THE CONTRIBUTION OF RURAL LAND USES TO GREENHOUSE GAS NEUTRAL REGIONS

A THESIS PRESENTED FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN GEOGRAPHY AND ENVIRONMENT AT THE UNIVERSITY OF ABERDEEN

Diana Feliciano

MSc Economics (Portuguese Catholic University)
BSc, MSc Forest Engineering (Technical University of Lisbon)

This research project was carried out in collaboration with The James Hutton Institute,
Aberdeen

2012
Declaration

I declare that this thesis has been composed by me and it has not been accepted in any previous application for degree, the work of which has been done by myself and sources of information specifically acknowledged.

Signed:

Diana Feliciano
Supervisors

Professor Pete Smith, University of Aberdeen, School of Biological Sciences.
Professor Colin Hunter, University of St. Andrews, School of Geography and Geosciences.
Professor Bill Slee, The James Hutton Institute, Social, Economic and Geographical Sciences Group.

Examiners

Dr Michelle Pinard (internal), University of Aberdeen, School of Biological Sciences and Aberdeen Centre for Environmental Sustainability.

Professor Terry Dawson (external), University of Dundee, School of the Environment.
Acknowledgments

First of all, I would like to thank my supervisors, Prof. Colin Hunter (St. Andrews University), Prof. Bill Slee (James Hutton Institute) and Prof. Pete Smith (University of Aberdeen) for their excellent guidance, support and encouragement. I was very lucky to have such a great mix of knowledge, expertise and wisdom.

I also want to thank ACES – Aberdeen Centre for Environmental Sustainability, and the James Hutton Institute (formerly the Macaulay Land Use Research Institute) for funding my PhD and enabling me to pursue and develop my research interests.

I would like to thank my colleagues from the Social, Economic and Geographical Sciences group at the JHI for all the support, knowledge exchange and great tea breaks. I would like to especially thank Prof. Ken Thomson and Dr. Iain Brown for their suggestions and interesting discussions about climate change mitigation and adaptation, and Dr. Dominic Duckett for philosophical conversations. I am also very grateful to the JHI graphics department for designing my posters and questionnaire and to the IT department for replacing my old desktop for a new one!

I would like to thank Lorna Paterson from the National Farmers’ Union of Scotland and David Ross from the Scottish Agricultural College for being so kind in helping in the recruitment of farmers and organisation of the focus groups. I am very grateful to the JHI researchers, farmers, land agents, estate owners and University of Aberdeen academics who attended the participatory workshops and the focus groups. I am especially thankful to the farmers who agreed to complete my questionnaire in the livestock marts, and online.

My friends in Aberdeen and others around the world were also very important to give me motivation and listen to me whenever I needed: Koen Arts, Julia Martin-Ortega, Javier Perez-Barbería, Jill Dunglinson, Shibu Muhammed, Irene Jimenez, Rob Lewis, Christian Birkel, Rita Veloso, Ana Vaz, Francisco Santos, Patrícia Azeiteiro. And thank you also to my dear cousins Liliana, Marta, Susana, Ricardo, Rita and uncle Nari.

Thank you to Chris Brown for his constant encouragement and for revising my English.

Finally, a huge thank you to my parents, Odília and Isidro, who always support me in everything I do, even if that keeps me away from them.
Publications arising from this thesis


**Feliciano, D., Slee, B., Hunter, C., Smith, P.,** *Selecting land-based mitigation practices to reduce GHG emissions from the rural land use sector: a case study of North East Scotland.* Manuscript submitted to *Journal of Environmental Management.*


Abstract

This thesis aims to assess the contribution of the rural land use sector to the greenhouse gas (GHG) emissions budget of a specific region and to explore the potential for implementation of practices that mitigate climate change by reducing emissions from this sector of the economy. The rural land use sector contributes to GHG emissions but can also offset carbon dioxide (CO₂) emissions in vegetation and soils. A range of mitigation practices can be implemented in the rural land use sector, and to assess this contribution, GHG emissions have to be inventoried and the mitigation potential has to be assessed.

The thesis comprises four main parts: Chapters 2, 3, 4 and 5. In Chapter 2, GHG emissions from rural land uses are estimated and guidance for the development of a GHG emission inventory at the regional level is provided. In Chapter 3, criteria to select mitigation practices suitable for the land use sector in North East Scotland are used and the barriers to their implementation are discussed. In Chapter 4, stakeholders’ perspectives about GHG mitigation practices are investigated, and in Chapter 5 the mitigation potential of woody biomass as a source of renewable energy for space and water heating is explored. This research was an interdisciplinary study that used several disciplines from natural and social sciences. It employed mixed-methods, which included quantitative and qualitative data collection and analysis.

I have demonstrated (Chapter 2) that a reliable assessment of GHG emissions from different rural land use activities is feasible at the regional level although there are several flaws associated with data availability, uncertainties in emission factors, and uncertainty about the activities to include in the inventory. I have shown (Chapter 3) that physical mitigation potential is not enough to select GHG mitigation practices, because there are local and regional barriers that can substantially reduce that potential. I found (Chapter 4) that farmers are more willing to adopt ‘easy-to-implement’ and ‘low-cost’ mitigation practices. I have shown (Chapter 5) that woody biomass could contribute to a significant reduction of CO₂ emissions from space and water heating but that, so far, its contribution has only been modestly successful, in spite of the efforts of the public sector. The overall discussion and conclusion (Chapter 6) integrates the findings of all chapters; it suggests future research, and proposes policy action to increase adoption of mitigation practices.
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Chapter 1

1 Introduction
Preface

Climate change has been considered a major challenge to the humankind. There is now compelling evidence that much recorded climate change is anthropogenic in origin (IPCC, 1996). According to Stern (2006), climate change “is the greatest and widest-ranging market failure ever seen”, and it threatens people’s access to water, food production, health, and use of land and the environment. The evidence gathered by Stern’s Review concluded that the benefits of taking strong early action to reduce emissions considerably overshadow the costs of the impacts of climate change. Even Bjorn Lomborg, a serious critic of Stern, recognises that the only option for the world is to “start seriously focusing, right now, on the most effective ways to fix global warming” (Lomborg, 2010).

This thesis assesses the contribution of the rural land use sector to the greenhouse gas (GHG) emissions budget of a specific region, and explores the potential for implementation of practices that mitigate climate change by reducing emissions from this sector.

This introductory chapter sets the context for the research by describing the main facts regarding climate change science, emphasising the importance of rural land uses to GHG emissions and climate change mitigation, presenting the evolving climate change policy architecture, explaining GHG emission accounting processes, highlighting rural land use mitigation options and pointing out the importance of stakeholders’ actions in climate change mitigation. It also identifies the scope of the thesis, explains the motivation behind the choice of a regional approach, presents the thesis framework and positions the study within philosophy. This is followed by the description of the region of study – the North East Scotland.

1.1 Climate change science

The atmosphere is considered the most unstable and rapidly changing part of the climate system, and its composition has changed with the evolution of the Earth (Baede et al., 2001). Both natural and anthropogenically induced events can cause perturbation of the atmosphere.
1.1.1 Natural climate change

The main natural perturbations result from volcanic eruptions which release gases such as sulphur dioxide (SO$_2$) and carbon dioxide (CO$_2$), and dusts. The dusts produced by volcanoes can have a significant effect on sunshine hours and on rainfall through the nucleation of water droplets and the production of aerosols. Dusts affect global weather and climate, reducing the temperature on Earth’s surface globally, and generating rainfall at a regional level (Baede et al., 2001). The oceans also influence the carbon, nitrogen, phosphorus and sulphur cycles. They absorb CO$_2$ mainly in the colder regions, causing the sinking of ocean waters, which then circulate as bottom waters, eventually coming to the surface again after a long period of time. In terms of the energy cycle, the most fundamental flux which links the various components of the planetary system is the energy derived from solar insulation. The flow of energy resulting from the sun, and associated latitudinal imbalances, produces the global circulation of the atmosphere and the oceans (Baede et al., 2001).

The energy cycle may be perturbed by external forcing due to changes in the Earth’s orbital characteristics such as the obliquity of the orbit and its eccentricity. Cyclical changes in orbit modify the amount of solar insulation over geological timescales. In addition, change of solar energy output is an external factor disturbing the energy cycle. Internal forcing of the system includes changing the albedo (the reflectivity of the Earth’s surface) and cloudiness resulting from natural climatic variation (Baede et al., 2001). As the albedo increases, more solar radiation is reflected back to space; ice sheets build up, sea level falls and surface temperature declines (Jenkinson, 2010). During the last million years or so, glacial and inter-glacial periods have alternated as a result of variations in the Earth’s orbital parameters. Information provided by Antarctic ice cores on the four full glacial cycles during the last 500,000 years has revealed that during the last glacial period very rapid temperature variations took place over large parts of the globe, in particular in the higher latitudes of the Northern hemisphere (Baede et al., 2001). In the other hand, it was found that the last 10,000 years have been relatively more stable, though quite large changes have occurred locally (Baede et al., 2001).
1.1.2 Anthropogenic climate change

The origins of the concept of anthropogenic climate change, i.e., a change in climate due to men’s interference in the atmosphere, come from the early years of the 19th century. The French scientist Jean Baptiste Fourier suggested that gases in the atmosphere affect the surface temperature of the Earth, and defined this phenomenon as the “greenhouse effect” (Robbins, 2011). Since then, several scientists have studied the causes of the “greenhouse effect”, namely Tyndall in the 1850s, Arrhenius in the last decade of the 19th century, Callendar in the 1930s, Keeling, Revelle and Suess in the mid-1950s, and, more recently, the many scientists contributing to the Intergovernmental Panel for Climate Change (IPCC) (Le Treut et al., 2007), and many others. It is widely assumed that since the Industrial Revolution humans have been contributing significantly to the GHG blanket surrounding the Earth (Harper et al., 2010). The IPCC estimated that pre-industrial atmospheric CO₂ concentration levels were 280 ± 10 parts per million (ppm) in 1750, and had been around that level for several thousand years until rising to 367 ppm in 1999 and 379 ppm in 2005 (IPCC, 2000; IPCC, 2001). Scientists working for the United Nations Framework Convention for Climate Change (UNFCCC) relate the increase of GHGs emissions resulting from human activity to the increase of global average temperature and ultimately to climate change (UNFCCC, 1992). The UNFCCC defines climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is, in addition to natural climate variability, observed over comparable time periods” (UN, 1998).

1.1.3 Main greenhouse gases and source of emissions

The main gases contributing to the enhanced greenhouse effect are carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFC), perfluorocarbons (PFT) and sulphur hexafluoride (SF₆) (IPCC, 2007a). Of these, this study focuses on the three biogenic gases (CO₂, CH₄ and N₂O). Anthropogenic CO₂ emissions are primarily the result of the consumption of energy from fossil fuels and land use change (e.g. deforestation) (Prentice et al., 2001). Humans have been releasing CO₂ since prehistoric times, by burning wood for warmth and cooking. It has been argued that only since the Industrial Revolution fossil fuels have been used on a
significant scale, causing the enhancement of the greenhouse gas effect (Jenkinson, 2010). Ruddiman (2003), however, defends that human’s contribution to GHG emissions did not begin in the eighteenth century with the coal-burning factories and power plants of the industrial era but date back to 8,000 years ago, triggered by the intense farming activities of early agrarian activities.

Clearing forests by fire and replacing them by grassland or cropland releases significant amounts of CO₂ to the atmosphere because the carbon stored in trees and soil is usually greater than carbon stored grassland and cropland (Jenkinson, 2010). Methane is released from anaerobic environments with very low concentrations of oxygen, during energy production and use, livestock production (e.g. ruminants), animal and human wastes (landfills), rice paddies, biomass burning, coal mining, gas leakage during natural gas processing, and petroleum exploitation (IPCC, 2001). Nitrous oxide concentration in the atmosphere has been increasing due to biomass combustion and the breakdown of products arising from fertiliser (organic and mineral) application to arable crops and grassland (Smith, 2008). The clearing of tropical forest for grassland increases N₂O emissions, as do leguminous crops such as soybeans through their ability to fix atmospheric nitrogen, some of which inevitably ends up as nitrate, and consequently N₂O emissions (Jenkinson, 2010). Nitrous oxide emissions result from soil microbial processes of nitrification and denitrification (Monteny et al., 2001; Smith and Conen, 2004). Nitrification is a two-stage microbial process found in all soils (except the most acid), that converts ammonium (NH₄⁺) first to nitrite (NO₂⁻) and then to nitrate (NO₃⁻). During this process a small percentage is lost as N₂O (Jenkinson, 2010). Denitrification is the name given to the sequence of reactions: (NO₃⁻) → nitrite (NO₂⁻) → nitric oxide (NO) → nitrous oxide (N₂O) → nitrogen gas (N₂). It is by far the most important microbial process generating N₂O emissions. It takes place in soils, swamps, lakes, rivers and at the bottom of the ocean and when a microbial population actively decomposes organic matter under anaerobic conditions (Jenkinson, 2010).

The ability of different gases to trap heat and thus their contribution to the GHG effect differs between them, and depends on their capacity to absorb and re-emit radiation, the time they remain in the atmosphere and their abundance (IPCC, 2007b). To compare emissions from different sources, the global warming potential (GWP) of each gas is equated to the global warming potential of CO₂. The GWP depends on both the
efficiency of the molecule as a GHG and its atmospheric lifetime. According to IPCC (2007a), CO₂ is defined to have a relative GWP of 1 over 100 years, CH₄ of 25 and N₂O of 298.

1.1.4 Impacts of climate change

The impacts of climate change at any particular location are determined by changes in mean temperature and precipitation, temperature and precipitation extremes and variability, and in the frequency of hurricanes and tropical storms (Wigley, 2001). The Climate Change 2007 report of the IPCC showed that the increase in global mean temperatures since the middle of the 20th century has led to regional changes in climate such as increased frequency of heat waves, heavy precipitation, floods, droughts and an overall rise in global sea level (IPCC, 2007a).

Professor John Beddington considers that the occurrence of these changes could work simultaneously to produce a “perfect storm” where food shortages, water scarcity and insufficient energy resources threaten to unleash public unrest, cross border conflicts and mass migration (Beddington, 2009). His words began to create a special case discourse for agriculture and the trade-offs between food production and climate change mitigation. The intensification of agricultural production aimed at combating the lack of food will potentially increase GHG emissions in countries with ability to produce this food, such as Scotland. Further, an increase in food demand will drive prices up for the most important agricultural crops (e.g. wheat, soybeans) and this will result in higher meat prices (Nelson et al., 2009). Farmers may be stimulated to intensify their production thus requiring additional climate change mitigation in the rural land use sector. The phrase ‘sustainable intensification’ has been applied to the need to plan for increased food demand (Garnett and Godfray, 2012). Part of that sustainability will be the requirement to reduce emissions per unit of output.

In Scotland, climate is expected to be wetter, especially in the west, and warmer (RSE, 2011). As a consequence of annual temperature increase in Scotland, the growing season has been extended by 33 days between 1961 and 2004, and this has already been impacting agriculture, both in terms of crop choice and their seasonal management (Barnett et al., 2006). Projections indicate that, during the 21st century, summers will
continue to be, on average, hotter and drier, and winters to be milder and wetter. In addition, large temperature variability from year to year and between groups of years is expected, and consequently weather extremes will increase from year to year (RSE, 2011). An analysis of the average annual temperature record for Scotland for the period 1800-2006 adds credibility to the above findings (Jenkins et al., 2008).

1.2 The relation between rural land uses and climate change

Land use is the management regime (e.g. agriculture, plantations, agro-forestry) that humans impose on a place and land cover is the type of vegetation at a place (e.g. forest, crop) (Dale, 2007). When aggregated globally, land-use and land-cover changes significantly affect vital aspects of Earth’s system functioning, including global, local and regional climate (Chase et al., 2000). Land management is an important mechanism for climate change mitigation (Rounsevell and Reay, 2009). The rural land use sector (forest, moorland, peatland, agriculture) has the unique capacity of delivering zero and negative carbon emissions because it can act as a sink and reservoir for CO₂.

1.2.1 The contribution of rural land uses to GHG emissions

The extensive use of organic and mineral nitrogen (N) fertiliser in cropland and grassland contributes to N₂O emissions, and livestock and poultry production directly and indirectly emit N₂O and CH₄ (Dale et al., 2005). According to Smith et al. (2008), arable land and livestock production are directly responsible for 10-12% (5.1-6.1 Gt CO₂e yr⁻¹) of global anthropogenic GHG emissions. Agricultural emissions are expected to increase in the next 30 years due to rises in population, income, agricultural intensification and meat and consumption of dairy products (Wollenberg et al., 2012). Agriculture is also a major cause of deforestation and other land-use change (Wollenberg et al., 2012). Land-use change such as forest conversion to arable land and grassland has deep impacts on the atmospheric flux of CO₂, and subsequently on climate change (Dale, 2007; Rounsevell and Reay, 2009). Land use change also influences other GHG emissions due to changes in the nutrient cycle and distribution of organic matter. This
has markedly contributed to decreased CH$_4$ oxidation, with the consequent increase in CH$_4$ emissions, and increased CO$_2$ emissions, as well as N$_2$O emitted from soils (Dale et al., 2005). It has been estimated that about one third of total carbon emissions into the atmosphere since 1850 have resulted from land use change (Houghton, 2003). The IPCC (2001) states that, if the totality of all the carbon released by historical land-use changes could be restored to the terrestrial biosphere over the course of a century, CO$_2$ concentration in the atmosphere could be reduced by between 11 and 20%.

It should be noticed that in developed countries there has been a change from contraction to expansion of forest area. According to Mather and Needle (1998), this transition has resulted from the concentration of agricultural production in smaller areas of good-quality land and the abandonment of larger areas of poorer-quality land, which become available for reforestation or afforestation$^1$. Even though the transition of other land uses to forest is important in increasing carbon sequestration in developed countries, recent discussion about food security and competition for productive land may constrain their expansion (Meyfroidt and Lambin, 2011).

In Scotland, the main GHGs emitted from the land use sector are N$_2$O from fertiliser application and from manure management, and CH$_4$ from enteric fermentation and manure management (Scottish Executive, 2006a). Carbon dioxide is directly emitted as a result of lime application to cropland. Indirectly, fuel used in agricultural machinery is also a source of CO$_2$ emissions. Although Scottish emissions from agriculture have fallen by 21% since 1990, emissions projections for agriculture are 7% higher than current levels, due to increases in N$_2$O emissions from agricultural soils, and slight increases in CH$_4$ from agricultural sources such as enteric fermentation from cattle (Committee on Climate Change, 2010). In addition, land for woodland creation and associated carbon sequestration is under pressure because of infrastructural developments, food production and renewable energy projects (RSE, 2011).

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1 Afforestation is the conversion from other land uses into forest, or the increase of the canopy cover to above 10% threshold. Reforestation is the re-establishment of forest formations after a temporary condition with less than 10% canopy cover due to human-induced or natural perturbations (FAO, 2000).
It is important to further understand the rural land use sector's potential to mitigate, adapt and make a positive contribution through GHG emissions reduction, production efficiency measures, including improvements in energy efficiency, biomass and renewable energy production, carbon sequestration and protection of carbon in soils based on innovation (European Commission, COM (2010)672).

1.2.2 The importance of rural land uses to climate change mitigation

The rural land use sector can become carbon-neutral, and also offset residual emissions from other sectors of the economy that cannot be entirely eliminated. A change in land use from cropland to forest or grassland, the maintenance and increase of existing carbon in forests and agricultural soils, the replacement of fossil fuels by biomass and the implementation of land use practices that reduce CH₄ and N₂O emissions are among the rural land use sector mitigation strategies (Richards et al., 2006). Peatlands can also contribute to climate change mitigation by sequestering and storing carbon. However, if such land is disturbed (e.g. peat extraction, drainage, removal of vegetation) or converted to tilled arable land, this carbon can be released (Harper et al., 2010). The sink effect of peatlands can be improved in various ways, such as adopting lower-impact agricultural and forestry practices, and restoring formerly drained peatlands (Scottish Government, 2011a; Wallace et al., 2006). Restoring peatlands does not always have a positive effect on GHG net fluxes. Komulainen et al. (1998) states that CO₂ losses can be reduced but may be accompanied by increased CH₄ emissions because of elevated water tables and soil water contents. Kemp and Wexler (2010) have stated that the best use for peatlands is probably very light grazing by sheep and deer.

1.3 The evolving climate change policy architecture

Greenhouse gas neutrality i.e., emissions are avoided or offset by CO₂ sequestration practices, has been the desire of a number of organisations, cities, councils and countries. Therefore, GHG-neutral approach does not require all activities or sectors of the economy to achieve a GHG-neutral status. The zero carbon britain 2030 report recommends the maintenance of cropland, grassland and peatland and the increase in forest cover in order to help Great Britain to achieve zero net emissions by 2030 (Harper et al., 2010). Ireland has also showed interest in becoming GHG neutral by
2050 in its *Climate Change Research Programme* (CCRP) (O'Reilly and O'Brien, 2008). The programme instigated the coordination between forestry and agriculture and energy sectors in order to have simultaneously a sink of carbon and a source of renewable energy to supply heating systems. Several councils in the UK also aspire for carbon neutrality (UNEP, 2012). Part of the strategy to achieve this is by offsetting CO₂ emissions.

In order to avoid dangerous climate change, more than 100 countries have adopted a target limit 2°C of temperature increase relative to preindustrial temperatures by 2020 (Meinshausen *et al.*, 2009). To provide an 84% chance of this to happen, current global greenhouse gas (GHG) emissions would have to be reduced by 74% by 2050 (Meinshausen *et al.*, 2009). Reducing GHG emissions and, eventually becoming carbon-neutral, is essential to minimize the risk of dangerous climate change and to keep the costs of adapting to a warmer world bearable (Kirby, 2008). Obviously, GHG neutrality is an ideal and most other targets are much less ambitious, including the Copenhagen targets (OECD, 2009). Reducing GHG emissions will require countries to limit overall net emissions and to enhance sinks of GHGs.

Attempts to address the problems of climate change are characterized by multi-level governance. Mitigation options in the land use sector depend on international, European Union, United Kingdom and Scottish policy. The following section describes how climate change policy is evolving and explores the contribution of different policies to GHG emissions reduction.

### 1.3.1 International policy on climate change and the rural land use sector

In the United Nations (UN) Conference on Environment and Development (UNCED), held in Rio de Janeiro in 1992, national governments committed to take into consideration the global environmental impacts of their economies and land uses (Adger *et al.*, 1997). In this Earth Summit, the ‘Rio Declaration on Environment and Development’, the ‘Agenda 21’ and the ‘Statement of Forest Principles’ were produced, and the Convention on Biological Diversity and the UN Framework Convention on Climate Change (UNFCCC) were opened for signature (UN, 2009). The ultimate
The objective of the UNFCCC was to “achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system” (UN, 1998).

The Kyoto Protocol, which entered into force in 2005 under the aegis of the UN, established legally binding obligations for developed countries (Annex 1 countries) to reduce their GHG emissions. These countries agreed to implement policies and measures, according to national circumstances, towards the achievement of the UN emission reduction goals (UN, 1998). The Kyoto Protocol recognised the mitigation potential of the ‘land use, land use change and forestry’ (LULUCF), and allowed Annex 1 countries to use LULUCF emissions and removals as credits or debits contributing to their emission reduction objectives. Among the examples of mitigation policies and measures were the promotion of more sustainable forest management practices, afforestation and reforestation, and the promotion of more sustainable forms of agriculture in the light of climate change considerations (UN, 1998). In the first commitment period of the Protocol (2008-2012), the LULUCF accounting rules established that afforestation, reforestation and deforestation since 1990 had to be accounted on a gross-net basis, that forests existing before 1990 were accounted on a gross-net basis, up to a country-specific “cap”, and that other activities such as cropland, grazing and revegetation were accounted on a net-net basis. These rules are criticised for not providing real incentives in the forest sector and for not ensuring environmental reliability, given that most of the credits were obtained without additional efforts (Grassi, 2012).

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3 Deforestation is the conversion of forest to another land use or the long-term reduction of tree canopy cover below the 10% threshold (FAO, 2000).

4 Gross-net basis: It means that a country’s total net GHG flow from LULUCF in a given year is accounted for in its GHG balance (http://ec.europa.eu/clima/events/0013/info_sheet_lulucf_final_en.pdf, last accessed 07/09/2012).

5 Net-net basis: It means that only the difference between the total net GHG flow from LULUCF in a given year and that in a defined base year is accounted for in the country’s GHG balance (http://ec.europa.eu/clima/events/0013/info_sheet_lulucf_final_en.pdf, last accessed 07/09/2012).
The Kyoto Protocol also established the Clean Development Mechanism (CDM), a project-based instrument to enable developed countries to meet their emission targets by buying offset credits from developing countries, contributing to their sustainable development (Wollenberg et al., 2012). The CDM covered reductions of emissions from power stations, industry and other sources as well as sinks under the LULUCF heading (Robbins, 2011). In the first commitment period (2008-2012), however, mainly reforestation and afforestation were eligible, and not agricultural sinks and standing forest (Robbins, 2011; Wollenberg et al., 2012). The decision not to include agricultural sinks in the CDM was taken in the Marrakech Accords in 2001. It reflected concerns over leakage of GHG emissions to other places, permanence of carbon in agricultural soils, sovereignty issues and measurement methods (Schlamadinger et al., cited in Robbins, 2011).

Since the 13th Conference of the Parties (COP13) in Bali in 2007, the inclusion of agriculture has been negotiated in the Kyoto Protocol and several Long-Term Cooperation Ad Hoc Working Groups (Wollenberg et al., 2012). The first Group discussed agricultural emission targets and the scope for CDM, and the second Group identified agriculture as a relevant sector for mitigation and established that nationally appropriate mitigation actions (NAMAs) should be reported (Wollenberg et al., 2012). It was also at COP13 that reduced emissions from deforestation and degradation (REDD), excluded in the CDM, were considered as part of a potential Kyoto II, after 2012. REDD, which subsequently evolved into REDD+, which considers forest quality as well as area (Robbins, 2011). In 2011, at the 17th Conference of the Parties to the UNFCCC in Durban, it was decided that Parties would adopt a universal legal agreement on climate change as soon as possible and no later than 2015. In addition, new LULUCF accounting rules were agreed. These are expected to be implemented in the second commitment period of the Kyoto Protocol (2012-2017). The new LULUCF rules allow national circumstances to be addressed, deal with “additionality”, i.e., recognition is given only to actions beyond business-as-usual (BAU), and treat equally different mitigation options (e.g. sink in the forest, harvested wood products, material substitution) (Grassi, 2012). Negra and Wollenberg (2012) consider that, although existing international and national policies provide some scope for mitigation in agriculture and the land use sector, not many of them directly support mitigation
practices. Robbins (2011) believes that, after the inclusion of avoided deforestation in world climate governance, the inclusion of agricultural sinks will be almost inevitable.

Twenty years after the 1992 Earth Summit, the necessity to promote, enhance and support sustainable agriculture in order to improve resilience to climate change and natural disasters was reinforced at the United Nations Conference on Sustainable Development (Rio+20). Countries also recognised that increasing the share of renewable energy was important for sustainable development and consequently to climate change mitigation (UN, 2012). In Rio+20 the prompt enabling of the Green Climate Fund was urged. This fund aims to support projects, programmes, policies and other activities in developing country Parties using thematic funding windows such mitigation through the reduction deforestation in developing countries (Green Climate Fund, 2012).

1.3.2 European climate change policies

In the global context, Europe has been important in the formulation, negotiation and implementation of the UN Framework Convention on Climate Change (Adger et al., 1997). Nonetheless, by 1994, there was some heterogeneity of policy positions, with some European Union (EU) countries undertaking carbon and energy taxes in order to reduce overall emissions (e.g. Denmark, Germany, Belgium) and others maintaining their right to increase emissions (e.g. Portugal, Spain, Greece).

Currently, EU level policies and measures aimed at reducing emissions include: to increase the use of renewable energy (wind, solar, biomass) and combined heat and power installations; to improve energy efficiency in buildings, industry, household appliances; to reduce CO₂ emissions from new passenger cars; and to implement abatement measures in the manufacturing industry in landfills (European Environment Agency, 2012). But, in the rural land use sector, other policies and strategies not specifically related to climate change have influenced GHG emissions.
1.3.2.1 European rural land use policies

In the EU, GHG emissions from agriculture have decreased by 20% since 1990 (European Commission, COM(2010)672). GHG emissions from land use activities are mainly due to land use change, energy use in forestry and agriculture, ruminants’ enteric fermentation and manure management, biomass burning, irrigated rice under anaerobic conditions and fertiliser application on cultivated soils (Adger et al., 1997). The 1992 reform of the Common Agricultural Policy (CAP), which was first implemented in 1962, is believed to have contributed to the decrease in GHG emissions from rural land uses. This was the result of the decoupling subsidies from production, which required farmers to reduce their cultivated area (set-aside) and livestock. In addition, Regulation 2080/92 on forestry measures in agriculture contributed to increasing on-farm afforestation and, consequently, carbon sequestration. However, some agricultural sectors, have been hardly affected by CAP reform in terms of GHG emissions (Storey and McKenzie-Hedger, 1997). According to the OECD, the dairy sector remained largely unchanged and surplus beef production was encouraged by export subsidies in the livestock sector (OECD, 1996).

In 1999, agri-environment schemes became compulsory with the ‘Agenda 2000’ reform. In Scotland, agri-environment systems consisted in the Countryside Premium, Habitats, Environmentally Sensitive Areas, Forestry and Rural Stewardship schemes (Scottish Government, 2012). In 2005, the Single Farm Payment (SFP) was introduced. This was subject to ‘cross-compliance’ conditions related to animal welfare, environmental, public and animal, and plant health standards. The SFP also required the maintenance of farm land in good agricultural and environmental condition (GAEC). Under GAEC, several practices (e.g. apply manure in arable soils, protection of permanent pasture) have contributed to climate change mitigation by increasing soil carbon sequestration.

In 2000, the Water Framework Directive (WFD) was introduced to establish a legal framework to protect and restore clean water (including inland surface waters) across European countries, and ensure its long-term, sustainable use. Because one of the objectives is to reduce nitrates from agriculture, the WFD have an effect on agricultural activities such as fertiliser application. The Nitrates Directive (91/676/EEC) aimed at
preventing nitrates originating from agricultural sources from affecting ground and surface waters. It required Member States to establish codes of good practice with the objective of limiting the amount and number of times that organic and mineral nitrogen fertiliser is applied in the soil, as well as promoting a better management of livestock manure (e.g. creating manure storage facilities) (European Commission, 2008). These requirements are likely to contribute to climate change mitigation in the future by reducing N₂O emissions from the rural land use sector.

In the period 2007-2013, EU’s rural development policy has provided further opportunities to reinforce the contribution of the CAP in climate change mitigation. Three key priority areas related to the environment were defined in the Community’s strategic guidelines for rural development: climate change, biodiversity and water. Actions include the reduction of GHGs emissions and the sustainable use of pesticides. To mitigate climate change, the current RDP also considers that forest resources should be extended and improved through the afforestation of agricultural and non-agricultural land. The programme exhorts Member States to designate areas suitable for afforestation. According to Article 54 (5) of Regulation (EC) No 1782/2003, these areas should be eligible for payments provided for in Article 36(b)(i) and (iii).

The role of forests in mitigating climate change had been earlier recognised in the Forestry Strategy for the European Union. This strategy aims at ensuring that forests are sustainably managed in ways that protect and enhance existing carbon stocks, establish new carbon stocks, and encourage the use of biomass and wood-based products (Council of the European Union, 1998). A workshop for the review of the strategy, held in Brussels in 2011, reinforced the idea that one of the main challenges to EU forests is to contribute to climate change mitigation (European Commission, 2011).

Presently, the EU is discussing another reform of the CAP which will coincide with the next financial perspectives package (2014-2020). Climate change is already one of the Community priorities for the current programming period (Matthews, 2012). Member states broadly support the principle that CAP should significantly contribute to addressing the challenges concerning environment, biodiversity and climate change mitigation and adaptation. In addition, the Commission suggests that member states spend a minimum of 25% of the total contribution from the European Agricultural Fund
for Rural Development (EAFRD) to each rural development programme on climate change mitigation and adaptation, and land management (Council of the European Union, 2012). The Commission proposes to identify six Union priorities for rural development, one of which has explicit climate change objectives. This would promote resource efficiency and support the shift towards a low-carbon and climate-resilient economy in agriculture, food and forestry sectors (Council of the European Union, 2012).

1.3.3 Scottish plans and policies on climate change mitigation and the rural land use sector

Scotland contributes around 0.2% of the global GHG net emissions (Scottish Executive, 2006a). Despite this small share, the Scottish Government has set ambitious targets for reducing GHG emissions, aligned with global reduction needs. These targets, set in the Climate Change (Scotland) Act 2009, are 80% GHG emission reduction by 2050 and 42% (interim target) reduction by 2020 (Scottish Government, 2009a). The GHGs considered are carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFTs) and sulphur hexafluoride (SF₆), and the baselines used are 1990 for CO₂, CH₄, and N₂O and 1995 for HFC, PFT and SF₆.

The Scottish Government is committed to working in partnership with the UK Government and other devolved administrations in developing and implementing the UK’s response to climate change. The UK target for 2050 is also to reduce GHG emissions by 80% in relation to 1990 levels. However, the Scottish targets have added burdens when compared to the UK because they include emissions from international aviation and shipping, are non-conditional on the European Union agreement of higher targets, and are annual targets, which reduce flexibility (RSE, 2011). To achieve the GHG emission reduction targets, the Scottish Government promotes action across all

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6 The Scottish Government is the executive branch of the devolved government of Scotland. The government was established in 1999 as the Scottish Executive under section 44(1) of the Scotland Act 1998. It was formally renamed in law to the Scottish Government at the beginning of July 2012, when section 12(1) of the Scotland Act 2012 came into force (National Archives, 2011).
sectors of the economy and recognises the existence of opportunities within the land use, land use change and forestry (LULUCF) to offset GHG emissions from the atmosphere.

The *Climate Change (Scotland) Act 2009* (Scottish Government, 2009a) originated a report to set the measures to reduce GHG emissions, a report setting the Climate Change Committee’s advice on the Act implementation framework, and a report on proposals and policies (Section 1.3.3.1). The opportunities offered by rural land uses, soils and peatland management to sequester carbon and mitigate the effects of climate change had been identified in previous documents (Section 1.3.3.2).

In parallel to the climate change programmes and Act, including their specific sections directed to the rural land use sector, a Scottish Forestry Strategy, the Scottish Rural Development Programme, a Land Use Strategy for Scotland and a Renewable Energy Strategy were created. These are more specific for sub-sectors within the rural land use sector (e.g. forestry, renewable energy) and mention the role of each of these sub-sectors in tackling climate change (Section 1.3.3.3).

Figure 1.1 presents the relation and evolution of climate change plans and programmes in Scotland.
1.3.3.1 Plans and policies derived from the Climate Change (Scotland) Act 2009

The Climate Change Delivery Plan - Meeting Scotland's Statutory Climate Change Targets (Scottish Government, 2009b) sets the high-level measures to meet the interim statutory targets for 2020 and the work to be done between 2010 and 2020 to prepare for the major changes needed by 2030 if the emissions reduction target for 2050 is to be achieved. The Plan specifies that emissions from agriculture and land use have to be reduced by 21% by 2020, relative to 1990 levels. The plan also stipulates that afforestation rates need to increase to 10,000 ha per year by 2015 (34% Scottish target) or 15,000 ha per year. The Plan considers that afforestation will deliver some carbon benefits by 2020 and high sequestration levels in the period 2020 to 2050 (Scottish Government, 2009b).

The Scotland’s path to a low-carbon economy (Committee on Climate Change, 2010), provides advice on the implementing framework for the Climate Change (Scotland) Act
2009 to the Devolved Administration on Climate Change (CCC), as requested by the Scottish Government. The Committee on Climate Change suggested an increased penetration of renewable heat technologies (e.g. biogas, biomass boilers and biomass Combined Heat and Power (CHP)) across residential, commercial, public and industrial sectors, changed farming practices and the use of new technology on farms to reduce emissions, and increased afforestation. The CCC also suggested the strengthening of existing policies and the introduction of new policies in order to provide support for farmers to improve resource efficiency, including advisory services and voluntary agreements, and to provide support for increased woodland cover and improved forest management. The CCC recognises that Scotland has particular advantages in terms of access to local forests for biomass and that many disadvantaged rural homes have emissions-intensive heating systems.

The Report on Proposals and Policies (RPP) - Low Carbon Scotland: Meeting the Emissions Reduction Targets 2010-2022 (Scottish Government, 2011b) identifies a range of proposals and policies launched in 2011-12 and explain how annual targets can be met annually up to 2022. The publication of this RPP for 2010-2022 completes a period in which a number of publications have been prepared, in part to accomplish particular requirements of the Climate Change (Scotland) Act 2009, and more generally to provide a clear strategic direction on how Scotland will approach climate change mitigation. Scottish policies to reduce GHG emissions from rural land use are presented in Table 1.1.
Table 1.1 Policies for reducing GHG emissions from rural land uses\(^7\) in Scotland

<table>
<thead>
<tr>
<th>Policy</th>
<th>Policy description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Farming for a Better Climate (FFBC)</strong></td>
<td>Encourages farmers to adopt efficiency measures that also reduce emissions, particularly those having an overall positive impact on business performance.</td>
</tr>
<tr>
<td><strong>Support for anaerobic digestion</strong></td>
<td>Grant funding through the Scotland Rural Development Programme (SRDP(^8)) is available for farmers to install anaerobic digestion facilities to process animal wastes.</td>
</tr>
<tr>
<td><strong>Woodland creation</strong></td>
<td>- Scottish Ministers have pledged to plant 100 million trees by 2015, increasing the current planting rate towards 10,000 ha yr(^{-1}), depending on planting density(^9). Net mitigation in 2020 assumes this planting rate is maintained from 2015 to 2020.</td>
</tr>
<tr>
<td></td>
<td>- Policy approach to expand woodland sustainably. SRDP grants for woodland planting.</td>
</tr>
<tr>
<td></td>
<td>- Woodland Carbon Code aimed at attracting finance to contribute to the costs of woodland creation.</td>
</tr>
<tr>
<td></td>
<td>- Support the use of Scottish timber for construction and fuel.</td>
</tr>
<tr>
<td><strong>Peatland restoration</strong></td>
<td>The Scottish Government will undertake research to improve the data available regarding the effectiveness of peatland restoration. This will help to inform the development of a programme to prevent further GHG emissions or bring about carbon sequestration.</td>
</tr>
<tr>
<td><strong>Soils</strong></td>
<td>- Promoting the sustainable management and protection of soils consistent with the economic, social and environmental needs of Scotland.</td>
</tr>
<tr>
<td></td>
<td>- Funding for a substantial research portfolio “Protecting the Nation’s Soils”.</td>
</tr>
<tr>
<td></td>
<td>- Working with partners in the UK Government and data providers to develop the Greenhouse Gas Emissions Inventory to provide a more accurate picture of the emissions arising from agriculture and other forms of land use.</td>
</tr>
<tr>
<td></td>
<td>- Advice to land managers on compliance with the Water Environment (Controlled Activities) (Scotland) Regulations 2005 General Binding Rules, including information on more efficient fertiliser use. This will help to reduce over-use of fertilisers, which will reduce nitrogen losses to water and air.</td>
</tr>
<tr>
<td><strong>Guidance on developments on high carbon soil</strong></td>
<td>- Guidance, including for Environmental Impact Assessment, from SEPA, Scottish Natural Heritage and Forestry Commission Scotland.</td>
</tr>
<tr>
<td></td>
<td>- Scottish Government ‘carbon calculator’ for wind farm developments on high carbon soil.</td>
</tr>
</tbody>
</table>

1.3.3.2 Climate change programmes preceding the Climate Change (Scotland) Act 2009

The *Scottish Climate Change Programme – Making it work together* (Scottish Executive, 2000), which in 2000 supplemented the UK Climate Change Programme, was designed to deliver the Kyoto commitment of reducing GHGs emissions by 12.5%

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\(^8\) SRDP: Scottish Rural Development Plan.

\(^9\) In 2012, this policy target became an ‘aspiration’.
below 1990 levels in the period 2008-2012. The objective was to move towards the domestic goal of 20% reduction in carbon dioxide emissions by 2010. In the Programme, the influence of agriculture, forestry and other land uses on establishing the levels and sources of GHGs emissions in Scotland was established. The Programme encouraged new woodland planting for carbon sequestration, through the Woodland Grant and Farm Woodland Premium Schemes. In relation to Scotland’s soils, it was recognised that changes of use involving high-carbon content soils have the potential for significant CO₂ emissions, both positively and negatively.

Following a review of the Scottish Climate Change Programme, the Scottish Executive produced the *Changing our Ways - Scotland’s Climate Change Programme* (Scottish Executive, 2006a). One of the objectives of this updated version was to set out new actions, future directions and targets across the main sectors of the economy. It also revealed the Executive’s commitment to establishing Scottish climate change targets and mitigate climate change. The document dedicated a whole chapter to the developments of agriculture, forestry and other land-use sectors. For agriculture, the Programme suggested increasing the effective use of renewable resources, managing land to minimize carbon loss, managing CH₄ emissions and reducing N₂O emissions. For the forestry sector, the Programme indicated that afforestation, the use of biomass as a source of renewable energy, the use of wood as a substitute for energy-intensive building materials and the decrease of timber miles would be the main activities contributing to carbon savings. In relation to land use, the Programme stated that the Executive was gathering evidence on the state of soils and relevant trends, and identifying threats such as deforestation, intensive cultivation and drainage of wetland and peatlands.

### 1.3.3.3 Other plans and strategies influencing rural land uses and climate change mitigation

The *Scottish Forest Strategy*, launched in 2006, is particularly linked to climate change mitigation (Scottish Executive, 2006c). The actions under this objective are to help increasing awareness of climate change, to prepare and implement a climate change action plan for Scottish forestry, to investigate potential climate change impacts and adaptation measures, to increase carbon sequestration in Scottish forests, to help
developing a prosperous wood fuel sector, to encourage the substitution of high embedded energy materials by wood, to encourage other appropriate renewable energy projects on forest land, and to contribute to sustainable flood management.

The *Scottish Rural Development Plan (SRDP) 2007-2013* (Scottish Executive, 2006b) also shows the Executive’s commitment to ensure that agriculture and forestry play a key role in mitigating climate change and that local food is promoted in order to reduce GHG emissions from food transportation. One of the priorities of the SRDP is to tackle climate change and to meet relevant international and UK commitments on air quality by reducing gaseous emissions from the management and use of rural land, enhancing the significant role played by carbon sinks in Scotland (e.g. peat bogs and woodland planting), conserving soil organic matter and encouraging targeted fertiliser applications to reduce GHG emissions.

In 2011, *Getting the best from our land* (Scottish Government, 2011a), the first Land Use Strategy for Scotland, was created. The strategy guides, supports and informs all those involved in deciding how land is used, by setting out a vision and long-term objectives for an integrated approach to sustainable land use in Scotland. The long-term objective is to build a prosperous and sustainable low-carbon economy, underpinned by successful land-based businesses, flourishing natural environments and vibrant communities. In relation to forestry, the strategy presents the government commitment to increasing the rate of woodland expansion, so as to realize a range of benefits including carbon sequestration. It explains that the main focus of woodland creation will be away from prime agricultural land and areas with deep peat soil. In relation to agriculture, the strategy supports the reduction of emissions from land use through initiatives such as Farming for a Better Climate. The Scottish Land Use Strategy (Scottish Government, 2011a) considers that renewable energy production is land-based business since the production of energy derives from the management of land (or water and air).

The Scottish Government target for renewable electricity is to generate the equivalent of 100% of Scotland’s gross annual electricity consumption from renewable sources by 2020 (Scottish Government, 2011c). This target is intended to help reducing Scottish GHG emissions and subsequently to contribute to the GHG emission reduction targets.
set by the Climate Change (Scotland) Act 2009. Scotland has seen a fast increase in renewable-sourced electricity, mainly from onshore wind (RSE, 2011). But, as other technologies become economically viable, there will be more of a renewables mix, including biomass. The main policies related to the use of biomass to produce renewable energy are described in Chapter 5.

1.3.3.4 Regional climate change policy

At local level, there are single outcome agreements (SOA) between the Scottish Government and all the 32 local authorities and their community partners. Each SOA sets out a series of local priorities for action in the context of the government’s national aspirations, including climate change mitigation and GHG emission reduction targets.

The Moray Single Outcome Agreement 2008-2009 (Moray Community Planning Partnership, 2009) identifies reducing carbon emission and adaptation as the first areas of action in relation to climate change. The document recognises Moray Council’s potential for carbon sequestration and for the implementation of a biomass market given the region’s extensive forestry coverage. Green initiatives already developed include accommodating windfarms in conformity with policy guidelines of the Council’s Development Plans and a Development Plan to promote sustainable development and practice, which requires developers to demonstrate energy-saving construction techniques. The Aberdeen City Single Outcome Agreement 2008-2011 states the Council’s target to become carbon-neutral by 2020. Similarly, the Aberdeenshire Single Outcome Agreement 2008-2009 expresses the aim of Aberdeenshire to be a sustainable and carbon neutral region by the year 2030.

In 2009, Aberdeen City and Aberdeenshire councils launched the Carbon Management Plan 2010-2015 and the Climate Change Action Plan 2011-2015, respectively. These plans set out how Aberdeenshire and Aberdeen City councils are working towards the goal of carbon neutrality. The Aberdeenshire Plan focuses on four main themes: energy, travel, waste and behavioural changes (Aberdeenshire Council, 2009). The Aberdeen City Council focuses on three top projects considered the “big hitters” in delivering the greatest carbon savings. These are the conversion of a CHP Scheme to biomass
gasification, a ‘Methane Capture’ project\textsuperscript{10}, and a staff awareness raising and training programme (Aberdeen City Council, 2009).

1.4 GHG emission mitigation in rural land uses

The mitigation of GHG emissions in the rural land use sector involves three essential steps: an inventory of the GHG emissions, the selection of potential mitigation options and the assessment of the barriers and supporting factors to the implementation of those options.

1.4.1 GHG emissions inventory

In order to assess the contribution of an individual or group of mitigation practices in a given country, province, region, district or council and for a given sector of economy (e.g. rural land use sector), GHG emissions have to be inventoried, i.e., estimated. The Kyoto Protocol (Article 5) established that each Party included in the list of “Annex 1 countries” should have in place a national system for the estimation of anthropogenic GHG emissions by sources and sinks (UN, 1998). In the UK, the National Atmospheric Emissions Inventory (NAEI) is the standard reference air emissions inventory and includes emission estimates for a wide range of important pollutants including CH\textsubscript{4}, CO\textsubscript{2} and N\textsubscript{2}O. The NAEI covers GHG emissions from 11 sectors of the economy, including agriculture and nature, and it takes into account the guidelines provided by the IPCC which govern inventory compilation on a national scale (Tsagatakis et al., 2010).

The Greenhouse Gas Inventory Protocol (GRIP) is intended to be used by regions, devolved administrations and entities at other spatial scales wishing to monitor their emissions and to gain an insight into emission drivers. It was first used to assess GHG emissions in Scotland in 2005, and considers four sectors: energy, industrial processes,  

\textsuperscript{10} Technology to capture and use methane from rotting waste which typically involves collecting organic waste in sealed tanks where bacteria digest it anaerobically, generating raw biogas - a mix of about 70% methane and 30% carbon dioxide with other trace elements (http://www.reliableplant.com/Read/15353/epa-honors-seven-lfill-methane-capture-projects, last accessed 07/09/2012).
agriculture and waste. The GRIP methodology has three stages, a first stage where a GHG inventory is produced, a second stage where the challenge of producing a GHG inventory based on different energy scenarios is tackled, and a third stage where those energy scenarios are used to inform carbon reduction plans for cities and regions (Carney et al., 2009).

Greenhouse gas emissions can be very specific to regional and local contexts since they are a function of land management, climate, geography and technology (Hillier et al., 2012). At a smaller (e.g. farm) scale, there has been interest in the development of software tools to estimate GHG emissions (Hillier et al., 2012). Some examples are the CPlan (Dick et al., 2008), the Carbon Accounting for Land Managers (CALM) (Country and Land Business Association, 2009) and the Cool Farm Tool (Hillier et al., 2011). The emission sources considered by the first two calculators are energy and fuel, livestock, fertiliser application, crops, forest harvest, land use changes, and primary processing and storage in the case of the Cool Farm Tool. The types of methods available for agricultural GHG emissions quantification are the IPCC Tier 1 default emission factors, hybrid approaches using process or empirical models to develop region-specific empirical equations with emission factors (Tier 2), process-based models (Tier 3), and sampling and measurement (Hillier et al., 2012). These methods differ in their complexity, data requirements, aggregation level and uncertainty.

Currently, the Soil Association is developing a Farm Carbon Assessment Tool which consists of an alternative approach to farm carbon footprinting (SWARM, 2012). This tool, instead of focussing on figures and tonnes of emissions, allows farmers to identify which farm activities contribute most significantly to their farm’s carbon footprint and scores key farm practices in relation to the impact they have on GHG emissions. It is a descriptive assessment based on the farmer’s knowledge of the practices currently employed on the farm.

1.4.2 Mitigation options

There is an extensive catalogue of potential individual mitigation practices for the rural land use sector, and these are often grouped for convenience (Moran et al., 2010). For example, in the IPCC Fourth Assessment Report, Smith et al. (2007a) considered seven
groups of mitigation practices: cropland management, grazing land management and pasture improvement, improved management of agricultural organic/peaty soils, restoration of degraded lands, livestock management, manure management and bio-energy production. Most of these groups of practices are based on the premise that most agricultural soils have not reached their carbon saturation point and so are potential sinks. Several studies (Freibauer et al. 2004; Radov et al., 2007; Smith et al., 2008) have gathered evidence on the technical mitigation potential of different proposed practices, defined as the full biophysical potential of a mitigation practice if all barriers could be overcome (Smith, 2012).

In direct response to the Climate Change Scotland Act 2009, where individual sectors such as agriculture, forestry or renewable energy were considered in isolation, the Land Use Strategy for Scotland considers land use as a whole and includes renewable energy as a land-based option to mitigate climate change (Scottish Government, 2011a). The interest in renewable energy has been growing in Scotland since the Climate Change Committee (CCC) has suggested an increased penetration of renewable heat technologies (e.g. biogas, biomass boilers and biomass CHP) across residential, commercial, public and industrial sectors (Committee on Climate Change, 2010). This has obvious implications on the land use sector. Moving beyond conventional farming into energy production is advocated by the local farmer and entrepreneur Maitland Mackie (Mackie, 2011). He advises policy-makers to support local ownership of the land-based renewable energy potential to deliver some £1 billion annually into Scotland’s rural sector (Mackie, 2011).

1.4.3 Barriers to implementation of mitigation options

Although there is a range of technically feasible practices to reduce GHG emissions, it is not obvious which of them will be implemented in a real-world situation. Different categories of barriers to implementation reduce the technical potential of mitigation practices (Smith et al., 2007b). These barriers are highly site and context-specific, and practices that may be act together in one context may have significant adverse effects in another (Streck et al., 2011). Thus, there is no universally optimal list of mitigation practices since they need to be evaluated for individual land use systems, specific climatic, edaphic, social settings, and historical land use and management (Smith,
2012), and arguably at farm level. Moran et al. (2008) identified mitigation practices that deliver the most economically efficient reductions in GHGs within the rural land use sector in the UK by using Marginal Abatement Cost Curves (MACCs). In the construction of MACCs, mitigation practices are put in the vertical axis of a graph in increasing cost per unit of CO₂ equivalent mitigated and the volume of emissions mitigated given the adoption of the practice is put in the horizontal axis of the same graph (Moran et al., 2010).

The most economically efficient mitigation practices are not always those actually implemented (Moran et al., 2010). Ultimately, land managers (e.g. farmers, estate owners, foresters) are those who decide whether a mitigation practice will be implemented or not, and several variables influence their behaviour and consequent decision. Van der Ploeg (1994) considered that within a farming community there are different styles or strategies of farming which farmers are very aware of, and which lead them to choose a specific strategy to guide their own management. This approach is based on Bourdieu’s notion of cultural habitus. In this notion, behaviours become part of the society’s structure when the reason for those behaviours is no longer recollected but is embedded in individuals and culture (Bourdieu, 1977). Willock et al. (1999) also pointed out that personal factors affect attitudes to farming and objectives in farming, and that these, together with external farm factors (e.g. climate), determine farming behaviours. According to Vanclay et al. (1998), farming extension has failed to recognise the importance of sociocultural diversity in developing extension programmes. Arguably, GHG mitigation programmes ought to take this diversity into consideration.

It is important to implement policy instruments that more directly target the reduction of GHG emissions from rural land uses. Storey and McKenzie-Hedger (1997) found a wide range of approaches in OECD\textsuperscript{11} countries, such as regulatory approaches (e.g. regulations on fertiliser application, restrictions on livestock density), economic instruments (e.g. taxes on fertiliser use, incentives to forestry), information and education (e.g. codes of good agricultural practices), research and development (e.g. …

\textsuperscript{11} OECD – Organisation for Economic Co-operation and Development.
ways to reduce enteric fermentation and liquid-manure production) and voluntary approaches (e.g. implementation of anaerobic digestion, reducing the use of fertiliser). These authors consider that the appropriate combination of instruments depends on political and socio-economic factors as well as the location-specific characteristics of rural land uses.

1.5 Scope of the thesis

The Climate Change (Scotland) Act 2009 presents a big challenge to the rural land use sector since this is expected to mitigate its own GHG emissions as well as contribute to reductions in GHGs emissions from other sectors that cannot be completely eliminated (e.g. transport, industry). At the same time, it also expects the rural land use sector to meet an anticipated rise in food demand which will consequently lead to a rise in GHG emissions. These facts present a clear justification of the need for local GHG emissions inventories despite the inherent uncertainties associated with the estimates. In addition, a number of authorities have called for regional-level analysis of the scope for mitigation. Even though regional agencies are recognised to have central roles in emissions reduction and in designing and implementing mitigation strategies, the regional management of GHGs is an underdeveloped theme in climate change mitigation research. Compared to assessing technical emissions reduction potential, relatively little work has been undertaken in relation to social, economic and policy barriers affecting the potential of land-based mitigation strategies at the regional level. In relation to the assessment of GHG emissions from the rural land use sector, current inventories (e.g. NAEI, GRIP) only include emissions from “agriculture”; emissions from other rural land uses (e.g. peatland, moorland) are not considered.

A regional GHG emissions inventory for Aberdeen City and Shire Strategic Development Planning Authority was carried out by Carney and Prestwood (n.d.) using the GRIP inventory approach for the year 2005, but only GHG emissions from farmyard animals and fertiliser application in agricultural soils were included in the rural land use sector. In addition, nothing was said about CO₂ sinks.
Thus, the overall aim of this study is to improve the understanding of the management of GHG emissions and removals at the regional level, with particular emphasis on agriculture (cultivation of land for crops and livestock production), forestry (plantation with trees) and sporting (hunting) areas, which include moorlands and peatlands. The main research questions investigated were:

a) What is the contribution of the rural land use sector to the overall GHG emissions budget of North East Scotland?
b) What are the suitable GHG emission reduction practices for the rural land use sector?
c) What, according to stakeholders’ perspectives, are the barriers and supporting factors to the implementation of mitigation practices?
d) Can woody biomass provide an appropriate a source of renewable energy for space and water heating to contribute to a GHG-neutral North East Scotland?
e) Is the rural land use sector likely to achieve a 21% GHG emission reduction target within eight years’ time period, i.e. by 2020 as specified by the Climate Change (Scotland) Act 2009?

To address these questions the baseline for GHG emissions from the rural land use sector was established. GHG emission estimates focused on the primary sector of the economy and not on the whole business chain. For example, emissions released during the industrial production of nitrogen (N) fertiliser to be applied on arable land were not included, while emissions resulting from the application of N in soils were. Mitigation practices for the rural land use sector were identified from the literature, their potential was estimated, and regional stakeholders’ perspectives on their implementation were assessed. Given the fact that renewable energy has now been integrated in the policy framework as a mitigation option for the rural land use sector, in which most renewables are produced (e.g. woodfuel, wind), the potential for woody biomass as a source of energy for space and water heating was discussed as a specific, potentially valuable option in reducing GHG emissions.
1.5.1 Research approach

The purpose of this section is to position the approach undertaken in this study within scientific philosophy (the study of general and fundamental problems). Although many scientists disregard the relevance of philosophical issues to their research, others consider that “no research takes place in a philosophical vacuum” (Kitchin and Tate, 2000: 3). All research is framed by philosophical beliefs which influence the choice of topics and methods for the research undertaken. Research aims to provide answers to questions and this necessarily raises ideological, epistemological, ontological and methodological questions about how and why research is conducted (Kitchin and Tate, 2000).

Ideology embodies the underlying social or political reasons for seeking knowledge; epistemology questions how knowledge is derived; ontology comprises the set of specific assumptions underlying a theory or system of ideas; and methodology can be seen as a coherent set of rules and procedures which can be used to investigate a phenomenon or situation (Honderich, 1995).

Philosophical contextualising is important because it helps us to understand what other researchers have done and why they have done it, as well as to find an approach on which to base the research. In addition, it frames the theoretical context in which to justify the findings (Kitchin and Tate, 2000).

1.5.1.1 A regional study approach

This thesis is built on the premise that a regional approach is an appropriate level to estimate GHG emissions and formulate appropriate land-based mitigation strategies. At the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro, Brazil, in 1992, it was implicitly recognised that a bioregional-type scheme for managing climate change would be significantly advantageous for GHG emission mitigation (Feldman and Wilt, 1999). Several activities contributing to global climate-change for example, energy production and consumption, deforestation and transportation are influenced by, and take place within, activity sectors in individual states, provinces and regions, and can be explored at a range of spatial scales.
Bioregionalism is a body of thought and related practice that was developed to respond to the challenge of linking socially just human cultures in a sustainable way to the region-scale ecosystems in which they are permanently embedded (Aberley, 1999). According to Lipschutz (1999), a bioregion links a place or community in which residents are related in historical, cultural and material terms, with the surrounding nature. Aberley (1999) considers that a bioregion offers a degree of decentralization best able to support the achievement of cultural and ecological sustainability. Further, “Agenda 21”, a non-binding and voluntary action plan related to sustainable development and produced during the UNCED, highlighted that programmes designed to reduce GHG emissions should be implemented at local and regional levels because “open governance responsive to diverse constituencies and decentralized feedback to national policies is most likely to occur at the local and regional level” (UNCED, 1992). The UN Development and Environment Programmes (UNDP and UNEP) also recognised that the implementation of climate strategies relies heavily on local behaviours and investment choices, and that success can only be guaranteed when activities targeting local populations and regions are carried out simultaneously with national level initiatives. Smith et al. (2007a) pointed out the significant regional differences in the relative importance of GHG emission sources. Winter and Lobley (2009) recommended that local responses should not be neglected, and called for an emergent sense of place in agricultural and food policy discourses, presumably also including land-based mitigation policies.

Regional approaches are also considered in Scottish policy. A key feature of the Scottish Rural Development Programme 2007-2013 (SRDP) is to deliver national objectives through local solutions, with distinctive Regional Priorities as a central tool in achieving this (Scottish Executive, 2006b). The Rural Priorities Scheme is a competitive mechanism to ensure that contracts are awarded for the proposals which are best able to deliver the agreed regional priorities. The Royal Society of Edinburgh (RSE) recommends that the Scottish Government and local authorities should actively assist local communities to introduce low-carbon initiatives because effective solutions require local knowledge and local buy-in (RSE, 2011). Such an approach is also supported because it is believed to reduce local resistance to large-scale externally driven schemes (RSE, 2011). The RSE considers that the actions of local authorities
will be what determine whether Scotland will accomplish the GHG emission reduction targets or not (RSE, 2011).

In summary, regions not only provide a pragmatic spatial entity in which to explore mitigation through land use, but also comprise a socio-economic entity favoured as a level of implementation of sustainable development practices.

1.5.1.2 An interdisciplinary approach

Climate change can be considered a ‘wicked problem’ (e.g. Prins, 2011), i.e. a complex problem with a certain group of characteristics that makes it difficult to address (Rittel and Webber, 1973). The ‘climate change problem’ is difficult to define for the following reasons: it has no definitive formulation; it changes as climate, knowledge and perceptions change; local sub-problems differ from place to place; stakeholders have different perspectives and goals; co-ordination and behavioural change are critical; to tackle it unintended consequences are likely to happen; and policies to address it have not been very successful.

To better understand such complex problems, some form of integration of the expertise, methodologies, or epistemological perspectives from different research disciplines and stakeholder knowledge has been proposed (Evely et al., 2008). Within the academic literature, this integration of knowledge is usually referred to as cross-disciplinarity, the overarching term that encompasses multidisciplinary, interdisciplinary and transdisciplinary approaches (Evely et al., 2010). Under a multidisciplinary approach, studies involve different academic disciplines to research one theme with multiple disciplinary goals, but the research process occurs as parallel disciplinary efforts, without integration (Tress et al., 2005). The interdisciplinary approach integrates different disciplines and methods in order to have a new understanding of the problem that would not be possible through the perspectives of one single discipline (Bammer, 2005). In this approach, the disciplines are forced to cross subject boundaries, to create new knowledge and theories and to solve a common research goal (Tress et al., 2005). The transdisciplinary approach combines interdisciplinarity with a participatory approach since it involves academics and non-academics working collaboratively to
define and develop the research goals and methods together (Tress et al., 2004; Evely et al., 2010).

This thesis follows the interdisciplinary approach because the subject boundaries of unrelated academic disciplines of different research paradigms (e.g. physics, biology, chemistry, geography, and economics) are crossed in order to create new knowledge and solve a common goal concerning how to assess the contribution of rural land uses to GHG emissions mitigation. The thesis does not follow a multidisciplinary approach because there is integration between disciplines and a common goal to reach, not multiple goals. It does not follow a transdisciplinary approach either, because the goals and methods of the research were set and directed by a single researcher. Experts and farmers were consulted but did not influence research goals or methods.

Evely et al. (2008) state that the integration of natural and social sciences is challenging because of the difficulty in dealing with the extensive range of underlying philosophies and epistemologies. In this thesis, natural science approaches were used in Chapter 2 to assess the GHG emissions from several rural land use practices in North East Scotland (e.g. GHG from mineral N fertiliser application and manure management), in Chapter 3 to estimate the physical potential of mitigation practices in rural land uses (e.g. woodland planting; using clover for biologic fixation of nitrogen) and in Chapter 5 to estimate the woodfuel available for space and water heating. Social science approaches dominated Chapters 4 and 5 to assess the stakeholders’ perspectives on the implementation of mitigation practices and were partly used in Chapters 3 and 5 to review the barriers to the implementation of mitigation practices.

There are different philosophies in the natural and social sciences. Positivism\(^{12}\) dominates most research in natural sciences (Evely et al., 2008) and also influences some types of social science inquiry. Positivists consider that the methods of the natural sciences may be applied to all areas of investigation, such as philosophical, social or scientific (Honderich, 1995). The principles of external validity and reliability defended by this philosophy are what drive many natural scientists in their choice of methods.

\(^{12}\) E.g. Auguste Comte (1798-1857).
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(Evely et al., 2008). Positivists argue that society operates according to its own laws like the physical world operates according to the laws of nature, and that, by systematically and empirically collecting data it is possible to predict and explain human behaviour in terms of cause and effect (Kitchin and Tate, 2000). Cloke et al. (cited by Kitchin and Tate, 2000) point out some criticisms of the use of positivism in social sciences. These relate to the underestimation of the complex relationship between theory and observation, the failure in recognising that spatial patterns and processes are bound up in economic, social and political structures and are reflections of the perceptions, intentions and actions of human beings. Scepticism towards positivism has been supported by philosophers such as Thomas Kuhn, and philosophical movements such as critical realism\(^{13}\) and neopragmatism\(^{14}\).

This thesis takes into account some of these criticisms, and acknowledges the facts that GHG emissions and the mitigation potential of rural land uses do not depend exclusively on physical processes and that the implementation of mitigation practices has to be analysed in a more ‘critical approach’. Thus, the philosophies underlying this thesis connect to ‘critical realism’ and ‘transcendental realism’\(^{15}\). These philosophies perceive reality as an interplay between concrete structures and actor perceptions (Evely et al., 2008). Realism aims to identify how something happens (causal mechanisms) and how extensive a phenomenon is (empirical regularity) (Kitchin and Tate, 2000). Realists want to discover what produces changes, what make things happen and what allows or forces changes (Kitchin and Tate, 2000). Social reality is produced by humans, but also exists objectively and dominates human experience (Orlikowski and Baroudi, 1991). Contrary to positivism, which can be seen as a closed system of discrete events that can be tested with specific hypothesis, critical realism presents an alternative by “assuming a stratified and differentiated world made up of events, mechanisms and structures in an open system where there are complex, reproducing and sometimes transforming interactions between structure and agency whose recovery will provide answers to questions posed about processes” (Cloke et al., 1992: 146, cited by Kitchin and Tate, 2000). Climate change mitigation can be looked at through the lens of Gidden’s theory:

\(^{13}\) E.g. Frankfurt School (Habermas, 1929-); American critical realists (Lovejoy, 1873-1962).

\(^{14}\) E.g. Haack (1945-); Dennett (1942-).

\(^{15}\) E.g. Kant (1724-1804); Bashkar (1944-).
the duality of structure. According to Giddens (1984), structures are rules and resources, recursively implicated in the reproduction of social systems, i.e., what is seen in society (e.g. relations, interactions). This means that people shape structure and are shaped by structure (Giddens, 1984). In climate change mitigation, the structures can be considered the rural land use policies, and this structure influences which mitigation practices or measures farmers and other land managers implement.

In this thesis, natural sciences, and consequently a more ‘positivist approach’, are used in Chapter 2 to assess the GHG emissions from several rural land use practices in North East Scotland (e.g. mineral N fertiliser application; manure management) and in Chapter 3 to estimate the physical potential of mitigation practices in rural land uses (e.g. woodland planting; using clover for biological fixation of nitrogen). The ‘critical approach’ is adopted in Chapters 3, 4 and 5 in order to investigate stakeholders’ involvement in the implementation of land use mitigation practices in North East Scotland. Using a ‘critical approach’ to investigate the implementation of land use mitigation practices is justified by the fact that this is concerned with human choices and actions: what Giddens terms agency (Giddens, 1984) and not mechanistically dependent relationships.

The nature of this interdisciplinary research and the underlying philosophies are best achieved by the adoption of a mixed-method approach. As a result, the sources of primary data include a mix of quantitative and qualitative data. The justification for the use of mixed methods is that the combination of quantitative and qualitative approaches provides a better understanding of research problems than either approach alone (Creswell and Clark, 2007). Both qualitative and quantitative data are used to get a full picture of the phenomena under investigation (Evely et al., 1998). The risks of this type of research design are of transcending the traditions of a particular discipline and failing to acquire a secure disciplinary identity (Brannen, 2005). This risk is accepted in this thesis given the necessity of working with different quantitative and qualitative data in order to investigate the potential of rural land uses to mitigate GHG emissions in North East Scotland. The type of research question necessitates a cross-disciplinary approach.

Qualitative methods included stakeholder participation, namely focus groups with farmers, workshops with key-informants and face-to-face questionnaires (Chapters 4),
analysis of secondary qualitative data from interviews and focus groups (Chapter 5) and policy analysis (Chapters 3 and 5). In this thesis, the use of stratified sampling design and the testing of hypothesis was not used. Instead, qualitative methods where participants were identified by snowball sampling techniques or other means (e.g. convenience sampling) were used.

Quantitative methods included the calculation of percentages about the current and potential uptake of land-based mitigation practices (Chapter 4), the use of an Excel-based model to estimate GHG emissions from several land use activities within the rural land use sector in North East Scotland, following the guidance of the 2006 IPCC guidelines for national GHG emissions inventories (Chapter 2). Quantitative methods were also used to estimate the physical potential of mitigation practices, GHG emissions reduction achieved if these were implemented (Chapter 3) and the quantity of wood available to produce woodfuel (Chapter 5). Quantitative data included secondary data from official statistics, policy documents, reports and peer reviewed articles. Quantitative methods were limited by the availability of secondary data. Quantitative data also included primary data collected by face-to-face questionnaires. Data collected was both inductive and deductive. It was inductive because the research came before the theory, which means that the theoretical propositions were generated from the data by identifying regularities (Kitchin and Tate, 2000). It was also deductive because, naturally, the researcher was probing for hypotheses as the data was gathered (e.g. to what extent do expert and farmer opinions on feasible mitigation options coincide) and the theory was constructed.

Figure 1.2 shows the methods used in each chapter:
1.5.2 Thesis framework

This thesis consists of six chapters, including this introduction, four empirical studies, and the general discussion and conclusion. The introduction entails a section on the main objectives, scope and structure of the thesis, as well as a section on the main facts about climate change science, including the relationship with the rural land use sector, and a section about the evolving climate change policy. Chapter 2 provides guidance for the development of a GHG inventory to estimate CH₄, N₂O and CO₂ emissions from the rural land use sector at the regional level and it estimates GHG emissions from this sector in North East Scotland. It compares the results with those for Scotland and
discusses the advantages of regional GHG inventories for rural land uses. Chapter 3 defines the physical mitigation potential of land-based mitigation practices, uses this as a criterion to select land-based mitigation practices for North East Scotland, and reviews whether or not a 21% GHG emission reduction could be achieved by 2020 in the region’s rural land use sector by implementing the selected mitigation practices. Chapter 4 identifies the barriers and supporting factors to implementation of land-based mitigation practices according to stakeholders’ perspectives. Data was collected through a farmers’ questionnaire, participatory workshops with experts and focus groups with farmers. Chapter 5 explores the scope for increasing the contribution of woody biomass for space and water heating. It reviews the changing policy context and the contextual factors behind increasing support for the use of wood for heating, and it assesses the potential benefits of a partial shift from non-renewable sources to wood energy. Chapter 6 presents the main findings of this thesis, as well as the discussion of the research questions and the contribution of this thesis to identify future climate change mitigation research and to suggest areas for policy action.

The relation between each chapter is described in Figure 1.3: Chapter 1 sets the context of the thesis. Mitigation practices collected from the literature and analysed in Chapter 3 were used in Chapter 4 for the farmers’ survey on the uptake of mitigation practices and in workshops with experts and the focus groups with farmers. GHG emission reductions that would be obtained if the land-based practices selected in Chapter 3 were implemented were compared to the forecast GHG emissions from rural land uses in North East Scotland between 2010 and 2020 estimated in Chapter 2. The results obtained Chapter 2 were used in Chapter 5 in order to assess the mitigation potential of using woody biomass as a renewable energy source for space and water heating in North East Scotland.
1.5.3 Characterisation of the study region

The region selected for study was North East Scotland (Figure 1.4). This region includes the council areas of Aberdeenshire, Moray and Aberdeen City. One of the reasons why this region was chosen was because it represents a diversity and intensity of agricultural use types, different styles for forestry, land under predominantly nature conservation and substantial areas of game management, which endowed it with considerable diversity and a high offsetting potential. Also, since most Scottish land uses can be found in North East Scotland, at different intensities, this makes the region a microcosm of Scotland’s land use sector. A further reason is the expressed aspiration of the largest council in North-East Scotland by land area (Aberdeenshire) to become carbon-neutral in the medium term (by 2030) (Aberdeenshire Community Planning Partnership, 2011).
In 2011, there were about 550,000 people living in North East Scotland, of which about 60% lived in rural areas (General Register Office for Scotland, 2001). Agricultural land covers almost 70% of the total land area, although the boundary between predominantly farmland and sporting land use is often inexactely defined. The main types of farm in North East Scotland are presented in Figure 1.5 (Scottish Government, 2010):

Note: LFA – Less Favoured Areas.
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Forest covers about 19% of the total area, with about 63% owned by private entities (e.g. landowners, farmers, NGOs) and 37% owned or leased to the Forestry Commission Scotland. Conifers are the main type of tree species, representing 72% of all woodland, with broadleaved woodland, mixed woodland open space within woodlands representing the remaining 25% of the woodland cover (Forestry Commission, 1997). Scots pine and Sitka spruce are the main conifer species, and birch and beech the main broadleaved species. Sporting land covers about 10% of the total land, and urban area about 2%. It is estimated that 2% of the total area is National Nature Reserves (NNR’s) and Sites of Special Specific Interest (SSSI’s).

1.6 Conclusion

Climate change is one of the major challenges facing the planet. The UNFCCC shows consensus in relating the increase of GHGs emissions resulting from human activity to the increase of global average temperature and ultimately to climate change (UNFCCC, 1992). In order to avoid dangerous climate change, countries need to take action in order to limit overall net GHG emissions and to enhance sinks of CO2. In Scotland, the Climate Change (Scotland) Act 2009 established an 80% and 42% GHG emission reduction targets by 2050 and 2020 respectively, comparative to 1990 levels.

Tackling the adaptive and mitigation challenges associated to climate change requires close consideration of the rural land use sector because this sector has the unique capacity of delivering zero and negative carbon emissions since it can act as a sink and reservoir for CO2. The Scottish Land Use Strategy (Scottish Government, 2011a) emphasises that this sector should be part of the country’s climate change mitigation strategy. There are several mitigation options for the rural land use sector, but the implementation of these depends, largely, on the willingness of key stakeholders to adopt them. In addition, the complexities of the rural land use policy, multilevel governance, and uncertainty of whether renewables should be accounted as a rural land use sector mitigation option or not are expected to affect stakeholders’ decisions.

This thesis takes an interdisciplinary approach to assess the contribution of GHG emissions from the rural land uses in a Scottish region – the North East Scotland and to investigate the potential of the rural land use sector to reduce GHG emissions. The
thesis uses quantitative (e.g. kg of mineral N fertiliser applied in cropland) and qualitative data (e.g. barriers to the implementation of mitigation practices).

This thesis contributes to better understanding of the application of Intergovernmental Panel for Climate Change (IPCC) methodology to estimate GHG emissions from rural land uses at a regional level, as well as the sources of uncertainty associated with these emissions, and the sources of data available. The thesis also contributes to better understanding the available mitigation options suitable for the region’s rural land use sector and the barriers to their implementation. In addition, it uses an example of a source of renewable energy, woodfuel, to exemplify the contribution of the rural land use sector to GHG emissions mitigation in the space and water heating sector.
References


Mackie, M. 2011. The real rationale for renewable energy and the important role land based wind energy generation has to play and its potential to revolutionise the rural economy while delivering Scotland’s renewable energy targets. [ONLINE] Available at: www.greenenergynet.com/scotlands-energy-challenge [Accessed 13 September 2011].


UN 2012 *The Future We Want*. [ONLINE] Available at: [http://www.unsd2012.org/content/documents/727The%20Future%20We%20Want%2019%20June%201230pm.pdf](http://www.unsd2012.org/content/documents/727The%20Future%20We%20Want%2019%20June%201230pm.pdf) [Accessed 13 July 12].


2 The contribution of rural land uses to greenhouse gas emissions
Abstract

Challenging greenhouse gas (GHG) emission reduction targets were set in Scotland by the Climate Change (Scotland) Act in June 2009. The national objective is to reduce GHG emissions by 42% by 2020 and 80% by 2050, compared to 1990 levels. The GHG emission reduction targets apply both to the traded and non-traded sectors, thus including the rural land use sector. In North East Scotland, rural land uses cover the majority of the land area, with agriculture and forestry representing ca. 90% and sporting land ca. 10% of the total area. The objectives of this study were to provide guidance for the development of a regional GHG inventory to estimate methane (CH$_4$), nitrous oxide (N$_2$O) and carbon dioxide (CO$_2$) emissions from rural land uses in North East of Scotland, to compare with that of the United Kingdom (UK), and to discuss the advantages of regional GHG inventories for rural land uses. The study mainly followed the guidance of the IPCC (Intergovernmental Panel on Climate Change) Revised Guidelines for National Greenhouse Gas Inventories and adapted these to the regional level. Data available for North East Scotland allowed an assessment of annual GHG emissions from livestock and grassland, cropland management and sporting land, as well as carbon sequestered by forests, between 1999 and 2010. Estimated GHG emissions of 1420 ktCO$_2$e from livestock, grassland and cropland management obtained in this study for 2009 compare well with estimates for the same region from larger-scale inventories. The methodology described, including the steps undertaken for data collection, the shortcomings found and strategies to overcome these, could be applied to other UK or European regions.

Keywords: GHG emissions, targets, rural land uses, regional, North East Scotland

2.1 Introduction

Scotland contributes around 0.2% of total global net GHG emissions (Scottish Executive, 2006). Despite this small contribution, the Climate Change (Scotland) Act 2009 created a challenging statutory framework for greenhouse gas (GHG) emission reductions in Scotland by setting an interim 42% reduction target for 2020, and an 80% reduction target for 2050 compared to 1990 levels. The Act covers non-synthetic GHGs, namely CO$_2$, CH$_4$, N$_2$O and also fluorinated synthetic gases known as F-Gases.
The ambitious target requires the Scottish Government to stimulate action across all sectors of society and the economy to achieve the agreed net GHG emission reduction targets by 2020 and 2050.

In order to achieve these demanding targets, emission reductions from rural land uses should be taken into account. On one hand, forestry can contribute to climate change mitigation through the reduction of atmospheric CO$_2$ by carbon uptake in growing forest biomass, forest vegetation and soils. On the other hand, agricultural activities are important contributors of CO$_2$, CH$_4$ and N$_2$O emissions (Cloy et al., 2012). The Climate Change Delivery Plan (Scottish Government, 2009) states that GHG emissions associated with land use have to be reduced, and that land use has to contribute to deliver climate change adaptation and mitigation objectives. The Land Use Strategy for Scotland (Scottish Government, 2011), which was a direct requirement of the Climate Change (Scotland) Act 2009, explicitly indicates that agriculture and agricultural land use emissions have to be reduced by 2020 and that rural land uses should be considered in any strategy to reduce GHG emissions. Reductions in agricultural emissions are considered important in decreasing the effects of climate change on the sector, and at the farm level are seen as an opportunity to improve business efficiency through increased productivity and water quality and quantity (Russell, 2011).

In order to reduce GHG emissions, it is essential that GHG emissions are recorded and monitored accurately, and that appropriate GHG mitigation strategies are identified. The IPCC (2006) considers that good knowledge of GHG emissions and removals enables the development of GHG mitigation policies in a cost-effective way, allows different policy options to be compared, provides a simple mechanism to monitor the implementation of these policies, and is a key input to scientific studies on many environmental issues. According to Otte (2008), the main objectives of GHG emissions accounting are to manage risks associated to the increase of GHG emissions, to identify GHG reduction opportunities, to facilitate participation in GHG markets and in mandatory or voluntary GHG reporting programmes, and to gain recognition for early action. The IPCC Revised Guidelines for National Greenhouse Gas Inventories provide guidance on compiling national estimates of emissions and removals of greenhouse gases (IPCC, 2006).
The United Nations recommend the compilation and publication of information about GHG emissions at national level, but both the United Nations Environmental Programme (UNEP) and the United Nations Development Programme (UNDP) acknowledge the importance of regional decision-making in climate change management (UNDP, 2008). These programmes recognise that local and regional governments implement national policies and have regulatory planning functions, and are policy-makers and investors in a number of sectors responsible for GHG emissions. Local behaviours and investment choices influence the implementation of climate strategies and mitigation policies link directly to the regional or local level.

Several municipal authorities around the world have already implemented local actions and policies in order to reduce GHGs emissions of regions and cities (SAC, 2008; UNEP, 2011; US EPA, 2011). In the UK, a key feature of the Scottish Rural Development Plan 2007-2013 (SRDP) is to deliver national objectives through local solutions with distinctive Regional Priorities acting as a central tool to achieve this. Climate change mitigation actions are a feature of the SRDP (Scottish Executive, 2006). Further, two of the council areas comprising North East Scotland, namely Aberdeen City and Moray Councils, have committed to reduce GHG emissions under National Outcome 14 – “We reduce the local and global environmental impact of our consumption and production” (Moray Community Planning Partnership, 2009; The Aberdeen City Alliance, 2009). Moray has also signed the Scottish Local Authority Climate Change Declaration, which aimed at linking the council in common purpose with other councils in Scotland and the Scottish Government. The Declaration supports wider national, European and international plans to address climate change. The council has identified areas to reduce GHG emissions and services to anticipate the impact of climate change. Several ‘green’ initiatives designed to raise awareness have been undertaken, such as accommodating windfarms in conformity with policy guidelines in the Development Plan16 and estimating the carbon footprint per capita and per hectare (Moray Community Planning Partnership, 2009). Aberdeen City Council has been recognised at the national level for its innovative approaches to address climate change, energy efficiency and horticultural products quality. The City already has Combined

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16 A Development Plan promotes sustainable development practices and requires developers to demonstrate energy-saving construction techniques.
Heat and Power Plants in order to supply affordable energy as part of the council’s Decentralised Energy Scheme, and there are plans to create an offshore windfarm and to support other renewable energy projects such as bio-energy (Aberdeen City Alliance, 2009). Aberdeenshire, the third council area covered by North East Scotland, has gone even further and aspires to become carbon-neutral in the medium term under Local Outcome 14.2 (Aberdeenshire Community Planning Partnership, 2011). To achieve this target, the council is applying principles of sustainability, social equality, economics and environment to both existing and future development. Strategies and plans which take into consideration the issues of climate change have also been produced, for example the ‘Aberdeenshire Sustainability Charter’ and the ‘Aberdeenshire Renewable Energy Strategy’. In addition, organisations in the public sector have introduced a joint sustainable procurement scheme. This collaborative work originated the North East of Scotland’s Global Footprint project and the North East of Scotland’s Climate Change Partnership.

Accounting for GHG emissions from rural land uses at regional level is a challenging process. Data are dispersed among several sources, and information about management practices in the region also has to be collected. To collect the data and information needed to estimate GHG emissions from rural land uses in a region is a time-consuming task. Smith et al. (2007) noticed the existence of significant limitations in the data required to make more complex inventories effective, and recognised the need to consider progressive enhancement of inventory structures, methods and data inputs. A possible approach to obtain information on GHG emissions from agriculture for a certain region is to use the data collected by the National Atmospheric Emissions Inventory (NAEI) which is available online¹⁷. This provides N₂O, CH₄ and CO₂ emissions for the Cartesian coordinates of all council areas of the UK, including the three councils covered by North East Scotland (Aberdeenshire, Aberdeen City and Moray). Data on emission sources available at the NAEI website are aggregated in 11 UNECE¹⁸ sectors including “agriculture” (UNECE Sector code 10) and “nature” (UNECE Sector code 11). “Agriculture” emission sources include livestock, fertiliser, machinery, incineration of animal carcasses, forests and land use change (Tsagatakis et

“Nature” emission sources include those from non-methane volatile compounds (NMVC), emissions from natural processes in forests, land-use change emissions resulting from deforestation and particulate emissions from mines and quarries (Tsagatakis et al., 2010). Another approach to estimating GHG emissions from agriculture and other rural land uses is to use a carbon footprint calculator. There are several carbon calculators to assess GHG emissions at the farm level such as CPlan (Dick et al., 2008), Carbon Accounting for Land Managers (Country and Land Business Association, 2009; Viner et al., 2006) or the Cool Farm Tool (Hillier et al., 2011). These have to be supplied with farm-specific data, to be inserted by farmers or land managers into a Graphical User Interface.

All these approaches have limitations if the intention is to identify the main rural land uses and activities contributing to GHG emissions of a certain region. In the first case, although a quick way of obtaining information, aggregated data is displayed for each x,y co-ordinate and it is not possible to differentiate individual contributions of each agricultural sub-activity (e.g. manure management, organic fertiliser application) to \( \text{N}_2\text{O}, \text{CH}_4 \) and \( \text{CO}_2 \) emissions. Furthermore, it is only possible to download the latest update of GHG emissions and since the updates take place every two years the most recent dataset is for 2009. According to Tsagatakis et al. (2010), data from NAEI are downscaled from the national estimates, and livestock and poultry distributions are not updated. In the second case, using farm carbon footprint calculators to estimate GHG emissions from rural land uses at regional level would require an estimate of farm GHG emissions of sample of farmers within the region. Data would have to be collected from farmers, and the sum of GHG emissions from farms would represent the total GHG emissions from the agriculture of the region. Although much of the data needed could be derived from the annual farm census, such data would be incomplete, lacking information, for example, on fertiliser application per farm. Without making it compulsory, it would be difficult that all farmers in a region would use a carbon calculator since some of them are simply not willing to do so, others do not record the data needed for the calculations, and others would not know how to use it without help and necessary computer skills. In addition, none of the carbon calculators described above account for GHG emissions from other rural land uses such as moorland (heath) or peatland.
The first step in identifying and targeting of the most suitable mitigation practices to implement in the rural land use sector of a region is to estimate GHG emissions and carbon sequestration, aiming to identify the contribution of each activity within the rural land use sector. This information is fundamental to address GHG emission reduction targets since it will facilitate the choice of relevant GHG mitigation practices in the rural land use sector in North East Scotland. Creating a GHG baseline for this region also intended to report on data availability and data sources needed to undertake GHG emission estimates using the lowest level of complexity of the IPCC methodology (Tier 1). With this in mind, the main objective of this study was to provide guidance for the development of a regional GHG inventory for rural land uses through:

a) Investigating which data sources are available to estimate the contribution of rural land uses to GHG emissions in North East Scotland;

b) Deciding which land use activities should be considered in the estimates of GHG emissions from rural land uses;

c) Estimating the contribution of different land use activities to total GHG emissions from the rural land use sector;

d) Examining the sinks of CO$_2$ within the rural land use sector;

e) Estimating the trends over time of GHG emissions and CO$_2$ sinks in the rural land use sector.

The mix and intensity of agricultural use types, forestry potential and substantial areas of game management (sporting areas) present in North East Scotland make the region a good case study as this can be viewed as a microcosm of Scotland. Of course North East Scotland has a subtly different climate and some distinct soil types which differ a little from other regions of Scotland and these are factors with a significant influence on GHG emissions. Nevertheless, the methodology described is readily transferable to other regions in the UK and elsewhere.

2.2 Methodology

This section includes the characterisation of the land use sector of the study region, North East Scotland, the data used in the estimates and the assumptions undertaken. It
also identifies the sources from which data was collected, the equations used to estimate GHG emissions and CO$_2$ sequestration, and the uncertainty associated to the estimates. Finally, it compares the estimates obtained with results from larger-scale inventories. To carry out the estimates, data from 12 consecutive years were used (1999-2010).

### 2.2.1 Case study description

Land use in North East Scotland is broadly representative of the mix of land uses found more widely in Scotland. Own estimates indicated that around 67% of the North East Scotland land area is under agricultural use, 20% is forestry, 2% is under conservation management, 2% is in urban use and 10-13% is managed as sporting shooting land. According to Cook et al. (2008), the full range of farming enterprises is represented in Aberdeenshire. Employment in agriculture, sporting shooting and forestry is twice the Scottish average (Cook et al., 2008). The area has a large ruminant livestock sector and is characterised by mixed farming. In terms of livestock, prime cattle, beef cows and cattle under one year old comprise the main part of the cattle population in the region, with ewes for breeding, other sheep and non-breeding pigs the main non-cattle livestock, excluding poultry (Scottish Government, 2010). According to Cook et al. (2008), almost 70% of Scotland’s pigs are raised in North East Scotland. The main crops are cereals and oilseed rape, these representing a third of Scotland’s total area of barley and oilseed rape, respectively. Forest land is diverse and the main forest types in North East Scotland comprise pine forests, spruce-dominated forests and riparian woodlands (Forestry Commission, 1997).

According to data published on the NAEI website total GHG emissions in 2009 in North East Scotland were approximately 6,600 ktCO$_2$e. The main sources of CH$_4$ and N$_2$O were agriculture and waste management, and the bulk of CO$_2$ emissions came from industrial and commercial electricity use (including agriculture) and road transport. Approximately 23% of the total GHG emissions (1,490 ktCO$_2$e), were allocated to “agriculture” and 0.008% (0.5 ktCO$_2$e) to “nature”. Data supplied by the NAEI website, in 2009, reveals that the most important GHG contributing to agricultural emissions was N$_2$O (~52%), followed by CH$_4$ (~39%) and CO$_2$ (~8%). The contribution of agricultural emissions to total GHG emissions in North East Scotland is much higher than in Scotland and in the UK as a whole. According to the report
“Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland 1990-2008”, agriculture contributed about 13% of total gross GHG emissions in Scotland and 7% of total GHG emissions in the UK (Sneddon et al., 2010). The reason for the high contribution (23%) of agriculture in North East Scotland is probably the relatively low population density and prevalence of agriculture in the region, particularly the high levels of ruminant livestock production.

2.2.2 Activity data for GHG emissions

To create an annual baseline for GHG emissions and carbon sequestration in the North East Scotland, the IPCC Revised Guidelines for National Greenhouse Gas Inventories for Agriculture, Forestry and Other Land Use Sector were followed (IPCC, 2006). The guidelines adopt six land-use categories, namely, forest land, cropland, grassland, wetlands, settlements and other land. These are further sub-divided into land remaining in the same category, and land converted from one category to another. In this study, the land uses considered were forest land, cropland, grassland, peatland and sporting areas (moorlands, heath). These were recognised as the rural land uses from which most GHG emissions resulting from biological processes in the North East Scotland were coming. In terms of land use change, soil GHG emissions resulting from the conversion of set-aside land into other land uses were not considered because of lack of data available to include in the calculations. The rural land uses and GHG emission sources and sinks covered by this study are presented in Table 2.1.
### Table 2.1 GHG emission sources from rural land uses in North East Scotland

<table>
<thead>
<tr>
<th>Rural land uses</th>
<th>Activities for emission sources and carbon sinks</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>Mineral nitrogen (N) fertiliser</td>
<td>In cropland and grassland, human-induced additions of nitrogen (N) result in direct and indirect N$_2$O emissions since the availability of N influences nitrification and denitrification reactions (IPCC, 2006).</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Organic nitrogen (N) fertiliser</td>
<td>The addition of carbonates to the soil in the form of lime cause CO$_2$ emissions by the dissolution of carbonate limes (IPCC, 2006). Liming is applied to acidic soils in order to reduce acidity and to achieve optimum crop yields and consistent quality (Defra, 2010).</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Liming of agricultural soils</td>
<td>Enteric fermentation is a digestive process occurring in ruminants (e.g. cattle), CH$_4$ is a by-product of enteric fermentation. Non-ruminants (e.g. horses) and monogastric animals (e.g. pigs) also produce CH$_4$ emissions from enteric fermentation but in much smaller quantities (IPCC, 2006).</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Livestock enteric fermentation</td>
<td>Manure management and storage produce CH$_4$ emissions by decomposition of manure in the absence of oxygen, and N$_2$O emissions. The manure management system influences the amount of CH$_4$ and N$_2$O emissions produced (IPCC, 2006).</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Livestock manure management</td>
<td>Addition of nitrogen (N) to grassland by deposition of dung result in direct and indirect N$_2$O emissions since the availability of N influences nitrification and denitrification reactions (IPCC, 2006).</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Livestock dung deposited on pasture</td>
<td>Burning grass or heath for regenerative purposes in order to improve grazing and habitat for red grouse is a source of N$_2$O, CH$_4$ and CO$_2$ emissions from rural land uses (Farage et al., 2009).</td>
</tr>
<tr>
<td>Hunting and shooting (moorland)</td>
<td>Moorland burning in peatland areas</td>
<td>Wild deer are ruminants and produce CH$_4$ emissions by enteric fermentation.</td>
</tr>
<tr>
<td>Peatland</td>
<td>Disturbed peatlands</td>
<td>Carbon dioxide, CH$_4$ and N$_2$O emissions from disturbed peatlands can occur due to excessive drainage, overgrazing and/or peat harvesting (Artz et al., 2012; Worrall and Evans, 2009).</td>
</tr>
</tbody>
</table>

#### 2.2.3 Data needed, assumptions and data sources

It was not always possible to find specific data for the region, and sometimes averaged data for Scotland or even for the UK had to be apportioned for North East Scotland. The main assumptions of this study are presented in Table 2.2.
Table 2.2 Data needed and assumptions to estimate GHG emissions from rural land uses in North East Scotland

<table>
<thead>
<tr>
<th>Sources</th>
<th>Data needed</th>
<th>Assumptions for North East Scotland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic fertiliser application</td>
<td>- Number of animals in each livestock category;</td>
<td>- All the organic manure from cattle, pigs, sheep and chicken, managed in each management system is applied to cropland and grassland for mowing and grazing;</td>
</tr>
<tr>
<td></td>
<td>- Excretion rate per animal (depending on average weight and average days alive);</td>
<td>- Manure from horses is sold for plant gardens and not applied in cropland;</td>
</tr>
<tr>
<td></td>
<td>- Type of manure management system and housing period per livestock category;</td>
<td>- Manure management: Around 75% of the cattle manure applied on farms is farm yard manure (FYM) and 25% is slurry; 70% of pig manure applied on farms is FYM and 30% is slurry systems; 100% of the laying hens and broilers manure applied on farms is poultry manure without litter;</td>
</tr>
<tr>
<td></td>
<td>- Area of crops per year;</td>
<td>- Housing period: Dairy cows spend 60% of the year inside, non-dairy cattle 50% of the year inside, pigs between 86% and 100%, depending on the life stage (sows or finishers), and poultry between 83%-97% of the year inside; For sheep, goats, farmed deer and wild deer, it was assumed 0% housing period, i.e., 100% time spent outside with all the dung produced deposited on pasture and not managed in a specific manure management system; it was also assumed 0% housing period for horses but that all the dung deposited on pasture was collected, managed in FYM systems and sold for plant gardens;</td>
</tr>
<tr>
<td></td>
<td>- Amount of N fertilizer applied per crop type per year;</td>
<td>- Crops receiving N fertiliser: wheat, triticale, barley, oats, oilseed rape and linseed, potatoes, peas, beans, turnips, swedes and beet for stock feeding, other crops for stock feeding, vegetables for human consumption, orchard and soft fruit and all other crops (Scottish Government, 2010);</td>
</tr>
<tr>
<td></td>
<td>- Percentage of crop area receiving dressing per year;</td>
<td>- Grass for mowing and grass for grazing receive N fertiliser, while rough grazing receives no fertiliser (Scottish Government, 2010).</td>
</tr>
<tr>
<td></td>
<td>- N\textsubscript{2}O emission factors.</td>
<td></td>
</tr>
<tr>
<td>Mineral fertiliser application</td>
<td>- All the organic manure from cattle, pigs, sheep and chicken, managed in each management system is applied to cropland and grassland for mowing and grazing;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Manure from horses is sold for plant gardens and not applied in cropland;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Manure management: Around 75% of the cattle manure applied on farms is farm yard manure (FYM) and 25% is slurry; 70% of pig manure applied on farms is FYM and 30% is slurry systems; 100% of the laying hens and broilers manure applied on farms is poultry manure without litter;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Housing period: Dairy cows spend 60% of the year inside, non-dairy cattle 50% of the year inside, pigs between 86% and 100%, depending on the life stage (sows or finishers), and poultry between 83%-97% of the year inside; For sheep, goats, farmed deer and wild deer, it was assumed 0% housing period, i.e., 100% time spent outside with all the dung produced deposited on pasture and not managed in a specific manure management system; it was also assumed 0% housing period for horses but that all the dung deposited on pasture was collected, managed in FYM systems and sold for plant gardens;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Crops receiving N fertiliser: wheat, triticale, barley, oats, oilseed rape and linseed, potatoes, peas, beans, turnips, swedes and beet for stock feeding, other crops for stock feeding, vegetables for human consumption, orchard and soft fruit and all other crops (Scottish Government, 2010);</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Grass for mowing and grass for grazing receive N fertiliser, while rough grazing receives no fertiliser (Scottish Government, 2010).</td>
<td></td>
</tr>
<tr>
<td>Disturbed peatlands</td>
<td>- Area of disturbed peatlands;</td>
<td>- Much of Scottish peatland is not in pristine condition, with some areas in poor condition and emitting GHGs (Artz et al., 2012);</td>
</tr>
<tr>
<td></td>
<td>- CO\textsubscript{2}, N\textsubscript{2}O and CH\textsubscript{4} emission factors.</td>
<td>- It was considered that disturbed peatland corresponds to peatland under acid grassland, arable, broadleaves, coniferous, calcareous grassland, improved grassland, inland bare ground, montane habitats and non-rotational agriculture.</td>
</tr>
<tr>
<td>Moorland (heath) burning</td>
<td>- Area of moorland burning per year;</td>
<td>- In the UK, around 18% of upland peat is burnt cyclically (Worrall and Evans, 2009). The same was assumed for North East Scotland.</td>
</tr>
<tr>
<td></td>
<td>- N\textsubscript{2}O, CO\textsubscript{2} and N\textsubscript{2}O emission factors.</td>
<td>- The burning cycle depends on the heather growth rate, which in turn is dependent on location, varying between 8 and 20 years. A burning cycle of 10 years was assumed for North East Scotland (Farage et al., 2009).</td>
</tr>
<tr>
<td></td>
<td>- Average annual temperature;</td>
<td>- It was assumed that 2% of the area of moorland on peatland was burnt every year in North East Scotland.</td>
</tr>
<tr>
<td></td>
<td>- CH\textsubscript{4} and N\textsubscript{2}O emission factors.</td>
<td></td>
</tr>
<tr>
<td>Enteric fermentation Manure management</td>
<td>- Number of animals in each livestock category;</td>
<td>- For sheep, goats, horses, deer and pigs, the default emission factors used were those given for developed countries, and for dairy and non-dairy cattle, those established for Western Europe.</td>
</tr>
<tr>
<td></td>
<td>- Type of manure management system and housing period per livestock category;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Average annual temperature;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- CH\textsubscript{4} and N\textsubscript{2}O emission factors.</td>
<td></td>
</tr>
<tr>
<td>Lime application</td>
<td>- Area of each crop receiving lime per year;</td>
<td>- Ground limestone was applied to croplands and grassland and not magnesium limestone. Magnesium limestone is effective for correcting acidity but if used continuously may cause potash deficiency in crops (Defra, 2010; Thomas, 2010).</td>
</tr>
<tr>
<td></td>
<td>- Total amount of limestone applied annually;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Percentage of crop area receiving the dressing per year.</td>
<td></td>
</tr>
</tbody>
</table>
Data collected to estimate GHG emissions were, as far as possible, specific for the North East Scotland. Data were distributed across several sources of information including official sources, as well as information collected from researchers working in projects related to land use systems. The main sources of data to estimate GHG emissions are presented and described in Table 2.3.

Table 2.3 Data sources used to estimate GHG emissions and carbon sequestration in North East Scotland

<table>
<thead>
<tr>
<th>GHG emission sources</th>
<th>Data sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application of mineral nitrogen (N) fertiliser</td>
<td>- The British Survey on Fertiliser Practice (1999-2010)(^{19}) (Thomas, 2010) publishes the overall application rate of mineral N fertiliser for each crop year and the percentage of crop area receiving dressing. The crop year is defined as the total quantity of nutrient used, in kilograms (kg), divided by the total extent of crop area, in hectares (ha), including areas without N application. Before 2007, data available covered certain crops in North East Scotland, but from 2007 onwards, data only covers crops in Great Britain(^{20}) and Scotland; - The area of crops, fallow, set aside and grass is published annually by the Economic Report on Scottish Agriculture (1999-2010) for four Scottish regions including Grampian, i.e. North East Scotland; - Default emission factors to estimate direct and indirect N(_2)O emissions from managed soils, which include cropland and grassland, are published in the IPCC 2006 Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).</td>
</tr>
<tr>
<td>Liming of agricultural soils</td>
<td>- The area of each crop in North East Scotland is published annually by the Economic Report on Scottish Agriculture (1999-2010)(^{21}) (Scottish Government, 2010); - The British Survey of Fertiliser Practice (1999-2010) (Thomas, 2010) publishes, annually, the average application rate of ground limestone (CaCO(_3)) in tonnes product per hectare for Scotland as well as the percentage of crop area receiving dressing. This information was overlapped with the recommended amounts of lime for the soil types present in cropland areas in North East Scotland (brown earths, humus-iron podzols, blanket peat and peaty podzols), provided by the Defra Fertiliser Manual (Defra, 2010); - The emission factors for limestone are published by the IPCC 2006 guidelines (IPCC, 2006).</td>
</tr>
<tr>
<td>Application of organic nitrogen (N) fertiliser</td>
<td>- Livestock numbers per region in the UK and per animal category are published annually by the Economic Report on Scottish Agriculture (1999-2010) (Scottish Government, 2010); - The manure management systems and housing periods per animal category for</td>
</tr>
</tbody>
</table>

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\(^{19}\) The Survey is sponsored by the Department for Environment, Food and Rural Affairs (Defra) and the Scottish Government. The Survey has the full support of the Farmers’ Unions in England, Scotland and Wales. The Survey is carried out annually and is based upon returns from a sample of farms.

\(^{20}\) In the British Survey of Fertiliser Practice the term Great Britain is defined to cover England (including the Isle of Wight), Wales, (including Anglesey) and mainland Scotland.

\(^{21}\) Original source: Agricultural Census.
Livestock manure management | the North East Scotland were deduced from the British Survey of Fertiliser Practice (1999-2010) (Thomas, 2010) and the Defra Fertiliser Manual (Defra, 2010), respectively;  
- The animal average weight and average days alive were collected from the Farm Management Handbook (SAC, 2006);  
- The housing period for each livestock category in North East Scotland was deduced from the Defra Fertiliser Manual (Defra, 2010);  
- The default emission factors were provided by the IPCC 2006 Guidelines (IPCC, 2006).

Livestock enteric fermentation | - Livestock numbers for the North East Scotland are published by the Economic Report on Scottish Agriculture (1999-2010) (Scottish Government, 2010);  
- Default CH₄ emission factors according to the North East Scotland average temperature are published by the IPCC 2006 Guidelines (IPCC, 2006).

Livestock dung deposited on pasture | - Livestock numbers for the North East Scotland are published by the Economic Report on Scottish Agriculture (1999-2010) (Scottish Government, 2010);  
- The animal average weight and average days alive were collected from the Farm Management Handbook (SAC, 2006);  
- The housing periods per animal category for the North East Scotland were collected from the Defra Fertiliser Manual (2010) (Defra, 2010), respectively.  
- Default CH₄ and N₂O emission factors are published by the IPCC 2006 guidelines (IPCC, 2006).

Moorland burning in peatland areas | - Area of peatland in North East Scotland – Land Cover Map 2000;  
- CO₂, N₂O and CH₄ emission factors were collected from Farage et al. (2009).

Wild deer | - Wild deer numbers in North East Scotland – personal communication, Irvine, J. (21/06/2011);  

Disturbed peatland | - Peatland area under different land management systems was extracted from the Macaulay Soil Map and the Land Cover Map 2000;  
- N₂O and CH₄ emissions from peatlands vary widely in space and time with no clear pattern of emissions with the type of soil (Slee et al., 2009). Likely current average emission factors (EF) for bare peat, afforested, drained and cultivated peatland were collected from Artz et al. (2012).

### 2.2.4 Equations and emission factors

Since it was known from the NAEI data that the main GHGs emitted from agriculture, which is the main rural land use in North East Scotland, were CH₄ and N₂O, the sources of these two gases were studied first. IPCC Tier 1 emission factors were used for a quick and straightforward assessment of GHG emissions, which also allows estimates to be compared to estimates for other world regions which use the same methodology and defaults. These emission factors require country-specific activity data but do not take into account different land cover, soil type, climatic conditions or management practices (IPCC, 2006). Tier 1 emission factors, therefore, have high uncertainty ranges. To assess GHG emissions from fertiliser application (organic and mineral), livestock enteric fermentation and manure management and lime application, the IPCC emission factors and IPCC equations were used. Some IPCC equations had to be adapted due to
data availability. For other sources of CH₄ and N₂O, (e.g. peatlands and moorland burning), emission factors from literature were used, and the assumptions described in Table 2.3 were considered for the calculations. The equations used to estimate GHG emissions from rural land uses in North East Scotland are presented in Appendix 1.

2.2.5 Estimating carbon sequestration

Carbon sinks in North East Scotland were also identified. Sinks considered were forests and peatlands. Sections 2.2.5.1 and 2.2.5.2 present the methodology followed to estimate carbon sequestration from these sinks.

2.2.5.1 Carbon sequestration from forests

Carbon sequestration from existing forest was estimated considering the decadal tree planting areas from the 1950s to the 2000s, when a wide range of coniferous and broadleaved trees were planted. For coniferous trees, the average rotation cycle considered was 50 years and for broadleaves 100 years (SAC, 2006). Green volumes (m³) were converted to carbon mass (tonnes) through the multiplication of the volume (m³) by the wood-specific density (tonnes m⁻³) and the mean fraction of carbon in the dry biomass (Edwards and Christie, 1981). In the UK, the wood-specific density of softwood (coniferous) varies between 0.33 and 0.45 tonnes per m³ and between 0.49 and 0.56 tonnes per m³ for hardwood (broadleaved) (Broadmeadow and Matthews, 2003). The mean fraction of carbon in dry biomass is 0.5 (Broadmeadow and Matthews, 2003; Dewar and Cannell, 1992). To convert carbon (C) mass (tonnes C ha⁻¹ yr⁻¹) in carbon dioxide tonnes CO₂ ha⁻¹ yr⁻¹, the conversion factor 1g C = 44/12 g CO₂ was used.

Broadmeadow and Matthews (2003) describe four types of carbon accumulation rates in trees, namely the establishment, full-vigour, mature and old-growth phases. In the establishment phase, the rate of carbon accumulation is relatively low and may even be negative as a result of carbon loss from vegetation and soil associated with ground preparation. In the full-vigour phase, there is rapid uptake, and in the mature phase, the uptake slows down and levels off. Finally, there is the old-growth phase in which forest stands are in long-term equilibrium, with losses of carbon through mortality and disturbance balancing any additional growth. The rate of carbon stored also depends on
the management regime for the woodland. In this study, the average yield class for the life period of each tree species was used rather than the yield class relative to each of the four phases described by Broadmeadow and Matthews (2003). The CO₂ emissions from the loss of biomass due to harvesting were not considered in the estimates since the final destination of the wood harvested was not known. For example, the wood used in building materials locks up the carbon for long periods of time, but wood used for fuel releases CO₂ almost immediately.

The areas by principal species and planting year classes from before 1961 until the 1990s were published in 1997 by the National Inventory of Woodland and Trees for the Grampian region (Forestry Commission, 1997). Afforestation areas between 2000 and 2007 correspond to the areas planted under the Woodland Grant Scheme (WGS) and the Scottish Forestry Grant Scheme (SFGS) in North East Scotland. These areas corresponded to only approximately 4,600 ha of coniferous and broadleaves planted in Moray, Aberdeenshire and Aberdeen City over the period 2000-2007, i.e., 0.52% of the total area of North East Scotland. Data on afforestation areas were provided by Forestry Commission Scotland in 2008. The Forestry Commission Scotland also provided the average yield class in cubic meters of dry wood per hectare per year (m³ ha⁻¹ yr⁻¹) for the main conifers and broadleaved species in Aberdeenshire and Moray.

### 2.2.5.2 Carbon sequestration in peatland

Peatlands are areas of land dominated by peat soils. These are formed in places where partially decomposed organic matter accumulates due to slow rates of decomposition and waterlogged conditions (Worrall et al., 2010). In order to estimate the peatland sequestration in North East Scotland, the area of peatland under different management systems was assessed by using Land Cover Map 2000 and Macaulay Soil Map. It was considered that peatland areas from the Macaulay Soil Map under bog (deep peat) and neutral grassland (unimproved/unmanaged) in the Land Cover Map 2000 were in good, near-natural condition (pristine peatlands). According to Artz et al. (2012) the likely net carbon sequestration factors for near-natural peatlands vary between -2.8 and -0.7 tonnes CO₂e ha⁻¹ yr⁻¹. In order to facilitate the estimates the average value was used (-1.75). It should be noticed that CO₂, N₂O and CH₄ sequestration from peatlands vary
widely in space and time with no clear pattern of emissions with the type of soil (Slee et al., 2009). Emission factors collected from literature by Artz et al. (2012) for near-natural peatlands vary between -4.1 and +0.3 tonnes CO$_2$e ha$^{-1}$ yr$^{-1}$ (negative value show net uptake, positive value show net loss). The following table presents examples of CO$_2$, N$_2$O and CH$_4$ sequestration rates for peatlands in tonnes of CO$_2$ equivalent per hectare per year according to several authors.

<table>
<thead>
<tr>
<th>Carbon dioxide</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.30</td>
<td>Billet et al. 2004</td>
</tr>
<tr>
<td>-0.73</td>
<td>Worrall et al. 2009</td>
</tr>
<tr>
<td>-2.2</td>
<td>Worrall et al. 2009</td>
</tr>
<tr>
<td>-2.5</td>
<td>Dinsmore et al. 2009</td>
</tr>
<tr>
<td>-3.3</td>
<td>Worrall et al. 2009</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Methane</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.4</td>
<td>Strack et al., 2008</td>
</tr>
<tr>
<td>-0.25</td>
<td>Clymo and Reddaway, 1971</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nitrous oxide</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.8046</td>
<td>Smith et al. 2007</td>
</tr>
</tbody>
</table>

### 2.2.6 Estimating uncertainties

The estimation of GHG emissions from rural land uses is subject to high uncertainty. The emission factors for enteric fermentation and manure management estimated using IPCC Tier 1 emission factors are not based on country-specific data, do not accurately represent the country’s livestock characteristics, and are unlikely to be more precise than ±30 or ±50% (IPCC, 2006). There are also high levels of uncertainty associated with the emission factors used to estimate direct and indirect N$_2$O emissions from application of mineral N fertilisers, dung deposited on pasture, and manure management.

The uncertainty levels for emissions from peatland and moorland burning are also high. The uncertainty ranges for carbon sequestration in peatlands were derived from Farage


In order to assess the extent to which the uncertainties can affect the estimates of GHG emissions from rural land uses in North East Scotland, two re-estimates were undertaken using the lower and higher value of the uncertainty range associated to each emission factor used. The year 2010 was chosen in the estimates.

### 2.2.7 Comparison with larger-scale inventories

To test the validity of the estimates, the total emissions from agriculture estimated for the year 2010 were compared with the values published online by the NAEI for N₂O, CH₄ and CO₂ emissions from “agriculture” and “nature” for 2009 (the latest update). In the NAEI, CH₄ and N₂O emissions from agricultural sources were estimated with data from the Agricultural Census for Scotland, the IPCC Tier 1 emission factors for livestock and fertiliser use, and the Centre for Ecology and Hydrology (CEH) Land Cover Map 2000 data. The AENEID model was used to create emission maps (Tsagatakis et al., 2010). To estimate CO₂ emissions from agricultural off-road machinery and vehicles, a combination of arable, pasture and forestry land use data was used together with off-road machinery activity data (hours of tractor use). The source for this was the AEA (see Tsagatakis et al., 2010). To estimate CO₂ emissions from agricultural soils, the Land Cover Map 2000 data from CEH was used. Agricultural stationary combustion was estimated with the Inter Department Business Register (IDBR) employment data for the agricultural sector. Methane emissions from “nature” (UNECE Sector code 11) included emissions from accidental fires in forests, straw and vegetation. These emissions were added to emissions from accidental fires in vehicles, small-scale waste burning and bonfires and displayed in the category “nature”. The distribution of accidental fires used the CEH Land Cover Map 2000 but regional fire statistics were not included (Tsagatakis et al., 2010).

Although the IPCC Tier 1 emission factors were used both in this study and in the NAEI there are some differences regarding data sources used and activities considered. In the case of fertiliser use, this study used the British Survey of Fertiliser Practice as a source of data while NAEI uses the Agricultural Census for England, Scotland, Wales
and Northern Ireland. In the case of activities considered, moorland burning and disturbed peatland were considered in this study but not included in the NAEI. In contrast, agricultural stationary combustion and agricultural off-road machinery were considered by NAEI but not included in this study. Table 2.1 presents activities considered in this study and data sources are presented in Table 2.3. Activities considered by the NAEI are described in Tsagatakis et al. (2010).

2.3 Results

2.3.1 GHG emissions from rural land uses in North East Scotland

The methods used to estimate GHG emissions from rural land uses in North East Scotland allowed the estimate of emissions for different rural land uses in the region, but the results obtained are necessarily dependent on the emission factors or sequestration rates chosen. This introduces uncertainty to the estimates. Not all the possible sources of emissions from rural land uses were considered, only those for which data were available. Annual GHG emissions were estimated for the period 1999-2010. According to the estimates, total GHG emissions from rural land use decreased from 1,636 ktCO₂e in 1999 to 1,474ktCO₂ in 2010, i.e., about 10% less GHG emissions in 2010 than in 1999 (Figure 2.1). Emissions allocated to agriculture represented about 98% of the total GHG emissions from rural land uses. These decreased from 1,600 ktCO₂e in 1999 to 1,440 ktCO₂ in 2010, i.e., a 10% decline in emissions in 12 years. Carbon sequestration from forestry increased between 2000 and 2010 from 530 ktCO₂ to 560 ktCO₂ (Figure 2.1), as a result of afforestation under the Woodland Grant Scheme (WGS) and the Scottish Forestry Grant Scheme (SFGS) over this decade. In 1999, carbon sequestration from forests was estimated approximately 740 ktCO₂; a higher value than in the following 10 years. This is most likely due to higher afforestation rates between 1950 and 1990 and to coniferous forests planted in the 1950s and 1960s reaching the end of the rotation in the 2000s. By subtracting the carbon sequestered by forests and peatlands from the total emissions from rural land uses in 2010, the GHG net emissions from rural land uses are obtained (914 ktCO₂e).
GHG emissions from rural land uses can be divided into nine different activity sources, namely enteric fermentation from domestic livestock, manure management, dung deposited on pasture, organic N fertiliser application, enteric fermentation from deer, disturbed peatland, mineral N fertiliser application, lime application and moorland (heath) burning. Over 1999-2010, the main sources of GHG emissions from rural land uses in North East Scotland were enteric fermentation from domestic livestock, manure management and mineral N fertiliser application (Figure 2.2).

Figure 2.1 Gross GHG emissions and carbon sequestration from rural land uses over 1999-2010 (ktCO$_2$e)
According to the calculations undertaken, the main GHG in terms of CO₂ equivalent emitted from agriculture over the period 1999-2010 in North East Scotland was CH₄, followed by N₂O. Carbon dioxide emissions were negligible (Figure 2.3).
2.3.2 GHG emission uncertainties

In terms of the uncertainty associated with the estimates, and using the year 2010 GHG emissions from rural land uses in North East Scotland estimated with the standard emission factors were 1,474 ktCO$_2$e (Table 2.5). However, these emissions may be 53% less or 200% more (Table 2.5) depending whether the lower or highest values of the uncertainty ranges associated to the emission factors are used. The upper estimate would only occur if all of the estimates were at the extreme of the uncertainty range. A more accurate estimate of uncertainty could be obtained via random sampling within individual uncertainty ranges using Monte Carlo techniques$^{23}$, but this was beyond the scope of the present study (Ogle et al., 2003).

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$^{23}$ A class of computational algorithms that rely on repeated random sampling to compute their results. Monte Carlo techniques are most suited to calculation by a computer and tend to be used when it is infeasible to compute an exact result with a deterministic algorithm (http://en.wikipedia.org/wiki/Monte_Carlo_method, last accessed 15/08/2012).
Table 2.5 GHG emissions from rural land uses considering the uncertainty associated to emission factors, in North East Scotland, in 2010

<table>
<thead>
<tr>
<th>Source of emissions</th>
<th>ktCO₂e</th>
<th>Lower bound</th>
<th>Standard</th>
<th>Higher bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application of mineral N fertiliser</td>
<td></td>
<td>87</td>
<td>188</td>
<td>920</td>
</tr>
<tr>
<td>Application of organic N fertiliser</td>
<td></td>
<td>18</td>
<td>80</td>
<td>423</td>
</tr>
<tr>
<td>Lime application</td>
<td></td>
<td>10</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td>Livestock</td>
<td></td>
<td>558</td>
<td>1146</td>
<td>2985</td>
</tr>
<tr>
<td>Wild deer</td>
<td></td>
<td>6</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>Moorland burning in peatland</td>
<td></td>
<td>3.6</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Peatlands</td>
<td></td>
<td>2</td>
<td>22</td>
<td>43</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>685</td>
<td>1474</td>
<td>4433</td>
</tr>
<tr>
<td>% range</td>
<td></td>
<td>53% less emissions</td>
<td>200% more emissions</td>
<td></td>
</tr>
</tbody>
</table>

2.3.3 Comparison with the National Atmospheric Emissions Inventory

In 2009, agricultural GHG emissions were estimated to be 1,440 ktCO₂e (Section 2.3.1), which was very close to the value calculated by using the data provided by the NAEI, i.e., 1,490 ktCO₂e, for the same year. There is, however, a difference in the contribution of each GHG to the total GHG emissions from agriculture between the results of the estimates undertaken in this study and the NAEI database. The estimates undertaken showed that, in 2010, in North East Scotland, the main GHG contributing to agricultural emissions was CH₄ (≈56%), followed by N₂O (≈44%) and CO₂ (≈2%) (Figure 2.3).

According to NAEI online database, for the same region and year, the main GHG contributing to agricultural emissions was N₂O (≈52%), followed by CH₄ (≈39%) and finally CO₂ (≈8%). The differences may occur because NAEI uses a low-resolution distribution map for CH₄ emissions (Tsagatakis et al., 2010). The higher contribution of CH₄ to the estimated GHG emissions from agriculture in North East Scotland may also be due to the high proportion of feeding cattle and pigs in this region compared to other regions in Scotland. In North East Scotland, feeding cattle represents almost 35% of all cattle. In addition, 60-70% of Scottish pigs are raised in North East Scotland (Cook et al., 2008; Scottish Government, 2010). These facts may not be captured by a larger-scale emission inventory such as the NAEI. In addition, Tsagatakis et al. (2010) indicated that there is scope for future improvements in the NAEI if livestock and poultry distributions will be updated.
Another explanation for the divergence in the contribution of N₂O emissions may be the fact that this study and NAEI use different sources of information for the amount of mineral N fertiliser application in arable and grassland. In this study, the average fertiliser application per crop type for North East Scotland was used, as provided by the British Survey of Fertiliser Practice. In NAEI, the distribution of N₂O emissions from agricultural sources and mapped at 5km resolution by the CEH was based on data from the Agricultural Census for Scotland (Tsagatakis et al., 2010). Nitrous oxide emissions from NAEI may be underestimated or less accurate, since data used related to a larger area (all Scotland, source: Agricultural Census) in contrast to data used in this study (North East Scotland, source: British Survey of Fertiliser Practice).

In the case of CO₂ emissions, the contribution of this gas to the total GHG emissions from agriculture in 2010 estimated in this study (2%) may have been underestimated when compared to the percentage (8%) estimated by using the NAEI online database. The NAEI considers soil disturbance, use of fossil fuel in agricultural activities and burning of residues as CO₂ emission sources, while this study disregarded such emission sources due to lack of published data at regional level. Of these, fossil fuel emissions from agricultural activities (e.g. agricultural machinery) are likely to be the most significant omission for North East Scotland.

2.4 Discussion

To estimate GHG emissions from rural land use in North East Scotland, a MS Excel-based model using the guidance of the IPCC Tier 1 methodology was used. This provided a breakdown of emissions per activity type that was not available from the NAEI online database, and the use of carbon calculators was not an option since it would require collection of data on GHG emissions from farms in North East Scotland, which would be wholly impractical. The GHG baseline for sources and sinks created for the region also allowed several activities within the rural land use sector to be investigated, promoting discussion on whether or not such activity should be considered for the estimates, the availability of data for each activity and respective data sources, and the default emission factors published in the literature. This study provides bottom-
up estimates of GHG emissions from the region using regionally specific activity data, and accounts for local land uses, taking into consideration land management practices.

The results obtained showed a general declining trend in emissions from 1999 to 2010 (Figure 2.1). This is mainly due to decreasing livestock numbers, especially dairy and beef cows, and a decrease in the amount of mineral N fertiliser application, possibly due to increases in fertiliser prices. However, in the 2009 and 2008 there was a recovery, i.e., in 2009 GHG emissions were the same than in the previous year and in 2010 GHG emissions were higher than in 2009. This coincided with the rise of wheat prices in 2009 and the end of set-aside scheme in European Union countries. A rise in the price of wheat and the removal of obligatory set-aside land were probably the main causes of the increase in the area of wheat and barley observed in North East Scotland in 2010. Wheat requires a high amount of mineral N fertiliser compared to other cereals. With a greater area of wheat planted and similar amount of fertiliser applied to soils, GHG emissions consequently increase. More grassland for mowing and for grazing in 2010 also contributed to the rise of GHG emissions in this year, especially grass for mowing which requires double the amount of mineral N fertiliser than grass for grazing. The increase in numbers of beef cows and prime cattle in 2010, also contributed to an increase in GHG emissions from enteric fermentation and manure management.

Since enteric fermentation, manure management and mineral N fertiliser application in soils are the main contributors to GHG emissions in North East Scotland, it is expected that the demand for meat and cereals in the future will be the main drivers of rural land use related GHG emissions. It is the aim of the Scottish Government to support the growth of the food and drink industry (Scottish Government, 2009). Projected trends in per capita consumption of meat products and milk in developed countries are positive. If the demand for these products increases from North East Scotland, GHG emissions from rural land uses will also increase, unless the numbers of dairy cows keep decreasing, as has happened since 1999, and compensates for any rise in the numbers of beef cows and in the area of cereals. Another means of avoiding an increase of GHG emissions due to a rise in meat demand is to increase the efficiency of livestock production which would result in higher milk yields per cow, or beef cows being slaughtered earlier in their life.
According to estimates, peatland emissions, enteric fermentation from wild deer, lime application to arable soils and moorland (heath) burning are minor contributors (4-25 ktCO$_2$e in 2010) to total GHG emissions from rural land uses in North East Scotland. The implementation of mitigation practices to reduce GHG emissions from rural land uses should mainly focus on the three largest sources of GHG emissions listed above. Many factors influence GHG emissions from enteric fermentation and manure management, namely level of feed intake, type of carbohydrate in the diet, feed processing, and addition of lipids or ionophores to the diet or alterations to the ruminal microflora (Smith et al., 2008). Mitigation practices related to mineral N fertiliser application include adopting nitrogen-efficient plants, planting crops with lower nitrogen requirement or simply reduced nitrogen fertiliser application (as long as yield is maintained so that emissions are not displaced) (Carlton et al., 2010).

Availability of data was the limiting factor that dictated the activities considered in the GHG baseline responsible for emission sources and carbon sinks. For example, complete sets of fuel consumption data by land uses are not available for England, Wales, Scotland or Northern Ireland, and the use of fossil fuels in agricultural activities was not considered. Emissions due to agricultural soil disturbance (e.g. tillage) were also not included because official data published on the area of disturbed agricultural soils was not available. Other GHG emissions not considered were those from afforestation. Tompkins (1989), states that afforestation of a bare hillside requires deep ploughing, drainage, planting and fertilisation. The reasons for leaving out afforestation emissions were the lack of official data published on the amount of fertiliser applied in forest trees in the British Survey of Fertiliser Practice (Thomas, 2010), and lack of a recommended value in the Defra Fertiliser Manual (Defra, 2010). Also, the area of trees planted in North East Scotland between 1999 and 2010 was only 4,600 ha, which would make emissions from afforestation activities negligible when compared to emissions from fertiliser application in cropland and grassland. The emission factors from deep ploughing of soils or soil drainage are also unknown. A recent study undertaken by the Forestry Commission assessed annual GHG emissions from operations, personal travel, road maintenance, administration and recreational visitors in two forests in England, namely Kielder Forest in Northumberland and the East Anglian District Forest. All these activities together accounted for 57 kg CO$_2$e ha$^{-1}$yr$^{-1}$ (CLA et al., 2007). If only emissions from forest operations were considered, the value would be even lower and,
again, it would be a negligible contribution to the total GHG emissions from rural land use in North East Scotland given the small area of forest planted between 1999 and 2010. As Ciesla (1997) pointed out, inefficient timber-harvesting operations result in excessive soil disturbance, logging residues and damage to residual trees. This would cause increased GHG emissions and reduce their capacity to sequester carbon.

The Scottish Government (2011) stresses the importance of Scottish soils and vegetation in carbon management and presents a figure of 3 billion tonnes stock of C, mainly held within peatlands. Bradley et al. (2005) estimated that the density of carbon in soil of semi-natural, wood, pasture, arable and garden lands in Scotland ranges between 2 and 17 kg m$^{-2}$ depending on the land type and soil depth (0-30 cm or 30-100 cm). Certain human activities, for example, peat extraction, drainage and ploughing, or removal of vegetation, cause disturbance and consequent release of carbon to the atmosphere. The release of the carbon stored in peatlands would substantially contribute to GHG emissions of a country or region. According to the Soil Macaulay Map, peatlands represent around 8-9% of the total area (including inland water) of North East Scotland.

In relation to GHG emissions from peatlands, all emission factors are associated with very substantial uncertainty (Table 2.5). This uncertainty is primarily caused by large inter-annual variability in carbon fluxes (Artz et al., 2012). This means that peatlands in good condition can act as a carbon sink in one year and as a carbon source in the following year. Uncertainty of emission factors for peatland under different uses is also due to the lack of such studies in Scotland. So far, there is only one complete budget published for a peatland in Scotland, this in Auchencorth Moss (Artz et al., 2012). Management types (e.g. intensive vs extensive farming/grassland, grouse shooting, deer management) are also likely to affect the amount of GHG emissions from peatlands. In addition, the estimates relied on the Macaulay Soil Map to identify the peatland area and this map does not cover most of the raised bogs (deep peatlands), especially in the uplands of this region (personal communication, Artz, R., 22/05/2012). It has been assumed that more than 90% of the raised bogs in Scotland are disturbed and releasing GHGs, and that less than 10% are sequestering carbon (Artz et al., 2012). But this may not also be the case for the North East Scotland given that currently, not even at the Scottish level peatland condition is well known (personal communication, Artz, R.,
22/05/2012). The estimates for GHG emissions and carbon sequestration from peatlands, therefore, may be under or overestimated depending on the condition of the raised bog area not covered by the Macaulay Soil Map and, consequently not included in the calculations.

Moorland (heath) burning in peatlands can cause peat erosion when incorrectly carried out. According to the Land Cover Map 2000, there are about 34,000 hectares of peatland under dense and open dwarf shrub heath in North East Scotland. It is not known how much of the moorland area that is burnt annually causes peat erosion and consequently C release. The likely current average emission factors for eroded peat are 0 to +5.5 t CO₂ e ha⁻¹ yr⁻¹ (Artz et al., 2012).

Another great source of uncertainty is N₂O emissions from soils due to mineral and organic N application. Such emissions occur by nitrification and denitrification, and these processes are strongly influenced by soil temperature, moisture, pH and availability of soluble organic matter (Sahrawat and Keeney, 1986; Bowman, 1990). For instance, anaerobic conditions favour denitrification but too much anaerobicity may lead to a decrease in N₂O emissions (Skiba et al., 1996). According to Brown et al. (2001), the large uncertainty in N₂O emissions is due to the large range in the N₂O emission factors, namely N leaching and runoff (EF₃) and the fraction of all N added to/mineralised in managed soils that is lost through leaching and runoff (Frac_LEACH(H)). To reduce this uncertainty, more data on N₂O emissions from rivers, groundwater and estuaries are required (Brown et al., 2001). The uncertainty in the estimates could also decrease if “hot spots” of high N₂O emissions in arable land and grassland were spatially identify and a new emission factor for these areas were established and used in the estimates.

In relation to grasslands, some studies suggest that in Europe they have strong potential to sequester carbon (Gilmanov et al., 2007; Janssens et al., 2003; Seguin et al., 2007; Soussana et al., 2010). However, soil carbon sequestration is reversible and factors such as soil disturbance (e.g. periodic tillage and resowing) lead to the release of part or all the C stored in the soil (Soussana et al., 2010). In the UK, there are both permanent and rotational grasslands. Grassland at least five years old is defined as permanent grassland and rotational grassland is grass sown every few years as part of an arable crop rotation,
in what is often termed a grass-ley. Permanent grass is considered to have more potential for carbon storage than short duration grassland (rotational grassland). If the sequestration rate suggested by Freibauer et al. (2004) was applied to the area of permanent grassland in North East Scotland, about 891 ktCO₂ would have been sequestered in 2010 and about 57% of the region’s emission would have been offset. As the science is not well settled in this matter and there is high variability across studies (Janssens et al., 2003; Soussana et al., 2010), sequestration of carbon through grassland was disregarded in the calculations. But as the science develops and if such sequestration rates are verified, there may be a need to adjust the regional figures.

Finally, even though the uncertainty associated with the use of IPCC Tier 1 default emission factors are likely to affect the accuracy of the GHG emission estimates from rural land uses in North East Scotland, it was still possible to obtain the trend of GHG emissions over a period of 12 years. This indicates if there is a decrease or increase in GHG emissions in the past years and it helps to inform about future GHG emission trends. It is also still possible to identify the activities within the rural land use sector that most contribute to GHG emissions in North East Scotland and the choice of mitigation options that can be supported by this information. In the future, improved regionally-specific Tier 2 and Tier 3 emission factors could be derived, and this will reduce the uncertainty of the estimates.

### 2.5 Conclusion

Published emission factors and the combination of national and regional statistics allows GHG emissions for North East Scotland to be estimated and allocated to different rural land-based sources for 12 consecutive years (1999-2010). This provided an advantage over the data on GHG emissions from agriculture and nature published by the NAEI website. In addition, only the last data update is available online (currently 2009). The other advantage of this bottom-up approach was the breakdown of GHG emissions into nine GHG source types. In relation to using carbon calculators to estimate GHG emissions from agriculture, the advantage was the flexibility to consider GHG emissions from other rural land uses, this depending on data availability.
Total GHG emissions from rural land uses in North East Scotland were, therefore, divided into livestock production, organic and mineral nitrogen (N) fertiliser application in cropland and grassland, lime application in cropland, moorland burning (heath burning), wild deer enteric fermentation, and peatland. Forestry clearly plays an important role in offsetting GHG emissions from rural land use, since it lowered gross GHG emissions of 1,474 ktCO$_2$ to a net figure of GHG emissions of 914 ktCO$_2$ (example year=2010), this corresponding to a decrease of 37% in total GHG emissions from rural land uses.

The MS Excel-based model for emission sources and carbon sequestration also broadened the choices of which data to use, as the availability of data and existing data sources to estimate emissions at regional level was explored. This can also be applied to other regions in the UK and beyond, and indicates which type of data needs to be collected. For smaller areas than North East Scotland, the same MS Excel-based model can be used, but the sources of emissions and sinks to be included will be dependent on data available at a smaller spatial scale (e.g. parish level). For example, the Integrated Administration and Control System (IACS) provide data with the number of ruminants per parish in Scotland.

This study demonstrates that a reliable assessment of GHG emissions from rural land uses at regional level, using published data and some enhanced specific information for the region, is feasible. The breakdown of GHG emissions by rural land use activities at regional level is an important source of information since it exposes the contribution of each activity to total GHG emissions from rural land uses, and feeds information into an assessment of whether the demands for reduction are likely to be met or not. It provides information that will underpin regional and local-scale action towards the delivery of national targets by establishing a reliable evidence base from which to propose solutions to the demanding emission reduction targets set by the Scottish Government.

Several flaws associated with data availability (e.g. non-inclusion of CO$_2$ emissions from fossil fuels and from afforestation-related activities), uncertainties in emission factors (e.g. peatland emission factors, N$_2$O emissions from soils) and the uncertainty regarding permanent grassland as a sink of carbon were identified. Because of this, results may be under- or over-estimated. Notwithstanding these limitations, the
identification of different underlying biophysical conditions and associated GHG emissions is necessary to select future GHG mitigation strategies.
References


Clymo, R. S., Reddaway, E. J. F. 1971, Productivity of Sphagnum (bogmoss) and peat accumulation, *Hydrobiologia*, 12, 181-192.


Chapter 2


constraints to implementation of greenhouse gas mitigation options in agriculture. *Agriculture, Ecosystems & Environment* 118, 6-28.


Appendix 1 Equations and variables

Managed manure N applied in cropland and grassland

\[ NMM_{SARB} = \sum_S \left\{ \sum_T \left[ N(T) \times N_{ex}(T) \times MS(T,S) \times \left(1 - \frac{FracLossMS}{100}\right)\right]\right\} \]

- \( N_{MMS_{AR}} \) = amount of managed manure nitrogen available for soil application, kgN yr\(^{-1}\);
- \( NT \) = number of head of livestock species/category T in the country;
- \( N_{ex}(T) \) = annual average N excretion per animal of species/category T in the country, kgN animal\(^{-1}\) yr\(^{-1}\);
- \( MS(T,S) \) = fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the country, dimensionless;
- \( FracLossMS \) = amount of managed manure nitrogen for livestock category T that is lost in the manure management system S, %;
- \( S \) = manure management system;
- \( T \) = species/category of livestock.

Source: Adapted from IPCC (2006)
## Direct and indirect N\textsubscript{2}O emissions

### Equations to estimate direct emissions

<table>
<thead>
<tr>
<th>Source: Adapted from IPCC (2006)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mineral and organic N applied to managed soils</strong></td>
</tr>
<tr>
<td>$N2O = \sum_i (Acrops \times FN)i \times EF1 \times \frac{44}{28}$</td>
</tr>
</tbody>
</table>

| **Urine and dung N deposited on pasture** |
| $N2O = \sum_T \left[ \left( N(T) \times Nex(T) \right) \times MS(T,PRP) \right] \times EF3 \times PRP, SO \times \frac{44}{28}$ |

| With |
| $Nex(T) = Nrate(T) \times \frac{TAM(T)}{1000} \times 365$ |

| **Manure management** |
| $N2O = \left[ \sum_T \left[ \sum_T \left( N(T) \times Nex(T) \right) \times MS(T,S) \right] \times EF3(S) \right] \times \frac{44}{28}$ |

### Equations to estimate indirect emissions - volatilisation

| **Mineral and organic N applied to managed soils** |
| $N2O = \sum_i (Acrops \times FN) \times FracGASF \times EF4 \times \frac{44}{28}$ |

| **Urine and dung N deposited on pasture** |
| $N2O = \sum_T \left( N(T) \times Nex(T) \right) \times MS(T,PRP) \times \left( \frac{FracGASMS}{100} \right) (PRP) \times EF4 \times \frac{44}{28}$ |

| **Manure management** |
| $N2O = \left[ \sum_T \left. \sum_T \left( N(T) \times Nex(T) \right) \times MS(T,S) \times \left( \frac{FracGASMS}{100} \right) (T,S) \right] \times EF4 \right] \times \frac{44}{28}$ |

### Equations to estimate indirect emissions – Leaching and runoff

| **Mineral and organic N applied to managed soils** |
| $N2O = \sum_i (Acrops \times FN)i \times FracLEACH - (H) \times EF5 \times \frac{44}{28}$ |

| **Urine and dung N deposited on pasture** |
| $N2O = \sum_T \left( N(T) \times Nex(T) \right) \times MS(T,PRP) \times \left( \frac{FracLEACH - H}{100} \right) (PRP) \times EF5 \times \frac{44}{28}$ |

| **Manure management** |
| $N2O = \left[ \sum_T \left. \sum_T \left( N(T) \times Nex(T) \right) \times MS(T,S) \times \left( \frac{FracLeachMS}{100} \right) (T,S) \right] \times EF5 \times \frac{44}{28}$ |
### Variable description

- $i$ = type of crop  
- $A_{crops}$ = area of each crop  
- $F_N$ = annual amount of mineral N (nitrogen) fertiliser or organic N fertiliser applied to soils of each crop, kg N yr$^{-1}$  
- $EF_1$ = emission factor for N$_2$O emissions from N additions from fertilisers, kg N$_2$O-N  
- 44/28 = conversion factor of N$_2$O emissions to N$_2$O

- $N_{i(T)}$ = number of head of livestock in category T  
- $N_{ex(T)}$ = annual N excretion for livestock in category T, kg N animal$^{-1}$ yr$^{-1}$  
- $N_{0.01(T)}$ = default N excretion rate, kg N (1000 kg animal mass)$^{-1}$ day$^{-1}$  
- $TAM_{i(T)}$ = typical animal mass for livestock in category T, kg animal$^{-1}$  
- $M_{s(T,PRP)}$ = fraction of total annual N excretion for sheep and goats that is deposited on pasture  
- $EF_{3PRP,SO}$ = emission factor for N inputs from sheep and ‘other animals’, kg N$_2$O-N  
- $T$ = sheep and goats

- $MS_{(T,S)}$ = fractions of total annual nitrogen excretion for each livestock category T that is managed in management system S  
- $EF_{(FYM)}$ and $EF_{(Slurry)}$ = emission factors for direct N$_2$O emissions from system FYM and slurry systems, kg N$_2$O-N  
- $T$= Dairy cattle, other cattle, swine and poultry  
- $S$ = manure management system (farmyard manure (FYM) and slurry)

- $FracGASF$ = fraction of synthetic fertiliser N that volatilises as NH$_3$ and NOx, kg N volatilised (kg of N applied)$^{-1}$  
- $FracGASM$ = fraction of organic fertiliser that volatilises from all organic N fertilisers applied, and of dung and urine deposited by grazing animals, (kg NH$_3$–N + NOx–N) (kg N applied or deposited)  
- $FracGasMS$ = percent of managed livestock manure nitrogen that volatilises as NH$_3$ and NOx for each defined livestock species/category T per each manure management system S, %  
- $EF_4$ = emission factor for N$_2$O emissions from atmospheric deposition of N on soils and water surfaces, [kg N–N$_2$O (kg NH$_3$–N + NOx–N volatilised)$^{-1}$]  
- $FracLEACH$ = fraction of all N added to/mineralized in managed soils that is lost through leaching and runoff, Kg N or fraction of urine and dung N deposited by grazing animals T (sheep and goats) that is lost by leaching and runoff, kg N  
- $EF_5$ = emission factor for N$_2$O emissions from N leaching and runoff, kg N$_2$O-N leached and runoff  
- $T$= sheep and goats

- $FracLEACH$=percent of managed manure N losses for livestock category T due to runoff and leaching during solid and liquid storage of manure (typical range 1-20%)  
- $T$= Dairy cattle, other cattle, swine and poultry

*Source:* IPCC (2006)
Default values and associated uncertainty ranges used to estimate direct and indirect $\text{N}_2\text{O}$ emissions from manure management

<table>
<thead>
<tr>
<th>Default emission factor</th>
<th>Default value</th>
<th>Range of uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{EF}_1$</td>
<td>0.01</td>
<td>0.003-0.03</td>
</tr>
<tr>
<td>$\text{EF}_3$ – FYM (solid storage)</td>
<td>0.005</td>
<td>Factor of 2</td>
</tr>
<tr>
<td>$\text{EF}_3$ – Slurry without natural crust cover</td>
<td>0.005</td>
<td>Factor of 2</td>
</tr>
<tr>
<td>$\text{EF}_3$ – Poultry manure without litter</td>
<td>0.001</td>
<td>Factor of 2</td>
</tr>
<tr>
<td>$\text{EF}_4$</td>
<td>0.01</td>
<td>0.002-0.05</td>
</tr>
<tr>
<td>$\text{EF}_5$</td>
<td>0.0075</td>
<td>0.0005-0.025</td>
</tr>
<tr>
<td>$\text{EF}_{\text{FPRP,S}}$</td>
<td>0.01</td>
<td>0.003-0.03</td>
</tr>
<tr>
<td>$\text{EF}_{\text{FPRP,C}}$</td>
<td>0.02</td>
<td>0.007-0.06</td>
</tr>
<tr>
<td>$\text{Frac}_{\text{GAS}}$</td>
<td>0.1</td>
<td>0.03-0.3</td>
</tr>
<tr>
<td>$\text{Frac}_{\text{GASM}}$</td>
<td>0.2</td>
<td>0.05-0.5</td>
</tr>
<tr>
<td>$\text{Frac}_{\text{GASM}}$ – FYM (dairy cows)</td>
<td>30%</td>
<td>10-40</td>
</tr>
<tr>
<td>$\text{Frac}_{\text{GASM}}$ – Slurry (dairy cows)</td>
<td>40%</td>
<td>15-45</td>
</tr>
<tr>
<td>$\text{Frac}_{\text{GASM}}$ – FYM (swine)</td>
<td>45%</td>
<td>10-65</td>
</tr>
<tr>
<td>$\text{Frac}_{\text{GASM}}$ – Slurry (swine)</td>
<td>48%</td>
<td>15-60</td>
</tr>
<tr>
<td>$\text{Frac}_{\text{GASM}}$ – Poultry without litter</td>
<td>55%</td>
<td>40-70</td>
</tr>
<tr>
<td>$\text{Frac}_{\text{GASM}}$ – FYM (other cattle)</td>
<td>45%</td>
<td>10-65</td>
</tr>
<tr>
<td>$\text{Frac}_{\text{GASM}}$ – FYM (other)</td>
<td>12%</td>
<td>5-20</td>
</tr>
<tr>
<td>$\text{Frac}_{\text{GASM}}$ – Slurry (dairy cows)</td>
<td>40%</td>
<td>15-45</td>
</tr>
<tr>
<td>$\text{Frac}_{\text{GASM}}$ – FYM (other cattle)</td>
<td>50%</td>
<td>20-70</td>
</tr>
<tr>
<td>$\text{Frac}_{\text{GASM}}$ – FYM (swine)</td>
<td>50%</td>
<td>20-70</td>
</tr>
<tr>
<td>$\text{Frac}_{\text{GASM}}$ – Slurry (swine)</td>
<td>48%</td>
<td>15-60</td>
</tr>
<tr>
<td>$\text{Frac}_{\text{GASM}}$ – Poultry without litter</td>
<td>55%</td>
<td>40-70</td>
</tr>
<tr>
<td>$\text{Frac}_{\text{GASM}}$ – FYM (other)</td>
<td>15%</td>
<td>5-20</td>
</tr>
<tr>
<td>$\text{Frac}_{\text{LEACH}}$</td>
<td>0.3</td>
<td>0.1-0.8</td>
</tr>
<tr>
<td>$\text{Frac}_{\text{LEACH}}$ (H)</td>
<td>0.2</td>
<td>(typical range 1-20%)</td>
</tr>
<tr>
<td>$\text{N}_{\text{rate(T)}}$ – Dairy cattle</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>$\text{N}_{\text{rate(T)}}$ – Other cattle</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>$\text{N}_{\text{rate(T)}}$ – Swine market</td>
<td>0.51</td>
<td></td>
</tr>
<tr>
<td>$\text{N}_{\text{rate(T)}}$ – Swine breeding</td>
<td>0.42</td>
<td></td>
</tr>
<tr>
<td>$\text{N}_{\text{rate(T)}}$ – Hens ≥1yr</td>
<td>0.96</td>
<td>The uncertainty of estimates is ± 50%</td>
</tr>
<tr>
<td>$\text{N}_{\text{rate(T)}}$ – Sheep</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>$\text{N}_{\text{rate(T)}}$ – Goats</td>
<td>1.28</td>
<td></td>
</tr>
<tr>
<td>$\text{N}_{\text{rate(T)}}$ – Horses</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>$\text{N}_{\text{rate(T)}}$ – Deer</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>$\text{MS}_{\text{(T,S)}}$ – S= FYM (dairy and non-dairy cattle)</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>$\text{MS}_{\text{(T,S)}}$ – S= Slurry (dairy and non-dairy cattle)</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>$\text{MS}_{\text{(T,S)}}$ – S= FYM (swine)</td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td>$\text{MS}_{\text{(T,S)}}$ – S= Slurry (swine)</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>$\text{MS}_{\text{T,PRP}}$ – S= Poultry without litter</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>$\text{MS}_{\text{T,PRP}}$ – manure deposited on pasture (sheep and goats)</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Sources: IPCC (2006) and British Survey of Fertiliser Practice
Equations and default values used to estimate CH₄ emissions from enteric fermentation and manure management

<table>
<thead>
<tr>
<th>Source of emissions</th>
<th>Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enteric fermentation</td>
<td>[ \text{CH}<em>4\text{Enteric} = \sum</em>{T} \text{EF}(T) \times N(T) ]</td>
</tr>
<tr>
<td>Manure management</td>
<td>[ \text{CH}<em>4\text{Manure} = \sum</em>{T} \text{EF}(T) \times N(T) ]</td>
</tr>
</tbody>
</table>

**Source:** Adapted from IPCC (2006)

### Variables

- \( \text{CH}_4\text{Enteric} \): Total methane emissions from enteric fermentation, kg CH₄ yr⁻¹
- \( \text{EF}(T) \): Enteric fermentation emission factor for the defined livestock population, kg CH₄ head⁻¹yr⁻¹ (developed countries)
- \( N(T) \): the number of head of livestock in category T in the country
- \( T \): category of livestock

### Emission factors

- EF\(_\text{Dairy}\) = 117
- EF\(_\text{OtherCattle}\) = 57
- EF\(_\text{Sheep}\) = 8
- EF\(_\text{Goats}\) = 5
- EF\(_\text{Horses}\) = 18
- EF\(_\text{Swine}\) = 1.5

**Uncertainty of ±30%-50%**

- EF\(_\text{Dairy}\) = 21
- EF\(_\text{OtherCattle}\) = 6
- EF\(_\text{MarketSwine}\) = 6
- EF\(_\text{BreedingSwine}\) = 9
- EF\(_\text{Sheep}\) = 0.19
- EF\(_\text{Goats}\) = 0.13
- EF\(_\text{Horses}\) = 1.56
- EF\(_\text{Layers}\) = 1.2
- EF\(_\text{Broilers}\) = 0.02

**Uncertainty of ±30%**

### Additional notes

- \( \text{CH}_4\text{Manure} \): CH₄ emissions from manure management, for a defined population, kg CH₄ yr⁻¹
- \( \text{EF}(T) \): Manure management emission factor for the defined livestock population kg CH₄ head⁻¹yr⁻¹ (cool countries, average annual temperature ≤10°C or <15°C for sheep, goats, horses and poultry in developed countries)
- \( N(T) \): the number of head of livestock category T in the country
- \( T \): category of livestock

**Source:** IPCC (2006)
Equation used to estimate CO$_2$ emissions from liming

\[
CO_2 = \sum_{i} Acrops \times MLimestone \times EFLimestone \times \frac{44}{12}
\]

- *Acrops* = Area of crops
- *CO$_2$-C Emission* = annual C emissions from lime application, tonnes C yr$^{-1}$
- *MLimestone* = annual amount of calcic limestone (CACO$_3$), tonnes yr$^{-1}$
- *EFLimestone* = Emission factor, tonne of C (tonne of limestone)
- $\frac{44}{12}$ – Conversion factor of CO$_2$-C emissions into CO$_2$

Source: Adapted from IPCC (2006)
3 Land-based mitigation practices to reduce GHG emissions from the rural land use sector
Abstract

The Climate Change (Scotland) Act 2009 commits Scotland to reduce GHG emissions by at least by 42% by 2020 and 80% by 2050, from 1990 levels. According to the Climate Change Delivery Plan, the necessary emissions reduction for the rural land use sector (agriculture and other land uses) is 21% in 2020, compared to 1990 levels. In 2010, in North East Scotland, gross greenhouse gas (GHG) emissions from rural land uses were about 1,470 ktCO$_2$e. Thus, to achieve a 21% reduction, these emissions would have to decrease to about 1,160 ktCO$_2$e. This study developed a method to select land-based practices to mitigate GHG emissions at a regional level. The main criterion used was the physical mitigation potential of each practice. A mix of methods was used to undertake this study, namely a literature review and quantitative estimates. The mitigation practice that offered greatest physical mitigation potential (700 ktCO$_2$) was woodland planting with Sitka spruce. Several barriers, such as economic, social, political and institutional barriers, affect the uptake of these practices in the region. Consequently the achieved mitigation potential of a practice may be lower than its physical mitigation potential. Surveys and focus groups, with relevant stakeholders, need to be undertaken to access the real area where mitigation practices can be implemented and the best way to overcome the barriers for their implementation.

Keywords: GHG emissions, mitigation practices, physical mitigation potential, North East Scotland

3.1 Introduction

The rural land use sector is a net contributor of carbon dioxide (CO$_2$), methane (CH$_4$) and nitrous oxide (N$_2$O) emissions, and these are mainly influenced by land and livestock management decisions. Carbon dioxide, CH$_4$ and N$_2$O are long-lasting gases in the atmosphere and contribute to global warming (IPCC, 2006). According to the Climate Change Delivery Plan (Scottish Government, 2009a), which establishes the GHG reduction targets for each sector of the Scottish economy, the rural land use sector needs to reduce its GHG emissions in 21% by 2020 from 1990 levels. A previous study (Feliciano et al., in press) estimated that, in 2010, in North East Scotland, GHG
emissions from agriculture were about 1,440 ktCO$_2$e and from sporting land (moorland and deer) and peatlands about 30 ktCO$_2$e (Feliciano et al., in press). To achieve the GHG emission reduction target established in the Climate Change Delivery Plan, mitigation practices have to be implemented in the rural land use sector, and these should focus on the main sources of emissions, i.e. agricultural activities.

Mitigation practices can abate GHG emissions through the sequestration of carbon in soil and plants, or by avoiding or reducing the release of GHGs. In the case of land-based mitigation practices, which are those implemented on arable land, grassland, peatland and moorland, this can be done through land management change or land use change. In the case of livestock-based mitigation practices, the only possibility is the reduction of GHG emissions, through animal and manure management.

Several authors and studies have listed GHG mitigation practices in the rural land use sector for different climatic regions of the world (Smith et al., 2008), Europe (Smith et al., 2000a), the UK (Moran et al., 2008) and England (Radov et al., 2007). Smith et al. (2008), for example, grouped mitigation practices to cropland management (e.g. improved nutrient management, improved tillage), grazing land management and pasture improvement (e.g. optimised grazing intensity, species introduction), improved management of agricultural organic/peaty soils, restoration of degraded lands, livestock management (e.g. improving feeding practices), manure management and bioenergy production.

Each mitigation practice is associated with a technical mitigation potential which is the amount of GHGs that a practice could mitigate in a specific area if all barriers to implementation were overcome (Smith, 2012). Barriers to the implementation of mitigation practices can be classified as physical, biological, economic, social, political, institutional, educational, and market barriers (Smith et al., 2012). Since the implementation of mitigation practices is constrained by physical barriers, such as land availability, the technical mitigation potential can be renamed as physical potential. Barriers to the implementation of mitigation practices might reduce the area where they can be implemented and consequently their physical mitigation potential.
Mitigation practices should satisfy the requirements of ‘additionality’, ‘permanence’, ‘lack of knowledge’, and ‘mechanism uncertainty’. To satisfy the ‘additionality’ requirement, the net reduction needs to be additional to what would have happened if the mitigation practices were not implemented (Smith et al., 2007). This requirement is important because several practices that increase soil carbon sequestration have been devised for other purposes than to mitigate climate change. Since these practices have been implemented, the GHG emissions reduction would be considered in the baseline (Robbins, 2011). In the case of soil and above-ground carbon sequestration practices, the ‘permanence’ requirement has to be taken into account because they only promote carbon sequestration if they are maintained (Robbins 2011). In addition, soil carbon sequestration practices only remove carbon from the atmosphere during 15 to 33 years, depending on management practice and system (West and Post, 2002). Finally, ‘mechanism uncertainty’ is related to the uncertainties about the complex biological and ecological processes involved in trace gas emissions and carbon storage in agricultural systems (Smith et al., 2007). This reflects the view ‘get the science right and then act’ Robbins (2011). Smith et al. (2007) also noted that when the processes of implementation of mitigation practices are not well known (lack of knowledge), farmers and other land managers are more doubtful about implementing mitigation practices.

The technical GHG mitigation potential of land-based mitigation practices is usually expressed as tonnes of CO₂ equivalent or tonnes of CO₂ emissions reduced per hectare per year: tCO₂ e ha⁻¹ yr⁻¹ and tCO₂ ha⁻¹ yr⁻¹, respectively. In the case of livestock-based mitigation practices, the technical mitigation potential is frequently expressed as a proportion of the animals’ enteric CH₄ production or a percentage of emitted GHG per head per year (Moran et al. 2010; Smith et al., 2008).

Previous studies have reviewed the technical mitigation potential in agriculture and agricultural soils (Freibauer et al., 2004; Smith et al., 1997; 1998; 2000a; 2000b, 2008) and have developed marginal abatement cost curves for GHGs emissions from UK agriculture (Moran et al., 2010). None, however, have evaluated the mitigation potential of practices taking into account the unique characteristics of a particular region. According to Smith et al. (2007), rural land use systems are substantially variable between locations. McCarl et al. (2005) consider that multi-region studies are important to overcome this variability. This chapter aims to select suitable land-based mitigation
practices for the North East Scotland by analysing the barriers described by Smith et al. (2012) and by taking into consideration the specificities of the region. Two of the three council areas covered by the North East Scotland (Aberdeenshire, Aberdeen City) are strongly committed to reducing their GHG emissions (SAC, 2008).

To select the most suitable mitigation practices for the region, the main stages undertaken were to:

1) Estimate the physical mitigation potential of land-based mitigation practices in North East Scotland based on their technical mitigation potential and the area where these could be implemented;
2) Select land-based mitigation practices with the highest physical mitigation potential, dismissing those which do not satisfy the requirements of ‘additionality’, ‘permanence’, ‘lack of knowledge’ and ‘mechanism uncertainty’;
3) Estimate the GHG emissions reduction that would be achieved if the selected mitigation practices were implemented;
4) Discuss the suitability of the selected mitigation practices, including economic, social, political, institutional and educational barriers to implementation.

Livestock-based mitigation practices were not included in order to ease the estimates. Usually, the technical mitigation potential of these practices is presented as a proportion or percentage of the amount of CH₄ emitted per animal per year, while the technical mitigation potential of land-based practices (e.g. biological fixation with clover) is given in tonnes of carbon dioxide equivalent emissions reduction per hectare per year. In addition, current livestock-practices (e.g. improved feeding practices) are difficult to assess due to the lack of data.

In this chapter a methodology to select suitable mitigation practices to implement in the rural land use sector of a specific region is suggested. The steps followed in this study can be followed and adapted for other regions in the world.
3.2 Methodology

Mixed-methods were used to identify the most suitable land-based mitigation practices for the rural land use sector. First, a literature review was undertaken in order to identify land-based mitigation practices for rural land uses in Europe, the United Kingdom (UK) and Scotland. The technical mitigation potentials of these practices were also collected. Official statistics were consulted in order to ascertain the area where these mitigation practices could be implemented. The physical mitigation potential, defined as a result of the multiplication of the technical mitigation potential (measured in tCO₂e ha⁻¹ yr⁻¹) by the area (in ha) where a practice could be hypothetically implemented, was considered. Barriers to implementation of a practice (e.g. economic, social, political, and educational, market) are likely to reduce the theoretical area where the mitigation practices could be implemented, and consequently, the physical mitigation potential.

Figure 3.1 presents the distinction between the three types of mitigation potential – technical, physical and reduced mitigation potential.

<table>
<thead>
<tr>
<th>Total potential</th>
<th>Barriers</th>
<th>Reduced potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical mitigation potential (tCO₂e ha⁻¹ yr⁻¹)</td>
<td>Social</td>
<td>Reduced physical mitigation potential (tCO₂e yr⁻¹)</td>
</tr>
<tr>
<td>Maximum area where a practice could be implemented (ha)</td>
<td>Economic</td>
<td>Physical mitigation potential (tCO₂e yr⁻¹)</td>
</tr>
<tr>
<td></td>
<td>Political</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Educational</td>
<td>Reduced area where a practice could be implemented (ha)</td>
</tr>
<tr>
<td></td>
<td>Market</td>
<td>=</td>
</tr>
<tr>
<td></td>
<td>Institutional</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3.1 Types of mitigation potential of a region**

The physical mitigation potential of each land-based mitigation practice was first estimated. Second, practices with the highest value (a cut-off value of 200 ktCO₂e was used) were further analysed in relation to ‘additionally’, ‘permanence’, ‘mechanism uncertainty’ and ‘lack of knowledge’. Subsequently, the GHG emissions reduction that would be obtained if suitable practices were implemented was estimated. Finally, the barriers to the implementation of mitigation practices were taken into account and their suitability for the region was discussed.
3.2.1 Literature review on land-based mitigation practices

From literature review (Freibauer et al., 2004; Macleod et al., 2010; Moran, et al., 2008; 2010; 2011; Radov et al., 2007; Smith, et al. 1997; 1998; 2000a, 2000b; 2008, 43 land-based mitigation practices and associated technical mitigation potentials were compiled. The review covered mitigation practices for Europe and the UK, and practices were grouped into soil and above-ground sequestration practices and practices to reduce or avoid GHG emissions. Soil-carbon sequestration practices were sub-grouped into soil-carbon sequestration with land management change and soil-carbon sequestration with land use change. An example of an above-ground carbon sequestration practice is the conversion of arable land into woodland which consequently leads to a change in land use. Practices to reduce GHG emissions indicate a change in management.

For some practices, more than one value for the technical mitigation potential was found in the literature. It was decided that in these cases, the maximum technical potential would be used in the estimates (Table 3.1).

Table 3.1 Maximum technical potential found in the literature and associated uncertainty ranges (tCO$_2$e ha$^{-1}$yr$^{-1}$)

<table>
<thead>
<tr>
<th>Categories</th>
<th>Mitigation practices</th>
<th>Max value found in literature</th>
<th>Uncertainty range</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil carbon sequestration - land management change</td>
<td>Vegetative cover</td>
<td>0.98</td>
<td>[0.51-1.45]</td>
<td>Smith et al., 2008</td>
</tr>
<tr>
<td></td>
<td>Sewage sludge</td>
<td>2.24</td>
<td>n.a.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No-tillage</td>
<td>1.46</td>
<td>&gt;50%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reduced tillage</td>
<td>1.46</td>
<td>&gt;&gt;50%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Deep rooting crops</td>
<td>2.20</td>
<td>&gt;50%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Permanent grassland</td>
<td>2.68</td>
<td>[2.68-3]</td>
<td>Radov et al., 2007</td>
</tr>
<tr>
<td></td>
<td>Organic farming</td>
<td>1.83</td>
<td>[0-1.83]</td>
<td>Freibauer et al., 2004</td>
</tr>
<tr>
<td></td>
<td>Apply animal manure</td>
<td>1.47</td>
<td>&gt;50%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crop residues</td>
<td>2.60</td>
<td>&gt;50%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Composting</td>
<td>1.47</td>
<td>&gt;&gt;50%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increase grass productivity</td>
<td>0.73</td>
<td>&gt;&gt;50%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Deep-rooting grasses</td>
<td>0.8</td>
<td>[0.11-1.50]</td>
<td>Smith et al., 2008</td>
</tr>
<tr>
<td></td>
<td>Grassland intensity</td>
<td>0.8</td>
<td>[0.11-1.50]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Extending crop rotations</td>
<td>0.98</td>
<td>[0.51-1.45]</td>
<td>Smith et al., 2008</td>
</tr>
<tr>
<td></td>
<td>Extensification</td>
<td>1.83</td>
<td>&gt;&gt;50%</td>
<td>Freibauer et al., 2004</td>
</tr>
<tr>
<td></td>
<td>Increase duration of grass leys</td>
<td>1.80</td>
<td>[0.37-1.8]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bioenergy crops</td>
<td>3.19</td>
<td>n.a.</td>
<td>Radov et al., 2007</td>
</tr>
<tr>
<td></td>
<td>Revegetation</td>
<td>2.10</td>
<td>[1.1-2.1]</td>
<td>Freibauer et al., 2004</td>
</tr>
<tr>
<td></td>
<td>Set-aside</td>
<td>2.68</td>
<td>[2.68-3]</td>
<td>Radov et al., 2007</td>
</tr>
<tr>
<td></td>
<td>Conversion of arable to woodland</td>
<td>3.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conversion of arable to grassland</td>
<td>6.20</td>
<td>[4.4-6.2]</td>
<td>Freibauer et al., 2004</td>
</tr>
<tr>
<td></td>
<td>Agro-forestry (soil)</td>
<td>0.53</td>
<td>[-0.04-1.12]</td>
<td>Smith et al., 2008</td>
</tr>
<tr>
<td>Soil carbon sequestration - land use change</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Chapter 3

| Soil carbon sequestration in organic soils - land management change | Woodland planting (soil) | 0.79 | n.a. | Radov et al., 2007 |
| Management of organic soils – avoid deep ploughing & avoid row crops and tubers | 5.10 | >50% |
| Management of organic soils – maintain shallow water table | 15 | [5-15] |
| Sheep grazing in undrained peatlands | 8 | >50% |
| Restoration | 16.9 | [0-16.9] |

| Soil carbon sequestration in organic soils - land use change |
| Abandon for conservation | 8 | >50% |
| Conversion of arable to woodland | 5.1 | [1.8-5.1] |
| Conversion of arable to grassland | 5.1 | n.a. |

| Above-ground carbon sequestration – land use change |
| Woodland planting - Oak | 2 | n.a. | Forestry Commission Scotland |
| Woodland planting -Sitka spruce | 12 | [10-12] |

| GHG emissions reduction - land management change |
| Biological fixation (clover) | 0.98 | [0.51-1.45] | Smith et al., 2008 |
| Reduce nitrogen fertiliser | 0.62 | [0.02-1.42] |
| Land drainage | 1.14 | [-0.55-2.82] |
| Better timing of fertiliser application | 0.62 | [0.02-1.42] |
| Controlled release fertilisers | 0.62 | [0.02-1.42] |
| Nitrogen inhibitors | 0.62 | [0.02-1.42] |
| Avoiding N excess | 0.62 | [0.02-1.42] |
| Precision farming | 0.62 | [0.02-1.42] |
| Species introduction | 0.98 | [0.51-1.45] |
| Less intensive cropping systems | 0.98 | [0.51-1.45] |
| Using manure or slurry as fertiliser | 0.4 | n.a. | Moran et al., 2010 |

Note: The values presented in this table were extracted from Appendix 2.

3.2.2 Estimating the physical mitigation potential of land-based mitigation practices in North East Scotland

The physical mitigation potential of a given practice in North East Scotland was estimated by multiplying the technical mitigation potential rate (tCO₂e ha⁻¹ yr⁻¹ or tCO₂ ha⁻¹ yr⁻¹) of each practice by the area (ha) where it could be implemented. For example, a reduction in nitrogen application aimed at decreasing N₂O emissions can only be implemented in areas where nitrogen (N) is usually applied, i.e. cropland and grassland for mowing and grazing. National and regional statistics, namely the Economic Report on Scottish Agriculture (Scottish Government, 2010a) and digital maps (land cover map 2000; land capability map for agriculture) and literature were the basis of the assumptions on the area where each land-based mitigation practice could be implemented. Several researchers working in the field of soil science, grazing management, animal production, peatland management, sheep ecology and climate change were informally approached in order to validate the assumptions made on the areas where land-based mitigation practices could be implemented. The mitigation
practices with highest physical mitigation potential (cut-off value 200 kt CO$_2$e) were chosen to be further analysed.

3.2.3 Additionality, mechanism uncertainty, permanence, lack of knowledge

Land-based mitigation practices with the highest physical mitigation potential were first considered. However, a mitigation potential based on the technical mitigation potential and the area where practices can be implemented is not sufficient to decide if these will contribute to GHG emission reductions or not. There are also certain requirements that are needed to be satisfied before undertaking the selection, namely, ‘additionality’, ‘mechanism uncertainty’, ‘lack of knowledge’ and ‘permanence’.

For the ‘additionality’ requirement to be satisfied, it must be demonstrated that GHG emissions will be lower than before their implementation (Robbins, 2011; Smith et al., 2007). This means that practices selected should not be widely implemented already in the region because the GHG emission reductions provided by these practices are reflected in the GHG emissions baseline. Similarly, mitigation practices for which there were ‘mechanism uncertainties’ were not selected. These are practices that, according to the literature, lead to GHG mitigation conflicts, i.e. mitigated one GHG (e.g. CO$_2$) but increase the emissions of another (e.g. N$_2$O). Mitigation practices should be also reasonably ‘well known’ by land managers. If there was ‘lack of knowledge’ about the implementation of a practice, it was not selected. In relation to ‘permanence’, it has been alleged that the maximum capacity for soil carbon sequestration is reached within 15-33 years (Freibauer et al., 2004; West and Post, 2002). It was assumed that soil carbon sequestration practices started in 2010 would be maintained until 2020, i.e., there would be no changes in management during the 10 years following their implementation so they would still be promoting carbon sequestration in 2020. The same was assumed for above-ground carbon sequestration practices (e.g. woodland planting).
3.2.4 Estimating GHG emissions reduction obtained after the implementation of the mitigation practices selected

Greenhouse gas emissions from rural land uses in North East Scotland between 1999 and 2010 were estimated in a previous study (Feliciano et al., in press). The estimates used GHG emission factors, published by the Intergovernmental Panel on Climate Change (IPCC, 2006b), for several agricultural activities, including fertilising application on grassland and cropland, lime application on cropland, enteric fermentation, manure management, moorland management and peatland. Data on emission sources was collected from official reports such as the Economic Report on Scottish Agriculture and the British Survey of Fertiliser Practice (see Chapter 2, Section 2.2.2). Region-level data was used whenever it was available.

To project GHG emissions from rural land uses, between 2011 and 2020, in North East Scotland, an extrapolation of total GHG emissions between 1999 and 2010 was undertaken. The extrapolation was obtained by using the trend-line equation associated with the GHG emissions between 1999 and 2010. To estimate the reduction obtained by the implementation of individual selected mitigation practices between 2010 and 2020, the physical mitigation of each individual practice was subtracted from the yearly GHG emissions over the same period.

3.2.5 Identifying the barriers affecting the implementation of the selected mitigation practices

Economic, social, political, institutional, educational and market barriers affect the implementation of mitigation practices and are likely to reduce the physical mitigation potential of these practices (Smith, 2012). Economic barriers happen when farmers or land managers cannot afford the costs of implementation of the practices, or there are profit decreases due to a reduction in yield/level of output (Smith, 2011). Social barriers occur when farmers and land managers have an opposing attitude to the implementation of a certain practice because of psychological reasons or beliefs (Smith, 2011). Institutional barriers take place when, for example, farmers/land managers are prevented from implementing a certain practice due to, for example, property rights (Smith et al., 2007). Political barriers (Smith et al., 2007) concern the incompatibility of mitigation practices with programmes or policies implemented at the European, UK or Scottish
levels. For example, the Scottish Food Strategy promotes local food production, and the Scottish Forest Strategy promotes woodland planting, so there is a conflict between food security and tree planting. Educational barriers are related to the ability of land managers to implement a certain practice. Finally, market barriers happen if, for example, farm products such as straw or compost have market value and are not likely to be used as mitigation practices (e.g. incorporation in soils to increase soil sequestration). Barriers to implementation of mitigation practices were identified through a literature review.

3.3 Results

The results consist of the assessment of the areas (in hectares) where land-based mitigation practices could be implemented in North East Scotland. With the areas assessed and the technical mitigation potential collected from literature, the physical mitigation potential was estimated. Land-based mitigation practices with the highest physical potential and which satisfied ‘additionality’, ‘mechanism uncertainty’, ‘lack of knowledge’ and ‘permanence’ requirements were considered to estimate the GHG emissions reduction by 2020. Finally the barriers affecting the implementation of the practices selected were identified and discussed.

3.3.1 Physical mitigation potential of land-based mitigation practices in North East Scotland

The first criterion used to choose suitable GHG mitigation practices was the physical mitigation potential estimated with the technical mitigation potential of each practice (tCO₂e ha⁻¹yr⁻¹ or tCO₂ ha⁻¹yr⁻¹) and the area where each practice could be implemented. In North East Scotland, land-based mitigation practices are directed to arable land (cropland and fallow), grassland, surplus arable land, cropland, undrained peatlands and farmed organic soils. Table 3.2 presents land-based mitigation practices grouped according to the land use type where these could be implemented, implementation area, and the explanation on how the practices were grouped.
### Table 3.2 Land-based mitigation practices and maximum implementation areas in North East Scotland

<table>
<thead>
<tr>
<th>Practices</th>
<th>Implemented in</th>
<th>Area (ha)</th>
<th>Data used and assumptions taken to estimate the area of implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Management of organic soils (avoid row crops and tubers &amp; deep ploughing)</td>
<td>Farmed peatlands</td>
<td>86</td>
<td>Area of crops in peatland extracted from LCM (Land Cover Map) 2000 and Macaulay Soil Map using ArcGIS.</td>
</tr>
<tr>
<td>- Abandon for conservation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Protection and restoration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sheep grazing on undrained peatlands</td>
<td>Unmanaged grass on undrained peatland</td>
<td>149</td>
<td>Areas of neutral grassland (unimproved/unmanaged) in undrained peatland derived from LCM 2000 and Macaulay Soil Map using ArcGIS.</td>
</tr>
<tr>
<td>Management of organic soils (maintaining a more shallow water table)</td>
<td>Managed grassland in peatland</td>
<td>4000</td>
<td>Areas of neutral grassland (unimproved/unmanaged) in undrained peatland derived from LCM 2000 and Macaulay Soil Map using ArcGIS.</td>
</tr>
<tr>
<td>Sewage sludge</td>
<td>Arable (cropland &amp; fallow)</td>
<td>5,000-7,500</td>
<td>Smith et al. (2008) assume a mitigation potential of 0.43 tCO₂ ha⁻¹ yr⁻¹ for an application of 1 odt (oven dried ton) of sludge per ha per yr. In NE Scotland about 10,000-15,000 odt of sewage sludge are produced and around 50% is recycled into arable soils (pers. comm. Towers, W., 2011). Considering that 50% of sewage sludge is applied into arable soils in NE Scotland, only 5000-7500 ha could receive 1ton of sewage per year.</td>
</tr>
<tr>
<td>- Increase duration of grass leys</td>
<td>Surplus arable land</td>
<td>9,884</td>
<td>- 10% of the cropland area in UK can be considered surplus arable land (Smith et al., 2000a).                                                                                                                       - During the early 1990s ≈10% of arable land in the EU was removed from production to limit agricultural surpluses under the set-aside scheme. In the UK, one of the motivations for the introduction of energy crops was to find a potentially worthwhile use of land that was, by definition, surplus to food production requirements (Slade et al., 2011); - In NE Scotland, average set aside land between 1999 and 2010 was 6% of the arable land (Scottish Government, 2010a).</td>
</tr>
<tr>
<td>Agro-forestry (Soil carbon)</td>
<td>10% of grass for mowing and for grazing</td>
<td>11,203</td>
<td>Agroforestry would increase the standing stock of carbon without affecting agricultural productivity.</td>
</tr>
<tr>
<td>Permanent grassland</td>
<td>Rotational grassland</td>
<td>53,631</td>
<td>Only rotational grassland (grassland &lt;5 years old) can become permanent.</td>
</tr>
<tr>
<td>No-tillage Reduced tillage</td>
<td>% of arable land suitable for zero tillage and reduced tillage</td>
<td>60,622</td>
<td>The implementation of zero and minimum tillage in the UK has been slow, covering no more than 3% of arable land at most. The area suitable for no-till farming was estimated to be 36.8% of the arable land in the UK (Smith et al., 2000a). The same was assumed for NE Scotland.</td>
</tr>
<tr>
<td>Woodland planting- Oak Woodland planting - Sitka spruce</td>
<td>Target for additional forest area</td>
<td>62,222</td>
<td>The national woodland cover target is 25% of the land cover (currently 18% in North East Scotland - 155,000 ha) (Scottish Executive, 2006). Woodland planting with Sitka spruce or oak was considered on 7% of the North East Scotland area (current forest area in NE Scotland ≈18%, FCS target 25%).</td>
</tr>
<tr>
<td>- Deep rooting crops</td>
<td>Cropland</td>
<td>157,532</td>
<td>- Deep-rooting crops planted annually in NE Scotland. Source: Economic Report on Scottish Agriculture; - In the uplands, much of the land has little or no fertiliser applied since main land use is rough grazing.</td>
</tr>
<tr>
<td>Organic farming</td>
<td>Area of organic</td>
<td>159,297</td>
<td>In Scotland, 97.7% is conventional agriculture with 3.3% being organic farming (Defra, 2011). The</td>
</tr>
</tbody>
</table>
The application of 10 t ha\(^{-1}\)yr\(^{-1}\) of animal manure in soils to achieve the mitigation potential estimated is recommended by Smith et al. (2008). In 2010, around 2,410,430 tonnes of manure were produced in NE Scotland. This would be enough to apply to the arable area at a rate of 10t ha\(^{-1}\)yr\(^{-1}\).

- Incorporation of crop residues in all arable land after the banning of crop residue burning in the UK in 1992 (Powlson et al., 2008; Smith et al., 2008);
- In relation to composting, data on the amount of compost produced per year was not available.

Vegetative cover

<table>
<thead>
<tr>
<th>Arable (cropland &amp; fallow)</th>
<th>167,733</th>
</tr>
</thead>
</table>
| It was considered that implementing vegetative cover between crops can also be applied to all arable land.

- High grass productivity
- Deep-rooting grasses
- Biological fixation (clover)
- Reduce nitrogen fertiliser in grassland

<table>
<thead>
<tr>
<th>Grassland for mowing and grazing</th>
<th>211,376</th>
</tr>
</thead>
</table>
| These practices are specific for grasslands.

Land drainage

<table>
<thead>
<tr>
<th>Arable and grassland for mowing and grazing</th>
<th>234,218</th>
</tr>
</thead>
</table>
| This practice is directed at wet agricultural soils. Drainage of these soils can promote productivity, increase soil C sequestration and reduce N\(_2\)O emissions. Improving land drainage is a standard agricultural practice to avoid drainage problems by maintaining land in Good Agricultural and Environmental Condition (GAEC 18) (Radow et al., 2007).

- Better timing of fertiliser application
- Controlled release fertilisers
- Nitrogen inhibitors
- Avoiding N excess
- Precision farming

<table>
<thead>
<tr>
<th>Cropland and grassland for mowing and grazing</th>
<th>368,908</th>
</tr>
</thead>
</table>
| These practices are directed at land uses where fertiliser application is usually applied, namely cropland and grassland for mowing and for grazing.

Grazing (intensity)

<table>
<thead>
<tr>
<th>All grassland</th>
<th>440,628</th>
</tr>
</thead>
</table>
| Low intensity grazing and overgrazing would only happen in grassland.

Table 3.2 shows that the areas where the land-based mitigation practices could be implemented varies from 86 to 440,628 hectares. “Management of organic soils (avoid row crops and tubers and deep ploughing), “abandon for conservation” and “protection and restoration” are mitigation practices directed to farmed organic soils, which represent a small area in North East Scotland (Table 3.2). The practice “Grazing intensity” is appropriate for all grassland, which in North East Scotland corresponds to about 50% of the region’s total area. In the case of sewage sludge, the area where this semi-solid material can be applied is limited by the amount produced annually. This practice helps the soil sequester a maximum of 2.24 t CO\(_2\) ha\(^{-1}\)yr\(^{-1}\) (Freibauer et al., 2004) for an application of one tonne of sewage sludge per hectare of arable land annually (Table 3.1). Incorporating animal manure, crop residues and composting into arable soils are similar incorporating sewage sludge in soils and the area where these
materials (manure, crop residues, compost, sewage sludge) can be applied is limited to the amount produced in the region.

The multiplication of the maximum implementation areas (Table 3.2) by the technical mitigation potentials (Table 3.1), gives the physical mitigation potential for each practice. According to the estimates each soil and above-ground carbon sequestration practice with land-use change could potentially mitigate between about 8 and 750kt CO$_2$ yr$^{-1}$ (Figure 3.2-A) in North East Scotland. Soil carbon sequestration practices through land management change could mitigate between about 16 and 665 ktCO$_2$ yr$^{-1}$ (Figure 3.2-B). Soil carbon sequestration practices in organic soils have low mitigation potential, between about 0.4 and 60 ktCO$_2$ yr$^{-1}$, compared to other types of mitigation practices (Figure 3.3-A) because of the small area (ha) where these practices can be implemented (Table 3.2). Finally, crop and soil practices to reduce GHG emissions through the change in land management could mitigate between about 90 and 230 ktCO$_2$e yr$^{-1}$ (Figure 3.3-B).

![Figure 3.2 Mitigation potential of soil and above-ground carbon sequestration practices with land use change (A)\textsuperscript{24} and with land management change (B)](image)

\textsuperscript{24} SC= Soil carbon sequestration; AG= Above-ground carbon sequestration; SS=Sitka spruce.
Figure 3.3 Mitigation potential of carbon sequestration practices in organic soils (A) and practices that avoid or reduce GHG emissions (B)

3.3.2 Selection of practices that satisfy the requirements of additionality, mechanism uncertainty, and lack of knowledge

The practices with the highest physical mitigation potential (≥ 200 ktCO₂ yr⁻¹) in each category (Figure 3.2-A, Figure 3.2-B, Figure 3.3-A, Figure 3.3-B) were investigated in relation to ‘additionality’, ‘mechanism uncertainty’, ‘permanence’ and ‘lack of knowledge’ (Table 3.3). It should be noticed that soil groups of carbon sequestration practices were assumed to be permanent in Section 3.2.3.

Table 3.3 Selection of mitigation practices according to additionality, mechanism uncertainty and lack of knowledge requirements

<table>
<thead>
<tr>
<th>Practices</th>
<th>Requirement</th>
<th>Reason</th>
<th>Selected (✓)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woodland planting (Sitka spruce)</td>
<td>All 4 requirement</td>
<td>N/A</td>
<td>✓</td>
</tr>
<tr>
<td>Incorporation of manure²⁵</td>
<td>No additionality</td>
<td>This practice is included in the standards of Good Agricultural and Environment Condition (GAEC) (Radov et al., 2007). According to Smith et al. (2000b), applying animal manure to arable land is a practice widespread in the UK.</td>
<td></td>
</tr>
<tr>
<td>Crop residues in soils²⁶</td>
<td>All 4 requirements</td>
<td>N/A</td>
<td>✓</td>
</tr>
<tr>
<td>Optimum grazing intensity</td>
<td>Mechanism uncertainty</td>
<td>Good management of rangelands promotes C sequestration (Ingram et al., 2008). However, the technical mitigation potential of this practice may be lower than its thought since</td>
<td></td>
</tr>
</tbody>
</table>

²⁵ Practice usually implemented in organic farming.
²⁶ Id.
the effects of grazing management in N\textsubscript{2}O and CH\textsubscript{4} emissions are not well-known (Smith et al., 2008).

<table>
<thead>
<tr>
<th>Deep-rooting crops</th>
<th>Mechanism uncertainty</th>
<th>Freibauer et al. (2004) point out a limited knowledge about the technical mitigation potential of this practice and claim the need for further research.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land drainage</td>
<td>No additionality</td>
<td>Improving land drainage is a standard agricultural practice to avoid drainage problems by maintaining land in GAEC (GAEC 18) (Radov et al., 2007).</td>
</tr>
<tr>
<td>Matching the timing for mineral/organic N fertiliser application</td>
<td>No additionality</td>
<td>Most arable land in NE Scotland is under Nitrate Vulnerable Zones (NVZs) and from 1\textsuperscript{st} January 2012 there must be sufficient storage for at least 6 months production of pig slurry between 1 October and 1 April inclusive to ensure the manure is applied at the right time (Scottish Government, 2010b).</td>
</tr>
<tr>
<td>Precision farming</td>
<td>All 4 requirements met</td>
<td>N/A</td>
</tr>
<tr>
<td>Avoiding N excess</td>
<td>Id.</td>
<td>N/A</td>
</tr>
<tr>
<td>Nitrification inhibitors/controlled release fertilisers</td>
<td>Id.</td>
<td>N/A</td>
</tr>
<tr>
<td>Biological fixation (clover)</td>
<td>Id.</td>
<td>N/A</td>
</tr>
<tr>
<td>Species introduction</td>
<td>Lack of knowledge</td>
<td>These plant varieties are not common in the UK (Moran et al., 2008).</td>
</tr>
<tr>
<td>Composting</td>
<td>Lack of knowledge</td>
<td>Compost is a limited resource and the quantity produced per annum in NE Scotland is not known. Thus, the arable area which could be spread with compost is also not known.</td>
</tr>
</tbody>
</table>

Widely implemented practices (no additionality) and those for which there is lack of knowledge and uncertainty about the mechanisms were not selected. Within organic farming, applying manure to soils was not selected because it does not satisfy the ‘additionality’ requirements, extensification and extending crop rotations were not selected because they have a small physical mitigation potential (Figure 3.3 –A). The practices selected to estimate GHG reductions up to 2020 which satisfy the requirements of ‘mechanism uncertainty’, ‘permanence’, ‘additionality’ and ‘lack of knowledge’ are:

1- Woodland planting with Sitka spruce;
2- Incorporation of crop residues;
3- Avoiding nitrogen (N) excess;
4- Precision farming;
5- Nitrification inhibitors;
6- Controlled release fertilisers.
7- Biological fixation with clover.
Woodland planting on 62,222 ha with Sitka spruce contributes both to soil and to above-carbon sequestration. Incorporating crop residues in the soil contributes to increasing soil carbon sequestration because these residues are the precursors of soil organic matter, the main store of carbon in the soil (Smith et al., 2008). Avoiding nitrogen (N) excess is a practice to implement in areas where its use is excessive. The practice aims at reducing nitrogen in the system and consequently N₂O emissions (Moran et al., 2010). Precision farming involves the application of mineral N fertiliser and other inputs based on observing and responding to intra-field variations. This practice increases the efficiency of N mineral use and reduces N₂O emissions. It relies on new technologies, such as satellite imagery, information technology and geospatial tools. Nitrification inhibitors are chemicals that reduce the conversion rate of ammonium to nitrate while reducing N₂O emissions. They have been successfully used to mitigate N₂O emissions when mixed with slurry and injected into grassland (Radov et al., 2007). Controlled release fertilisers supply nitrogen more slowly than conventional fertilisers, ensuring that microbial conversion of mineral N in the soil to N₂O and ammonia is lowered (Moran et al., 2010). Applying nitrification inhibitors or controlled release fertilisers, adopting precision farming and avoiding nitrogen (N) in excess would equally reduce GHG emissions since the technical mitigation potential of these practices is the same (Smith et al., 2008). Using legumes (e.g. clover) to biologically fix nitrogen (N) reduces the requirement for mineral and organic N fertiliser, and consequently reduces N₂O emissions (Moran et al., 2010).

### 3.3.3 GHG emissions reduction obtained with selected mitigation practices

It was assumed that farmers and other land managers would choose only one of the practices that reduce N₂O emissions through increased efficiency of mineral N fertiliser application. This means that precision farming, controlled release fertilisers, nitrification inhibitors or avoiding nitrogen (N) excess would not be implemented together to avoid double accounting on GHG emissions reduction of these activities. It was also assumed that farmers using biological fixation (with clover) to provide N inputs in grassland would not apply mineral N fertiliser. Thus, precision farming, nitrogen inhibitors and controlled release fertilisers were not implemented when biological fixation was used. According to Moran et al. (2008), a mitigation practice can be implemented on its own...
or in combination with other practices. If implemented in combination with other practices, the technical mitigation potential changes in response to the practices they combine with. In the case of incorporation of crop residues, there is a possible slight increase in N\textsubscript{2}O emissions due to more organic material in the soil as a source of mineralised N (Freibauer et al., 2004). As this could influence the technical mitigation potential of the mitigation practices mentioned above, it was assumed that incorporation of crop residues would be implemented on its own. Finally, an increase of woodland planting would take area out of cropland, fallow and/or grassland use. This means that the area to incorporate crop residues, apply controlled release fertilisers/nitrogen inhibitors, adopting precision farming, avoiding N excess and using biological fixation (with clover) to provide N inputs would be reduced. As a consequence, the physical mitigation potential of these practices would also reduce. By taking into account these assumptions and to simplify the estimates, it was considered that all the practices would be adopted independently from each other. The GHG emission reductions obtained by the implementation of each individual practice are presented in Figure 3.4.

Figure 3.4 GHG emission reductions after implementation of selected land-based mitigation practices between 2010 and 2020, in North East Scotland
GHG emissions in a Business as Usual (BAU) scenario in which the world continues to emit heat-trapping gases at an increasing rate.

*Or nitrification inhibitors, or controlled release fertilisers, or avoiding nitrogen (N) excess. These practices all have the same technical mitigation potential and are directed to the same areas.

3.3.4 Barriers affecting the implementation of selected practices

In relation to woodland planting, which presents the highest mitigation potential of all practices analysed, two barriers that may affect its uptake in North East Scotland were found in the literature reviewed. One was social, i.e., the negative attitude expressed by farmers in the region against tree planting and the other was political, relating to the Scottish Food and Drink Strategy (Scottish Government, 2009b). On the one hand, Scotland’s national food and drink strategy supports the growth of the food and drink industry, but on the other hand the Scottish Government aspires to increase forest cover in Scotland to 25% (Scottish Executive, 2006). Whether the two government targets are compatible or not should be further analysed. In relation to the social factor, a previous study undertaken by Towers et al., (2006) revealed the high potential for farm woodland creation but a negative attitude by the farmers towards woodland. Large landowners and community groups have been said to have a more positive attitude towards woodland creation (Clark, 1995). The Forestry Commission Scotland has pointed out that it will take over a century to reach the 25% target at the rate of progress achieved to date through the “Challenge Fund” and “Locational Premium” mechanisms established over the last decade (Stubbs, 2010). According to Stubbs (2010) there are significant opportunities for expansion of woodland in Scotland uplands and farms, and farmers might be willing to plant trees on about 10% of their farmland. This would create over 5,000 ha of new woodland but is far below the national target which, if accomplished, would add about 62,200 hectares of tree cover in North East Scotland (7% of the total land area) (See Table 3.2).

What might motivate land managers to plant trees in the uplands can be speculated upon: firstly, grants available for woodland planting would have to cover the costs of forest planting (∼£5,400-£7,400 ha⁻¹ for conifers and ∼£2500-£2600 for broadleaves); secondly, carbon trading, i.e., receiving payment for sequestering carbon or a tax on farm emissions could stimulate land owners to plant trees; third, single farm payment on planted land should be maintained. As a tax on farm GHG emissions is not likely to be
implemented before 2020, it is unlikely that 25% tree cover will be achieved in North East Scotland by 2020 and the GHG emission reduction provided by this practice achieved (Figure 3.4). A recent report from the Woodland Expansion Advisory Group (WEAG, 2012) admitted that planting levels in the last years have been at their lowest level for half a century, that there is a deep cultural divide between forestry and farming strategy, and that those who want to plant woodlands believe “the system is not helping them to achieve this”.

Taxes and incentives will only address economic barriers to the implementation of woodland planting, not social barriers. Towers et al. (2006) argues that farmers have no history of woodland planting and are generally negative towards planting of woodland on good agricultural land, which is also where the greatest potential land bank for future woodland expansion is. Some interest is shown, however, in places where woodland planting is beneficial to existing interests, as for example, sporting cover, uses of poorer ground or amenity purposes.

In relation to precision farming, the cost of the technology may limit the implementation of this practice. In addition, time and ability of farmers to exploit new technologies are also required and might constitute a barrier. To overcome the high costs of precision farming, machinery sharing rings could be implemented. The implementation of training schemes to help farmers to learn how to use this technology can also be suggested.

Cost is also a barrier against the uptake of nitrification inhibitors and controlled-release fertilisers. However, part of this cost can be compensated for by a reduced number of applications required, and by reduced labour/machine costs in the case of nitrification inhibitors (Moran et al., 2008).

Finally, in relation to biological fixation with clover, implementing it may reduce stocking rates (Radov et al., 2007), and, a consequent conflict with the Scottish Food and Drink Strategy. If the adoption of this practice causes stock reduction and the demand for meat increases or remains at current levels, meat production can shift to

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other countries, which are not so committed in meeting GHG emission reduction targets. This would result in GHG emissions leakage27 (Smith et al., 2007).

3.4 Discussion

From 43 crop and soil mitigation practices, 11 were selected for their high physical mitigation potential (Table 3.3). As the requirements of ‘additionality’, ‘lack of knowledge’ and ‘mechanism uncertainty’ and ‘permanence’ were not always satisfied, only seven mitigation practices (precision farming, clover, woodland planting, crop residues, nitrification inhibitors, controlled release fertilisers, avoiding nitrogen excess) were selected to estimate GHG emission reduction in North East Scotland by 2020, assuming their adoption. The GHG emissions reduction obtained with each individual practice represents an optimistic estimate because the maximum available area and highest technical mitigation potential found in literature were used to estimate their physical mitigation potential. For example, implementing clover in improved grassland would lower GHG emissions in 15% by 2020, compared to the projected emissions between 2011 and 2020 (Extrapolation in Figure 3.4). Adopting other practices that reduce GHG emissions from the application of N fertiliser, namely precision farming, nitrification inhibitors, controlled release fertilisers and avoiding nitrogen excess, would lower GHG emissions by approximately 20%. Incorporating crop residues in the soils would lower GHG emissions by 36%. Finally, woodland planting with Sitka spruce would contribute to a reduction of GHG emissions 58% when the compared the projected emissions between 2011 and 2020 (Extrapolation in Figure 3.4).

Relative to 1990 levels, implementing clover on improved grassland would reduce GHG emissions from rural land uses in about 33% by 2020. Adopting one of the practices that reduce GHG emissions from the application of N fertiliser would reduce GHG emissions by approximately 37%. Incorporating crop residues in the soils would sequester about 50% of GHG emission reduction and woodland planting with Sitka spruce would offset about 67% of the GHG emissions from rural land uses (Figure 3.4). This means that the adoption of any one of these seven practices would be enough to

27 Also known as GHG emissions displacement or carbon laundering.
reach the GHG reduction target of 21% by 2020 relative to 1990 for the rural land use sector in North East Scotland.

However, these are optimistic estimates and that for most of the practices the technical mitigation potential is associated with high uncertainty ranges (Table 3.1). For example, the technical mitigation potential used for incorporating crop residues in soils was 2.60 tCO$_2$ ha$^{-1}$yr$^{-1}$ and, according to Freibauer et al. (2004), the uncertainty for this potential is higher than 50%. In the case of avoiding N excess$^{28}$, the technical mitigation potential used was 0.64 tCO$_2$e ha$^{-1}$yr$^{-1}$, while the lower bond of the uncertainty range is 0.02 tCO$_2$e ha$^{-1}$yr$^{-1}$ (Smith et al., 2008). Thus, the technical mitigation potential can be 97% lower than the one used in the estimates.

The GHG emission estimates for the period 2011-2020 (extrapolation), which were based on the GHG emissions trend between 1999 and 2010, are also uncertain (Figure 3.4). This decreasing trend may not happen in the future. In fact, the Scottish Government (2011) estimates that under a BAU scenario, net emissions from rural land use will increase from a low in 2008 and rise again to almost 1990 levels by 2022. If this is the case, achieving a 21% reduction target by implementing a single mitigation practice for the whole region (e.g. woodland planting with Sitka spruce) will be more difficult.

Barriers to the adoption of mitigation practices identified in Section 3.4 were also considered. These are likely to contribute to a reduction in the area where mitigation practices can be implemented. In the case of woodland planting, several studies recognised the difficulty of achieving the 25% woodland cover objective. In relation to the incorporation of crop residues in soils, it is believed that, in North East Scotland, almost all straw is baled and used for the livestock feeding and bedding markets. Therefore, land managers would need an incentive (e.g. payment) to incorporate straw in soils or they would lose money by choosing to mitigate climate change instead of selling the straw residues in the market. Obviously, there would be a need to replace the straw used in livestock feeding and bedding by other materials. In the case of replacing

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$^{28}$ This is also the case of controlled release fertilisers, nitrogen inhibitors and precision farming.
the straw for livestock feeding by other feedstuffs, this might require importing feedstuffs from other regions and ‘export’ GHG emissions to other regions (carbon leakage). Straw for livestock bedding can be replaced by woodpellets, which can be produced with local wood.

Using biological fixation (with clover) to provide N inputs with clover might be already widely implemented in North East Scotland, and there would be little or no ‘additionality’ by implementing this practice. Thus, GHG emission reduction provided by this practice would be much lower than indicated in Figure 3.4. In addition, some attention must be given to the practice ‘avoiding N excess’ because there is an underlying assumption in the literature reviewed that farmers apply N fertiliser in excess. Current high fertiliser prices suggest that farmers rationalise fertiliser application in cropland and grassland in order to lower their production costs. Avoiding N excess may not, therefore, offer significant additional GHG emissions reduction if it is confirmed that most farmers are adopting it already. Ground-truthing, i.e, gathering data in the field, should be undertaken in order to decide whether this practice brings ‘additionality’ or not.

It is important to undertake farmers’ questionnaire and focus groups with experts, farmers and other land managers in order to ascertain which practices have been already implemented, and where geographically. This would inform which the area where the implementation of mitigation practices would bring ‘additionality’ to GHG emission reduction. It is also necessary to assess the area available to implement mitigation by taking into account implementation barriers. For example, farmers in North East Scotland are perceived to be averse to woodland planting. It would be important to discover if the effect of this barrier on the potential area for planting trees can be overcome, and how. Slee et al. (in press) believe that, if carbon emissions were taxed, a significant flow of resource from low-ground farms to the disadvantaged hill areas would be likely, which would become very important with respect to climate change mitigation. In addition, woodland planting is part of the Scottish Government policy to increase tree cover, but this policy seems to be in conflict with the Scottish Food and Drink Strategy, which potentially promotes the growth of food production and the maintenance of the agricultural area. Recently, the Scottish Government announced that the forest cover target (25% land cover) would become an ‘aspiration’ (FC, 2009). This
indicates the importance of food security to the policy agenda. To avoid conflict with food production, woodland planting should occur in poorer-quality land, as for example, some hills and upland areas in North East Scotland. This would also prevent the displacement of GHG emissions (leakage) to other regions in case of an increase in food demand. Smith et al. (2007) noted that the adoption of agricultural mitigation practices may reduce production within implementing regions but with no consequences to global net reduction of GHG emissions due to food imports from other regions. Murray et al. (2004) recommends that “leakage correction factors” are employed whenever a mitigation practice implemented in a region leads to food imports from other regions.

Among the practices not selected are those implemented in organic soils (Figure 3.3-A). According to the literature reviewed, these practices have high technical mitigation potential (5-33 tCO$_2$ ha$^{-1}$ yr$^{-1}$) and uncertainty range (>50%) (Freibauer et al., 2004; Radov et al. 2007; Smith et al., 2008), but the areas where they can be implemented are very small. In fact, it was assumed that these practices could only be implemented on farmed organic soils, unmanaged grassland in undrained peatland and managed grassland in peatland which together correspond to around 4,200 hectares (about 0.55% of the region’s total area) in North East Scotland. This may suggest that mitigation practices to reduce GHG emissions in organic soils are not relevant at the regional level. However, it should be noticed that organic soils are important stores of carbon (C) accumulated over many centuries, and that if this carbon is released, GHG emissions can significantly increase. Smith et al. (2008) suggest that avoiding C loss is the most important mitigation practice for this type of soils.

3.5 Conclusion

The aim of this study was to suggest a methodology for selecting suitable land-based mitigation practices for a specific region in Scotland using a literature review which included published information about the region. The suggested methodology followed several steps to select land-based mitigation practices. The first step was to estimate the physical mitigation potential of land-based practices using the technical mitigation potential of each practice and the area where the practice could be implemented. The
technical mitigation potentials were collected from the literature and the area of implementation was derived from official land use data published for the region.

Eleven land-based mitigation practices, with physical technical mitigation potentials above 200 ktCO₂e in North East Scotland, were chosen for further analysis. Seven of these practices were considered to satisfy ‘additionality’, ‘lack of knowledge’, ‘permanence’ and ‘mechanism uncertainty’ requirements, and were used to estimate GHG emission reductions between 2010 and 2020. These seven practices were woodland planting (with Sitka spruce), precision farming, incorporation of crop residues, controlled release fertilisers, nitrification inhibitors, avoiding N excess and using biological fixation to provide N inputs with clover. By considering the maximum area where the mitigation practices could be implemented and the highest technical mitigation potentials found in literature, the adoption of any of the seven selected mitigation practices would be enough to achieve a 21% GHG emission reduction in the rural land use sector by 2020 relative to 1990 levels (Figure 3.4). Woodland planting with Sitka spruce was the mitigation practice with the highest physical mitigation potential (67% net GHG emission reduction), almost decarbonising the rural land use sector in North East Scotland. However, barriers to the implementation of this practice are likely to reduce its mitigation potential in the region. It should be mentioned that some mitigation practices (e.g. woodland planting) also provide other ecosystem services (e.g. flood management, increase biodiversity, improve landscape). In fact, the provision of ecosystem services partly justifies the Scottish Government’s rationale for woodland expansion (FC, 2009).

The estimates undertaken in this study are optimistic estimates and did not consider a possible scenario where GHG emissions from rural land uses continuously increase after 2010, due for example, increased food production. There is evidence that future shortage of food and increased food prices are likely to drive up fertiliser use, which, even when applied using best practices, would contribute to an increase in GHG emissions.

It should be noted that undertaking an appraisal of barriers to mitigation practices in the whole region may not be the solution since different farms/land management units have different characteristics, and what may be a barrier on one farm may not be for another.
In the future, each farmer should appraise the mitigation practices at the farm level, and implement those that cut more GHG emissions at a lower cost, in line with his/her own preferences (individual values) and government policy. By recognising this, it can be recognised that practices with a small potential at a regional level can become more relevant at the farm/land management unit level. Policy makers should decide whether climate change mitigation policies should prioritise the practices with highest physical mitigation potential at the regional level, or if farmers who achieve GHG emission reductions should be rewarded, independent of the land-based mitigation practices they adopt.

The methodology suggested in this study may be useful for an initial assessment of possibilities. Since it is based on a review of the literature and official statistics, it involves few resources. A further analysis to ground-truth the findings of such an assessment (participatory workshops with experts, farmers’ questionnaire, focus groups) should be the next step. It is anticipated that such ground-truthing would improve the understanding of which practices are widely implemented already, what are the most popular land-based mitigation practices, and what could trigger a change in land manager behaviour towards the adoption of currently unpopular land-based mitigation practices.
References


Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G.,


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Appendix 2 Technical mitigation potentials

Note: See CD-ROM.
4 Stakeholders’ perspectives
Abstract

In Scotland, the rural land use sector is subject to greenhouse gas (GHG) emission reduction targets of 21% by 2020 relative to 1990 levels. Land managers have to take steps to reduce GHG emissions. The literature presents a diverse range of technically feasible mitigation practices for the rural land use sector but their uptake by farmers and land managers is not well studied at regional level. This chapter presents data on current and potential uptake of mitigation practices and barriers to uptake of mitigation practices collected through one farmers’ survey, two participatory workshops and three focus groups. Findings suggest that the favoured mitigation practices for future adoption are those that farmers already know and have no, or minimal, additional costs. Financial incentives and access to knowledge were considered important in increasing the uptake of mitigation practices by experts. Renewable energy, feeding additives to livestock and precision farming were well supported by farmers in the focus groups, but renewable energy may not be regarded as a strategy to offset GHG emissions in the rural land use sector by the government since emission reductions occur in the energy sector.

Keywords: Mitigation practices, uptake, barriers, GHG emission targets

4.1 Introduction

In North East Scotland, agricultural activities are responsible for 60% of total methane (CH₄), 87% of nitrous oxide (N₂O) and 3% of total carbon dioxide (CO₂) emissions (AEA, 2011). Over a 100-year timescale, CH₄ and N₂O greenhouse gases (GHGs) have a much higher global warming potential (GWP) than CO₂ (Forster et al., 2007), being important contributors to climate change. Tackling climate change is regarded by government as the responsibility of all sectors of the economy, and Scottish farming will also have to take steps to reduce GHG emissions (SAC, 2011). The Delivery Plan (Scottish Government, 2009) for the Climate Change (Scotland) Act (2009) expects agriculture and agricultural land use to reduce their emissions in 2020 by 21%, compared to 1990 levels. Reducing GHG emissions from agriculture can be done either by increasing the efficiency of production through a change in management practices or
by increasing carbon storage in soil, biomass (e.g. wood) or by avoiding or displacing emissions (Smith et al., 2008).

Several studies have suggested technologies and practices to mitigate GHG emissions from agriculture at global (Johnson et al., 2007; Smith et al. 2008), European (Freibauer et al., 2004; Ovando and Caparros, 2009; Powlson et al., 2008; Smith et al., 1997; 1998; 2000a; 2001) and UK levels (Smith et al., 2000b; Smith et al., 2000c). In the UK, marginal abatement cost curves (MACCs) for agriculture and land use, land use and forestry have been developed (Macleod et al., 2010; Moran et al., 2008; Moran et al., 2010; Moran et al., 2011), although, being based on average conditions, these may not apply to individual farm holdings. These indicate the cost of reducing an additional unit of carbon equivalent emissions given the adoption of a certain mitigation practice. It has been estimated that some mitigation costs can be negative, i.e., the practices adopted to reduce emissions are simultaneously financially beneficial to farmers (Moran et al., 2011; RSE Committee of Inquiry, 2011). However, it has been noticed that negative cost (so-called win-win) options are not always adopted (RSE Committee of Inquiry, 2011). Smith et al. (2007) reviewed policy and technological constraints to the implementation of GHG mitigation options in agriculture. Examples of constraints were property rights, risk attitudes, need for new knowledge or availability of extension services.

A Defra-commissioned project (Barnes et al., 2010) focused on understanding the barriers and supporting factors for additional uptake of mitigation practices. It was found that in England, the main supporting factors for uptake were the reduction of costs, best management practice, markets and peer pressure. The main barriers were structural (e.g. tenure, age), financial and educational factors, and resistance to change current practices and administration (e.g. complexity of policies, time to implement the schemes). The project also showed that the uptake of mitigation practices varies according to the type of farm system, with dairy and arable farmers showing greater uptake in comparison to upland livestock farmers.

Several authors (Edwards et al., 1993; Flamant et al., 1999; Smith et al., 2007) recognise that agricultural systems have considerable variation in emissions between seasons (e.g. site-specific factors) and locations (e.g. regional policy; socio-economic
and cultural conditions). The co-benefits and trade-offs associated with a mitigation practice may vary geographically because of differences in climate, soil, or the way the practice is adopted (Smith et al., 2007). Streck et al. (2011) consider that it is challenging to express the mitigation potential of agriculture in marginal abatement cost curves because agriculture is highly site- and context-specific, and practices that work in a certain context may not work in another. Given this, it is possible that the cost of mitigating one additional unit of carbon equivalent emitted with a certain practice is negative at the UK level but positive at, for example, the farm scale.

Another important aspect to take into account when estimating the potential for GHG emissions reduction is ‘additionality’. Smith et al. (2007) noted that GHG net emissions have to be additional to what would happen in the absence of a climate policy driver. If GHG net emissions are reduced even without the implementation of a mitigation practice then the ‘additionality’ requirement will not be satisfied (Robbins, 2011). In the case of agriculture, many carbon sequestration practices (e.g. reduced application of nitrogenous fertiliser) have been implemented for reasons other than mitigating climate change, and it may be difficult to identify how much activity is additional to evolving practices (Robbins, 2011; Smith et al., 2007). Defra’s project revealed that the uptake level of mitigation practices considered in the study was significant (Barnes et al., 2010). A farmers’ survey undertaken by Dick et al. (2008) revealed that 93% of UK farmers are already implementing practices that reduce GHG emissions, in spite of most of them being unaware that they were contributing to climate change mitigation.

Smith et al. (2007) notes that farmers prefer to have the opportunity to address a particular matter on their farm in the most appropriate and cost-effective way. A recent report recommended that “local perspectives need to be heard in order to achieve some shared understanding of the meaning of low carbon-transition, including farmers and other land managers” (RSE Committee of Inquiry, 2011). Several studies have been examining the suitability of GHG mitigation practices at the global, European and UK level but none investigated the stakeholders’ perspectives on the suitability of mitigation practices relatively to the region where they are located. Thus, the main objective of this study was to investigate the stakeholders’ perspectives on the appropriateness of
mitigation practices for the North East Scotland rural land use sector. The main research questions that this study attempted to address were:

1) What are the current mitigation practices in North East Scotland?
2) What are the preferred mitigation practices to be implemented in the future?
3) What are the barriers and supporting factors to the uptake of mitigation practices?

This study takes a regionally grounded approach. North East Scotland contains a variety of farming systems and is, in many ways, a microcosm of Scottish farming, albeit under-represented with respect to dairy farming. It provides a suitable study context to explore the challenges of adopting mitigation practices in the farm sector.

4.2 Methodology

This study involved a literature review to identify potential mitigation practices for the rural land use sector in North East Scotland as well as the barriers and supporting factors for their uptake. It also involved both qualitative (farmers’ questionnaire, participatory workshops; focus groups) and quantitative (farmers’ questionnaire) research methods. Brannen (2005) considers that mixed-methods research has several advantages, namely the elaboration and expansion of the data analysis, the possibility of pursuing hypotheses arisen during the use of a first method, the complementarity of data obtained with different methods which, together, create a bigger picture of the object of research, and the fact that any contradictions can be explored in further research. The participatory workshops were intended to find out what are the practices that experts considered most suitable for North East Scotland rural land use sector. The farmers’ questionnaire aimed at assessing the current and potential mitigation practices undertaken by farmers from North East Scotland. Finally, the main objective of the focus groups was to ascertain farmers’ views on current and potential mitigation farmers in relation to its implementation in North East Scotland. The methodology undertaken according to each research tool is described below.
4.2.1 Participatory workshops

Two participatory workshops were held in Aberdeen and in Inverurie, Aberdeenshire, North East Scotland, in June 2011. The objective of these workshops was to collect the stakeholders’ opinions on the suitability of listed mitigation practices for the rural land use sector in North East Scotland, and on which practices should be implemented in the future. According to Freeman (1984), stakeholders are those affected by the decisions and actions taken by decision-makers and those who have the power to influence the policies outcome. The objective of the participatory workshops was also to provide an insight of the mitigation practices that were already implemented in the region and of barriers and supporting factors to the implementation of mitigation practices. Stakeholders invited were researchers in land use issues, land agents, industry representatives and estate owners. The term “experts” was used in this dissertation to define this group of stakeholders in order to distinguish them from farmers.

The first workshop was directed at rural land use and climate change researchers from the James Hutton Institute in Aberdeen, Scotland. Stakeholders included 13 experts in soil science, bio-energy, ecosystem services, sheep ecology, upland management, rural development, forestry, ruminant nutrition, biodiversity and grasslands. The second workshop was directed at experts from outside the James Hutton Institute. For it, 29 people were invited and 13 accepted the invitation to participate, but three were unable to attend and provided their opinion by e-mail on the topics discussed. Among the 13 people who contributed to the discussion were estate owners, agricultural consultants, industry and farming sector representatives, business advisors, academics from the University of Aberdeen, and Forestry Commission representatives. Participants were selected by snowball sampling, i.e. a number of initial contacts were made, and, from these, the names and addresses of other people who fulfilled the sampling requirements were collected, i.e. having an expertise in rural land management issues. The workshops lasted approximately two hours and participants were asked to:

1) Identify technically feasible GHG mitigation practices for the rural land use sector;
2) Rank practices according to mitigation potential in North East Scotland;
3) Discuss why the highest ranked mitigation practices were chosen;
4) Point out what should be done to increase the uptake of highly ranked mitigation practices.

Technically feasible GHG mitigation practices were defined as those capable of providing a reduction in GHG emissions measured in CO$_2$e ha$^{-1}$yr$^{-1}$ or CO$_2$e animal$^{-1}$ yr$^{-1}$. It was explained to the participants that the implementation of these practices should not have a negative impact on agricultural productivity. Renewable energy options were also excluded because the GHG emission reduction they provide is accounted in the energy sector and not in the rural land use sector. The participatory workshops also served as a research base to design the farmers’ questionnaire.

### 4.2.2 Farmers’ questionnaire

To gain information about current implementation of mitigation practices, preferences on mitigation practices, and barriers and supporting factors to the implementation of mitigation practices, an anonymous questionnaire survey was undertaken (Appendix 3). The questionnaire included 27 mitigation practices relating to cropland and grassland management (13 practices), soil-carbon sequestration (4), livestock management (9) and above-ground carbon sequestration (1). These were selected from Moran et al. (2008), Radov et al. (2007) and Smith et al. (2008). Several closed questions aimed at collecting general information about the respondents (e.g. postcode, type of farm, size of farm) and about the use of carbon footprint calculators were also included. The reason why the carbon footprint question was integrated in the questionnaire was to obtain information about farmers’ awareness of climate change. In order to collect information about current mitigation practices in North East Scotland, farmers were asked to signal which ones they already implement in their farms. They were also asked to indicate the top three favourite practices to implement if it became compulsory to reduce farm GHG emissions by 20% in 2020. Finally, an open question which required farmers to justify the choice of the top three mitigation practices was inserted in order to collect information about barriers and supporting factors to uptake.

The sampling method used was convenience sampling. This is a type of non-probability sample in which a population is selected because it is readily available and convenient. The sample used in this study included farmers attending local livestock marts and
farmers’ meetings, and members of Scottish Land & Estates, i.e. a landowners’ association which promotes the wide range of benefits provided by land-based businesses. Convenience sampling was used because of time constraints, ease of gaining data and quickness in getting a significant number of responses in a short time. However, by using such a sample it is not possible to make scientific generalisations about the total population of farmers because it would not be representative enough.

The questionnaire was conducted in two different ways: in person and by e-mail. Questionnaires conducted in person were randomly undertaken with farmers at two main livestock marts in North East Scotland (Thainstone and Huntly). One of these livestock marts attracts farmers from different council areas within the region, as well as further afield; the other mart is more local in its farming clientele. Face-to-face questionnaires were chosen because they require less time to complete than a semi-structured interview, but still include personal contact, and result in a higher response rate. It was also assumed that a more stratified response in terms of farmers’ age and knowledge about climate change would be obtained in the marts as opposed to postal questionnaires. Farmers were approached specifically on Friday and Saturday auctions, during three months (July, August and September) in 2011. Questionnaires conducted in person were also undertaken at three farmer evening meetings organised by the National Farmers’ Union Scotland (NFUS). The objective of these meetings was to discuss issues related to farmers’ businesses as well as national and European agricultural policies. At the end of each meeting the questionnaires were distributed to the audience to be completed. The questionnaire was also available as an online version. The link to the questionnaire was sent via e-mail to farmers and land managers from the Scottish Land & Estates mailing list, and was included on the “Farming for a Better Climate” website29. The objective of the online questionnaire was to give farmers opportunity to complete it at their own convenience and to increase response rate. Evans and Mathur (2005) argue that online surveys increase the response rate of surveys. The objective of the e-mail questionnaires was also to reach farmers who do not attend the local marts.

A total of 99 questionnaires were completed, including 17 online. Since there were not enough responses per sample type (face-to-face and online), tests of significance were

29 Source: http://www.sac.ac.uk/climatechange/farmingforabetterclimate/ (last accessed, 18/09/2012).
not carried out and all the responses were treated the same. Seventy-five per cent of the people approached in the livestock marts were farmers and agreed to complete the questionnaire. This compares favourably with a farming and bio-energy postal survey undertaken in North East Scotland in 2008, with a 20% response rate and 150 questionnaires completed (Brown, 2011).

### 4.2.3 Focus groups

To verify, build on and add depth to the results from the questionnaire survey, three focus groups were held at two different locations (Fettercairn and Thainstone, Aberdeenshire, Scotland) in October and November 2011. The objective of these focus groups was to investigate whether farmers agreed with the list of suitable GHG mitigation practices selected by the experts who attended the participatory workshops and barriers and supporting factors for its adoption, or not. Mixed and arable farmers attended the three focus groups. The focus groups were divided into three main parts:

1. Farmers identified feasible GHG mitigation practices for the rural land use sector;
2. Farmers discussed barriers and supporting factors towards the implementation of mitigation practices identified;
3. Farmers examined whether a 21% GHG emission reduction in the rural land use sector by 2020 was possible or not.

To ensure the successful recruitment of farmers, the focus groups were integrated into the monthly farmers meetings organised by the Scottish Agricultural College (SAC) and National Farmers’ Union Scotland (NFUS). Fettercairn farmers meet monthly to discuss specific topics, and the focus groups held for this study were integrated as part of one of these monthly meetings. This meeting was attended by eight farmers. Subsequently, three focus groups were held in Thainstone as part of a special session on farming efficiency and climate change organised by the NFUS. The first two sessions were attended by eight farmers whilst the third had seven attendees. To compensate farmers for their participation, they were given the opportunity to estimate the carbon footprint.
of their farms using the carbon calculator CPlan\textsuperscript{30}, free of charge (normal cost £40). The discussions were recorded with a digital dictaphone and lasted between one and two hours. They were subsequently transcribed and organised into topic areas and key-themes using NVivo9 software to permit coding, analysis and interpretation.

4.3 Results

A total of 46 GHG mitigation practices were identified in the participatory workshops: 28 in the first workshop and 18 in the second workshop. A total of six mitigation practices were prioritised by participants in a scoring activity at the workshops. Participants discussed the reasons why each of these six mitigation practices were prioritised in relation to others, the barriers to uptake, and who should do what to improve its uptake.

The questionnaires allowed the perception of farmers’ awareness of climate change policies and agricultural GHG mitigation practices to be assessed and involved personal contact. Some farmers were keen on continuing the conversation beyond the standard questions. Often, in the case of older farmers, questions had to be reformulated because they were not familiar with some of the terms used in the questionnaire (e.g. biological fixation). Respondents covered all the types of farm reported in the Economic Report on Scottish Agriculture (Scottish Government, 2010a), namely cereals, general cropping, horticulture, specialist pigs, specialist poultry, dairy, cattle and sheep (less favoured areas - LFA), cattle and sheep (lowlands) and mixed. Most farmers interviewed were LFA cattle and sheep farmers in and cereal farmers (Figure 4.1). Mixed (19%) and cattle and sheep farmers in lowlands (15%) were also well represented in the group of farmers who completed the questionnaire. Since most of the questionnaires were undertaken at a livestock mart, it was not surprising to see that around 85% of the farmers who categorised themselves as cereal farmers also raised cattle and sheep (either in LFA, lowlands, or both). The least represented farm types were horticulture, specialist poultry and dairy (Figure 4.1). This is not a problem; dairy cattle have been

\textsuperscript{30}Source: http://www2.cplan.org.uk/ (last accessed 12/04/2011).
decreasing in North East Scotland, and in 2010 represented only 4% of the total cattle raised in the region (Scottish Government, 2010a).

![Figure 4.1 Distribution of farmers surveyed by farm type](image)

Farmers in the sample owned between 2 and 2,900 hectares of land (rough grazing and enclosed area), but mainly owned farms bigger than 20 hectares (Figure 4.2). This does not compare well with data from the Economic Report on Scottish Agriculture (2010) for the North East Scotland, where the majority of farmers surveyed had farms smaller than 20 hectares. Although the sample was not representative in relation to farm sizes, mitigation options will have a higher impact when implemented in larger size farms and these were covered by the farmers’ survey as it shows Figure 4.2.

![Figure 4.2 Comparison between farm sizes of the study sample and farm sizes of the Economic Report on Scottish Agriculture for North East Scotland (in %)](image)
In the focus groups, farmers were asked to identify land-based mitigation practices, and discuss barriers and supporting factors to its uptake. As farmers often related GHG emission reductions to fuel savings and found it difficult to identify other feasible GHG mitigation practices for the rural land use sector in the region, the list of GHG mitigation practices identified by the experts in the participatory workshops was presented to them. A total of 14 mitigation practices were discussed in relation to the barriers and supporting factors to implementation. In addition, farmers’ attitudes towards potential implementation were recorded.

4.3.1 Current mitigation practices in North East Scotland

The main instrument used to assess the current implementation of mitigation practices in North East Scotland was the farmers’ questionnaire. According to data collected during the survey, all farmers in the study sample were undertaking at least one of the 26 GHG mitigation strategies listed in the questionnaire. This is similar to the result obtained by Dick et al. (2011) (93% of the farmers surveyed were taking measures to reduce their GHG emissions). The top three practices currently implemented by farmers were using all the manure or slurry produced on the farm as fertiliser (78%), matching the timing of mineral N fertiliser application with the time that the crop will make the most of it (71%) and using biological fixation to provide nitrogen inputs (60%) (Figure 4.3). All of these practices are related to the reduction of nitrogen fertiliser application. It was verified that some livestock-related practices such as dietary additives (e.g. ionophores and probiotics), animal breeding (e.g. adopting genetically improved animals) and manure management (e.g. covering slurry tanks or lagoons) were not very popular amongst farmers of the study sample, with only 10% saying they were currently implementing them. In contrast, 46% of the farmers in the study sample were currently increasing the concentrate ration in the diet of dairy and beef (Figure 4.3).
Farmers were also asked if they were implementing other GHG mitigation practices not included in the list provided. This question was intended to probe which other practices farmers considered as GHG emission mitigation practices. Only eight farmers answered this question. They considered that planting hedgerows, being organic, creating ponds for wildlife, keeping buffer strips in grassland fields, changing livestock diet and erecting wind turbines were other options to mitigate climate change.

In the focus groups, farmers confirmed that using biological fixation to provide N inputs with clover, applying manure in arable land were practices already widely implemented in North East Scotland. They also considered that adopting genetically improved animal was broadly implemented.
4.3.2 Preferred mitigation practices to be implemented in the future and barriers and supporting factors to uptake

In the participatory workshops, experts pointed that the most suitable mitigation practices to be implemented, in the future, in North East Scotland were those related to the reduction of N$_2$O emissions (precision farming, implementing more clover in grassland, adopting mixed farming systems) and CH$_4$ emissions (adopting low-emitting livestock breeds), and to the increase in carbon sequestration and storage (restoring peatland and planting woodland) (Table 4.1).

**Table 4.1 Mitigation practices considered most suitable for North East Scotland by experts attending the participatory workshops**

<table>
<thead>
<tr>
<th>Mitigation practices</th>
<th>Why chosen</th>
<th>Barriers to uptake</th>
<th>What should be done to increase uptake</th>
<th>Who should act</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precision farming</td>
<td>It promotes the efficient use of resources without penalizing production; Higher yields of spring cereals; Much better return on nitrogen.</td>
<td>Complex software installed in the machinery; Costs.</td>
<td>Make it simpler for farmers; Machinery rings; Training; Subsidies for soil analysis.</td>
<td>Farmers</td>
</tr>
<tr>
<td>Biological fixation - More clover in grassland</td>
<td>Significant potential given to significant acreage in NE Scotland; It replaces artificial nitrogen; Local experience; Most farmers in NE Scotland could produce around 90% of the current grass growth with clover.</td>
<td>Lack of incentives; Lack of awareness of the benefits: Historically seen as an “eccentric/not for business” practice, associated with organic production; It may cause sheep bloating; Difficult to manage.</td>
<td>Demonstration; Farm visits; Monitoring farms; Co-operative approach; Spreading information; Incentives.</td>
<td>Farmers</td>
</tr>
<tr>
<td>Low emitting livestock breeds</td>
<td>Increase efficiency; Increase fertility.</td>
<td>Existing breeders who are against Estimated Breeding Values (EBVs) and against change and the costs; Long-term project which may take up to 10 years to achieve; Mechanisms not well understood: risks.</td>
<td>Adoption of EBVs, of genetic modified animals (GM), and of certain traits; Cutting input costs; Improve growth rates/productivity; Decreasing mortality; Knowledge transfer; Monitoring farms, demonstration.</td>
<td>Existing breeders and producers; SAC (Scottish Agricultural College); Quality Meat Scotland (QMS); Breeding societies; Veterinaries.</td>
</tr>
<tr>
<td>Mixed farming systems</td>
<td>Internalises nitrogen use- increases efficiency.</td>
<td>Economies of scale; Not great margins for farmers; Labour intensive.</td>
<td></td>
<td>Farmers</td>
</tr>
<tr>
<td>Peatland restoration</td>
<td>There is a large area of abandoned peatland in the NE Scotland that can be restored; Practice with high technical potential because peatland is a good store of carbon.</td>
<td>Cost; Lack of knowledge about the timescale and where to restore; Restored peatland does not have a financial value for the land owner/farmer.</td>
<td>Financial incentives; Market-based instruments.</td>
<td>Land managers</td>
</tr>
</tbody>
</table>
Chapter 4

| Woodland planting (including hedgerows; agro-forestry) | Trees can sequester CO₂; Trees provide wood energy, which can displace fossil fuels; Farms can become carbon neutral; More timber can be used in construction and to store carbon for a longer period; Hedgerows: Improve the microclimate of the field; Agro-forestry: Heritage. | Agro-forestry: Labour intensive; Potential soil carbon emissions; May look like an imposition to tell land owners/farmers where to plant trees; Productivity of farm woodland tends to be neglected; Farmers do not want to be foresters. | Forestry grants. | Farmers |

Precision farming was considered to promote the efficient use of resources without having a negative impact on production. Experts suggested that farmers should implement this practice. The main barrier highlighted regarding implementation was the complexity of the software installed in the machinery, and its costs. Experts recommended the wider use of machinery rings (sharing of machinery) to increase the uptake of this practice. Using more clover was considered to be relevant to most farmers in North East Scotland because of the significant grassland area in the region and because it replaces artificial nitrogen. It was claimed that the identification of target segments are needed to implement the practice, as well as demonstrations, farm visits, monitor farms and a co-operative approach. It was also said that the process needs to be simplified, potential delivery mechanisms should be selected and information should be widely spread across the key target sector, so farmers could understand the benefits of the practices. The main barriers identified regarding the use of clover were the lack of incentives, the lack of awareness of the benefits and the fact that it has historically been associated to organic farming. Adopting low-emitting livestock breeds was another mitigation practice considered suitable for North East Scotland. It was pointed out that existing breeders are against estimated breeding values (EBVs) and associated costs because achieving them may take up to 10 years. Existing breeders and existing producers should be responsible for the implementation of the practice, together with SAC (Scottish Agricultural College) and their veterinarians, Quality Meat Scotland (QMS) and breeding societies. The adoption of EBVs, genetically modified animals (GM) and specific livestock traits were highlighted as necessary intermediate steps to increase the implementation of the practice. Other steps pointed out were to cut input costs and to improve the growth rates. Knowledge transfer, monitoring farms, and demonstration of working examples that farmers could physically see were suggested as ways to promote the adoption of the practice.
Adopting mixed farming systems were chosen because of the capacity to internalise nitrogen use and increase efficiency. The existence of economies of scale can be a disincentive to the adoption of this type of system because farmers do not produce a single product. It is also more labour-intensive than arable crop farming. Peatland restoration was identified as an important mitigation practice for the North East Scotland given the area of abandoned peatland in the north-eastern part of the region. It was agreed that the practice is technically feasible but that farmers and other land managers do not have an incentive to do it since they do not benefit directly from peatland restoration. It was also revealed that it is an expensive practice, and that society should pay for the positive externalities of peatland restoration through the government (grants, subsidies). It was recommended that, before prioritising this practice, its benefits were compared with the benefits of forestry, that the timescale needed to obtain results was assessed, and the best places to restore peatland were identified.

Farm woodland planting, including hedgerow planting and agro-forestry, was among the practices prioritised by the workshop participants. Although several supporting factors were identified (e.g. carbon neutrality, wood energy, favourable micro-climate), a soil researcher attending the first workshop pointed out that soil carbon may be released due to soil disturbance and an estate owner attending the second workshop doubted that farmers in North East Scotland wanted to become foresters. Planting trees in marginal land was suggested, and this generated a discussion between supporters and non-supporters of this idea. Supporters of this practice mentioned that trees could be planted in the non-productive parts of a farm, as for example in the upland areas, and crop and animal production intensified in the lowlands so inputs were applied where farmers could get the most out of it. Non-supporters claimed that marginal land does not always ensure tree growth since this depends on species and soil type. They also pointed out may impose on farmers and land managers where to plant trees in case mechanisms to guide the decision were not established.

Education, cooperation and incentives were the main options considered to increase the uptake of mitigation practices presented in Table 4.1. Participants suggested that access to knowledge could be done through demonstrations, and visits to farms and training. Neighbour influence and peer pressure were also mentioned as a way of accessing
knowledge (e.g. farmers learning with each other), but sometimes worked against GHG emission mitigation (e.g. getting a bigger tractor which consumes more fossil fuels). Forms of cooperation such as setting up machinery rings, non-dairy farmers supplying silage to dairy farmers, in addition to lambs and calves from the uplands being finished in the lowlands, were suggested. Forestry grants, subsidies for soil analysis and market-based instruments were the main financial incentives identified. Workshop participants considered that farmers should be responsible for overcoming the barriers to uptake of mitigation practices (Table 4.1).

Although poorly ranked in the workshop scoring activity, organic farming, animal health and diet, and the use of marginal land for food production were also discussed in the workshops. Organic farming was raised by participants because it was believed to increase soil carbon sequestration, but this view did not gain consensus among participants. In fact, the soil researcher attending the JHI workshop informed the attendees that research has not been able to show if organic farming is better for soil carbon sequestration than conventional farming. The support for organic farming was claimed, again for the principle itself, because it uses no mineral fertiliser and provides better soil management. Other issues arising in the discussion concerned the timescale for a potential payment to farmers for soil carbon sequestration, and permanence, i.e., if crops were intensively ploughed the carbon stored in soil would be lost.

In relation to animal health, the discussion was related to the importance of the rumen in sheep and cattle and how keeping animals free of sub-clinical diseases could improve productivity and consequently decrease CH\textsubscript{4} emissions. Using probiotics and rumen fermentation enhancers\textsuperscript{31} were the practices suggested for maintaining a healthy rumen and decrease CH\textsubscript{4} emissions. In relation to animal diet, it was discussed whether livestock should be mainly fed on grass or on grain. Participants were aware that increasing concentrates in the diet increases productivity, and decreases CH\textsubscript{4} emissions, but it was pointed out that if the amount of fertiliser used in growing concentrate food was taken into account, grain could be used more efficiently as food for humans. The

\textsuperscript{31} Probiotics are used to divert hydrogen from methanogenesis towards acetogenesis in the rumen. This means that methane levels in the rumen are altered resulting in a reduction in the overall methane produced by enteric fermentation (Moran et al., 2008). Rumen fermentation enhancers supply the essential nutrients needed by rumen bacteria to produce more microbial protein.
importance of finishing livestock to the right specification and the fact that energy has been wasted to produce highly-emitting, over-fat livestock, were other points raised. Finally, feeding additives (e.g. probiotics, ionophores) to cattle and sheep to increase productivity was also considered.

Marginal land was defined as land with very low grazing intensity, that has not been used for crop production, or was used in the past but it is not any more. Views on how to use marginal land centred on two main options. One was to use marginal land to produce crops and contribute to reduce fertiliser application over a larger area. The other option was not producing crops on marginal land avoiding the inefficient use of inputs. It was mentioned that, in North East Scotland, farmers were currently growing grain crops on land with poor agricultural capability (classes 4 and 5). One statement illustrated well the vision against using marginal land to produce crops: “What a waste of time, resources, energy, fertiliser, fuel...”

As well as experts who participated in the workshops, farmers who completed the questionnaire pointed to a preference in the future reduction of mineral N fertiliser application. In fact, most farmers signalled that, if they had to reduce the GHG emissions of their farm, they would implement or expand the implementation of biological fixation to provide nitrogen inputs (≈40%), reducing nitrogen fertiliser (≈30%) and adopting new plant varieties that can produce the same yields using less nitrogen (≈25%) (Figure 4.4). The least-preferred mitigation practices to be adopted in the future were using probiotics, managing organic soils, using genetically improved animals, covering slurry tanks and lagoons, and feeding cows with bovine somatotropin, a feed additive to increase livestock productivity and decrease CH$_4$ emissions, which is currently banned in the European Union (Figure 4.4).
The main reasons given for a potential adoption or expansion of mitigation practices listed in Figure 4.4 are presented in Table 4.2. Most practices were selected for economic reasons (to reduce costs, to increase profit or to take advantage of available grants), but some were selected because they matched the characteristics of the farms.
Table 4.2 Reasons given by farmers surveyed for the uptake of the preferred GHG mitigation practices

<table>
<thead>
<tr>
<th>Land-based practices</th>
<th>Reasons for uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using biological fixation to provide nitrogen</td>
<td>Ease of implementation</td>
</tr>
<tr>
<td></td>
<td>No additional costs</td>
</tr>
<tr>
<td></td>
<td>To increase productivity</td>
</tr>
<tr>
<td></td>
<td>Grassland yield is not affected</td>
</tr>
<tr>
<td>Reduce fertiliser application</td>
<td>To reduce costs</td>
</tr>
<tr>
<td></td>
<td>Compulsory in organic farms</td>
</tr>
<tr>
<td></td>
<td>To stop leaching to the ground</td>
</tr>
<tr>
<td>Adopting new plant varieties that can produce the same</td>
<td>Easiness of implementation</td>
</tr>
<tr>
<td>yields using less nitrogen</td>
<td>No additional costs</td>
</tr>
<tr>
<td></td>
<td>To reduce costs</td>
</tr>
<tr>
<td></td>
<td>To save fertiliser</td>
</tr>
<tr>
<td>Using all the manure produced in the farm as a fertiliser</td>
<td>Already doing it</td>
</tr>
<tr>
<td></td>
<td>To save money</td>
</tr>
<tr>
<td></td>
<td>Compulsory</td>
</tr>
<tr>
<td>Matching the time the crop will make the most use of</td>
<td>Better value for money</td>
</tr>
<tr>
<td>mineral N fertiliser</td>
<td>Efficiency</td>
</tr>
<tr>
<td>Matching the time the crop will make the most use of</td>
<td>To minimise nutrient loss</td>
</tr>
<tr>
<td>organic fertiliser</td>
<td>Already doing it</td>
</tr>
<tr>
<td></td>
<td>Easiness of implementation</td>
</tr>
<tr>
<td>Introduce plant species that take up more nitrogen from</td>
<td>To reduce costs</td>
</tr>
<tr>
<td>the system</td>
<td>To save N fertiliser</td>
</tr>
<tr>
<td></td>
<td>Easiness of implementation</td>
</tr>
<tr>
<td>Improving land drainage</td>
<td>To increase profit</td>
</tr>
<tr>
<td></td>
<td>To increase production</td>
</tr>
<tr>
<td>Using controlled release fertilisers</td>
<td>To save money</td>
</tr>
<tr>
<td></td>
<td>Less time and labour</td>
</tr>
<tr>
<td></td>
<td>Better soil husbandry</td>
</tr>
<tr>
<td></td>
<td>It works longer</td>
</tr>
<tr>
<td>Minimum tillage/Zero tillage</td>
<td>To save fuel</td>
</tr>
<tr>
<td></td>
<td>To reduce costs</td>
</tr>
<tr>
<td>LEAF (Linking Environment and Farming Systems)</td>
<td>Easiness of implementation</td>
</tr>
<tr>
<td></td>
<td>To reduce fertiliser costs</td>
</tr>
<tr>
<td></td>
<td>To save fuel</td>
</tr>
<tr>
<td>Farm woodland planting</td>
<td>Availability of grants</td>
</tr>
<tr>
<td></td>
<td>It matches farm characteristics</td>
</tr>
<tr>
<td></td>
<td>Fuel security</td>
</tr>
<tr>
<td></td>
<td>Aesthetic reasons</td>
</tr>
<tr>
<td>Adopting vegetative cover between crops</td>
<td>Easiness of implementation</td>
</tr>
<tr>
<td>Restore degraded land</td>
<td>To increase profit</td>
</tr>
<tr>
<td>Separating slurry from fertiliser</td>
<td>To reduce costs</td>
</tr>
<tr>
<td>Adopting enhanced management of organic soils</td>
<td>It matches farm characteristics</td>
</tr>
<tr>
<td>Livestock-based practices</td>
<td>Reasons for uptake</td>
</tr>
<tr>
<td>Increasing concentrate in the diet</td>
<td>To mitigate climate change</td>
</tr>
<tr>
<td></td>
<td>No additional costs</td>
</tr>
<tr>
<td></td>
<td>It matches farm characteristics</td>
</tr>
<tr>
<td>Adopting genetically improved animals</td>
<td>To increase profit</td>
</tr>
<tr>
<td>Cover slurry tanks</td>
<td>Compulsory</td>
</tr>
<tr>
<td>Other practices</td>
<td>Reason for uptake</td>
</tr>
<tr>
<td>Wind turbines</td>
<td>To increase profit</td>
</tr>
<tr>
<td></td>
<td>To decrease heating costs</td>
</tr>
<tr>
<td></td>
<td>It matches farm characteristics</td>
</tr>
<tr>
<td></td>
<td>To generate power to sell to the grid</td>
</tr>
<tr>
<td>Small-scale anaerobic digester</td>
<td>To handle manure better</td>
</tr>
</tbody>
</table>

Although it was not asked in the questionnaire, some farmers also gave reasons for not adopting certain mitigation practices. For example, a farmer wrote that he could not
adopt genetically improved animals or increasing concentrate in cattle diet because he had an organic farm. Other farmers wrote that lack of storage for manure and weather conditions were impediments to matching the timing of organic fertiliser application with the time the crop would most utilise the nutrient inputs. In relation to adopting biological fixation with clover, the main reason given for non-adoption was the incompatibility between clover and higher rates of fertiliser application for grass production.

Farm characteristics were considered both favourable and unfavourable to the implementation of certain practices. For example, a farmer who was looking to install wind turbines had a farm in a windy location, and this was a favourable characteristic to this mitigation practice. In the case of farm woodland planting, small-scale farmers considered that they had ‘no room’ for trees, while farmers with ‘spare’ land thought that they might plant trees. Soil type (e.g. bare and rough ground) and land tenure (e.g. tenanted farms) were mentioned as not favourable to tree planting. Apart from this, a negative attitude to tree planting was also revealed by a farmer who wrote he does not agree with the practice since the “ground should be to produce food”. In terms of renewable energy, the difficulty in obtaining planning permission was mentioned as a barrier to the installation of wind turbines. Finally, a farmer mentioned that he did not know what ionophores were. Another farmer wrote that he was not aware which new plant varieties that take up more nitrogen from the system were available in the market.

In the focus groups, farmers were asked to point out the barriers and supporting factors to the implementation of mitigation practices considered suitable for the North East Scotland in the participatory workshops and in the responses given by the farmers surveyed (Table 4.3). The main barriers identified were the weather (a, b, c, f – see Table 4.3), cost (i), fuel consumption (h), the planning system (n), policy (n, m) and biophysical aspects (d). For about half of the practices identified, farmers were able to point out supporting factors for their implementation. These were related to profit (a, b, i, j), policy (b, e), biophysical aspects related to soils (a, h, j), efficiency (k) and GHG emissions reduction (n). Attitudes to the implementation of mitigation practices were extracted from the transcripts. It was considered that farmers were positive about the adoption of practices c, g, n (Table 4.3), negative about practices b, d, f, g, l (Table 4.3) or neutral about practices a and h (Table 4.3). Apart from the mitigation practices
discussed in Table 4.3, there were solitary suggestions of producing cattle more extensively and reducing the number of recreational horses in North East Scotland to mitigate climate change.

**Table 4.3 Farmers’ perceptions of barriers and supporting factors to the implementation of mitigation options and attitudes to potential implementation**

<table>
<thead>
<tr>
<th>Mitigation practices</th>
<th>Barriers</th>
<th>Supporting factors</th>
<th>Attitude to potential implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Minimum tillage/Reduced tillage</td>
<td>Weather dependent;</td>
<td>Increase profit margin;</td>
<td>“Use it when you think you can”</td>
</tr>
<tr>
<td></td>
<td>In some cases it affects yields, in others do not;</td>
<td>Save some fuel;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Do not save much fuel;</td>
<td>Increases the speed of operations;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Some years are favourable, some are not.</td>
<td>Reduces soil compaction.</td>
<td></td>
</tr>
<tr>
<td>b. Reduce nitrogen application</td>
<td>Every year is different. It is variable according to the years.</td>
<td>Nitrate Vulnerable Zone regulations;</td>
<td>“I still carry on. I have to keep my production”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High fertiliser prices.</td>
<td>“People never wasted it”</td>
</tr>
<tr>
<td>c. Biological fixation with clover</td>
<td>It only works at certain temperatures;</td>
<td>“We have been doing that for years”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>It is difficult to establish clover. Not all farmers are good at it;</td>
<td>“You can use clover. A small amount of it.”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heavy stock dealers cannot reduce fertiliser application.</td>
<td>“Definitely a plus”</td>
<td></td>
</tr>
<tr>
<td>d. Permanent grassland</td>
<td>The quality of the grass is not satisfactory;</td>
<td>“It does not really work for me”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5-7 year grasses are more productive than permanent grass;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>After 7 years the quality decreases;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>It is not economic.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. Using the manure produced in the farm</td>
<td></td>
<td>Nitrate Vulnerable Zone regulations.</td>
<td>“I think we all do that”</td>
</tr>
<tr>
<td>f. Matching the time of organic fertiliser</td>
<td>Depends on the weather;</td>
<td>“We now have dates when we can spread and we cannot spread. But these dates mean nothing to us”</td>
<td></td>
</tr>
<tr>
<td>application with the time the crop take</td>
<td>Seasons are very variable in NE Scotland;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the most out of it</td>
<td>Official dates for spreading manure do not ensure the practice is</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>implemented when the weather conditions are right.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g. Increase the amount of concentrate</td>
<td></td>
<td>Livestock becomes fat earlier.</td>
<td>“If I stand still (do not increase concentrate) someone is going to overtake me.”</td>
</tr>
<tr>
<td>h. Incorporating residues in the soils</td>
<td>The straw has high market value;</td>
<td>“The only thing that would be incorporated would be oilseed rape straw”</td>
<td></td>
</tr>
<tr>
<td>i. Precision farming</td>
<td>Fuel consumption (straw has to be chopped).</td>
<td>Increases soil carbon.</td>
<td>“I always increased”</td>
</tr>
<tr>
<td>j. Feeding ionophores/probiotics to livestock</td>
<td>There is an extra cost. An annual charge to pay for the connection;</td>
<td>Save fuel;</td>
<td>“... some Government help could be good”</td>
</tr>
<tr>
<td></td>
<td>Does not compensate in small scale.</td>
<td>Save fertiliser.</td>
<td></td>
</tr>
<tr>
<td>k. Improve genetics</td>
<td></td>
<td></td>
<td>“We have been doing it for years.”</td>
</tr>
<tr>
<td>l. Plant trees</td>
<td></td>
<td></td>
<td>“It is a waste”</td>
</tr>
<tr>
<td>m. Land drainage</td>
<td></td>
<td></td>
<td>“Only because I get paid for it to be honest.”</td>
</tr>
<tr>
<td>n. Renewable energy</td>
<td>Planners do not like to see turbines in the top of the hill;</td>
<td>Wind turbines can be implemented in the poorest ground.</td>
<td>“If every farmer could have one (wind turbine) they would be delighted”</td>
</tr>
</tbody>
</table>
4.4 Discussion

In North East Scotland, several current mitigation practices are mainly related to soil carbon sequestration (e.g. using manure in arable land; matching the time that organic fertiliser is applied to the time that the crop will get most benefit from it) and reducing GHG emissions (e.g. adopting biological fixation with clover; matching the time that mineral N fertiliser is applied with the time that the crop will get most benefit from it). The results from the questionnaire showed that about 60% of those farmers apply manure on arable land, match mineral N fertiliser application with the time the crops make the most out of it, and use biological fixation to provide N inputs with clover in grassland to provide nitrogen inputs (Figure 4.3). The wide implementation of these mitigation practices is understandable since about 61% of the respondents had livestock, which is fed on grassland, and about 27% of the respondents were cereal farmers, who require large quantities of fertiliser application on their cereal crops (Figure 4.1). Mixed-farming encourages integrated management practices. Land drainage, matching the time that organic fertiliser is applied with the time the crops best utilise it and reducing nitrogen fertiliser had been implemented by over 50% of the farmers surveyed.

It makes sense that matching the time that organic fertiliser is applied to the time that the crop will obtain most benefit from it is the most currently implemented mitigation practice because it is a requirement of the Nitrate Vulnerable Zone (NVZ) regulation. In Scotland, NVZs “are areas of land which drain into and contribute to pollution of the waters which the Scottish Ministers have identified as waters affected by pollution and waters which could be affected by pollution if action is not taken” (Scottish Government, 2010b). The NVZ regulation states that farmers have to provide 6 months’ (1 October to 1 April inclusive) storage capacity for pig slurry and poultry manure, and 5 months (1 October to 1 March inclusive) storage capacity for other livestock slurry (e.g. cattle slurry). In North East Scotland, most of the arable area is under the NVZ
regulation (Scottish Government, 2010b). Farmers’ views on NVZ regulation were that the application of manure on arable land should be determined by weather conditions not by specified dates which do not mean anything to them. They think that “official dates for spreading manure do not ensure that the practice is implemented when the weather conditions are right” (Table 4.3). This suggests, particularly in North East Scotland, that the effect of NVZs regulation on climate change mitigation should be further analysed.

In terms of livestock-based mitigation practices, increasing concentrate in the diet of cattle and sheep was implemented by about 50% of the respondents (Figure 4.3). This means that the practices mentioned above were currently adopted by 50-60% of the respondents and would only be additional if the remaining 50% of the farmers surveyed adopted it. To be additional, a mitigation practice has to demonstrate that emissions are lower than they would be under a ‘business as usual’ (BAU) scenario (Robbins, 2011). Several practices have been implemented for reasons other than climate change mitigation (e.g. cross-compliance), and the reductions obtained are already included in the 1999-2010 baseline. Only the expansion or first-time adoption of those practices with the objective of reducing GHG emissions can be considered additional.

The workshop participants considered that adopting or expanding the uptake of mitigation practices that reduce fertiliser consumption should be a priority (Table 4.1). The practices they considered most suitable to be implemented or expanded in the future in North East Scotland were precision farming, using biological fixation with clover to provide nitrogen inputs, adopting low-emitting livestock breeds, adopting mixed farming systems, restoring peatland and woodland planting. Farmers’ responses (from the survey) only agreed with using biological fixation to provide nitrogen inputs. Apart from this, the main preferred practices were applying manure to arable land and matching the time of organic and mineral N fertiliser application with the time the crop most benefits with it. However, these were, the same practices currently adopted by the farmers surveyed (Figure 4.3 and Figure 4.4).

In relation to biological fixation with clover, about 60% of the farmers surveyed indicated that they were already undertaking this measure, and about 80% said they would do more in the future (Figure 4.3 and Figure 4.4). It is accepted that results from
the survey are not representative of the whole North East Scotland. Nonetheless, farmers who attended the focus groups also mentioned that biological fixation with clover, was widely implemented in the region (Table 4.3). Experts believed there was potential to expand its implementation even more as they believed that about 90% of grassland in North East Scotland could grow with clover in their grasslands (Table 4.1). Experts pointed out that more should be done in terms of training on how to manage clover and this need was confirmed by farmers in the focus groups who recognised that not all of them were good at establishing clover (Table 4.3). Barnes et al. (2010) report similar findings relative to farmers’ perceptions of biological fixation using clover and current and future implementation of this practice. The main reasons given by farmers to choose this practice for future adoption was because there were “no additional costs” and “to reduce costs” (Table 4.2).

Adopting new plant varieties that can produce the same yields, while using less nitrogen inputs, was not currently adopted by farmers surveyed but was one of the most popular practices to be expanded or implemented in the future (Figure 4.4). This may be explained by the fact that adopting new plant varieties is directly related to reducing N fertiliser application, which was the second most popular practice to be implemented or expanded in the future (Figure 4.4). Barnes et al. (2010) found out that farmers were clear about the need for a development of the market of new plant varieties and recognised that the potential of low N crops was based on relatively limited evidence which needs to be validated to improve farmers’ uptake.

Precision farming, i.e., adjusting fertiliser application rates based on precise estimation of crop needs, was another mitigation practice considered appropriate for North East Scotland by the experts who participated in the workshops (Table 4.1). Farmers’ views on precision farming were collected in the focus groups. They recognised the costs associated to this practice but admitted that it saves fuel and fertiliser. The only barrier mentioned by them was that it was not suitable in the case of small farms because of the cost of it (Table 4.3). The suggestion given by experts about introducing machinery rings to decrease costs was seen as an option to overcome this barrier (Table 4.1). Both farmers and experts considered that financial incentives could increase the uptake of precision farming. Barnes et al. (2010) collected different farmers’ perceptions of this mitigation practice. Precision farming was only seen relevant by farmers with modern
family businesses and challenged enterprises. Moran et al. (2008) did not include precision farming in the interim list of cost-effective measures because of its small abatement potential in the UK.

Experts also listed peatland restoration and woodland planting as important mitigation practices to reduce GHG emissions in North East Scotland (Table 4.1). These practices are included in the Report on Proposals and Policies (Scottish Government, 2011) to reduce emissions from rural land uses. Peatland restoration was not raised by any farmer attending the focus groups, possibly because, as it was pointed out by experts, it has no financial advantage for the farmer or land owner. To support this was the fact that one of the least preferred mitigation practices to be implemented in the future by the farmers’ surveyed was the management of organic soils, including peatland (Figure 4.4).

In terms of woodland planting, less than 5% of farmers surveyed said they would consider its adoption in the future. Farmers’ attitudes in the focus groups were not very favourable to this practice either (Table 4.3). In contrast, this was one of the practices considered most suitable for North East Scotland in the participatory workshops. The same happened with peatland restoration, which was prioritized by experts in the participatory workshops but not by farmers in the focus groups. It can be argued that the mismatch between mitigation practices considered suitable for the rural land use sector in North East Scotland by experts and farmers could be addressed by undertaking a transdisciplinary approach in selecting suitable mitigation practices for a specific region. According to Lawrence (2010), there are applicability gaps which have led to criticisms of researchers by professional practitioners. These criticisms point out to misunderstandings about research and practice (Lawrence, 2010). According to Evely et al. (2010) transdisciplinary approach involves all parties, both academic and non-academic to define and develop the research goals and methods together in order to reach a common goal.

Experts suggested that afforestation grants would incentivise farmers and land owners to plant trees but the expected effect of incentives on the uptake of woodland planting was not consistent across data collected. There were farmers for whom future and current uptake of woodland planting depended on the availability of grants (Table 4.2
and Table 4.3) but others simply did not agree with it. There were also tenant farmers who believed they were not supposed to plant trees because they thought that rights concerning trees belonged to landlords. Previous research on farmers’ attitudes to tree planting and forestry incentive schemes in the UK found that farmers have little interest in planting, incentives are inadequate and tenure conditions pose difficulties for tenants (Crabtree et al., 2001). A recent report from the Woodland Expansion Advisory Group (WEAG, 2012) concluded that there is a deep cultural divide between forestry and farming and that planting levels in recent years have been at their lowest level for half a century.

Interestingly, the mitigation practice that received plenty of support from farmers attending the workshops was the use of ionophores and probiotics in cattle and sheep (Table 4.3). This was unexpected since only a few farmers questioned in the marts indicated that they would adopt this practice in the future (Figure 4.4). The reason for this difference in results was probably because in the focus groups the word “monensin”, which farmers recognised very quickly, was used as an example of an ionophore, while in the questionnaire no example was given. Although forbidden in European Union countries, farmers attending the focus groups said they have been asking for this feed additive and that they would be happy to adopt it. According to Moran et al. (2008), this is a very cost-effective mitigation practice since for each tonne of CO₂ equivalent abated, farmers would get £1,748 (at 2006 prices). Other mitigation practices that received a favourable attitude from farmers were minimum tillage and increasing the amount of concentrate in the diet of cattle and sheep (Table 4.3).

In relation to soil carbon sequestration practices, the responses from the questionnaire and the focus groups showed that using the manure produced in the farm was a current practice in North East Scotland and one of the favourite to be adopted in the future (Figure 4.3 and Figure 4.4 and Table 4.3). Other cases of practices said to increase soil carbon sequestration were permanent grassland and incorporating crop residues in soils (e.g. straw). There have been several published works suggesting the importance of grassland for soil carbon sequestration (Soussana et al., 2004; Seguin et al., 2007; Gilmanov et al., 2007). This evidence was brought to the focus groups in order to promote discussion and to assess farmers’ views on potential adoption of this practice. It was verified that for the farmers attending the focus group this was not an option. They
considered that the quality of the grass was not good enough and that after 5-7 years it had to be ploughed to maintain productivity. Even though recommended, the implementation of this practice is not likely to satisfy the ‘permanence’ requirement in North East Scotland. This is because by ploughing the grass there is a change in management, and carbon sequestered during the 5-7 year period can be lost (Smith et al., 2007; Powlson et al., 2008). In relation to incorporation of straw in the soils, farmers attending the focus groups mentioned that in North East Scotland only oil seed rape straw was incorporated, as other straw was sold in the market (e.g. for animal bedding). Powlson et al. (2008) considers that the straw removed from a given site will later be returned to the soil elsewhere, in addition to the carbon associated to that straw. Only the direct incorporation of straw in the soil can, therefore, be regarded as additional retention, and consequently as climate change mitigation through carbon sequestration.

The lack of interest from farmers in the implementation of practices that they do not currently use may be explained by farmers’ risk attitudes, the requirement for new knowledge or farmers’ consistency with traditional practices (Smith et al., 2007). The fact that “ease of implementation” was one of the most common reasons given by farmers for potential adoption or expansion of mitigation practices might support the idea that they are only willing to mitigate GHG emissions with the minimum effort and that they do not want to embark on new practices, which they do not know much about (Table 4.2). Reducing costs and increasing profit were other common reasons pointed out by farmers to explain why the top five mitigation practices in Figure 4.4 are the favourite to be adopted or expanded in the future (Table 4.2). This indicates that for the less preferred mitigation practices to be implemented in the future some sort of incentive may have to be given to farmers. Lack of awareness may also suggest why some mitigation practices are so unpopular, as in the case of the farmer that did know what ionophores were. To increase awareness amongst farmers there is an important tool for knowledge transfer for climate change mitigation practices, the Farming for a Better Climate website32 launched by the Scottish Agricultural College (SAC) in 2009. The website provides advice on cost-effective measures that can be taken in five key

32 http://www.sac.ac.uk/climatechange/farmingforabetterclimate/ (last assessed 06/06/2012).
areas of action namely, efficient use of energy and fuels, renewable energy
development, carbon storage in the soil and vegetation, optimisation of fertiliser
application, optimisation of livestock management and waste storage. The Report on
Proposals and Policies (Scottish Government, 2011) even recommends the creation of a
target for the number of farm businesses that adopt measures from the Farming for a
Better Climate project. This strategy for spreading information between farmers may,
however, exclude those farmers with no internet access.

In general, experts considered that it was the responsibility of farmers and land
managers to do something to overcome the barriers to the implementation of mitigation
practices (Table 4.3). Farmers revealed that they feel the pressure to do something about
climate change mitigation, but the results support the idea that they do not want such
responsibility. This was also supported by the fact that none of the farmers who
attended the focus groups accepted the offer of estimating the carbon footprint of their
farms using the “CPlan” carbon calculator for free. In addition, the fact that only 16 out
of 75 farmers invited attended the special session on farming efficiency and climate
change organised by the NFUS represents some evidence of the disconnection between
farmers and GHG emissions mitigation/climate change topics. However, most of those
who did attend the focus groups participated fully in the discussion.

The lack of interest or awareness about the need of reducing GHG emissions in the rural
land use sector can be concluded from the responses to the question about the use of
carbon footprint calculator in the farmers’ questionnaire. In the first case, only 11% of
the farmers surveyed said they have used a carbon footprint calculator before, with half
of those owning farms with an area above 1000 hectares. One farmer wrote that the
reason why he did not use a carbon footprint calculator is because “there are too many
and it is all too confusing”. This may indicate a lack of interest on climate change in
general and/or on reducing farm-GHG emissions more specifically.

In the focus groups there was a general view that agriculture was special because it has
to deliver food to an increasing world population. There were concerns that increasing
the pressure on agriculture to mitigate climate change would drive farmers out of
business and negatively impact on food production unless there were financial
incentives. In addition to this, farmers considered they were the “only ones left to do it”
because “the youngsters are in reducing numbers and are walking away”. Streck et al. (2011) also consider that agriculture is special because it produces food and contributes to the basic needs of people. Farmers believed that they were already as efficient as they possibly could be and reiterated that inefficiency was costly. They also argued that their crops and meat store carbon, and this should be accounted for climate change mitigation as well as the carbon sequestered in grasslands. It was largely agreed that a 21% GHG emissions reduction relative to 1990 was not going to be achieved by 2020, unless incentives were maintained and planning permissions for wind turbines approved\(^\text{33}\). One farmer in particular said he believed that the national GHG emission reduction targets were set on purpose to identify Scotland as a separate nation to the rest of the UK. Policy-makers were invited to come and talk to farmers if they wanted to find a way of collectively working towards the reduction of GHG emissions. None of the farmers attending the three focus groups showed a wish to take up the offer of estimating the carbon footprint of their farms using CPlan free of charge, this again indicating that they were not yet prepared to assume the GHG emissions from their farms or to take action in reducing them.

Renewable energy was not discussed in the participatory workshops with experts because one of the rules was to only list and discuss practices that mitigated or offset GHG emissions in the rural land use sector and renewable energy offsets GHG emissions in the energy sector. But this option had to be included in the focus groups given farmers’ support for the implementation of wind turbines and anaerobic digestion when they were questioned in the livestock marts. The statement “if every farmer could have one wind turbine they would be delighted” (Table 4.3) and the agreement that the 21% GHG emission target could only be achieved in the rural land use sector if renewable energy was encouraged, illustrate farmers’ positive attitude to this mitigation practice. However, farmers were well aware of the difficulties in obtaining planning permission for wind turbines in North East Scotland.

\(^{33}\) Wind turbines do offset farm emissions but are technically accounted under the energy not the land use sector.
4.5 Conclusion

So far, there have been no studies dedicated to the implementation of climate change mitigation practices for the rural land use sector based on ground-truthing an using a regional level approach. It was noticeable that farmers resent prescriptions which are inflexible and which sometimes result in suboptimal land management activities in terms of GHG emission reduction. This, *per se,* justifies such a study.

The study has shown that, in North East Scotland, farmers are already undertaking mitigation practices, albeit sometimes for other reasons than climate change mitigation. Current mitigation practices are mainly related to soil carbon sequestration and reducing GHG emissions (through reducing N₂O emissions). These most widely adopted mitigation practices were probably implemented because of NVZ regulations and/or high fertiliser prices, and not because of climate change mitigation. Thus they do not bring additionality in reducing GHG emissions.

If reducing GHG emissions would become compulsory in the rural land use sector in the future, farmers seemed to be willing only to adopt easy-to-implement and low-cost mitigation practices. Wind turbines and using livestock feed additives such as ionophores and probiotics were well accepted amongst farmers attending the focus groups but they recognised the difficulties of getting planning permission in the first case and of lifting the European prohibition in the second case. Farmers’ attitudes to precision farming, which was considered by experts as one of the most suitable mitigation practices for the North East Scotland, were positive. Interestingly, precision farming was not even considered by Moran *et al.* (2008) in the estimate of marginal abatement cost curves for UK agricultural greenhouse gas emissions because of its small mitigation potential.

Most farmers are becoming aware of the need to reduce their GHG emissions, but the reduction in emissions sought in policy was considered to be hard to obtain given the current practices and knowledge levels. Past reductions are almost wholly a result of rising fertiliser prices or regulatory measures for water quality. Farmers seem to accept some widely practised low-cost activities such as use of clover, but are often antagonistic to tree planting. They often appear to shelter behind the food security
rhetoric and see themselves as a special case. The policy and advisory sectors face a major challenge in designing and delivering appropriate adjustment responses if the GHG reduction targets are to be met. Experts who participated in the workshops believed that financial incentives should be part of the strategy to increase the uptake of mitigation practices. Farmers agreed with this in the case of precision farming.

Future work should include more focus groups with farmers from different regions of Scotland, and different farm types, in order to gain more evidence of which regional and farm characteristics are associated with the uptake of each GHG mitigation practice. Further, there is a clear need to raise awareness and to explore new policy and extension means to address this apparently intractable problem.
References


## Appendix 3 Farmers questionnaire

### Mitigation Measures in Agriculture in North East Scotland

This questionnaire is designed to gather information for a PhD research project being carried out in conjunction with the University of Aberdeen and The James Hutton Institute. The aim is to identify current and potential uptake of mitigation measures in agriculture without reducing the level of output. As you may know the Scottish Government has set a 42% greenhouse gas emission reduction target for the rural land use sector by 2020.

This questionnaire will be treated totally confidentially and none of the information provided will be associated to you or your farm business.

### Question 1

Please indicate your postcode (please note your postcode will only be used for geographical analysis and not used to identify individual farming businesses)

Postcode: 

### Question 2

What type of farm (primary production) do you run? (please indicate with a cross in the appropriate box)

- Cereals
- General cropping
- Horticulture
- Specialist Pigs
- Specialist Poultry
- Dairy
- Cattle and Sheep (LFA)
- Cattle and Sheep (Lowlands)
- Mixed
- Other - please describe:

### Question 3

What is the approximate size of your farm?  

Enclosed land hectares

Rough grazing hectares

### Question 4

Did you ever use a carbon footprint calculator to estimate greenhouse gas emissions for your farm?

- NO
- YES

If yes enter which calculator:

### Question 5

**a)** In column A of the table overleaf, please indicate with an X any practice(s) you currently carry out at your farm.

**b)** In column B of the table overleaf, please indicate with an X the top three practices, including any current practices, you would implement if you had to reduce the greenhouse gas emissions of your farm by 20% in 2020.

**c)** In column C of the table overleaf, please state the main reason for your choice.
<table>
<thead>
<tr>
<th>Practices</th>
<th>A</th>
<th>B</th>
<th>C: Main Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cropland and grassland management</strong></td>
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<tr>
<td>Using biological fixation to provide nitrogen inputs (e.g. clover)</td>
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<td></td>
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<tr>
<td>Reducing nitrogen fertiliser</td>
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<td>Improving land drainage</td>
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<td>Using all the manure/slurry produced on your farm as fertiliser</td>
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<tr>
<td>Introducing plant species that take up more nitrogen from the system</td>
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<tr>
<td>Matching the timing of mineral fertiliser application with the time the crop will make most use of the fertiliser</td>
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<tr>
<td>Using controlled release fertilisers</td>
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<td>Using nitrification inhibitors</td>
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<tr>
<td>Matching the timing of manure/slurry application with the time the crop will make most use of the fertiliser</td>
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<td>Adopting systems less reliant on energy intensive inputs (e.g. LEAF farm type system)</td>
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<td>Adopting new plant varieties that can produce the same yields using less nitrogen</td>
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<td>Separating slurry applications from fertiliser applications by several days</td>
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<tr>
<td>Adopting vegetative cover between crops</td>
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<tr>
<td><strong>Soils</strong></td>
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<td>Adopting reduced tillage or no-till</td>
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<tr>
<td>Using composts, straw-based manures in preference to slurry</td>
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<td>Adopting enhanced management of organic soils</td>
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<td>Restoring degraded land</td>
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<td><strong>Livestock</strong></td>
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<tr>
<td>Increasing concentrate in the diet (dairy and beef)</td>
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<td>Using propionate precursors (dairy and beef)</td>
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<td>Using probiotics (dairy and beef)</td>
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<td>Using ionophones (dairy and beef)</td>
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<tr>
<td>Using bovine somatotropin (dairy and beef)</td>
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<tr>
<td>Adopting genetically improved animals (dairy and beef)</td>
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<tr>
<td>Using transgenic offspring (dairy)</td>
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<tr>
<td>Covering slurry tanks/lagoons</td>
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<td>Adopting aerobic slurry tanks/lagoons</td>
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<td><strong>Forestry</strong></td>
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<td>Farm woodland planting</td>
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<tr>
<td><strong>Other</strong></td>
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<td>Other</td>
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Please leave your contact details, if you wish. All participants who do so will be placed in a draw for a bottle of port. Thank you.

THANK YOU FOR TAKING THE TIME TO COMPLETE THIS QUESTIONNAIRE.
Chapter 5

5 Wood fuel for renewable heat production: potential uptake and greenhouse gas emissions mitigation
Abstract

This chapter explores the scope for increasing the contribution of woody biomass for space and water heating in North East Scotland. It reviews the changing policy context and the contextual factors behind increasing support for the use of wood for heating and assesses the potential benefits of a partial shift from non-renewable sources to wood energy. The Land Use Strategy for Scotland explicitly mentions that renewable energy should be included in the list of strategies available in the rural land use sector to mitigate GHG emissions. Woody biomass is an important case to study because it is a source of renewable energy that directly depends on land management. In addition, the trade-off between food security and energy production has to be taken into account. North East Scotland has good potential for woody biomass production. Forests occupy 19% of the land area, and a number of towns and villages are close to extensive forested areas. Local councils in the region have supported the development of wood energy through the development of woodfuel-based school heating and the institutional climate is broadly conducive. However, large up-front capital costs and delays in establishing support systems and the nature of support offered all contribute to the likely failure to deliver policy targets such as reduced fuel poverty and CO₂ emission reductions.

Keywords: Space and water heating, policy, CO₂ emissions, climate change

5.1 Introduction

The Climate Change (Scotland) Act 2009 created a statutory framework for greenhouse gas emission (GHG) reductions, by setting an interim 42% reduction target for 2020 and an 80% reduction target for 2050. Burning fossil-fuel to produce energy is one of main human activities contributing to GHG emissions, specifically carbon dioxide (CO₂), into the atmosphere which consequently leads to climate change (McKay, 2003). In Scotland, about one third of primary energy consumption is for heat purposes (Scottish Executive, 2007a). One option to deliver significant carbon savings is the production of heat from renewable energy (Scottish Government, 2009a). Renewable heat can be produced with solar, geothermal, heat pumps or biomass technologies. This chapter focuses on the production of renewable heat from biomass and considers it as a land-based GHG mitigation option since it directly depends on rural land uses, primarily but not exclusively forestry. This mitigation
option has repercussions not only on the rural land use sector. It contributes to above-ground and soil carbon sequestration and consequently mitigation of GHG emissions within the sector, but also in the energy sector where it displaces fossil fuels with high carbon content by a low-carbon emission fuel, the biomass. Biomass is a renewable source of energy that can be obtained from forestry, energy crops such as short-rotation coppice and short-rotation forestry, waste and agricultural residues such as straw (Slade et al., 2011). Woody biomass used as fuel is generally called woodfuel. In Scotland, over 90% of the renewable heat is generated from woodfuel (Scottish Government, 2011b).

Apart from climate change mitigation, the production of renewable heat from woodfuel has also been advocated because of the rise of energy prices, to support energy security and address fuel poverty (Lund, 2010; McKay, 2003; Slade, et al., 2011; SDC, 2005). A household is said to be in fuel poverty if it needs to spend 10% or more of its income on fuel to meet its energy needs (Baker et al., 2004).

High oil and gas prices have underlined Europe’s increasing dependency on imported energy and this encouraged the European Union to respond with a range of measures to reduce energy imports, including support for the use of biomass (Scottish Executive, 2007a). Rising energy costs have pushed many consumers to fuel poverty, especially those off the gas grid (Hills, 2012). In Scotland, about 30% of the households are in fuel poverty, and 34% of these are off the gas grid (Baker, 2011). Abundant resources of woodfuel at local level may provide a sustainable source of energy, contributing to a decrease in the dependence on globally regulated fossil fuels. In the United Kingdom (UK), the fall in market price of mature coniferous timber in the last decade, and the increase in timber ready to harvest may contribute to future capacity of the forest sector to produce energy (Millar, 2004).

According to the Sustainable Development Commission (SDC, 2005), small to medium-scale woodfuel heating could make a significant contribution to climate change mitigation in Scotland, given the established forest culture together with a high demand for heat and high fuel prices, especially in rural areas. The Forum for Renewable Energy Development in Scotland (FREDS) believes that market penetration of renewable heat must reach the private sector to deliver significant renewable heat capacity (Scottish Government, 2008). There has been substantial policy rhetoric for the use of renewable heat from woodfuel in Scotland, but
several factors have slowed down the uptake in the domestic sector and this may create a gap between political ambitions and the reality of woodfuel use in Scotland.

North East Scotland, which includes the council areas of Aberdeenshire, Aberdeen City and Moray, was the study region chosen to explore the critical factors affecting renewable heat uptake because local forest resources to produce woodfuel are abundant, some of the coolest places in the UK are located in this region and around 60% of the households are in rural areas. In addition, Aberdeenshire aspires to become carbon neutral by 2030 (SAC, 2008). Previous studies have given an overview of different governmental strategies to stimulate the use of renewable energy sources (Ericsson et al., 2004; Hillring, 1998) and presented a framework for the understanding of barriers and supporting factors behind bioenergy technology implementation and commercialisation (Roos et al., 1999).

This chapter gives an overview of the renewable heat policy in Scotland and explores potential scenarios for the uptake of woodfuel systems in the domestic sector in North East Scotland. It estimates GHG emissions from domestic space and water heating in North East Scotland for different woodfuel uptake scenarios and it links this to the contribution of woodfuel to the Scottish GHG emission reduction targets. The study also estimates the availability of wood to produce woodfuel in the region and identifies the barriers (e.g. economic, education, planning) to the expansion of the woodfuel market for space and heating purposes.

5.2 Data and methods

Firstly, a literature review on national and regional programmes, strategies and actions plans was undertaken and the types of support for renewable heat production from woodfuel in the domestic sector described. Secondly, two scenarios for renewable heat uptake in the domestic sector were created using the General Register Office for Scotland for data on household projections in North East Scotland until 2031, the IPA Energy + Water Economics report on Renewable Heat in Scotland: 2020 Vision to Scottish Renewables for the Scottish housing stock in 2001 and the report Off-gas consumers (Baker, 2011) for the main heating fuel in North East Scotland and the main heating fuel by dwelling type in Scotland. Thirdly, GHG
emissions from heating in the domestic sector were estimated for each of the two scenarios using fuel emission factors provided by the Biomass Energy Centre website\textsuperscript{34}. Fourthly, the availability of small round wood from thinning and felling in private and public forests was estimated using data from the Forestry Commission Scotland and the Forest Enterprise and the volume of woodpellets that could be produced from that wood. The moisture content of conifers and broadleaves were derived from published estimates (Forestry Commission, 2006). Finally, the critical factors to the uptake of woodfuel heating systems in the North East Scotland were identified through the analysis of documentary sources, such as published reports about renewable heat systems and the analysis of archived transcripts of interviews and a focus group with relevant stakeholders, including woodfuel producers. The interviews were carried out in 2009 for a European-funded study (COST Action E51), to investigate drivers of innovation, the degree and importance of networks, and policies impeding and fostering development of the wood-bioenergy sector. The focus group was held in 2009 under the project ‘Realising the potential contributions of Scotland’s Rural Land to delivering Sustainable Economic Growth’, carried out by the Macaulay Land Use Research Institute, the Scottish Agricultural College and the University of Aberdeen.

5.3 Overview on policies and financial support for renewable heat production

Policies to address climate change are a UK responsibility, but in an era of devolved governance, the Scottish Government has also taken a strong interest in climate change and has some capacity to create its own policies. Consequently, policies in Scotland include UK-wide policies and Scotland-specific policies.

In 2006, the Scottish Executive published the \textit{Scottish Climate Change Programme}, a framework of actions to deliver carbon savings through devolved policy measures. One of the actions considered in the Programme is the promotion of renewable heat in the residential sector where 80% of the energy consumed is for heating purposes (Scottish Executive, 2006). To follow-up this programme, the \textit{Biomass Action Plan} was launched the following year. The objective of the Plan was to coordinate the development of the biomass sector and the

\textsuperscript{34}http://www.biomassenergycentre.org.uk/portal/page?_pageid=73,1&_dad=portal&_schema=PORTAL (last accessed 05/06/2012)
production of a renewable heat strategy for Scotland, with targets on the production of renewable heat by 2020 (Scottish Executive, 2007a). The strategy, due by the end of 2007 is not yet published. Nevertheless, in 2008, the Scottish Government published a document where it recommended Scottish Ministers to identify an adequate target for the production of renewable heat by 2020 (Scottish Government, 2008). Only in 2009, the target was finally established. This corresponded to 11% of heat consumed to be supplied from renewable sources by 2020 (Scottish Government, 2009a). To achieve the 2020 heat target, the framework of activity was set in the Renewable Heat Action Plan published in 2009 (Scottish Government, 2009b). The FREDS Renewable Heat Implementation Group was nominated to deliver the actions of this Plan, which consisted mainly in stimulating the renewable heat market over the following two years. The Plan was updated and extended in 2011 by the 2020 Routemap for Renewable Energy in Scotland. Actions are now focussed on the following targets: 1) 100% electricity demand equivalent from renewables by 2020; 2) 11% heat demand from renewables by 2020; 3) At least 30% overall energy demand (heat, transport, electricity) from renewables by 2020; 4) 500 MW community and locally-owned renewable energy by 2020.

In North East Scotland, Aberdeenshire Council published its own Renewable Energy Strategy in 2004 to provide specific support and encouragement for the biomass and biofuel sector (Aberdeenshire Council, 2004). The Single Outcome Agreement between the Aberdeenshire Community Planning Partnership and the Scottish Government committed local partners to create a biomass industry through partnerships in Aberdeenshire and Europe (Aberdeenshire Community Planning Partnership, 2009). Finally, the Forest District Strategic Plan for Moray and Aberdeenshire expresses the councils’ interest on facilitating woodfuel utilisation both through local firewood sales and early initiatives on a more commercial scale, focussing on products that would stimulate the developing market (Forestry Commission Scotland, 2009).

In terms of financial support for the production of heat from wood, there have been several schemes historically in both the public and private sectors. In 2002, the Scottish Community & Householder Renewables Initiative (SCHRI) was introduced by the Scottish Government to assist the development of new community and household renewable energy schemes, including woodfuel-fired boilers. It was later replaced by the Energy Savings Scotland Home Renewables Grant and the Communities and Renewable Energy Scheme (Ciccarese et al., 2011) both closed in 2010 and 2011, respectively. Between 2004 and 2006 the Highlands and
Islands Woodfuel Development Programme supported woodfuel suppliers and end users such as Small and Medium Enterprises (SMEs) and community groups. Between 2006 and 2007 it was the Scottish Biomass Support Scheme providing grants to support both supply chain and Combined Heat and Power (CHP) installations (Scottish Government, 2009b). This scheme proposed to transform the woodfuel sector in Scotland and it was only open to producer groups, organisations and businesses.

Currently there is the Renewables Obligation Scotland (ROS), the Feed-in-Tariffs (FITs) and the Renewable Heat Incentive (RHI). The ROS was introduced in 2002 and has been the key driver for promoting the development of renewables, including biomass, across Scotland. ROS provides support for renewable electricity generating stations, including Combined Heat and Power (CHP) plants fuelled by biomass and energy crops, and CHP plants fuelled by energy from waste. From 2011, the production of heat from biomass was supported by FITs. The aim of FITs is to encourage organisations, businesses, communities and individuals to invest in small-scale low carbon electricity and heat generation in exchange for a guaranteed payment. It works together with the RHI, which was introduced in 2011, and also aims at encouraging the installation of renewable heat equipment, including biomass boilers. The first phase of the RHI started in July 2011 and introduced tariffs for non-domestic installations and the second phase is expected to start in October 2012 with the introduction of tariffs for domestic properties. These tariffs intend to bridge the financial gap between the cost of conventional and renewable heat systems (Department of Energy & Climate Change, 2010). Until the start of the second phase of the RHI, the Renewable Heat Premium Payment is the scheme available to support the installation of biomass boilers in the household sector. This scheme is mainly focused on areas off the gas grid. The installation of low and zero carbon equipment for heating purposes is also regulated by the Scottish Planning Policy 6 (SPP6) (Scottish Executive, 2007b). The SPP6 sets out the national planning policies for renewable energy developments that planning authorities should consider when preparing development plans and determining planning applications (Scottish Executive, 2007b).

Contrary to the Forum for Renewable Energy Development in Scotland (FREDS), which believes that market penetration of renewable heat must reach the private sector to deliver significant renewable heat capacity (Scottish Government, 2008), the Department of Energy and Climate Change believes that the first phase of the RHI for non-domestic installations will provide the vast majority of the renewable heat needed to meet the heat target and that it
represents the most effective option to increase the production of renewable heat (Department of Energy & Climate Change, 2010).

### 5.4 Scenarios for woodfuel heating systems uptake in the domestic sector in North East Scotland and associated GHG emissions

Scottish houses generally have relatively poor insulation and consequently high GHG emissions and high heating costs, this contributes to fuel poverty and climate change (IPA, 2009). A cost-effective way of reducing emissions from heating is to improve energy efficiency of households through better insulation but retrofitting better insulation is often rather challenging because of house design. The acceleration of renewable heating distribution in the domestic sector is the objective of the second phase of the RHI (Department of Energy & Climate Change, 2010). The RHI prioritises the support of biomass boilers for households off the gas grid since these areas are more prone to fuel poverty and higher GHG emissions due to the use of expensive heating fuels with high-carbon content (Scottish Government, 2008). Households that depend on other fuels than gas for heating have much lower energy efficiency standards than households heated on gas (Baker, 2011).

Domestic energy consumption in the UK is, on average, 1.9 tonnes of oil equivalent (toe) per year (Department of Energy & Climate Change, 2012). About 85% of this value (1.6 toe ≈ 20 MWh) is used for space and water heating (Baker, 2011; Department of Energy & Climate Change, 2012). It is likely that domestic energy intensity for space and water heating is higher in North East Scotland since some parts of this region are the coolest parts of the UK. Total domestic energy intensity for space and water heating in North East Scotland is obtained by multiplying the domestic energy intensity by the number of existing and projected households between 2011 and 2031 (Figure 5.1).
5.4.1 Estimating the potential number of houses that could install woodfuel systems in North East Scotland

The gas-grid only covers Aberdeen and the east coast south of Aberdeen with most villages and rural areas in Aberdeenshire and Moray being off-gas grid (SDC, 2005). A report on off-gas consumers revealed that in North East Scotland around 68% of the households are on gas, 1.1% are on Liquefied Petroleum Gas (LPG) and bottled gas, 8.7% use heating oil, 10% are on solid fuel, 20.7% use electric heating and 0.5% are in a communal heating scheme (Baker, 2011). As gas is popular, clean and convenient and has previously been cheaper than other heating fuels, it is assumed that existing houses heated by gas will be less likely to retrofit their heating systems with woodfuel boiler systems than those on LPG and bottled gas, heating oil, solid fuel and electric heating. There are also space constraints that may make the installation of woodfuel boilers difficult, especially in existing flats and terraced houses. A flat is defined as having “separate and self-contained premises constructed or adapted for use for residential purposes and forming part of a building from some other part of which it is divided horizontally”\(^{36}\), and with no individual gardens. Terraced houses are those in a row of similar houses situated side by side and sharing common walls with

\(^{35}\) 1 toe=11,666 KW-h. **Source:** General Register Office for Scotland for existing and projected houses between 2011 and 2031.

\(^{36}\) Building Regulations 2000 (SI 2000 no.2531).
relatively small gardens. According to Baker (2011), 82% of high rise purpose built flats in Scotland are heated by electricity and about 83% of the terraced houses are heated by gas.

Detached houses, which are free-standing residential buildings, and semi-detached houses, which consist of a pair of similar houses built side by side and sharing a parting wall, are not so constrained in terms of space. It was assumed that existing detached and semi-detached houses that are not heated by gas have enough room to install woodfuel boilers and to store the woodfuel needed for their heat requirements and are more likely to retrofit their heating systems with woodfuel boilers. In 2001, 44% of Scottish houses were detached and semi-detached (IPA, 2009). About 64% of the detached houses that are not heated by gas relied on oil for heating purposes and about 56% and 30% of the semi-detached houses that are not heated by gas rely on electricity and oil, respectively (Baker, 2011).

In relation to the projected houses for North East Scotland, it was assumed that all types of new houses (flats, detached, semi-detached, terraced) are less constrained to install woodfuel boilers because this can be planned beforehand. The SPP6 (Scottish Executive, 2007b) anticipates 15% of energy requirements in large new developments with a cumulative floor space over 500 m² is to come from renewable technologies (Scottish Executive, 2007b).

### 5.4.2 Estimating GHG emission savings from woodfuel heating systems in the domestic sector

Woodfuel is considered a renewable, low-carbon energy source because it comes from harvested timber that has necessarily sequestered atmospheric carbon dioxide (CO₂) while it was growing, emits CO₂ back into the atmosphere when the woodfuel is burnt to produce energy and sequesters CO₂ when trees are planted again (Lattimore et al., 2009). Woodfuel is not entirely a carbon-neutral source of energy only because there are additional factors to take into account, namely, the net changes in the carbon stored in trees, litter and soil, the fossil fuels used in the harvesting, transport and processing of woodfuel, temporary variations in carbon stocks and fluxes and the complete life-cycle analysis of products and systems used in extraction, processing and delivery (Millar, 2004). Fossil fuel combustion takes carbon that was locked away underground over millions of years (e.g. coal, crude oil and gas) and releases it back to the atmosphere in the form of CO₂ emissions.
Data used to estimate GHG emission savings from woodfuel heating systems in domestic dwellings in North East Scotland by 2020 include CO₂ emissions factors per fuel type (hard coal, oil, natural gas, LPG, electricity, woodchips and wood pellets) to heat a typical house during a year (20,000 kWh yr⁻¹) (Table 5.1), the potential number of houses that would adopt woodfuel systems by 2020 (drawn from the assumptions made in Section 5.4.1) and the main fuel used by dwelling type (flats, terraced, detached and semi-detached houses) ‘off gas’ (from Baker, 2011). In Scotland, existing flats, terraced houses and semi-detached houses ‘off gas’ are mainly heated by electricity and detached houses ‘off gas’ are mainly heated by heating oil. The same was assumed for North East Scotland.

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>KgCO₂yr⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>10,600</td>
</tr>
<tr>
<td>Hard coal</td>
<td>9,680</td>
</tr>
<tr>
<td>Heating oil</td>
<td>7,000</td>
</tr>
<tr>
<td>LPG</td>
<td>6,460</td>
</tr>
<tr>
<td>Natural gas</td>
<td>5,400</td>
</tr>
<tr>
<td>Wood chips</td>
<td>300</td>
</tr>
<tr>
<td>Wood pellets</td>
<td>140</td>
</tr>
</tbody>
</table>

Source: Biomass Energy Centre³⁷

The potential number of houses that could install woodfuel boilers for heating purposes and the GHG emissions resulting from that adoption are presented in Figure 5.2.

³⁷http://www.biomassenergycentre.org.uk/portal/page?_pageid=73,1&_dad=portal&_schema=PORTAL (last accessed 13/09/12).
Figure 5.2 Scenarios for woodfuel boilers adoption in the period 2011-2020 and associated GHG emissions
As described in Figure 5.2 only existing detached and semi-detached houses ‘off gas’ were considered regarding installation of woodfuel boilers by 2020. In relation to projected houses there are two possibilities: A) all the projected houses will potentially, install woodfuel boilers (100%); B) 15% of the projected houses will, potentially, install woodfuel boilers. Due to these assumptions the number of houses that could install woodfuel boilers by 2020 varies between 39,931 houses and 61,068 houses (Table 5.2):

### Table 5.2 Maximum number of houses that can install woodfuel boilers by 2021 (No)

<table>
<thead>
<tr>
<th>Existing houses (in 2011)</th>
<th>Projected houses between 2012-2021 (new houses)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A 15% install woodfuel boilers</td>
<td>B 100% install woodfuel boilers</td>
</tr>
<tr>
<td>100% existing detached and semi-detached houses ‘off gas’ install wood-fuel boilers</td>
<td>(17,253+18,253)+3,729=39,931</td>
<td>(17,253+18,253)+24,860=61,068</td>
</tr>
</tbody>
</table>

**Note:** Refer to Table 5.2 for further clarification.

In this study two different scenarios for woodfuel boiler adoption in the domestic sector, were compared: A and B. When comparing the emissions of these two scenarios with a hypothetical ‘business as usual’ (BAU) scenario, it can be seen that the adoption of woodfuel boilers fuelled by woodpellets (more common for domestic use than woodchips) would almost halve the emissions from heating in the domestic sector by 2020 (Figure 5.3). GHG emissions resulting from the non-adoption of woodfuel boilers (BAU) were estimated by taking into account that existing detached houses ‘off gas’ would remain on heating oil (most common fuel in this dwelling type) and existing semi-detached houses ‘off gas’ would remain on electricity (most common fuel in this dwelling type). It was also assumed that 68% of the projected houses would be ‘on gas’ and 32% would be ‘off gas’ and that projected flats, terraced and semi-detached houses off gas would be heated by electricity and projected detached houses would be heated by oil.
5.5 Availability of wood resources: the supply side

According to Aberdeenshire Council, one of North East Scotland’s strengths lies in its forest resources which suggest significant potential for renewable heat production (Aberdeenshire Council, 2004). Moray, the other council area of this region, has also an extensive forest coverage which offers potential for a biomass market (Moray Community Planning Partnership, 2009). The Forest District Strategic Plan for Moray and Aberdeenshire considers the expansion in lowland broadleaved woodlands as a further development of an appropriately scaled woodfuel and biomass market (Forestry Commission Scotland, 2009). The proximity of forest resources, mostly within a 15 mile radius of significant settlements, is seen as a supporting factor for woodfuel businesses in North East Scotland since it contributes to lower transportation costs.

Small round wood from thinning and felling available for woodfuel production can be derived from the sum of forecast thinning and felling volumes in public and private forests. The Forestry Commission (Scotland) and the Forest Enterprise provide data for the annual forecast of thinned and felled volumes (cubic meters, over bark) of several coniferous and broadleaved species from public and private forests, respectively. Data cover the periods 2006-2099 for public forests and 2009-2036 for private forests.

Figure 5.3 GHG emissions from heating in North East Scotland by 2020 according to three different scenarios
In Scotland, the main source of woodfuel is small roundwood from coniferous, i.e. with top diameter up to 14 cm$^3$. Mackay et al. (2008) estimated that only about 10% of this wood has no market and is immediately available for wood energy. In the first instance and to avoid competition with other markets for timber it was, therefore, assumed that the total volume available to produce woodfuel was only 10% of the forecast for freshly thinned and felling volumes of coniferous with top diameter up to 14 cm$^3$ (Figure 5.4). The conversion of volume (m$^3$) of coniferous felled and thinned into weight (kg) used the conversion factor 1m$^3$ over bark = 1.06 metric ton under bark (1006 kg).

![Figure 5.4 Forecast of freshly thinned and felling wood with diameter ≤14 cm$^3$ and wood available for woodfuel production between 2011 and 2022 (in thousand kg)](image)

Source: Forestry Commission Scotland.

In Scotland, woodfuel grants are for woodchips and woodpellets boilers. Wood burning stoves and open fires fuelled with logs are disregarded by the Renewable Heat Incentive (RHI) (Renewable Energy Forum, 2010). Woodpellets are made of dry compressed wood by-products (e.g. sawdust, wood shavings, and whole tree removals) and are mainly suitable for domestic use and small to medium scale district heating. Woodchips are small fragments of timber mechanically chipped by machine, and are widely used by businesses, communities and public sector organisations with larger burners.
Woodpellets have lower moisture content (≈10%) than woodchips (≈30%) and this has to be taken into account when estimating the wood available to produce these products. Since the moisture content of coniferous timber is 60%, there are 0.4 oven dried tons in 1 ton of freshly thinned plus felled wood (Forestry Commission, 2006). Taking into account the moisture content of woodpellets and woodchips, it was estimated that 1 ton of freshly thinned plus felled wood can produce 0.5 tons of wood pellets and 0.7 tons of woodchips. Since it was assumed that only 10% of the forecasted small round wood thinned plus felled will go to the woodfuel market, it was estimated that about 56,638,000 kg of pellets and 79,294,424 kg of chips could be produced by 2020.

As mentioned above, wood pellets are particularly suitable for the domestic sector. To estimate the weight of woodpellets needed to satisfy the potential requirement of renewable heat from woodfuel, it was assumed that the average energy consumption to heat a typical house in the UK (20,000 KWh yr\(^{-1}\))\(^{38}\) will be fairly constant until 2020. In addition, because different tree species have different energy contents\(^{39}\), it was assumed that coniferous, and more specifically Sitka spruce, were the main source of raw material to produce woodpellets. The energy content of 650 kg of pellets is 3,055 kWh (1kg=4.7kWh). This, results in 39,931 houses (Scenario A, Table 5.2) requiring 169,919,149 kg of woodpellets and 61,068 houses (Scenario B, Table 5.2) requiring 259,863,830 kg of woodpellets by 2020. These estimates show that the wood pellets that could be produced with the available wood in 2020 (56,638,000 kg) would not be enough to meet the requirements of both scenarios A and B (Table 5.2). To overcome this situation more wood should be released from other markets to the woodfuel market or poorer quality materials should be used. Poorer quality materials such as stumps and roots not removed during forestry operations and with no market value can potentially be accounted as significant contributors to woodfuel supply if technology to use these products becomes available (Woodfuel Task Force, 2008). Sawdust and wood shavings from sawmills are other wood by-products that could be added to overall wood availability since these materials are suitable for woodpellet production. Stacks of wood, semi-abandoned in the borders of forest roads, and near forest stands, are widely

\(^{38}\)http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,163182&_dad=portal&_schema=PORTAL (last accessed 13/09/12).

\(^{39}\)For energy contents of tree species see website presented in the footnote above (30).
seen in rural areas and are another potential source of wood to produce woodfuel. The total amount of such wood waste is, however, unknown.

5.6 Barriers to the expansion of the woodfuel market for space and water heating purposes in North East Scotland

Despite policy support, both at UK, Scottish and regional level, the availability of forest resources in the region and the GHG emission savings that woodfuel heating systems could offer, there remain several barriers affecting the uptake in the domestic sector. These barriers, specific to Scotland, were collected from documentary sources and from archived transcripts of interviews carried out with relevant informants:

**Capital costs**- Up-front capital costs are usually higher for renewable heating technologies than for other comparable fossil-fuel equipment, for example heating oil (Scottish Executive, 2007a; Scottish Government, 2008). Not only are wood energy boilers very expensive, but also there is a need for storage systems for pellets or chips and in some situations for pumps to link dispersed homes to the main boiler.

**Infant industry ‘teething problems’** –The high capital costs can be aggravated if storage systems are badly designed, this being pointed out as one of the causes of failure in the success of woodfuel heating systems. Maker (2004) stated that one of the most important tasks in putting together a successful biomass system is building a fuel storage facility that will meet both the immediate and long-term needs of the system, the owners, and the operators.

**Supply chain**- Poorly developed supply chains and the absence of a viable market for small round wood from young coniferous plantations are obstacles to the development of the sector. Several sources (Millar, 2004; Scottish Executive, 2007a; Woodfuel Task Force, 2008), point at the lack of market trading floor for biomass and the need for improved assessment of available and future resources. The lack of a developed supply chain may be one of the reasons why larger estates, which have security of supply, engage more concerning the use of woodfuel than individuals.
Training- Lack of trained boiler installers and lack of maintenance personnel able to give good technical advice are other barriers (Scottish Government, 2008; IPA, 2009). The FREDS Renewable Heat Group (Scottish Government, 2008) argues that the installation of renewable heat technologies depends on appropriate knowledge and skills and recognises that training availability is currently limited. The Micro-generation Certification Scheme, which certifies micro-generation technologies used to produce heat from renewable sources, is considered a barrier to the development of the market because of the costs and limited number of locations where training occurs (IPA, 2009). Low trainee numbers lead to low competition and high installation costs. In terms of undergraduate studies, the University of Aberdeen offers a taught programme on renewable energy but this is not specific to biomass energy production and development.

Planning- The Woodfuel Task Force Report (Woodfuel Task Force, 2008) suggests that there is no regulation or effective and integrated planning. The regulatory and support system remains too slow and unresponsive to meet needs. If an oil boiler breaks down and needs replacing, the slow turnaround on grant applications and the delays in planning and installation makes it less likely that a woodfuel solution will be adopted.

Terrain conditions- Although there are reasonable forest resources for the production of woodfuel, these may not be always available because of high costs of harvesting machinery in the case of difficult work terrain and small-scale and fragmented woodland plots (Woodfuel Task Force, 2008). Costs of extraction are lower in lowland areas, and more favourable for planting short rotation coppice (SRC). However, this may raise concerns that biomass production displaces food production, unless poorer quality agricultural land is used.

Competition in the woodfuel market- Balcas, a wood pellet manufacturing facility based at Invergordon, North of Inverness, with support from Highlands and Islands Enterprise, is becoming a significant competitor for local woodfuel producers. The plant has an output capacity of 100,000 tonnes per annum which is equivalent to the woodfuel needed to heat 20,000 households during the same period. The Biomass Action Plan for Scotland (Scottish Executive, 2007a), considers this as “giant leap forward in biomass development” but small woodfuel producers view Balcas with apprehension because
such a significant degree of market power can undercut them. The implications are positive for supply, notwithstanding the risks of concentrated market power.

The Renewable Heat Incentive (RHI) - The Renewable Energy Forum considers that the current costs are high and outcomes of the RHI are highly uncertain and will expose the consumer to high energy costs for conventional energy. The Forum believes that if the funding mechanism for the RHI is a levy on fossil fuel, fuel poverty in rural areas will increase because fuel poor and rural heat consumers will not normally be able to invest in RHI eligible technologies. There will be a net transfer from poorer to richer consumers who can afford to adopt renewable heat technologies (Renewable Energy Forum, 2010).

5.7 Discussion

In the last six years, Scottish policy has been overtly supportive of renewable heat systems. There has been an array of action plans, strategies and programmes recognising the contribution of renewable heat to reduce GHG emissions. In North East Scotland, the promotion of renewable heat systems in the domestic sector is highlighted in local strategies and single outcome agreements, motivated by the abundant forest resources of the region. The Moray & Aberdeenshire Forest District Strategic Plan (2009-2013) recognise the importance of forest resources for woodfuel utilisation (Forestry Commission Scotland, 2009). The Single Outcome Agreement between Aberdeenshire Community Planning Partnership and the Scottish Government (2009-10) specifies the desire to create a biomass and biofuel industry through partnerships in Aberdeenshire and, more throughout Europe.

In relation to the strategy needed to achieve higher GHG emissions reduction, there seems to be two different discourses: FREDs believes it is the uptake of renewable heat systems by the private sector (including domestic installations) that represents the optimal strategy and the Department of Energy and Climate Change (DECC) believes it is the uptake of renewable heat by non-domestic installations (e.g. businesses). Further, according to Ericsson et al. (2004), individual heating systems are necessary in rural areas where heat densities are too low for district heating to be cost-effective. It is mainly in these areas that high-carbon content fuels, such as heating oil, are used for
heating purposes. However, the financial support seems to be more directed to non-domestic installations. In the past, only the Scottish Community & Household Renewable Initiative (SCHRI) supported the installation of renewable heat systems in the domestic sector. This initiative was only available for a three year period being followed by the Energy Savings Scotland Home Renewable Grant available for the same period of time. Currently, there is only the Renewable Heat Premium Payment supporting the installation of renewable heat systems, including biomass boilers, in households, until the Renewable Heat Incentive (RHI) is introduced for domestic customers. The discontinuities in funding of schemes may well have slowed down the installation of renewable heat systems because of time needed to learn the new application processes and paperwork.

There are higher expectations on the uptake of renewable heat systems by the service sector (commercial offices, communication, transport, education, government, health, hotel and catering, retail, sport and leisure and warehouses) and communities (Department of Energy & Climate Change, 2010; Scottish Government, 2011a). Schools and government buildings are especially seen as an opportunity to demonstrate to the public the practical application of renewable systems and to educate children on how to become advocates of ‘green energy’ in the future (Department of Energy & Climate Change, 2010). Community projects have been the main beneficiaries of SCRHI grants. The SCRHI funded 378 households and 146 community projects but the last received £3.6 million compared to £673,000 received by households (Scottish Government, 2006). The SCRHI for communities was substituted by the Community and Renewable Energy Scheme – CARES, which provided £13.7 million worth of grants for community renewable projects. Currently, the Renewable Heat Incentive (RHI) stimulates communities to get together and find suitable solutions for local energy needs, including community-owned biomass cooperatives sourced by woodfuel from sustainable local woodlands (Department of Energy & Climate Change, 2010). District heating, which in certain occasions can be more cost-effective than installing individual heating systems in individual properties, is also eligible for RHI. However, there is very little history of community heat co-operatives in Scotland. In contrast, in Austria, the success of renewable energy from biomass and rapid development of biomass district heating is believed to be linked to high capital grants and generous subsidies available from several funding sources (Roos, et al. 1999; Reinhard, 2007).
However, Ericsson et al. (2004) asserts that small-scale consumer reaction to government policies is different from that of larger utilities and municipalities because they are constrained by the alternatives available in their specific location, the low fuel flexibility of existing systems and limited information about new heating schemes. Although there is apparently strong policy support for the uptake of woodfuel heating systems by the service sector, communities, and district heating, this has been slow to take off in North East Scotland. There are 330 schools, 40 community centres and 499 council buildings (council offices, swimming pools, libraries) in the region and only 13 projects have been approved so far (Table 5.3).

### Table 5.3 Awarded grants for biomass heating systems in North East Scotland

<table>
<thead>
<tr>
<th>Project name</th>
<th>Objective</th>
<th>Building type</th>
<th>Woodfuel type</th>
<th>Financial support</th>
<th>ktCO₂ emission savings yr⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macphie of Glenbervie</td>
<td>Steam</td>
<td>Factory</td>
<td>Chips</td>
<td>Scottish Biomass Support Scheme (SBSS)</td>
<td>2.1</td>
</tr>
<tr>
<td>Aboyne Academy</td>
<td>Heat and hot water</td>
<td>School, swimming pool, library, theatre, community centre</td>
<td>Chips</td>
<td>Energy Savings Trust (EST); Scottish Community and Householder Renewables Initiative (SCRHI)</td>
<td>0.6</td>
</tr>
<tr>
<td>Burnot sawmill</td>
<td>Heat</td>
<td>Sawmill</td>
<td>Chips</td>
<td>SBSS</td>
<td>n.a.</td>
</tr>
<tr>
<td>Seaton flats</td>
<td>Heat and hot water</td>
<td>District Heating Scheme</td>
<td>Chips</td>
<td>EST; Aberdeen City Council’s Warm and Dry programme; SBSS.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Dafling farm</td>
<td>Heat</td>
<td>Commercial and residential units</td>
<td>Chips</td>
<td>SBSS</td>
<td>0.06</td>
</tr>
<tr>
<td>Richie Hall</td>
<td>Heat</td>
<td>Community Hall</td>
<td>Pellets</td>
<td>SBSS</td>
<td>n.a.</td>
</tr>
<tr>
<td>Haddo Estate</td>
<td>Heat</td>
<td>District Heating Scheme</td>
<td>Chips</td>
<td>SBSS</td>
<td>0.216</td>
</tr>
<tr>
<td>Aberdeen Winter Gardens</td>
<td>Heat</td>
<td>Public gardens</td>
<td>Chips</td>
<td>CARES</td>
<td>n.a.</td>
</tr>
<tr>
<td>Scottish Sculpture Workshop</td>
<td>Heat</td>
<td>Public building</td>
<td>Chips</td>
<td>CARES</td>
<td>n.a.</td>
</tr>
<tr>
<td>Scottish School of Forestry</td>
<td>Heat</td>
<td>School</td>
<td>Chips</td>
<td>CARES</td>
<td>n.a.</td>
</tr>
<tr>
<td>Tomintoul Wood CHP</td>
<td>Heat</td>
<td>n.a.</td>
<td>n.a.</td>
<td>Highlands and Islands Community Energy (HICEC)</td>
<td>n.a.</td>
</tr>
<tr>
<td>Foresthill Health Campus</td>
<td>Heat</td>
<td>Hospital</td>
<td>Chips</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Tullynessle &amp; Forbes Community Hall</td>
<td>Heat and hot water</td>
<td>Community Hall</td>
<td>Pellets</td>
<td>SCRHI; Global Environment Facility (GEF)</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

Sources:

- [http://www.aberdeenrenewables.com](http://www.aberdeenrenewables.com);
- [http://www.communityenergyscotland.org.uk](http://www.communityenergyscotland.org.uk);
- [http://www.scotland.gov.uk](http://www.scotland.gov.uk);
(last accessed 05/03/2012)

In practice, there has also a big discrepancy in the type of renewable energy funded by the SCRHI. In households, about 50% of the grants were awarded for solar heating systems and 26% for ground source heat pumps (GSHPs). In the case of community projects, the distribution of grants was more uniform across renewable energy types.
Biomass, biofuels and energy from waste projects received only 10% and 1% less funding than wind turbines and heating, respectively. This seems to suggest that less funding is needed to support a bigger number of households and that biomass systems are more suitable for community projects.

The second phase of the RHI is expected to start in October 2012 to support the installation of renewable heat systems in households, especially off the gas grid. It is not known to which extent the incentive is going to stimulate the uptake of woodfuel systems in the domestic market and which of the scenarios developed in Section 5.4.2 will be closest to the actual uptake. The challenge is to retrofit existing houses with woodfuel boilers. Price differences between woodfuel boilers and heating oil boilers are large. While an oil boiler costs on average £2000 (including VAT and excluding fitting), an automatically fed pellet boiler for an average home costs around £11,500 (including installation, fuel, fuel store and 5% VAT), with the manual option being slightly cheaper. An additional point to take into account is the time to payback the investment. According to the Energy Saving Trust website, the replacement of a domestic oil boiler by a wood pellet boiler would save about £280 per year in a typical three-bedroom, semi-detached house with basic insulation, which means that it would take about 40 years to payback the investment at current oil prices. In terms of the supply side, it is probably cheaper for suppliers to produce woodchips and focus on supplying the service sector, communities and district heating scheme markets. Capital and energy costs of pellets production, more suitable for domestic use, are higher than for wood chip production. Prioritising the support of woodfuel systems in the service sector may however, limit the availability of wood for the domestic market. As shown in Section 5.5, there will be insufficient round wood to satisfy the heating requirements of existing and new built houses in 2020, and much less will be available than the amount required in the region if the service sector starts buying the woodfuel offered by the market. In addition, in 2022, a drop in the supply of small round wood with no market is forecasted (Figure 5.4). Of course, wood energy can compete with other markets, especially chip and oriented strand board (OSB), so if the price of wood chips and wood pellets rises, wood may be freed from other markets to the woodfuel market.

In terms of GHG emissions, it is possible to estimate and compare emissions for two different scenarios of woodfuel boilers uptake in the domestic sector. It is clear that a
bigger uptake would result in higher GHG emission reductions (Figure 5.3), which, could make a significant contribution towards the Scottish GHG emission reduction target (42% by 2020) and regional GHG emission reduction aspirations. It was not possible to estimate GHG emissions reductions from the uptake of woodfuel boilers in the service sector due to lack of data available.

From the analysis of the qualitative data, some critical factors to the implementation of the wood market were identified. There is some evidence that, as concluded Nybakk et al. (2011) concluded, there also is a gap between political ambitions and real bioenergy use in Aberdeenshire. On the one hand, the Aberdeenshire Council Renewable Energy Strategy (2004) asserts that Aberdeenshire has considerable potential for the generation of heat from “renewable” sources and that renewable energy is a necessary component of strategies to mitigate climate change, address fuel poverty and promote sustainable development. On the other hand, local producers allege that Aberdeenshire has been very slow getting into the market and getting public sector involvement in terms of renewable energy compared to other local authorities, perceived to be better in the installation of woodpellet and woodchip boilers in public buildings. In fact, according to Use Woodfuel Scotland website, in 2010, only 14% of the Scottish woodfuel suppliers were based in North East Scotland, with 25% in the Highlands and Islands, 20% in Perth and Argyll, 23% in Central Scotland, and 18% in South Scotland.

Some of the barriers can possibly be solved if some additional thought and finance are made available. Financial support should go into training programmes, better planning and better designed storage systems for woodfuel. Constraining factors such as high capital costs, weak supply chains and uncertainty are more difficult to overcome. In terms of capital costs and development of the supply chain, it can be questioned whether government incentives are sufficient to promote significant adoption of woodfuel boilers. Capital costs for households would certainly go down in time if the demand for this type of heating system grows.

There would appear to be reasonable prospects for further developments in woodfuel markets in North East Scotland. Expected increases in oil prices in the future compared to woodfuel prices were often mentioned in documents and archived qualitative data as
an important driver. This factor, linked to the availability of local resources, could also contribute to improving fuel security in the region.

5.8 Conclusion

Renewable heating for space and water purposes is expected to rise in the next 20 years due to an increase in the number of projected houses (Figure 5.1). The increase in the number of new houses and the requirements of the SPP6 in terms of renewable technologies anticipate an increase in the demand of woodfuel for space and water heating, in addition to high fuel prices. In case that 100% of the existing detached and semi-detached houses and at least 15% of the projected houses in North East Scotland install woodfuel boilers fuelled with woodpellets, 10% of the small roundwood produced annually in the region would not be enough to satisfy the potential demand for woodfuel by 2020. To satisfy the potential demand for woodfuel needed to heat the households assumed in scenarios A and B (Figure 5.3), wood for fuel would have to be released from other markets. GHG emissions reductions from the adoption of woodfuel systems would be significant compared to non-adoption (Figure 5.3) and this would contribute to the Scottish GHG emission reduction 2020 target.

Even though wood energy systems remain the object of much attention and a degree of public support, the actuality of developments to date in North East Scotland, suggests that household demand will remain modest, unless the RHI offers substantial incentives when it is finally launched. Industry and public sector use is likely to be the major beneficiary of support. Further, the high cost of pellet and chip-based heating systems for households means that any financial support derived from non-renewable fuel use will compound fuel poverty and offer opportunities only for the well-off.

North East Scotland comprises a useful ‘laboratory’ in which to consider the opportunities for renewable heat production from woody biomass. It has an abundant forest resource but an incipient supply system. However, the experiment to date has been only moderately successful, in spite of efforts made by the public sector to stimulate growth. A rapidly changing policy support system and long delays in developing and implementing policy have cast a shadow over the sector’s development.
Chapter 5

and the opportunities in the household sector remain constrained. Further, current funding mechanisms seem highly likely to compound fuel poverty and offer subsidised greening of heat energy supply to affluent households. Notwithstanding these significant problems, the high level of provision of space and water heating from fossil fuels means that cost effective mitigation of climate change should still be sought in industrial, public and household sectors. To create the opportunity, it would seem important to review and revise the existing policy architecture and shield the fuel poor from having to support such developments with their energy bills.

The study enabled an exploration of the data needed to estimate the availability of wood fuel to satisfy the potential demand of renewable heating in North East Scotland by 2020.
References


Chapter 5


6 Overall discussion and conclusion
6.1 Overall discussion

This thesis sought to assess the contribution of the rural land use sector to the greenhouse gas (GHG) emissions budget of North East Scotland and to explore the potential for implementation of land use mitigation practices to mitigate climate change by reducing CH$_4$ and N$_2$O emissions and sequestering carbon. This aim was pursued in Chapter 2 by estimating the contribution of the rural land use sector to total GHG emissions and in Chapter 3 by exploring approaches to choose suitable mitigation practices for North East Scotland. Chapter 4 introduced stakeholders’ perspectives concerning the implementation of mitigation practices in the rural land use sector, and Chapter 5 investigated the potential of woody biomass as a source for renewable space and water heating. Chapter 6 discusses the findings of this thesis according to each research question cited in Chapter 1. The conclusion explains the scientific contribution of this thesis, and present ideas about opportunities for future work. The research questions of this thesis are addressed below.

6.1.1 What is the contribution of the rural land use sector to the overall GHG emissions budget of North East Scotland?

Agriculture and other land uses produce significant GHG emissions, both globally and nationally. These emissions are mainly due to enteric fermentation in livestock (methane - CH$_4$), manure management (CH$_4$, nitrous oxide - N$_2$O), mineral and organic N fertiliser application (N$_2$O), lime application (carbon dioxide - CO$_2$) and tillage of agricultural soils (CO$_2$). GHG emissions from rural land uses in North East Scotland were estimated in Chapter 2.

In 2010, GHG emissions from rural land uses as a whole in North East Scotland (1,474 ktCO$_2$e) were largely driven by emissions from agriculture (1,440 ktCO$_2$e) and, within this, by emissions from livestock (1,146 ktCO$_2$e) and fertiliser application (organic N, mineral N, lime) on cropland and grassland (293 ktCO$_2$e). According to data published by the National Atmospheric Emissions Inventory (AEA, 2012), in 2009, the aggregate GHG emissions from all sectors of the economy in North East Scotland (Aberdeen City, Aberdeenshire and Moray) were 6,550 ktCO$_2$e. This means that the rural land use sector contributes about 23% to the total GHG emissions of the region. This compares well
with a previous study by Carney and Prestwood (n.d.) which found that, in 2005, agriculture contributed 24% to overall emissions released in Aberdeen City and Aberdeenshire. This percentage is much higher than the contribution of agriculture to overall Scottish emissions which is about 13% (Jackson et al., 2009). This is due primarily to the diverse and relatively intensive agricultural sector in the North East Scotland which produces about 40% of all barley, approximately 30% of Scottish prime cattle, and 63% of pigs (Scottish Government, 2010).

Forests are a CO₂ sink that can offset part of these emissions, together with grasslands and near-natural (pristine) peatlands. There are, however, issues of permanence and sink saturation in the case of forests and grassland soils, and difficulties in the assessment of the area of pristine peatlands. Permanent grassland (defined as grassland ploughed less than once in every seven years) can sequester significant amounts of carbon (Gilmanov et al., 2007; Janssens et al., 2003; Seguin et al., 2007; Soussana et al., 2010). This carbon may, however, be released if the grassland is ploughed. Similarly, peatlands store large amounts of carbon, but this can be emitted into the atmosphere due to soil disturbance or peatland extraction, i.e. non-permanence. If the carbon stored in peatland is emitted, overall GHG emissions from rural land uses in a specific year would be much higher than estimated. It is also known that soils do not have unlimited potential to sequester CO₂ emissions (Freibauer et al., 2004; Smith, 2005). Even though soil carbon levels may not reach a new equilibrium until 100 years after land-use or land-management changes, carbon sequestration potential may be minimal after 20 years (Smith et al., 1997). Trees can sequester carbon for longer periods of time, and, depending on the use of timber, the carbon can be stored beyond felling (Smith et al., 1997). The most desirable uses of forests and forest products are those which extend rotation ages and production of goods that are durable and long-lasting (Ciesla, 1997).

In terms of carbon flux, the facts that most coniferous forests in North East Scotland are now mature and that little additional planting has occurred in the last decade mean that net carbon sequestration is likely to fall in coming years in North East Scotland forests.

Between 1999 and 2010, total GHG emissions from rural land uses in North East Scotland decreased by about 10% with spikes in 2000 and 2005 (Figure 2.1, p71). This decreasing trend can be ascribed to the Common Agricultural Policy (CAP) and high fertiliser prices. Climate change policies have little or no influence in GHG emission
reductions. The introduction of compulsory set-aside in 1992, with the MacSharry Reforms of the CAP, led to a large increase in fallow arable land in Scotland which was not fertilised. The MacSharry Reforms also placed constraints on the beef and sheep sector with compensation payments being subject to regional ceilings and maximum stocking rates (Angus et al., 2009). On the other hand, there were additional incentives for farmers to grow oilseed rape and protein-rich crops such as linseed, peas and beans. While it is true that these crops are very demanding in terms of fertiliser requirements (Thomas, 2010), higher fertiliser prices have possibly induced more careful fertiliser practices among farmers. In addition, prices for selected major commodities for the UK have been relatively low between 1998 and 2008, reducing farm incomes by 60% in real terms in 2008, compared to 1973 (Angus et al., 2009). This potentially resulted in a decrease of food production in North East Scotland, and consequently a decrease in GHG emissions. In 2010, GHG emissions started rising again, and it is not known how food prices will develop in the future. Forecasts (FAO and OECD, 2008) suggest that prices for major agricultural products in the UK will remain high until 2017, reflecting a strong demand for agricultural products (including fuel) in the future (Angus et al., 2009). A rise in GHG emissions from 2010 onwards may, therefore, be expected, unless the demand for forest products, and consequently the need for afforestation, also increases and offsets the additional GHG emissions. The Scottish Government (2011a) has estimated that, in a ‘business-as-usual’ scenario (see Figure 3.4, p113), net emissions from rural land use will increase from a low in 2008 to almost 1990 levels by 2022.

It can be argued that the contribution of the rural land use sector to GHG emissions in North East Scotland is higher than what has been estimated. In the case of agriculture, GHG emissions are only associated with the production of farm inputs, i.e., life-cycle GHG emissions were not considered. Among these inputs are mineral N fertiliser, soybean fed to livestock (e.g. pigs in North East Scotland) and fuel used in agricultural machinery. To account for these emissions, a demand-based (from farmers to agricultural products) inventory would have to be undertaken in addition to a production-based inventory. Greenhouse gas emissions resulting from the production of farm inputs were not estimated in this thesis for being considered ‘indirect’ GHG emissions. It is recognised, however, that they result from the demand for agricultural products and contribute to world GHG emissions. The production of mineral N fertiliser
is very energy-intensive, but the GHG emissions released as part of their production are attributed to industrial processes by the NAEI (UNECE Sector 3 and 4)\textsuperscript{40}. The rapid increase in soybean production has been achieved through the expansion of cropland into natural habitats, often associated with deforestation (FAO, 2009a). GHG emissions associated with soybean production are accounted for in the rural land use sector of the country of origin (e.g. Brazil). Finally, GHG emissions released during the combustion of fuel in agricultural machinery are reported under UNECE sector 8\textsuperscript{41}. According to Pimentel \textit{et al.} (1990), fuel requirements by the food sector as a whole (including processing, preservation, storage and distribution) account for 10-20\% of total fossil-energy consumption. The percentage for North East Scotland is not, however, known.

In producing regional inventories, activity data are often derived from various sources, such as national and regional statistics, local experts and literature. Application of IPCC Tier 1 emission factors can identify emission hotspots, where there are likely to be significant mitigation options, and also help expose key sources of uncertainty in activity data and emission factors (Streck \textit{et al.}, 2011). Default emission factors are associated with high uncertainties. One of the reasons is the fact that they do not take into account the wide range of practices used to produce single commodities, or diverse biophysical conditions. For example, in the case of fertiliser application, emissions may differ considerably spatially depending on the soil characteristics of farm systems and even within a specific farm system (Angus \textit{et al.}, 2009). There is a need to better understand the spatial (local and regional) differences in $\text{N}_2\text{O}$ emissions (Royal Society, 2011). According to Streck \textit{et al.} (2011), uncertainty associated with emission factors can be reduced by increasing data available (e.g. improved collection of agricultural statistics), and by investing in basic research on agricultural GHG emissions. New inventories should be able to differentiate between farms where there are underlying identifiable differences (in practices or biophysical conditions) that lead to different emissions per unit volume of output on different farms. Currently, work has been undertaken to produce UK-specific Tier 2 and 3 emission factors (e.g. Defra GHG Monitoring Projects AC0112, AC0114, AC0115, AC0116) (ADAS, 2011).

\textsuperscript{40} UNECE Sector 3 – Combustion in industry; UNECE Sector 4 – Production processes.
\textsuperscript{41} UNECE Sector 8 - Other transport and machinery.
Chapter 3 showed that the implementation of certain mitigation practices would be enough to achieve a 21% GHG emission reduction in the rural land use sector by 2020 relative to 1990 levels, if the maximum possible area in North East Scotland and the maximum technical mitigation potential were exploited (Figure 3.4, p113). These practices are woodland planting (with Sitka spruce), precision farming, incorporation of crop residues in soils, using controlled-release fertilisers or nitrification inhibitors, avoiding N excess, and using biological fixation with clover to provide N inputs. There are, however, barriers to adoption that reduce the maximum area where the mitigation practices can be implemented and consequently their physical mitigation potential. There is also relatively high uncertainty (>>50%) in relation to the technical mitigation potentials of mitigation practices. Due to these factors, the contribution of the practices identified in Chapter 3 is likely to be over-estimated.

Barriers to the adoption of mitigation practices were collected from literature (Chapter 3) and generated in the focus groups, questionnaires and participatory workshops with key stakeholders (Chapter 4). It was found that North East Scotland farmers are mostly more willing to expand the adoption of mitigation practices they already know and have been implemented than those they are not familiar with. They are also more willing to expand the implementation of practices that increase their profit. This will not bring ‘additionality’ in GHG emission reduction until 2020 (e.g. adopting biological fixation with clover).

In relation to the contribution of woody biomass as a source of renewable energy for space and water heating, its adoption by households and consequent contribution to GHG emissions reduction in North East Scotland, is likely to be very dependent on the Renewable Heat Incentive (RHI) for households, which was only launched in spring 2012 (Chapter 5).

6.1.2 How to select GHG emission reduction practices for the rural land use sector in a specific region?

The first step to select suitable mitigation practices for a specific region is to gain knowledge on the scope for mitigation per area of land and on the available area where practices can be implemented. The technical mitigation potential of a practice multiplied
by the area where this practice could be implemented was defined as its physical mitigation potential in Chapter 3. Since the objective is to reduce significantly GHG emissions from the rural land use sector in a short period of time (21% by 2020, relative to 1990 levels), practices with high physical mitigation potential were considered to have priority in their implementation. Even while providing for food security, agriculture offers considerable mitigation possibilities, especially in above and below-ground carbon sequestration (Streck et al., 2011). The agricultural sector mitigation potential is predominantly in the sequestration of carbon (above and below-ground) and in reducing mineral N use as well as clover-based N fixation. Employing the criteria described in Chapter 3 allowed mitigation practices to be chosen. These were woodland planting with Sitka spruce, incorporation of crop residues in soils, avoiding nitrogen (N) excess, biological fixation with clover, precision farming, nitrification inhibitors and controlled release fertilisers (Chapter 3).

The implementation of country level win-win options is likely to be discouraged by a range of financial, cultural, knowledge, and policy barriers at a more local level (Streck et al., 2011). According to Ciesla (1997), economic factors must be taken into account in the design and implementation of climate change mitigation practices, including the analysis of costs and benefits and cost-effectiveness analysis. Cost-benefit analysis is a systematic process that compares all costs and benefits expressed in terms of a common monetary unit. Cost-effectiveness analysis compares costs and effects (outcomes) of two or more actions. Mitigation actions should also be sustainable, adaptable, and easy to implement. This means that these actions should have positive impact (economic benefits, social acceptability) on current and future generations (including local people) and on the ecosystems where they are implemented. Actions should also be flexible to adapt to changing climatic conditions and able to be adopted without the need of much specialised equipment or training on the adopter’s side.

Woodland planting, for example, has been suggested as a cost-effective approach to mitigate the predicted consequences of climate change (Ciesla, 1997; Nijnik and Bizicova, 2008; Nijnik, 2010). The costs for conserving and sequestering carbon in biomass and soil are estimated to vary widely but can be competitive with other mitigation options (Ciesla, 1997, Slee et al., in press). Factors affecting costs include
opportunity costs of land, planting and establishment, nurseries, annual maintenance, monitoring and transactions (Ciesla, 1997).

Abandoning marginal agricultural land can be an option to increase carbon sequestration in wet temperate areas, such as North East Scotland, but can create a major fire risk in areas with dry summers. Most land use scenarios are consistent in indicating that, in the UK, the area of agricultural land used for food production will decline, this being partly offset by the increased use of agricultural land for bioenergy and forest (Rounsevell and Reay, 2009). However, recent rhetoric regarding the prospect of a ‘perfect storm’, (Beddington, 2009), with global future food shortages, which finds almost daily expression in international discourse about food availability, may make afforestation and farm emission reduction less likely.

In some cases, tree planting has not resulted in an increase in net carbon sequestration. The historical afforestation in the UK in the last half-century on former peat and on sites of old-growth forest provoked a net flux of carbon to the atmosphere rather than net sequestration (Adger et al., 1992). Further, there is major dissent from farmers in North East Scotland about the government forest cover aspiration (25% forest cover by 2020). According to Ciesla (1997), the interests and needs of local people living in areas proposed for woodland planting and of landowners that may live elsewhere need to coincide with goals and objectives of forestry projects, otherwise conflicts may arise.

The methodology suggested in Chapter 3 was mainly based on a literature review and secondary data from official statistics. It helped to identify the options with higher physical mitigation potential and to investigate the barriers to the implementation of these practices. It also introduced the idea that there is no ‘one size fits all’ GHG mitigation practice that could be applied to the diverse rural land uses in North East Scotland. The Royal Society (2011) considers that mitigation practices need to be tailored to fit the range of agricultural systems and soil types which have evolved under different climate circumstances of the country. This almost certainly requires local institutions (e.g. extension services, NFUS local offices) to provide support and guidance.
The biggest doubts in estimating the mitigation potential are related to the uncertainty ranges associated with the technical potentials of mitigation practices and the likely maximum area where the practices will be implemented. For example of uncertainty in technical mitigation potentials, practices undertaken on organic farms can improve soil carbon sequestration but mitigation can vary between 0 and 1.83 tCO$_2$e ha$^{-1}$yr$^{-1}$ (Freibauer et al., 2004). Zero tillage can also improve soil carbon sequestration but there is about 50% uncertainty in relation to the amount sequestered (in ha$^{-1}$yr$^{-1}$) (see Table 3.1). According to FAO (2009b), reliable systems for measurement and monitoring of agricultural soil carbon stock changes and N$_2$O flux due to improved management practices exist, but the challenge is how to design cost-effective and efficient spatially explicit measurement and modelling regimes. The area where mitigation practices can be implemented depends on the barriers to their implementation as discussed in Chapter 3. The barriers to adoption can, for certain mitigation practices, be derived from the literature (Chapter 3 and 5). However, social research as undertaken in Chapter 4, namely participatory workshops, questionnaires, focus groups and in Chapter 5, namely analysis of secondary interview data, is essential to assess these barriers in more depth and more specifically according to the region that has been studied. The information collected has to be taken into account when selecting suitable mitigation practices for the region.

6.1.3 What are the barriers and supporting factors to the implementation of mitigation practices in North East Scotland according to stakeholders’ perspectives?

The mitigation potential of mitigation practices can be assessed along with their costs of implementation. Some of the identified cost-effective practices by Moran et al. (2008) for the UK and Scotland, would clearly save money to farmers, such as for example, reducing the application of mineral N fertiliser. Cost-negative and low-cost practices are sometimes referred to as ‘low-hanging fruit’, and have been highlighted in recent initiatives of Defra and the Devolved Administrations. However, it has been noticed that they are rarely being employed (The Royal Society, 2011). This demonstrates the existence of non-economic barriers preventing their implementation (e.g. risk-related, political, bureaucratic, logistical, educational and societal) that may be difficult to overcome. Chapter 4 helped to better understand such non-economic barriers that
prevent cost-effective GHG mitigation practices being implemented in the agricultural sector in North East Scotland.

In North East Scotland, the main practices implemented by farmers that responded to the survey undertaken were assessed in Chapter 4. Among these was ‘using biological fixation (with clover) to provide nitrogen (N) inputs’. This practice would almost certainly be expanded or initiated by most livestock farmers if it was compulsory to reduce farm-related GHG emissions. Both currently implemented and preferred practices to be implemented by farmers surveyed related to reduction of mineral N fertiliser, and this suggests, understandably, that mitigation practices which save them money are most favoured. However, farm woodland planting, which is considered a cost-effective option to mitigate GHG emissions, especially on lightly stocked upland areas, was one of the least preferred practices. This suggests an aversion of farmers to this practice, which may be due to the perceived risk of losing European Union decoupled farm support (Single Farm Payment - SFP) for that land. ‘Using all the manure or slurry produced on the farm as fertiliser’ and ‘matching the timing of N fertiliser application when the crop will make the most of it’, two other practices widely implemented by farmers, are already included in the list of Good Agricultural and Environmental Condition (GAEC) requirements with which compliance is required to receive the SFP. The reduction in GHG emissions due to mineral N fertiliser being substituted by organic N fertiliser is already happening, and does not bring much ‘additionality’ to GHG emission reduction. Precision farming, which was suggested by experts in participatory workshops as a suitable practice for North East Scotland, received ample support from farmers attending the focus groups. This practice is also related to the reduction of mineral N fertiliser, but requires high upfront investment for the technology required (e.g. satellite imagery, information technology).

Agricultural practices that improve soil carbon sequestration (e.g. minimum tillage) obtained less attention from surveyed farmers, experts and focus groups participants than those related to the reduction of mineral N fertiliser application. Giller et al. (2009) justifies this with the following question: ‘How can resource-constrained farmers be expected to adopt practices that in the long term may improve production, but in the short term realise no net benefits, or even net losses?’. Great GHG emission reductions in livestock result from the use of ionophores (e.g. monensin) in cattle feed. Ionophores
increase livestock productivity while reducing CH$_4$ emissions but these are currently banned in the EU. Farmers who attended the focus groups showed a high support for lifting the ban to these products.

Woodland planting, considered a cost-effective option to mitigate GHG emissions (Ciesla, 1997; Nijnik and Bizikova, 2008; 2010), was suggested by experts in the participatory workshops as a suitable practice. However, ground-truthing with North East Scotland farmers revealed their opposition to this practice. They considered this as one of their least preferred practices (Figure 4.4, p.145), and those who attended the focus groups showed no interest, apart from one farmer that divulged that he only planted trees to receive a grant (Table 4.3, p.148). In contrast, in-farm renewable energy production, especially wind turbines, was well supported by farmers because, according to them, it increases profit, provides ‘free’ electricity for heating, and can be implemented on the poorest (or non-productive) land.

There are, consequently, signs that incentives might influence farmers’ behaviour in the implementation of mitigation practices. Apart from grants being highlighted as a reason for woodland planting, it was also mentioned that government help would be useful for incentivising the implementation of precision farming (Table 4.3, p.148). According to the Royal Society (2011), policy levers$^{42}$ involving both incentives and education are required in order to induce the required changes in behaviour. Streck et al. (2011) consider that a mix of instruments and governance arrangements that include both positive incentives, regulations and sanctions is needed to achieve the multiple objective of food security and effective GHG mitigation.

Taxes on mineral N fertiliser have been used in Austria, Finland, Norway and Sweden (Enquete Commission, 1995). In Austria, following the introduction of the tax, mineral N fertiliser application fell by 11%. However, in Sweden, a 30% tax on the price of fertiliser led to no reduction in demand. According to Storey and MacKenzie-Hedger (1997), a tax on fertiliser is a blunt and inefficient instrument for mitigating the environmental effects of fertiliser use because these can vary across a wide range.

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$^{42}$ Policies are considered as levers that can pull to change the behaviours of individuals and groups.
depending on the type of crop to which the fertiliser is applied, soil conditions, temperature and rainfall. In addition, the rate of GHG emissions due to N fertiliser application is normally non-linear, starting at a low level and rising sharply as the rate begins to exceed the crop requirements, while the fertiliser tax is linear. This may penalise farmers who are causing very little GHG emissions due to the land management practices they undertake. Without good field data, it is difficult to compare different production systems, and hence a tax on GHG emissions could be inefficient.

Payments for carbon sequestration might also change farmers’ behaviour. The standard\textsuperscript{43} carbon value for 2012 used in UK policy appraisal\textsuperscript{44} is 53£/tCO\textsubscript{2}e (DECC, 2012). Thus, one hectare of land in the Scottish hills might produce a store lamb and one grouse shot or 14 tonnes of timber\textsuperscript{45}, the carbon sequestration of which is worth around £1,000 at UK government values used in policy evaluation (JHI, 2012).

Once the most preferred and least-preferred mitigation practices, as well as the barriers to their implementation, have been identified, future work should be undertaken in assessing how these barriers could be overcome. Multi-criteria analysis, which is designed to address problems where some benefits or costs are measured in non-monetary units, is one of the techniques that could be used to undertake this assessment.

\textbf{6.1.4 Can woody biomass, as a source of renewable energy for space and water heating, contribute to a GHG neutral North East Scotland?}

In Chapter 3, it was observed that, in North East Scotland, a 21\% GHG emission reduction in the rural land use sector by 2020 could be obtained if there were no constraints to the implementation of certain practices. However, results from Chapter 4 suggested that 25\% forest cover is going to be difficult to reach given the lack of


\textsuperscript{44} For appraising policies that affect emissions in sectors covered by the EU ETS the ‘traded price of carbon’ is recommended whereas for policies that affect emissions in sectors not covered by the EU ETS (the non-traded sector) a ‘non-traded price of carbon’ is used (www.decc.gov.uk, last accessed 12/09/2012).

\textsuperscript{45} About 50\% carbon (C). The conversion factor of C to CO\textsubscript{2} is 44/12.
interest from farmers in this practice. Biological fixation with clover is already implemented by approximately 80% of farmers who responded to the questionnaire in the livestock marts (Figure 4.3, p.139). Thus, this practice could only bring additionality in reducing GHG emissions if the remaining 20% of farmers in the sample would also adopt it. Precision farming may not be economically viable in the case of small-scale farming because of its high implementation costs (Table 4.3, p.148). Incorporating residues in agricultural soils to increase soil carbon sequestration may be associated with high opportunity cost, since there is a market value for the main crop residue (e.g. straw) because of the large livestock sector (Table 4.3, p.148). However, renewable energy was very strongly supported by the farmers who attended the focus groups, especially wind turbines. Abundant resources of woodfuel at local level may also provide a sustainable source of energy.

The Intergovernmental Panel for Climate Change (IPCC) Second Assessment Report (AR2) identified the use of biomass (e.g. woodfuel) for energy production as the agricultural option offering the greatest potential to mitigate global CO₂ emissions, if it is assumed that there are no land-availability constraints (Storey and McKenzie-Hedger, 1997). The combination of high oil prices, ambitious goals for use of renewable energy set by governments around the world and subsidies in many OECD46 countries has been the main driver of the growth in woodfuel use (FAO, 2009b). According to Davis (2009), fossil fuel prices are expected to increase in real terms in future, thus increasing the demand for woodfuel.

If grown sustainably, woodfuel can provide a virtually CO₂-neutral energy source and, by displacing fossil fuels (e.g. heating oil), can contribute to reduce CO₂ emissions from other sectors of the economy (e.g. domestic heating). According to the Royal Society (2011), the potential of woodfuel to substitute fossil fuels and thereby provide energy with much lower GHG emissions is particularly attractive when considered in terms of an on-farm solution. The CO₂ emissions saved due to the production and use of renewable energy in farms is not yet accounted for within the ‘agriculture’ section of

46 Organisation for Economic Co-operation and Development.
GHG inventory, but the Land Use Strategy for Scotland considers it as a land-based option to mitigate climate change (Scottish Government, 2011b).

In North East Scotland, the promotion of renewable heat systems in the domestic sector is highlighted in local strategies and single outcome agreements, motivated in part by the abundant forest resources of the region. The use of woodfuel as a source of renewable energy for space and water heating can cut GHG emissions from space and water heating, in a business-as-usual scenario, by almost 50% (Chapter 5). This would be a significant contribution to the Scottish GHG emission reduction target of 42% by 2020. However, there is competition for timber in other markets, and the low-grade wood with no market, which is available for the woodfuel market (about 10% of the total), will not be sufficient to meet the demand for woodfuel required to cut CO₂ emissions from space and water heating by approximately 50% in 2020. The introduction of more efficient cooking stoves and industrial processes could reduce woodfuel requirements at a low investment cost, also resulting in reduced GHG emissions (Ciesla, 1997). In addition, the use of better-quality woodfuel, in terms of size, moisture content and heating value, can contribute to increased efficiencies and reduced GHG output. The release of low-grade timber from other markets would also increase the amount available for woodfuel production. However, this might be difficult because of other demands from the wood-processing industry, especially Oriented Strand Board (OSB) manufacture which has been supported by the government and uses low-grade wood products.

Wood energy systems remain the object of much attention and have a degree of public support, although the actuality of developments to date suggests that household demand will remain modest. This can be changed if the Renewable Heat Incentive (RHI) offers substantial incentives at the domestic level. However, domestic RHI support has been consistently deferred. It is possible that the threat to reduce support for on-shore wind by the UK government, which will impact adversely on Scotland’s renewable energy targets, will make the Scottish Government and stakeholders look more seriously at other sources of renewable energy (including woodfuel), in order to meet Scottish targets. A rise in the area of forest for carbon sequestration could also bring opportunities to increase the amount of low-grade timber in the market, but this might be blocked by the food security discourse and farmers’ aversion to woodland planting.
6.1.5 Is the rural land use sector likely to achieve a 21% GHG emission reduction target within an eight year time period (by 2020)?

The *Climate Change Delivery Plan - Meeting Scotland's Statutory Climate Change Targets* (Scottish Government, 2009) set a 21% GHG emission reduction target for the rural land use sector to be achieved in 2020. In a decreasing GHG emission trend scenario (see extrapolation in Figure 3.4, p.113) this target could potentially happen without the contribution of climate change policies. However, food security has been re-established as a policy target in response to the challenges posed by climate change (Sustainable Development Commission, 2009; Defra 2006).

In Scotland, GHG emissions in the future from rural land uses will depend on the extent to which food demand will be met by domestic agricultural production and the share of domestic food consumption be sourced through food imports, and on woodland planting rates. Other countries and regions may have comparative advantages in the production of bulk agricultural commodities such as wheat, plant oils and beef compared to the UK. However, these potentials may be threatened by climate change, and the UK may be able to gain advantage in markets that differentiate on food quality rather than price (Angus et al., 2009), especially red meat produced from livestock fed from grass.

The Royal Society (2011) considers that the logical assumption is that, in order to sustain food production in the UK, agriculture should be spared from reducing its emissions by 80% in 2050. GHG emission reduction targets for GHG emissions should be more realistic, and part of agriculture’s GHG emission burden should be transferred to other sectors. Streck *et al.* (2011) consider that agriculture is special because it is difficult to formulate generally applicable mitigation options given highly site- and context-specific implementation issues. However, the special case argument could also be used to meet the basic human need for warmth. The Royal Society (2011) also recommends that emissions from agriculture are not treated in isolation from other inventories.

A change in diets in the future could also contribute to a decrease in GHG emissions from agriculture. FAO (2009b) pointed out that a shift away from ruminants towards
pigs and poultry meat in the past has 30 years has contributed to GHG emission reduction because monogastric animals have better feed conversion, higher-yielding breeds and improved management practices. According to Trostle (2008), to produce 1kg of chicken, pork and beef, 2.6, 6.5 and 7 kg of maize feed are required, respectively. Recent concerns about the growing incidence of obesity may encourage healthier eating, with implications for the quantity of livestock consumed and consequently GHG emissions from agriculture (Foresight, 2007). However, in the past decade fresh red meat sales have remained steady (Angus et al., 2009). But by 2030, it is forecast that per capita consumption of livestock products could rise by a further 44% from current levels (WHO, 2003). Such an increase in demand for meat will increase demand for cereals and other grains for animal feeds (Angus et al., 2009).

High international prices for commodities could sustain a high demand of land use for agriculture in North East Scotland, to substitute for expensive imports and in supplying local products. Globally, meeting future demand for livestock products will require further improvements in livestock and land productivity as well as expanding feed production area, at the expense of pastureland and natural habitats (FAO, 2009a). Given the prevalence of grass-fed livestock in North East Scotland, this global trend may not be realised in this region.

In terms of woodland carbon sequestration, the production of more wood is certainly contingent on greater land manager acceptance, but it would also be nurtured by a reconfiguration of the policy architecture, including no loss of the SFP and an appropriate reward for carbon sequestered. A great deal of afforestation could take place on lightly stocked uplands with almost no cost to farming output, but currently farmers would be at risk of losing subsidy payments. A change in the institutional architecture is probably needed to preface and precede any change in farmer attitudes. Estate managers and hobby farmers may lead the way in such ventures. According to Sutherland et al. (2011), the land managers identified as being primarily oriented towards environment and ecological attitudes did not identify income as highly important. Bohnet et al. (2003) suggest that hobby farmers may be better resourced to undertake conservation practices, which might include climate change mitigation practices, and, more specifically woodland planting.


6.2 Conclusion

Climate change is asserted by many to be the major environmental problem facing the planet. The Kyoto Protocol has emerged as the most important international climate change policy document framing international responses. It has established GHG emission reduction targets and suggested mitigation actions to be implemented by signatory countries, in the period 2005-2012. However, the future of the Protocol and GHG emission reduction commitments is uncertain.

Whatever happens to the Kyoto Protocol, the Scottish Government has set ambitious targets for the reduction of GHG emissions by all sectors of the economy. Aberdeenshire Council, in North East Scotland, is an example of a regional authority that has gone even further in the desire to reduce GHG emissions by pledging an ambition for GHG neutrality of the Council and Shire.

Changes in the rural land use sector have been considered as an essential part of the strategy to mitigate GHG emissions with woodland planting, peatland protection and renewable energy production as the main actions to be undertaken. There are, however, major barriers to the implementation of these actions. Woodland planting aspirations stumble over the currently strengthening food policy discourse, which embodies the rumours of future high food prices and increasing food demand. Peatland protection measures depend on the collection of more and accurate data on carbon sequestration, and renewable energy production is often delayed or even thwarted by planning permissions (e.g. wind) or subject to weakly developed markets (e.g. woodfuel). Several other practices (e.g. biological fixation with clover, minimum tillage) have been listed as potential mitigation practices for the rural land use sector but their implementation has not been well studied at the regional level. To be effective, an action plan to decrease GHG emissions of a country or region and specific sector of the economy requires information about GHG emissions per source type and GHG mitigation potentials of mitigation practices in grounded, locally relevant studies. In addition, better understanding of the technical potentials of mitigation practices (e.g. social, economic) and of the areas of potential implementation of these practices, and barriers to their implementation, is required.
Chapter 6

Given that global and country climate change policies, and mitigation actions resulting from these, have to be implemented at the local level, it is important to establish guidelines that can be understood and then followed by key local actors. This thesis therefore provided an enhanced understanding of the sources of GHG emissions from rural land uses, of the methods to collect data for the estimates, and of the uncertainties associated with these estimates (Chapter 2). It describes the steps required to estimate GHG emissions from rural land uses, and it shows that it is possible to estimate GHG emissions at a regional level and to identify its sources. It also provides a better understanding of the potential of GHG mitigation practices and the barriers and supporting factors to the implementation of these practices (Chapters 3, 4 and 5).

A regional-level approach was appropriate for the study undertaken, considering time and resource constraints. Estimates used in Chapters 2, 3 and 4 were highly dependent on the availability of secondary data. In addition, findings and estimates obtained in Chapter 4 were limited by the difficulty in setting up focus groups with farmers and other land managers in the region. However, data available allowed a regional level approach, and the methodologies developed in the four studies undertaken (Chapters 2, 3, 4 and 5) can be followed for other regions, provided that relevant region-specific adjustments to data inputs are made.

This thesis has ascertained that the GHG emission reductions observed in North East Scotland, over the period 1999-2010 resulted primarily from rural land use policies (e.g. CAP, WFD) and input price effects and not from climate change policies (Chapter 2). These land use policies were responsible for a decrease in livestock numbers, cultivated area and fertiliser application. However, estimates for 2009 and 2010 (Section 2.3.1) indicate an increase of GHG emissions from the North East Scotland rural land use sector.

These estimates are important to inform policy-makers of the evolution of GHG emissions in the rural land use sector of a region and, consequently, the activities that should be targeted to reduce GHG emissions. However, they do not inform individual farmers about their on-farm GHG emissions, their situation in relation to other farmers and what specifically they should do to reduce their emissions.
In Chapter 3, a methodology and criteria to select suitable mitigation practices for rural land uses were suggested. This thesis has shown that there are regional characteristics which might influence the uptake of mitigation practices in the future (e.g. farmers’ aversion for woodland planting vs importance of the region for food production). It was shown that a first assessment of suitable mitigation practices for the rural land use sector of a region can be drawn from literature (Chapter 3). However, ground-truthing is crucial to better understand mitigation practices’ ‘additionality’ and the implementation barriers in specific terrestrial settings (Chapter 4). For example, in the case of woodland planting, barriers to implementation were reasonably well documented (Chapter 3). In the cases of biological fixation with clover and precision farming, however, only the farmers’ questionnaire, the participatory workshops and the focus groups provided information on the implementation barriers and supporting factors, and on current implementation in North East Scotland (Chapter 4). Concerning this last point, it was concluded that farmers are, in the main, willing to adopt the mitigation practices they consider easy to implement or to sustain those that they have already implemented, and/or those that increase their profits (Section 4.3.2). There was some reluctance of farmers to engage in emission reduction for the sake of emission reductions. Farmers who participated in this study considered that agriculture was a ‘special case’ because of its essential role in food production (as well as other ecosystem services), and that it should be exempted from GHG mitigation strategies (Chapter 4). However, there was some indication that incentives might increase the adoption of certain practices (e.g. woodland planting). In addition, and although it cannot be generalised to all North East Scotland, it was found all the farmers that responded the questionnaire were undertaking at least one of the 27 GHG mitigation strategies listed in the questionnaire (Section 4.2.2).

Chapter 5 showed that the adoption of woodfuel systems for space and water heating could reduce GHG emissions by almost 50% from what is projected by 2020. The woodfuel market is currently weak to provide such reduction in GHG emissions, and only with a large increase in demand could woodfuel make a difference.

There is scope for refining the results of this thesis. More data could improve the understanding of sources of GHG emissions and of barriers to the implementation of...
GHG mitigation practices. Potential future work might involve semi-structured interviews with estate owners and farmers to gather data concerning their opinions on the potential contribution of the rural land use sector to mitigate GHG emissions. Such efforts could include questions about preferred mitigation practices and barriers and supporting factors to implementation. For example, more focus groups could be carried out with landowners to discuss the influence of potential forestry incentives (e.g. grants for woodland planting) and the input of the Renewable Heat Incentive (RHI) for households in their decision to plant trees and produce woodfuel. Other potential incentives could also be discussed, as for example incentives to protect peatland areas.

To improve data on the implementation of mitigation practices by farmers, more ground-truthing studies could be undertaken, for example, by selecting a range of case studies (farms), reflecting different management systems, and exploring their capacity to reduce emissions. Data collected could include GHG emissions estimated with the Excel-based model developed in this thesis (Chapter 2), taking into account potential GHG emission ‘hotspots’, e.g. areas where N₂O emissions are higher due to soil conditions. The costs of implementation of a pre-chosen list of mitigation practices, the areas where these could be implemented and the barriers associated to the implementation of those practices could also be collected. The mitigation potential of each practice, as defined in Chapter 3, could be estimated with an optimisation model which would employ information on the costs of implementing the mitigation practices, the area where they could be implemented and the barriers to their implementation. This could be used to estimate the GHG emissions reduction obtained with the implementation of the mitigation practices with the highest potential. Further, it may be desirable to undertake a farmers’ survey, covering the whole region, to investigate the influence of available incentives or carbon taxes in farmers’ attitudes to the implementation of mitigation practices, and the areas they would be willing to implement these practices on their holdings.

In relation to the potential of woodfuel in contributing to GHG mitigation in North East Scotland, an assessment of the scope for substituting wood energy in heating systems of public-sector buildings in the region could be made, and a similar analysis to that undertaken in Chapter 5 for private households could be undertaken. The number of sawmills, the amount of ‘wasted’ wood that could be sold to the woodfuel market, and
the appraisal of the contribution of these wood residues in GHG emission mitigation would be also interesting to assess.

A refinement of the estimates would be used to better inform policy-makers about the mitigation practices that should be prioritised due to substantial reduction in GHG emissions. A politically agreed apportionment of emission reductions is essential, and is indeed implicit in the planned mitigation strategies evidenced in the Report on Proposals and Policies (Scottish Government, 2011b). This explicitly includes the rural land use sector. However, at the moment there seems to be a mismatch between Scottish Government GHG emission reduction targets, and policy support for local implementation of GHG emission mitigation practices in the rural land use sector, because:

1) Farming for a Better Climate (FFBC) promotes voluntary GHG emission reduction in rural land uses, and its contribution to climate change mitigation might be marginal since land managers/farmers are likely to adopt only the above-described “low-hanging fruit” practices or those that are profitable (e.g. wind turbines);

2) Farmers/land owners who claim the Single Farm Payment (SFP) on woodland cannot also claim the Farm Premium scheme for woodland planting. In addition, the Social Cost of Carbon (SCC) is only a theoretical ‘floating’ value which while considerable is not transferred to farmers/land owners to reward them for carbon sequestration and only used in policy appraisal;

3) As the Renewable Heat Incentive is not available for private households, the adoption rate of woodfuel systems for space and water heating is expected to be slow. In addition, this incentive only covers woodpellet and woodchip boilers and these require high upfront investment. Cheaper woodfuel boilers, such as log boilers do not benefit from the incentive.

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47 The Social Cost of Carbon (SCC) measures the full cost of an incremental unit of carbon (or greenhouse gas equivalent) emitted now, calculating the full cost of the damage it imposes over the whole of its time in the atmosphere. Source: http://www.decc.gov.uk/en/content/cms/emissions/valuation/social_cost/social_cost.aspx (last accessed 18/09/2012).
Currently, the rural land use sector is only a modest contributor to the GHG emission reduction targets. A potential increase of GHG emissions, associated with a rise in food prices and food demand, will require mitigation actions beyond what farmers and other land managers have been currently undertaken and are currently willing to implement in the future.

Since there is a target for GHG emissions reduction in the rural land use sector (21% by 2020), the government could exert more leverage on the land based sector. Additional or higher level grants should be made available (e.g. woodland planting, soil carbon sequestration) through, for example, the Scottish Rural Development Programme (SRDP). Extension services to disseminate information and to provide assistance for farmers in the application for grants should be implemented. It should be noted that the adoption of a mitigation strategy by land managers might be more likely if a tax was threatened or imposed on GHG emissions or if mitigation practices were included in the Good Agricultural and Environmental Condition (GAEC) requirement.

Any mitigation strategy should include a list of practices considered feasible/suitable by key local actors to implement on their management units (e.g. farms). Evidence of clear ‘additionality’ should be gathered and the area where the practices could be implemented should be assessed. The list of mitigation practices should be revised to include new mitigation practices considered promising by researchers (e.g. grasslands to sequester CO₂), and more accurate uncertainty ranges and adjustments required by the effect of climate change. It is recommended that more research is undertaken in order to reduce the uncertainty range of the carbon sequestration potential of permanent grassland which occupies a significant area in North East Scotland, and which could make a significant contribution in GHG emissions mitigation (Section 2.4). It is also recommended that an assessment of the area of pristine and disturbed peatlands, including carbon sequestration and GHG emissions in these areas, is made.

These findings and recommendations raise questions on whether GHG emissions reduction should be compulsory in the rural land use sector or voluntary, and whether the rural land use sector should be considered ‘special’ over other sectors (e.g. tourism, energy) and the GHG emission reduction targets simply removed because of food security needs.
It should be accepted that climate change mitigation can only be more effectively tackled with the contribution from all sectors of the economy, together with the action of individuals and policy-makers. Certainly, without stronger intervention from government to achieve the GHG emission targets in the land use sector, these are not likely to be achieved.
References


Defra 2006. Food Security and the UK. RuSource, the rural information network. Briefing 445 [ONLINE] Available at:


Sustainable Development Commission, 2009. Food Security and Sustainability: The Perfect Fit. [ONLINE] Available at: http://www.sd-


Glossary

**Additionality** of a carbon offset means showing that the emissions reductions being used as "carbon offsets" are not 'business as usual'.

**Anaerobic digestion (AD)** is a treatment process breaking down biodegradable, particularly waste, material in the absence of oxygen. It produces methane-rich biogas that can be substitute by fossil fuels.

**Biomass** is biological material that can be used as fuel or for industrial production. It includes solid biomass, industrial waste and municipal waste.

'Business as usual' is the 'high scenario' according to IPPC and consists of a world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies.

**Carbon credits** are part of a tradable permit scheme. They provide a way to reduce greenhouse gas emissions by giving them a monetary value. A credit gives the owner the right to emit one tonne of carbon dioxide. Carbon credits held in offshore funds, primarily hedge funds, will now be treated as exempt from tax on profits in the same way as equities or bonds.

**Carbon dioxide** is a chemical compound composed of one carbon and two oxygen atoms. It is often referred to by its formula CO\(_2\). It is present in the Earth's atmosphere at a low concentration and acts as a greenhouse gas. In its solid state, it is called dry ice. It is a major component of the carbon cycle.

**Carbon dioxide equivalent (CO\(_2\)e)** emissions is the amount of carbon dioxide emission that would give rise to the same level of radiative forcing, in a given time period, as a given amount of well-mixed greenhouse gas emission. For an individual greenhouse gas species, carbon dioxide equivalent emission is calculated by the Global Warming Potential over the given time period for that species. Standard international reporting processes use a time period of 100 years.
**Carbon footprint** is the measure of the amount of carbon dioxide or CO₂ emitted through the combustion of fossil fuels in carrying out a process or making a product. The scope of a carbon footprint analysis can vary and may or may not include all GHGs or reflect a life cycle approach to quantify upstream and downstream emissions. When it includes all GHGs (e.g. with nitrous oxide and methane) the footprint is expressed as a “CO₂ equivalent units”.

**Carbon leakage** occurs when there is an increase in emissions in one country/region as a result of emissions reduction by a second country/region, with a strict climate policy.

**Carbon neutral** is the potential for net carbon emissions to be zero, all else being equal. For operational activity, this would involve some form of offset, with the question of ‘additionality’ being central. For plans and policies: carbon neutrality might mean no net increase in carbon emissions from the proposed activity/development, with offsetting done through investments in other sectors or locations”.

**Carbon offset** is the act of reducing or avoiding GHG emissions in one place in order to "offset" GHG emissions occurring elsewhere. Because GHGs mix well in the atmosphere, it does not matter where that mitigation occurs.

**Carbon price** is the price at which 1 tonne of CO₂e can be purchased.

**Carbon sequestration** refers to the provision of long-term storage of carbon in the terrestrial biosphere (soil, vegetation and organisms) or the oceans, so that the build-up of carbon dioxide concentration in the atmosphere will reduce.

**Carbon sink** is a carbon reservoir that is increasing in size. The main natural sinks are the oceans, soil, plants and other organisms that use photosynthesis to remove carbon from the atmosphere by incorporating it into biomass. Carbon dioxide sinks are a form of carbon offset.

**Clean Development Mechanism** (CDM) is an emissions trading mechanism under the Kyoto Protocol. It is intended to help industrialised countries to reduce the costs of
meeting their targets by achieving reductions elsewhere, in a cheaper way than if they reduce their own emissions.

**Climate** can be described as the ‘average weather’ typically taken over a period of 30 years. More rigorously, it is the statistical description of variables such as temperature, rainfall, snow cover, or any other property of the climate system.

**Climate change** originally meant changes in climate over a period of time, although now it means the changes in climate, in particular temperature and rain, over the last few decades, and widely considered to be due to changes in industrial processes. It is also called "global warming".

**Direct emissions** refer to those released from activities occurring in specified area - eg UK. Indirect emissions refer to those created elsewhere in order for the UK activities to occur – e.g. fires in Malaysia to make way for palm oil that then is imported for biofuel to the UK.

**Emissions** are releases of gases to the atmosphere, caused by human behaviour. In the context of global climate change, they consist of important greenhouse gases, e.g., the release of carbon dioxide during fuel combustion.

**Enteric fermentation** is a fermentation process that takes place in the digestive system of ruminant animals (e.g. cattle and sheep) to break down ‘hard-to-digest’ grassy materials, leading to the release of methane.

**Estimated Breeding Values (EBV’s)** are used to calculate how future progeny of cattle and sheep will compare to progeny of other animals within the breed. An animal’s breeding value is its genetic merit, half of which will be passed onto its progeny. EBV’s are expressed as the difference between an individual animal’s genetics and the genetic base to which the animal is compared. EBV’s are reported in the units in which the measurements are taken e.g. Kilograms (Kg) for weight. Thus a value of +12kg for 400-day weight means the animal is genetically superior by 12kg at 400 days compared with the genetic base of the relevant cattle population. The absolute value of any EBV is not
critical, but rather the differences in EBVs between animals. Particular animals should be viewed as being "above or below breed average" for a particular trait.

**Feed-in-tariffs** is a type of support scheme for electricity generation in which generators obtain a long term guaranteed price for the output they deliver to the grid.

**Fluorinated gases (F-gases)** are a family of greenhouse gases containing fluorine: Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF₆). These gases are used in industrial processes, refrigeration and air conditioning and have a high global warming potential.

**Fuel poverty** A fuel poor household needs to spend more than 10% its income in fuel use in order to maintain a satisfactory heating regime.

**Global warming** is the observed increase in the average temperature of the Earth's atmosphere and oceans in recent decades, and its projected continuation. The Intergovernmental Panel on Climate Change (IPCC) concluded in its fourth report that global warming was happening, and was very likely to be caused by human activities.

**Global warming potential (GWP)** is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is a relative scale which compares the gas in question with carbon dioxide (GWP=1). It is a measure of the carbon dioxide radioactive forcing.

**GHGs or greenhouse gases** are atmospheric gases (either natural or anthropogenic in origin) which absorb thermal radiation emitted by the Earth’s surface. GHGs trap the heat in the atmosphere, keeping the surface at a warmer temperature than it would otherwise be possible. This effect is is commonly called the Greenhouse Effect. Naturally occurring greenhouse gases include water vapour, carbon dioxide, methane, nitrous oxide, and ozone. Human activities are responsible for increasing the levels of most of these naturally occurring gases.

**Intergovernmental Panel on Climate Change (IPCC)** The IPCC was formed in 1988 by the World Meteorological Organisation (WMO) and the United Nations
Environment Programme (UNEP). The IPCC’s mission is to assess the latest scientific, technical and socio-economic literature on climate change in an open, transparent and neutral way with respect to policy. The IPCC has been publishing a range of special reports and assessment reports and the most recent of which (the Fourth Assessment Report, or AR4) was produced in 2007.

**Ionophores** are feed additives that can improve the cattle performance. They are currently banned in the EU.

**Kilowatt-hour (kWh)** is a unit of energy, equal to the total energy consumed at a rate of 1,000 watts for one hour.

**Kyoto Protocol** is the internationally binding agreement under the UN Framework Convention on Climate Change that set GHG targets for signatories to abide by. Drawn up in 1997, it came into effect in 2005. It required developed countries to reduce emissions by 5 per cent, compared with 1990 levels, by 2012.

**Life cycle analysis** measures the environmental impacts of a product or processes from 'cradle to grave' – i.e. from the production of raw materials, to manufacturing and processing, to the final product and waste.

**LULUCF** Land Use Land Use Change and Forestry.

**Marginal Abatement Cost Curve (MACC)** is graph showing costs and potential for GHG emissions reduction from different measures or technologies, ranking these from the cheapest to most expensive to represent the costs of achieving incremental levels of emissions reduction.

**Methane** (CH₄) Greenhouse gas with a global warming potential of 25 (1 tonne of methane corresponds to 25 tonnes CO₂e). Agricultural sources are the digestive systems of ruminant animals (e.g. cattle and sheep), as well as manures.

**Mitigation** is an action to reduce the sources (or enhance the sinks) of factors causing climate change, such as greenhouse gases.
MtCO$_2$ Million tonnes of carbon dioxide (CO$_2$).

**National Atmospheric Emissions Inventory (NAEI)** is data source compiling estimates of the UK’s emissions to the atmosphere of various gases (including greenhouse gases).

**Nitrification inhibitors** are chemical additives that slow down the rate of conversion of fertiliser ammonium to nitrate, reducing nitrogen losses.

**Nitrous Oxide (N$_2$O)** is a greenhouse gas with a global warming potential of 298 (1 tonne of nitrous oxide corresponds to 298 tonnes of CO$_2$e). It arises naturally in agricultural soils through biological processes and it is influenced by a variety of soil and nutrient management practices and activities (e.g. synthetic fertiliser application).

**NOx** are oxides of nitrogen, defined as the sum of the amounts of nitric oxide (NO) and nitrogen dioxide (NO$_2$).

**Propionate precursors** are feed additives that reduce the production of methane in ruminants.

**Radiative forcing** is the difference between the incoming radiation energy and the outgoing radiation energy in a given climate system. Is expressed in units of Watts per square meter (Wm$^{-2}$) and is usually taken as a global average value in a given year, relative to the balance during pre-industrial times.

**Renewables** are energy resources, where energy is derived from natural processes that are replenished constantly. They include geothermal, solar, wind, tide, wave, and hydro power and biomass and biofuels.

**Renewable Obligation Certificates (ROCs)** are representations of the amount of energy generated from renewable sources.
**Scenarios** There are two main scenarios used to predict climate change: the ‘low emissions’ scenario and the ‘high emissions’ scenario. The ‘low emissions’ scenario consists of a “convergent world with the same global population that peaks in mid-century and declines thereafter but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies”. The ‘high emissions’ scenario (‘business as usual’) consists of a "world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies". The IPCC predicts that, surface air warming during the 21st century for a ‘low emissions’ scenario is 1.8 °C, uncertainty range of [1.1 - 2.9 °C]. For a ‘high emissions’ scenario the best estimate is 4.0 °C, uncertainty range [2.4 to 6.4 °C].

**Sustainable development (SD)** is a pattern of economic growth in which resource use aims to meet human needs while preserving the environment so that these needs can be met not only in the present, but also for generations to come (sometimes taught as ELF-Environment, Local people, Future.

**Technical potential** is the theoretical maximum amount of emissions reduction that is possible from a particular technology. This measure ignores constraints on delivery and barriers to firms and consumers that may prevent up take.

**United Nations Framework Convention on Climate Change (UNFCCC)** was signed at the Earth Summit in Rio de Janeiro in 1992 by over 150 countries and the European Community. The UNFCCC has an ultimate aim of “stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system”.

**Zero carbon** is any activity (whether an operation, plan or policy) where absolute carbon emissions are zero.

Adapted from:
http://www.epaw.co.uk/carbon/glossary.html
http://unfccc.int/kyoto_protocol/mechanisms/items/1673.php
http://www.ukerc.ac.uk/support/tiki-index.php/view/367/763
http://www.theccc.org.uk/reports/fourth-carbon-budget
http://www.gelbvieh.asn.au/Breedplan.html
http://abri.une.edu.au/online/pages/understanding_ebvs_char.htm
(last accessed 02/09/2012)