Modelling the effect of genetic improvement programmes on methane emissions in the Welsh sheep industry

A report prepared for HCC by

The Institute of Biological, Environmental and Rural Sciences (IBERS), KN Consulting and Innovis Ltd

funded by the Rural Development Plan

February 2011

IBERS
Sefydliad y Gwyddorau Biolegol, Amgylcheddol a Gwledig
Institute of Biological, Environmental and Rural Sciences

Cronfa Amaethyddol Ewrop ar gyfer Datblygu Gwledig: Ewrop yn Buddsoddi mewn Ardaloedd Gwledig
The European Agricultural Fund for Rural Development: Europe Investing in Rural Areas

Llywodraeth Cynulliad Cymru
Welsh Assembly Government

Modelling the effect of genetic improvement programmes on greenhouse gas emissions in the Welsh sheep industry

Partners: Institute of Biological, Environmental and Rural Sciences (IBERS), KN Consulting, Innovis Ltd.

Summary 3

1 Background 4

2 Literature Review 4

Relationship between productivity and reducing emissions 5

The role of genetic improvement in reducing methane emissions 5

Measuring methane emissions 6

3 Description of the Model 6

3.1 Genetic model 6

3.2 Flock performance model 7

3.3 Energy requirements model 9

3.4 Industry structure 12

4 Results 13

4.1 Baseline estimates of likely changes in methane emissions as a consequence of genetic improvement 13

4.2 Effect of single trait selection on emissions 17

5 Discussion 20

6 Conclusions 23

References 24

Appendix 1 Genetic Parameters used in the model 26

Appendix 2 Details of methods used for calculation in Flock Performance model 27

Appendix 3 Breed parameters used in the flock performance model 29

Appendix 4. Details of methods used for calculation of energy requirements and methane emissions 30

Appendix 5. Distribution of energy requirements 33

Summary

This report addresses the role that breeding can play in helping sheep farmers to reduce enteric methane emissions, emitted as a result of rumen digestion, without negatively impacting on livestock numbers or profit margins.

Currently greenhouse gas emissions from primary agricultural production contribute around 9% of total annual Welsh emissions; a significant proportion of this is attributed to enteric emissions of methane from ruminant livestock, including sheep. The Welsh Assembly Government has given clear signals that the livestock sector needs to develop emission reduction strategies.

Genetic improvement can provide a long term, cost effective strategy as it brings about permanent and cumulative changes. This strategy should be used in-conjunction with other management practices that also seek to address emissions. This may bring additional benefits particularly if improvements in nutrition and forage utilisation lead to better expression of superior genetics.

A model has been developed to predict the expected changes in methane emissions that could result from the use of widespread genetic improvement of production efficiency within Welsh sheep.

The model was used to predict genetic changes in individual traits in hill, crossing sire and terminal sire breeds and the influence these would have on flock inputs and outputs in hill, upland and lowland flocks in Wales. These data were then used to model the energy requirements of all stock on such farms, and in turn to predict the methane emissions on an individual animal basis.

The study has shown that, if adopted across the whole industry, current genetic improvement programmes are expected to result in an annual decrease of 0.03% in methane emissions per tonne of carcase produced. A reduction of 0.08% per year could be expected if correlated changes in ewe weight in hill and crossing sire breeds, and thus crossbred ewes, were restricted.

The greatest predicted reductions in methane emissions were associated with genetic improvement of productivity in lowland flocks in which methane emissions per tonne of carcase produced could be reduced by 1.8% over a ten year period if the weight of the crossbred ewe did not increase. Genetic improvement in both terminal and crossing sires made a significant contribution to this reduction.

In hill breeds the expected reductions in methane emissions were very small. This is partly due to an expected increase in ewe size resulting from selection for lamb growth. Purebred hill ewes make up approximately half of the Welsh ewe flock and this has contributed to the relatively low expected reduction across the industry as a whole.

Of the traits examined in this study, those that are most likely to have a beneficial effect on methane emissions through genetic selection or breed substitution are ewe prolificacy, ewe longevity, muscle depth (through its correlated effect on carcase weight) and lamb growth (if changes in ewe weight are restricted). Genetic improvement of these traits, through within breed selection programmes or breed substitution, could lead to substantial reductions in methane emissions per tonne of carcase produced.

1 Background

Greenhouse gas (GHG) emissions from primary agricultural production contribute around 9% of total annual Welsh emissions. The primary contributor to methane emissions is enteric fermentation in ruminant livestock (some 70% of all anthropogenic emissions in Wales). The Welsh Assembly Government is committed to reducing GHG emissions by 3% per year from 2011 in areas of devolved competence (One Wales Agreement). In order to play its part in the achievement of this target the Welsh sheep industry needs to have a clear understanding of how the national sheep flock contributes to methane emissions and the options for reducing this while maintaining and improving the economic sustainability of agricultural production in rural Wales.

Reduction of GHG emissions from the national sheep flock will only be successful if approached from a number of different angles. Genetic improvement is one approach that can provide a long term, cost effective solution as it brings about permanent and cumulative changes. Genetic improvement could prove a very effective approach to achieve significant reductions in GHG emissions via improvements in production and reproductive efficiency within existing sheep production systems. Additional improvements may be achieved through selecting for sheep that are 'low emitters'; however, although there is evidence of permanent variation in the methane emissions of individual sheep it is not yet known whether these differences are due to genetic variation and thus heritable.

Genetic improvement of the national sheep flock continues to be a key strand of the Hybu Cig Cymru (HCC) Red Meat Strategy 'to improve the business performance of primary producers in response to changing environmental requirements and climate change' (HCC, 2009). However, whilst it has been suggested that genetic improvement in livestock could help play a role in decreasing GHG emissions on a UK wide basis (Wall *et al*, 2008) the relative importance of this approach in reducing emissions in Wales has not yet been quantified. The aim of this report is to provide baseline estimates of likely changes in methane emissions as a consequence of genetic improvement programmes and to identify opportunities for decreasing emissions from the Welsh sheep flock while also improving economic efficiency. This will provide much needed objective information for farmers, advisors and policy makers to draw upon when discussing future strategies for flocks at both an individual and a national level.

2 Literature Review

Alongside carbon dioxide and nitrous oxide, methane forms one of the three main greenhouse gases. With a global warming potential approximately 21 times higher than carbon dioxide, methane represents a potent greenhouse gas. Methane is produced by the action of microbes during the mineralisation of organic carbon under anaerobic conditions (Moss 1993). The gas is released from both human activities (anthropogenic) and as a result of natural processes. Anthropogenic sources of methane production include fossil fuel burning, coal mining, oil and gas drilling, rice production, landfills and waste disposal and farmed ruminant livestock. Natural sources of methane include wetlands, wild ruminants, oceans, lakes and termites. Methane is one of the main greenhouse gases targeted for reduction by the Kyoto protocol.

The National UK inventory of greenhouse gas emissions estimates that methane emissions from agriculture make up approximately 38% of the UK's total methane output (Mills, *et al* 2010). Given that methane production from agriculture primarily arises from enteric fermentation, with a small amount derived from the storage of manure, reducing methane emissions represents a key challenge for producers of ruminants. Since manure contributes very little methane in extensive systems it is emissions from rumen processes that must be targeted to reduce methane production.

Ruminant livestock are significant producers of methane through the microbial processes that naturally take place in the rumen via enteric fermentation. Non-ruminants (e.g. horses) and monogastric livestock (e.g. pigs) also produce methane but have relatively lower methane emissions since much less methane-producing fermentation takes place in their digestive systems. Plant material consumed by ruminants is fermented by approximately 200 species of microbes (bacteria, fungi and protozoa) in the rumen. The microbes convert this material into nutrients that livestock can use, such as volatile fatty acids. Methane, a by-product of this fermentation process, is released to the atmosphere mainly via the mouth and nostrils. Many factors influence methane emissions from ruminants including: level of feed intake, type of carbohydrate in the diet, feed processing, addition of lipids or ionophores to the diet, and alterations in the rumen microflora.

Relationship between productivity and reducing emissions

Improving animal productivity decreases methane emissions per unit of product. At the basic level, feed goes to maintenance and productivity. Maintenance is the proportion of feed needed to satisfy the basic metabolic requirements that keep the animal alive. A significant percentage of the methane emitted comes from the proportion of the feed used for maintenance. The remaining feed energy is used for production. Maintenance requirements generally remain constant, therefore, as maintenance remains constant and animal productivity increases, methane emissions go up but methane emissions per unit of product decrease.

The role of genetic improvement in reducing methane emissions

Genetic improvement is widely recommended as a means of improving production efficiency with a resulting improvement in profitability. Whilst the financial benefits will remain the main driver for increasing uptake of genetic improvement the potential for secondary benefits in the reduction of methane emissions per unit of output could provide further encouragement for the increased use of genetically improved livestock. Furthermore, gains made in reducing methane emissions through genetic improvement are permanent and cumulative.

There are three routes through which genetic improvement can help to reduce emissions per kg of product: via improving productivity and efficiency, reducing livestock wastage and directly selecting on emissions (Wall *et al* 2009). Selection on various traits has been highlighted for the reduction of enteric methane emissions from sheep production including prolificacy (Hegarty, 2009) and longevity (Garnsworth, 2004). Genetic improvement of livestock to reduce methane emissions is therefore of increasing interest to the global research community. Breeding specifically for the reduction of methane as a trait is also being considered with evidence of between animal variation in methane emissions (Ulyatt *et al*, 1997). Since methane emissions also represent an energy loss to the animal, with typically 5-9% of gross dietary energy lost in this way (Blaxter and Clapperton, 1965), this approach may lead to corresponding improvements in productivity. Further research is required to underpin this trait and to develop methods for large-scale measurements on which to base subsequent genetic selection.

Measuring methane emissions

Methane is a colourless, odourless gas, therefore to develop strategies to mitigate emissions it must be possible to quantify emissions under a wide range of circumstances. There are a range of different techniques for measuring methane output from individual animals ranging from short-term expired air samples to more elaborate chamber systems (Johnson and Johnson, 1995). Elaborate chamber based systems include whole animal chambers, head boxes, or ventilated hoods and face masks, whilst the use of non-isotopic tracer techniques are also available whereby sulphur hexafluoride(SF6), an inert gas tracer, is placed in the rumen. This second technique allows animals to undergo natural grazing but does require training of stock to wear a halter and collection canister (Johnson and Johnson, 1995).

3 Description of the Model

The model, written in MS Excel, is composed of three separate elements: Genetic improvement, flock performance and energy requirements and methane production. Three versions of the model are used in this study: A self-replacing hill flock; an upland flock in which hill ewes are mated to a crossing sire to produce crossbred ewes, and a lowland flock in which crossbred ewes are mated with a terminal sire.

3.1 Genetic model

Genetic improvement within each of a hill breed, a crossing sire breed and a terminal sire breed is modelled over a 20 year period using gene flow techniques. For each of twenty years the mean breeding values of flock rams, flock ewes, ewe hogs, lambs and rams for sale as breeding stock are calculated, taking into account the age structure of each class of livestock. The traits modelled are summarised in Table3.1.

The selection criteria available included all the traits included in Table 3.1 plus indexes based on the current Lean Index, Longwool Index and Welsh Hill Index used by Signet.

Ram lambs within the purebred population were selected from the top 10% of lambs born in terms of breeding value for the chosen selection criterion. Sufficient ewe lambs to maintain a stable flock size were also selected on the basis of breeding value for the selection criterion allowing for 10% of selected ewe lambs to be rejected on the basis of type or structural faults. It was assumed that the poorest 20% of all ram lambs in purebred crossing sire and terminal sire flocks were culled and not sold for breeding.

Table 3.1 Traits included in the genetic improvement model

20 week weight
Ewes lambing/ewe joined
Lambs weaned/ewe joined
Ewe longevity
Ewe mature size
Lamb birth weight (both direct and maternal effects)
Growth rate to 150 days (both direct and maternal effects)
Lamb Survival (both direct and maternal effects)
Killing out percentage
Conformation (EUROP)
Fat class
Ultrasonic muscle depth
Ultrasonic fat depth
Carcase weight

In addition to the direct response in the selection criterion, the correlated responses in all traits listed in Table 3.1, are modelled.

The genetic parameters used in the genetic improvement model are summarised in Appendix 1. The values used are derived from literature, and represent the most up to date and robust set of parameters available.

3.2 Flock performance model

Three types of flock are modelled separately. A self-replacing hill flock; an upland flock in which hill ewes are mated to a crossing sire to produce crossbred ewes, and a lowland flock in which crossbred ewes are mated with a terminal sire. The appropriate breeding values for each stock class are taken from the genetic model of each breed and used to calculate mean performance in the flock performance model. The parameters used for each breed type are shown in Appendix 3.

The effects of heterosis of ewe and lamb performance are incorporated where appropriate. The heterosis effects used in the calculations were based on the review of Nitter (1978) and are also shown in Appendix 1.

Number of lambs reared

For each of the 20 years modelled the number of barren ewes and number of single, twin and multiple bearing ewes is calculated from the ewe breeding values for rearing percentage (number of lambs weaned per ewe joined), ewe fertility (number of ewes lambing/ewe joined) and lamb survival rate plus estimates of the heterosis effects for these traits (for crossbred ewe and lambs). Details of the methods used are given in Appendix 2.

Lamb performance

The mean birth weight, survival and growth rate of lambs are calculated from breeding values for both individual and maternal components of the trait. Data derived from the Innovis nucleus flock were used to estimate the average effect of birth type (single, twin or multiple) on each of these traits. Details of these values are shown in Appendix 2.

It is assumed lambs were selected for slaughter at a target carcase weight (15 kg for hill flocks, 17.5 kg for upland flocks and 19 kg for lowland flocks), and the number of days required for lambs to achieve this is calculated from the mean breeding values for growth rate, birth weight (both adjusted for birth type) and killing out percentage. The carcase weight is allowed to increase as a correlated response to selection for other traits.

Ewe and ram longevity

The annual rate of loss of ewes is based on results reported by Mekkawy *et al* (2009). The proportion of ewes present at each parity that were lost due to culling or death before the next parity (marginal loss) is related to the mean breeding values for ewe longevity taken from the genetic model. Details of the calculations used are given in Appendix 2. It is assumed that all remaining ewes are culled after weaning their lambs at the age of six years of age in all flock types.

Rams are assumed to have a marginal loss of 10% per year and are otherwise culled at a fixed age (5 years). The number of rams maintained in the flock is based on a mating ratio of one ram to 60 ewes.

Female replacements and mating of ewe hogs

The number of ewe lambs retained as replacements (in self-replacing flocks) is based on the number required to maintain a stable flock size taking into account the loss of adult ewes through culling or death. It is assumed that female replacements are only selected from adult ewes.

In lowland flocks it is assumed that ewe lambs that had achieved 60% of mature weight are mated at an average age of 214 days. The proportion of ewe lambs attaining the critical mating weight (60% of mature weight) is estimated using a normal distribution of the weight at mating, calculated from the average growth rate and birth weight of selected ewe lambs (taken from the genetic model).

The conception rate of ewe lambs is assumed to be 80% and the lambing percentage 68% that of mature ewes (based on data from ADAS, 2010). The distribution of litter sizes of ewe lambs lambing is estimated using the same methods as for mature ewes. The distribution of singles and twins closely reflects that found in the Innovis nucleus flock and those reported by Olesen *et al* (1994).

The effect of dam age on the performance of the lambs of ewe hogs is estimated using performance data from the Innovis nucleus.

Flock ouputs

Weight of lambs weaned per ewe is calculated for a weaning age of 120 days. Total carcase weight produced by the flock includes both lambs and culled ewes and rams. The killing out percentage is assumed to be 39.7% for cull ewes and 43.3% for cull rams based on Muir and Thompson (2008). For hill and upland flocks the total carcase weight includes all lambs not required as replacements, as this represents output from the flock even if in practice lambs would normally be finished off farm (sold as stores).

3.3 Energy requirements model

Estimation of methane emissions per animal

Methane emissions from enteric fermentation are estimated using the 2006 guidelines published by the Intergovernmental Panel on Climate Change (IPCC) using Tier 2 methodology (IPCC 2006). The Tier 2 approach is based upon detailed characterisation of the animal population and allows for varying methane emissions according to specific animal information and level of production. This contrasts with the more generalised UK National Inventory methodology upon which Carbon footprinting studies tend to be based. Such studies are based upon Tier 1 methodology which allocates a single methane value per sheep irrespective of level of performance. It is considered that using the most sensitive internationally recognised methodology available is necessary in order to accurately reflect the impact of changing production levels as a consequence of genetic improvement. Use of the Tier 2 methodology therefore developed a model more reflective of changing energy requirements with differing levels of production upon which estimation of methane emissions are subsequently based.

Estimation of energy requirements

Energy requirements are estimated for four different classes of stock: Ewes, rams ewe hogs (replacement females for the breeding flock) and lambs.

Using equations presented in Tier 2 methodology (Appendix 4), energy requirements are partitioned into a number of biological functions (Table 3.2).

Table 3.2 Energy partitioning by stock class

Class of stock	**Ewes**	**Ewe hogs**	**Rams**	**Lambs**
Maintenance	✓	✓	✓	✓
Growth	n/a	✓[1]	n/a	✓
Pregnancy	✓	✓[2]	n/a	n/a
Lactation	✓	✓[2]	n/a	n/a
Activity	✓	✓	✓	✓
Wool	✓	✓	✓	✓

[1] Growth from ewe hog to yearling weight, [2] Estimated for ewe lamb mating where appropriate

Estimation of these energy requirements is based on animal productivity appropriate to each class of stock and flock type.

Energy requirement for maintenance

Energy requirements for maintenance are derived from a function of live-weight and a coefficient based upon age and sex of each class of stock (Appendix 4 Equation 1). Energy requirements for maintenance in ewe hogs and lambs are estimated using an average of the start and end live-weight. In growing lambs this is derived from the difference between birth weight and estimated live-weight at slaughter and in ewe hogs it is estimated using the difference between weight at selection as breeding females and yearling weight. Adult mature live-weight is used to estimate maintenance requirements for ewes and rams. Appropriate live-weights for lambs, ewe hogs, ewes and rams are established for each flock type within the Flock Model in year 0 and subsequently changes in birth weight, yearling weight and mature weight for each class of stock are based on genetic improvement.

Energy requirement for activity

Energy requirements for activity are estimated using average live-weight and a coefficient based on activity level (Appendix 4 Equation 2). It is assumed that the ewes and ewe hogs on the hill and upland farm graze hilly pasture, with an activity coefficient of 0.0240, and rams and growing lambs graze flat pasture, with an activity coefficient of 0.0107. For the lowland flock it is assumed that all stock classes graze flat pasture (activity coefficient 0.0107). There are no changes in activity levels associated with genetic improvement.

Energy requirement for growth

Energy requirements for growth are derived from weight gain within each class of stock and coefficients based upon sex and days on farm (Appendix 4 Equation 3). Energy requirements for lamb and ewe hog growth are estimated from increases in live weight. Lamb growth pre-weaning is assumed to be a consequence of energy provided via ewe or ewe hog lactation. Energy requirement for lamb growth is therefore estimated from live-weight gain between weaning and live weight at slaughter. Weaning weights are calculated from a function of lamb birth weight and growth rate adjusted for birth type and genetic improvement. Energy requirements for ewe hog growth are estimated from weight gain between selection for breeding and final yearling weight. It is assumed that no growth takes place in adult ewes and rams.

Energy requirement for pregnancy

Energy requirements for pregnancy in ewes and ewe hogs (where appropriate) are derived from maintenance energy requirements and a coefficient based on predicted birth type (Appendix 4 Equation 6). Birth types are adjusted for flock scanning percentage and changes due to genetic improvement.

Energy requirement for lactation

Energy requirements for pregnancy in ewes and ewe hogs (where appropriate) are estimated from total weight of lamb reared to weaning (Appendix 4 Equation 4). Age at physiological weaning (56 days) is fixed for all flock types and represented the age at which the contribution of lactation to lamb growth has become minimal. This is consistent with the current protocol for measuring maternal ability in UK genetic improvement programmes. The actual weight of lamb at weaning is derived from appropriate growth rates for each of the flock types taking into account weight at birth and number of lambs reared. It is assumed that increasing growth rates pre-weaning are a function of increasing efficiency of milk production in the ewe and so changes in lamb growth rate as a result of genetic improvement are not reflected in an increase in energy requirements associated with lactation.

Energy requirement for wool

Energy requirements for wool growth are estimated from average wool production per year for each class of stock (Appendix 4 Equation 5). Wool output is assumed to remain unchanged over the period modelled.

Adjustment for feed digestibility between different flock types

Tier 2 methodology includes a coefficient for digestibility of feed. Inherent variation in feed quality between different flock types is therefore included within the model. Table 3.3 illustrates the digestibility coefficients selected from recommended values within the IPCC report for the various flock types. It is assumed that there are no differences in feed digestibility within each of the flock types modelled.

Table 3.3 Representative feed digestibility for different flock types

Class of stock	Predominant feed type	Digestibility Coefficient (Digestible energy as a percentage of gross energy)
Hill flock		
Ewes	Low quality forage	50%
Ewe hogs	Low quality forage	50%
Rams	Medium quality pasture	65%
Lambs	Medium quality pasture	65%
Upland flock		
Ewes	Medium quality pasture	60%
Ewe hogs	Medium quality pasture	60%
Rams	Good quality pasture	70%
Lambs	Good quality pasture	70%
Lowland flock		
Ewes	Good quality pasture	70%
Ewe hogs	Good quality pasture	70%
Rams	Good quality pasture	70%
Lambs	High quality pasture	75%

Methane conversion factor

Following the estimation of gross energy requirement for a given level of production and flock type, the level of methane production is estimated using default methane conversion factors given in the Tier 2 methodology. The methane conversion factors used were 6.5% for ewes and rams, 6.0% for ewe hogs and 4.5% for lambs.

3.4 Industry structure

Data relating to breed and industry structure are drawn from the Welsh Sheep Strategy breed survey of 2000, the national sheep breed survey of 2003 (Pollott and Stone, 2004) and the most recent estimates of the ewe numbers in Wales (Welsh Assembly Government, 2010).

4 Results

4.1 Baseline estimates of likely changes in methane emissions as a consequence of genetic improvement

Genetic improvement in hill breeds

The expected annual genetic progress in individual traits in a hill flock using the Welsh Hill Index as a selection criterion is shown in Figure 4.1. The expected annual genetic changes in flock efficiency and methane outputs are shown in Table 4.1 together with the consequential genetic progress that would be expected to occur in lowland flocks using crossbred ewes bred out of improved purebred hill ewes.

In hill flocks the weight of lamb weaned per ewe is expected to increase by approximately 0.4% per year representing an increase of approximately 0.8 kg per ewe over a ten year period of selection. The time required to finish lambs is expected to decrease at a similar rate. Methane emissions are expected to decrease very slightly as a consequence. If changes in ewe weight are limited, methane emissions per ewe and per unit of output (tonne of carcase) are expected to be reduced by approximately 0.05% per year.

It is not only hill flocks that benefit from genetic improvement of hill ewes, but also lowland flocks that use their crossbred daughters. Small benefits in reduced methane emissions from lowland flocks are also expected as a result of genetic improvement in hill flocks. The rate of reduction in methane emissions is greater if change in ewe weight of the hill breed, and therefore, the crossbred ewe, is limited.

Taking into consideration the genetic contribution of the hill breeds to hill, upland and lowland sectors in Wales, genetic improvement of the entire hill ewe population using current indexes is expected to have a negligible effect on methane emissions per tonne of carcase produced per year. If there is no change in ewe weight the expected annual reduction in methane emissions is 0.03%.

Figure 4.1 Expected annual genetic change in individual traits in a hill flock (% mean per year)

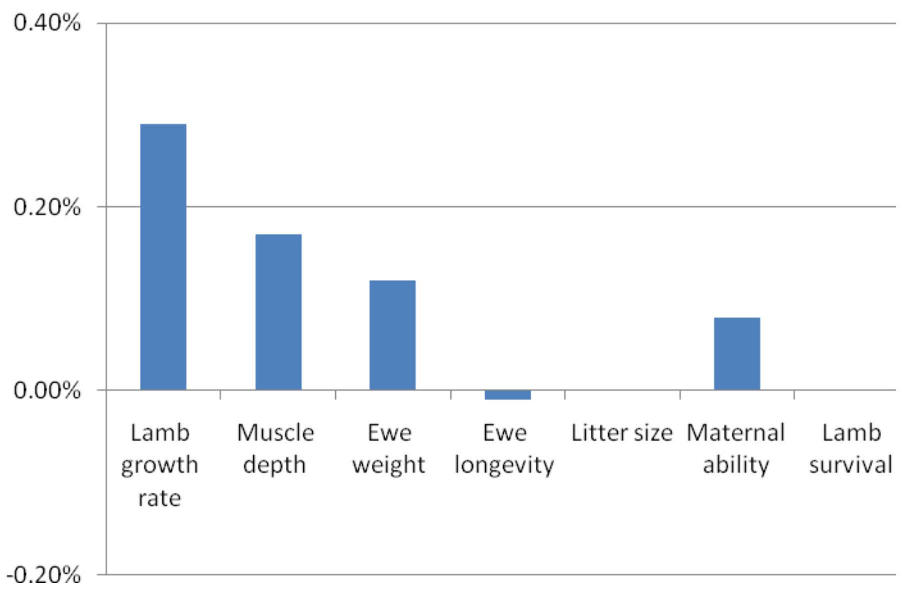


Table 4.1 Expected annual genetic change in flock efficiency and methane production resulting from the genetic improvement of hill ewes

	Improved hill flock	(% of mean)	Lowland flock using improved ewes	(% of mean)
Flock efficiency				
Lamb weaned (kg live weight) per ewe	0.08	0.37%	0.05	0.09%
Lamb weaned (kg live weight) per kg ewe weight	<0.01	0.24%	0.00	0.03%
Carcase* produced per ewe (kg)	0.01	0.05%	0.01	0.01%
Days to finish/lamb	-0.60	-0.33%	-0.11	-0.07%
Days to finish per kg carcase*	-0.05	-0.37%	-0.01	-0.08%
Methane emissions				
Methane emissions (kg) per ewe	0.01	0.04%	<0.01	0.01%
Methane emissions (kg) per tonne carcase	-0.02	0.00%	-0.01	0.00%
If no change in ewe weight				
Methane emissions (kg) per ewe	-0.01	-0.03%	<-0.01	-0.01%
Methane emissions (kg) per tonne carcase	-0.45	-0.05%	-0.07	-0.02%

*Equivalent of the carcase weight produced if all lambs were finished on farm

Genetic improvement in crossing sire breeds

The genetic improvement of crossing sires (e.g. Blue Faced Leicester and Border Leicester) contributes to performance in upland flocks that use these sires to produce breeding ewes for sale, but also produce wether lambs for finishing, and the lowland flocks that use the crossbred daughters of the crossing sire. The expected annual genetic changes in both these flock types are shown in Table 4.2. It is assumed that selection is based on the Longwool Index that was designed to improve the performance of the crossbred mule, and not necessarily output in the upland flock using a crossing sire.

Selection using the current Longwool Index is expected to result in a small increase in weight of lamb weaned, but also an increase in ewe weight. These changes in performance are expected to result in a slight decrease in methane emissions per tonne of carcase produced in hill flocks as lamb growth rate is improved, and a very slight decrease in emissions in lowland flocks. If there is no increase in ewe weight the annual reduction in methane emissions is considerably higher (0.09% per tonne of carcase produced).

Across the industry, taking into account the genetic contribution of crossing sires in the different sectors, the expected results of genetic improvement of all crossing sires is expected to be a 0.01%

decrease in methane emission per tonne of carcase produced per year if ewe weight increases and a 0.03% decrease per year if ewe mature weight remains stable.

Table 4.2 Expected annual genetic change in flock efficiency and methane production resulting from the genetic improvement of crossing sires

	Upland flock using improved crossing sires	(% of mean)	Lowland flock using improved ewes	(% of mean)
Flock efficiency				
Lamb weaned (kg live weight) per ewe	0.01	0.02%	0.02	0.01%
Lamb weaned (kg live weight) per kg ewe weight	<0.01	0.02%	0.05	0.18%
Carcase* produced per ewe (kg)	0.05	0.18%	0.07	0.15%
Days to finish/lamb	0.34	0.22%	0.10	0.06%
Days to finish per kg carcase*	<0.01	0.00%	<0.01	0.00%
Methane emissions				
Methane emissions (kg) per ewe	0.01	0.07%	0.02	0.14%
Methane emissions (kg) per tonne carcase	-0.47	-0.10%	-0.03	-0.01%
If no change in ewe weight				
Methane emissions (kg) per ewe	0.01	0.07%	0.01	0.07%
Methane emissions (kg) per tonne carcase	-0.48	-0.10%	-0.27	-0.09%

*Equivalent of the carcase weight produced if all lambs were finished on farm

Genetic improvement in terminal sire breeds

The expected annual genetic improvement in a lowland flock using improved terminal sires selected on the Lean Index is shown in Figure 4.2 and the influence of these improved sires on flock efficiency and methane emissions is shown in Table 4.3

Genetic improvement of terminal sires is expected to increase lamb growth rate and muscle depth and thus the weight of lamb weaned per ewe and decrease the number of days each lamb is on farm, thus reducing methane emissions by 0.07% per kg carcase produced per year. On an industry basis genetic improvement of terminal sires is expected to reduce methane emissions per kg carcase produced by 0.02% per year.

Figure 4.2 Expected annual genetic change in individual traits in a lowland flock as a result of genetic improvement of terminal sires (% mean per year)

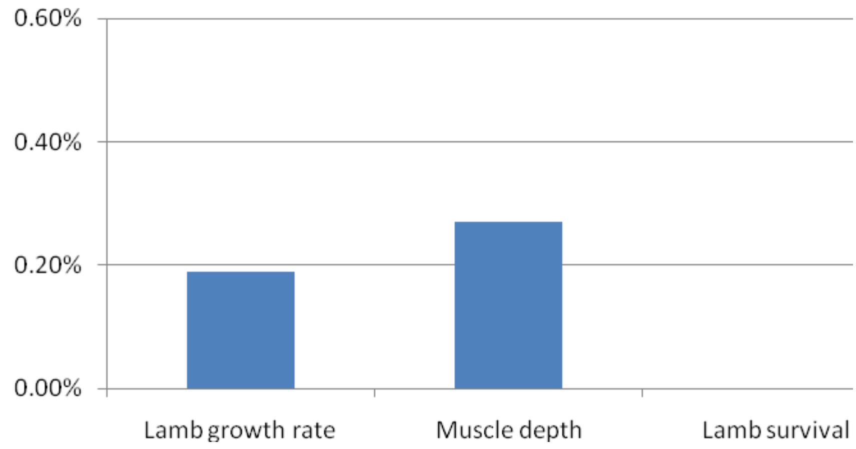


Table 4.3 Expected annual genetic change in flock efficiency and methane production resulting from the genetic improvement of terminal sires

	Lowland flock using improved terminal sires	(% of mean)
Flock efficiency		
Lamb weaned (kg live weight) per ewe	0.14	0.24%
Lamb weaned (kg live weight) per kg ewe weight	<0.01	0.24%
Carcase* produced per ewe (kg)	0.03	0.07%
Days to finish/lamb	-0.13	-0.08%
Days to finish per kg carcase*	-0.01	-0.15%
Methane emissions		
Methane emissions (kg) per ewe	0.00	0.00%
Methane emissions (kg) per tonne carcase	-0.22	-0.07%

*Equivalent of the carcase weight produced if all lambs were finished on farm

Genetic improvement in all breed types

The expected genetic improvement that could be achieved by combined genetic improvement of all breeds types is shown in Table 4.4. In both upland and lowland flocks this is likely to result in an improvement of flock efficiency and a reduction of methane emissions by 0.08% per year. The annual reduction in methane emissions is expected to be greater if ewe weight remains unchanged. Across the industry as a whole genetic improvement in all breed types combined is expected to result in a decrease of 0.03% per year in methane emissions per kg carcase produced if ewe weight increases and a decrease of 0.08% per year if ewe weight is unchanged.

Table 4.4 Expected annual genetic change in flock efficiency and methane production resulting from the genetic improvement of all breed types

	Improved upland flock using improved crossing sires	(% of mean)	Lowland flock using improved ewes and improved terminal sires	(% of mean)
Flock efficiency				
Lamb weaned (kg live weight) per ewe	0.07	0.19%	0.26	0.44%
Lamb weaned (kg live weight) per kg ewe weight	<0.01	0.06%	<0.01	0.18%
Carcase* produced per ewe (kg)	0.05	0.21%	0.11	0.24%
Days to finish/lamb	0.08	0.05%	-0.14	-0.09%
Days to finish per kg carcase*	-0.01	<-0.01%	-0.01	-0.23%
Methane emissions				
Methane emissions (kg) per ewe	0.02	0.12%	0.02	0.15%
Methane emissions (kg) per tonne carcase	-0.38	-0.08%	-0.25	-0.08%
If no change in ewe weight				
Methane emissions (kg) per ewe	0.01	0.05%	0.01	0.06%
Methane emissions (kg) per tonne carcase	-0.62	-0.13%	-0.56	-0.18%

*Equivalent of the carcase weight produced if all lambs were finished on farm

4.2 Effect of single trait selection on emissions

The potential for genetic improvement in individual traits to alter methane emissions from hill and lowland flocks is shown in Table 4.5 and 4.6 respectively, together with the expected correlated changes in other traits. The expected rates of genetic gain achieved for the traits selected are considerably higher than could be achieved with index selection but it serves as a useful comparison of the traits in terms of their potential benefits in reducing methane emissions.

Table 4.5 Expected annual genetic change (% mean) in traits in a hill flock following single trait selection in a hill breed

	Selected Trait				
	Lamb growth	Prolificacy	Ewe Longevity	Muscle Depth	Lamb Survival
Individual Traits					
Lamb growth rate (g/day)	**1.4%**	0.0%	0.0%	0.4%	0.2%
Muscle Depth (mm)	0.2%	0.0%	-0.1%	**1.1%**	0.0%
Ewe Mature Size (kg)	0.4%	0.2%	0.1%	0.0%	0.0%
Ewe Longevity (years)	0.0%	0.1%	**2.3%**	-0.2%	0.0%
Litter Size (lambs)	0.0%	**1.5%**	0.4%	0.0%	0.0%
Maternal ability (kg)	0.1%	0.0%	0.0%	0.0%	0.0%
Lamb survival	0.1%	0.0%	0.0%	0.0%	**0.2%**
Flock efficiency					
Lamb weaned (kg live weight) per ewe	1.5%	1.3%	0.3%	0.4%	0.2%
Lamb weaned (kg live weight) per kg ewe weight	0.9%	1.0%	0.2%	0.4%	0.2%
Carcase* produced per ewe (kg)	0.1%	1.6%	0.5%	0.4%	0.0%
Days to finish/lamb	-1.0%	0.1%	0.0%	0.2%	-0.2%
Days to finish per kg carcase*	-1.1%	0.0%	-0.1%	-0.2%	-0.2%
Methane emissions					
Methane emissions (kg) per ewe	0.15%	0.34%	0.0%	0.14%	-0.03%
Methane emissions (kg) per tonne carcase	0.04%	-0.88%	-0.38%	-0.25%	-0.03%
If no change in ewe weight					
Methane emissions (kg) per ewe	-0.13%	0.21%	-0.03%	-	-
Methane emissions (kg) per tonne carcase	-0.13%	-0.94%	-0.43%	-	-

*Equivalent of the carcase weight produced if all lambs were finished on farm

Table 4.6 Expected annual genetic change in traits (% mean) in a lowland flock following single trait selection in all breeds

	Selected Trait				
	Lamb growth	**Prolificacy**	**Ewe Longevity**	**Muscle Depth**	**Lamb Survival**
Breeds selected	**All**	**Hill and Longwool**	**Hill and Longwool**	**All**	**All**
Individual Traits					
Lamb growth rate (g/day)	**1.0%**	0.0%	0.0%	0.6%	0.0%
Muscle Depth (mm)	0.2%	0.0%	-0.1%	**1.1%**	0.0%
Ewe Mature Size (kg)	0.3%	0.1%	0.1%	0.0%	0.0%
Ewe Longevity (years)	0.0%	0.1%	**2.4%**	-0.2%	0.0%
Litter Size (lambs)	0.0%	**1.1%**	0.3%	0.0%	0.0%
Maternal ability (kg)	0.7%	0.0%	0.0%	0.0%	0.0%
Lamb survival	0.9%	0.0%	0.0%	0.3%	**0.1%**
Flock efficiency					
Lamb weaned (kg live weight) per ewe	1.2%	0.9%	0.2%	0.4%	0.2%
Lamb weaned (kg live weight) per kg ewe weight	0.8%	0.7%	0.1%	0.4%	0.2%
Carcase* produced per ewe (kg)	0.1%	0.9%	0.0%	0.5%	0.0%
Days to finish/lamb	-0.8%	0.0%	-0.2%	0.3%	-0.1%
Days to finish per kg carcase*	-0.9%	-0.1%	0.0%	-0.2%	-0.1%
Methane emissions					
Methane emissions (kg) per ewe	0.00%	0.27%	-0.11%	0.21%	-0.03%
Methane emissions (kg) per tonne carcase	-0.07%	-0.53%	-0.13%	-0.27%	-0.06%
If no change in ewe weight					
Methane emissions (kg) per ewe	-0.16%	0.21%	-0.15%	n/a	n/a
Methane emissions (kg) per tonne carcase	-0.23%	-0.60%	-0.17%	n/a	n/a

*Equivalent of the carcase weight produced if all lambs were finished on farm

Despite increases in flock efficiency, selection for lamb growth in the hill breed is expected to also increase ewe weight and so the potential benefit of selecting on this trait in terms of methane emissions is negated. In lowland flocks, however, the benefits of improved lamb growth rate are sufficient to counteract the effect of increased ewe weight resulting in an annual reduction of methane emissions. Due to the numerical dominance of hill ewes in Wales, across the industry as a whole, selection for increased lamb growth rate in all breed types would result in a very small annual increase in methane emissions (0.01% per year) if ewe size was allowed to increase and a significant reduction if there was no change in ewe size (0.13% per year).

The potential benefits of genetic improvement of both prolificacy and ewe longevity are significant in terms of reducing methane emissions in all sectors of the industry. Across the industry as a whole the potential decrease in methane emissions is 0.6% to 0.7% per year if selection is based on prolificacy. Once again, the numerical dominance of hill ewes in the national flock means that selection for prolificacy in hill breeds contributes most to reductions in methane emissions across the industry but genetic improvement in this trait in the crossing breeds also has a significant effect, potentially contributing an annual reduction of 0.08% in methane per tonne of carcase produced.

Genetic improvement of carcase quality by selection on traits such as muscle depth is also expected to have an effect on methane emissions in hill flocks due to correlated improvements in carcase weight and therefore result in an annual reduction in methane emissions per kg carcase in both hill and lowland flocks. Genetic improvement of lamb survival is expected to be low in all flocks because of the low heritability of this trait, but nevertheless it is expected to result in a small annual decrease in methane emissions in lowland flocks.

5 Discussion

The study has shown that current genetic improvement programmes for terminal sire breeds are expected to result in a significant decrease in methane emissions per tonne of carcase produced. Genetic improvement of hill and crossing sire breeds are expected to result in slight decreases in methane emissions.

In both hill and crossing sire breeds the expected correlated increase in ewe weight reduces the impact of current genetic improvement programmes on methane emissions. The influence of ewe weight on methane emissions is related to the increased energy requirement of heavier sheep for maintenance and activity which account for a high proportion of total energy requirements (and thus methane emissions) within the flock. Estimates from the model suggest that for lowland ewes 70% of their total energy requirements are associated with maintenance and activity. For hill ewes this increases to 82% (see Appendix 5).

Ewe weight is expected to increase as a correlated response to selection for lamb growth due to the positive genetic correlation of the two traits (0.5 in the current study), and the relatively high heritability of mature weight (0.36). The estimate of the genetic correlation and heritability used in this study are conservative. In a comprehensive review of genetic parameter estimates Safari *et al* (2005) reported a genetic correlation of 0.78 between ewe weight and lamb growth rate, and a genetic correlation of 0.68 between 20 week weight and ewe weight was found in the Longwool project (IRS, 2006). The estimates of heritability for ewe weight were 0.3 to 0.4, and 0.35 to 0.45, respectively, depending on breed type.

The main index used for the genetic improvement of hill sheep in Wales is the Welsh Hill Index. This index was designed to improve lamb growth, carcase weight and composition and ewe maternal ability. As a consequence ewe size is expected to increase. For this to be achieved the Welsh Hill Index could be modified to restrict changes in ewe weight, however, this will reduce the rate of genetic improvement that can be achieved in other positively correlated traits. Alternatively the alternative Hill 2 Index, which has not been examined in this study, could be used as this index is designed to restrict changes in ewe weight.

The Longwool Index was developed to achieve genetic improvement in crossbred ewes through selection within crossing sire breeds (Blue Faced Leicester and Border Leicester). In the development of the original index a stated aim was to restrict changes in ewe weight. However, the weightings have since been changed and the modified index would appear to result in an increase in ewe weight. Despite this, this study has shown that genetic improvement of crossing sires using this index are expected to lead to a slight decrease in methane emissions in lowland flocks. The rate of reduction could, nevertheless, be accelerated if increases in ewe weight were actually restricted.

Other breeds of crossing sire use different indexes that have not been examined in this study, but the results suggest that any breed or selection policy that increases the prolificacy and longevity of the crossbred ewe without significantly increasing ewe weight are likely to be beneficial in terms of reducing methane emissions.

This study has examined the potential improvements that could be achieved through breed improvement of sheep within Wales if all sheep used to supply breeding stock were performance recorded and selected. In reality only a small proportion of the ewes that produce future breeding stock are in flocks that are currently actively involved in performance recording and genetic improvement programmes. Recent figures supplied by Signet show that the recorded ewe population in Wales accounts for less than 1% of purebred hill ewe flocks, 7% of crossing sire flocks and 3% of terminal sire flocks in Wales. Those flocks that are actively involved in performance recording are likely to supply a disproportionate number of breeding rams and recorded rams are bought in from other regions of the UK, but it is unlikely that this level of performance recording is going to make any significant contribution to the reduction of methane emissions. The Welsh Breed Improvement Scheme administered by HCC aims to increase the rate of uptake of genetic improvement and performance recording within pedigree flocks and so could have an important role to play in helping the industry achieve reductions in methane emissions through genetic improvement.

The expected genetic changes achieved through single trait selection in the model have shown that genetic improvement of prolificacy and ewe longevity has potential for achieving significant changes in methane emissions. Again this relates to the relative importance of the energy requirement for maintenance of ewes. The study carried out by Genesis Faraday in 2008 reached a similar conclusion with respect to prolificacy. Cruikshank, Thomson and Muir (2008) also concluded that increasing prolificacy and increasing ewe longevity through management changes had the greatest potential for reducing methane emissions.

Ewe longevity is not currently included in improvement programmes within Wales. If it is to be included in selection objectives information on genetic parameters within hill breeds are required. Robust genetic parameters have been reported for ewe longevity in the Blue Faced Leicester and their Mule progeny (Mekkawy *et al*, 2009), but similar data does not exist for hill breeds. Given the importance of this trait to flock efficiency and it's potential for helping to reduce methane emissions, together with the influential role of the hill breeds to the Welsh industry, there is a clear need to establish sound genetic parameters for ewe longevity in hill flocks.

Traits such as residual feed intake and feed efficiency have not been included in the study as currently there are no robust methods of recording these traits on a large scale flock basis. However, previous studies have shown that these are also likely to have a significant effect on reducing methane emissions. Research carried out in Australia has focused on the identification of beef cattle with increased efficiency of utilisation of feed. Hegarty *et al* (2007) showed that enteric methane emissions from beef cattle could be reduced through the selection of more feed-efficient animals based on their estimated breeding value. This offered a mechanism for reducing feed costs, methane production, and potentially the nitrous oxide emissions without compromising growth rate. It is recognised that there is between-sheep variation in methane emissions (Pinares-Patino *et al*, 2003). The reasons for this difference are likely to be multi-factorial, and not necessarily genetic, but the work carried out by Pinares-Patino *et al* (2003) suggests that low methane emitters were able to retain a greater proportion of gross energy intake for biological functions, although it was noted that this was based upon a small dataset. Traits such as feed efficiency and low methane production are likely to further reduce emissions through genetic selection if they are shown to be heritable. However, considerable research is still needed to develop protocols for large-scale measurements of these traits and for estimation of genetic parameters. The identification of genetic markers to enable wide-scale screening of sheep populations would lead to higher rates of genetic progress. The beef sector already uses DNA tests such as GeneSTAR® (Pfizer), a panel of DNA markers which includes predictors of feed efficiency.

A number of other studies have predicted the effect of genetic changes in production traits on methane emissions from sheep but few have based it on actual or predicted genetic changes in correlated traits. The study carried out by Genesis Faraday in 2008 (Genesis Faraday, 2008) used actual genetic trends recorded over the period 1987 to 2007, but used lifecycle analysis rather than focusing just on enteric emissions as in this study. The Genesis Faraday report concluded that the genetic changes were likely to contribute to a reduction in methane emissions of 4.2% after 15 years, if all sires used in the industry were from performance recorded flocks. It was noted that most of the benefit was achieved through genetic improvements of fecundity. Our study predicts that, if all flocks were using performance recorded breeding stock, a reduction of methane emissions of 1.2% could be achieved over a 15 year period, however, the Welsh flock has a higher proportion of hill ewes (approximately 50%) compared to the UK flock (approximately 25%), which in our study have a negligible impact of reducing methane emissions, and none of the breed types included in our model actively select to improve fecundity. The rates of genetic gain predicted in individual traits are comparable in the two studies but in our study a greater number of correlated traits were considered, including lamb survival, ewe longevity, carcase weight and maternal components of a number of lamb traits. This may mean that estimates of both flock outputs and inputs are likely to be more greatly influenced by genetic changes than the model used by Genesis Faraday.

Direct comparison of the two studies is problematic due to the range of assumptions that are required as part of the modelling process. Due to the inherent difficulties in measuring methane gas production a great deal of research on emissions is based upon mathematical modelling. Currently, national inventories of methane emissions from enteric fermentation are estimated using the IPCC Tier 1 methodology, which calculates methane emissions for each animal category by multiplying the animal population by the average emissions factor associated with the specific animal category (IPCC 2006). This Tier 1 methodology assumes that weight, age, gender and feeding systems are within animal category. This method of calculating enteric methane emissions does not account for differences in animal management, feeding strategy or days on farm. Using the IPCC Tier 2 methodology can improve emission estimates and reduce uncertainties as this methodology considers a number of variables influencing enteric methane emissions, including weight, age, gender and feeding systems. The selection of either Tier 1 or Tier 2 methodology can therefore have a significant impact on findings of such models. The current project used the more sensitive Tier 2 methodology which whilst proving a very robust methodology is likely to underestimate some of the benefits of genetic improvement. Whilst current genetic improvement programmes are widely recognised to improve animal productivity the element of feed efficiency in the expression of traits such as growth rate is not completely understood.

6 Conclusions

Current genetic improvement programmes used in the Welsh sheep industry are expected to achieve small but significant reductions in methane emissions if widely applied across the industry.

Of the traits examined in this study, those that are most likely to have a beneficial effect on methane emissions through genetic selection or breed substitution are ewe prolificacy, ewe longevity and muscle depth (through its correlated effect on carcase weight).

References

ADAS (2010) Breeding from ewe lambs. Report prepared for EBLEX 29 June 2010. http://www.eblex.org.uk/documents/content/research/rd_an_s_f_fr_-ewelambblueprint_210710.pdf

AFRC (1983) Technical Committee on Responses to Nutrients. CAB International, Wallingford, UK

AFRC (1993) Energy and protein requirements of Ruminants. CABI, Wallingford, UK.

Annett R W, Carson A F, Dawson L E R, Irwin D and Kilpatrick D J (2009) Lifetime performance of crossbred ewes in the hill sheep sector. Proceedings of the British Society of Animal Science pp 72. http://www.animalbytes.org/wp-content/uploads/2010/03/8_2009_072annett.pdf

Blaxter K L and Claperton J L (1965) Prediction of the amount of methane produced by ruminants. *British Journal of Nutrition* **19**: *511–522*.

Cruikshank G T, Thomson B C and Muir P D (2008) Modelling management change on production efficiency and methane output within a sheep flock. Report for Ministry of Agriculture and Forestry, New Zealand. http://www.maf.govt.nz/news-resources/publications.aspx?title=Modelling%20management%20change%20on%20production%20efficiency%20and%20methane%20output%20within%20a%20sheep%20flock

Garnsworthy PC (2004) The Environmental impact of fertility in dairy cows: a modelling approach to predict methane and ammonia emissions. Animal Feed Science and Technology **112**: *211-223.*

Genesis Faraday. (2007) Appendix 2: Modelling the effect of genetic improvement on emissions from livestock systems using Life Cycle Analysis. Project AC0204, Defra, London.

HCC (2009) Strategic Action Plan for Welsh Red Meat Industry. HCC, Aberystwyth, UK. http://www.hccmpw.org.uk/medialibrary/publications/Action%20Plan%20(English).pdf

Hegarty R (2009). Workshop report "Livestock breeding for greenhouse gas outcomes" March 3-5 2009 Museum Hotel, Wellington, New Zealand http://www.livestockemissions.net/Portals/0/Publications/Animal%20variationWkshp/Report_part1.pdf

Hegarty R S, Goopy J P, Herd R M and McCorkell (2007). Cattle selected for lower residual feed intake have reduced daily methane production. Journal of Animal Science **85**: 1479 - 1486

Intergovernmental Panel on Climate Change. (2006). 2006 IPCC guidelines for national greenhouse gas inventories. Volume 4: Agriculture, Forestry and other land use. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Japan: IGES.

IRS (2006) The development of multi-trait selection indices for longwool sheep to breed halfbred ewes of superior economic performance http://www.hccmpw.org.uk/farming_and_industry_development/research_and_development/longwool_sheep.aspx

Johnson K A and Johnson D E (1995) Methane emissions from Cattle. Journal of Animal Science **73**: *2483-2492*

Mekkawy W, Roehe R, Lewis R M, Davies M H, Bünger L, Simm G and Haresign H (2009) Genetic relationship between longevity and objectively or subjectively assessed performance traits in sheep using linear censored models . Journal of Animal Science **87**:3482-3489.

Mills J A N, Crompton L A, Bannink A and Reynolds C K (2010) Estimating methane emissions from enteric fermentation for the UK greenhouse gas inventory. Proceedings of the Nutrition Society **69**: *E336*

Muir P D and Thomson B C (2008) A review of dressing out percentage in New Zealand livestock. Report produced by On-Farm Research Ltd for the Ministry of Agriculture and Forestry, New Zealand. www.maf.govt.nz/.../review-dressing-out-percentage-in-nz-livestock.pdf

Nitter G (1978) Breed utilization for meat production in sheep. Animal Breeding Abstracts. 46:131-143

Olesen I, Perez-Enciso M, Gianola D and Thomas D L (1994) A comparison of normal and non-normal Mixed Models for number of lambs born in Norwegian sheep. Journal of Animal Science **72**: 1166-1173

Pinares-Patino C.S, Ulyatt M.J, Lassey K.R, Barry T.N and Holmes C.W. (2003) Persistence of differences between sheep in methane emission under generous grazing conditions. *Journal of Agricultural Science* **140:** 227-233

Pollot G E and Stone D G (2004) The breeding structure of the British sheep industry 2003. DEFRA, London, UK.

Safari E, Fogarty N M and Gilmour A R (2005) A review of genetic parameter estimates for wool, growth, meat and reproduction traits in sheep. *Livestock Production Science* **92** : 271–289

Ulyatt M J, Lassey K R, Martin R J, Walker C F and Shelton I.D (1997) Methane emissions from grazing sheep and cattle. Proceedings of the New Zealand Society of Animal Production **57**: *130-133*

Wall E; Bell M J; Simm G (2008). Developing breeding schemes to assist mitigation. Proceedings of the International Conference for Livestock and Global Climate Change. May, Hammemet, Tunisia. (Rowlinson, P; Steele, M; Nefzaoui, A ,eds) Cambridge University Press. p44-47.

Wall E, McVittie A, Eory V, Moran D (2009) Cost effectiveness of abating greenhouse gases from UK livestock systems. Proceedings of the British Society of Animal Science 2009. UK 30 March – 1 April 2009

Welsh Assembly Government (2010) Farming Facts and Figures 2010. Welsh Assembly Government, Cardiff, UK.

Appendix 1 Genetic Parameters used in the model

Appendix 2 Details of methods used for calculation in Flock Performance model

Distribution of litter sizes

The distribution of litter sizes across ewes was estimated using a threshold model based on an underlying normal distribution, with a mean equal to the number of lambs born per ewe lambing and a standard deviation based on a coefficient of variation of 0.35.

Number of lambs born per ewe lambing was calculated from mean values for number of lambs weaned per ewe joined, number of ewes lambing per ewe joined, and lamb survival rates taken from the Genetic model.

Effect of lamb birth type on birth weight, survival and growth rate

The effect of birth type on lamb performance traits was based on 3800 records collected within the Innovis genetics nucleus between 2007 and 2010. These values (Table A2.1) were used to adjust the birth weight, probability of survival and growth rate to 150 days in the flock performance model.

Table A2.1 Mean birth weight, survival and growth rate to 140 days of lambs in the Innovis nucleus 2007 - 2010

	Mean values			Relative values (used in model)		
	Single	Twin	Multiple	Single	Twin	Multiple
Birth weight (kg)	4.9	3.8	3.1	1	0.78	0.63
Survival (%)	96	95	88	1	0.99	0.92
Growth rate (g/day)	289	276	266	1	0.96	0.92

Longevity of ewes

The annual rate of loss of ewes was based on results from 1 797 mule ewes involved in the Longwool project reported by Mekkawy *et al* (2009). The marginal loss of ewes (proportion of ewes present at each parity that were lost due to culling or death before the next parity) was assumed to change equally across all parities and the change was approximated from the following equation:

Change in marginal loss/parity = $-0.0375\,\Delta L^4 - 0.0516\,\Delta L^3 + 0.0478\,\Delta L^2 - 0.1056\Delta L - 0.0014$

where ΔL = the change in mean age at culling/loss of the ewe (taken from Genetic model).

The marginal loss per parity was set to a minimum of 2%.

The reasons for loss of ewes at each parity was based on data from Mekkawy *et al* (2009), and is shown in Table A2.2

Table A2.2 Proportion of ewes leaving the flock at each parity due to culling and other reasons.

Parity	Proportion lost due to culling	Proportion lost due to other reasons (death/missing etc)
2	0.69	0.31
3	0.67	0.33
4	0.72	0.28
5	0.90	0.10
6	0.96	0.04

The timing of deaths of ewes was based on data from Annett *et al* (2009), who found that on average 31% of losses occurred between tupping and lambing, 37% between lambing and weaning and the remaining 32% occurred after weaning.

Appendix 3 Breed parameters used in the flock performance model

Breed Parameters	Hill breed	Crossing sire breed	Terminal sire breed
Ewes lambing/ewe joined	0.95	0.95	0.95
Lambs weaned/ewe joined	1.1	1.8	1.4
Longevity (mean age of culling) (years)	4.8	4.8	4.8
Ewe mature size* (kg)	45	85	85
Lamb survival (single lamb)	95%	95%	95%
Lamb birth weight (single lamb) (kg)	3.8	4.6	5.5
Growth rate (g/day)	170	280	320
20 week weight (kg)	27	44	50
Killing out	44%	44%	47%
Conformation (E=5,P=1)	2.5	2.8	3.5
Fat Class	3	3	3
Muscle Depth (mm)	23.2	22	27
Fat depth (mm)	3.5	2	3
Fleece weight (kg)	0.8	0.8	0.8
Percentage of rams sold for breeding	0	80%	80%

*Relative mature size of rams was assumed to be 1.3.

Appendix 4. Details of methods used for calculation of energy requirements and methane emissions

Equation 1. Net Energy requirement for maintenance

$NE_m = Cf_i * (kg\ live\text{-}weight)^{0.75}$

Where:
NE_m = net energy for maintenance, MJ day^{-1}
Cf_i = coefficient corresponding to animal category (Table 1)

Table A4.1: Coefficients for calculating net energy for maintenance (*NE_m*)

	Cf_i	
Animal Category	**Males**	**Females**
Ewe	n/a	0.217
Ram	0.250	n/a
Lamb	0.271	0.236

Equation 2. Net Energy requirement for activity

$NE_a = C_a * (kg\ live\text{-}weight)$

Where:
NE_a = net energy for activity, MJ day^{-1}
C_a = coefficient corresponding to animal's feeding situation

Equation 3. Net Energy requirement for growth

$$NE_g = \frac{WG_{lamb} * (a + 0.5b(BW_i + BW_f))}{365}$$

Where:
NE_g = net energy for growth, MJ day^{-1}
WG_{lamb} = live-weight (kg) at 1 year or at slaughter – live-weight at weaning (kg)
BW_i = live-weight (kg) at weaning
BW_f = live-weight(kg) at 1 year or at slaughter
A, b = constants as described in Table A4.2

Table A4.2: Constants used for calculating NE_g

Animal Category	**a (MJ kg^{-1})**	**b (MJ kg^{-1})**
Males	2.5	0.35
Females	2.1	0.45

Equation 4. Net Energy requirement for lactation

$$NE_l = \frac{(5*WG_{wean})}{365} * EV_{milk}$$

Where:
NE_l = net energy for lactation, MJ day^{-1}
WG_{wean} = weight gain of lamb(s) between birth and weaning (kg)
EV_{milk} = default value of 4.6 MJ kg^{-1} as energy requirement to produce 1kg of milk

Equation 5. Net Energy requirement for wool

$$NE_w = \frac{EV_{wool} * Production_{wool}}{365}$$

Where:
NE_W = net energy for wool, MJ day^{-1}
EV_{wool} = default value of 24 MJ kg^{-1} wool produced
$Production_{wool}$ = annual wool production, kg yr^{-1}

Equation 6. Net Energy requirement for pregnancy

$$NE_p = C_{pregnancy} * NE_m$$

Where:
NE_p = net energy required for pregnancy, MJ day^{-1}
$C_{pregnancy}$ = pregnancy coefficient according to birth type (Table 4)

Table A4.3: Constants used for calculating NE_p

Birth type	$C_{pregnancy}$
Single	0.077
Twin	0.126
Triplet	0.150

Equation 7. Ratio of net energy available in a diet for maintenance to digestible energy consumed

$$REM = [1.123 - (4.092*10^{-3}*DE\%)+[1.126*10^{-5}*(DE\%)^2]-(25.4/DE\%)]$$

Where:

REM = ratio of net energy available in a diet for maintenance to digestible energy consumed
DE% = digestible energy expressed as a percentage of gross energy

Equation 8. Ratio of net energy available in a diet for growth to digestible energy consumed

$$REG = [1.164 - (5.160*10^{-3}*DE\%)+[1.308*10^{-5}*(DE\%)^2]-(37.4/DE\%)]$$

Where:
REG = ratio of net energy available in a diet for growth to digestible energy consumed
DE% = digestible energy expressed as a percentage of gross energy

Equation 9.Gross energy

$$GE = \frac{\dfrac{NE_m + NE_a + NE_l + NE_p}{REM} + \dfrac{NE_g + NE_{wool}}{REG}}{\dfrac{DE\%}{100}}$$

Where:

GE = gross energy, MJ day^{-1}

NE_m = net energy for maintenance (Equation 1) MJ day^{-1}

NE_a = net energy for activity (Equation 2) MJ day^{-1}

NE_g = net energy for growth (Equation 3) MJ day^{-1}

NE_l = net energy for lactation (Equation 4) MJ day^{-1}

NE_W = net energy for wool (Equation 5) MJ day^{-1}

NE_p = net energy required for pregnancy (Equation 6) MJ day^{-1}

REM = ratio of net energy available in a diet for maintenance to digestible energy consumed (Equation 7)

REG = ratio of net energy available in a diet for growth to digestible energy consumed (Equation 8)

DE% = digestible energy expressed as a percentage of gross energy

Equation 10.Emissions factor for methane emissions

$$EF = \frac{GE * \dfrac{(Y_m)}{100} * 365}{55.65}$$

Where:

EF = emission factor, kg methane head^{-1} yr^{-1}

GE = gross energy intake (Equation 9), MJ head^{-1} day^{-1}

Y_m = methane conversion factor, percent of gross energy in feed converted to methane

Appendix 5. Distribution of energy requirements

Figure A5.1: Distribution of energy requirements in Hill ewes (Year 0)

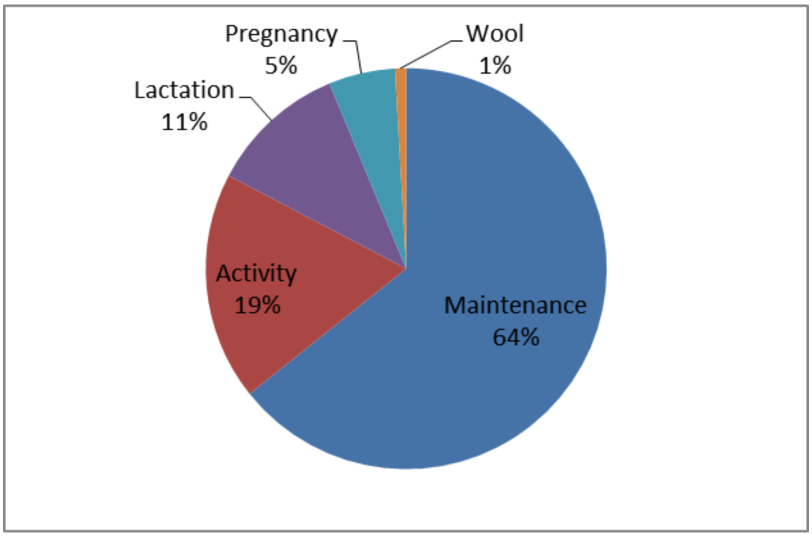
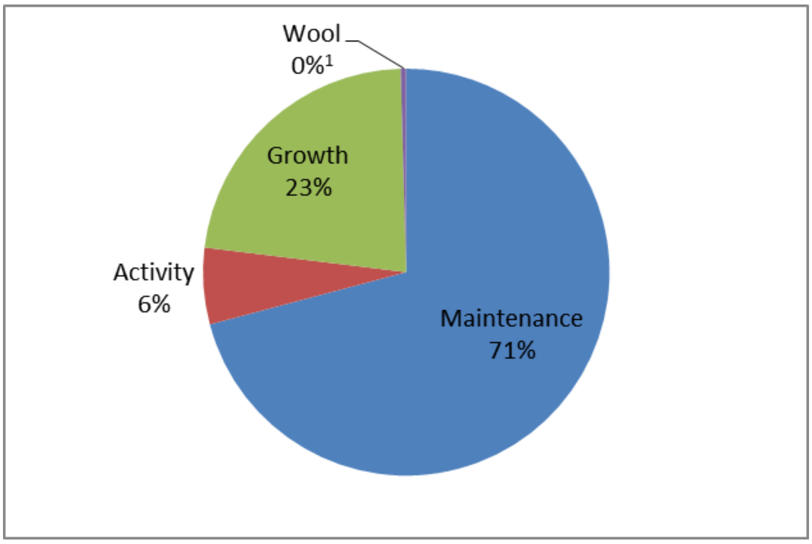


Figure A5.2: Distribution of energy requirements in Hill lambs (Year 0)



[1] <0.05%

Figure A5.3: Distribution of energy requirements in Lowland ewes (Year 0)

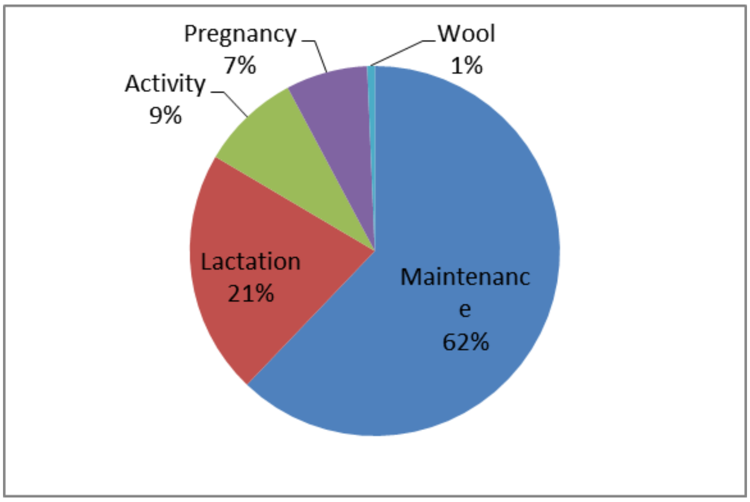
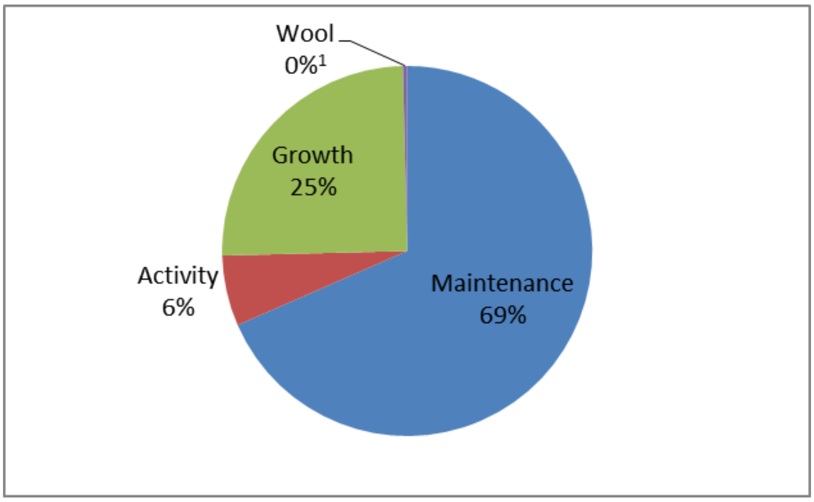


Figure A5.4: Distribution of energy requirements in Lowland ewes (Year 0)



[1] <0.05%

Appendix 1 Genetic Parameters used in the model

Traits	units	Vp	FEC	20 week weight	Ewes lambing/ewe joined	Lambs weaned /ewe joined	Longevity	Mature size	Lamb Birth weight	Maternal effect on birth weight	Growth rate	Maternal effect on lamb growth	Lamb Survival	Survival (maternal effect)	KO %	Conformation	Fat Class	Muscle Depth	Fat depth	Carcase weight	Individual Heterosis (%)	Maternal Heterosis (%)
FEC		0.5	0.3	-0.10	0	0	0	-0.12	0.11	0	0	0	0	0	0	0	0	-0.05	0	0	-	-
20 wk wgt	kg	36		0.25	0	0	0	0.50	0.27	0	0.75	0	0	0	0	-0.13	0.16	0.34	0.36	0	-	-
Ewes lambing/ewe joined		0.6			0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.60	8.70
Lambs weaned/ewe joined		0.3				0.07	0.12	0.33	0	0	0	0	0	0	0	0	0	0	0	0	15.20	14.70
Longevity	years	0.78					0.30	0.10	0.05	0	0	0	0	0	0	0	0	-0.09	-0.07	0	-	-
Mature size	kg	16						0.36	0.22	0	0.50	0	0	0	0	0	0	0	0	0	-	-
Lamb birth weight	kg	1.00							0.19	0	0.27	0	0	0	0	0	0	0	0	0	3.20	5.10
Birth weight (maternal)	kg	1.00								0.18	0	0	0	0	0	0	0	0	0	0	-	-
Growth rate	g/day	1156									0.17	0.10	0	0	0	0	0	0.23	0.34	0	5.30	
Lamb growth (maternal)	g/day											0.05	0	0	0	0	0	0	0	0	-	-
Lamb Survival		0.01											0.05	0	0	0	0	0	0	0	9.80	2.70
Survival (maternal)		0.01												0.06	0	0	0	0	0	0	-	-
KO %		0.04													0.42	0	0	0	0	0	-	-
Conformation	points	0.36														0.16	0.19	0.30	-0.08	0	-	-
Fat Class	points	0.14															0.14	0.20	0.97	0	-	-
Muscle Depth	mm	4.3																0.30	0.33	0.33	-	-
Fat depth	mm	0.15																	0.28	0.36	-	-
Carcase weight	kg	6																		0.27	-	-