Costs and benefits of reducing livestock related greenhouse gas emissions for extensive sheep farms in Great Britain

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Thesis Code:
BEC-80433

Wageningen, March 2011

Dedication

To my husband and best friend, Godwin A. Mavima. Thank you for your love and support.

Acknowledgements

Firstly, I wish to thank my supervisors, Dr. Paul Berentsen, Dr. Alistair Stott and Dr. Bouda Vasough Ahmadi for their support throughout the thesis period. I also wish to acknowledge the help and expert advice from Dr. Tony Waterhouse and Dr. Colin Morgan. Special mention goes to friends and colleagues both in Wageningen and at SAC for their support and contributions towards this thesis. Not forgetting my family for the encouragement and for believing in me. Lastly, I thank the Lord Almighty for His abundant grace that has carried me through.

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Summary

Livestock production contributes to climate change when the greenhouse gases methane, nitrous oxide and carbon dioxide are produced and released into the atmosphere. Ruminants are major culprits of the production of methane. Many policies have been put in place that requires nations to reduce their greenhouse gas emissions. It is therefore important for livestock farmers to try and find ways of reducing these emissions. The main objective of this research is to find out how reducing greenhouse gas emissions will affect the profitability of extensive sheep farmers in Great Britain.

The growing concern of the effects of climate change resulted in the passing of the Climate Change (Scotland) Act 2009 that sets out to reduce greenhouse gas emissions to less than 80% of the 1990 levels in the year 2050 and an interim target of 42% by 2020. The Scottish Government in its Climate Change Delivery Plan set a target to reduce emissions from agriculture in 2020 from 2006 levels by 0.7MtCO_2e. Hill sheep farmers fall into this category and therefore need to participate as ruminants contribute to methane emissions. Greenhouse gas emissions may be reduced by improving feeding practices, increasing productivity through breeding or by reducing livestock numbers.

Data from four extensive sheep farms from Cumbria and Scotland were used as input for a linear programming model that calculated the optimal farm feeding plan and maximized gross margin. From this, greenhouse gas emissions were calculated for methane and nitrous oxide. These emissions were converted to their carbon dioxide equivalents (CO_2e) and were reported as kg CO_2e per ha or per kg lamb. The model was run separately for each farm. This model was used to calculate how different interventions made to the farming systems may reduce the greenhouse gas emissions on each of the four farms. The following measures were tested using the model and each is descdribed below. The first scenario was to establish what the current level of greenhouse gas emissions and the gross margin of the farm were. Then there was the choice of reducing the current flock size, introducing concentrates to the diet and alternating that hill grazing pattern. These were measures tested in order to see how they affect the levels of greenhouse gas emissions on the farm and in turn the gross margin. A fifth scenario that included a cost for labour was conducted as a sensitivity analysis.

The first scenario for each farm gave the baseline emissions and gross margin at the current flock size. These were then used to compare with the other scenarios to see whether the interventions introduced would have an effect in reducing greenhouse gas emissions, by what percentage and how this affects the gross margin of the farm.

The second scenario looked at how the emissions could be reduced by the farmers keeping a smaller flock. The total emissions (kgCO_2e/ha) were decreased by up to large percentages as the flock size got

smaller. However, kg CO_2e/kg lamb and average daily emissions of methane per ewe increased. The gross margin also had big reductions as the flock size grew smaller.

In the third scenario, where concentrates were included into the diet, the total farm emissions (kgCO_2e/ha) reduced by small percentage when the flock size was the same but would increase if the flock size became smaller. The methane emissions per ewe (g) and kg CO_2e/kg lamb generally went down. The reductions in gross margins were rather large in this case.

The scenario that included the change in hill grazing showed a lot of variations on the different farms. In all cases, the total farm emissions (kgCO_2e/ha) would reduce but the other greenhouse gas emissions would either increase or decrease depending on the farm and the option of hill grazing. The gross margin would always decrease in each option, although with variation in the extent of change.

The fifth scenario was a sensitivity analysis to see how the model responds when a cost of £5 per hour was introduced for labour. Generally, flock size reduced, total farm emissions reduced but there were increases in the other emissions.

Finally, three measures of reducing greenhouse gases were assessed. These included reducing the flock size, adding concentrates to the diet and alternating use of hill land for grazing. These measures showed small percent reduction in emissions that resulted in large drops in the gross margins of the farms. The issue of reducing emissions still needs to be researched especially for extensive sheep farming where the animals are not only there to produce meat but also have a role to play in maintaining the ecosystems and biodiversity in the hill areas.

1 Introduction

In order to identify what impact livestock farming has on climate change we need to know its carbon footprint. A carbon footprint is defined as the total amount of greenhouse gases produced to directly and indirectly support livestock farming, usually expressed in equivalent tonnes of carbon dioxide (Peterson and Rohrer 2010). Greenhouse gases (GHGs) are gaseous components of the atmosphere that absorb solar energy reflected from the earth’s surface. This energy is transferred to the major non GHGs (nitrogen (N) and oxygen (O_2)) resulting in an overall temperature increase in the lower atmosphere (De Klein et al. 2008). The main GHG emissions associated with livestock production are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Emissions from livestock are measured either in terms of kg CO_2 equivalent per kg meat or milk produced or per hectare of land used. The former is focused on measuring impacts in terms of how much is produced and the latter in terms of land area allocated to livestock farming. Ruminants in extensive systems have been found to have a lower per hectare footprint than intensive grain fed systems but a higher footprint expressed in terms of kg/product (Garnett 2010). In extensive sheep systems, where productivity is low and absolute production small in comparison to proportion of land use, this issue of indicators is particularly important. The influence that extensive sheep systems have on the ecosystems services that flow from Scotland’s ‘less favoured’ areas and the impact that changes to or even absence of these systems might have on such services is also an important but poorly understood related issue. Total greenhouse gas emissions in the UK stands at around 179 million tonnes of carbon equivalent and 7% are from agriculture (Garnett 2009).

To identify the type, extent and source of emissions on a farm a carbon audit is required and can also be used in the identification of possibilities in the reduction of greenhouse gas emissions. A whole farm approach can be used to measure carbon footprint for benchmarking purposes and as a basis for development of strategies to reduce emission (SAC 2010). Garnett (2007) identifies four main approaches to mitigating livestock greenhouse gas impacts. These approaches focus on the areas of husbandry (feed, genetics and lifespan), the management system, the number of livestock and managing the output (manure).

With increasing awareness of climate change and its effect, the government in the UK published the UK Low Carbon Transition Plan (Government 2009). This plan requires that English farmers continue to reduce their annual greenhouse gas emissions. Scotland is bound separately by the Climate Change Scotland Act (2009) (ScottishGovernment 2009). This Act aims to establish a framework that will assist in the efforts towards reducing Kyoto Protocol greenhouse gas emissions in Scotland and also creating mandatory climate change targets to reduce these emissions (Rosado and Lobato 2009). The associated delivery plan includes a chapter (6) devoted to land use (Donnelley

2009). The delivery plan highlights the importance of mitigation strategies for the farm livestock sector. It points out the need to provide incentives to farmers through the new Scottish Rural Development Programme. These will need to be targeted at the most cost effective actions in the most influential sectors of the farming industry. This project will contribute towards this prioritization process. However, there is particular concern about the future of extensive sheep farming systems in Great Britain with the decoupling of subsidies (Stott et al. 2009). The question therefore is what costs these farmers will encounter when they have to reduce greenhouse gas emissions?

The research objective of this study was to investigate the effects on profitability of reducing greenhouse gas emissions on typical extensive sheep farms in the Great Britain.
Specific research objectives were:

i. To identify how greenhouse gas emissions may be assessed on sheep farms.
ii. To determine possible measures extensive sheep farmers can take in order to reduce greenhouse gas emissions.
iii. To investigate the impacts of these measures on the profitability of the farms under study.

This thesis is structured in the following way. Chapter two reviews relevent literature related to the topic. It deals with the causes and effects of climate change in livestock production with a focus on sheep farming, how greenhouse gas emissions have been assessed and what mitigation measures may be taken to reduce these emissions. The chapter on materials and methods describes the model used and the scenarios that were explored with the aim of answering the third specific research objective. The results are then presented in Chapter four and these are then dicsussed in relation to literature in Chapter five. In Chapter six are the conclusions and recommendations for further study in this area.

2 Literature review

In this chapter relevant literature on climate change and livestock production were reviewed. Firstly, the causes and effects of climate change were discussed followed by a look at how agriculture contributes towards it. A section was dedicated to the assessment of greenhouse gas emissions and what policies were in place with respect to these. As this study was focused on extensive sheep farming, the hill sheep farming system of Great Britain was discussed and the chapter concluded with the possible measures that farmers could take in order to reduce livestock related greenhouse gas emissions.

2.1 Climate change – causes and effects

"Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer" (IPCC 2007). Climate change is considered to be a threat to the earth because of the effects that an increase of the earth's temperatures by more that $2^{o}C$ would have (European 2008). The activities of man have contributed greatly to climate change and subsequently to global warming (Gill et al. 2010).

The earth's surface is heated by the visible radiation from the sun as well as by infrared radiation emitted by the atmosphere. The flow of energy from the atmosphere to the earth's surface is what is referred to as the 'greenhouse effect'. There are gases in the atmosphere that absorb part of the radiation emitted back into space by the warmed earth and these are called greenhouse gases (GHG). The greater proportions (about 96-99%) of the gases (nitrogen (N), oxygen (O_2) and argon (Ar)) that make up the atmosphere do not absorb or emit infrared radiation. The remaining constituents of the atmosphere are responsible for the greenhouse effect. These are primarily water vapour and carbon dioxide (CO_2) along with some other trace gases. These trace gases make up about 0.05% of the atmosphere however, they have a part to play in atmosphere pollution and also contribute to the greenhouse effect (Dessler and Parson 2010). Of these trace gases, CO_2 has the largest share and is the largest contributor to the greenhouse effect after water vapour. The next largest is methane (CH_4) and it absorbs infrared some 20 times more than CO_2 on a per molecular basis. Smaller greenhouse contributions come from nitrous oxide (N_2O), chlorofluorocarbons (CFC) and related synthetic chemicals and ozone (O_3). The earth's temperature continues to rise as the concentration of these gases continues to increase.

The concentration of CO_2, CH_4, and N_2O in the atmosphere are now above their pre-industrial levels (Latif et al. 2009). This is due to the rise in the consumption of fossil energy sources (i.e. oil, natural gas and coal), the expansions of industrial production, change in land usage, and the expansion of animal husbandry and intensive agriculture. The anthropogenic greenhouse gases emitted into the atmosphere have a relatively long life span and their persistence causes them to disperse across the earth, making their effects felt globally.

The greenhouse gases have different warming influence (radiative forcing) on the global climate system due to their different radioactive properties and time they remain in the atmosphere. These warming influences are expressed through a common metric based on the radiative forcing of CO_2. The CO_2 equivalent (CO_2e) emission is the amount of CO_2 emission that would cause the same time integrated radiative forcing over a given time horizon as an emitted amount of a long lived GHG or a mixture of GHGs. This is obtained by multiplying the emission of the GHG by its Global Warming Potential (GWP) for the given time horizon (IPCC 2007). A GWP is an indicator that reflects the relative effect of a greenhouse gas in terms of climate change considering a fixed time period such as 100 years (GWP_{100})(EPLCA 2007) and is also used for the comparison between different greenhouse gases and their ability to trap heat in the atmosphere. GWPs are based on the heat absorbing ability as well as the decay rate of each gas relative to that of carbon dioxide. The decay rate of a gas is the amount of the gas removed from the atmosphere over a given number of years (Garnett 2008).

Man and the natural environment are continuously being affected by the effects of climate change. The changes in temperature may affect planting and breeding seasons, may cause stress in livestock, and may trigger the emergence and spread of new and more aggressive pests and diseases. At the same time there may also be longer growing seasons and opportunities of growing wider range of crops. Changes in annual rainfall amounts and patterns, more frequent extreme weather conditions, rising sea level due to melting polar ice caps and changes in the ecosystem are other outcomes of climate change.

2.2 Contribution of agriculture to climate change

According to Popp et al. (2010), agriculture accounts for approximately 14% of the global anthropogenic greenhouse gas emissions. These GHGs, mainly CH_4, CO_2 and N_2O, are generated throughout the food and agricultural supply and distribution system, from production of agricultural inputs through to the final consumption of food products (Blandford and Josling 2009). The sources of greenhouse gas emissions in agriculture can be directly or indirectly attributed to activities that are carried out in both crop and livestock production. Hockstad and Weitz (2009) identified the following to be both direct and indirect sources of GHG emissions in agriculture:

1. Agricultural soil management
2. Enteric fermentation
3. Manure management
4. Rice cultivation

5. Field burning of agricultural residues

A greater proportion of the global anthropogenic CO_2 emissions associated with farming are mainly from the use of fossil fuels on the farm. These fuels are used for powering vehicles and farm machinery, irrigation, heating, cooling and ventilation of buildings, processing and distribution of final products. Carbon dioxide from livestock respiration has a net zero effect because plants that sequestered CO_2 are consumed by livestock and then CO_2 is released back into the atmosphere through respiration to be absorbed once again by plants (Pitesky et al. 2009). Approximately 40% of the global anthropogenic CH_4 comes from agriculture, mainly from enteric fermentation in livestock, wetland rice cultivation and anaerobic decomposition of manure. The 65% of global anthropogenic N_2O attributed to agriculture results from the application of synthetic and manure fertilizers, from nitrification and denitrification of manure and urine and from field burning of agricultural residues (Pitesky et al. 2009). Nitrous oxide emissions can be from direct or indirect sources. Some direct sources of N_2O emissions are inorganic nitrogen fertilizers and manure application, deposition of urine and dung at grazing, crop residues and biological fixation of nitrogen. Indirect sources include deposition of nitrogen from the atmosphere and nitrate leaching.

Thornton and Gerber (2010) observed that the livestock food chains are major contributors to greenhouse emissions in agriculture. Steinfeld (2006) also attributes a larger proportion of greenhouse gas emissions in agriculture directly or indirectly to livestock production. He refers to the following as livestock related sources of greenhouse gas emissions: enteric fermentation and respiration, animal manure, livestock related land use change, deforestation linked to livestock, livestock related release from cultivated soils, feed production, on farm fossil fuel use and post harvest emissions. Garnett (2007) states that livestock reared in extensive systems, such as ruminants, tend to have a lower per area footprint than those in intensive systems like poultry and pigs, but have a higher footprint when expressed in terms of per kg of product. However, livestock not only provide food, but have other contributions to the environment such as the role they play in maintaining ecosystem services and in the biodiversity of the landscape. Ruminants are also able to make use of plants that grow on non arable land and to consume agricultural byproducts that humans cannot make use of, meaning that they can utilize land that otherwise would not be suitable for food production (Garnett 2007; Pitesky et al. 2009).

2.3 Assessment of GHG emissions

The greenhouse gases associated with livestock production are carbon dioxide, methane and nitrous oxide. This section looks into various ways that these emissions have been assessed in the livestock sector. The measurement of methane and nitrous oxide produced by individual animals requires equipment that is expensive and complicated. Prediction equations have been derived and models have been developed, modified or adapted to estimate emissions. The Intergovernmental Panel on Climate Change (IPCC) has published guidelines (IPCC 2006; Sejian et al. 2010) that may be used to estimate emissions at national and global level.

Life Cycle Assessment (EPLCA)

A Life Cycle Assessment (LCA) is a process of evaluating the environmental impacts of a product through the stages of its production, use up until its disposal - from “cradle to grave” (Garnett 2009). A carbon footprint or carbon profile is the overall amount of carbon dioxide and other greenhouse gas emissions that are associated with a product along its supply chain and is quantified using indicators such as the Global Warming Potential (EPLCA 2007). It is a subset of the data covered by a more complete LCA and is therefore a LCA with the analysis limited to emissions that have an effect on climate change (EPLCA 2007).

The British Standard Institute produced a document that offers guidelines for preparing a carbon footprint. The document is called PAS 2050 (Publicly Available Specifications 2050) (BSI 2008). The calculation of the carbon footprint is part of the five step Life Cycle Assessment process that is described in PAS 2050. This calculation requires two sets of data, the activity data and the emission factors. The activity data describe all the material and energy amounts that are involved in the lifecycle of the product and these may include the material inputs and outputs, energy used and transport. The emission factor is the amount of greenhouse gas emitted, expressed as CO_2 equivalent and relative to a unit of activity (kg GHGs per kg input or per kWh energy used)(BSI 2008).

Whole Farm Systems Modeling

Whole farm system modeling can be used to determine the greenhouse emissions that are associated with agricultural produces and their production. This approach looks at all activities that take place on the farm as well as various other aspects of the farm such as soil type, location and weather patterns which are then converted to their carbon dioxide equivalents. The whole farm approach is a tool that can be used to develop cost effective greenhouse gas mitigation options because of its ability to show the interactions between farm components (Sejian et al. 2010). Whole farm models use a diverse mix of empirical and mathematical modeling. Computer simulation can provide a cost effective and efficient method of estimating and analyzing effects of management strategies on methane emissions on farms (Sejian et al. 2010). The GrassGro™ grazing simulation software is an example of a model that is used to simulate changes in annual methane, meat, wool and gross margin for sheep production (Alcock and Hegarty 2006). It generates pasture growth and digestibilty during the simulation period. Animal growth is computed using algorithms based on Australian Feeding Standards and methane production is predicted from the equations of Blaxter and Clapperton within the model and enterprise gross margins are determined using local cost structures (Alcock and Hegarty 2006).

IPCC Methodology

The Intergovernmental Panel on Climate Change (IPCC) in their Volume 4 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories set out guidelines on how to prepare annual greenhouse gas inventories for the Agriculture, Forestry and Other Land Use (AFOLU) Sector (IPCC 2006). Chapter ten of volume 4 gives the guidelines for the methods of estimating emissions of methane from enteric fermentation in livestock and methane and nitrous oxide emissions from manure management. There is a three tiered approach that may be used to estimate the greenhouse gas emission. The higher tiers give better estimates of the inventory while reducing the uncertainty as well but, the complexity and the resources required increase as well. The Tier I method is the simplest to use with default values and equations provided in the guidelines. Tier II follows the same methodological approach as Tier I but makes use of emission and stock change factors that are based on country or regional specific data for the important livestock categories. The equations for this second approach can be found in the guidelines as well. The tier III method is the most complicated to use and requires higher order methods that include models and inventory measurement systems that are country specific and address national circumstances, repeated over time. Tier III methods provide estimates with greater certainty than the lower tiers (IPCC 2006).

Measurement and Prediction of Enteric Methane Emission

The amount of methane emissions differs in ruminants depending on factors such as animal species, breed, pH of rumen fluid, methanogen population, composition of diet and amount of concentrate fed. A significant amount of fermentation takes place in the rumen of ruminants that results in relatively large amounts of methane emissions per unit of feed energy consumed (Sejian et al. 2010). The amount of emissions also differs between developed and developing countries (Table 2.1). Cattle produce the most greenhouse gas emission among ruminants followed by sheep, goats and buffalo.

The prediction of methane production is based on equations that involve dry matter intake (DMI), digestibility, intake of carbohydrates and dietary energy and animal size. Models developed to predict methane may either be empirical (statistical) models that relate nutrients intake directly to the methane produced or dynamic mechanistic models that try to simulate the methane emissions based on mathematical descriptions of ruminal fermentation biochemistry.

Table 2.1 Average estimated methane emission rate through enteric fermentation for ruminants (adapted from Sejian et al. 2010)

Animal Type	Region/countries	Methane emission rate (g/animal/day)
Cattle	Developed	150.7
	Developing	95.9
Sheep	Developed	21.9
	Developing	13.7
Buffalo		13.7
Goats		13.7

Some other techniques to measure enteric methane emissions include whole animal chambers and the sulfur hexachloride (SF6) tracer technique (Sejian et al. 2010). The methane emission can be accurately measured for individual animals by use of open circuit respiration chambers. These chambers are not suitable to evaluate emissions of grazing animals. The SF6 tracer technique makes use of the inert gas sulfur hexachloride and was developed to determine methane emission from cattle and sheep under grazing conditions. This technique is able to determine emissions from both individual and large groups of animals.

2.4 Policies to reduce GHG emissions

Climate Change (Scotland) Act 2009

The UK was the first country to have a Climate Change Act in 2008. Scotland is bound separately by the Climate Change (Scotland) Act 2009 (ScottishGovernment 2009). The act aims to establish a framework that will assist in the efforts towards reducing greenhouse gas emissions in Scotland and also to create mandatory climate change targets to reduce these emissions. The Act has a main target of reducing the net Scottish emissions account for the year 2050 by at least 80% of the baseline, which is the year 1990 for the three main GHGs, carbon dioxide, methane and nitrous oxide. There is also an interim target of reducing the net Scottish account by at least 42% of the baseline by the year 2020. The Act also provides for annual targets for the reduction of the greenhouse gases for the period 2010 to 2050. A target is set for the maximum amount of net Scottish emission account and these targets should not be exceeded each year.

There is a delivery plan that was developed to meet the targets of the Climate Change Act. This delivery plan includes a chapter (6) devoted to land use. It states that “the emissions from agriculture and land use have to be reduced in 2020 from the 2006 levels by 0.7 Mt CO_2e (million tonnes carbon dioxide equivalent)”. The interim target of the delivery plan is that emissions are required to be at least 34% below the 1990 levels by 2020. The delivery plan highlights the importance of mitigation strategies for the farm livestock sector. Listed below are the measures that will contribute to the delivery of the 34% Scottish target in 2020 (Donnelley 2009):

- Measures to improve livestock production
- Improved manure and slurry management
- Development of anaerobic digestion
- Improved nutrient management systems
- Protecting high carbon soils
- Afforestation rates of 10 000ha/year

UK Low Carbon Transition Plan

This plan highlights how the government in the UK intends to reach its goals of reducing greenhouse gas emissions in all sectors (Government 2009). The focus of the plan on the agricultural sector is that the government would like to encourage farmers to take actions on reducing their emissions by 6% of 2008 levels. This should be through the efficient use of fertilizers and better management of livestock. In 2012 there will be review of the voluntary progress to assess whether there is need for further government intervention. The government will also ensure that comprehensive advice programmes are available to the farmers. They would also like to see to it that there is private funding for woodland creation because of the carbon uptake that will rise with the increase in forest areas. There will be support for cost effective efforts of farmers and for interventions that will help reduce emissions such as anaerobic digestion.

Common Agricultural Policy (CAP) 2003

Single Farm Payment decoupled from production replaces the previous area based payments. Farmers are paid independently of how much they produce. They will receive a direct income payment that is not linked to production. However, the income support is conditional to statutory environmental management requirements and the obligation to maintain land under permanent pasture. Failure to do so will result in reduction in the direct payment (cross compliance) (IPCC 2007). There have been reduced GHG emissions due to the reduced number of livestock and to reduction in the use of nitrogen inputs following CAP reform (Schils et al. 2007).

2.5 Hill sheep farming

Much of the land use in Great Britain can be classified as hill grazing such as in the Scottish Highlands and Cheviot Hills. These hill farms are operating extensive systems of production. Extensive systems may be described based on the number of animals per labour unit, the stocking density and to what degree the animal’s movements are restricted (Dwyer and Lawrence 2005). The hill land offers poor grazing that may support 0.5 to 2 breeding ewes per hectare (Dwyer and

Lawrence 2005) and these hill areas are often referred to as the less favoured areas (LFA) of the country. The sheep that are grazed on the hills are small, hardy breeds that vary in mature live weight between 35kg to about 60kg and with a lambing rate of around 1.0 (Armstrong et al. 1997). Breeds that have been kept in these areas for centuries are Scottish Blackface, Welsh Mountain, Swaledale and Cheviot (Dwyer and Lawrence 2005). The hill sheep farm has two main defined areas: the in-bye and the higher open hill (comprised of the fell and the intake or lower slope). The tops of the hills over 300m altitude are referred to as the fell and sheep graze on this open land during the summer. The intake is divided into fields by stone walls and some pasture is improved by adding drainage and fertiliser. The in-bye is a fenced area containing the farmhouse, buildings, and sheep pens and flocks are held here during periods when they are taken off the hill due to adverse weather conditions in winter, mating or at lambing. Grass may also be grown in the in-bye for conservation either as hay or silage. The vegetation of the hills consists of poorer quality species of grass (Goodwin 1979). The hill areas are characterized by a short growing season with generally cold, wet conditions. The type of vegetation that grows varies with altitude and soil type. *Nardus stricta, Molinia caerulea, Agrostis spp and Festuca* are some grass species that can be found on the hills as well as the shrub, *Calluna vulgaris* (Armstrong et al. 1997).

Ewes are kept for up to five years on the hills. Supplementary feeding is supplied during the late winter and may also be provided towards the lambing period. Supplementary minerals are supplied throughout the year and the sheep are left to forage freely (Armstrong et al. 1997). The main income for hill farms is from the sale of fat or store lambs, the sale of cast ewes as breeding stock or for mutton and the sale of wool. This may also be supplemented by the sale of ewe lambs for breeding and the sale of rams. The profitability of most sheep enterprises in the UK is closely related to lamb output (the number of lambs produced). This is dependent upon the number of lambs produced and their growth rate. Ewe nutrition is important, but when the ewes are grazing on the hills it is difficult to assess the feed intake and to provide an appropriate supplementary feed system. The housing of hill ewes in the later stages of pregnancy, lambing and early lamb suckling phase makes it easier to assess the ewe diet during these critical stages of the reproductive cycle. The nutritional requirements are not influenced by the breed or the environment but rather they are a function of body weight, body condition and the number of lambs carried (Alderman and Cottrill 1993).

The numbers of sheep in Great Britain has declined from 23 million breeding ewes to about 16 million (Thompson 2009). About 50% of these animals were part of hill flocks. According to Thompson (2009), the reduction in the number of hill sheep is due to “the effects of the various subsidies, the increased costs, the low prices for sheep products and the social pressure.” Stott et al. (2009) point out that the hill sheep farming system has been uneconomic and without subsidies there is no incentive for production.

2.6 Measures to be taken by farmers and their efficiency in reducing GHG emission

The dominant emissions from livestock systems are those of CH_4 and N_2O and mitigation efforts are directed to limiting the emissions of these two gases. It is essential to ensure that the reduction of one greenhouse gas is not done at the expense of another. The mitigation of the greenhouse gases from livestock could be done by reducing emissions (efficient management of carbon and nitrogen flows in the livestock system), enhancing removals (carbon sequestration and building carbon sinks) or avoiding or displacing emission (crops and residues from the land are used as a source of fuel thereby displacing emissions from fossil fuels) (IPCC 2007). When developing mitigation strategies it is important to take into account the interactions that exist between the various gases. Practices to reduce GHG emissions from livestock can be grouped as: improved feeding practices, use of specific agents or dietary additives, longer term management changes and animal breeding (Garnett 2007; IPCC 2007).

Improved feeding practices

Methane emissions from livestock are mainly a result of enteric fermentation and eructation of methane represents a loss of energy to the animal (Gill et al. 2010). Mitigation options for enteric fermentation may either be aimed at an increased animal productivity such as increasing number of lambs produced or aimed to affect rumen functioning like increased levels of starch or the use of additives. Nitrous oxide emissions result from the excretion of nitrogen in the urine and faeces. The amount of N_2O emitted is dependent upon the composition of the urine and the faeces excreted by the animal.

Changing the feed that is given to the livestock may be a way of reducing the greenhouse gas emissions that may be produced. In intensive systems the aim is to balance feeding in such a way that will maximize the production of the output that is of interest such as the meat or the milk while reducing the unwanted output i.e. the greenhouse gas emissions. Garnett (2007) says that greenhouse gases may be reduced by modifying the feed in such a way that the diet is adjusted to meet the nutritional needs more closely, by breeding new strains of grasses and cereals, improving pasture quality and by adding various nutritional supplements.

- Feeding more concentrates

What the animal is fed will have a bearing on the amount of enteric and faecal methane emissions as well as the nitrous oxide emitted. When trying to reduce these greenhouse gas emissions through the adjustment of feed the main focus is on the balance between proteins, starch and fibre in the diet. This is because these have an influence on the levels of methane and nitrous oxide that will be produced. Methane emissions may be reduced by feeding more concentrate and reducing the intake of forage (IPCC 2007). This is because the fraction of feed converted to methane decreases when feed intake and feed quality increase (Garnett 2007). However, concentrates may also increase the daily methane emissions of the animal but reduce the emissions per kg feed intake and per kg product (IPCC 2007). By how much the emissions are reduced per kg product decreases as the production increases. Feed conversion efficiency is improved when animals are fed concentrates and growth rate improves. They reach slaughter weight sooner resulting in fewer emissions.

With N_2O the issue is not only about reducing the quantity of nitrogen that enters the system but about how efficiently the nitrogen inputs are converted into useful nitrogen outputs rather than being converted into urea and faeces. One way would be to optimize the protein intake to reduce the N excretion and nitrous oxide emissions. As changes are made to reduce N_2O emissions from ruminants through the increase of starch or sugar content relative to protein, this will also have an effect on the reduction of CH_4 emissions because the cause of emissions is inadequate digestion (Garnett 2007).

- Improving pasture quality

Forage quality may be improved by feeding forage that has lower fibre and higher soluble carbohydrates or changing from C4 to C3 grasses. Cellulose and hemicelluloses ferment more slowly than non structured carbohydrates thereby yielding more methane per unit of substrate digested (Eckard et al. 2010). There are lower methane emissions when higher proportions of forage legumes are in the diet partly because of the lower fibre content, the faster rate of passage and also the presence of tannins (Eckard et al. 2010). Also, the nutrition that can be derived from legume forage is superior to that which can be found in grass only pastures due to the high protein content (Garnett 2007). Improving pasture quality, particularly in less developed regions improves animal productivity and reduces the methane emissions.

- Nutritional and other supplements

One practice is the inclusion of oils and oil seeds to the diet (IPCC 2007). The addition of unsaturated fats such as coconut oil to the feed ration keeps the energy intensity of the diet high, reduces the need for grain based concentrates and also aids in the digestibility of fibre (Garnett 2007).

There are a number of additives that have been proposed for the reduction of methane emissions. These are ionophores, antibodies, halogenated compounds, novel plant compounds (condensed tannins, saponins or essential oils) and propionate precursors (fumarate and malate). Vaccines are being developed that contain an antigen derived from methanogenic bacteria and an immunogenic preparation that reduces the activity of rumen protozoa (Sejian et al. 2010). Bovine somatotropin (bST) and hormonal growth implants do not specifically suppress methane formation but improve the animals performance and thereby reduce emissions per kg of product (Garnett 2007; IPCC 2007).

Long term management and animal breeding

In dairy cows, increasing the productivity through breeding and the use of better management practices like reducing the number of replacement heifers often reduces methane output per unit of product that is produced (IPCC 2007). According to Eckard et al. (2010) it was observed that there are variations between animals in the methane emissions per unit of feed intake and these variations suggest that there may be heritable differences in methanogenesis. Breeding animals for the reduction of methanogenesis may not be compatible with other breeding objectives, however breeding for feed conversion efficiency (low net feed intake, NIF) may. Therefore genetic selection for animals that consume less feed or produces less methane per unit of feed may be another way of reducing emissions.

Reducing livestock numbers could be the best possible solution in countries where there are large livestock populations and who want to reduce their livestock related greenhouse gas emissions (Sejian et al. 2010). However, this is not an option in countries where livestock plays a large role in the contribution of national income. If productivity increases through nutritional and breeding strategies, the number of livestock can be reduced without losing the quantity of meat that is currently produced (Garnett 2007). Another option would be to reduce the number of unproductive livestock. This may improve productivity as well as reduce emissions.

3 Materials and Methods

The model that was used for the animal welfare project AW1024, “A further study to assess the interactions between economics, husbandry and animal welfare in large extensively managed flocks” (SAC 2009) was adapted to include greenhouse gas emissions. Data from four farms were used as input for the model and these farms were part of the 20 farms that were assessed in the AW1024 project and were based on the 2008 lambing season. The model was run separately for each farm. The developed model is described below including an explanation of calculations that were used to determine the methane and nitrous oxide emissions. This model is used to calculate how different interventions made to the farming systems may reduce the greenhouse gas emissions on each of the four farms.

3.1 Data

The animal welfare project made use of data from 20 commercial extensive sheep farms in Great Britain (equal numbers from Cumbria, Mid-Wales, Peak District and the Scottish Highlands). The average flock size of the farms was 850 ewes and the average farm size was 1290Ha. This area was made up of an average of 1175Ha of open hill and additional 115Ha of pasture land. The distribution of the farm size was positively skewed with majority of the farms falling between 110 and 1500 Ha. Additional questionnaires had been sent out to the 20 farmers from the AW1024 project. The purpose of these questionnaires was to obtain data that had not been collected initially, which included identification of the number of livestock other than sheep that were also fed on the limited feed supply available on the farms. The other aim was to obtain updated data on the following:

- the area of hay or silage grown on the farm,
- the altitude of the farm,
- the estimated percentage of the hill covered by heather,
- the average percentage of single and twin lambs born,
- the percentage of barren ewes in the flock,
- whether the hill and pasture land were open for grazing throughout the year,
- when hay or silage land was open for grazing,
- the main tupping and lambing periods as well as when the lambs were weaned off the ewes for the 2008 lambing season.

The data gathered was then used to update the model. The questionnaires did not request for data on greenhouse gas emissions from the farmers. Ten completed questionnaires were returned and from these four farms, two from Cumbria and two from Scotland, were selected for the evaluation of greenhouse gas emissions in extensive sheep systems. The farms were selected on the basis that they kept sheep and no other livestock. Farm 2 had a flock size of 850 ewes, which was the average of all the farms. Farm 3 had more sheep while farms 1 and 4 had less. These four farms will help to understand, to some extent greenhouse gas emission on extensive sheep farms in Great Britain. A summary of the data used is provided in Table 3.1.

Table 3.1 Input data used in the model for 2008 lambing season

	Farm 1	Farm 2	Farm 3	Farm 4
Farm Technical Data				
Number of ewes	530	850	1240	660
Number of lambs weaned	520	950	1530	789
Number of retained female lambs	190	280	760	223
Number of retained male lamb	4	0	5	4
Number of store lambs sold	0	250	0	261
Number of finished lambs sold	326	400	750	172
Number of draft ewes sold	96	0	300	156
Gross output (£/ewe)	29.02	24.60	27.22	24.33
Land				
Hill area (Ha)[1]	300	470	627	666
Pasture area (Ha)[2]	32	168	135	27
Hay land area (Ha)[3]	15	32	6	8
Farm Details				
Height above sea level (m)	200	244	366	122
N on improved grass (kg)	120	48	70	108
Heather cover on hill (%)	0	20	20	50
Timing				
Average date of conception	01/12/07	04/12/07	21/11/07	09/12/07
Average date of lambing	26/04/08	29/04/08	16/04/08	04/05/08
Duration of lactation	120	124	113	119
Average date of weaning	24/08/08	31/08/08	07/08/08	31/08/08
Mating starts	26/10/08	02/11/08	09/10/08	02/11/08
Duration of mating	35	31	42	36

[1]Consists of open hill and intake (hill park) area, [2]Consists of true in bye (i.e. improved land near farm buildings) minus estimated hay land area, [3]Assumed 0.004 ha/ewe (SAC 2008), Sale price of draft ewes: £25/head

3.2 Model Description

The model used was for the management of extensive sheep farms throughout the year. It was set to represent an average commercial sheep farm. This model used linear programming with the objective of maximising gross margin subject to the constraints of land, labour, flock size and feeding. Feeding refers to allocating sheep to grazing areas, hay making, storing then feeding hay or silage and buying in extra hay and or concentrates if necessary. Other management decisions such as breed as well as performance factors that include lambing rates, growth rates, and grass growth each month were fixed. The main output was a monthly plan of land use by the sheep over a typical year for a specific farm. The general structure of the model can be summarized as follows and is also presented in Table 3.2:

Maximise $Z = cx$

Subject to $Ax \leq b$

And $x \geq 0$

Where Z is the farm gross margin, c denotes the vector of gross margin or cost / revenue per unit of activity, x is the vector of activities, A represents the matrix of technical coefficients and b is the technical or physical constraint. The grass feed energy supply was based on the model by Armstrong et al. (1997).

Table 3.2 Summarised* general representations of the sheep nutritional linear programming model**

Activities	Ewe	Consumption/grazing (DM/day)						Transfer energy from feed to sheep (MJ/day)						Land (Ha)			Grass prod (Ha)			Store hay	Transfer stored	Sell hay	Lab.	RHS
	E	H	P	A	Oh	Bh	C	H	P	A	Oh	Bh	C	H	P	S	H	P	S	Oh	Oh, S	Oh	CL	
Constraints																								
Max DM intake	$+a_{ij}$	-1	-1	-1	-1	-1	-1																	≥0
ME demand	$+a_{ij}$							-1	-1	-1	-1	-1	-1											≤0
ME Hill Grass		$-a_{ij}$						1																=0
ME Pasture			$-a_{ij}$						1															=0
ME Aftermath				$-a_{ij}$						1														=0
ME Own hay					$-a_{ij}$						1													=0
ME Bought hay						$-a_{ij}$						1												=0
ME Concentrate							$-a_{ij}$						1											=0
Max Concentrate		$-a_{ij}$	$-a_{ij}$	$-a_{ij}$	$-a_{ij}$	$-a_{ij}$	$+a_{ij}$																	≤0
Max sheep	1																							≤Max
Hill supply		1															$-a_{ij}$							≤0
Max Hill														1										≤Max
Pasture supply			1															$-a_{ij}$						≤0
Max Pasture															1									≤Max
Aftermath supply				1															$-a_{ij}$					≤0
Max hay land																1								≤Max
Tie Own hay																			$-a_{ij}$	$+a_{ij}$				≤0
Use store hay					$+a_{ij}$															-1	$\pm a_{ij}$	1		≤0
Tie Hill to prod.														-1			1							≤0
Tie Pasture prod.															-1			1						≤0
Tie Hay to prod.																-1			1					≤0
Labour	$+a_{ij}$																						-1	≤Max
Objective function	Gross margin £/head											Cost £/kg		Cost £/ha								Revenue £/kg	Cost £/hr	

a_{ij} the technical coefficient that relates activity *i* to the constraint *j*.

[*] In the actual model daily energy demand and feed supply was modeled on a *monthly* basis throughout a farming year.

[**] Notations: E: Ewes; H: Hill; P: Pasture; A: Aftermath; Oh: Own hay; Bh: Bought hay; C: Concentrate; S: Silage; CL: Casual Labour; RHS: Right-hand side constraints.

Taken from (Vosough-Ahmadi et al. 2010)

Land

Grazing land available on all farms were the hill, pasture and conservation (hay) lands. The hill and pasture were availible for grazing all year round while the conservation was closed for grazing when the land was used for the production of hay. The months closed for hay production were specific to each farm. The total area of hill, pasture and conservation land availible on each farm was a constraint in the model for each farm. Hill variable costs were assumed to be £0/Ha while pasture and hay land variable costs excluding fertiliser costs were £11/Ha and £27/Ha respectively.

Feeding

- *Demand*

The nutritional demand was based on the already established relationships between feed energy intake and sheep production (Alderman and Cottrill 1993). There was a constraint to limit the daily dry matter intake (DMI) in the LP. This maximum DMI (kg/day) was calculated for each month and was specific to each farm as it was based on the average dates of conception, lambing and weaning for each farm (see Table 3.3 for DMI of Farm 1).

Table 3.3 Utilisable Digestive yield, Dry Matter Intake and ME for Farm 1

	Utilisable Digestive yield (kgDM/Ha/day)			DMI Capacity (kg/day)
Month	Hill	Pasture	Hay land	
Jan	0.36	2.07	2.07	0.917
Feb	0.48	2.65	2.65	0.917
Mar	1.10	5.90	5.90	0.917
Apr	2.05	22.73	22.73	0.917
May	3.40	25.66	25.66	1.300
Jun	4.08	26.19	26.19	1.300
Jul	8.33	24.39	24.39	1.300
Aug	4.23	20.24	20.24	1.300
Sep	1.99	13.67	13.67	1.300
Oct	1.67	9.56	9.56	1.300
Nov	0.97	5.60	5.60	1.300
Dec	0.56	3.19	3.19	0.917

Metabolisable energy (ME) demand per ewe for each month of a typical sheep farming year was calculated for an average ewe based on average dates of conception, lambing and weaning (Table 3.1). The proportion of barren and twin bearing ewes in the flock was specific to the individual farms. The mature ewe body weight was assumed to be 51kg in the model. The variations in the daily energy demand for each month in the year for Farm 1 are shown in Table 3.4. The general trend was that energy demand was lowest in the months prior to parturition and highest during the lactation period.

- *Supply*

Dry matter supply was from the following sources: grass from the hill, pasture and hay lands, hay that was either grown on the farm or purchased or from concentrates. The ration that was to be consumed by the ewes had to meet the energy required by these animals.

The energy content of the grass feed was based on the model by Armstrong et al. (1997), calculated separately for hill and in-bye (the improved land near the buildings) land. This model allows for adjustments to reflect the grass growing conditions applicable to each farm, including height above sea level for hill and in bye land, region (England or Scotland), stocking rate, nitrogen application rate (£0.47/kg), proportion of improved pasture and heather cover on the hills (Stott et al. 2010). The energy available from the grass produced on the different lands varied each month. The energy content of the grasses grazed by the sheep for all farms are given in Table 3.4 and those for the hay grown on the farm, bought hay and concentrates were also the same for all farms at 8.4 MJ/kg, 9.0 MJ/kg and 12.0 MJ/kg respectively.

Table 3.4 Metabolisable Energy of grasses grazed by sheep, all farms and daily ME demand of the sheep for Farm 1

	ME grasses grazed by sheep (MJ/kg DM)			**ME Demand (MJ/day)**
Month	Hill	Pasture	Hay Land	
Jan	8.47	9.50	9.50	7.94
Feb	9.18	10.30	10.30	7.73
Mar	10.15	11.39	11.39	6.49
Apr	10.41	11.68	11.68	7.63
May	9.52	10.68	10.68	13.07
Jun	9.29	10.43	10.43	13.35
Jul	9.74	10.93	10.93	11.92
Aug	8.47	9.50	9.50	11.14
Sep	10.00	11.22	11.22	8.50
Oct	8.47	9.50	9.50	8.50
Nov	8.47	9.50	9.50	8.50
Dec	8.66	9.71	9.71	7.69

The utilisable digestive yield (measured in $kgDMHa^{-1}day^{-1}$) (Table 3.3) was calculated as the product of the following parameters: annual dry matter yield of the grass, seasonal growth pattern of grass species, digestibility and stocking rate influence. The utilisable digestible yields were highest during the summer (May to August) when grass would be expected to grow well and lowest during the winter months (November to February) when the hills are normally covered in snow thereby making it difficult for the sheep to graze. These utilisable digestible yields were related to the amount of grass (kg per day), supplied from the hill, pasture and hay lands, the grass production (Ha) as well as the grass consumption (DM/day).

Hay was consumed when it was produced with any surplus being transferred from month to month for the rest of the year. Any hay remaining at year end was assumed to be wasted. Home grown grass and forage could be supplimented at any time by purchase of hay at £70/tonne and or concentrates at £250/tonnes (Stott et al. 2010). Concentrates were constrained to a maximum of 0.15 of the dietary energy supply. This restriction has to do with forage to concentrate ration which is important in getting highest ruminant digestion.

Labour and Flock size

Labour requirements per ewe per month were based on the labour supplied as indicated in the labour profile of each farm (Table 3.5). The constraint of maximum number of sheep was introduced in order to simulate the current scenario that the farmers had reported.

Table 3.5 Supplied labour from farm inventories

	Supplied labour (hours/ewe)			
Month	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 4**
Dec	0.2449	0.1744	0.3261	0.2818
Jan	0.0729	0.1744	0.3301	0.0939
Feb	0.1365	0.1225	0.2982	0.1485
Mar	0.1511	0.1550	0.3301	0.1879
Apr	0.5798	0.1688	0.7773	0.5455
May	0.3803	0.1938	0.8032	0.4697
Jun	0.2571	0.2063	0.2700	0.3636
Jul	0.2657	0.2131	0.2657	0.3758
Aug	0.1719	0.2131	0.2536	0.2416
Sep	0.1664	0.2063	0.3156	0.2727
Oct	0.1719	0.1938	0.3261	0.3758
Nov	0.2723	0.1688	0.3156	0.2727

The greenhouse gases, methane and nitrous oxide were not included in the linear programming model as additional constraints but were calculated after the optimal solution had been generated from the LP. A description of the calculations is given in the following paragraphs.

Methane Calculation

The calculations for the methane emissions were based on the gross energy (GE) (MJ/kg DM) of the feed and the methane energy as a proportion of GE (CH_4E/GE). The values used were adapted from UK Tables of Nutritive value and Chemical Composition of Feeding stuffs (Givens and Moss 1990) and are shown in Table 3.6. The amount of methane energy (MJ/kg) lost from the feed was calculated from the GE and was then converted to kg by multiplying by the energy density of methane (55MJ/kg) (Eckard et al. 2010). The value of methane energy was then used to calculate the total amount of methane lost from the feed consumed by the sheep that was estimated by the LP to provide the amount of methane (kg/year) that were emitted by the sheep. The methane emission was then converted to its CO_2 equivalent by multiplying by its GWP_{100} of 23.

Table 3.6 Gross energy and methane energy of feedstuffs

	GE (MJ/kg DM)	CH_4E/GE	Methane(MJ/kg)	Methane(kg)
Hill grass	18.5	0.08	1.480	0.0269
Pasture grass	18.7	0.08	1.496	0.0272
Aftermath grass	18.7	0.08	1.496	0.0272
Own hay	18.4	0.07	1.288	0.0234
Bought hay	18.4	0.08	1.472	0.0268
Bought concentrates	19.1	0.08	1.528	0.0278

Nitrous Oxide Calculation

Nitrous oxide emissions were calculated using the IPCC Tier 1 methodology (IPCC 2006). The above stated method was applied using IPCC default N_2O emission factors, default nitrogen excretion data and default manure management systems. Direct Nitrous oxide emissions were calculated using the following formula:

$$N_2O\text{-}N = F*EF_1 \qquad \text{Equation 3.1}$$

Where:

N_2O-N is annual direct N_2O-N emissions from urine and dung inputs to grazed soils (expressed in kg N_2O-N yr^{-1}). F is the annual amount of urine and dung N deposited by grazing animals on pastures, range and paddock (expressed as kg N yr^{-1}). EF_1 (IPCC 2006) is the emission factor for N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals, kg N_2O-N (kg N $input)^{-1}$).

$$F=N*N_{ex} \qquad \text{Equation 3.2}$$

Where N is the number of head of livestock and N_{ex} is annual average N excretion per head (kg N $animal^{-1}yr^{-1}$)

$$N_{ex} = N_{rate}*TAM/1000*365 \qquad \text{Equation 3.3}$$

Where N_{ex} is annual average N excretion per head (kg N $animal^{-1}yr^{-1}$), N_{rate} is default N excretion rate (kg N (1000 kg animal mass)$^{-1}$ day^{-1}) and TAM is the typical animal mass of livestock (kg $animal^{-1}$).

Nitrous oxide emissions from synthetic fertilisers were calculated as follows:

$$N_2O\text{-}N_f = F_f*EF_2 \qquad \text{Equation 3.4}$$

Where N_2O-N_f is the annual direct N_2O-N emissions from N inputs to managed soils (kg N_2O-Nyr^{-1}), F_f is the annual amount of synthetic fertiliser N applied to soils (kg N yr^{-1}) and EF_2 (IPCC 2006) is the emission factor for N_2O emission from N inputs (kg N_2O-N (kg N_{input})$^{-1}$).
N_2O-N emissions were converted to N_2O emissions as follows:

$$N_2O = N_2O\text{-}N*44/28 \qquad \text{Equation 3.5}$$

Nitrous oxide emissions were also converted to their CO_2 equivalents by multiplying by its GWP_{100} of 296.

Model Outputs

The solution of the model gives the maximised gross margin of the farm, the number of ewes, a feeding and grazing pattern across the different land areas that include the hill, pasture and forage producing areas. The solution also provides the dry matter intake (kgDM/day) and the ME intake (MJ/day) for the different diet components for each month, daily labour utilised as well as the greenhouse gas emissions. The emissions of nitrous oxide were given on an annual basis while those of methane were given daily and annually for the whole flock as well as for each individual sheep.

3.3 Model Validation with Respect to Methane Emissions

Published estimated values of methane per ewe were compared to those generated by the model. Sejian et al. (2010) give an estimated value of 21.9g/ewe/day. Pelchen and Peters (1998), in their paper looking through 1137 databases that dealt with methane emissions and rations fed to sheep from 89 references, came up with an average methane emission of 22.15g/day and the percentage loss of methane (% of gross energy intake) averaged 7.22%. The data sets used by the aforementioned authors came from a wide range of observations of growing and adult sheep of different breeds and fed on various rations. According to Pelchen and Peters (1998) energy lost by sheep via methane ranges between 3.5% and 9.7%. The calculations of methane that were done made use of percentage loss of methane (% of gross energy intake) of 8% for all feedstuffs except for own hay which had 7% (Table 3.6) and these values were within the range mentioned above. Values generated from the model are given in Table 3.7. The values of average daily methane emissions from sheep generated in the model were higher than those published due to the higher percentage loss of methane that was used. No adjustments were made to the model.

Table 3.7 Average Daily Methane Production per ewe for the 4 farms

	Ewe (g/day)
Farm 1	24.92
Farm 2	25.72
Farm 3	26.05
Farm 4	25.25

3.4 Using the Model to address the Objectives

The model was used to address the third specific objective of investigating the impacts of the measures that farmers can take in order to reduce greenhouse gases on their farm profitability. Five scenarios were simulated as described below. The fifth scenario was an additional one which examined the sensitivity of the outputs of the model when a cost was introduced for labour.

Scenario 1: Baseline

This scenario was done to establish the optimal (gross margin maximizing) farm plan with the parameters and constraints that reflect the current values as supplied by the farm inventory. The current levels of greenhouse gas emissions were identified and used as a basis of comparison with the measures that were introduced in the other scenarios in an attempt to reduce the greenhouse gas emissions.

Scenario 2: Reduction of flock size

By relaxing the constraint on flock size, the current flock size of each farm was reduced using the following decrements: 0.9, 0.75, 0.5, 0.25 and 0.1. The change in flock size is important as livestock numbers in Great Britain have been falling at a fast rate and there have been changes in the farming system (Waterhouse et al. 2009). According to Waterhouse et al. (2009), the Net Farm Income (NFI) and direct income from farming are not enough to sustain farming and that The Single Farm Payment (SFP) and the Less Favoured Area payments were helping to sustain the farming business. These subsidies are independent of the number of sheep kept on the farm. Hill farmers were finding farming more challenging and were therefore opting to reduce or remove sheep stock (Waterhouse et al. 2009).

Scenario 3: Inclusion of concentrates to diet

In the optimal farm plan no concentrates were included in the diet because they were an expensive source of energy. In this scenario a new constraint is added to the model that requires a minimum percentage of concentrates to be included in the diet of the ewes. Not less than the following percentages of concentrates were included in the sheep diet: 2.5, 5.0, 7.5, 10.0, 12.5 and 15.0. According to IPCC (2007) feeding more concentrates and reducing forage should reduce methane emissions per kg feed intake and per kg product. However, concentrates may increase daily methane emissions per animal (IPCC 2007). This scenario will look at how the addition of concentrates to the diet of the sheep will affect the levels of emissions produced.

Scenario 4: Changing hill grazing pattern.

Hill grazing was assumed to be available throughout the year in the model. In reality, sheep can be taken off the hill for management and nutritional reasons. The sheep are kept off the hill so that they may be provided with better feed from the improved pasture and hay (thin sheep or ewes with twins or triplets) as well as improving reproduction rates by better nutrition at mating (November/December). Target groups such as twin or crossbred lambs may be moved from the hill during the summer in order to make the best use of the improved pasture. When sheep are given better feed, there should be changes in GHG emissions. The aim of this scenario was to find out the rate of reduction of greenhouse gas emissions when sheep consume the other availible feedstuffs rather than hill grass. Forestry, game management and land focused primarily on nature conservation are alternatives to hill farming. With biodiversity becoming more on the focus of policy makers, the hills may have less sheep stocked during certain periods of the year (Waterhouse et al. 2009).

In this scenario five different management decisions on the hill were simulated. These are listed below:

A – No changes made to the hill grazing (Baseline)

B – No Hill grazing

C – No hill grazing from November to February

D – No hill grazing from May to August

E – No hill grazing March, April, September and October

The year was divided into three periods based on the amount of utilisable digestible yield (Table 3.3) of the hill grass as well as the weather conditions at these times.

Scenario 5: Sensitivity Analysis when labour costs £5/hour.

This scenario was conducted in order to find out how other management practices such as the use of paid labour affect the operations on the farm and how this in turn affects the greenhouse gas emissions on the farm. The initial scenario showed the current state of each farm when labour was free. A cost of £5/hour for labour was introduced and results compared to those when labour had no cost. Labour was identified as being a major cost in hill sheep systems by Stott et al.(2005). The SFP and LFA payments are used to cover cost of labour. Hill farmers have been finding it more difficult to source labour to assist with gathering and shepherding of the sheep (Waterhouse et al. 2009).

4 Results

In this chapter the results obtained after each model run for the five scenarios mentioned earlier are presented. Detailed explanations of the results for each scenario are given for Farm 1 and any deviations from these will be described briefly for the other three farms. Farm 1 was selected because it did not have any variations in the flock size in any of the other scenarios except for scenario 2 where the flock size was reduced. Another reason for discussing Farm 1 in detail is that energy requirements for the baseline scenario could be met by the farm without the need to purchase additional hay or concentrates.

Feed intake graphs of the baseline scenario were used to illustrate the amount and type of feed the ewes consumed each month. The level of emissions emitted was related to the quantity of the different feedstuffs that made up the ration given to the ewes. The greenhouse gas emissions for each farm for the different scenarios were presented in tables together with their percentage change (increase or decrease) with respect to the baseline scenario. These emissions were given as kgCO_2e per hectare, kg CO_2e per kg lamb as well as the average daily methane emissions per ewe (g). Gross margins (£) were also presented along with the percentage changes when compared to that of the baseline.

4.1 Farm 1

A summary of the gross margins and greenhouse gas emissions for all scenarios for Farm 1 are shown in Table 4.1. Also shown in this table are the percent changes in emissions for each scenario with respect to scenario 1 and these help to identify when and to what extent greenhouse gas emissions are reduced on the farm.

Scenario 1: Baseline

Figure 4.1 shows the allocation of dry matter intake for scenatio 1. Grass, hay and concentrate feed were allocated as shown in order to meet the feed requirements of the ewes for each month during the year. These requirements were met mainly from grass from hill, pasture and aftermath grazing as well as from hay made on the farm in some months. The energy requirements for this farm could be met without purchasing additional hay or concentrates.

Table 4.1: The percentage change of emissions from the optimal farm plan using different scenarios

Scenario	Number of ewes	kgCO2e/ha	% change	kgCO2e/kg lamb	% change	Ewe Methane (g/day)	% change	Farm GM (£)	% change
Baseline	530	434		27.94		24.92		7463	
Proportion flock size									
1.00	530	434		27.94		24.92		7463	
0.90	477	384	-11.6	27.43	-1.8	24.84	-0.3	6857	-8.1
0.75	398	327	-24.6	28.09	0.6	25.03	0.4	5821	-22.0
0.50	265	221	-49.1	28.41	1.7	25.38	1.8	4042	-45.8
0.25	133	113	-74.0	29.04	3.9	25.76	3.3	2132	-71.4
0.10	53	46	-89.4	29.62	6.0	25.84	3.7	853	-88.6
Proportion concentrates									
0.000	530	434		27.94		24.92		7463	
0.025	530	431	-0.8	27.71	-0.8	24.65	-1.1	6311	-15.4
0.050	530	431	-0.7	27.74	-0.7	24.68	-1.0	5161	-30.8
0.075	530	431	-0.6	27.77	-0.6	24.72	-0.8	4014	-46.2
0.100	530	432	-0.6	27.78	-0.6	24.73	-0.8	2858	-61.7
0.125	530	432	-0.5	27.78	-0.5	24.74	-0.7	1698	-77.3
0.150	530	432	-0.5	27.80	-0.5	24.76	-0.7	540	-92.8
Hill Grazing									
A	530	434		27.94		24.92		7463	
B	530	419	-3.4	26.99	-3.4	23.77	-4.6	5573	-25.3
C	530	430	-1.0	27.65	-1.0	24.57	-1.4	6014	-19.4
D	530	429	-1.2	27.59	-1.2	24.51	-1.7	7149	-4.2
E	530	427	-1.7	27.46	-1.7	24.36	-2.3	7060	-5.4
Labour (£0/hr)	530	434		27.94		24.92		7463	
Labour (£5/hr)	355	294	-31.9	28.26	1.7	25.24	2.0	5254	-29.6

A – No changes (scenario 1), B – No Hill grazing, C – No hill grazing from November to February, D – No hill grazing from May – August, E – No hill grazing March, April, September and October

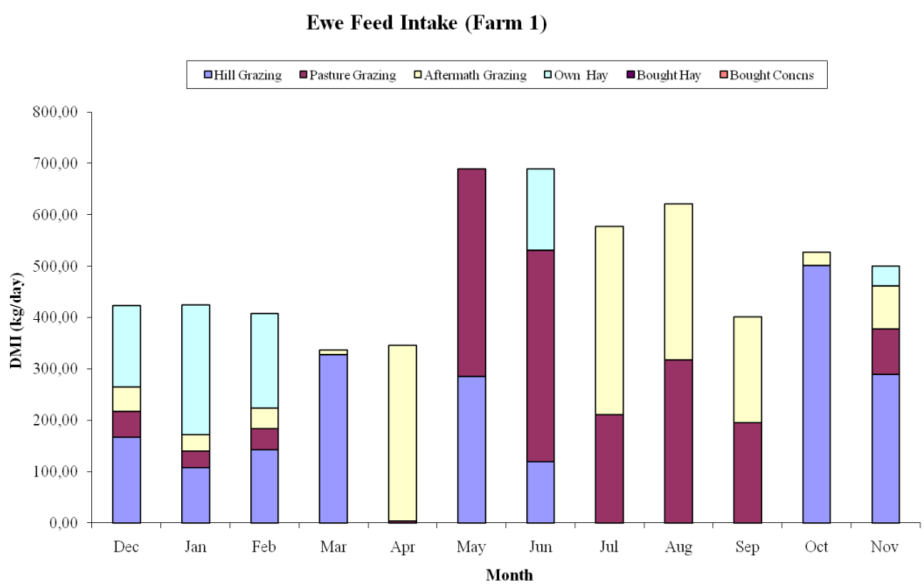

Figure 4.1: Ewe feed intake scenario 1

All of the hill and hay land and 15.7 ha of the pasture land were ustilised in supplying the feed requirements of the sheep on this farm. 16.3 ha of pasture land were left unused. Hay was produced in May and June and hence no aftermath grazing during these months.

Scenario 2: Reducing flock size

The interval between each decrease in flock size for scenario 2 was not constant therefore resulting in the variation in the change in ewe mathane and kg CO_2e per kg lamb. More hay was included in the diet of the flock that is reduced by 10% resulting in the 1.8% reduction in kg CO_2e/kg lamb (Table 4.2). The decrease in kg CO_2e/ha was proportionate to the percentage reduction in the flock size. When there was a flock size 10% less than the current, the GHG emissions for the farm per year reduce by 11.6%. As the flock size got smaller, the farm emissions per hectare also reduced but emissions per kg lamb and the daily methane also increased. This was because less hay and more grass from the hill and pasture were being consumed (see Table 3.6 for methane content). No hay or concentrates were purchased in this scenario. Each ewe would eat more kilograms of DMI per year when the feed consisted of more hill grass.

Table 4.2: The annual DMI per ewe for different feed components for a reduction in flock size

		Dry matter intake (kg/ewe/year)				
Proportion flock size	**Number of ewes**	**Hill Grazing**	**Pasture Grazing**	**Aftermath Grazing**	**Own Hay**	**Total**
1.00	530	112.43	101.23	83.57	44.75	341.98
0.90	477	110.39	109.40	74.49	47.05	341.33
0.75	398	135.95	111.83	54.81	41.96	344.55
0.50	265	168.29	111.88	38.34	30.44	348.94
0.25	133	214.27	107.82	18.65	14.58	355.33
0.10	53	212.32	106.89	21.33	14.58	355.12

Scenario 3 Including concentrates

This scenario looked at the inclusion of concentrates in the ration. From Table 4.1 it was observed that all emissions tended to reduce as the amount of concentrates in the diet increased. However, this reduction was very small. The reduction in the emissions became smaller with each increase in concentrates. When more concentrates were added to the diet, fewer kg of DM were required to meet the nutritional requirements of the sheep (Table 4.3). When concentrates are included in the diet, there was a change in quantity of the other feed componets of the diets. This is because energy and nutrients was now also being supplied by the concentrates. Gross margin reduced as a result of the purchase of the concentrates. No hay was purchased in this scenario.

Table 4.3: The annual DMI per ewe for different feed components when concentrates are included in diet

Proportion of concentrates	Number of ewes	Dry matter intake (kg/ewe/year) Hill Grazing	Pasture Grazing	Aftermath Grazing	Own Hay	Concentrates	Total
0.000	530	112.43	101.23	83.57	44.75	0.00	341.98
0.025	530	90.47	99.15	94.89	44.75	8.44	337.71
0.050	530	99.04	82.24	94.39	44.75	16.86	337.28
0.075	530	107.52	65.42	93.89	44.75	25.26	336.85
0.100	530	113.88	53.28	91.69	43.75	33.62	336.22
0.125	530	120.84	42.02	88.63	42.24	41.96	335.69
0.150	530	128.12	30.46	85.60	40.74	50.28	335.19

Scenario 4 Hill grazing

When hill grazing was limited in certain periods, the energy that the ewes would have got from the hill grass had to be supplied from elsewhere. All other feed options had a cost associated with them and therefore a reduction in the gross margin was observed as more of these other options are utilised. Greenhouse gas emissions reduced in all cases although it was by very small margins. The biggest change was observed when hill grazing was taken out completely (option B).

When hill grazing was excluded completely (option B), hay had to be purchased in order to suppliment the feed availible from the farm. Most of that hay was used in January with small quantities in March and October. All pasture and hay land (Table 4.4) was used in this case resulting in more costs and a reduction in the gross margin.

Table 4.4: Land Use

Scenario	Number of ewes	Land use (Ha) Hill	Pasture	Hay	Slack (Ha) Hill	Pasture	Hay
Hill Grazing							
A	530	300.0	15.7	15.00	0.0	16.3	0.0
B	530	0.0	32.0	15.00	300.0	0.0	0.0
C	530	300.0	22.6	15.00	0.0	9.4	0.0
D	530	300.0	25.3	11.01	0.0	6.7	4.0
E	530	300.0	21.7	15.00	0.0	10.3	0.0

A – No changes (scenario 1), B – No Hill grazing, C – No hill grazing from November to February, D – No hill grazing from May – August, E – No hill grazing March, April, September and October

Hay was purchased for use in Decmber and January when the hill was closed for grazing from November to February (option C). Very little pasture and aftermath grazing was carried out because the DM yield (Table 3.3) at this time was very low and therefore the need for hay. Most of the hay that was purchased was used in December with some also used in January.

Table 4.5: The annual DMI per ewe for different feed components when hill grazing changes

		Dry matter intake (kg/ewe/year)					
Hill Grazing	**Number of ewes**	**Hill Grazing**	**Pasture Grazing**	**Aftermath Grazing**	**Own Hay**	**Bought Hay**	**Total**
A	530	112.43	101.23	83.57	44.75	0.00	341.98
B	530	0.00	191.47	75.79	44.75	18.12	330.13
C	530	60.43	127.16	83.57	44.75	22.52	338.44
D	530	88.83	169.96	47.74	32.86	0.00	339.39
E	530	53.68	162.50	75.79	44.75	0.00	336.73

A – No changes (scenario 1), B – No Hill grazing, C – No hill grazing from November to February, D – No hill grazing from May – August, E – No hill grazing March, April, September and October

When sheep are kept off the hill from May to August (option D), energy requirements of the ewes was met by hay produced on the farm, hill, pasture and aftermath grazing. More pasture and less hay land were used than in scenario 1. All months except April, May, June and August in this option had a feed ration that was similar to that of scenario 1.

More pasture grazing is done in option E. Apart from option B, this option has the least dry matter intake from hill grazing. This option has reduction in greenhouse gas emissions with a small reduction in gross margin (5%).

Scenario 5 Cost for Labour

For scenario 1, when labour is free, 2444 hours of labour were used on the farm. However, when labour had a cost of £5 per hour only 1637 hours of labour were used. It was nolonger economic for the farmer to maintain the current number of sheep. What was also noted was that the emissions per kg lamb and methane per ewe increased. This is attributed to the diet that the fewer ewes consume (Table 4.6). Given the constraint of labour as well as the other constraints, the model locates the closest feasible corner point that generates the greatest gross margin and this is observed when there are 355 ewes.

Table 4.6: The annual DMI of different feed components for when labour has a cost

		Dry matter intake (kg/ewe/year)				
Scenario	**Number of ewes**	**Hill Grazing**	**Pasture Grazing**	**Aftermath Grazing**	**Own Hay**	**Total**
Labour (£0/hr)	530	112.43	101.23	83.57	44.75	341.98
Labour (£5/hr)	355	155.30	101.92	50.42	39.22	346.86

4.2 Farm 2

A summary of the greenhouse gas emissions and gross margins for farm 2 are presented in Table 4.7 above.

Table 4.7 The percentage change of emissions from the optimal farm plan using different scenarios

Scenario	Number of ewes	kgCO2e/ha	% change	kgCO2e/kg lamb	% change	Ewe Methane (g/day)	% change	Farm GM (£)	% change
Baseline	850	368		22.93		25.72		8122	
Proportion flock size									
1.00	850	368		22.93		25.72		8122	
0.90	765	330	-10.5	22.82	-0.5	25.54	-0.7	7356	-9.4
0.75	638	272	-26.0	22.62	-1.4	25.21	-2.0	6206	-23.6
0.50	425	182	-50.7	22.63	-1.3	25.23	-1.9	4291	-47.2
0.25	213	92	-75.1	22.83	-0.4	25.39	-1.3	2298	-71.7
0.10	85	37	-89.9	23.14	0.9	25.74	0.1	957	-88.2
Proportion concentrates									
0.000	850	368		22.93		25.72		8122	
0.025	850	359	-2.5	22.36	-2.5	24.86	-3.4	6228	-23.3
0.050	850	358	-2.7	22.32	-2.7	24.79	-3.6	4347	-46.5
0.075	850	357	-2.9	22.27	-2.9	24.72	-3.9	2480	-69.5
0.100	850	357	-3.1	22.23	-3.1	24.66	-4.1	625	-92.3
Hill Grazing									
A	850	368	0.0	22.93		25.72		8122	
B	850	358	-2.8	22.29	-2.8	24.75	-3.8	6952	-14.4
C	850	362	-1.7	22.55	-1.7	25.14	-2.3	7045	-13.3
D	850	361	-1.8	22.51	-1.8	25.09	-2.5	8070	-0.6
E	850	364	-1.0	22.70	-1.0	25.37	-1.4	7989	-1.6
Labour (£0/hr)	850	368		22.58		25.18		8122	
Labour (£5/hr)	199	89	-75.8	23.71	3.4	26.82	4.3	2164	-73.4

A – No changes made to the hill grazing, B – No Hill grazing, C – No hill grazing from November to February, D – No hill grazing from May – August, E – No hill grazing March, April, September and October

Scenario 1

From Figure 4.2, Farm 2 was self sustainable in meeting the energy requirements of the ewes. There was no need for the purchase of hay or concentrates. The farm made use of its own hay during the months when grass was least. The land use of this farm for hill, pasture and hay land was 470, 69.9 and 29.30 ha respectively. The unused pasture and hay land were 97.7 and 3.1 ha respectively.

Scenario 2 Reducing flock size

There was a reduction in kg CO_2e/ha for each reduction in the flock size. The emissions per kg of lamb and the methane also showed small reductions for all but the smallest flock size which showed a small increase in both cases. This was due to the diet that consisted mostly of pasture and hill grazing with no hay (Table 4.8).

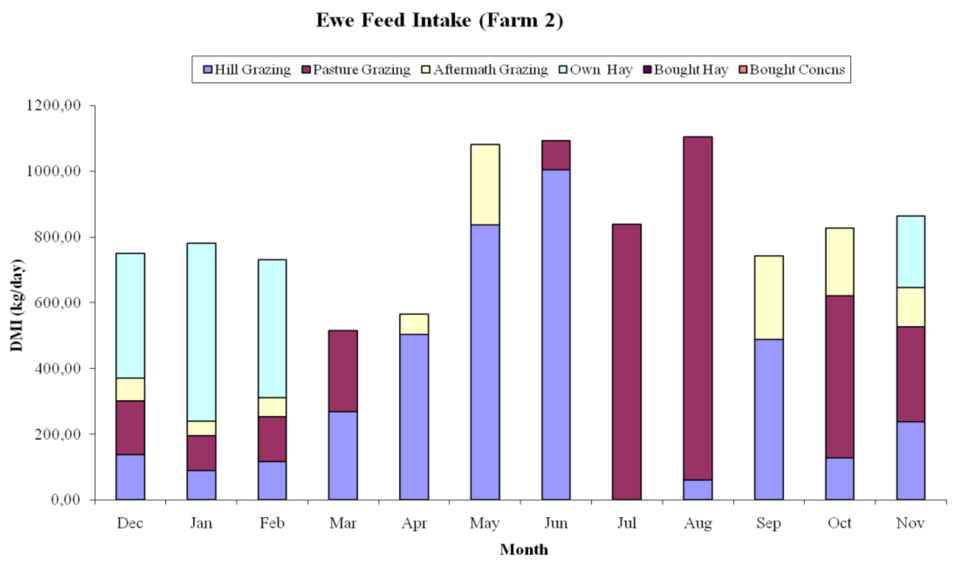

Figure 4.2: Ewe Feed intake scenario 1

Table 4.8: DMI of different feed components when reducing flock size

		Dry matter intake (kg/ewe/year)				
Proportion flock size	**Number of ewes**	**Hill Grazing**	**Pasture Grazing**	**Aftermath Grazing**	**Own Hay**	**Total**
1.00	850	138.43	123.33	37.86	55.13	354.75
0.90	765	113.92	153.98	30.74	53.19	351.83
0.75	638	71.38	172.61	53.39	49.32	346.70
0.50	425	70.44	191.90	45.00	37.70	345.03
0.25	213	102.57	211.82	16.22	14.53	345.14
0.10	85	135.15	212.28	0.00	0.00	347.44

Scenario 3 Including concentrates

There was a decrease, by small percents, of all emissions when concentrates were included in the ration. A level of concentrates more that 10% was not economic for this farm.

Scenario 4 Hill grazing

The various changes to hill grazing resulted in small percent reductions in all emissions for this farm. Hay was purchased in February for options B and in November for option C (Table 4.9). The land use for this farm is shown in Table 4.10.

Scenario 5 Cost for Labour

There was a decrease in flock size and only 571 hours of labour were used instead of the 2440 hours from the baseline. There were more emissions because the ewes ate more hill grass (Table 4.11).

Table 4.9: The annual DMI per ewe for different feed components when hill grazing changes

		Dry matter intake (kg/ewe/year)					
Hill Grazing	**Number of ewes**	**Hill Grazing**	**Pasture Grazing**	**Aftermath Grazing**	**Own Hay**	**Bought Hay**	**Total**
A	850	138.43	123.33	37.86	55.13	0.00	354.75
B	850	0.00	213.84	58.16	60.93	8.19	341.12
C	850	51.36	149.96	71.59	60.93	13.20	347.05
D	850	52.03	188.62	48.15	56.77	0.00	345.56
E	850	88.85	138.38	62.85	60.19	0.00	350.26

A – No changes made to the hill grazing, B – No Hill grazing, C – No hill grazing from November to February, D – No hill grazing from May – August, E – No hill grazing March, April, September and October

Table 4.10: Land Use

		Land use (Ha)			Slack (Ha)		
Scenario	**Number of ewes**	**Hill**	**Pasture**	**Hay**	**Hill**	**Pasture**	**Hay**
Hill Grazing							
A	850	470.0	69.9	29.3	0.0	97.7	3.1
B	850	0.0	83.1	32.4	470.0	84.5	0.0
C	850	470.0	69.9	32.4	0.0	97.7	0.0
D	850	470.0	70.2	30.2	0.0	97.5	2.2
E	850	470.0	69.9	32.0	0.0	97.7	0.4

A – No changes made to the hill grazing, B – No Hill grazing, C – No hill grazing from November to February, D – No hill grazing from May – August, E – No hill grazing March, April, September and October

Table 4.11: The annual DMI of different feed components for when labour has a cost

		Dry matter intake (kg/ewe/year)				
Scenario	**Number of ewes**	**Hill Grazing**	**Pasture Grazing**	**Aftermath Grazing**	**Own Hay**	**Total**
Labour (£0/hr)	850	138.43	123.33	37.86	55.13	354.75
Labour (£5/hr)	199	295.89	53.70	4.01	12.14	365.74

4.3 Farm 3

The greenhouse gas emissions and gross margins for this farm are summarised in Table 4.12.

Scenario 1

The dry matter intakes for the farm are shown in Figure 4.3. The farm makes use of all 627 ha of the hill land, all 6 ha of hay and only 99.2 ha of the pasture land, leaving 35.8 ha of pasture unused. Hay has purchased to supplement the feed that is available on the farm in the months from November to February. This farm only has 6 ha of hay land and is therefore unable to meet the energy requirements of the flock during the months (November to February) when grass from the pasture and hill is low in quantity. Thus the idle pasture land on this farm.

Table 4.12 the percentage change of emissions from the optimal farm plan using different scenarios

Scenario	Number of ewes	kgCO2e/ha	% change	kgCO2e/kg lamb	% change	Ewe Methane (g/day)	% change	Farm GM (£)	% change
Baseline	1240	473		29.29		26.05		10782	
Proportion flock size									
1.00	1240	473		29.29		26.05		10782	
0.90	1116	427	-9.6	29.40	0.4	26.19	0.5	10014	-7.1
0.75	930	358	-24.2	29.59	1.0	26.19	0.5	8861	-17.8
0.50	620	245	-48.2	30.33	3.6	27.28	4.7	6940	-35.6
0.25	310	124	-73.7	30.77	5.1	27.74	6.5	4451	-58.7
0.10	124	50	-89.5	30.78	5.1	27.57	5.8	1888	-82.5
Proportion concentrates									
0.000	1240	473		29.29		26.05		10782	
0.025	1240	459	-3.1	28.39	-3.1	25.00	-4.0	8134	-24.6
0.050	1240	457	-3.4	28.30	-3.4	24.90	-4.4	5508	-48.9
0.075	912	337	-28.9	28.42	-3.0	24.91	-4.4	2928	-72.8
0.100	370	142	-70.0	29.49	0.7	26.15	0.4	1836	-83.0
0.125	380	145	-69.3	29.44	0.5	26.05	0.0	977	-90.9
0.150	196	75	-84.1	29.52	0.8	26.09	0.1	158	-98.5
Hill Grazing									
A	1240	473		29.29		26.05		10782	
B	1240	454	-4.1	28.09	-4.1	24.64	-5.4	8545	-20.7
C	1240	472	-0.1	29.25	-0.1	26.01	-0.2	9404	-12.8
D	1240	460	-2.8	28.46	-2.8	25.09	-3.7	10782	0.0
E	1240	468	-1.1	28.95	-1.1	25.65	-1.5	9923	-8.0
Labour (£0/hr)	1240	473		29.29		26.05		10782	
Labour (£5/hr)	200	79	-83.3	30.44	3.9	27.16	4.2	2963	-72.5

A – No changes made to the hill grazing, B – No Hill grazing, C – No hill grazing from November to February, D – No hill grazing from May – August, E – No hill grazing March, April, September and October

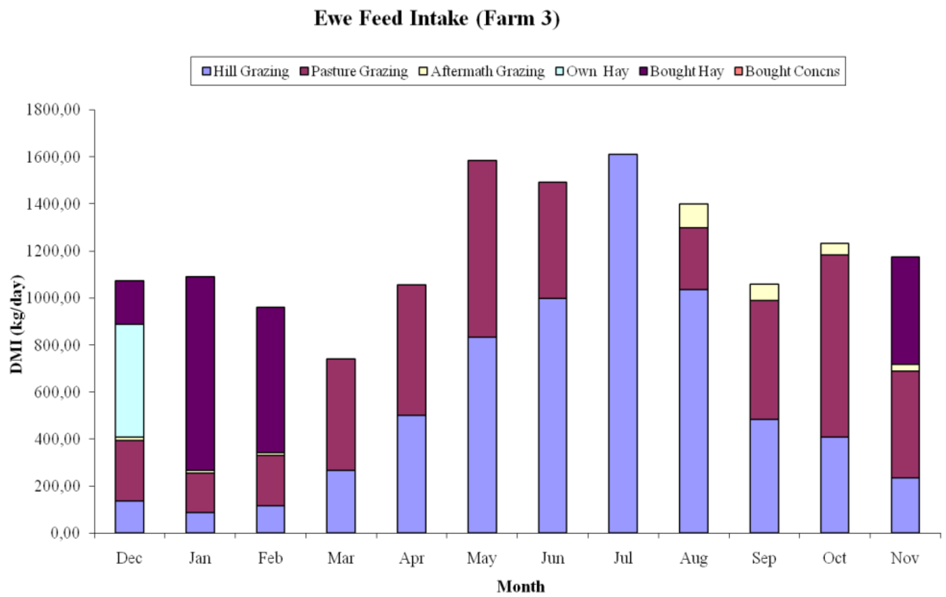

Figure 4.3: Ewe feed intake scenario 1

Scenario 2 Reducing flock size

The total farm emissions (kg CO_2e/ha) reduce as the flock size becomes smaller. The greenhouse gas emissions per kg product and methane emissions increase as the flock size reduces. In the month January, for the two smallest flocks, small quantities of concentrates are included in the diet (Table 4.13). In the baseline, hay is bought but in these two farms it is more economic for the use of concentrates.

Table 4.13: DMI of different feed components when reducing flock size

		Dry matter intake (kg/ewe/year)						
Proportion flock size	**Number of ewes**	**Hill Grazing**	**Pasture Grazing**	**Aftermath Grazing**	**Own Hay**	**Bought Hay**	**Concentrates**	**Total**
1.00	1240	166.16	120.76	6.88	11.94	50.30	0.00	356.05
0.90	1116	180.14	107.53	7.65	13.27	49.05	0.00	357.65
0.75	930	180.32	110.61	7.29	15.93	46.57	0.00	360.71
0.50	620	245.35	54.16	9.08	23.89	39.11	0.00	371.59
0.25	310	263.85	64.66	9.02	38.79	0.00	1.38	377.70
0.10	124	316.58	52.64	0.83	3.63	0.00	1.34	375.03

Scenario 3 Including concentrates

Addition of concentrates beyond 5% (Table 4.14) results in a change in flock size as it becomes infeasible to maintain the current flock size. The flock size changes due to the constraint on concentrates as well as the combination of the other constraints as the percentage of concentrates increase in the ration.

Table 4.14: The annual DMI per ewe for different feed components when concentrates are included in diet

		Dry matter intake (kg/ewe/year)						
Proportion of concentrates	**Number of ewes**	**Hill Grazing**	**Pasture Grazing**	**Aftermath Grazing**	**Own Hay**	**Bought Hay**	**Concentrates**	**Total**
0.000	1240	166.16	120.76	6.88	11.94	50.30	0.00	356.05
0.025	1240	30.20	230.56	7.60	11.94	48.26	8.42	356.05
0.050	1240	30.32	222.55	7.60	11.94	46.27	16.77	337.00
0.075	912	44.23	200.67	9.10	16.24	40.25	25.18	335.45
0.100	370	220.35	32.22	25.46	40.00	0.00	35.34	335.68
0.125	380	225.67	18.80	24.83	39.00	0.00	44.04	353.37
0.150	196	277.97	5.39	6.30	9.90	0.00	52.86	352.42

Scenario 4 Hill grazing

Reductions of emissions were observed in all cases. Tables 4.15 and 4.16 show the dry matter intake and the land use for this scenario that explain the trends observed in the greenhouse gas emissions.

Table 4.15 The percentage of total DMI of different feed components for when changes are made to hill grazing

		Dry matter intake (kg/ewe/year)					
Hill Grazing	**Number of ewes**	**Hill Grazing**	**Pasture Grazing**	**Aftermath Grazing**	**Own Hay**	**Bought Hay**	**Total**
A	1240	166.16	120.76	6.88	11.94	50.30	356.05
B	1240	0.00	262.39	7.60	11.94	56.81	338.75
C	1240	152.12	120.76	6.88	11.94	63.79	355.50
D	1240	54.91	220.10	6.88	11.94	50.30	344.13
E	1240	125.29	163.06	7.60	11.94	43.31	351.21

A – No changes made to the hill grazing, B – No Hill grazing, C – No hill grazing from November to February, D – No hill grazing from May – August, E – No hill grazing March, April, September and October

Table 4.16: Land Use

		Land use (Ha)			Slack (Ha)		
Scenario	**Number of ewes**	**Hill**	**Pasture**	**Hay**	**Hill**	**Pasture**	**Hay**
Hill Grazing							
A	1240	627.00	99.20	6.00	0.00	35.80	0.00
B	1240	627.00	135.00	6.00	0.00	0.00	0.00
C	1240	627.00	99.20	6.00	0.00	35.80	0.00
D	1240	627.00	99.20	6.00	0.00	35.80	0.00
E	1240	627.00	135.00	6.00	0.00	0.00	0.00

A – No changes made to the hill grazing, B – No Hill grazing, C – No hill grazing from November to February, D – No hill grazing from May – August, E – No hill grazing March, April, September and October

Scenario 5 Cost for Labour

Results are of a similar trend to those of the same scenario in Farm 1 but concentrates are also purchase here (Table 4.17) also in January. From Table 4.12 it was observed that when the flock size was small, concentrates were purchased and no hay was bought. This is what is also observed here where there is a flock size of 200.

Table 4.17: The annual DMI of different feed components for when labour has a cost

		Dry matter intake (kg/ewe/year)						
Scenario	**Number of ewes**	**Hill Grazing**	**Pasture Grazing**	**Aftermath Grazing**	**Own Hay**	**Bought Hay**	**Concentrates**	**Total**
Labour (£0/hr)	1240	166.16	120.76	6.88	11.94	50.30	0.00	356.05
Labour (£5/hr)	200	257.26	77.54	12.27	19.52	0.00	1.41	368.00

4.4 Farm 4

Table 4.18 shows the greenhouse gas emissions and gross margins for the different scenarios for Farm 4.

Table 4.18 the percentage change of emissions from the optimal farm plan using different scenarios

Scenario	Number of ewes	kgCO2e/ha	% change	kgCO2e/kg lamb	% change	Ewe Methane (g/day)	% change	Farm GM (£)	% change
Baseline	660	270		26.41		25.25		5432	
Proportion flock size									
1.00	660	270		26.41		25.25		5432	
0.90	594	241	-10.7	26.21	-0.8	24.99	-1.0	5166	-4.9
0.75	495	202	-25.3	26.31	-0.4	25.09	-0.6	4768	-12.2
0.50	330	136	-49.5	26.67	1.0	25.50	1.0	3435	-36.8
0.25	165	71	-73.8	27.68	4.8	26.62	5.4	1834	-66.2
0.10	66	28	-89.6	27.59	4.5	25.94	2.7	758	-86.1
Proportion concentrates									
0.000	660	270		26.41		25.25		5432	
0.025	660	272	0.7	26.60	0.7	25.49	1.0	4003	-26.3
0.050	480	198	-26.7	26.51	0.4	25.51	1.0	2634	-51.5
0.075	493	203	-24.9	26.46	0.2	25.42	0.7	1573	-71.0
0.100	506	208	-23.0	26.40	0.0	25.36	0.4	461	-91.5
Hill Grazing									
A	660	270		26.41	0.0	25.25	0.0	5432	0.0
B	449	178	-33.9	25.58	-3.1	24.26	-3.9	2751	-49.4
C	660	269	-0.2	26.35	-0.2	25.18	-0.3	4201	-22.7
D	563	228	-15.7	26.02	-1.5	24.85	-1.6	4519	-16.8
E	639	260	-3.6	26.20	-0.8	25.10	-0.6	4099	-24.5
Labour (£5/hr)	660	270		26.41		25.25		5432	
Labour (£5/hr)	355	88	-67.3	29.36	11.2	29.00	14.8	2108	-61.2

A – No changes made to the hill grazing, B – No Hill grazing, C – No hill grazing from November to February, D – No hill grazing from May – August, E – No hill grazing March, April, September and October

Scenario 1

In order to meet the feed requirements of the Farm 4 for the first scenario, there was a need for purchase of hay in the months of January, February and November (Figure 4.4). All 666ha of hill, all 8 ha of hay land and 24.3 ha of pasture with a remainder of 2.2ha was used. This farm had 50% heather cover, and sheep prefer grass over heather.

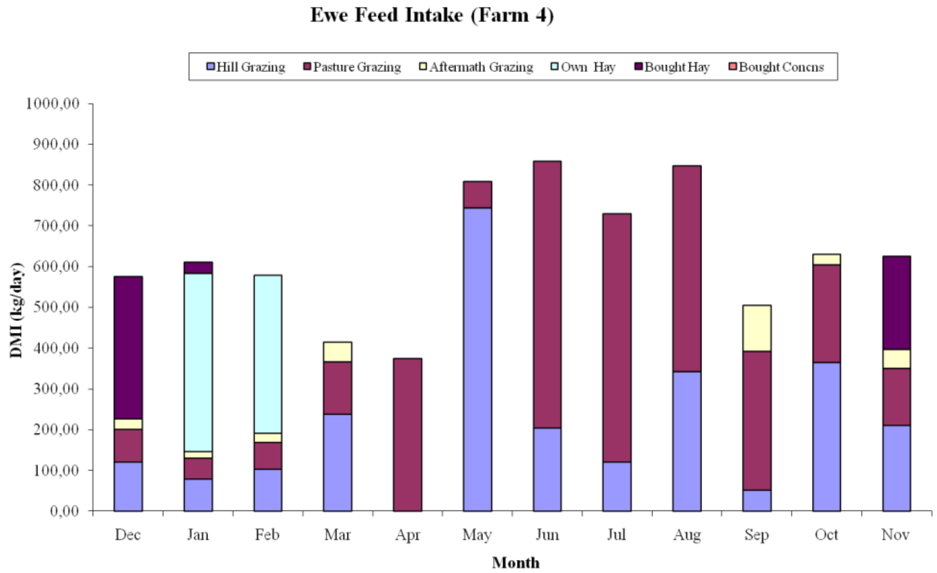

Figure 4.4 Ewe Feed Intake Scenario 1

Scenario 2 Reducing flock size

Table 4.19 shows the dry matter intake for this scenario and explains why greenhouse gas emissions are as observed in Table 4.18.

Table 4.19: DMI of different feed components when reducing flock size

		Dry matter intake (kg/ewe/year)					
Proportion flock size	**Number of ewes**	**Hill Grazing**	**Pasture Grazing**	**Aftermath Grazing**	**Own Hay**	**Bought Hay**	**Total**
1.00	660	120.59	150.00	13.64	36.90	27.99	349.12
0.90	594	95.45	175.14	13.80	41.00	21.04	346.44
0.75	495	105.74	169.00	16.56	49.20	7.15	347.65
0.50	330	149.57	155.50	5.72	41.84	0.00	352.63
0.25	165	202.96	149.16	1.14	14.25	0.00	367.51
0.10	66	206.81	151.77	0.00	0.00	0.00	358.58

Scenario 3 Including concentrates

The addition of concentrates did not reduce the greenhouse gas emissions when the flock size was constant which was at an inclusion of 2.5% concentrates. From Table 4.20 it was observed that subsequent additions of concentrates up to 10% resulted in a change in the flock size. Concentrates levels beyond 10% were not economic. This farm exhibits different behaviour to the other farms and this may be due to the fact that the farm has a 50% heather cover and the hay land are not available for grazing from May to August. This farm has the largest hill area of the four farms but the smallest area for hay and pasture land. These constraints when in combination with the constraint of concentrates contribute to the changes in flock size that have been observed.

Table 4.20: DMI of different feed components when concentrates

		Dry matter intake (kg/ewe/year)						
Proportion of concentrates	**Number of ewes**	**Hill Grazing**	**Pasture Grazing**	**Aftermath Grazing**	**Own Hay**	**Bought Hay**	**Concentrates**	**Total**
0.000	660	120.59	150.00	13.64	36.90	27.99	0.00	349.12
0.025	660	92.27	164.79	16.11	36.90	25.69	8.61	344.37
0.050	480	102.21	151.70	22.13	50.69	0.00	17.20	343.94
0.075	493	107.59	138.62	21.56	49.38	0.00	25.71	342.86
0.100	506	112.99	125.53	21.00	48.10	0.00	34.18	341.80

Scenario 4 Hill grazing

The changes made towards hill grazing also had an effect of reducing the greenhouse gas emissions on Farm 4 however the change in flock size is also observed here. Table 4.21 and 4.22 show the land use and dry matter intake for this scenario.

Table 4.21: Land Use

		Land use (Ha)			Slack (Ha)		
Scenario	**Number of ewes**	**Hill**	**Pasture**	**Hay**	**Hill**	**Pasture**	**Hay**
Hill Grazing							
A	660	666.4	24.3	8.00	0.0	2.2	0.0
B	449	0.0	26.5	8.00	666.4	0.0	0.0
C	660	666.4	24.3	8.00	0.0	2.2	0.0
D	563	666.4	26.5	8.00	0.0	0.0	0.0
E	639	666.4	26.5	8.00	0.0	0.0	0.0

A – No changes made to the hill grazing, B – No Hill grazing, C – No hill grazing from November to February, D – No hill grazing from May – August, E – No hill grazing March, April, September and October

Table 4.22: The annual DMI per ewe for different feed components when hill grazing changes

		Dry matter intake (kg/ewe/year)					
Hill Grazing	**Number of ewes**	**Hill Grazing**	**Pasture Grazing**	**Aftermath Grazing**	**Own Hay**	**Bought Hay**	**Total**
A	660	120.59	150.00	13.64	36.90	27.99	349.12
B	449	0.00	237.38	16.19	54.27	31.38	339.21
C	660	97.03	150.00	13.64	36.90	50.64	348.21
D	563	84.15	188.63	8.58	43.27	20.69	345.34
E	639	80.35	166.61	16.64	38.11	46.12	347.83

A – No changes made to the hill grazing, B – No Hill grazing, C – No hill grazing from November to February, D – No hill grazing from May – August, E – No hill grazing March, April, September and October

Scenario 5 Cost for Labour

The results for this scenario follow the same trend that was explained in Farm 1.

Table 4.23: The annual DMI of different feed components for when labour has a cost

		Dry matter intake (kg/ewe/year)					
Scenario	**Number of ewes**	**Hill Grazing**	**Pasture Grazing**	**Aftermath Grazing**	**Own Hay**	**Bought Hay**	**Total**
Labour (£0/hr)	660	120.59	150.00	13.64	36.90	27.99	349.12
Labour (£5/hr)	355	263.67	100.21	6.82	22.01	0.00	392.72

5 Discussion

5.1 The Model

Many methods of predicting methane and nitrous oxide emissions in ruminants have been discussed in literature. Equations such as those by Kriss (1930), Blaxter and Clapperton (1965) and IPCC (2006) are among others that have been used in the prediction of methane emissions in sheep. The model used made use of proportion of methane energy of the gross energy of the feedstuffs that were given to the sheep on these farms. This method was chosen after consideration and consultations with experts in animal nutrition and sheep production.

Nitrous oxide was calculated by way of the IPCC tier 1 methodology (IPCC 2006). The calculation made use of default values provided in the IPCC guidelines. Some example of parameters that made use of default values are N_2O emission factors, and nitrogen excretion data. This calculation was very basic and the only variables that made a difference in each model run were the number of ewes and the annual amount of synthetic fertiliser nitrogen that was applied to the soils for each farm. There are many factors that contribute to the generation of nitrous oxide emissions from sheep that were not considered by the simple IPCC tier 1 method of calculation. Since most factors in the equations used for the calculation of nitrous oxide were default values, the emissions did not necessarily reflect the effect of the variations that may arise because of the change in the ration that was being given to the ewes. For example, in Equation 3.3, used to calculate the annual average nitrogen excretion per head, the nitrogen excretion rate, a default value, did not necessarily reflect the actual excretion rate of the ewes on these 4 farms. According to Smith and Frost (2000), data on the excretal output for sheep is not as freely available as that for other livestock. They also mention that the factors that affect the amount and the nitrogen content of sheep excreta include the feed and water intake, the liveweight and whether the ewe is in lactation. These things were not considered in the Tier 1 equation for the ewes on these four farms.

The greenhouse gas emissions calculated for the four farms only account for enteric methane emissions and nitrous oxide from manure and from soil related to fertiliser usage. The appoach used here did not consider emissions from other sources on the farm such as the use of fuel and electricity neither did it consider emissions from external sources arising from the manufacture and distribution of farm inputs. There is limited use of fuel and electricity in these kinds of farming systems and as well as the procurement of inputs therefore the exclusion of GHG emissions from these other sources does not have a significant effect on the results. Carbon sequestration was not considered as well. There may have been opportunities of sequestration on these farms but they have not been accounted for.

5.2 The Results

The four farms that were assessed showed to have higher CO_2 emissions per kilogram of lamb than the 18.44kg CO_2e/kg lamb published by EBLEX (2009) as the current baseline for English lamb production in hill flock. Higher greenhouse gas emissions per kilogram of lamb produced are attributed to the fact that there is poorer quality nutrition from lower quality forages in hill sheep production systems.

According to Hegarty et al. (2010) an increase in the DMI of sheep is associated with an increase in the daily methane production. The diets consumed in extensive grazing systems are of low to moderate digestibility. The methane generated when an additional unit intake of these diets is higher than when there is an increase in intake of feeds that are of higher digestibility (Hegarty et al. 2010). From the results it can be seen that there are very small effects on the methane emissions that are produced and this therefore questions that values that are used in the model. This was observed when the ewes on the four farms consumed more grass in their diet than when the diet included hay and or concentrates.

As the flock size became smaller, the annual total farm emissions (kgCO_2e/ha) also reduced. The fewer the animals the more they made use of hill and pasture for grazing. The gross margin of the farm also decrease as there is less production on the farm. A large proportion of the land that is devoted to livestock grazing in the UK is comprised of permanent pasture or rough grazing land that is only suitable for grass production. Sheep dominate these areas of less productive grassland because of their ability to utilize the poor quality forage.

The addition of concentrates to the diet resulted in an overall decrease in the annual greenhouse gas emission (kgCO_2e/ha), a reduction in the emissions per kilogram of product and a reduction in the daily methane emissions of the ewes. This addition of concentrates did have a major effect on the gross margin. The changes observed were small.

When hill grazing was completely abandoned, there was a reduction in the annual farm emissions, the greenhouse emissions per kilogram of product as well as the average daily methane emissions of the ewes. If the sheep are kept completely off the hill then other wild life, such as deer may move in and this may not solve the problem of reducing greenhouse gas emissions as these also generate emissions. However, there may be vegetative growth that may also contribute to carbon sequestration and other ecological processes that may occur. However, this area is not well understood.

6 Conclusions

The first research objective was: "To identify how greenhouse gas emissions may be assessed on sheep farms."

Greenhouse gas emissions may be assessed either by measuring the actual amount from the individual animals or by predicting these emissions by use of models and equations. The sulfur hexachloride technique can be used to measure methane emissions from grazing sheep while whole farm chambers can be used to measure emissions from individual animals. Prediction equations make use of various feed intake data as well as the size and condition of the animal. Whole farm system models as well as the IPCC methodology are also methods that may be used in the assessment of greenhouse gas emissions on farms.

The second reserch objective was: "To determine possible measures extensive sheep farmers can take in order to reduce greenhouse gas emissions."

Several methods where identified as measures for reducing greenhouse gas emissions in ruminats. These include improving feeding practices by increasing concentrates and reducing forage, improving pasture quality or the inclusion of nutritional and other suppliments such as ionophers, antibodies and oils. Other management practices such as improving productivity through breeding and reducing livestock numbers may also reduce greenhouse gas emissions. The following were considered in the case of extensive sheep farming: reducing the flock size, the use of concentrate feeds and changing the composition of the ration that is already available on the farm by means of limiting the use of the hill for grazing.

Reducing the flock size reduced the overall farm emissions but the individual methane emissions and emissions per kg of product increased. This was due to the composition of the diet which would comprise mainly of the hill and pasture grazing. The inclusion of concentrates showed minute decreases in all the emissions. Various options of making use of the hill for grazing also had some effect in reducing greenhouse gas emissions althought as with concentrates, the reduction was small. The biggest effect was observed when no hill grazing was allowed at all.

The third research objective was: "To investigate the impacts of these measures on the profitability of the farms under study".

Although these measures had some positive effect in reducing greenhouse gas emissions on these farms, their effect on the gross margin was negetive. Reducing the flock size resulted in a decrease in the gross margin because fewer lambs would be produced. The scenario that included concentrates had the worst effect on gross margin. This was primarily because use of concentrates made the ration more expensive. Options D and E from the hill grazing scenario had the smallest changes in the gross margin with some reduction, although very small, in the greenhouse gas emissions. Labour costs resulted in a drastic drop in the gross margin as well as the flock size.

These measures of reducing greenhouse gas emissions had very small percent changes in the emissions that caused large drops in the farm gross margin. Other measures of reducing emissions on these farms need to be looked into that will not result in big losses in the farm gross margins.

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