the ES]"* (Farmer H) and *"HLS and so on are just another way of getting money"* (Farmer A). These farmers believed that the Government gives conflicting advice on farm practices, in particular regarding waste management, where *"you can make a case to them and get a derogation"* (Farmer M).

As an example, increasing the amount of legumes such as clover in ruminant diets is an effective strategy to mitigate emissions from enteric fermentation (chapter 3). However, farmers under HLS agreement may encounter difficulties in increasing the percentage of legumes in their livestock diets based on HLS prescriptions i.e. seed mixes allowed on HF10 permanent grassland usually include just around 20% clover.

During the first farm visit Farmer L stated that he was not interested in signing the HLS agreement because he *"would have to take too much land off production and it took some time to reach the balance on farm. HLS is not interesting here."*

Interestingly, 8 out of 14 farmers stated that the bureaucracy linked to obtaining grants has a negative impact on their choices. However, the relationship farmers had with ES and regulations showed great diversity. Only one farmer stated that he is prepared to follow the guidelines to apply for grants, provided the proposed solution is viable. Farmer B and Farmer N were very adamant in stating their disappointment with the grant schemes, describing them as a *"scandal"* and *"the Government makes them so complicated, that it almost seems they just don't want to give you the money"*. In most cases, these farmers believed that grants were not worth the amount of work one has to go through and the farmers that were under ELS were not considering signing HLS in the future.

Although these results cannot be representative of the entire livestock farming sector, they provide valuable insight on farmers' perceptions of government policies in relation to GHG emission mitigation. During the interviews, 9 out of 14 farmers stated that information provided by DEFRA, such as the manuals cited in section 2.1.2, didn't seem to match with their farm profile because of the small scale of their businesses. Therefore, they were often sceptical over the validity of the recommendations provided. As a reason for mistrusting the government, Farmer C cited the fact that every time he calls the appropriate department at DEFRA to communicate with a farm adviser, he is connected to a different adviser. He mentioned that the lack of consistency in advice and lack of relationship with one extension officer or farm adviser throughout the years was very inefficient and a nuisance because he had to explain or describe his farm situation over and over at every call. A similar disconnection between farmers and government was found by Hernández-Jover et al. (2012) among small-scale pig farmers in Australia, where the lack of trust in state agencies was linked to the lack of extension services and to previous negative experiences.

Therefore, the results of this study seem to confirm and highlight the importance of transparent and effective extension advisory services, with an emphasis on consistency of face-to-face interaction and knowledge exchange between small-scale farmers and government agencies (Islam et al., 2013; Rydberg et al., 2008). Lack of interaction with farmers could be linked to the fact that agri-businesses may be listed on multiple databases from agricultural surveys as part of government funded projects. In particular, farm registers and business registers are often separate databases (Everears, 2010).

These conditions may lead to confusion and lack of efficiency of government action, especially taking into account how privacy concerns may affect the degree of representativeness of agricultural surveys (Wallgren and Wallgren, 2010). The narratives collected during the interviews indicated that farmers' lack of trust in government action was related to confusion over government agendas. Therefore, it is not unreasonable to suggest that such scepticism may also affect farmers' attitudes and perceptions of GHG emission scientific evidence.

### 6.4.3 Scientific validity of farm advice on GHG mitigation

It was mentioned in section 2.2 that there is still uncertainty regarding carbon footprint calculations and the actual impact of some strategies in terms of GHG emission mitigation. In certain areas of scientific research, this uncertainty is due to the large number of variables on which emissions factors depend. While farmers acknowledged that the variability in weather conditions affects soils and livestock, 8 out of 14 farmers cited that they do not trust the scientific basis of GHG mitigation. The reasons for such responses were different; for example, farmers linked this lack of trust in scientific studies to the source and funding of certain studies. In fact, it is reasonable to hypothesise that the farmers who responded to the survey citing a lack of trust in the government were also less likely to trust scientific studies cited in official documents, manuals and handbooks provided by the government. However, only 3 out of 14 farmers cited both factors as negative influences on their decisions. The reason for such discrepancy may be found in the motivations behind the farmers' scepticism regarding scientific advice. Farmer H and Farmer N stated that they do trust science when it comes to GHG emission mitigation, but they make a clear distinction between lab-driven science and evidence-based science. They prefer to look for scientific information from research facilities like Animal & Grassland Research and Innovation

Centre, Teagasc, Moorepark, Fermoy, Co. Cork, Ireland or Rothamsted Research, North Wyke in Okehampton, Devon, which they consider as centres that carry out research with an outlook on its practical application, rather than adopting a science-for-scientists approach.

Overall, farmers interviewed were not against on-farm innovation and scientific studies that can benefit the environment, livestock and more in general, agri-businesses.

> *“I have 100% trust in science. Communicating science is the problem.”* (Farmer C).

In fact, they were open to interactions that can lead to transparent knowledge exchange and they voiced repeatedly the desire to have their say on government policies regarding GHG emission mitigation. However, these results showed that this proactive attitude seems to be hindered by confusion and lack of confidence in governmental strategies to disseminate scientific knowledge, as found by Islam et al. (2013), Jones et al. (2013) and recently confirmed by a study on farmer decision-making in relation to risk perception which highlighted the importance of clear advice provided to farmers (Barnes et al., 2013). On a positive note, 6 out of 14 farmers stated that they have some degree of trust in science, but they are more interested in the application of it. This result highlights the need for farmers to see a connection between scientific research and its on-farm application, in order to attribute enough validity to claims brought by scientific evidence.

Finally, the barriers discussed suggest that the farmers interviewed were interested in GHG emission mitigation strategies from a very practical perspective. Financial aspects of mitigation seem to remain the biggest obstacle for the majority of them. However, their responses to questions on government action and scientific evidence of GHG mitigation show that farmers, although cynical about possible ulterior motives behind scientific farm advice, were open to discussions and interactions. These results show that in spite of the uncertainty and scepticism over GHG mitigation, successful on-farm innovation could still be achieved by taking into account farmers attitudes and perceptions of issues that will affect their agribusinesses.

## 6.5 Opportunities and drivers for change

The study highlighted some of the barriers that are most often encountered by a group of 14 livestock farmers in the South West of England. However, the outcomes of interactions with these farmers also presented opportunities for development and greater engagement of scientists and farmers on GHG emission mitigation.

### 6.5.1 Interest in GHG mitigation

As illustrated in section 6.3.3, all 14 farmers participated in the farm management practices assessments and responded to the survey on factors influencing decision-making on farm. Although 8 out of 14 farmers stated that the topic of renewable energies does not have any influence on their decisions, 10 out of 14 farmers responded that their interest in environmental matters, such as conservation, sustainability, carbon sequestration, has a positive influence on their decisions, motivating them to adopt a proactive behaviour towards the acquisition of knowledge that could bring on-farm innovation and sustainability. Two farmers did not show interest in participating in the farmer focus group, while the other 12 farmers were actively involved in the discussions, in some cases acting as delegates for their local farmer groups, so as to report back to a wider number of farmers on the benefits of meeting with the researchers involved in the study and participating in a knowledge sharing activity with researchers and other farmers.

During the focus group, farmers voiced their wish to have access to unbiased scientific knowledge. In fact, it was not unreasonable to expect that, given the confusion and mistrust over government action as a source of scientific knowledge on GHG emission mitigation (Section 6.4.2), farmers in this study seemed to prefer direct interaction with scientists and researchers oriented towards the practical application of science. In this context, scepticism can be considered a double edged sword, which may discourage some to engage with the wider community, but it may also motivate others to look for other sources of knowledge that could be perceived as more valuable by the farmer. When evaluating farmers' scientific knowledge in relation to various farm management practices, it is important to consider that farmers tend to lack in-depth knowledge of specific scientific phenomena e.g. soil management (Ingram, 2008) and they are more likely to rely on experience limited to their farm (Ingram et al., 2010), although it is not possible to exclude the possibility of knowledge to originate from experiences of other peers. As a result, farmers also tend to sign up to the agri-environmental schemes out of interest in the *"economic viability"* of their businesses, rather than an actual understanding of the environmental benefits from the schemes (Sutherland, 2010). This argument seems to support the findings that, although more than half of the farmers interviewed had an interest, their interest in acquiring knowledge may be driven by financial motivations. However, a universal answer cannot be obtained at this stage, as the individuality of each farm in terms of physical conditions (i.e. soil, weather, water), size, position within the market and social context are likely to play key roles in determining great variability in farmers' interest in environmental matters.

### 6.5.2 The social dimension

Farmers' beliefs system plays an important role in their attitudes and perceptions of environmental conservation and it is strongly influenced by social factors, rather than awareness of farms environmental impact (Michel-Guillou and Moser, 2006). The study addressed the dynamics within the three types of social capital (Table 6.11) and observed the peculiar interactions between 14 livestock farmers, initially between farmer and researcher on an individual basis, to then expand to farmer-to-farmer contexts involving researchers as knowledge brokers (Klerkx and Jansen, 2010).

It is important to take into account that, as it has been explained in chapter 4, farmers may rely on networks of influence to gather information and support needed. The farmers interviewed tend to rely on local or regional farmers' groups (i.e. Pasture-Fed Livestock Association, Tamar Valley Organic Group, Conservative Rural Affairs Group) to find information, advice and support. Only when these networks of influence do not succeed in compensating for the need for agricultural consultants, the farmers interviewed resort to external advice, which in England tends to be fragmented and therefore its effectiveness tends to be inconsistent (Klerkx and Proctor, 2013). As a result, although the farmers were not selected based on their membership of such associations, it is reasonable to suggest that their proactive attitude to knowledge sharing within the study could have been influenced by pre-existing similar activities. However, it is important to consider that farmers' knowledge of the topic addressed by the study was relatively limited and that the study aimed to test a methodology to successfully engage with farmers specifically on the topic of GHG emission mitigation.

A very important result, 13 out of 14 farmers stated that the trust in the individual (i.e. researcher, adviser) was a positive influence on their decisions. Among the reasons given, farmers stated that they appreciate personal contact with the adviser, especially if the person has no obvious marketing agenda. Results showed that trust in the source of recommendation, e.g. Soil Association, nationally and internationally renowned research centre or academic institution, was another important factor in farmer decision-making, with 10 out of 14 farmers stating that the source of scientific knowledge was key to their acceptance of the information. Farmers showed openness to interact with advisers with earned credibility, which is in line with what was found by Mugnier et al. (2012), highlighting the need for agricultural advisers to be highly competent in their field (Solano et al., 2006). Therefore, competence and personal contact seem to be key elements in farmers' uptake of recommendations regarding the management of their businesses.

Furthermore, farmers appreciated not only the support given, but the fact that their own knowledge and experience were valued during the study. This result confirms that participatory approaches allow researchers to positively interact with farmers in a transparent and effective way (Röckmann et al., 2012) and highlights the importance of face-to-face communication between advisers and farmers, regardless of whether or not the recommendations given are subsequently implemented (Rydberg et al., 2008). It is reasonable to suggest a link between this result and the fact that farmers' cognitive system applied to scientific knowledge tends to adopt approaches different from those of scientists and researchers. On the one hand, farmers tend to rely more on intuition and empirical data; while on the other hand, scientists adopt more rigorous analytical methodologies to process information and generate knowledge (McCown et al., 2012). This aspect has to be considered in the context of agricultural development. Farmers interviewed showed a latent lack of confidence in institutions and government agencies, which affects their uptake of science-based recommendations. Farmers' attitudes can be influenced by the way science is communicated and by the way advisers present themselves to farmers (Schöll and Binder, 2009). However, farmers seemed to appreciate interaction with individual researchers and this led to a 100% engagement in farm assessment visits with a 50% uptake of GHG emission mitigation recommendations. Moreover, farmers who participated in the group meeting asked about the continuation of the project, showing interest in the interaction with researchers.

Building up from a strong pre-existing *bonding social capital*, with openness to communication between peers, farmers in the study showed competent use of information technologies. As an example of farmer-to-farmer interaction, all farmers used e-emails and 8 out of 14 farmers participated in discussions on on-line forums. On-line communication was considered economical and fast, as well as an effective way to raise a voice and possibly make connection with more farmers across the country. Such context can be considered favourable to promote *linking social capital* and therefore achieve successful two-way communication between farmers, researchers and policy makers (Table 6.11). In particular, the decision-systems theory described by Farmar-Bowers and Lane (2009), in relation to the adoption of practices that promote environmental biodiversity among Australian farmers, highlights the importance of farmers' social contexts and how these influence their behaviour. The authors suggest that changes proposed by policies are more likely to be adopted in the long-run by farmers that take decisions using a family-oriented belief system. Conversely, farmers that base their decisions on business factors are less likely to maintain long-term changes in practice management. Therefore, projects with the goal of promoting long-term engagement and the adoption of on-farm innovation are more likely to succeed if participatory activities do not focus exclusively on financial benefits of innovation, but rather include farmers as valuable co-researchers.

In this context, the results of the study suggest that the methodology adopted was perceived as beneficial by the farmers not only from a financial point of view. Therefore, future studies could possibly be expanded to include a larger sample of farmers and a wider range of variables, in order to further evaluate best approaches to farmer engagement on GHG emission mitigation, along with the importance of social inclusion with the research process. In particular, it is important to remember the impact the 3 types of social capital illustrated in table 6.11, not only from the farmers' perspective, but also from the perspective of the researcher, who should engage with other researchers and specialists in the field in order to further strengthen their social capital.

Table 6.11 Outline of social capital dimensions and their inclusion in the study.

| Social Capital | Characteristics | Actors | Engagement activities | Observations | Opportunities |
|---|---|---|---|---|---|
| Bonding | Homogeneous | Extensive low-input livestock farmers (ELILF) | - Knowledge sharing and knowledge transfer: farmer-to-farmer | - Strong bonds within groups<br>- Sub-groups: e.g. interest groups (PFLA), geographic (TVOG), political (CRAG) | - Very open to dialogue with farmers from other groups<br>- Knowledge sharing |
| Bridging | Heterogeneous | ELILF – interest groups | - Knowledge sharing: farmers network expansion<br>- Capacity building: fostering social capital | - Self-selective<br>- Self-promoting<br>- “Virtual”, Online networks | - Online communication preferred: economical, fast and easy way to have a voice, make connections, attract other SSLF out of the main networks |
| Linking | Heterogeneous | ELILF – Researchers (academia) | - Knowledge sharing: farmer-to-researcher<br>- Knowledge transfer: researcher-to-farmer | - Lack of trust<br>- Researchers seen as distant from reality | - Importance of knowledge transfer<br>- SSLF request for more interaction (translational research) |
| | | ELILF – Government | Beyond the scope of the study | - Lack of trust in policies<br>- Confusion<br>- Fear of hidden agendas<br>- Top-down approach | - Will to influence policy making<br>- Will to have a voice (ELILF)<br>- Understanding that researchers and farmers need one another to influence policy making |
| | | Government – Researchers (academia) | Beyond the scope of the study | - Difficulty in obtaining funding for certain types of projects | - Promote importance of social capital in environmental assessment to support policy making |
| | | Government – National Agencies and larger groups (e.g. large producers) | Beyond the scope of the study | - Commercial interests<br>- Stats to support policy making | - ELILF do not feel they can identify with types of farms used in studies to support policy making<br>- Reports don’t represent all types of realities |

***Keys:*** ELILF: Extensive low-input livestock farmers, PFLA: Pasture-Fed Livestock Association, TVOG: Tamar Valley Organic Group, CRAG: Conservative Rural Affairs Group.

### 6.5.3 The impact of translational research

Communication of climate change information is a very important factor in the adoption of mitigation strategies by farmers (Wheeler et al., 2013). Farmers are more likely to understand and apply scientific knowledge if this is communicated in a clear, consistent and transparent way by advisers and researchers (Blackstock et al., 2010). This can be related to the contexts illustrated in section 4.2.2, in which fragmented advisory services and the impact of farmers' networks of influence are important factors in the dissemination of scientific knowledge within farming communities, in particular when associated with lack of knowledge transfer activities (Sjögersten et al., 2013).

Participatory research methodologies described in section 4.3.2 can be used to engage with farmers and promote on-farm innovation (Gomontean et al., 2009), with the aim to raise awareness on possible risks related to climate change impacts (Gandure et al., 2013) and, in the case of this study, on the estimated benefits from GHG emission mitigation. However, it is important to consider the design of models that aim at supporting farmer decision-making. Stakeholder participation and bottom-up approaches to the assessment of agricultural sustainability are more effective than top-down models with little participation (Marshall et al., 2013), especially if transdisciplinary methodologies are not adopted (Binder et al., 2010). This approach is particularly useful in contexts where uncertainty regarding risks and outcomes from changes in farm practices may affect farmers' attitudes to climate change, but at the same time these contexts may promote farmer-to-farmer interaction in order to cope with uncertainty (Alpizar et al., 2011). The interaction between farmers and researchers has a positive influence on farmers' entrepreneurial behaviour, provided collaboration and learning are at the centre of participatory studies (Iivonen et al., 2011). Therefore, this study represents a classic example of translational research with the aim to engage with farmers and promote on-farm innovation to mitigate GHG emissions.

In order to address the possible obstacles to engagement, the RFPA tool was based on adopting a methodology based on the expected mitigation from the most acknowledged practices, giving short explanations for each recommended practice to illustrate the potential benefits of GHG emission mitigation. Participation was encouraged and farmers were given multiple opportunities to voice their opinions and concerns, initially to the researcher and subsequently within a group consisting of farmers and researchers from various branches of academia (i.e. sustainable rural development, sustainable use of soil and water, agronomy, veterinary science).

All farmers showed interest and appreciation of the RFPA tool because of its straight-forward approach and ease of use. This is particularly interesting because during the interviews it emerged that 8 out of 14 farmers consider the user-friendliness of GHG emissions assessment tools as a positive influence on their decisions. Interestingly, only 3 out of 14 farmers considered carbon footprinting tools as not user-friendly, while another 3 out of 14 farmers do not use the tools or had carbon audits carried out by external consultants. Farmers who appreciated carbon accounting tools stated that these have improved lately and tend to become more user-friendly. However, Farmer J and M cited the need for more descriptions and explanations from the tools' developers.

Therefore, the relatively simple yet versatile design the RFPA tool generated positive feedback in terms of usefulness of the tool and its applicability. The results of the study show that the methodology adopted has the potential for future development to include detailed socio-economic variables in the assessment tool. At the same time, the results show that there are opportunities for further engagement with extensive livestock farmers in the area by enabling them to play an active role in research on on-farm GHG emission mitigation.

## 6.6 Further considerations

It is important to remember that the convenience sampling technique adopted in this study does not allow generalisation of findings, as the sample is not representative of the wider sector. However, the combination of quantitative and qualitative research methodologies in a participatory study produced interesting findings that can lead to further considerations on the impact that farmers' attitudes can have on the uptake of innovation in mitigating on-farm GHG emissions.

Initially, results from the 2 rounds of farm assessments showed that there can be practical obstacles to GHG emission mitigation. These include the lack of space available for additional facilities in order to improve the practices related to the storage and treatment of manure and slurry, the possible impact of limited labour force on the amount of work needed to implement certain mitigation strategies (e.g. increased frequency of livestock grazing rotations). However, findings do not seem to support the possibility of a relationship between the presence of these obstacles and specific farm characteristics, as farms were of varying sizes and livestock production. Nor do the findings indicate the type of management (i.e. family-run v farm manager), either under entry level or higher level environmental stewardship agreements, as a possible explanation for mitigation strategies not being adopted.

Nevertheless, half the farmers could implement mitigation strategies in at least 1 sector of the farm practices assessed. Results from farmers' interviews showed that financial limitations can play a major role in farmers' decision-making. These, however, can present themselves under different guises. Farmers' responses did not highlight any relationship between specific farms' or farmers' characteristics and the adoption of change, as financial obstacles were cited by both farmers who did adopt change and others who did not adopt change. Furthermore, 3 out of 5 of the financial factors assessed during the interviews were identified by the majority of farmers as irrelevant to their decision-making process. However, 10 out of 14 farmers identified general financial limitations as the economic factor with the greatest negative influence on their decisions. The reasons given by farmers differed, not showing any particular link to farm size, livestock production and farm management or farmer background. Moreover, narratives highlighted similar explanations linked to opposite responses (i.e. yearly actions or programs of investments seen as a positive influence by Farmer K, but a negative influence by Farmer A). Therefore, based on these findings, it is reasonable to suggest that farmers may not identify economic factors such as the cost of agricultural consultants or the possibility to contract additional labour as specific obstacles to innovation. They identify instead general limitations linked to the lack of financial capital, even though innovation may still be adopted (i.e. Farmer A). This finding seems to suggest that the understanding of farmers' behaviour facing tangible obstacles, such as financial limitations, may be linked to other motivations farmers may have for embracing change and innovation, which could relate to market pressures and consumers' demand for climate-friendly products, although this specific topic was not addressed by the study.

Further insight was obtained from the responses farmers provided to the survey questions referring to the influence of political factors on their decision-making.  The overall results suggest that marked lack of confidence in government action combined with scepticism around the validity of scientific claims represent obstacles to the adoption of on-farm innovations. There was no clear link between farms' or farmers' characteristics and the degree of trust given to government action. The majority of farmers did not show trust in reports provided by the government, speculating on hidden agendas and lobbying being the reasons for their reluctance to follow government advice. However, all but 2 farms were under environmental schemes and Farmer H, who clearly stated his scepticism around GHG emission mitigation, both in terms of scientific evidence and in terms of political action, did not oppose to following official reports and guidelines provided by the government. Farmers' responses show contradictions that could be explained by the possibility that a gap exists between their perceptions of negative influences on their business and the actual existence of such negative impacts. This is supported by the positive influence exercised instead by the source of information (i.e. research institution, individual contact with researcher). Results from the farmers' attitudes survey and focus group seem to suggest that political factors that may hinder the process of accepting advice on on-farm innovation to reduce GHG emissions could be overcome by focusing on fostering linking social capital between research institutions, researchers and farmers on the one hand, and on strengthening bonding social capital among farmers on the other hand. The adoption of change at the farm level seemed to depend on individual circumstances rather than a common perception of GHG emission mitigation by farmers in the study. Although some farmers mentioned their interest in practice-led rather than lab-driven research, the source of scientific knowledge and its effective communication seemed to have a more prominent role than the knowledge itself. Farmers' responses did not seem to acknowledge the fact that some of the research institutions they cited may carry out research under government funding. This finding provides interesting grounds for further investigating the impact of farmers’ perceptions of climate action and the source of scientific information on their adoption of on-farm innovation.

Finally, the study obtained positive results in terms of farmer engagement. Farmers’ responses highlighted the need for collaborative environments in which farmers’ can be active participants to the research process. This approach is more likely to overcome the scepticism that still surrounds the application of scientific evidence of GHG emission mitigation, in particular regarding the usefulness and user-friendliness of carbon accounting tools. Farmers’ feedback on the methodology adopted and their interest in engaging with researchers suggest that the use of the RFPA tool, farmers’ interviews and the farmers’ focus group at the end of the study contributed to establishing relationships between farmers and researchers based on clear and transparent two-way communication and which can be considered likely to influence positively farmers’ uptake of innovation. Farmer engagement, in particular at the focus group meeting, did not seem to depend on farms’ or farmers’ characteristics such as size, type of livestock, farm management, or even distance from the location of the event. These results give a positive outlook on the possibility of engaging with a larger group of farmers in the future and obtaining valuable information on farmers’ attitudes to climate change, while promoting the implementation of effective GHG emission mitigation strategies at the farm level through co-research and sharing experiences.

# Chapter 7

# Conclusion

# 7 Conclusion

The aim of the study was to evaluate the potential for adoption of GHG emission mitigation strategies by a selected group of livestock farmers and identify possible barriers to innovation in farm management practices, as well as create opportunities to establish collaborative engagement between farmers and researchers in order to overcome obstacles to on-farm innovation. Results highlight the challenges related to research that aims to include a social component in studies that originate with a primary focus on hard science.

## 7.1 Key findings

The study set out to address the 6 objectives listed in chapter 1, which included assessing farm practices based on their GHG emission mitigation potential, evaluate the feasibility of mitigation strategies and identify possible barriers to the implementation of on-farm innovation, while establishing successful researcher-farmer collaboration through a series of participatory activities.

### 7.1.1 Challenges in farm assessment

The review of estimates of GHG emission mitigation has shown that there is still a great deal of uncertainty regarding the impact of certain mitigation strategies. This is due primarily to the wide range of factors that affect the effectiveness of a practice in mitigating GHG emissions and the fact that it is difficult to standardise the impact of emissions affected by weather conditions or to compare studies carried out under different experimental conditions. Moreover, the review of carbon calculators currently available for farmers has shown that estimates obtained using calculators may differ significantly depending on the system boundaries adopted in the design of the calculators. Life Cycle

Analysis provides a useful tool to define system boundaries, but its implementation may vary between different carbon calculators, therefore influencing the results from the calculations. However, the review has shown that there is a sufficient amount of data regarding GHG emission mitigation to provide guidelines for farmers in order to reduce the impact of farm practices.

The study focused on practices that could be assessed within 1 year in order to review possible changes and their impact in terms of emissions and farm management. The RFPA tool was created as a user-friendly tool for farmers to allow them to assess their farm management practices and monitor their GHG emissions impact over time. The tool proved to be effective in assessing practices in a fast and clear way. Farmers appreciated the simplicity of the tool and its versatility due the separation of the practices in 5 sections, each containing decision trees and scoring sheets that clearly identified which practices had the greater impact in terms of GHG emissions. The positive feedback received from farmers is encouraging and suggests that the design of the tool is a strong foundation for developing it further to include a larger set of practices that could apply to a wider range of farms and farming systems.

### 7.1.2 Feasibility of GHG emission mitigation

The type of farms that participated in the study had an extensive, low-input type of production, predominantly organic and pasture-based. The recommendations obtained using the RFPA tool proposed mitigation options taking into consideration the unique conditions of each farm. Therefore, recommendations were tailored to the farm specific circumstances. Half the farms in the study adopted changes in farm practices and all these farms registered an improvement in the expected GHG impact reduction over the timeframe of the study. The study showed that farmers' willingness to adopt mitigation strategies may face obstacles in being translated into action and on-farm innovation. Mitigation strategies related to dietary management and grazing and pasture management were already adopted by the majority of farmers, as these practices tend to match with good agricultural practices and advice regarding the protection of soil on pastures. Livestock housing, albeit having a limited impact on the majority of farms in the study because of the limited time the livestock was housed, presented limitations similar to the ones observed in the manure management section. Mitigation strategies related to the storage and treatment of manure and slurry encountered feasibility obstacles due to the capital investment needed to install the machinery and the labour required to operate it. Results suggest that financial limitations were among the main obstacles to the adoption of on-farm innovation. It also needs to be noted that results suggest that it could be difficult for farmers to find a link between changes in practices related to the storage and treatment of manure and slurry and the possible benefits in terms of income generation or reduction in financial losses. While it is fairly easy to see that an improvement in the treatment of manure and slurry that are then applied to field could lead to a more effective use of fertiliser or a reduction in need to purchase of fertiliser, the economic impact of such change in practices may be too great for farms adopting extensive low-input farming practices. Similarly, practices recommending an increase in frequency of livestock rotational grazing patterns, such as the installation of additional movable fencing structures, may require not only financial investment to build the additional infrastructure, but also financial capital to pay for the additional labour required to maintain a higher frequency of livestock rotations. Such examples suggest that, although effective in mitigating emissions, certain practices may encounter strong financial obstacles in their adoption by farms with limited financial capital, which tend to be businesses with an extensive low-input type of production. Therefore, further studies that compare farms differing in size and type of production are needed in order to evaluate the actual feasibility and cost-effectiveness of GHG emission mitigation strategies.

### 7.1.3 Farmers' attitudes to GHG emission mitigation

Results showed that even though farmers provided different reasons for the same attitude, such as trusting in scientific knowledge of GHG emission mitigation but still being sceptical by pointing out that the problem lies in the communication of science or in its application, certain common factors can be found which explain possible motivations behind the lack of on-farm innovation in GHG emission mitigation.

The study highlighted the influence of political factors such as lack of trust in government action and lack of support in integrating practices related to environmental schemes with practices that reduce GHG emissions, and the negative impact these factors have on farmers' decision-making, fuelling their reluctance to change farm management practices and slowing down the uptake of on-farm innovation. Interestingly, results showed that the source of scientific knowledge and the way scientific knowledge is presented to them have a great influence on farmers' attitudes to GHG emission mitigation. While 9 out of 14 farmers did not show trust in government action and the information provided by DEFRA, only 3 out of 14 farmers stated that both their lack of trust in the government and their scepticism over scientific evidence related to GHG emission mitigation are affecting their decisions, showing that farmers' attitudes are more affected by political factors, rather than understanding of scientific evidence of mitigation.

This leads to another interesting result regarding the influence that the source of knowledge can have on farmers' decision-making. The study suggests that farmers prefer to gain scientific knowledge via organisations and research institutions that they perceive as independent from the government and carrying out research that is practice-led rather than lab-driven. Moreover, farmers' networks of influence and peer-to-peer knowledge exchange play important roles in shaping farmers' decision-making. Eight (8) out of 14 farmers expressed scepticism over current carbon accounting tools and 6 out of 14 stated that they do not always trust advice from agricultural consultants, as these may have hidden agendas. Nevertheless, these farmers showed interest in the study, which suggests that greater focus should be placed on the way science is communicated and on how trust in the source of knowledge affects farmers' attitudes to innovation in GHG emission mitigation. The study also suggests that the adoption of an approach oriented to practical problem-solving and to valuing farmers' contribution to the knowledge pool ensures that the barriers created by the lack of trust in individuals external to farmers' networks of influence, are overcome.

### 7.1.4 The impact of farmer engagement

The participatory approach of the study set to address the issue of farmers tending to be influenced by the social networks in which they operate and being more likely to accept knowledge and advice from peers or advisors with earned credibility, rather than from official channels such as governmental bodies. However, even though farmers showed interest in innovation and willingness to improve farming practices provided there was a clear benefit for the farm, primarily as a business, 13 out of 14 of farmers stated that the trust in the individual carrying out the study positively affects their decisions. The approach used in the study was to listen to farmers' views and give them an opportunity to be co-researchers on GHG emission mitigation, therefore valuing both scientific knowledge and farmers' knowledge and highlighting the importance of participatory studies and farmer engagement in the dissemination of knowledge. The study showed that farmers appreciate the provision of transparent knowledge transfer from scientists, in a language accessible to them, and they are also interested in farmer-to-farmer knowledge sharing activities, such as the farmers' focus group organised at the end of the study.

Therefore, successful engagement with farmers cannot be achieved relying solely on farm management economics, technology or published guidance, but rather by participatory activities that adopt a two-way communication between farmers and researchers and integrate multidisciplinary knowledge provided by hard sciences and social sciences, with farmers' experience. By promoting linking social capital, farmer engagement could be successful in building long-term collaborations between farmers and researchers in order to disseminate knowledge and promote on-farm innovation, having a greater understanding of farmers' attitudes towards GHG emission mitigation and the possible obstacles farmers could encounter in adopting mitigation strategies.

## 7.2 Critique of the methodology adopted

The methodology adopted in the study combined qualitative and quantitative research in order to design a participatory framework for successful engagement with a selected group of livestock farmers. Results in terms of farmers' participation and the amount and quality of information collected on farmers' attitudes to GHG emission mitigation can be considered encouraging and they provide useful grounds for further studies on farmers' behaviour and decision-making. However, the approach presented strengths and limitations related to both qualitative and quantitative research approaches.

The RFPA tool created for this purpose was particularly well received by farmers because it provided tailored, practical advice on farm management practices and generated interest in the following stages of the study. Such result can be considered very positive and it shows great potential for further development of the tool to allow the assessment of a wider range of farm practices.

Participatory case studies were chosen for the field study, as according to literature, the creation of opportunities for on-farm innovation is more successful when based on participatory action and translational research and case study research provides in-depth analysis of context-dependent situations. While this type of methodology can be useful to investigate the individuality of agricultural businesses, in order to obtain greater knowledge a larger sample of farmers would have to be selected using randomised sampling or other probability sampling techniques. This would ensure the sample is representative of the sector and it would reduce the risk of results being influenced by biases related to the type of sample and its size.

The study highlighted the importance of face-to-face contact between farmers and researchers and that of consistent interaction between them. Such interaction is likely to help building researcher-farmer relationships based on mutual understanding and trust. However, in order to provide effective long-term farmer engagement, this type of activity needs great investments both financially and in terms of time and facilities available. In the agricultural sector, the individuality of each farm is likely to influence farmers' responses and behavioural attitudes and researchers need to engage with farmers on individual level, as well as in groups, in order to build longstanding relationships over time. Therefore, even though such studies are essential to reach a greater understanding of the dynamics within certain sectors of society, they are not time-resources efficient and this could put excessive pressure on researchers and funding bodies to achieve successful researcher-farmer interaction over a limited time.

## 7.3 Wider implications for future research

The positive results obtained by this study suggest that the tool and the methodology could be further developed in order to engage with a larger number of farmers and provide a more comprehensive assessment of GHG emission mitigation strategies.

Future research could evaluate the impact of larger farm samples representative of the livestock sector. The RFPA tool could be expanded to include criteria needed for the assessment of a wider range of farming systems with the possibility of comparison between farms differing in size and type of production (i.e. organic v conventional, small-scale v large-scale) or market links (i.e. local producers v producers for big retailers). Moreover, one of the greatest barriers encountered by farmers in adopting GHG emission mitigation strategies was the financial limitations and the uncertainty regarding the actual effect that implementing mitigation strategies could have on farm budgets. Therefore, the addition of criteria evaluating the cost-effectiveness of each mitigation option would provide a more comprehensive assessment, including possible financial benefits from adopting on-farm innovation in order to reduce agri-businesses' carbon footprint. This approach could provide valuable information to integrate with studies on the influence of consumers' demands for climate-friendly products.

Future studies using the RFPA tool could benchmark the impact of the livestock sector in terms of GHG emissions. The benefits could be multiple, as this approach could simultaneously provide support to farmers, researchers and policy-makers. On the one hand researcher-farmer interactions could be enhanced and more participatory research could provide a greater understanding of farmers' behaviour and decision-making, helping researchers address issues related to farmers' attitudes and perceptions of climate change and, more generally, their scepticism or reluctance to change. Farmers could receive support in improving their agri-businesses' management and activities such as knowledge exchange between farmers and researchers could overcome the obstacle represented by the lack of trust in government action and privatised extension services. On the other hand this approach and the RFPA tool could provide useful information to policy-makers by highlighting the key issues that need to be addressed in future environmental policies, therefore supporting government action under the second phase of the GHG Action Plan, which includes farmer engagement and farmer training activities.

Finally, the user-friendliness of the RFPA tool and its success with farmers in this study suggest the possibility for it to be used without the help of an agricultural advisor or researcher. This can be considered one of the greatest advantages of the tool and in the future the tool could be integrated in the current self-assessment procedure under Environmental Stewardships Schemes. This would benefit both policy-makers and farmers, as results from the study highlighted the difficulty some farmers encounter in adopting certain mitigation strategies on agribusinesses that are under environmental schemes. Even though many practices that reduce GHG emissions are effectively good agricultural practices already recommended by the government under other policies, results from farmers' interviews highlighted the possibility of conflict arising from attempting to integrate prescriptions under environmental schemes and GHG emission mitigation. Therefore, the RFPA tool could provide an easy-to-use, farmer-friendly way to obtain an integrated assessment of farm management practices.

# Chapter 8

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# Appendix I

# Field study

**I.1 Sample of guidelines for GHG emission mitigation**

**I.2 Sample reports**

**I.3 Questionnaire on farmers' attitudes and perceptions of GHG emission mitigation**

# Appendix I. Field study

## I.1 Sample of guidelines for GHG emission mitigation

This section features an extract of the guidelines booklet used during the field assessment.

Guidelines for practices related to manure storage and treatment are reported.

School
of
Agriculture

Royal
Agricultural
College

# Guidelines to improve farm practices

# and reduce greenhouse gas emissions

Sara Burbi
Dr Richard Baines
Dr John Conway

***Guidelines to improve farm practices and reduce greenhouse gas emissions***



*Introduction*

This booklet is aimed at providing support to livestock farmers wanting to reduce the carbon footprint of their farm. The booklet can be used with the decision support tool developed by the same team, or as an informative summary of farm practices that reduce greenhouse gas (GHG) emissions. Pollutants taken into account are methane ($CH_4$), nitrous oxide ($N_2O$) and other nitrogen losses, such as ammonia ($NH_3$) and nitrogen oxides ($NO_x$).

The guidelines are divided in 5 sections, representing the key areas where greenhouse gases can be reduced. They are based on up-to-date knowledge on greenhouse gas emissions, their sources and the effectiveness of the mitigation strategies most commonly applied in Europe and the United States. Clear figures are given for the expected outcomes, e.g. -15% $CH_4$, and a short explanation of the processes involved is also provided.

For further information, please contact:


Sara Burbi, PhD researcher
Royal Agricultural College
Cirencester, Glos., GL7 6JS, England
Tel.: 01285 652531 ext. 2366
M.: 07503 224061
sara.burbi@rac.ac.uk

| Ref # | Guidelines | Expected outcomes | Further information |
|---|---|---|---|
| **ST1** | Use liquid fraction for anaerobic digestion | Increased $NH_3$<br>Lower $N_2O$<br>AD yield +2-14.6% $CH_4$ | The slurry liquid fraction should only be aerated in then used in a digestate. In fact, aeration usually involves mixing, without the formation of a crust. This practice creates aerobic conditions, having multiple effects on emissions:<br>(i) increased $CH_4$ yields from digestate;<br>(ii) increased $NH_3$ emissions, which are usually reduced in anaerobic conditions (see, ST6);<br>(iii) lower $N_2O$ emissions. |
| **ST2** | Liquid fraction aeration | AD yield +2-14.6% $CH_4$ | Intermittent mixing increases biogas production yields by maintaining an optimum level of aeration and particles distribution. Crust layers are less likely to consolidate and the overall yield of the biogas plant increases, at virtually very little or no cost. |
| | Addition of glycerol | AD yield +200% $CH_4$ | Methane yield from the digestate can double by adding 1% of glycerol. The process remains stable, the quality of the end products do not vary and the yield is significantly increased. |
| **ST3** | Liquid fraction aeration | AD yield +2-14.6% $CH_4$ | Intermittent mixing increases biogas production yields by maintaining an optimum level of aeration and particles distribution. Crust layers are less likely to consolidate and the overall yield of the biogas plant increases, at virtually very little or no cost. |
| | Use liquid fraction for anaerobic digestion | -75% $CH_4$ | The use of a digestate to treat the liquid fraction has a positive impact on methane emissions from manure, significantly lowering their impact on the farm emissions balance. |
| | Addition of glycerol | AD yield +200% $CH_4$ | Methane yield from the digestate can double by adding 1% of glycerol. The process remains stable, the quality of the end products do not vary and the yield is significantly increased. |

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| **ST4** | Composting solid fraction | Static composting:<br>-60% $NH_3$<br><br>Monthly turning:<br>-46% $N_2O$<br>-89.8% $CH_4$<br>+66% $NH_3$ | | Static composting of the solid fraction, without turning or cover, increases its dry matter (DM) content, consequently reducing $NH_3$ losses.<br>Monthly turning of the compost bed increases aeration, influencing the porosity and the structure of the compost pile. It also helps maintaining a more homogeneous temperature. Gaseous emissions due to anaerobic processes are reduced, while nitrate leaching could be significantly increased. |
| | Addition of straw | -32% $N_2O$ | | Mixing solid manure with straw (1 : 1 ratio) can increase the Dry Matter content of the compost pile, influencing the C : N ratio and therefore reducing $N_2O$ emissions. |
| **ST5** | OK | | | |
| **ST6** | Slurry separation,<br>i.e. screw-press<br><br>$NH_3$<br>$CO_2$<br>$CH_4$ | Pig slurry<br>(liquid / solid)<br>-12% / -89.5%<br>-12% / -42.5%<br>-7.5% / -95% | Cattle slurry<br><br>2% / -72%<br>-22% / +4%<br>-22%/-80.5% | Slurry separation, especially when combined with lower temperatures and uncovered conditions, can effectively reduce ammonia and methane emissions, in particular from the solid fraction. Storing fractions separately allows a better control over factors influencing emissions: temperature, water content, aeration, cover.<br>In addition, separation can increase slurry storage capacity and both fractions will have a higher nutrient content. This is an advantage if slurry is used as fertiliser. |
| | | Little to no $N_2O$ emissions | | Storage of liquid fraction in anaerobic conditions doesn't promote nitrification ($NH_3$ to $NO_3^-$) and therefore, denitrification rates are also reduced to a minimum. |
| | Prevent encrustation | Little to no $N_2O$ emissions | | The effect of encrustation of the surface of slurry or its cover is twofold: it increases $N_2O$ emissions but lowers $NH_3$ emissions. To effectively reduce $N_2O$ emissions, a cover and additives can be used (see, ST7; ST25 Use of additives). |

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| **ST6 (cont'd)** | Leave natural crust* | | -38% $CH_4$<br>-50% $NH_3$ | Natural crusts prevent the proliferation of aerobic microorganisms that produce methane.<br>*However, the effectiveness of a natural crust can vary greatly depending on its thickness (influence of N losses) and durability. Therefore it is generally not advised to leave a natural crust form. |
| **ST7** | Slurry separation, i.e. screw-press | <br><br>$NH_3$<br>$CO_2$<br>$CH_4$ | Pig slurry (liquid / solid) — Cattle slurry<br>$NH_3$: -12% / -89.5% — -2% / -72%<br>$CO_2$: -12% / -42.5% — -22% / +4%<br>$CH_4$: -7.5% / -95% — -22%/-80.5% | Slurry separation, especially when combined with lower temperatures and uncovered conditions, can effectively reduce ammonia and methane emissions, in particular from the solid fraction. Storing fractions separately allows a better control over factors influencing emissions: temperature, water content, aeration, cover.<br>In addition, separation can increase slurry storage capacity and both fractions will have a higher nutrient content. This is an advantage if slurry is used as fertiliser. |
| | | | Little to no $N_2O$ emissions | Storage of liquid fraction in anaerobic conditions doesn't promote nitrification ($NH_3$ to $NO_3^-$) and therefore, denitrification rates are also reduced to a minimum. |
| | Homogenisation<br>Water addition | | N.A. (lower $N_2O$ and $CH_4$) | $N_2O$ emissions are only registered in slurry with a dry encrusted surface, in particular when containing straw. This is cause by the lack of oxygen and the higher temperatures and pH developing during storage (see, ST6 Prevent encrustation). |
| **ST8** | OK | | | |
| **ST9** | Slurry separation, i.e. screw-press | <br><br>$NH_3$<br>$CO_2$<br>$CH_4$ | Pig slurry (liquid / solid) — Cattle slurry<br>$NH_3$: -12% / -89.5% — -2% / -72%<br>$CO_2$: -12% / -42.5% — -22% / +4%<br>$CH_4$: -7.5% / -95% — -22%/-80.5% | Slurry separation, especially when combined with lower temperatures and uncovered conditions, can effectively reduce ammonia and methane emissions, in particular from the solid fraction. Storing fractions separately allows a better control over factors influencing emissions: temperature, water content, aeration, cover.<br>In addition, separation can increase slurry storage capacity and both fractions will have a higher nutrient content. This is an advantage if slurry is used as fertiliser. |

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| **ST9 (cont'd)** | | Little to no $N_2O$ emissions | Storage of liquid fraction in anaerobic conditions doesn't promote nitrification ($NH_3$ to $NO_3^-$) and therefore, denitrification rates are also reduced to a minimum. |
| **ST10** | Slurry separation, i.e. screw-press | Pig slurry (liquid / solid) / Cattle slurry<br>$NH_3$ -12% / -89.5% -2% / -72%<br>$CO_2$ -12% / -42.5% -22% / +4%<br>$CH_4$ -7.5% / -95% -22%/-80.5% | Slurry separation, especially when combined with lower temperatures and uncovered conditions, can effectively reduce ammonia and methane emissions, in particular from the solid fraction. Storing fractions separately allows a better control over factors influencing emissions: temperature, water content, aeration, cover.<br>In addition, separation can increase slurry storage capacity and both fractions will have a higher nutrient content. This is an advantage if slurry is used as fertiliser. |
| | | Little to no $N_2O$ emissions | Storage of liquid fraction in anaerobic conditions doesn't promote nitrification ($NH_3$ to $NO_3^-$) and therefore, denitrification rates are also reduced to a minimum. |
| | Sloped / slatted floors | Little to no $N_2O$ emissions<br>$CH_4$ emissions vary based on production cycle | (see, Section 2. Housing, rH1 and mH1) |
| **ST11** | OK | | |
| **ST12** | Composting dry manure | Static composting:<br>-60% $NH_3$<br><br>Monthly turning:<br>-46% N2O<br>-89.8% $CH_4$<br>+66% $NH_3$ | Static composting of the solid fraction, without turning or a cover, increases its dry matter (DM) content, consequently reducing $NH_3$ losses. Monthly turning of the compost bed increases aeration, influencing the porosity and the structure of the compost pile. It also helps maintaining a more homogeneous temperature. Gaseous emissions due to anaerobic processes are reduced, while nitrate leaching could be significantly increased. |
| | Addition of straw | -32% N2O<br>-45% $CH_4$ | Mixing solid manure with straw (1 : 1 ratio) can increase the Dry Matter content of the compost pile, influencing the C : N ratio and therefore reducing $N_2O$ and $CH_4$ emissions. |

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| **ST12 (cont'd)** | Addition of phosphogypsum | -54% GHG (composition: little-no $N_2O$, 14% $CH_4$) | Phosphogypsum is a by-product of the fertiliser industry. It influences the pH of the compost pile and its sulphur content. The majority of gaseous losses are as $CO_2$ (lower Global Warming potential) and the end product has potentially higher value as fertiliser, depending on its use (unchanged N content, higher sulphur content). |
| **ST13** | Composting dry manure | Static composting:<br>-60% $NH_3$<br><br>Monthly turning:<br>-46% $N_2O$<br>-89.8% $CH_4$<br>+66% $NH_3$ | Static composting of the solid fraction, without turning or cover, increases its dry matter (DM) content, consequently reducing $NH_3$ losses.<br>Monthly turning of the compost bed increases aeration, influencing the porosity and the structure of the compost pile. It also helps maintaining a more homogeneous temperature. Gaseous emissions due to anaerobic processes are reduced, while nitrate leaching could be significantly increased. |
| | Addition of straw | -32% $N_2O$<br>-45% $CH_4$ | Mixing solid manure with straw (1 : 1 ratio) can increase the Dry Matter content of the compost pile, influencing the C : N ratio and therefore reducing $N_2O$ and $CH_4$ emissions. |
| | Addition of phosphogypsum | -54% GHG (composition: little-no $N_2O$, 14% $CH_4$) | Phosphogypsum is a by-product of the fertiliser industry. It influences the pH of the compost pile and its sulphur content. The majority of gaseous losses are as $CO_2$ (lower Global Warming potential) and the end product has potentially higher value as fertiliser, depending on its use (unchanged N content, higher sulphur content). |
| | Addition of water | -30-70% $NH_3$ & $N_2O$ | The addition of water can reduce the free air space by 20-60%, lowering N losses. |
| | Use impermeable cover, i.e. tarpaulin, plastic | -60-90% $NH_3$ | Impermeable covers provide the anaerobic conditions necessary to prevent $NH_3$ losses. They are more expensive than other types of covers, but they have several advantages: they are durable and can be used to effectively capture methane produced by the manure storage units (e.g. heap, lagoons) to take it to combustion plants such as anaerobic digesters. |

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| **ST13 (cont'd)** | Ensure cover is airtight<br>Use ventilation hoses | -54% $CH_4$ | Airtight covers do not provide favourable conditions for the aerobic microorganisms responsible for the production of $CH_4$.<br>When impermeable covers are used, it is necessary to make sure the cover is airtight to avoid gas leaks. Ideally, pipes or hoses should be used to redirect emissions to ventilation units.<br>During storage of liquid manure, peaks of emissions can be registered when the pit is covered by a thick crust and cracks occur under pressure from gases underneath the surface. |
| **ST14** | Composting dry manure | Static composting:<br>-60% $NH_3$<br><br>Monthly turning:<br>-46% $N_2O$<br>-89.8% $CH_4$<br>+66% $NH_3$ | Static composting of the solid fraction, without turning or cover, increases its dry matter (DM) content, consequently reducing $NH_3$ losses.<br>Monthly turning of the compost bed increases aeration, influencing the porosity and the structure of the compost pile. It also helps maintaining a more homogeneous temperature. Gaseous emissions due to anaerobic processes are reduced, while nitrate leaching could be significantly increased. |
| | Addition of straw | -32% $N_2O$<br>-45% $CH_4$ | Mixing solid manure with straw (1 : 1 ratio) can increase the Dry Matter content of the compost pile, influencing the C : N ratio and therefore reducing $N_2O$ and $CH_4$ emissions. |
| | Addition of phosphogypsum | -54% GHG<br>(composition: little-no $N_2O$, 14% $CH_4$) | Phosphogypsum is a by-product of the fertiliser industry. It influences the pH of the compost pile and its sulphur content. The majority of gaseous losses are as $CO_2$ (lower Global Warming potential) and the end product has potentially higher value as fertiliser, depending on its use (unchanged N content, higher sulphur content). |
| | Addition of water | -30-70% $NH_3$ & $N_2O$ | The addition of water can reduce the free air space by 20-60%, lowering N losses. |

| | | | |
|---|---|---|---|
| **ST15** | Composting dry manure | Static composting:<br>-60% $NH_3$<br><br>Monthly turning:<br>-46% $N_2O$<br>-89.8% $CH_4$<br>+66% $NH_3$ | Static composting of the solid fraction, without turning or cover, increases its dry matter (DM) content, consequently reducing $NH_3$ losses.<br>Monthly turning of the compost bed increases aeration, influencing the porosity and the structure of the compost pile. It also helps maintaining a more homogeneous temperature. Gaseous emissions due to anaerobic processes are reduced, while nitrate leaching could be significantly increased. |
| | Addition of straw | -32% $N_2O$<br>-45% $CH_4$ | Mixing solid manure with straw (1 : 1 ratio) can increase the Dry Matter content of the compost pile, influencing the C : N ratio and therefore reducing $N_2O$ and $CH_4$ emissions. |
| | Addition of phosphogypsum | -54% GHG<br>(composition: little-no N2O, 14% $CH_4$) | Phosphogypsum is a by-product of the fertiliser industry. It influences the pH of the compost pile and its sulphur content. The majority of gaseous losses are as $CO_2$ (lower Global Warming potential) and the end product has potentially higher value as fertiliser, depending on its use (unchanged N content, higher sulphur content). |
| | Addition of water | -30-70% $NH_3$ & $N_2O$ | The addition of water can reduce the free air space by 20-60%, lowering N losses. |
| | Ensure cover is airtight<br>Use ventilation hoses | -54% $CH_4$ | Airtight covers do not provide favourable conditions for the aerobic microorganisms responsible for the production of $CH_4$.<br>When impermeable covers are used, it is necessary to make sure the cover is airtight to avoid gas leaks. Ideally, pipes or hoses should be used to redirect emissions to ventilation units.<br>During storage of liquid manure, peaks of emissions can be registered when the pit is covered by a thick crust and cracks occur under pressure from gases underneath the surface. |

| | | | |
|---|---|---|---|
| **ST16** | Composting dry manure | Static composting:<br>-60% $NH_3$<br><br>Monthly turning:<br>-46% $N_2O$<br>-89.8% $CH_4$<br>+66% $NH_3$ | Static composting of the solid fraction, without turning or cover, increases its dry matter (DM) content, consequently reducing $NH_3$ losses.<br>Monthly turning of the compost bed increases aeration, influencing the porosity and the structure of the compost pile. It also helps maintaining a more homogeneous temperature. Gaseous emissions due to anaerobic processes are reduced, while nitrate leaching could be significantly increased. |
| | Addition of straw | -32% $N_2O$<br>-45% $CH_4$ | Mixing solid manure with straw (1 : 1 ratio) can increase the Dry Matter content of the compost pile, influencing the C : N ratio and therefore reducing $N_2O$ and $CH_4$ emissions. |
| | Addition of phosphogypsum | -54% GHG<br>(composition: little-no $N_2O$, 14% $CH_4$) | Phosphogypsum is a by-product of the fertiliser industry. It influences the pH of the compost pile and its sulphur content. The majority of gaseous losses are as $CO_2$ (lower Global Warming potential) and the end product has potentially higher value as fertiliser, depending on its use (unchanged N content, higher sulphur content). |
| | Addition of water | -30-70% $NH_3$ & $N_2O$ | The addition of water can reduce the free air space by 20-60%, lowering N losses. |
| | Provide cover:<br>Use impermeable cover, i.e. tarpaulin, plastic | -60-90% $NH_3$ | Impermeable covers provide the anaerobic conditions necessary to prevent $NH_3$ losses. They are more expensive than other types of covers, but they have several advantages: they are durable and can be used to effectively capture methane produced by the manure storage units (e.g. heap, lagoons) to take it to combustion plants such as anaerobic digesters. |
| | Ensure cover is airtight<br>Use ventilation hoses | -54% $CH_4$ | Airtight covers do not provide favourable conditions for the aerobic microorganisms responsible for the production of $CH_4$.<br>When impermeable covers are used, it is necessary to make sure the cover is airtight to avoid gas leaks. Ideally, pipes or hoses should be used to redirect emissions to ventilation units. During storage of liquid manure, peaks of emissions can be registered when the pit is covered by a thick crust and cracks occur under pressure from gases underneath the surface. |

| | | | |
|---|---|---|---|
| **ST16 (cont'd)** | Use permeable cover, i.e. straw<br>Apply directly to land | -60-90% $NH_3$<br>+200% $N_2O$ | The addition of straw effectively reduces $NH_3$ losses from FYM heaps; however, $N_2O$ losses more than double. In the case of straw-based storage systems, it is advised to apply FYM directly to field and reduce the storage period to minimum, as storage accounts for ca. 85% of $N_2O$ emissions. |
| **ST17** | Compacting | -90% $NH_3$<br>-30% $N_2O$<br>Lower $CH_4$ in colder months | Gaseous losses from manure can only be effectively by controlling the temperature of the compost pile and the balance between aerobic and anaerobic conditions. Compacting can reduce $NH_3$ and to a certain extent $N_2O$ as well; $CH_4$emissions are reduced in colder months, but may significantly increase in warmer months. |
| | Use impermeable cover, i.e. tarpaulin, plastic | -30-70% $NH_3$ & $N_2O$ | Compacting can reduce the free air space by 20–60%, lowering N losses. |
| | | -60-90% $NH_3$ | Impermeable covers provide the anaerobic conditions necessary to prevent $NH_3$ losses. They are more expensive than other types of covers, but they have several advantages: they are durable and can be used to effectively capture methane produced by the manure storage units (e.g. heap, lagoons) to take it to combustion plants such as anaerobic digesters. |
| | Ensure cover is airtight<br>Use ventilation hoses | -54% $CH_4$ | Airtight covers do not provide favourable conditions for the aerobic microorganisms responsible for the production of $CH_4$.<br>When impermeable covers are used, it is necessary to make sure the cover is airtight to avoid gas leaks. Ideally, pipes or hoses should be used to redirect emissions to ventilation units. During storage of liquid manure, peaks of emissions can be registered when the pit is covered by a thick crust and cracks occur under pressure from gases underneath the surface. |
| **ST18** | Compacting | -90% $NH_3$<br>-30% $N_2O$<br>Lower $CH_4$ in colder months | Gaseous losses from manure can only be effectively by controlling the temperature of the compost pile and the balance between aerobic and anaerobic conditions. Compacting can reduce $NH_3$ and to a certain extent $N_2O$ as well; $CH_4$ emissions are reduced in colder months, but may significantly increase in warmer months. |
| | | -30-70% $NH_3$ & $N_2O$ | Compacting can reduce the free air space by 20–60%, lowering N losses. |

| | | | |
|---|---|---|---|
| **ST19** | Compacting | -90% $NH_3$<br>-30% $N_2O$<br>Lower $CH_4$ in colder months | Gaseous losses from manure can only be effectively by controlling the temperature of the compost pile and the balance between aerobic and anaerobic conditions. Compacting can reduce $NH_3$ and to a certain extent $N_2O$ as well; $CH_4$ emissions are reduced in colder months, but may significantly increase in warmer months. |
| | | -30-70% $NH_3$ & $N_2O$ | Compacting can reduce the free air space by 20–60%, lowering N losses. |
| | Ensure cover is airtight<br>Use ventilation hoses | -54% $CH_4$ | Airtight covers do not provide favourable conditions for the aerobic microorganisms responsible for the production of $CH_4$.<br>When impermeable covers are used, it is necessary to make sure the cover is airtight to avoid gas leaks. Ideally, pipes or hoses should be used to redirect emissions to ventilation units. During storage of liquid manure, peaks of emissions can be registered when the pit is covered by a thick crust and cracks occur under pressure from gases underneath the surface. |
| **ST20** | Compacting | -90% $NH_3$<br>-30% $N_2O$<br>Lower $CH_4$ in colder months | Gaseous losses from manure can only be effectively by controlling the temperature of the compost pile and the balance between aerobic and anaerobic conditions. Compacting can reduce $NH_3$ and to a certain extent $N_2O$ as well; $CH_4$ emissions are reduced in colder months, but may significantly increase in warmer months. |
| | | -30-70% $NH_3$ & $N_2O$ | Compacting can reduce the free air space by 20–60%, lowering N losses. |
| | Provide cover:<br>Use impermeable cover, i.e. tarpaulin, plastic | -60-90% $NH_3$ | Impermeable covers provide the anaerobic conditions necessary to prevent $NH_3$ losses. They are more expensive than other types of covers, but they have several advantages: they are durable and can be used to effectively capture methane produced by the manure storage units (e.g. heap, lagoons) to take it to combustion plants such as anaerobic digesters. |

| | | | |
|---|---|---|---|
| | Ensure cover is airtight<br>Use ventilation hoses | -54% $CH_4$ | Airtight covers do not provide favourable conditions for the aerobic microorganisms responsible for the production of $CH_4$.<br>When impermeable covers are used, it is necessary to make sure the cover is airtight to avoid gas leaks. Ideally, pipes or hoses should be used to redirect emissions to ventilation units. During storage of liquid manure, peaks of emissions can be registered when the pit is covered by a thick crust and cracks occur under pressure from gases underneath the surface. |
| | Use permeable cover, i.e. straw<br>Apply directly to land | -60-90% $NH_3$<br>+200% $N_2O$ | The addition of straw effectively reduces $NH_3$ losses from FYM heaps; however, $N_2O$ losses more than double. In the case of straw-based storage systems, it is advised to apply FYM directly to field and reduce the storage period to minimum, as storage accounts for ca. 85% of $N_2O$ emissions. |
| **ST21** | Monthly turning | -46% $N_2O$<br>-89.8% $CH_4$<br>+66% $NH_3$ | Monthly turning of the compost bed increases aeration, influencing the porosity and the structure of the compost pile. It also helps maintaining a more homogeneous temperature. Gaseous emissions due to anaerobic processes are reduced, while nitrate leaching could be significantly increased. |
| | Use impermeable cover, i.e. tarpaulin, plastic | -60-90% $NH_3$ | Impermeable covers provide the anaerobic conditions necessary to prevent $NH_3$ losses. They are more expensive than other types of covers, but they have several advantages: they are durable and can be used to effectively capture methane produced by the manure storage units (e.g. heap, lagoons) to take it to combustion plants such as anaerobic digesters. |
| | Ensure cover is airtight<br>Use ventilation hoses | -54% $CH_4$ | Airtight covers do not provide favourable conditions for the aerobic microorganisms responsible for the production of $CH_4$.<br>When impermeable covers are used, it is necessary to make sure the cover is airtight to avoid gas leaks. Ideally, pipes or hoses should be used to redirect emissions to ventilation units. During storage of liquid manure, peaks of emissions can be registered when the pit is covered by a thick crust and cracks occur under pressure from gases underneath the surface. |

| | | | |
|---|---|---|---|
| **ST22** | Monthly turning | -46% $N_2O$<br>-89.8% $CH_4$<br>+66% $NH_3$ | Monthly turning of the compost bed increases aeration, influencing the porosity and the structure of the compost pile. It also helps maintaining a more homogeneous temperature. Gaseous emissions due to anaerobic processes are reduced, while nitrate leaching could be significantly increased. |
| **ST23** | Monthly turning | -46% $N_2O$<br>-89.8% $CH_4$<br>+66% $NH_3$ | Monthly turning of the compost bed increases aeration, influencing the porosity and the structure of the compost pile. It also helps maintaining a more homogeneous temperature. Gaseous emissions due to anaerobic processes are reduced, while nitrate leaching could be significantly increased. |
| | Ensure cover is airtight<br>Use ventilation hoses | -54% $CH_4$ | Airtight covers do not provide favourable conditions for the aerobic microorganisms responsible for the production of $CH_4$.<br>When impermeable covers are used, it is necessary to make sure the cover is airtight to avoid gas leaks. Ideally, pipes or hoses should be used to redirect emissions to ventilation units. During storage of liquid manure, peaks of emissions can be registered when the pit is covered by a thick crust and cracks occur under pressure from gases underneath the surface. |
| **ST24** | Monthly turning | -46% $N_2O$<br>-89.8% $CH_4$<br>+66% $NH_3$ | Monthly turning of the compost bed increases aeration, influencing the porosity and the structure of the compost pile. It also helps maintaining a more homogeneous temperature. Gaseous emissions due to anaerobic processes are reduced, while nitrate leaching could be significantly increased. |
| | Provide cover:<br>Use impermeable cover, i.e. tarpaulin, plastic | -60-90% $NH_3$ | Impermeable covers provide the anaerobic conditions necessary to prevent $NH_3$ losses. They are more expensive than other types of covers, but they have several advantages: they are durable and can be used to effectively capture methane produced by the manure storage units (e.g. heap, lagoons) to take it to combustion plants such as anaerobic digesters. |

| | | | |
|---|---|---|---|
| **ST24 (cont'd)** | Ensure cover is airtight<br>Use ventilation hoses | -54% $CH_4$ | Airtight covers do not provide favourable conditions for the aerobic microorganisms responsible for the production of $CH_4$.<br>When impermeable covers are used, it is necessary to make sure the cover is airtight to avoid gas leaks. Ideally, pipes or hoses should be used to redirect emissions to ventilation units. During storage of liquid manure, peaks of emissions can be registered when the pit is covered by a thick crust and cracks occur under pressure from gases underneath the surface. |
| | Use permeable cover, i.e. straw, clay pebbles<br>Apply directly to land | -60-90% $NH_3$<br>+200% $N_2O$ | The addition of straw effectively reduces $NH_3$ losses from FYM heaps; however, $N_2O$ losses more than double. In the case of straw-based storage systems, it is advised to apply FYM directly to field and reduce the storage period to minimum, as storage accounts for ca. 85% of $N_2O$ emissions. |
| **ST25** | OK | | |
| **ST26** | Use additives, i.e. lactic acid, saccharose | -43% $NH_3$ | Use of additives combined with temperature of 4°C has greater effect on $NH_3$ volatilisation. |
| **ST27** | Reduce pH | -40% $CH_4$<br>N.A. (lower $NH_3$, $N_2O$) | $CH_4$ emissions are significantly reduced when slurry is uncovered and has a pH below 4.5-5.<br>The effect of acidification of slurry can vary:<br>pH < 6.0 reduces $CH_4$ and $N_2O$<br>pH < 5.0 reduces also $NH_3$ |
| **ST28** | Reduce pH | -40% $CH_4$<br>N.A. (lower $NH_3$, $N_2O$) | $CH_4$ emissions are significantly reduced when slurry is uncovered and has a pH below 4.5-5.<br>The effect of acidification of slurry can vary:<br>pH < 6.0 reduces $CH_4$ and $N_2O$<br>pH < 5.0 reduces also $NH_3$ |
| | Use additives, i.e. lactic acid, saccharose | -43% $NH_3$ | Use of additives combined with temperature of 4°C has greater effect on $NH_3$ volatilisation. |

| | | | |
|---|---|---|---|
| **ST29** | Reduce T˚ (shades, pipes) | Little to no $N_2O$ emissions | Very little $N_2O$ emissions are registered at temperatures were in the range of 5-25°C, e.g. when a surface crust if formed.<br>However, higher $NH_3$ losses are registered at 25°C. |
| | | N.A. (lower $CH_4$) | $CH_4$ emissions from slurry stored below 15- 20°C are lower than at 24°C. For instance, $CH_4$ emissions during the summer are about 20% higher than the annual average. This could be explained by the fact that in cold month, a surface crust can form and prevent the release of $CH_4$ and other gases. |
| **ST30** | Reduce T˚ (shades, pipes) | Little to no $N_2O$ emissions | Very little $N_2O$ emissions are registered at temperatures were in the range of 5-25°C, e.g. when a surface crust if formed.<br>However, higher $NH_3$ losses are registered at 25°C. |
| | | N.A. (lower $CH_4$) | $CH_4$ emissions from slurry stored below 15- 20°C are lower than at 24°C. For instance, $CH_4$ emissions during the summer are about 20% higher than the annual average. This could be explained by the fact that in cold month, a surface crust can form and prevent the release of $CH_4$ and other gases. |
| | Use additives, i.e. lactic acid, saccharose | -43% $NH_3$ | Use of additives combined with temperature of 4°C has greater effect on $NH_3$ volatilisation. |
| **ST31** | Reduce T˚ (shades, pipes) | Little to no $N_2O$ emissions | Very little $N_2O$ emissions are registered at temperatures were in the range of 5-25°C, e.g. when a surface crust if formed.<br>However, higher $NH_3$ losses are registered at 25°C. |
| | | N.A. (lower $CH_4$) | $CH_4$ emissions from slurry stored below 15- 20°C are lower than at 24°C. For instance, $CH_4$ emissions during the summer are about 20% higher than the annual average. This could be explained by the fact that in cold month, a surface crust can form and prevent the release of $CH_4$ and other gases. |
| | Reduce pH | -40% $CH_4$<br>N.A. (lower $NH_3$, $N_2O$) | $CH_4$ emissions are significantly reduced when slurry is uncovered and has a pH below 4.5-5.<br>The effect of acidification of slurry can vary:<br>pH < 6.0 reduces $CH_4$ and $N_2O$<br>pH < 5.0 reduces also $NH_3$ |

| | | | |
|---|---|---|---|
| **ST32** | Reduce T˚ (shades, pipes) | Little to no $N_2O$ emissions | Very little $N_2O$ emissions are registered at temperatures were in the range of 5-25°C, e.g. when a surface crust if formed.<br>However, higher $NH_3$ losses are registered at 25°C. |
| | | N.A. (lower $CH_4$) | $CH_4$ emissions from slurry stored below 15- 20°C are lower than at 24°C. For instance, $CH_4$ emissions during the summer are about 20% higher than the annual average. This could be explained by the fact that in cold month, a surface crust can form and prevent the release of $CH_4$ and other gases. |
| | Reduce pH | -40% $CH_4$<br>N.A. (lower $NH_3$, $N_2O$) | $CH_4$ emissions are significantly reduced when slurry is uncovered and has a pH below 4.5-5.<br>The effect of acidification of slurry can vary:<br>pH < 6.0 reduces $CH_4$ and $N_2O$<br>pH < 5.0 reduces also $NH_3$ |
| | Use additives, i.e. lactic acid, saccharose | -43% $NH_3$ | Use of additives combined with temperature of 4°C has greater effect on $NH_3$ volatilisation. |

## I.2 Sample reports

This section includes two samples of the type of report provided to farmers after each farm assessment i.e. initial report after the first visit and follow-up report after the second visit.

School
of
Agriculture

Royal
Agricultural
College

# An assessment of mitigation options for reducing greenhouse gas emissions at the farm level

Report prepared for
**Sample Farm**

Release date: 12/04/2012

Report prepared by: Sara Burbi
PhD Research - Royal Agricultural College
Stroud Road
Cirencester
Gloucestershire
GL7 6JS
Telephone: +44 (0) 1285 652531 ext. 2366
Fax: +44 (0) 6505 219235
Email: Sara.BURBI@student.rac.ac.uk
Internet: www.rac.ac.uk

Approved by: Dr Richard N Baines

# Executive Summary

Sample Farm follows a number of good agricultural practices, in particular regarding the dietary management of their dairy herd, housing and grazing and pasture management (Table 1 and Figure 1). We have identified areas of improvement in the manure management, notably the storage, treatment and subsequent application to field.

Sample Farm committed to regular carbon footprint assessments via the Cotswold Conservation Board, which ensures the efficacy and long-lasting effects of good agricultural practices on farm.

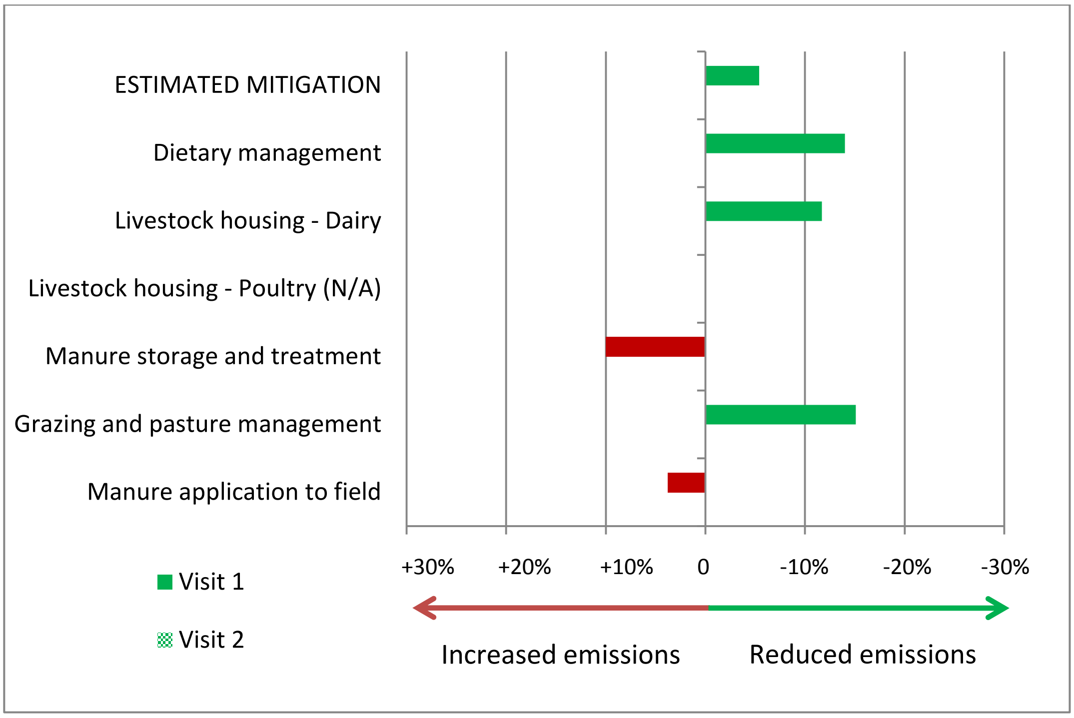
**Table 1.** Summary of farm management evaluation.

| | Strengths | Limitations |
|---|---|---|
| **General considerations** | • Recent carbon footprint assessment done by the Cotswold Conservation Board<br>• Very good dietary management<br>• Use of software and nutrition manual to formulate ration<br>• Regular cleaning of dairy unit | • Winter grazing (heifers) |
| **Manure management** | • Follows guidelines from DEFRA Fertiliser Manual (RB 209) and Code of Good Agricultural Practice<br>• Slurry stored in concrete pit | • Slurry storage surrounded by straw |
| **Soil management** | • Crops and pasture rotations<br>• Livestock rotations<br>• No overstocking<br>• Drainage system on heavier soils | • Winter grazing (heifers) |

### *Greenhouse gas mitigation*

The mitigation scores reported for each section have been obtained during the first visit of Sample Farm on 15/02/2012. Figure 1 highlights the sections where successful practices are adopted, as well as key areas for improvement, i.e. manure storage and treatment, and manure application to field. A second visit is proposed in 6 to 9 months' time where modification to greenhouse gas mitigation will be re-evaluated.

**Figure 1.** Summary of greenhouse gas mitigation results.




***Summary of recommendations for greenhouse gas mitigation***

- Sample Farm doesn't hold organic certification. However, it is effectively run as an organic farm. Dietary management and grazing and pasture management of the dairy herd are considered appropriate for the current size of the farm. Their impact on GHG emissions is positive, applying all mitigations options available at the moment on the farm.

- Current management is suggesting that no excess nitrogen is applied to field. We advise testing slurry used on field as fertiliser, to verify that NVZ restrictions are respected and ensure an appropriate, long-term management of fertiliser and effluent.

- Composting and regularly turning Farm Yard Manure before application to field will reduce nitrous oxide and methane emissions. Mixing with green waste should also be considered, as green waste retains more nitrogen in the soil, reducing both nitrates and nitrous oxide losses. Manure application in autumn should be avoided. Split applications should be considered later in the season or in spring instead. This will increase the efficiency of nitrogen uptake and reduce nitrous oxide emissions.

- Slurry stored outside in open air for up to 6 months before being applied to fields in autumn. The slurry is not covered, leaving a natural crust with variable thickness forming during the storage time. This situation usually reduces methane and ammonia emissions, whilst nitrous oxide emissions can be increased. The breaking of the crust would result in the opposite situation. We recommend monitoring the temperature of storage to ensure that nitrous oxide emissions are kept to their minimum level.

# Table of Contents

## Abbreviations

| | |
|---|---|
| BCS | Body Condition Score |
| C | Carbon |
| $CH_4$ | Methane |
| CFF | Climate Friendly Food carbon calculator |
| CLA CALM | Country Land & Business Association Carbon Accounting for Land Managers |
| $CO_2$ | Carbon dioxide |
| CP | Crude Protein |
| DEFRA | Department for Environment, Food and Rural Affairs |
| DM / DMI | Dry Matter / Dry Matter Intake |
| FYM | Farm Yard Manure |
| GE | Gross Energy |
| GHG | Greenhouse gases |
| LU | Live Unit |
| MAFF | Ministry of Agriculture, Fisheries and Food |
| N | Nitrogen |
| $N_2O$ | Nitrous oxide |
| $NH_3$ | Ammonia |
| $NO_x$ | Nitrogen oxides |
| NVZ | Nitrate Vulnerable Zone |
| RPA | Rural Payments Agency |
| $tCO_2eq$ | Tonnes of carbon dioxide equivalents |
| WFPS | Water Filled Pore Space |

# 1 Introduction

## 1.1 Terms of reference

This report is the result of an initial farm assessment carried out at Sample Farm on 15/02/2012 with the aim to identify the potential for improvement in order to reduce greenhouse gas emissions from livestock management practices. Recommendations are selected based on the interview carried out during the farm visit, using decision trees to identify the most appropriate solutions for Sample Farm.

## 1.2 Report layout

This report is structured as follow:-

| | |
|---|---|
| Section 1 | The **introduction** provides a brief explanation of the purpose of this document and of its layout. |
| Section 2 | **Farm assessment** and **recommendations** are listed for every aspect of farm management analysed during the farm assessment. Advice is given regarding which recommendation best suits the farm, in order to provide a personalised report based on the most recent scientific knowledge and information provided by DEFRA or other official sources. |
| Appendix I | This section reports the **farm assessment methodology** used and the detail of each farm practice evaluation. Appendix I is the result of the combination of an interview with the farm owner or manager, the use of a decision tree tool and that of a scoring system to identify potential for improvement in greenhouse gases mitigation. |
| Appendix II | This sections reports information regarding the **carbon footprint assessment** of the farm. |

# 2 Farm assessment and recommendations

## 2.1 Introduction

Sample Farm is a dairy and beef conventional farm, although many of the farm activities reflect organic farm management practices. The farm is situated within a Nitrate Vulnerable Zone (NVZ) and it has taken part in the Higher Level Stewardship scheme.

The size of the farm is 360 ha., of which 180 ha. are used as pasture, with long term ley and permanent grass, while the remaining 180 ha. is arable land, with barley, wheat and oilseed rape.

***Size of herd:*** around 350 animals; young stocks on pasture are 20 during the winter and 40-60 during the summer; male calves reared for beef.

Current farm practices were taken into consideration and were then divided in 5 categories, as follows:-

- Dietary management;
- Livestock housing;
- Manure storage and treatment;
- Grazing and pasture management;
- Manure application to field.

## 2.2 Dietary management

Current dietary management of dairy cattle at Sample Farm is appropriate for the size and type of farm. Rations are formulated following nutritional guidelines[1] and dedicated software is used. The impact of dietary management on GHG emissions is positive, applying all mitigations options available at the moment on the farm.

The recommendations listed in Table 2.1 aim at reducing greenhouse gas emissions from practices related with dietary management. They can be considered to further improve the current practices.

[1] National Research Council. "Front Matter." Nutrient Requirements of Dairy Cattle: Seventh Revised Edition, 2001. Washington, DC: The National Academies Press, 2001. 1. Print

**Table 2.1.** Guidelines to improve dietary management.

| Current management | Guidelines | Expected outcomes | Scientific or other evidence |
|---|---|---|---|
| The ration consists of grass silage to appetite and animals fed according to yield. The mixture is 1 part standard ley and 2 parts clover.<br>The ration is topped up with wheat and barley concentrate and rapeseed meal.<br>No supplementation is given.<br>The diet is formulated following the guidelines "Nutrient requirements for Dairy Cattle", using the software provided. | High fibre dried grains, i.e. beans, brewers' spent grain, are useful for animals with low energy requirements (e.g. dry cows, over-wintering beef) | -12% $CH_4$ | Generally speaking, concentrates provide low fibre and high energy compared to forage. They lower ruminal pH, reducing $CH_4$ emissions.<br><br>*Note:* Barley has more fibre compared to maize and wheat, hence its potential to reduce ruminal pH and $CH_4$ emissions is lower. It is better used in animals with low energy requirements. |
| (see above) | Grinding and pelleting forage and/or concentrate | -22-30% manure N | Grinding and pelleting feed, especially in pigs and poultry, increases feed digestibility, maximizing feed efficiency. |

## 2.3 Livestock housing

We observed good practices related to the cleaning and management of the farm housing units.

Housing at Sample Farm consists of a dairy unit with cubicles, a barn and a straw yard. Bedding in cubicles is sand over concrete floors and the area where slurry is collected is scraped 3 times a day.
The dairy unit is cleaned with high pressure water. The barn is cleaned daily and the straw yard is cleaned every two months. We estimate higher emissions originating from the straw yard, but given that the majority of animals are either on pasture or in the dairy unit, we estimate the overall impact of housing management is positive.

Table 2.2 lists recommendations to further improve current housing management practices.

**Table 2.2.** Guidelines to improve livestock housing management.

| Current management | Guidelines | Expected outcomes | Scientific or other evidence |
|---|---|---|---|
| Dairy unit with cubicles (sand) and slurry collection area (scraped 3 times a day). The barn cleaned daily.<br><br>Cleaning with high pressure water. | Flush with water and formalin | -50% $NH_3$ | Hard standing areas such as collection yards register very low to no $N_2O$ emissions, because the conditions are less favorable to the processes transforming ammonia and nitrates in nitrous oxide.<br><br>Washing regularly decreases $NH_3$ emissions rates, indirectly decreasing $N_2O$ emissions as well. |
| Straw yard cleaned every two months. | *(refer to table 2.3 for management of manure from straw yard)* | | |

## 2.4 Manure storage and treatment

Manure is stored on farm as slurry and as Farm Yard Manure (FYM).

FYM is collected from the straw yard, which is cleaned every 2 months. Table 2.3a and Table 2.3b list recommendations in order to reduce emissions from FYM storage.

Table 2.3c and Table 2.3d highlight recommendations related to slurry storage.

The slurry collected from the dairy unit is stored for about 6 months in a sloped pit with concrete floors. Concrete floors have a positive influence on GHG emissions, registering little to no $N_2O$ emissions. However, the pit is surrounded by straw. Even though a straw cover is not present, straw as a containment materiel can be inconsistent and varying in thickness. We cannot accurately estimate its impact in this particular case. Therefore, we report two situations that are expected to occur in similar slurry storage conditions. These are explained below:-

a. *Encrustation is prevented*. When the crust formation is prevented very little to no $N_2O$ emissions are registered. This is due to the aerobic conditions and lower temperature ensured by the mixing and breaking of the natural crust.

   The effect of encrustation of the surface of slurry or its cover is twofold: it increases $N_2O$ emissions but lowers ammonia $NH_3$ emissions.

b. *Natural crust*. When the natural crust is left intact, the proliferation of aerobic microorganisms that produce methane is reduced. A decrease in methane emissions is then registered. However, this same conditions influence the nitrogen losses, with a reduction of ammonia ($NH_3$) losses, but an increase in $N_2O$ emissions. An important factor is the temperature of the storage. In fact, In the case of a natural crust on slurry storage, very little $N_2O$ emissions are registered at temperatures in the range of 5-25°C.

   Moreover, the effectiveness of a natural crust can vary greatly depending on its thickness (i.e. influence of nitrogen losses) and durability. Therefore, nitrous oxide having a greater impact in terms of global warming potential, compared to methane, it is generally not advised to leave a natural crust form.

At Sample Farm, FYM from the straw yard is spread on arable fields in the autumn and ploughed in. Slurry is applied in spring on the rest of the land. Plans are underway to applied both FYM and slurry in the spring, which will possibly influence the length of storage, in particular during the warmer months. We advise monitoring the storage temperature when storage occurs, as well as preventing slurry encrustation during storage.

**Table 2.3a.** Guidelines to improve the management of manure storage and treatment.

| Current management | Guidelines | Expected outcomes | Scientific or other evidence |
|---|---|---|---|
| Manure from the straw yards is stored is an open air heap (Farm Yard Manure, FYM) outside of the livestock housing facilities. | Composting dry manure<br><br>Monthly turning of compost pile | Static composting:<br>-60% $NH_3$<br><br>-46% $N_2O$<br>-89.8% $CH_4$<br>+66% $NH_3$ | Static composting of the solid fraction, without turning or a cover, increases its dry matter (DM) content, consequently reducing $NH_3$ losses.<br><br>Monthly turning of the compost bed increases aeration, influencing the porosity and the structure of the compost pile. It also helps maintaining a more homogeneous temperature. Gaseous emissions due to anaerobic processes are reduced, while nitrate leaching could be increased. |
| (see above) | Addition of straw to compost pile | -32% $N_2O$<br>-45% $CH_4$ | Mixing solid manure with straw (1 : 1 ratio) can increase the Dry Matter content of the compost pile, influencing the C : N ratio, reducing $N_2O$ and $CH_4$ emissions. |
| (see above) | Addition of phosphogypsum to compost pile | -54% GHG<br>Composition:<br>Little to no $N_2O$ and 14% $CH_4$. | Phosphogypsum is a by-product of the fertiliser industry. It influences the pH of the compost pile and its sulphur content. The majority of gaseous losses are as $CO_2$ (lower Global Warming potential) and the end product has higher value as fertiliser depending on its use (unchanged N content, higher sulphur content). |
| (see above) | Addition of water to compost pile | -30-70% $NH_3$ & $N_2O$ | The addition of water can reduce the free air space by 20-60%, lowering N losses. |
| (see above) | Compacting | -90% $NH_3$<br>-30% $N_2O$<br>Lower $CH_4$ in colder months | Gaseous losses from manure can only be effectively reduced by controlling the temperature of the compost pile and the balance between aerobic and anaerobic conditions. Compacting reduces the free air space by 20–60%, thus reducing $NH_3$ losses and to a certain extent $N_2O$ emissions as well; $CH_4$ emissions are lower in colder months, but may increase in warmer months. |

**Table 2.3b.** Guidelines to improve the management of manure storage and treatment.

| Current management | Guidelines | Expected outcomes | Scientific or other evidence |
|---|---|---|---|
| The manure is left uncovered and unturned from collection till autumn, when it is applied to field. | Use impermeable cover, i.e. tarpaulin, plastic | -60-90% $NH_3$ | Impermeable covers provide the anaerobic conditions necessary to prevent $NH_3$ losses. They are more expensive than other types of covers, but they have several advantages: they are durable and can be used to effectively capture methane produced by the manure storage units (e.g. heap, lagoons) to take it to combustion plants such as anaerobic digesters. |
| (see above) | Ensure cover is airtight; use ventilation hoses | -54% $CH_4$ | Airtight covers do not provide favourable conditions for the aerobic microorganisms responsible for the production of $CH_4$.<br>When impermeable covers are used, it is necessary to make sure the cover is airtight to avoid gas leaks. Ideally, pipes or hoses should be used to redirect emissions to ventilation units. |
| (see above) | Apply directly to land<br><br>Use permeable cover i.e. straw, clay pebbles | Lower $N_2O$<br><br>-60-90% $NH_3$<br>+200% $N_2O$ | In the case of straw-based storage systems, it is advised to apply FYM directly to field and reduce the storage period to minimum, as storage accounts for ca. 85% of $N_2O$ emissions.<br><br>The addition of straw effectively reduces $NH_3$ losses from FYM heaps; however, $N_2O$ losses more than double. |

**Table 2.3c.** Guidelines to improve the management of manure storage and treatment.

| Current management | Guidelines | Expected outcomes | Scientific or other evidence |
|---|---|---|---|
| Slurry is stored in a concrete pit, surrounded by straw. | Slurry separation, i.e. screw-press | Cattle slurry (liquid / solid)<br>-2% / -72% $NH_3$<br>-22% / +4% $CO_2$<br>-22% / -80.5% $CH_4$<br><br>Little to no $N_2O$ emissions | Slurry separation, especially when combined with lower temperatures and uncovered conditions, can effectively reduce ammonia and methane emissions, in particular from the solid fraction. Storing fractions separately allows a better control over factors influencing emissions: temperature, water content, aeration, cover. In addition, separation can increase slurry storage capacity and both fractions will have a higher nutrient content. This is an advantage if slurry is used as fertiliser.<br><br>Storage of liquid fraction in anaerobic conditions doesn't promote nitrification ($NH_3$ to $NO_3$-) and therefore, denitrification rates are also reduced to a minimum. |

**Table 2.3d.** Guidelines to improve the management of manure storage and treatment.

| Current management | Guidelines | Expected outcomes | Scientific or other evidence |
|---|---|---|---|
| Length of storage: about 6 months, before being spread in autumn. | Prevent encrustation | Little to no $N_2O$ emissions | The effect of encrustation of the surface of slurry or its cover is twofold: it increases $N_2O$ emissions but lowers $NH_3$ emissions. To effectively reduce $N_2O$ emissions, a cover and additives can be used.<br>When the crust formation is prevented very little to no $N_2O$ emissions are registered. This is due to the aerobic conditions and lower temperature ensured by the mixing and breaking of the natural crust. |
| (see above) | Leave natural crust | -38% $CH_4$<br>-50% $NH_3$ | When the natural crust is left intact, the proliferation of aerobic microorganisms that produce methane is reduced. A decrease in methane emissions is then registered. However, this same conditions influence the nitrogen losses, with a reduction of ammonia ($NH_3$) losses, but an increase in $N_2O$ emissions.<br>Moreover, the effectiveness of a natural crust can vary greatly depending on its thickness (i.e. influence of nitrogen losses) and durability.<br><br>Therefore, nitrous oxide having a greater impact in terms of global warming potential, compared to methane, it is generally not advised to leave a natural crust form. |

## 2.5 Grazing and pasture management

The land available for pasture is 180 ha. of long-term ley with a clover mix and permanent grass. The farm adopts a rotational system between arable land and pasture.
Young stocks graze permanent grass, around 20 animals in the winter and up to 40-60 animals in the summer. Concrete pads are used in the feeding areas. Heifers are left on pasture during the winter months. However, there are plans to overwinter them from the end of November till mid-April. Therefore, only a small part of the 350 total animals on farm follow rotations on pasture.

The soil at Sample Farm can be classified as heavy (Cotswolds limestone, Fuller's earth). The current management of pasture is considered acceptable, but some improvements in grazing times could have a positive impact by reducing emissions in the colder and wetter months. Table 2.4 lists the recommendations for heavy soil management, in relation to current grazing and pasture management practices.

**Table 2.4.** Guidelines to improve soil management.

| Current management | Guidelines | Expected outcomes | Scientific or other evidence |
|---|---|---|---|
| About 20 young stocks graze permanent grass in the Summer. Heifers are left on pasture during the winter. Plans are underway to overwinter them from late November till mid-April. | Avoid grazing in colder, wetter months (Autumn, Winter) | -7-11% $N_2O$ (IPCC)<br>-40% $N_2O$ and $NO_3$ | $N_2O$ emissions are higher in wet conditions and from soils with higher moisture content.<br>Also, September has the most available grass cover (kg/DM) and intensive grazing during this period of time maximizes pasture performance. |
| A drainage system is in place in the fields with the heavier soil. | Use strip grazing system<br>*(minimise poaching)*<br><br>Avoid grazing on slopes<br>*(minimise runoff and animal treading)* | -27% $N_2O$ | Waterlogged soils have lower soil aeration, which promotes denitrification of nitrates, increasing $N_2O$ emissions.<br>Animal treading causes a temporary reduction in soil aeration and, secondly, reduced soil N utilisation prompted by reduced plant growth increases soil $NH_4$+-N and $NO_3$−-N availability. |
| | Apply nitrification inhibitors<br>*(experimental strategy)* | -70-80% $N_2O$ | Even whit different soil types and management, the use of a fine-particle suspension nitrification inhibitor (e.g. dicyandiamide, DCD) reduces the rate of ammonium ($NH_4$+) converted into nitrate ($NO_3$-), which then is converted into nitrous oxide ($N_2O$) by denitrification. The use of DCD then reduces nitrate leaching and gaseous losses as $N_2O$. |

## 2.6 Manure application to field

Slurry, FYM and fertiliser are applied to fields, following crops rotations. Considering the combination of fertiliser and organic manures, we recommend testing slurry for composition. This is to ensure compliance with NVZ regulations and to ensure that no excess nitrogen is applied to soils. We also recommend splitting applications on each field whenever possible, and avoiding application in autumn. Further details on recommendations are listed in Table 2.5 and aim at reducing greenhouse gas emissions from practices related with the application of manure to field, in particular emissions of nitrous oxide.

***Further information on manure application techniques:***

Nitrogen losses consist mostly of ammonia ($NH_3$) and nitrous oxide ($N_2O$). $N_2O$ emissions are higher when conditions promoting denitrification are present, i.e. heavy soil texture, high soil moisture content. Whilst $NH_3$ emissions, are usually reduced when the manure is not in contact with atmospheric oxygen for a prolonged time. However, emissions factors and reduction rates can vary greatly based on weather, soil type and manure treatment prior to application to soil. Indicatively, the deeper the slurry or manure is injected, the greater the reduction of $N_2O$ emissions. Surface deposition usually leads higher $NH_3$ emissions.

**Table 2.5.** Guidelines to improve the management of manure application to field.

| Current management | Guidelines | Expected outcomes | Scientific or other evidence |
|---|---|---|---|
| Manure is not tested for composition. Fertiliser is also used on farm. | Manure analysis *(yearly)* | -18% $N_2O$ | Ensure optimum fertiliser and effluent management to avoid application of excess nitrogen and review compliance with NVZ regulations. |
| Manure is applied untreated after 6 months storage on average. | Application mixed with green waste | -64% $N_2O$ | Green waste reduces $N_2O$ emissions by retaining N in the soil, consequently reducing both nitrates and mineral N content in the soil. A decrease in nitrates availability leads to lower denitrification and nitrification rates, reducing N losses. |
| Manure is applied in autumn, following crops rotations. | Avoid autumn applications | N/A | They should be avoided to prevent N overload, especially on pasture/fields with fertility building crops (e.g. legumes) and when the crop growth has slowed down from the winter. |
| Manure is applied in a single application. | Split applications | -30% $N_2O$ | Split applications increase the efficiency of the N uptake, considering a yearly fertiliser application rate. |
| Spreading of fertiliser and organic manure. | Ensure regular maintenance and calibration of machinery | N/A | Machinery kept in good condition and regularly calibrated allows to easily knowing the actual application rate of a given fertiliser. This ensures a more uniform application as well. |

# Appendix I - Farm assessment methodology

## I.1 Methodology

The visit touched 3 essential points:

(i) Farm visit to assess condition of housing, pasture and manure management.

(ii) Interview with the farm owner, Mr Sam Farmer. During the interview, a questionnaire has been used to record greenhouse gas mitigation strategies applied on farm. Practices are divided in categories to cover dietary management, livestock housing, manure storage and treatment, grazing and pasture management, and manure application to field.

(iii) In depth discussion over carbon accounting, farm management and changes in practices that could reduce the farm carbon footprint, while maintaining the business productivity.

The following reports have been used to assign a score to each farm practice and identify key areas for improvement.

## I.2 Results

### I.2.1 Keys

*Mitigation potential score:*

1 <10%
2 10-30%
3 >30%

*Farm management score:*

+ practice is adopted
- practice is not adopted
0 N/A, Not Applicable. Two possible situations:
  - The practice doesn't fit within the farm profile;
  - No official mitigation potential is available.

### I.2.2 Farm practices evaluation

**Table I.1.** Dietary management evaluation.

| Current practice | Score |
|---|---|
| **1. Improve feed conversion efficiency** | **0.8** |
| a. Use legumes in the ration | 2 |
| b. Use of maize-based concentrate | 0 |
| c. Use of wheat-based concentrate | 3 |
| d. Use of barley-based concentrate | 3 |
| e. Use of high fibre dried grains (e.g. beans) | -2 |
| f. Grinded / pelletized feedstuff (concentrate and/or forage) | -2 |
| **2. Reduced Crude Protein intake** | **2** |
| a. Use of legumes combined with cereal grains | 2 |
| b. Use of oilseed meals | 2 |
| **3. Supplementation** | **/** |
| a. Tannins (e.g. condensed tannins in plant extracts) | 0 |
| b. Saponins (e.g. corn, potato starch, wild rye concentrate, hay concentrate) | 0 |
| c. Fatty acids (e.g. whole cottonseed, sunflower, rapeseeds) | 0 |
| d. Oils (e.g. sunflower, canola, flaxseed, coconut) | 0 |
| **4. Accuracy of diet formulation (relative to different production stages)** | **/** |
| a. Use of Total Mixed Ratio system | 0 |
| b. Other | 0 |
| **BALANCED SCORE** | **1.4** |
| Total score | 2.8 |
| Number of sections | 2 |
| **ESTIMATED IMPACT Emissions mitigation** | **10-30%** |

**Figure I.1.** Estimated mitigation from dietary management.

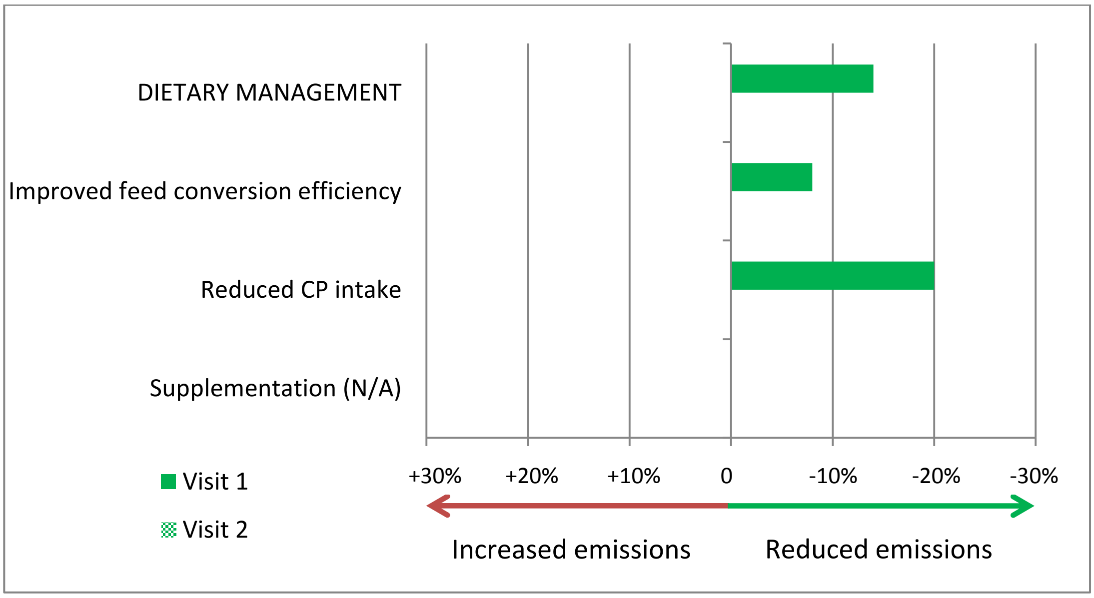
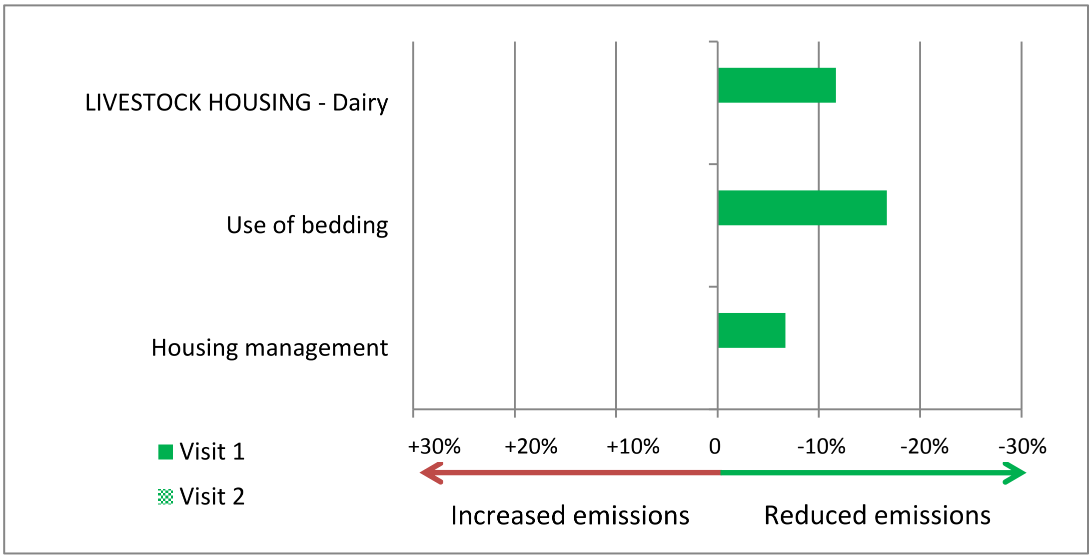


**Table I.2a.** Livestock housing evaluation – Dairy

| Current practice | Score |
|---|---|
| **1. Use of bedding** | **1.67** |
| a. Straw (ruminants) / straw flow system (pigs) | -1[2] |
| b. Deep Litter | 0 |
| c. Slurry based | 3 |
| d. Fully slatted floor | 0 |
| e. Partially slatted floors, grid floors | 0 |
| f. Concrete floor | 3 |
| g. Rubber mats | 0 |
| **2. Housing management** | **0.67** |
| a. Floor washed with water | 2 |
| b. Floor washed with water and formalin | 0 |
| c. Floor washed with water and other | 0 |
| d. Manure removed daily | 0 |
| e. Manure removed twice/day or more often | 3 |
| f. Manure removed at end of cycle (eg. 2-6 months beef/dairy, 12 weeks pigs) | -3 |
| **BALANCED SCORE** | **1.17** |
| Total score | 2.34 |
| Number of sections | 2 |
| **ESTIMATED IMPACT Emissions mitigation** | **10-30%** |

**Figure I.2.** Estimated mitigation from dairy housing.




[2] The use of bedding increases emissions, as opposed to bare concrete floors. For obvious reasons related also to animal welfare, bedding is used. The use of straw is estimated to lead to an increase of emissions by more than 30% (score -3). No official figure is available for sand bedding. We assign the score -1 following the precautionary principle.

**Table I.2b.** Livestock housing evaluation – Poultry (N/A)

| Current practice | Score |
|---|---|
| **1. Use of bedding** | **/** |
| a. Straw<br>b. Woodchips, wood shavings<br>c. Concrete floor<br>d. Grid floor | 0<br>0<br>0<br>0 |
| **2. Free range management** | **/** |
| a. Chicken coop with outdoor run<br>b. Rotations system<br>c. Yarding with other animals (* considered as mixed housing) | 0<br>0<br>0 |
| **3. Intensive units** | **/** |
| a. Outdoor run<br>b. Bedding: straw, woodchips, wood shavings<br>c. Bedding: straw or other, with zeolite<br>d. No bedding: grid floor<br>e. No bedding: concrete floor<br>f. Ventilation units<br>g. Trees or woodland nearby | 0<br>0<br>0<br>0<br>0<br>0<br>0 |
| **BALANCED SCORE** | **/** |
| Total score<br>Number of sections | |
| **ESTIMATED IMPACT**<br>**Emissions increase or mitigation** | **/** |

**Table I.3.** Manure storage and treatment evaluation.

| Current practice | Score |
|---|---|
| **1. Slurry storage** | **0** |
| a. Slurry separation | 0 |
| i. Use of liquid fraction in anaerobic digestion | 0 |
| 1. Aeration | 0 |
| 2. Addition of glycerol | 0 |
| ii. Solid fraction composted | 0 |
| b. Surface cover | |
| i. No cover, crust | -3 |
| ii. Surface layer of straw | 0 |
| iii. Fixed cover (e.g. wood, plastic, rubber) | 0 |
| c. Sloped or slatted floors | 3 |
| **2. Farm Yard Manure (FYM) heaps** | **-2** |
| a. Turned | -3 |
| b. Compacted | -3 |
| c. Composted | -3 |
| d. Addition of straw | -3 |
| e. Addition of water | 3 |
| f. Covered | |
| i. In livestock pens (e.g. straw over manure) | -3 |
| ii. Impermeable cover | 0 |
| iii. Airtight cover | 0 |
| iv. Straw cover or other permeable cover | 0 |
| g. Piping system or shades to reduce temperature | 0 |
| h. Use of additives to reduce pH | 0 |
| i. Use of other additives (e.g. saccharose) | 0 |
| **BALANCED SCORE** | **-1** |
| Total score | -2 |
| Number of sections | 2 |
| **ESTIMATED IMPACT** | |
| **Emissions increase** | **<10%** |

**Figure I.3.** Estimated mitigation from manure storage and treatment.

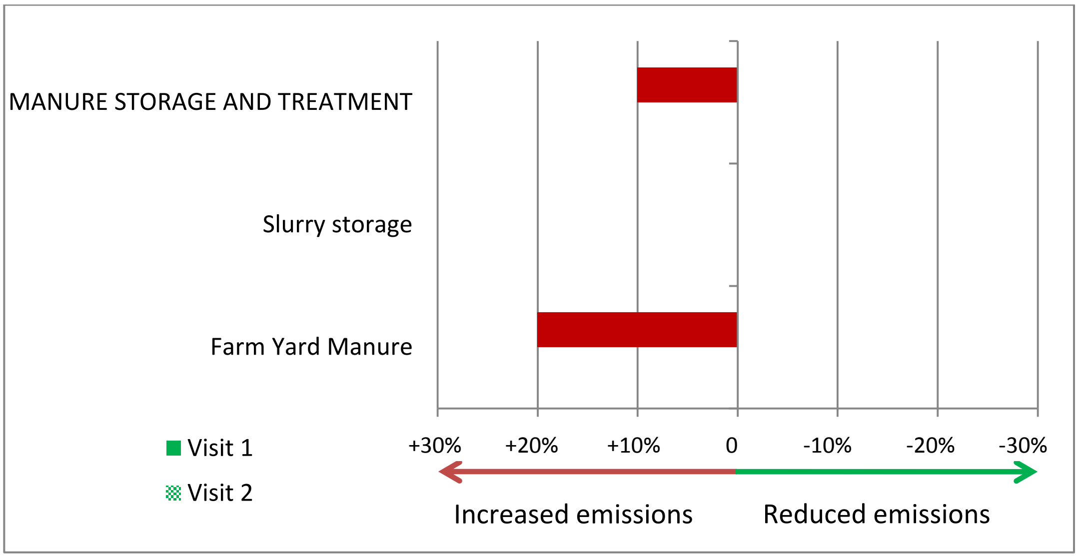


**Table I.4.** Grazing and pasture management evaluation.

| Current practice | Score |
|---|---|
| **1. Livestock management** | **1.2** |
| a. Avoid grazing on colder and wetter months | -3 |
| b. Use of stand-off / feed pads in colder and wetter months | 3 |
| c. Adopt Whole Farm Management approach | 1 |
| d. Adopt rotational grazing | 2 |
| e. Reduce grazing density / stocking rate | 3 |
| **2. Pasture management** | **2** |
| a. Legumes in pasture | 2 |
| b. Graze on younger pasture (more frequent grazing cycles) | 2 |
| **3. Soil management** | **1.33** |
| a. Drainage system | 3 |
| b. Strip grazing system, minimize poaching | -2 |
| c. Avoid grazing on slopes, minimize run off | 0 |
| d. Avoid compaction | 3 |
| e. Apply nitrification inhibitors | 0 |
| **BALANCED SCORE** | **1.51** |
| Total score | 4.53 |
| Number of sections | 3 |
| **ESTIMATED IMPACT Emissions mitigation** | **10-30%** |

**Figure I.4.** Estimated mitigation from grazing and pasture management.

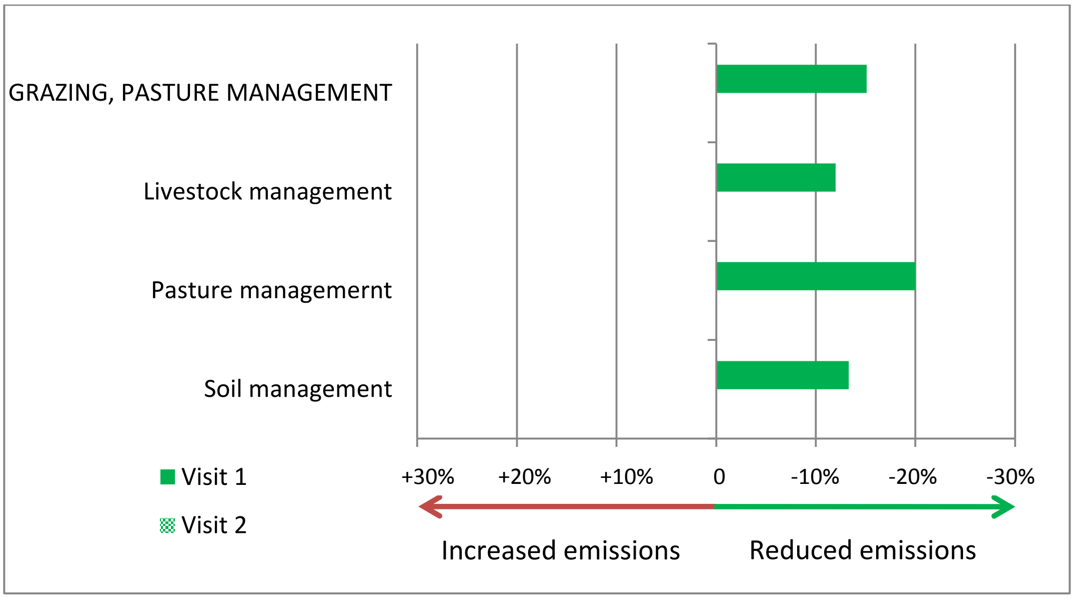
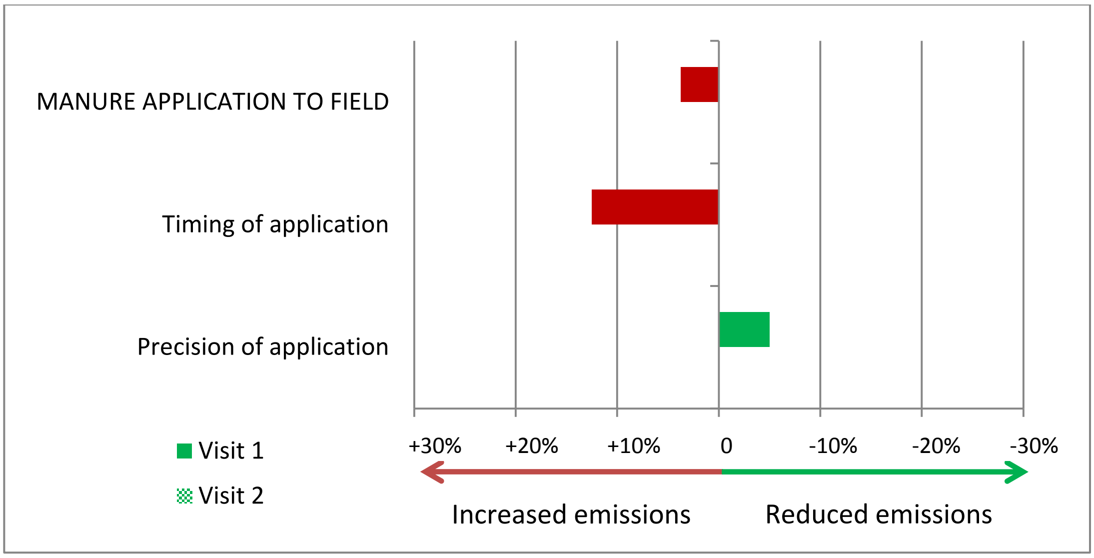


**Table I.5.** Manure application to field evaluation.

| Manure Application to Field | Score |
|---|---|
| **1. Timing of application** | **-1.25** |
| a. Application mixed with green waste | -3 |
| b. Split applications | -2 |
| c. Avoiding autumn applications | -3 |
| d. Avoiding application to soil with high moisture content | 3 |
| **2. Precision of application** | **0.5** |
| a. Manure analysis (e.g. yearly tests or more frequently) | -2 |
| b. Type of application | |
| i. Injection | 0 |
| ii. Shallow injection | 0 |
| iii. Surface application | 0 |
| iv. Incorporation | 0 |
| v. Spreading | 3 |
| c. Ensuring regular maintenance and calibration of machinery used for application | 0 |
| **BALANCED SCORE** | **-0.38** |
| Total score | -0.75 |
| Number of sections | 2 |
| **ESTIMATED IMPACT Emissions increase** | **<10%** |

**Figure I.5.** Estimated mitigation from manure application to field.



## I.3 Summary of findings

The scores reported for each section were obtained during the first visit of Sample Farm on 15/02/2012.They are summarised in Table I.6. Figure I.6 highlights the sections where successful practices are adopted, as well as key areas for improvement, i.e. manure storage and treatment, and manure application to field. A second visit is proposed in 6 to 9 months' time where modification to greenhouse gas mitigation will be re-evaluated.

**Table I.6.** Farm practices assessment summary table.

| **Farm practices assessment** | **Visit 1** 15/02/2012 | **Visit 2** To be scheduled |
|---|---|---|
| Dietary management | 1.4 | |
| Livestock housing – Dairy | 1.17 | |
| Livestock housing – Poultry | N/A | |
| Manure storage and treatment | -1 | |
| Grazing and pasture management | 1.51 | |
| Manure application to field | -0.38 | |

**Figure I.6.** Summary of mitigation results.

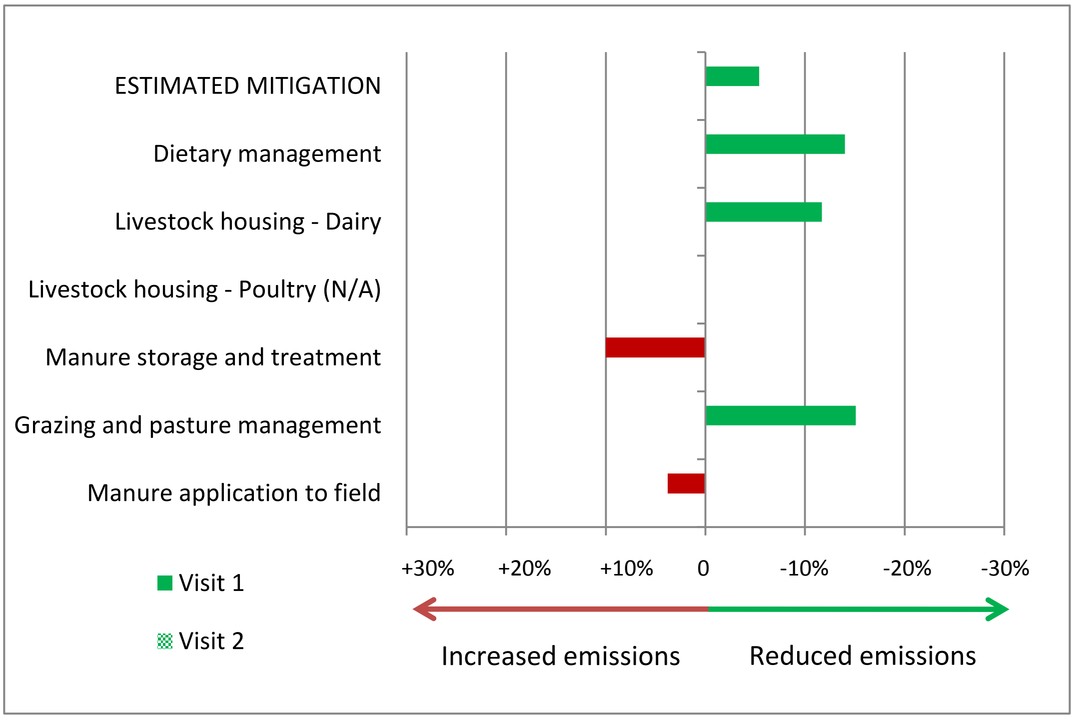


**Figure I.7.** Detail of mitigation results.

### *Farm management evaluation*

An evaluation of the current management has been completed, based on the farm visit and the interview of the farm owner. Three core sections have been taken into consideration: overall farm management, manure management and soil management. Strengths and limitations are summarised in Table I.7.

**Table I.7.** Summary of farm management evaluation.

| | **Strengths** | **Limitations** |
|---|---|---|
| **General considerations** | • Recent carbon footprint assessment done by the Cotswold Conservation Board<br>• Very good dietary management<br>• Use of software and nutrition manual to formulate ration<br>• Regular cleaning of dairy unit | • Winter grazing (heifers) |
| **Manure management** | • Follows guidelines from DEFRA Fertiliser Manual (RB 209) and Code of Good Agricultural Practice<br>• Slurry stored in concrete pit | • Slurry storage surrounded by straw |
| **Soil management** | • Crops and pasture rotations<br>• Livestock rotations<br>• No overstocking<br>• Drainage system on heavier soils | • Winter grazing (heifers) |

# Appendix II – Carbon footprint assessment

The carbon footprint of Sample Farm was recently assessed by the Cotswold Conservation Board and the report issued is enclosed at the end of this document. *(omitted)*

Below we report general information regarding greenhouse gas emissions and carbon calculators available for farmers.

## II.1 Types of emissions

The Greenhouse Gas Protocol[3] standard is commonly used to categorise an organisation's emissions into 3 groups or *scopes*, described as follows:-

- ***Scope 1 - Direct emissions:*** Direct emissions resulting from activities within the organisation's control. Includes on-site fuel combustion, manufacturing and process emissions, refrigerant losses and company vehicles.

- ***Scope 2 - Indirect emissions:*** electricity, heat or steam purchased and used by the organisation.

- ***Scope 3 - Indirect emissions:*** any other indirect emissions from sources not directly controlled by the organisation. Examples include: employee business travel, outsourced transportation, waste disposal, water usage and employee commuting.

Under the Greenhouse Gas Protocol, an organisation must include scope 1 and 2 emissions within its carbon footprint. There is broad discretion about which scope 3 emissions should be included in a business carbon footprint - for example; organisations often include waste disposed to landfill and employee business travel from scope 3.

We offer assistance in using the calculators and we recommend the usage of CLA CALM, but we also briefly report on a calculator available for organic farmers, should Sample Farm obtain organic certification in the future. The following paragraphs report links where to find further information and guidelines on how to use the calculators.

[3] The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard, revised edition. World Business Council for Sustainable Development and World Resources Institute.

## II.2 Country Land & Business Association Carbon Accounting for Land Managers (CALM)

CALM, Carbon Accounting for Land Managers, is the first, fully-free, business activity-based calculator showing the balance between annual emissions of the key Greenhouse Gases and carbon sequestration associated with the activities of land-based businesses.

The calculator measures emissions of carbon dioxide, methane and nitrous oxide from a land-management business and any carbon which is stored in soil and trees.

The emissions come from:-

- Energy and fuel use,
- Livestock,
- Cultivation and land-use change,
- The application of nitrogen fertilisers and lime.

These are balanced against carbon sequestration in soil and trees.

The calculator also assesses the impact of Environmental Stewardship options. This is calculated as a partial budget to estimate what would be saved following entry into Stewardship or what has been saved where the business is already in the scheme. It is not a measure of carbon capture (sequestration) but the annual change in emission pre and post entry, although some of the changes, such as new grass margins on arable land do sequester carbon (where they remain in place).

Further information and guidelines on how to use CLA CALM can be found here:
http://www.calm.cla.org.uk/index.php?section=help

## II.3 Climate Friendly Food Calculator (CFF)

The Climate Friendly Food calculator was developed to assist organic farmers in assessing their carbon footprint and improving farm efficiency, both from a financial and environmental point of view.

More information can be found here:
http://www.cffcarboncalculator.org.uk/calc_download

# RAC Report Feedback Form

This feedback form refers to the report "An assessment of mitigation options for reducing greenhouse gas emissions at the farm level".

The report is part of a pilot study to evaluate greenhouse gas mitigation strategies and their sustainability at the farm level.

We highly value farmers' views and input, as it will help us improve the delivery of information and the engagement with the farming community. Therefore we would like to ask you to fill out this form and send us your comments on the report.

Thanking you in advance.

Kind regards,

Sara Burbi
Royal Agricultural College
PhD Office
Stroud Road
Cirencester
Gloucestershire
GL7 6JS
01285 652531 ext.2366
Sara.BURBI@student.rac.ac.uk

School of Agriculture

Royal Agricultural College

## Questions

(Please, tick all that apply)

**1. How easy is it to find the information you are looking for on our report?**

- ☐ Extremely easy
- ☐ Very easy
- ☐ Moderately easy
- ☐ Slightly easy
- ☐ Not at all easy

Comments:

**2. How clear is the information available on our report?**

- ☐ Extremely clear
- ☐ Very clear
- ☐ Moderately clear
- ☐ Slightly clear
- ☐ Not at all clear

Comments:

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**3. How visually appealing is our report? (i.e. report layout, scoring system and charts)**

- ☐ Extremely appealing
- ☐ Very appealing
- ☐ Moderately appealing
- ☐ Slightly appealing
- ☐ Not at all appealing

Comments:

______________________________

______________________________

______________________________

______________________________

______________________________

______________________________

**4. Overall, are you satisfied with our report?**

- ☐ Extremely satisfied
- ☐ Very satisfied
- ☐ Moderately satisfied
- ☐ Slightly satisfied
- ☐ Not at all satisfied

Comments:

______________________________

______________________________

______________________________

______________________________

______________________________

______________________________

**5. How likely are you to follow any of the recommendations we provided in the report?**

- ☐ Extremely likely
- ☐ Very likely
- ☐ Moderately likely
- ☐ Slightly likely
- ☐ Not at all likely

Comments:

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

**6. Contact details:**

Please note that your contact information will not be disclosed, at any time.

Name ______________________________________________

Business ______________________________________________

Address ______________________________________________

City/Town ______________________________________________

County ______________________________________________

Post Code ______________________________________________

Email Address ______________________________________________

Phone Number ______________________________________________

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# An assessment of mitigation options for reducing greenhouse gas emissions at the farm level

Follow Up

Report prepared for

**Sample Farm**

Release date: 03/12/2012

Report prepared by: Sara Burbi
PhD Research - Royal Agricultural College
Stroud Road
Cirencester
Gloucestershire
GL7 6JS
Telephone: +44 (0) 1285 652531 ext. 2366
Fax: +44 (0) 6505 219235
Email: Sara.BURBI@student.rac.ac.uk
Internet: www.rac.ac.uk

Approved by: Dr Richard N Baines

## Executive Summary

An evaluation of the current management has been completed, based on two farm visits and interviews of the farm owner. Three core sections have been taken into consideration: overall farm management, manure management and soil management. Strengths and limitations are summarised in Table 1.

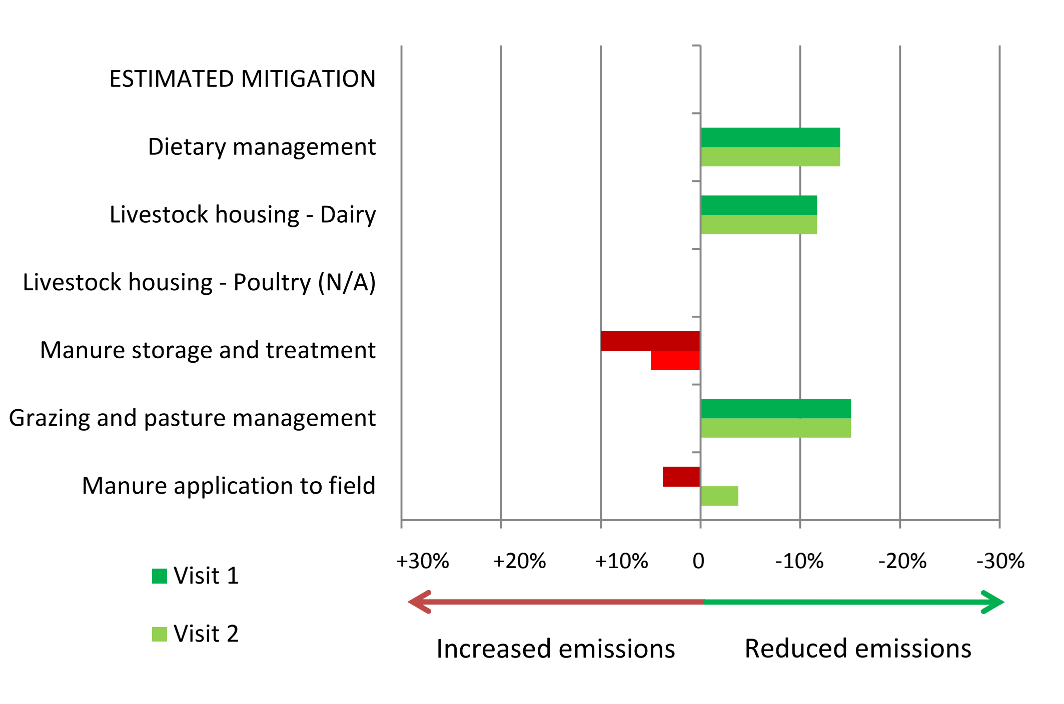
**Table 1.** Summary of farm management evaluation.

| | Strengths | Limitations |
|---|---|---|
| **General considerations** | • Recent carbon footprint assessment done by the Cotswold Conservation Board<br>• Very good dietary management<br>• Use of software and nutrition manual to formulate ration<br>• Regular cleaning of dairy unit | • Winter grazing (heifers) |
| **Manure management** | • Follows guidelines from DEFRA Fertiliser Manual (RB 209) and Code of Good Agricultural Practice<br>• Monthly turning of compost pile | • Slurry storage surrounded by straw |
| **Soil management** | • Crops and pasture rotations<br>• Livestock rotations<br>• No overstocking<br>• Drainage system on heavier soils<br>• Manure applications in spring instead of autumn | • Winter grazing (heifers) |

### *Greenhouse gas mitigation*

The mitigation scores reported for each section have been obtained during the visits of Sample Farm on 15/02/2012 and on 22/10/2012. Figure 1 highlights the sections where successful practices are adopted, as well as key areas for improvement.

**Figure 1.** Summary of greenhouse gas mitigation results.




***Summary of greenhouse gas mitigation***

- Following up on the initial farm assessment, dietary management and grazing and pasture management of the dairy herd are considered appropriate for the current size of the farm. Their impact on GHG emissions is positive, applying all mitigations options available at the moment on the farm. Improved ryegrass silage utilisation is being considered at the moment, depending on the results from silage quality analysis.

- Current management is suggesting that no excess nitrogen is applied to field. We advise testing slurry used on field as fertiliser, to verify that NVZ restrictions are respected and ensure an appropriate, long-term management of fertiliser and effluent.

- Improvements in the manure management have been observed. Farm Yard Manure is now regularly turned before application to field. Manure application in autumn is now avoided. Split applications are not considered at the moment due to the land area to cover and the relatively small amount of manure to apply.

- We consider the recent changes in manure management to have a positive effect on the overall impact of the farm in terms of GHG emissions.

# Table of Contents

## Abbreviations

| | |
|---|---|
| BCS | Body Condition Score |
| C | Carbon |
| $CH_4$ | Methane |
| CFF | Climate Friendly Food carbon calculator |
| CLA CALM | Country Land & Business Association Carbon Accounting for Land Managers |
| $CO_2$ | Carbon dioxide |
| CP | Crude Protein |
| DEFRA | Department for Environment, Food and Rural Affairs |
| DM / DMI | Dry Matter / Dry Matter Intake |
| FYM | Farm Yard Manure |
| GE | Gross Energy |
| GHG | Greenhouse gases |
| LU | Live Unit |
| MAFF | Ministry of Agriculture, Fisheries and Food |
| N | Nitrogen |
| $N_2O$ | Nitrous oxide |
| $NH_3$ | Ammonia |
| $NO_x$ | Nitrogen oxides |
| NVZ | Nitrate Vulnerable Zone |
| RPA | Rural Payments Agency |
| $tCO_2eq$ | Tonnes of carbon dioxide equivalents |
| WFPS | Water Filled Pore Space |

# 1 Introduction

## 1.1 Terms of reference

This report features the follow up on the results obtained from a farm assessment carried out at Sample Farm on 15/02/2012 with the aim to identify the potential for improvement in order to reduce greenhouse gas emissions from livestock management practices. A second visit was carried out on 22/10/2012 to evaluate any changes in the farm management.

## 1.2 Report layout

This report is structured as follow:-

| | |
|---|---|
| Section 1 | The **introduction** provides a brief explanation of the purpose of this document and of its layout. |
| Section 2 | In this section, the implementation of the recommendations provided 6-9 months prior the visit is analysed to obtain a detailed **farm management evaluation** to assess the progress towards the targets chosen by the farm manager or owner. |
| Appendix I | This section reports the **farm assessment methodology** used and the detail of each farm practice evaluation. Appendix I is the result of the combination of an interview with the farm owner or manager, the use of a decision tree tool and that of a scoring system to identify potential for improvement in greenhouse gases mitigation. |

# 2 Farm management evaluation

## 2.1 Introduction

Sample Farm is a dairy and beef conventional farm, although many of the farm activities reflect organic farm management practices. The farm is situated within a Nitrate Vulnerable Zone (NVZ) and it has taken part in the Higher Level Stewardship scheme.

The size of the farm is 360 ha., of which 180 ha. are used as pasture, with long term ley and permanent grass, while the remaining 180 ha. is arable land, with barley, wheat and oilseed rape.

***Size of herd:*** around 350 animals; young stocks on pasture are 20 during the winter and 40-60 during the summer; male calves reared for beef.

The report issued on 12/04/2012 identified a series of recommendations in the following categories of farm practices:-

- Dietary management;
- Livestock housing;
- Manure storage and treatment;
- Grazing and pasture management;
- Manure application to field.

This report is a follow up that summarizes changes and recommendations for future consideration.

## 2.2 Follow up results

**Table 2.1.** Follow up on dietary management.

| Previous management | Report 1 Recommendations | Expected outcomes | Changes in management | New management options |
|---|---|---|---|---|
| The ration consists of grass silage to appetite and animals fed according to yield. The mixture is 1 part standard ley and 2 parts clover.<br>The ration is topped up with wheat and barley concentrate and rapeseed meal.<br>No supplementation is given.<br>The diet is formulated following the guidelines “Nutrient requirements for Dairy Cattle”, using the software provided. | High fibre dried grains, i.e. beans, brewers’ spent grain, are useful for animals with low energy requirements (e.g. dry cows, over-wintering beef) | -12% $CH_4$ | At the moment of the visit, samples of ryegrass silage were being taken to analyse their composition. Ryegrass allowing 3-4 cuts a year, as opposed to the 2-3 cuts of clover, ryegrass silage quality has to be tested before introducing it in the ration. | - |
| (see above) | Grinding and pelleting forage and/or concentrate | -22-30% manure N | None. | As the farm is currently focusing on improving silage quality, introducing grinded or pelleted forage and/or concentrate could be considered in the future, where it fits within the dietary requirements of the various stages of production. |

**Table 2.2.** Follow up on livestock housing management.

| Previous management | Report 1 Recommendations | Expected outcomes | Changes in management | New management options |
|---|---|---|---|---|
| Dairy unit with cubicles (sand) and slurry collection area (scraped 3 times a day). The barn cleaned daily.<br><br>Cleaning with high pressure water. | Flush with water and formalin | -50% $NH_3$ | None. | Using formalin with water to clean the units is considered a further improvement to current livestock housing management. At the moment, we consider this practice optional. |
| Straw yard cleaned every two months. | *(refer to table 2.3 for management of manure from straw yard)* | | - | - |

**Table 2.3a.** Follow up on the management of manure storage and treatment.

| Previous management | Report 1 Recommendations | Expected outcomes | Changes in management | New management options |
|---|---|---|---|---|
| Manure from the straw yards is stored is an open air heap (Farm Yard Manure, FYM) outside of the livestock housing facilities. | Composting dry manure<br><br>Monthly turning of compost pile | Static composting:<br>-60% $NH_3$<br><br>-46% $N_2O$<br>-89.8% $CH_4$<br>+66% $NH_3$ | Monthly turning of the compost pile. | - |
| (see above) | Addition of straw to compost pile | -32% $N_2O$<br>-45% $CH_4$ | None. | Large amounts of straw in the FYM coming from the straw yard. At the moment, adding more straw is not considered, given the financial implications. |
| (see above) | Addition of phosphogypsum to compost pile | -54% GHG<br>Composition: Little to no $N_2O$ and 14% $CH_4$. | None. | Not considered at the moment, given the financial implications and the fact that improved compost mixing practices have been introduced recently. |
| (see above) | Addition of water to compost pile | -30-70% $NH_3$ & $N_2O$ | None. | Not considered at the moment, given that improved compost mixing practices have been introduced recently. |
| (see above) | Compacting | -90% $NH_3$<br>-30% $N_2O$<br>Lower $CH_4$ in colder months | None. | Not considered at the moment, given that improved compost mixing practices have been introduced recently. |

**Table 2.3b.** Follow up on the management of manure storage and treatment.

| Previous management | Report 1 Recommendations | Expected outcomes | Changes in management | New management options |
|---|---|---|---|---|
| The manure is left uncovered and unturned from collection till autumn, when it is applied to field. | Use impermeable cover, i.e. tarpaulin, plastic | -60-90% $NH_3$ | None. | Not considered at the moment, given that improved compost mixing practices have been introduced recently. |
| (see above) | Ensure cover is airtight; use ventilation hoses | -54% $CH_4$ | Considered the possibility of installing pipes under the manure storage system to generate electricity from the heat produced by the storage system. At the moment this option is not viable and it would involve such changes and building works that this solution cannot be implemented. | - |
| (see above) | Apply directly to land<br><br>Use permeable cover i.e. straw, clay pebbles | Lower $N_2O$<br><br>-60-90% $NH_3$<br>+200% $N_2O$ | None. | Not considered at the moment, given that improved composting practices have been introduced recently. |
| Slurry is stored in a concrete pit, surrounded by straw. | Slurry separation, i.e. screw-press | Cattle slurry (liquid / solid)<br>-2%/-72% $NH_3$<br>-22%/+4% $CO_2$<br>-22%/-80.5%$CH_4$<br><br>Little to no $N_2O$ emissions | None. | Not considered at the moment. The total amount of manure makes slurry separation by screw press not viable for the size of the farm. |

**Table 2.3c.** Follow up on the management of manure storage and treatment.

| Previous management | Report 1 Recommendations | Expected outcomes | Changes in management | New management options |
|---|---|---|---|---|
| Length of storage: about 6 months, before being spread in autumn. | Prevent encrustation | Little to no $N_2O$ emissions | None. | - |
| (see above) | Leave natural crust | -38% $CH_4$<br>-50% $NH_3$ | Adopted at the moment. | - |

**Table 2.4.** Follow up on soil management.

| Previous management | Report 1 Recommendations | Expected outcomes | Changes in management | New management options |
|---|---|---|---|---|
| About 20 young stocks graze permanent grass in the Summer.<br>Heifers are left on pasture during the winter. Plans are underway to overwinter them from late November till mid-April. | Avoid grazing in colder, wetter months (Autumn, Winter) | -7-11% $N_2O$ (IPCC)<br>-40% $N_2O$ and $NO_3$ | Young stocks are 33. | Housing of all livestock is not doable at the moment. Therefore we recommend focusing on optimising grazing and pasture management. |
| A drainage system is in place in the fields with the heavier soil. | Use strip grazing system *(minimise poaching)*<br><br>Avoid grazing on slopes *(minimise runoff and animal treading)* | -27% $N_2O$ | Rotational grazing is adopted. Strip grazing is not considered at the moment due to landscape and fields layout.<br>Animals graze each field until grass is too low; then move on to another field. Times of rotation may vary. | - |
| | Apply nitrification inhibitors *(experimental strategy)* | -70-80% $N_2O$ | - | - |

**Table 2.5.** Follow up on the management of manure application to field.

| Previous management | Report 1 Recommendations | Expected outcomes | Changes in management | New management options |
|---|---|---|---|---|
| Manure is not tested for composition.<br>Fertiliser is also used on farm. | Manure analysis *(yearly)* | -18% $N_2O$ | None. | Manure analysis is recommended to ensure optimum nutrient management. |
| Manure is applied untreated after 6 months storage on average. | Application mixed with green waste | -64% $N_2O$ | None. No access to green waste at the moment. This practice is therefore not cost-effective as of now. | - |
| Manure is applied in autumn, following crops rotations. | Avoid autumn applications | N/A | Manure is never applied on permanent grassland. Application to field depends on weather conditions. | Ensure minimum manure quantities are applied in autumn, only if necessary. |
| Manure is applied in a single application. | Split applications | -30% $N_2O$ | None. | Not enough area to cover; therefore this option is not considered at the moment. |
| Spreading of fertiliser and organic manure. | Ensure regular maintenance and calibration of machinery | N/A | - | - |

# Appendix I - Farm assessment methodology

## I.1 Methodology

The visit touched 3 essential points:

(i) Farm visit to assess condition of housing, pasture and manure management.

(ii) Interview with the farm owner, Mr Sam Farmer. During the interview, a questionnaire has been used to record greenhouse gas mitigation strategies applied on farm. Practices are divided in categories to cover dietary management, livestock housing, manure storage and treatment, grazing and pasture management, and manure application to field.

(iii) In depth discussion over carbon accounting, farm management and changes in practices that could reduce the farm carbon footprint, while maintaining the business productivity.

The following reports have been used to assign a score to each farm practice, identify key areas for improvement and follow up on the progress in 6-9 months' time.

## I.2 Results

### I.2.1 Keys

*Mitigation potential score:*

1 <10%
2 10-30%
3 >30%

*Farm management score:*

+ practice is adopted
- practice is not adopted
0 N/A, Not Applicable. Two possible situations:
  - The practice doesn't fit within the farm profile;
  - No official mitigation potential is available.

### I.2.2 Farm practices evaluation

**Table I.1.** Dietary management evaluation.

| Current practice | Visit 1 | Visit 2 |
|---|---|---|
| **1. Improve feed conversion efficiency** | **0.8** | **0.8** |
| a. Use legumes in the ration | 2 | 2 |
| b. Use of maize-based concentrate | 0 | 0 |
| c. Use of wheat-based concentrate | 3 | 3 |
| d. Use of barley-based concentrate | 3 | 3 |
| e. Use of high fibre dried grains (e.g. beans) | -2 | -2 |
| f. Grinded / pelletized feedstuff (concentrate and/or forage) | -2 | -2 |
| **2. Reduced Crude Protein intake** | **2** | **2** |
| a. Use of legumes combined with cereal grains | 2 | 2 |
| b. Use of oilseed meals | 2 | 2 |
| **3. Supplementation** | **/** | **/** |
| a. Tannins (e.g. condensed tannins in plant extracts) | 0 | 0 |
| b. Saponins (e.g. corn, potato starch, wild rye concentrate, hay concentrate) | 0 | 0 |
| c. Fatty acids (e.g. whole cottonseed, sunflower, rapeseeds) | 0 | 0 |
| d. Oils (e.g. sunflower, canola, flaxseed, coconut) | 0 | 0 |
| **4. Accuracy of diet formulation (relative to different production stages)** | **/** | **/** |
| a. Use of Total Mixed Ratio system | 0 | 0 |
| b. Other | 0 | 0 |
| **BALANCED SCORE** | **1.4** | **1.4** |
| Total score | 2.8 | 2.8 |
| Number of sections | 2 | 2 |
| **ESTIMATED IMPACT Emissions mitigation** | **10-30%** | **10-30%** |

**Figure I.1.** Estimated mitigation from dietary management.

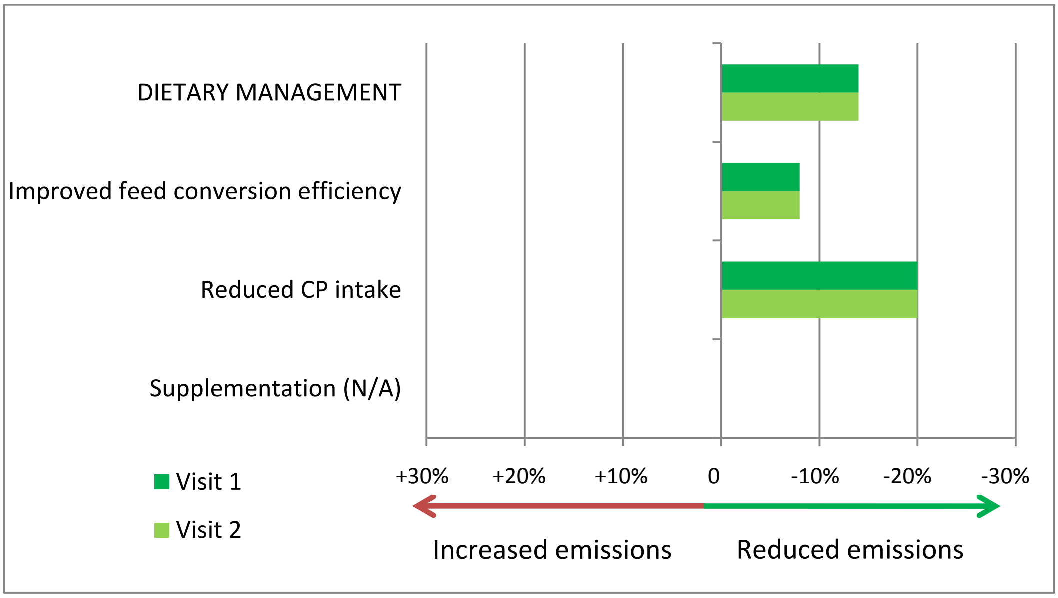
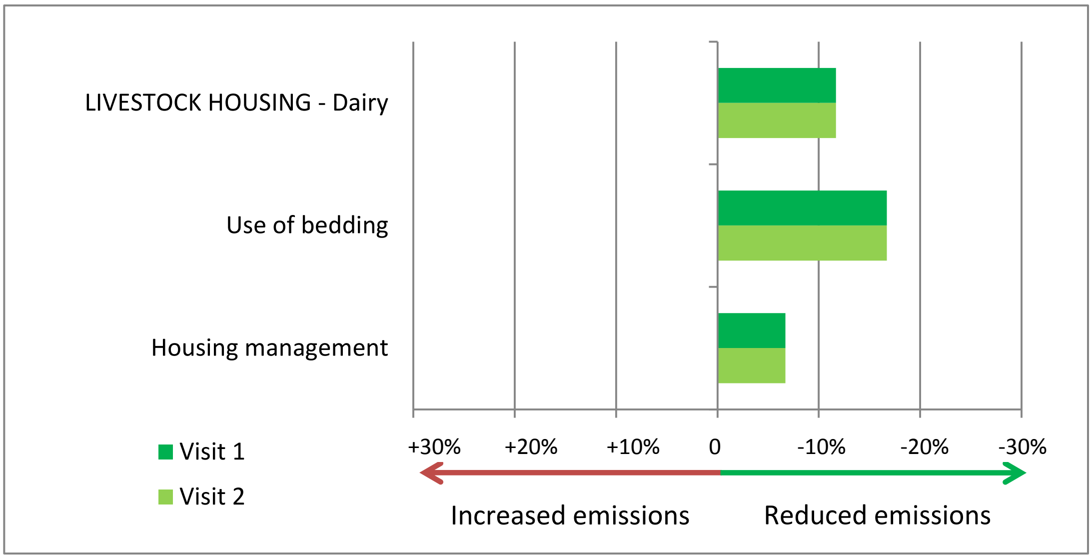


**Table I.2a.** Livestock housing evaluation – Dairy

| Current practice | Visit 1 | Visit 2 |
|---|---|---|
| **1. Use of bedding** | **1.67** | **1.67** |
| a. Straw (ruminants) / straw flow system (pigs) | -1[1] | -1[1] |
| b. Deep Litter | 0 | 0 |
| c. Slurry based | 3 | 3 |
| d. Fully slatted floor | 0 | 0 |
| e. Partially slatted floors, grid floors | 0 | 0 |
| f. Concrete floor | 3 | 3 |
| g. Rubber mats | 0 | 0 |
| **2. Housing management** | **0.67** | **0.67** |
| a. Floor washed with water | 2 | 2 |
| b. Floor washed with water and formalin | 0 | 0 |
| c. Floor washed with water and other | 0 | 0 |
| d. Manure removed daily | 0 | 0 |
| e. Manure removed twice/day or more often | 3 | 3 |
| f. Manure removed at end of cycle (eg. 2-6 months beef/dairy, 12 weeks pigs) | -3 | -3 |
| **BALANCED SCORE** | **1.17** | **1.17** |
| Total score | 2.34 | 2.34 |
| Number of sections | 2 | 2 |
| **ESTIMATED IMPACT Emissions mitigation** | **10-30%** | **10-30%** |

**Figure I.2.** Estimated mitigation from dairy housing.




[1] The use of bedding increases emissions, as opposed to bare concrete floors. For obvious reasons related also to animal welfare, bedding is used. The use of straw is estimated to lead to an increase of emissions by more than 30% (score -3). No official figure is available for sand bedding. We assign the score -1 following the precautionary principle.

**Table I.2b.** Livestock housing evaluation – Poultry (N/A)

| Current practice | Visit 1 | Visit 2 |
|---|---|---|
| **1. Use of bedding** | / | / |
| a. Straw | 0 | 0 |
| b. Woodchips, wood shavings | 0 | 0 |
| c. Concrete floor | 0 | 0 |
| d. Grid floor | 0 | 0 |
| **2. Free range management** | / | / |
| a. Chicken coop with outdoor run | 0 | 0 |
| b. Rotations system | 0 | 0 |
| c. Yarding with other animals (* considered as mixed housing) | 0 | 0 |
| **3. Intensive units** | / | / |
| a. Outdoor run | 0 | 0 |
| b. Bedding: straw, woodchips, wood shavings | 0 | 0 |
| c. Bedding: straw or other, with zeolite | 0 | 0 |
| d. No bedding: grid floor | 0 | 0 |
| e. No bedding: concrete floor | 0 | 0 |
| f. Ventilation units | 0 | 0 |
| g. Trees or woodland nearby | 0 | 0 |
| **BALANCED SCORE** | / | / |
| Total score<br>Number of sections | | |
| **ESTIMATED IMPACT**<br>**Emissions increase or mitigation** | / | / |

**Table I.3.** Manure storage and treatment evaluation.

| Current practice | Visit 1 | Visit 2 |
|---|---|---|
| **1. Slurry storage** | **0** | **0** |
| a. Slurry separation | 0 | 0 |
| i. Use of liquid fraction in anaerobic digestion | 0 | 0 |
| 1. Aeration | 0 | 0 |
| 2. Addition of glycerol | 0 | 0 |
| ii. Solid fraction composted | 0 | 0 |
| b. Surface cover | | |
| i. No cover, crust | -3 | -3 |
| ii. Surface layer of straw | 0 | 0 |
| iii. Fixed cover (e.g. wood, plastic, rubber) | 0 | 0 |
| c. Sloped or slatted floors | 3 | 3 |
| **2. Farm Yard Manure (FYM) heaps** | **-2** | **-1** |
| a. Turned | -3 | 3 |
| b. Compacted | -3 | -3 |
| c. Composted | -3 | -3 |
| d. Addition of straw | -3 | -3 |
| e. Addition of water | 3 | 3 |
| f. Covered | | |
| i. In livestock pens (e.g. straw over manure) | -3 | -3 |
| ii. Impermeable cover | 0 | 0 |
| iii. Airtight cover | 0 | 0 |
| iv. Straw cover or other permeable cover | 0 | 0 |
| g. Piping system or shades to reduce temperature | 0 | 0 |
| h. Use of additives to reduce pH | 0 | 0 |
| i. Use of other additives (e.g. saccharose) | 0 | 0 |
| **BALANCED SCORE** | **-1** | **-0.5** |
| Total score | -2 | -1 |
| Number of sections | 2 | 2 |
| **ESTIMATED IMPACT Emissions increase** | **<10%** | **<10%** |

**Figure I.3.** Estimated mitigation from manure storage and treatment.

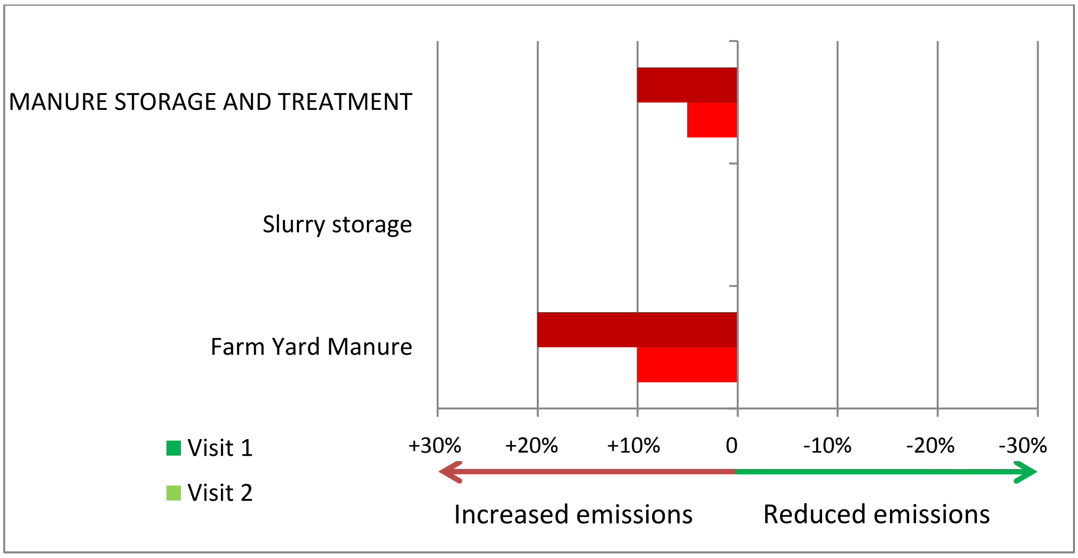


**Table I.4.** Grazing and pasture management evaluation.

| Current practice | Visit 1 | Visit 2 |
|---|---|---|
| **1. Livestock management** | **1.2** | **1.2** |
| a. Avoid grazing on colder and wetter months | -3 | -3 |
| b. Use of stand-off / feed pads in colder and wetter months | 3 | 3 |
| c. Adopt Whole Farm Management approach | 1 | 1 |
| d. Adopt rotational grazing | 2 | 2 |
| e. Reduce grazing density / stocking rate | 3 | 3 |
| **2. Pasture management** | **2** | **2** |
| a. Legumes in pasture | 2 | 2 |
| b. Graze on younger pasture (more frequent grazing cycles) | 2 | 2 |
| **3. Soil management** | **1.33** | **1.33** |
| a. Drainage system | 3 | 3 |
| b. Strip grazing system, minimize poaching | -2 | -2 |
| c. Avoid grazing on slopes, minimize run off | 0 | 0 |
| d. Avoid compaction | 3 | 3 |
| e. Apply nitrification inhibitors | 0 | 0 |
| **BALANCED SCORE** | **1.51** | **1.51** |
| Total score | 4.53 | 4.53 |
| Number of sections | 3 | 3 |
| **ESTIMATED IMPACT Emissions mitigation** | **10-30%** | **10-30%** |

**Figure I.4.** Estimated mitigation from grazing and pasture management.

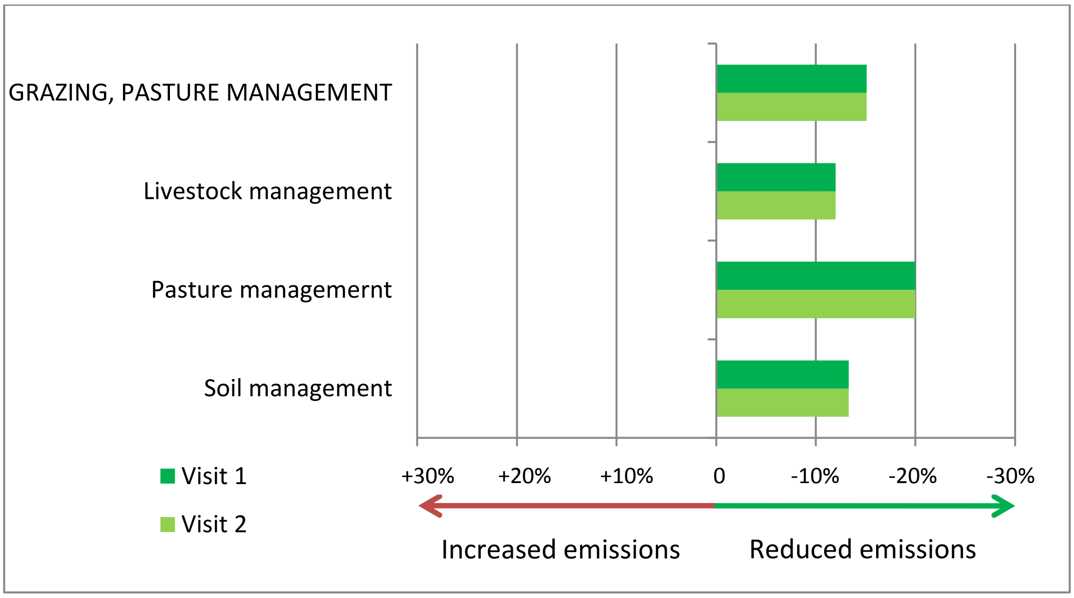
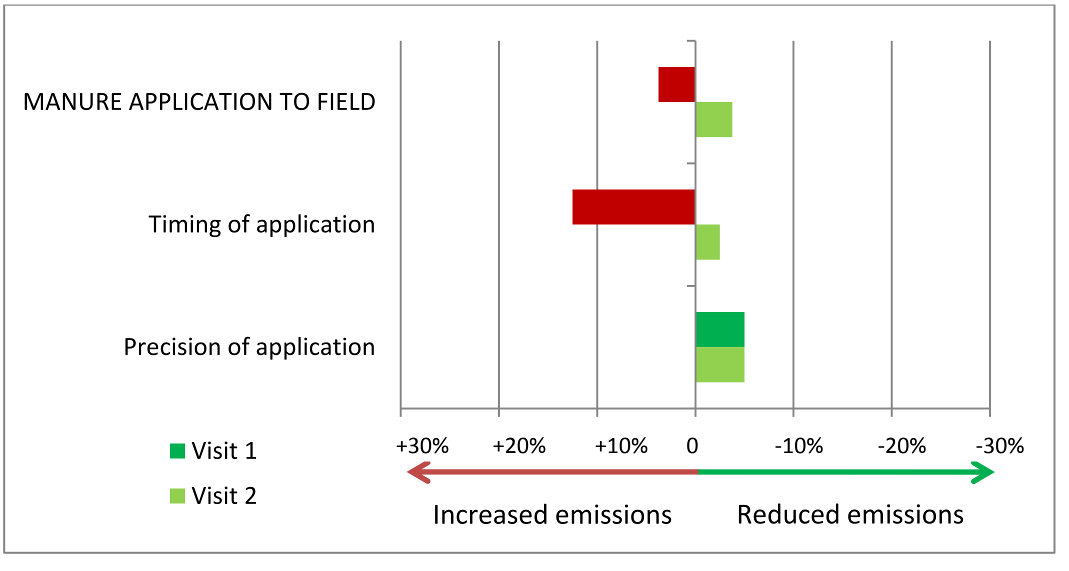


**Table I.5.** Manure application to field evaluation.

| Current practice | Visit 1 | Visit 2 |
|---|---|---|
| **1. Timing of application** | **-1.25** | **0.25** |
| a. Application mixed with green waste | -3 | -3 |
| b. Split applications | -2 | -2 |
| c. Avoiding autumn applications | -3 | 3 |
| d. Avoiding application to soil with high moisture content | 3 | 3 |
| **2. Precision of application** | **0.5** | **0.5** |
| a. Manure analysis (e.g. yearly tests or more frequently) | -2 | -2 |
| b. Type of application | | |
| i. Injection | 0 | 0 |
| ii. Shallow injection | 0 | 0 |
| iii. Surface application | 0 | 0 |
| iv. Incorporation | 0 | 0 |
| v. Spreading | 3 | 3 |
| c. Ensuring regular maintenance and calibration of machinery used for application | 0 | 0 |
| **BALANCED SCORE** | **-0.38** | **0.38** |
| Total score | -0.75 | 0.75 |
| Number of sections | 2 | 2 |
| **ESTIMATED IMPACT** *Emissions mitigation* | **<10%** | ***<10%*** |

**Figure I.5.** Estimated mitigation from manure application to field.



## I.3 Summary of findings

The scores reported for each section were obtained during the visits of Sample Farm on 15/02/2012 and on 22/10/2012.They are summarised in Table I.6. Figure I.6 highlights the sections where successful practices are adopted, as well as key areas for improvement.

**Table I.6.** Farm practices assessment summary table.

| Farm practices assessment | Visit 1 15/02/2012 | Visit 2 28/09/2012 |
|---|---|---|
| Dietary management | 1.4 | 1.4 |
| Livestock housing – Dairy | 1.17 | 1.17 |
| Livestock housing – Poultry | N/A | N/A |
| Manure storage and treatment | -1 | -0.5 |
| Grazing and pasture management | 1.51 | 1.51 |
| Manure application to field | -0.38 | 0.38 |

**Figure I.6.** Summary of mitigation results.

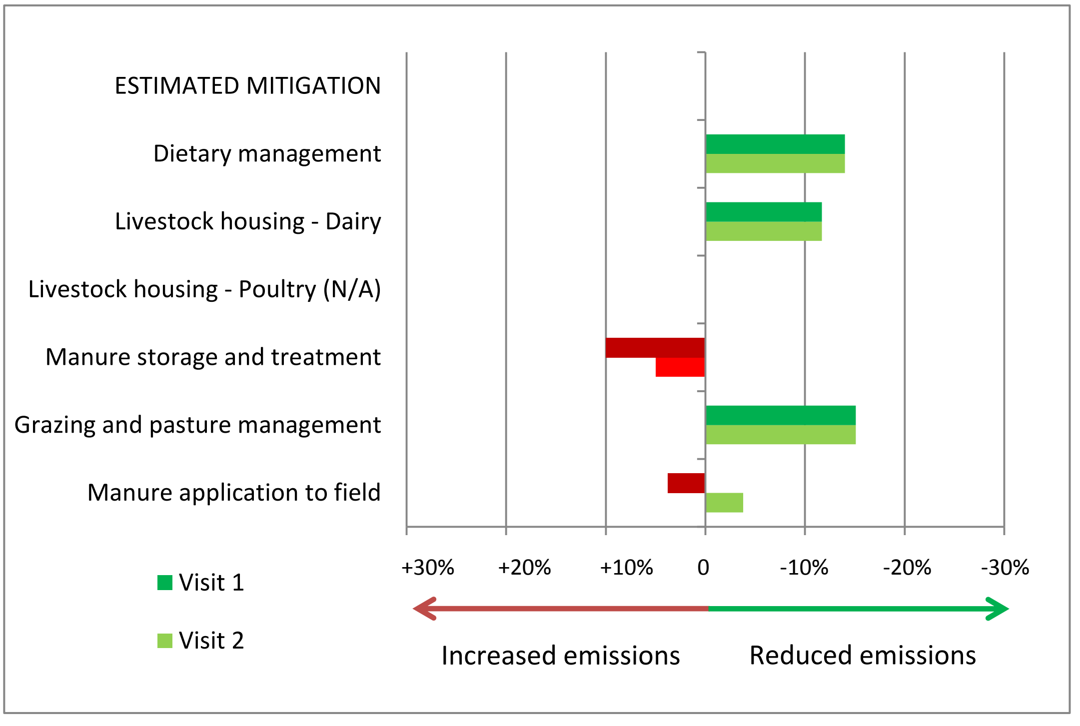
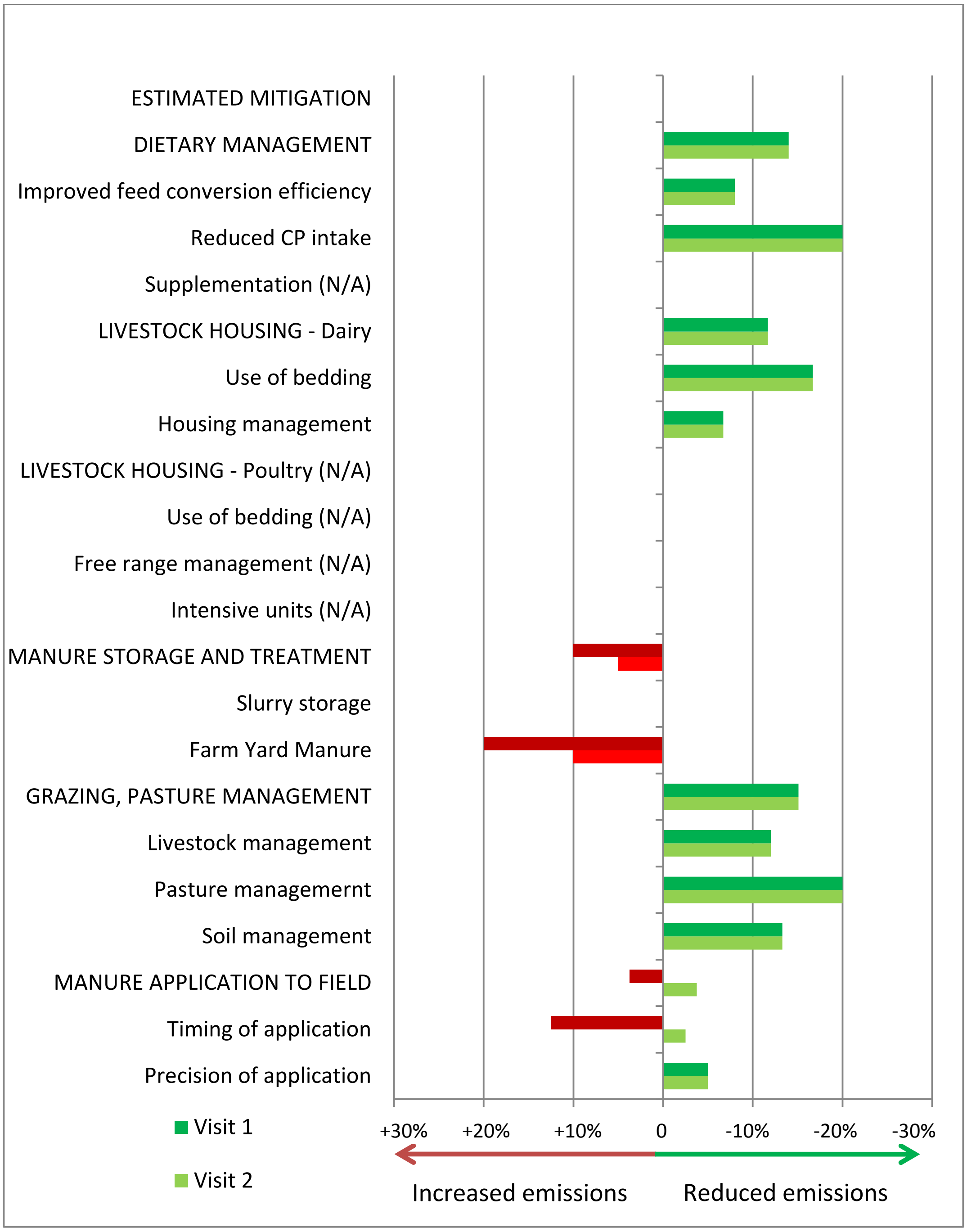


**Figure I.7.** Detail of mitigation results.



### *Farm management evaluation*

An evaluation of the current management has been completed, based on the farm visit and the interview of the farm owner. Three core sections have been taken into consideration: overall farm management, manure management and soil management. Strengths and limitations are summarised in Table I.7.

**Table I.7.** Summary of farm management evaluation.

| | **Strengths** | **Limitations** |
|---|---|---|
| **General considerations** | • Recent carbon footprint assessment done by the Cotswold Conservation Board<br>• Very good dietary management<br>• Use of software and nutrition manual to formulate ration<br>• Regular cleaning of dairy unit | • Winter grazing (heifers) |
| **Manure management** | • Follows guidelines from DEFRA Fertiliser Manual (RB 209) and Code of Good Agricultural Practice<br>• Monthly turning of compost pile | • Slurry storage surrounded by straw |
| **Soil management** | • Crops and pasture rotations<br>• Livestock rotations<br>• No overstocking<br>• Drainage system on heavier soils<br>• Manure applications in spring instead of autumn | • Winter grazing (heifers) |

## I.3 Questionnaire on farmers' attitudes and perceptions of GHG emission mitigation

A questionnaire on decision-making was presented to farmers. The questionnaire included 17 factors divided in 5 sections: political (P), economic (E), social (S), technological (T) and environmental (En). During the interview, farmers were given a copy of the questionnaire for the record.

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# Farmers' engagement feedback questionnaire

Dear Farmer,

Thank you for agreeing to complete the attached survey.

The data collected will provide useful information on farmers' attitudes to climate change and the reduction of greenhouse gas emissions from livestock farms. The information will be used to evaluate the factors involved in your decision-making and to assess their impact at the farm level. A series of possible factors are grouped in 5 categories: political, economic, social, technological and environmental.

The questionnaire will require approximately 15-20 minutes to complete. Please follow the instructions provided below. Do not hesitate to contact me with any questions or comments you may have about this survey.

In order to ensure that all information will remain confidential, please **do not** include your name. **Please return** the completed questionnaire **before November 30th, 2012** using the pre-stamped envelope provided.

Many thanks.

Sincerely,

Sara Burbi

---

**Instructions**

*Right-hand column:* For each factor, please tick the following:-

- **Yes +**. The factor is taken into account during the decision-making process and it influences the implementation of the resolution taken.
  *e.g. There is trust in official reports and information given by the government, and its recommendations are followed.*
- **Yes -**. The factor is taken into account during the decision-making process, but the factor does not affect the implementation of the resolution taken.
  *e.g. There is no trust in official reports and information given by the government, and its recommendations are questioned and/or not followed.*
- **No.** The factor is not taken into account during the decision-making process.
  *e.g. Decisions are taken without considering official reports and information given by the government.*
- **Sector.** Sectors represent types of farm practices. Please tick all sectors that apply.

*Left-hand column:* Please use the blank space to write any additional comments.

Sara Burbi – PhD Research Office – sara.burbi@rac.ac.uk – Tel.: 01285 652531 ext. 2366 / 07503 224061
The Royal Agricultural College, Stroud Road, Cirencester, Gloucestershire, GL7 6JS, England

# Farmers' engagement feedback questionnaire

## Group 1. Political. In making decisions, the following does / does not influence me?

| | | |
|---|---|---|
| P1. | Trust in official reports<br>i.e. government (DEFRA, Environment Agency) | ☐ Yes + ☐ No<br>☐ Yes - |
| | | Sector:<br>☐ Dietary Management<br>☐ Livestock Housing<br>☐ Manure Storage and Treatment<br>☐ Grazing and Pasture Management<br>☐ Manure Application to Field |
| P2. | Trust in source of recommendations (institution)<br>i.e. research centres, universities, associations | ☐ Yes + ☐ No<br>☐ Yes - |
| | | Sector:<br>☐ Dietary Management<br>☐ Livestock Housing<br>☐ Manure Storage and Treatment<br>☐ Grazing and Pasture Management<br>☐ Manure Application to Field |
| P3. | Support in integrating environmental schemes (i.e. ELS, OELS, HLS) and greenhouse gas emissions reduction | ☐ Yes + ☐ No<br>☐ Yes - |
| | | Sector:<br>☐ Dietary Management<br>☐ Livestock Housing<br>☐ Manure Storage and Treatment<br>☐ Grazing and Pasture Management<br>☐ Manure Application to Field |
| P4. | The level of bureaucracy linked to obtaining grants | ☐ Yes + ☐ No<br>☐ Yes - |
| | | Sector:<br>☐ Dietary Management<br>☐ Livestock Housing<br>☐ Manure Storage and Treatment<br>☐ Grazing and Pasture Management<br>☐ Manure Application to Field |

**Group 2. Economic. In making decisions, the following does / does not influence me?**

| | | |
|---|---|---|
| E1. | Financial constraint, i.e. limited budget | ☐ Yes + ☐ No<br>☐ Yes - |
| | | Sector:<br>☐ Dietary Management<br>☐ Livestock Housing<br>☐ Manure Storage and Treatment<br>☐ Grazing and Pasture Management<br>☐ Manure Application to Field |
| E2. | Current management is profitable already | ☐ Yes + ☐ No<br>☐ Yes - |
| | | Sector:<br>☐ Dietary Management<br>☐ Livestock Housing<br>☐ Manure Storage and Treatment<br>☐ Grazing and Pasture Management<br>☐ Manure Application to Field |
| E3. | External support for budget and farm management matters | ☐ Yes + ☐ No<br>☐ Yes - |
| | | Sector:<br>☐ Dietary Management<br>☐ Livestock Housing<br>☐ Manure Storage and Treatment<br>☐ Grazing and Pasture Management<br>☐ Manure Application to Field |
| E4. | Cost of agricultural consultants | ☐ Yes + ☐ No<br>☐ Yes - |
| | | Sector:<br>☐ Dietary Management<br>☐ Livestock Housing<br>☐ Manure Storage and Treatment<br>☐ Grazing and Pasture Management<br>☐ Manure Application to Field |

| | | |
|---|---|---|
| E5. | Labour force availability | ☐ Yes + ☐ No<br>☐ Yes - |
| | | Sector:<br>☐ Dietary Management<br>☐ Livestock Housing<br>☐ Manure Storage and Treatment<br>☐ Grazing and Pasture Management<br>☐ Manure Application to Field |

**Group 3. Social. In making decisions, the following does / does not influence me?**

| | | |
|---|---|---|
| S1. | Trust in source of recommendations (individual)<br>i.e. the person conducting the study | ☐ Yes + ☐ No<br>☐ Yes - |
| | | Sector:<br>☐ Dietary Management<br>☐ Livestock Housing<br>☐ Manure Storage and Treatment<br>☐ Grazing and Pasture Management<br>☐ Manure Application to Field |
| S2. | Community support | ☐ Yes + ☐ No<br>☐ Yes - |
| | | Sector:<br>☐ Dietary Management<br>☐ Livestock Housing<br>☐ Manure Storage and Treatment<br>☐ Grazing and Pasture Management<br>☐ Manure Application to Field |

| | | |
|---|---|---|
| S3. | Previous bad experiences<br>i.e. consultants, community actions, interest groups | ☐ Yes + ☐ No<br>☐ Yes - |
| | | Sector:<br>☐ Dietary Management<br>☐ Livestock Housing<br>☐ Manure Storage and Treatment<br>☐ Grazing and Pasture Management<br>☐ Manure Application to Field |

**Group 4. Technological. In making decisions, the following does / does not influence me?**

| | | |
|---|---|---|
| T1. | Trust in scientific basis of greenhouse gas emissions reduction strategies | ☐ Yes + ☐ No<br>☐ Yes - |
| | | Sector:<br>☐ Dietary Management<br>☐ Livestock Housing<br>☐ Manure Storage and Treatment<br>☐ Grazing and Pasture Management<br>☐ Manure Application to Field |
| T2. | Trust in assessment tools currently available<br>i.e. carbon accounting tools | ☐ Yes + ☐ No<br>☐ Yes - |
| | | Sector:<br>☐ Dietary Management<br>☐ Livestock Housing<br>☐ Manure Storage and Treatment<br>☐ Grazing and Pasture Management<br>☐ Manure Application to Field |

| T3. | User-friendliness of assessment tools | ☐ Yes + ☐ No<br>☐ Yes - |
|---|---|---|
| | | Sector:<br>☐ Dietary Management<br>☐ Livestock Housing<br>☐ Manure Storage and Treatment<br>☐ Grazing and Pasture Management<br>☐ Manure Application to Field |

**Group 5. Environmental. In making decisions, the following does / does not influence me?**

| En1. | Interest in conservation and environmental matters | ☐ Yes + ☐ No<br>☐ Yes - |
|---|---|---|
| | | Sector:<br>☐ Dietary Management<br>☐ Livestock Housing<br>☐ Manure Storage and Treatment<br>☐ Grazing and Pasture Management<br>☐ Manure Application to Field |
| En2. | Renewable energy more important greenhouse gas emissions reduction | ☐ Yes + ☐ No<br>☐ Yes - |
| | | Sector:<br>☐ Dietary Management<br>☐ Livestock Housing<br>☐ Manure Storage and Treatment<br>☐ Grazing and Pasture Management<br>☐ Manure Application to Field |

**Thank you for taking time to complete this form.**

**Please return to the Royal Agricultural College, PhD Research Office using the pre-stamped envelope provided.**

# Appendix II

# European Network

# Appendix II . European Network

All throughout the PhD, meetings with internationally known scientists were organised in order to validate specific aspects of the study (Table II.1). The author also attended a series of events, listed in Table II.2.

Table II.1 List of meetings with European scientists and their contribution to the study.

| Date | Name | Affiliation | Themes discussed | Contribution to the study |
|---|---|---|---|---|
| **04/02/2011** | Dr Theun Vellinga | Wageningen University, Netherlands | Farm assessment; Farmers' perceptions of climate change | Issues in carbon accounting; Value of farmers' perceptions of climate change and their potential influence on uptake of climate change mitigation and adaptation measures |
| **11/04/2011** | Prof Sven G. Sommer<br>Prof H. Wenzel<br>Dr L. Hamelin | Syddansk Universitet, University of Southern Denmark<br><br>Danish Ministry of Environment Odense, Denmark | Quantitative studies on GHG emissions from manure | Challenges in assessing emissions; Issues related to Life Cycle Analysis; Issues related to the uncertainty in quantifying emissions from a large number of different systems |
| **23-24/05/2011** | Prof Lena Rodhe<br>Dr Erik Sindhöj<br>Agnes Willén<br><br>Prof Jan Bertilsson<br>Rebecca Danielsson<br>Mikaela Patel<br>Dr Lotta Levén<br>Dr Johnny Ascue | JTI - Institutet för jordbruks- & miljöteknik, Swedish Institute of Agricultural & Environmental Engineering<br><br>SLU - Sveriges lantbruksuniversitet, Swedish University of Agricultural Sciences Uppsala, Sweden | Impact of livestock husbandry; Methane production from cattle; Biogas production. | Relation between enteric and manure methane production, GHG measurements from manure in storage and after field application; Mitigation strategies for enteric emission from cattle and monitoring techniques; Reactor feeding, gas sampling |
| **11/03/2013** | Prof Uno Svedin<br>Prof Carole L. Crumley<br>Mike Jones | Stockholm Resilience Institute, Sweden<br><br>Centrum för biologisk mångfald, CBM, Swedish Biodiversity Centre, SLU - Sveriges lantbruksuniversitet, Swedish University of Agricultural Sciences and Uppsala University Uppsala, Sweden | Farmers networks; Multidisciplinary studies; Agro-ecosystems resilience | Farmer engagement strategies; Validation of methodology to integrate scientific knowledge and farmers historical knowledge; Achieving resilience through working with farmers as co-researchers. |
| **12/03/2013** | Dr Ö. Bodin | Stockholm Resilience Institute, Sweden | Social Networks Analysis | Impact of social dynamics on participatory studies |

Table II.2 List of events attended and author's contribution.

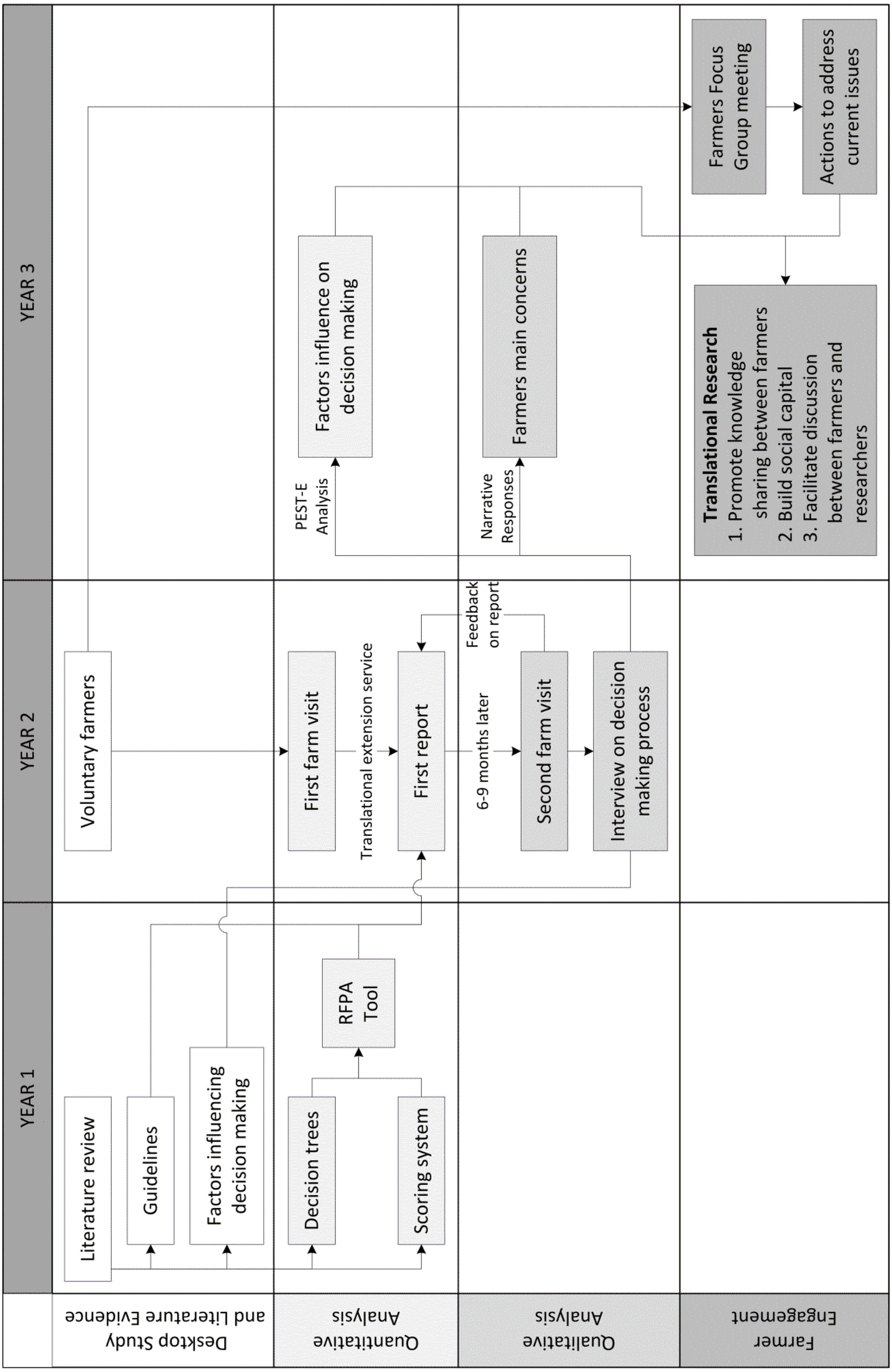
| Date | Event | Location | Author's contribution |
|---|---|---|---|
| **28/02/2011 – 01/03/2011** | Conference<br>"Reducing greenhouse gas emissions from agriculture" | Royal Society<br>London, United Kingdom | |
| **06/09/2011** | 3rd CREST Research Symposium | GuildHE<br>Woburn House<br>London, United Kingdom | Speaker |
| **20-21/09/2011** | British Grassland Society 10th Research Conference | Belfast<br>Northern Ireland<br>United Kingdom | Poster presentation and article |
| **16/05/2012** | "Ruminant Innovation Network"<br>Environmental Strategy Knowledge Transfer Network | Aberystwyth University<br>Wales<br>United Kingdom | Speaker |
| **11/09/2012** | 4th CREST Research Symposium | GuildHE<br>Coin St. Neighborhood Centre<br>London, United Kingdom | Speaker |
| **19/09/2012** | *By invitation*<br>Pasture-Fed Livestock Association (PFLA) Annual General Meeting | Sheepdrove Farm<br>Berkshire<br>United Kingdom | |
| **4/12/2012** | Seminar<br>"Low Carbon Farming" | Campden BRI,<br>Chipping Campden<br>Gloucestershire<br>United Kingdom | |
| **01/02/2013** | *By invitation*<br>Launch of the FCCT Farm Carbon Calculator | Duchy Home Farm<br>Tetbury<br>Gloucestershire<br>United Kingdom | |
| **21/05/2013** | Conference<br>"Investment in Agricultural Technology"<br>Environmental Strategy Knowledge Transfer Network | Syngenta Jealott's Hill<br>Bracknell<br>Berkshire<br>United Kingdom | |
| **10/09/2013** | 5th CREST Research Symposium | GuildHE<br>Woburn House<br>London, United Kingdom | Speaker |
| **30/09- 01/10/2013** | *By invitation*<br>XXVII Euragri Conference<br>"Framing the Challenges of European Agricultural Research – Innovation, Stakeholder Involvement and the Supply and Production Chain" | Part of a series of conferences organised by the Lithuanian Presidency of the Council of the European Union 2013<br>Vilnius<br>Lithuania | Co-chaired the session titled "Diversity of end-users, what are the consequences for innovation strategies including investments, involvement of stakeholders, knowledge flow and circulation?" |
| **18/10/2013** | Seminar<br>"The Future of Global Agribusiness"<br>Ray Goldberg<br>Harvard Business School | Royal Agricultural University<br>Cirencester<br>Gloucestershire<br>United Kingdom | |
| **06/11/2013** | *By invitation*<br>3rd Animal Task Force Seminar "Responsible Livestock Farming Systems" | Animal Task Force, Sustainable European Livestock Production<br>Brussels<br>Belgium | |
| **18-19/12/2013** | Conference<br>"Rethinking agricultural systems in the UK"<br>Association of Applied Biologists | St. Catherine's College<br>Oxford<br>United Kingdom | Poster presentation and article |

# Appendix III

# Publications

The publications have been removed

Figure 1. Methodology timeline.




Note: RFPA: Rapid Farm Practices Appraisal

Figure 2. Farm assessment report feedback survey.

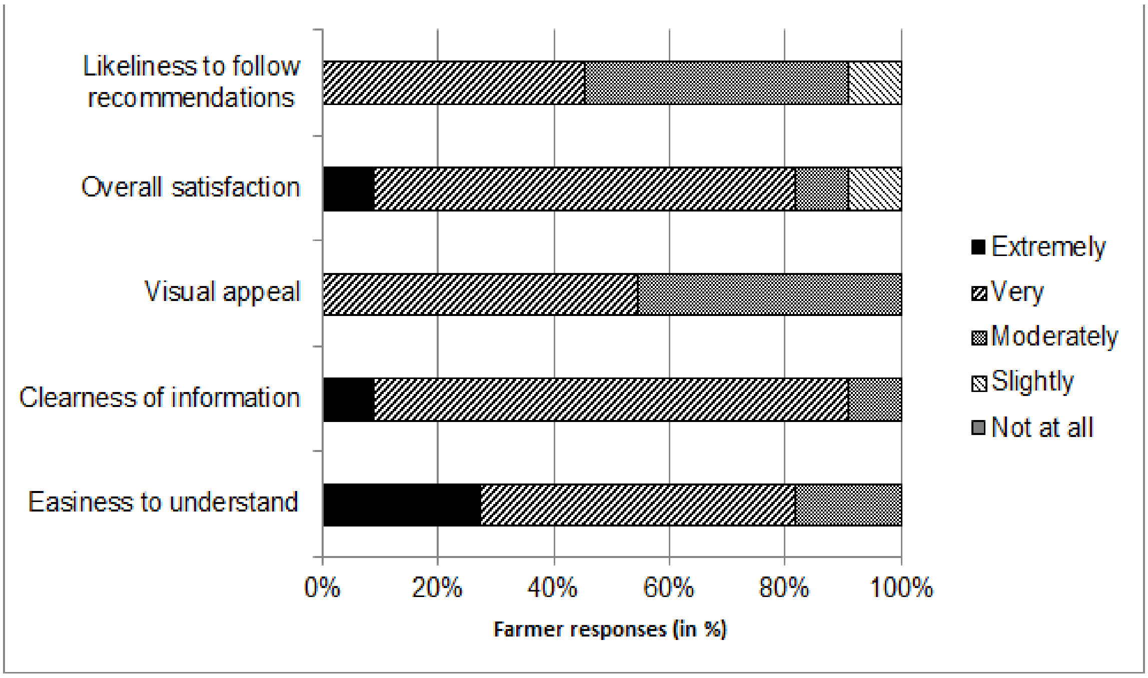


Table 1. Characteristics of different learning approaches (adapted from German and Stroud, 2007).

| Characteristics | Participatory Action Research | Action Research | Conventional (Empirical) Research |
|---|---|---|---|
| 1. Purpose | Solve localized problems | Derive lessons for the global community on how to solve certain types of problems | Characterize current or future situations and trends |
| 2. Tools[1] | Interactive (facilitation, negotiation, participatory monitoring and evaluation) | Extractive (monitoring the performance of scientific indicators, impact assessment, process documentation) and Interactive (PAR methods) | Extractive (a large body of methods derived from diverse social and biophysical sciences) |
| 3. Carried out by whom? | Actors in a change process (farmers, leaders of organizational change, policymakers, urban residents) | Researchers with an interest in “process” (how transformation occurs); change agents interested in deriving generalizable lessons | Researchers. At times, change agents will also turn to conventional research either for inputs (i.e. technologies) or to evaluate the impact of change processes they facilitated |

[1] PAR is not just a set of tools, but a philosophy and broad approach to knowledge generation and societal engagement.

Table 2. Factors influencing decision making at the farm level, grouped according to PESTE analysis models.

| Type of factor | Reference | Description |
|---|---|---|
| Political | P1 | Trust in official reports |
| | | i.e. government (DEFRA, Environment Agency) |
| | P2 | Trust in source of recommendations (institution) |
| | | i.e. research centres, universities, associations |
| | P3 | Support in integrating Environmental Stewardship schemes (i.e. ELS, OELS, HLS) and GHG emissions reduction |
| | P4 | The level of bureaucracy linked to obtaining grants |
| Economic | E1 | Financial constraint, i.e. limited budget |
| | E2 | Current management is profitable already |
| | E3 | External support for budget and farm management matters |
| | E4 | Cost of agricultural consultants |
| | E5 | Labour force availability |
| Social | S1 | Trust in source of recommendations (individual) |
| | | i.e. the person conducting the study |
| | S2 | Community support |
| | S3 | Previous bad experiences |
| | | i.e. consultants, community actions, interest groups |
| Technological | T1 | Trust in scientific basis of GHG emissions reduction strategies |
| | T2 | Trust in assessment tools currently available |
| | | i.e. carbon accounting tools |
| | T3 | User-friendliness of assessment tools |
| Environmental | En1 | Interest in conservation and environmental matters |
| | En2 | Renewable energy more important greenhouse gas emissions reduction |