Modelling management change on production efficiency and methane output within a sheep flock

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Index

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1. Summary

An model has been developed in Microsoft Excel which enables us to test the impact of different management strategies such as hogget lambing, improving lambing percentage and increasing ewe longevity on the methane production (relative to farm output) of a hypothetical 1000 ewe sheep flock.

The data used in the model has been obtained from the Poukawa Elite Lamb flock which comprises some of the only data available on “modern” sheep genotypes. The dataset used involves some 6000 ewe records from four genotypes and 8100 lamb records over 8 years. The base flock of 1000 ewes with 160% scanning produced 989 lambs for sale (a further 288 lambs are kept as replacements) and resulted in the production of 15.99 kg CH_4/lamb sold. Methane production is linked to feed intake and factors that improved flock efficiency meant that more lamb was produced for the same amount of dry matter intake. This resulted in reductions in methane per lamb sold.

- Lambing hoggets had the biggest impact and reduced methane/lamb sold by 13.6%. This was because the flock was producing more lambs without the maintenance cost of running any more ewes.

- Increasing ewe scanning percentage from 160 to 180% reduced methane output by 7.8%. This is assuming no increase in ewe liveweight and is achievable with Androvax or a breed change.

- Increasing ewe longevity from 5 to 6 years reduced methane output by 6.4%. In this scenario, fewer replacement hoggets need to be maintained to enter the flock.

These reductions are not necessarily cumulative as a ewe flock is a complex dynamic system and altering one factor will alter other components in the system and impact on methane output. Nevertheless, the combined effect of increasing longevity from 5 to 6 years, hogget lambing and increasing the scanning percentage from 160 to 180% resulted in a reduction of 21% in methane output per lamb sold.

Improving farm efficiency will not impact on the amount of methane produced at either the farm or a national level. However, management strategies which improve efficiency will change the amount of methane produced per unit of saleable product. Management practices which increase performance without markedly contributing to ewe maintenance requirement will have the biggest impact.

2. Introduction

The move to some form of emission trading scheme (ETS) means that in future farmers are likely to incur some form of carbon tax on methane (CH_4) emissions. Methane production by sheep is directly related to feed intake. The figures used in the New Zealand agricultural inventory model are 20.9 g CH_4/kg DMI (6.5% GEI) for adult sheep and 6.8 g CH_4/kg DMI (5.1% GEI) for sheep less than 1 year of age (Clark *et al*, 2003). For any defined level of production the energy requirement of individual sheep can be calculated and methane production predicted. Management changes that improve farm and animal efficiency and result in a greater meat and wool output per unit of methane production are likely to benefit sheep farmers as well as the general public.

This project set out to develop a model to test the impact of a wide range of changes in production efficiency within a sheep flock. Other models exist to predict methane production but are generally based on total numbers of animals. The original Tier 1 national inventory model used a fixed methane emission factor multiplied by an annual population estimate. The more accurate Tier 2 national inventory uses a breakdown of growing and breeding animals, the calculation of herbage intakes based on performance data for each animal sub-category on an annual or seasonal timescale, and the utilization of New Zealand derived information to calculate the extent to which feed energy is converted to methane (Clark *et al*, 2003). The model described in this report incorporates a much greater level of detail at an individual farm level. In effect, this model is a Tier 3 methane inventory applied at the level of an individual farm.

The objective was to develop a model that would enable us to test a range of management strategies on methane production relative to farm output. These included increasing lambing percentage, improving ewe and lamb survival, improving lamb growth rate, changing breed, hogget lambing and increasing ewe age by reduced culling.

3. Model description

3.1. Outline

The model is written in MS Excel. It is based on a flexible sheep production system (Figure 1) and allows for variation in numerous farm production traits. The traits which can be altered in the model include sire, ewe and lamb parameters as well as flock structure (Table 1).

Figure 1. Outline of the sheep production system within the model.

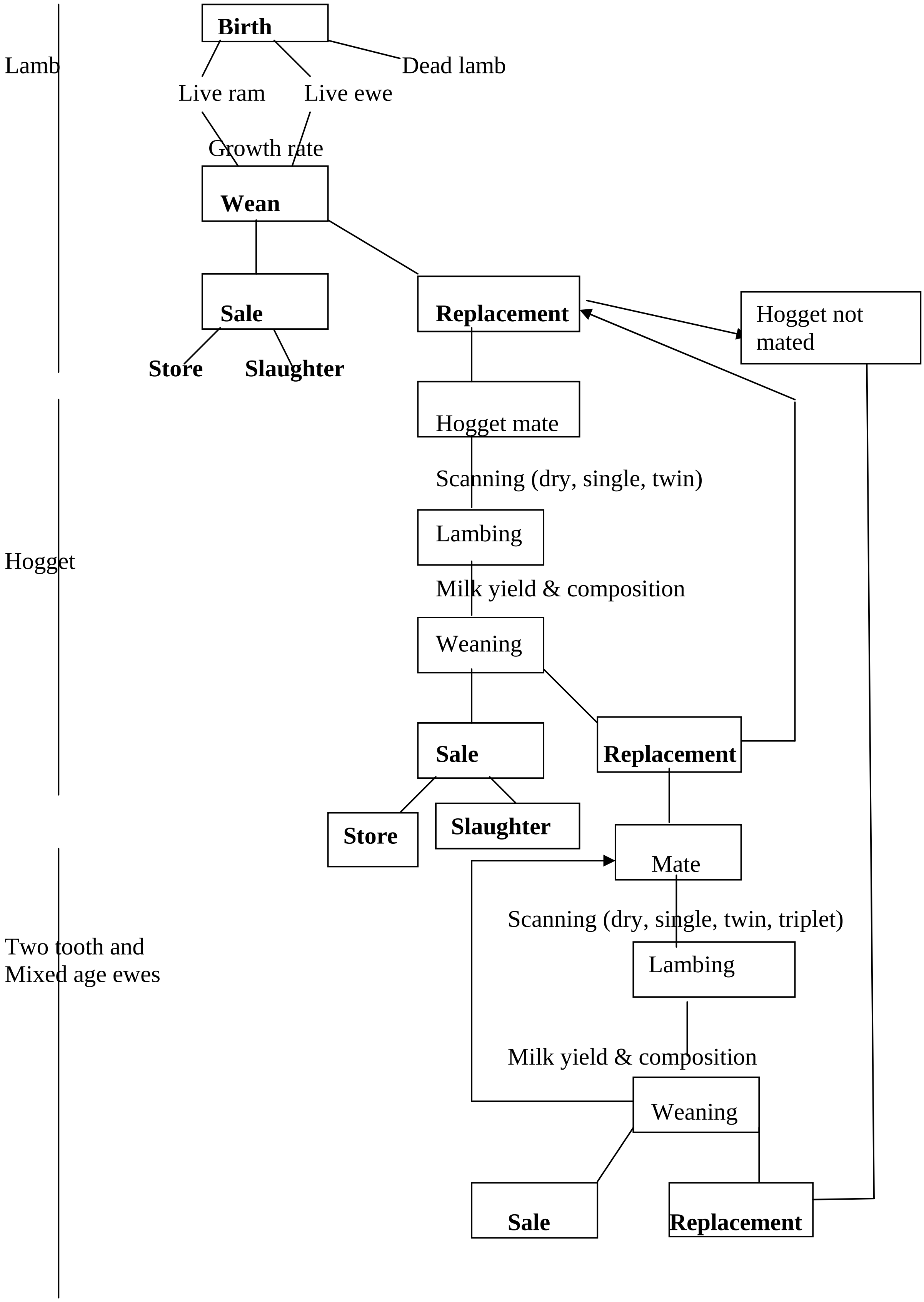


Table 1. Variables which can be changed within the model.

	Trait	Variable
Flock	Mating	Hogget lambing optional
	Replacement policy	Retain or buy in replacements
Hogget	Liveweight	Date and liveweight
	Survival	Percentage mortality
	Culling	Percentage culled
	Scanning	Percentage dry, single, twin
	Lambing	Date
	Lactation	Yield and composition
Two tooth	Liveweight	Date and liveweight
	Survival	Percentage mortality
	Culling	Percentage culled
	Scanning	Percentage dry, single, twin, triplet
	Lambing	Date
	Lactation	Yield and composition
Ewe	Liveweight	Date and liveweight
	Survival	Percentage mortality by age
	Culling	Percentage culled by age
	Culling	Age all removed
	Scanning	Percentage dry, single, twin, triplet
	Lambing	Date
	Lactation	Yield and composition
Lamb	Birth	Date and liveweight by single, twin and triplet
	Weaning	Date and liveweight by single, twin and triplet
	Growth	Liveweight gain by birth rank and age of dam
	Slaughter	Drafting weight
		Dressing percentage
		Carcass value
	Store lambs	Optional, date and value
	Survival	Perinatal and pre-weaning mortality by single, twin and triplet
Sire	Growth rate	Terminal sire effect on lamb growth rate

3.2. Production data used in the base model

The data used in the base model has been obtained from the Poukawa Elite Lamb flock which comprises some of the only data available on “modern” sheep genotypes. The dataset used involves some 6000 ewe records from four genotypes and 8100 lamb records over 8 years. Where ewe genotype differences were significant, only data from Romney ewes was used. In the Poukawa flock, ewes have been weighed and condition scored 3 times yearly and ewe milk production and composition data measured by breed and lamb rearing rank. Lamb birth weights, survival and growth rate figures are also available by breed and birth rank. Where data is unavailable a “best guess” approach has been used. The base model uses a 1000 ewe flock plus replacements.

3.2.1. Liveweight profiles. Lamb and ewe liveweights have been collected routinely at Poukawa for numerous years. Data for Romney ewes and their progeny have been used to create a reference liveweight profile. Lamb growth rates are determined by birth rank, sex and age of dam. Observed variation in growth rate within each sex and birth rank group was modeled by creating individual lamb growth profiles for 50 lambs per group. When hogget lambing is switched on, the model creates 800 individual growth profiles, allowing meaningful variation in lamb liveweights and drafting/ slaughter strategies. The reference liveweights for lambs are shown in Table 2.

An additional effect on lamb growth is available by using a terminal sire, with the ability to increase (or decrease) lamb growth rate depending on the genetic growth potential of the sire.

Annual variation on ewe liveweights are shown in Table 3. These include hogget, two tooth and mixed age ewe liveweights and the effect of pregnancy on ewe liveweight.

Table 2. Average lamb liveweights (kg) by age of dam and rear rank.

	Single		Twin		Triplet	
	Ram	Ewe	Ram	Ewe	Ram	Ewe
Hoggets						
1 September	4.7	4.3	3.7	3.5		
24 November	26.5	24.5	23.5	21.7		
13 December	30.6	28.1	27.1	24.9		
12 January	34.6	32.1	30.6	28.4		
12 February	37.4	34.9	32.8	30.6		
12 April	43.2	40.7	37.6	35.3		
12 June	53.0	50.6	45.8	43.5		
11 August	61.2	58.7	52.9	50.6		
Two tooth ewe						
15 August	5.74	5.32	4.52	4.34	4	3.8
7 November	29.9	27.6	26.5	24.4	23	21
26 November	34.4	31.7	30.5	28.0	27	25
26 December	38.9	36.2	34.4	31.9	30	28
26 January	42.0	39.3	36.8	34.4	33	30
26 March	48.4	45.8	42.2	39.7	39	35
26 May	59.4	56.7	51.3	48.9	47	43
25 July	68.6	65.9	59.2	56.8	55	51
MA ewe						
15 August	5.74	5.32	4.52	4.34	4	3.8
7 November	31.4	29.0	27.8	25.7	24.2	22.1
26 November	36.2	33.3	32.1	29.5	28.4	26.3
26 December	40.9	38.1	36.2	33.6	31.6	29.5
26 January	44.2	41.3	38.8	36.2	34.7	31.6
26 March	51.0	48.2	44.4	41.8	41.1	36.8
26 May	62.6	59.7	54.0	51.4	49.5	45.3
25 July	72.2	69.4	62.4	59.8	57.9	53.7

Table 3. Reference dates and ewe liveweights (kg).

	Date	Dry	Single	Twin	Triplet
Hoggets					
Ram out	11 April	41	41	41	
60 day "scan"	10 June	45	50	51	
Lambing	1 September *	49	60	65	
Weaning	24 November	52	50	48	
	5 February	53	52	50	
	31 March	57	57	57	
Two tooths					
Ram out	25 March	57	57	57	57
60 day "scan"	24 May	60	60	62	65
Lambing	15 August*	65	65	70	75
Weaning	7 November	65	63	61	60
	7 January	67	66	65	65
Ram out	25 March	70	70	70	70
MA ewes					
Ram out	25 March	70	70	70	70
60 day "scan"	24 May	73	73	73	73
Lambing	15 August *	76	76	80	82
Weaning	7 November	76	73	72	72
	7 January	73	72	71	71
Ram out	25 March	70	70	70	70

* Dates are derived from selected lambing dates

3.2.2. Ewe mortality. Ewe mortality has been taken from Poukawa ewe longevity data. Age of ewe was related to mortality rate and an increase of 0.5% per year was used in the model (Table 4).

Table 4**.** Ewe mortality losses by ewe age (years)

Age	% Mortality
1	0
2	0.5
3	1
4	1.5
5	2
6	2.5
7	3
8	3.5
9	4
10	4.5

3.2.3. Ewe culling rate. In the model, ewes are culled for three reasons:

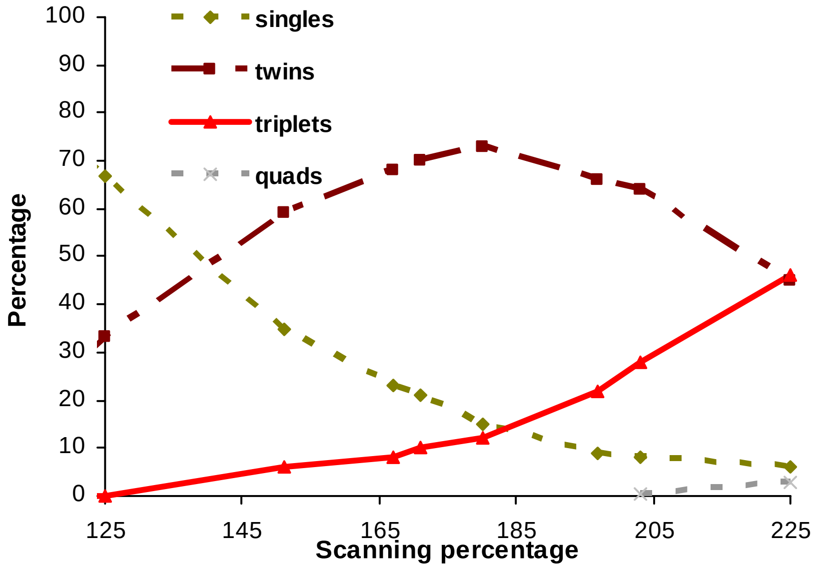
- Dries culled at pregnancy scanning (approximately 8% in the mixed age ewes)
- Culled for serious faults (feet, teeth, udder, etc) two weeks post-weaning and two weeks pre-mating (Table 5)
- All remaining ewes are age culled (base flock culled at 5 years of age).

Table 5. Percentage of ewes within each age group culled for serious faults

Age	% of age
1	0.0
2	0.15
3	0.7
4	1.2
5	2.0
6	2.5
7	3.0
8	3.0
9	3.0
10	3.0

3.2.4. Lambing % in two tooth and mixed aged ewes. The base model uses 150% and 160% scanning, for in lamb two tooth and mixed age ewes respectively, with 8% dries. The proportion of singles, twins and triplets was calculated from the data in Figure 2. This results in a weaning percentage of 127.7% (lambs weaned/ewe mated) using the lamb survival data in Table 6.

Figure 2. Percentage of singles, twins, triplets and quads in scanned ewes at Poukawa as scanning percentage increased



3.2.5. Lamb survival. Lamb survival and age of death was recorded for single, twin and triplet lambs. The time of death was grouped into two categories - birth to 2 days of age (this takes into account the resources utilized during pregnancy) and 2 days to weaning (this takes into account the resources needed during lactation as well as resources during pregnancy). The size of these losses varies with birth rank (Muir *et al.*, 2005). In particular, there are greater losses within triplets. Therefore, the model uses different mortality rates for the different birth ranks (Table 6). For this reason, lamb mortality accelerates as scanning rate increases.

Table 6**.** Lamb mortalities by age at death and litter size

Ewe Age	Age at death	% Single	% Twin	% Triplet
Hogget	Born dead	1.9	5.6	
	Birth to weaning	5.6	10.7	
2 tooth	Born dead	4.8	4.2	9.5
	Birth to weaning	4.9	7.6	15
MA ewe	Born dead	4.8	4.2	9.5
	Birth to weaning	4.9	7.6	15

3.2.6. Milk yield and composition. Milk yield and composition were measured at three weekly intervals in mixed age ewes rearing single, twin and triplet lambs. Milk yield at lambing was assumed to be 90% of milk yield at 3 weeks lactation and milk consumed by lambs was assumed to be 80% of total milk yield (Table 7). Milk yield for hoggets and two tooth ewes were assumed to be 80% and 90% of mixed age ewe yield respectively. Milk composition was assumed to be unaffected by age of ewe.

Milk energy content was calculated from milk composition (Table 8) and using the formula: Milk energy (J) = Fat x 38.12 + Protein x 24.52 + Lactose x 16.54.

There was little variation in the ME of the milk over lactation so a constant milk energy content of 5.63 MJ/l was used.

Table 7. Total milk consumption of lambs reared by MA ewes (litres/day)

	Single	Twins	Triplets
Lambing	1.465	1.906	2.126
3 weeks	1.628	2.117	2.362
6 weeks	1.307	1.675	1.858
9 weeks	1.152	1.135	1.127
12 weeks	0.889	0.846	0.824
15 weeks	0.720	0.615	0.562

Table 8. Milk composition of mixed aged ewes over lambing

Date	Fat (g/kg)	Protein (g/kg)	Lactose (g/kg)	Energy (MJ)
3 weeks	86.4	54.3	55.4	5.54
6 weeks	79.9	58.8	57.7	5.44
9 weeks	77.6	65.5	55.3	5.48
12 weeks	90.0	62.0	49.9	5.78
15 weeks	90.0	66.9	52.1	5.94
			Average energy content	5.63

3.2.7. Lamb sales (store, slaughter, drafting weights). The model drafts lambs on a weekly basis to a target weight of 37 and 40 kg for ewe and ram lambs respectively. This results in average hot carcass weights of 17.4 kg under this drafting strategy. The variation in growth rate and birth rank means that in the base model there are 23 drafts resulting in 989 lambs for sale between 11 November and 25 July.

Liveweight, hot carcass weight and GR were measured on all lambs slaughtered from the Poukawa progeny test. The model calculates hot carcass weight using a predictive equation derived from Poukawa lamb slaughter data.

3.3. Pasture quality and production

The energy content of pasture (ME) varies seasonally. The values used in the base model are taken from the data of Litherland et al (2002) and are the same as those used in the New Zealand inventory model (Clark et al 2003). Mean monthly values are indicated in Table 9.

Table 9. Pasture energy content (MJME) used in the model

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MJME/ kg DM	9.9	9.9	9.6	9.6	9.6	10.8	10.8	10.8	11.4	11.4	11.4	9.9

3.4. Calculation of animal energy requirements

ME requirements are calculated daily for individual animals (Table 10). These are derived from data published by AFRC (1993), CSIRO (1990) and Cruickshank (1986).

3.5. Calculation of methane production

Methane production is related to dry matter intake and the values used are those used in the methane model (Clark et al, 2003) of 16.8 g/kg DMI for sheep under one year of age and 20.9 g/kg DMI for sheep over one year of age.

Table 10. ME requirements for individual animals

Stock class	Trait	ME requirement
Ram lamb	Maintenance (lact)	$(0.0106*W+0.4025*(W/1.08)^{0.75})/0.85$
Ewe lamb	Maintenance (lact)	$(0.0106*W+0.35*(W/1.08)^{0.75})/0.85$
Ram lamb	Maintenance (wean)	$(0.0106*W+0.289*(W/1.08)^{0.75})/(0.35*q+0.503)$
Ewe lamb	Maintenance (wean)	$(0.0106*W+0.251*(W/1.08)^{0.75})/(0.35*q+0.503)$
Lamb	Growth (lactation)	LWG*EVg/0.7
Lamb	Growth (weaned)	LWG*EVg/(1.32*q-0.318)
Lamb	EVg	$10^{(0.11*LOG_{10}(LWG*1000)+0.004*W+0.88)}$
Ewe	Maintenance	$(0.0106*W+0.251*(W/1.08)^{0.75})/(0.35*q+0.503)$
Ewe	Growth (lactation)	LWG*EVg*0.81
Ewe	Growth (non-lact)	LWG*EVg/(1.32*q-0.318)
Ewe	EVg	$10^{(0.11*LOG_{10}(LWG*1000)+0.004*W+0.88)}$
Ewe	Pregnancy	$10^{(3.322-4.979*EXP(-0.00643*Dg))}*0.07372*EXP^{(-0.00643*Dg)}$ /0.133*0.25*BW
Ewe	Lactation	MY*EVm/(0.42+0.35*q)
Ewe	EVm	Fat*38.12+Protein*24.52+Lactose*16.54
Ewe	ME from weight loss	LWL*EVg*0.7

W = liveweight (kg)
LWG = liveweight gain (g/d)
LWL = liveweight loss (g/d)
BW = birthweight (kg)
Dg = stage of gestation (day)
EVg = energy value of gain (MJ)
MY = milk yield (l)
EVm = energy value of milk (MJ/kg)
q = metabolisability (pasture ME content divided by pasture GE content)

4. Model scenarios

4.1. Base flock overview

The reference flock used in the base model is comprised of 1000 ewes (including two tooth ewes) plus replacements. This means total dry matter intake (DMI) and methane (CH_4) production in tonnes are equivalent to kg per ewe. The number of replacements required is influenced by ewe survival, ewe culling rate and the age when ewes are culled. The number of lambs sold (lambs weaned minus replacements) has been used as the output criteria. Under the current format, lambs are slaughtered at a set liveweight so the net lamb figure is equivalent to net lamb weight sold. If drafting criteria are changed then we would need to take into account differences in weight of lamb sold. The base model has a 1000 ewe flock (average ewe mating weight 70 kg), scanning 1378 lambs, producing 989 lambs for sale and keeping 288 replacements. The cost is 15.99 kg of CH_4 per lamb sold. Changes in methane are expressed as percentage changes from the reference flock in terms of methane production per net lamb sold (Table 11).

Table 11. Output from the reference flock

Input		Reference	Table
Hogget	Liveweight	Average	3
Two tooth	Liveweight	Average	3
MA Ewe	Liveweight	Average	3
MA Ewe	Milk yield	Average	7
Two tooth	Milk yield	Average	7
Two tooth	Liveweight gain	Average	2
Lamb	Liveweight gain	Average	2
Sire	Liveweight gain	Average	
Ewe	Survival	Average	4
Ewe	Culling rate	Average	5
Lamb	Survival at birth	Average	6
Lamb	Survival to weaning	Average	6
Ewe	Age culled	5	
Two tooth & MA	Lambing date	15-Aug	
Two tooth & MA	Weaning date	7-Nov	
Two tooth	Dry %	8	
Two tooth	Scan %	150	
Ewe	Dry %	8	
Ewe	Scan %	160	
Hogget data when hogget lambing turned on			
Hogget	Milk yield	80% of average ewe	7
Hogget	Lambing date	1-September	
Hogget	Weaning date	24-November	
Hogget	Scan dry %	30	
Hogget	In lamb scan %	130	
Hogget lamb	Liveweight gain	Average	2
Hogget lamb	Survival birth	Average	6
Hogget lamb	Survival later	Average	6
Outputs			
Number of lambs produced		1277	
Number of replacements		288	
	Net lambs sold	989	
	Total DMI (Tonnes)	850.0	
	Total CH_4 (Tonnes)	15.818	
	kg CH_4/lamb sold	15.987	

4.1.1. Changing ewe liveweight. Increasing the liveweight of mixed age ewes without changing production levels increased the methane output per lamb sold (Table 12) simply because the maintenance requirement of the ewe increased. This can occur with lower performance ewes that tend to put on fat with improved feeding rather than increasing the weight of lamb they rear. On the other hand, decreasing ewe liveweight without altering production will increase ewe efficiency and reduce the amount of methane produced per lamb sold. In this case the model suggests a 10% decrease in ewe liveweight over the year will decrease methane output by 3.9%. The model can also be used to vary the change in ewe liveweight pattern throughout the year in order to determine the most efficient liveweight pattern.

Table 12. Effect of changing ewe liveweight on methane output per lamb.

Change in ewe liveweight	Methane output per lamb
Decreased by 10%	-3.9%
Base flock	15.987 kg
Increased by 10%	+4.8%
Increased by 20%	+9.8%

4.1.2. Changing lamb growth rate. Lamb growth rate in the model is calculated for sixteen classes of lamb - male singles, female singles, male twins, female twins, triplet males and triplet females born to two tooth and mixed age ewes and male singles, female singles, male twins and female twins born to hoggets (Table 2). Within each group there is a range in both directions to reflect the natural variability that occurs within each group. Increasing lamb growth rate by 10% in the model means all groups of lambs have their growth rates increased by 10%. Improving lamb growth rate by 10% across all groups whilst keeping everything else constant means lambs will reach killable weights faster and leave the property earlier. This results in a 2.6% reduction in methane output (Table 13) due to a reduction in the size of the lamb maintenance component. This increase in growth rate can be achieved through better feeding or through the selection of rams with higher breeding values for weaning weight/growth.

Table 13. The effect of increasing lamb growth rate on methane output per lamb

Change in lamb growth rate	Methane output per lamb
Decreased by 10%	+1.8%
Base flock	15.987 kg
Increased by 10%	-2.6%
Increased by 20%	-5.5%

4.1.3 Changing liveweights of all stock classes (ewes, hoggets and lambs). Selecting for an increase in ewe liveweight will also mean that her progeny (lambs and replacement hoggets) will grow faster and be heavier at any point. This faster growth rate in the lambs means that lambs can be slaughtered earlier but unlike in the previous example, this is off set by an increase in the maintenance requirements of the ewes and the replacement hoggets (Table 14).

Table 14. Effect of changing stock class liveweights on methane output

Liveweight of all classes of stock	Methane output per lamb
Decreased by 10%	-3.5%
Base flock	15.987 kg
Increased by 10%	+2.7%
Increased by 20%	+5.8%

4.1.4 Changing ewe mortality. Ewe mortality is affected by ewe age and the age structure of the flock will affect the overall ewe mortality. In the base flock ewe mortality is quite low (Table 4) and reducing the mortality of a 4 year old ewe by 10% only results in a reduction from 1.5% to 1.35% or 1.5 ewes per 1000 ewes. This small change has only a minor effect on methane output, with a 10% reduction in mortality leading to a 0.04% reduction in methane output per lamb (Table 15).

Table 15. Effect of changing ewe mortality on methane output per lamb

Change	Methane output per lamb
Increased by 10%	+0.04%
Base flock	15.987 kg
Decreased by 10%	-0.04%
Decreased by 20%	-0.08%

4.1.5 Changing ewe culling. Culling rates in the base (Poukawa) flock are relatively low as only ewes with severe issues are culled (Table 5). Therefore, changing the level of culling had a very small effect on methane output (Table 16). However, delaying culling on age for a year (i.e. at 6 years rather than 5) had a larger effect and decreased methane emissions by 6.5% as fewer replacements were needed and a higher proportion of the flock was productive (Table 17). Selection for ewe longevity has a role to play in reducing the methane output on New Zealand sheep farms.

Table 16. Effect of changing ewe culling rates on methane output per lamb

Change in culling rate	Methane output per lamb
Decreased by 10%	-0.03%
Base flock	15.987 kg
Increased by 10%	+0.03%
Increased by 20%	+0.06%

Table 17. Effect of delaying ewe culling age on methane output per lamb

Ewe culling age	Methane output per lamb
Base flock (5 years)	15.987 kg
6 years	-6.4%
7 years	-10.2%
8 years	-12.8%

4.1.6. Changing lamb mortality. The model calculates mortalities based on litter size. In this flock, lamb mortalities were relatively low (Table 6) and, therefore, reducing mortality only had a small effect on methane production (Table 18) with a 10% decline in mortality e.g. from 11.8% to 10.6% in twin lambs from mixed aged ewes reduced methane production by 1.8%. In flocks with higher mortality levels this effect is likely to be larger.

Table 18. Effect of changing lamb mortality rates on methane output per lamb

Lamb mortality rate	Methane output per lamb
Increased by 10%	+1.3%
Base flock	15.987 kg
Decreased by 10%	-1.3%
Decreased by 20%	-2.5%

The effect of a major storm at lambing was also modeled. In this scenario, a doubling in perinatal lamb mortality (9.6, 8.4 and 19% for singles, twins and triplets respectively) with no change in any other mortality figure, had the effect of increasing methane output per lamb by 3.6%.

4.1.7. Changing the proportion of dry ewes. Reducing the level of dries in the base model from 8% to 6% for both two tooth and mixed age ewes reduced the methane output by 2.7 % (Table 19).

Table 19. Effect of reducing dries at scanning on methane output per lamb.

% dries at scanning	Methane output per lamb
Decreased to 6%	-2.7%
Base flock (8% dry)	15.987 kg
Increased to 10%	+2.9%
Increased to 12%	+6.1%

4.1.8. Changing ewe scanning percentage. Changing the scanning percentage alters the number of multiples (Figure 2). This affects lamb growth rates and survival as the numbers of single, twin and triplet lambs change. Assuming a constant scanning difference of 10 units between two tooth and mixed age ewes, lifting scanning % of mixed age ewes from 160% to 180% will result in 14.7% more lambs weaned. However, an increase from 200% to 220% in the mixed aged ewes means only 11.7% more lambs weaned because of the higher mortality in triplet lambs (Table 20).

Table 20**.** Effect of changing scanning percentage on methane output per lamb

Two tooth	Mixed age	Wean %	Methane output per lamb
Base flock (150%)	Base flock (160%)	127.7	15.987
170%	180	142.4	-7.8%
190%	200%	156.5	-13.0%
210%	220%	168.2	-18.1%

Wean % = lambs weaned per ewe mated.

4.2. Hogget lambing.

The base model discussed above does not include lambing hoggets, although the option is contained in the model. Hoggets have different profiles to mixed aged ewes in terms of the scanning and weaning percentages and liveweight and survival of their lambs. Data from composite ewe hoggets at Poukawa was used to calculate lamb growth rates, birth weights and lamb survival. When the hogget lambing option is switched on in the model, hogget performance is calculated using this data. The hogget base data uses 70% conception and 130% scanning, resulting in a weaning percentage (lambs weaned/hogget mated) of 81%. The proportion of hoggets having single and twin pregnancies at different scanning percentages was calculated using the data in Figure 2. Lamb mortality of the hogget lambs was separated by birth rank and age at death (Table 6). The age at death was separated into two categories - those that died early (prior to tagging) where the main cost is that of the pregnancy and those that died later (from tagging to weaning) where there is an energy loss associated with lactation as well. As in the mixed aged ewes the growth rates of the hogget lambs varied with birth rank and sex and were calculated at a daily rate based on liveweight data (Table 2). Hogget milk yield was assumed to be 80% of ewe milk yield although there is currently no data to support this assumption.

4.2.1. Changing hogget lambing. Hogget lambing in the base model gave a 70% pregnancy rate and a scan of 130%. This increases the number of lambs produced by the base flock by 18% and resulting in a 13.6% reduction in methane production per lamb sold (Table 21). This comes about because there are more lambs spread over the same ewe flock maintenance requirement. As with mixed aged ewes the magnitude of this methane reduction increases if the hogget performance improves but the size of the increase reduces. Factors that affect the performance of the mixed aged ewes will also affect hogget lambing.

Table 21. Effect of hogget reproductive performance on methane output per lamb

	Pregnancy rate %	Pregnant scan %	Methane output per lamb
Reference	Not mated	Not mated	15.987 kg
Wean 81% (base model)	70	130	-13.6%
Wean 92%	80	130	-15.1%
Wean 98%	80	140	-15.9%
Wean 104%	80	150	-16.6%

5.0. Discussion

Factors that will improve flock efficiency and produce more lamb for the same level of dry matter intake will also result in less methane per lamb sold. The flock and management factors having most significant impact on efficiency and methane production are indicated in Table 22.

- Hogget lambing reduced methane by 13.6%. This is because the flock is producing more lambs without the maintenance cost of running any more ewes.

- Increasing ewe scanning percentage from 160 to 180% reduced methane output by 7.8%. This assumes no increase in ewe liveweight and is achievable with Androvax or a breed change (e.g. utilising Finn genetics).

- Increasing ewe longevity from 5 to 6 years reduced methane output by 6.4%. In this scenario, fewer replacement hoggets need to be maintained to enter the flock.

- Reducing ewe liveweight by 10% reduced methane per lamb by 3.9%. This is a less likely scenario but is achievable with Finn genetics.

- Increasing lamb growth rate by 10% reduced methane output per lamb by 2.6%. This can be achieved with better feeding or by using rams with above average breeding values for weaning weight and growth

Table 22. Summary of effects modeled on flock methane output per lamb

Trait	Change	% reduction
Hogget lambing	Yes	13.6
Scanning %	160 to 180	7.8
Age at cull	5 to 6 year	6.4
Ewe liveweight	-10%	3.9
Ewe dries	8 to 6%	2.7
Lamb growth rate	+10%	2.6
Lamb survival	+10%	1.3

Unfortunately, these reductions in methane output are not necessarily cumulative as a ewe flock is a complex dynamic system and altering one factor will alter other components in the system and impact on methane output (Table 23). For example, increasing scanning percentage will increase the number of multiples born and this will affect lamb growth rate and survival. Many of these interactions have been included directly in the model e.g. effect of increasing scanning on lamb survival and growth rate, while others like the indirect effects of ewe liveweight have not been and need to be included. For example, if ewe liveweight increases, there is usually a corresponding increase in lambing percentage, lamb birth weights, lamb growth rates and ewe milk production.

For the scenario's we have run with the base flock, the combined effect of increasing longevity from 5 to 6 years, hogget lambing and increasing the scanning percentage from 160 to 180% results in a reduction of 21% in methane output per lamb sold.

Table 23. Cumulative effects of changing ewe longevity, hogget lambing and scanning % on methane output per lamb.

Longevity	Scanning %	Hogget lambing	Methane output per lamb
5	160	No	15.987 kg
6	180	No	-12.6%
6	160	Yes	-16.8%
5	180	Yes	-18.2%
6	180	Yes	-21.0%

In this model, the flock has been maintained at a constant 1000 ewes and the extra feed has been calculated to produce the production level set. We can constrain the model to a constant total dry matter to simulate a farm where extra feed cannot be produced or purchased. In this situation, the number of ewes carried declines as production increases but the total dry matter intake and methane produced remains relatively constant. However, the amount of methane produced per lamb sold declines (Table 24). This means that any emissions trading scheme which places a carbon charge per animal will effectively penalize more efficient operators. On the other hand, a carbon charge per ewe is likely to encourage the adoption of more efficient farming practices.

Table 24. Effect of changing performance on flock size on methane output when available dry matter is held constant.

Scan %	Cull age	Hogget lambing	Ewe #	Hog #	Net Lamb Sold	DMI	Methane	Methane/ lamb sold	% change
160	5	No	1000	288	989	833.3	15.8	15.99	
160	6	No	1021	248	1060	833.3	15.9	14.96	-6.4
180	5	No	933	269	1061	833.3	15.7	14.82	-7.3
180	6	No	951	231	1128	833.3	15.8	13.97	-12.6
160	5	Yes	930	268	1136	833.3	15.7	13.81	-13.6
160	6	Yes	959	233	1183	833.3	15.7	13.31	-16.8
180	5	Yes	872	251	1194	833.3	15.6	13.08	-18.2
180	6	Yes	897	218	1239	833.3	15.7	12.63	-21.0

The calculations on methane production in this model have been based on the premise that any carbon tax is likely to be imposed on saleable output (i.e. lambs). However the national methane inventory expresses methane as per head of sheep present at the 30th June. In other words, the total methane produced by the farm's sheep flock (lambs included) is divided by the sheep on the farm at balance date. Calculated in this manner the methane produced by the base model is 12.3 kg/sheep (15,999 kg divided by 1000 ewes and 288 replacements). This compares favourably with the methane output from the inventory model of 8.9 and 10.6 kg/sheep calculated for lower performing ewes in 1990 and 2001, respectively (Table 25).

Table 25. Comparison of methane production between the current model and the national inventory model.

	Ewe LW (kg)	Lambing %	Lamb carcass weight (kg)	CH4/sheep
Inventory 1990	47.3	96.6	13.7	8.9
Inventory 2001	55.1	117.6	16.7	10.6
Present study	70.0	127.7	17.4	12.3

Improving farm efficiency will not impact on the amount of methane produced at either the farm or a national level. However, improvements in efficiency will change the amount of methane produced per unit of saleable product. Management practices which increase performance without markedly affecting ewe maintenance requirements will have the greatest impact.

6.0. Acknowledgements

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7.0. References

AFRC (1993) Energy and protein requirements of Ruminants. Prepared by the AFRC Technical Committee on Responses to Nutrients. CAB International, Wallingford, UK.

Clark, H.; Brookes, I. and Walcroft, A. (2003). Enteric methane emissions from New Zealand ruminants 1990-2001 calculated using an IPCC Tier 2 approach. Report to the Ministry of Agriculture and Fisheries.

Cruickshank, G. (1986). Nutritional Constraints to Lamb Growth at Pasture. PhD thesis, University of Canterbury.

CSIRO (1990). Feeding standards for Australian Livestock. Ruminants. Australian Agricultural Council. Ruminants Subcommittee. CSIRO Publications. Melbourne, Australia

Litherland, A.J., Woodward, S.J.R., Stevens, D.R., McDougal, D.B., Boom, C.J., Knight, T.L. and Lambert, M.G. (2002). Seasonal variations in pasture quality on New Zealand sheep and beef farms. New Zealand Society of Animal Production 62:138-142

Muir, P.D., Thomson, B.C. and Knight, T.W. (2005) Factors affecting lamb survival. Proceedings of the 35th Seminar of the Society of Sheep and Beef Cattle Veterinarians. NZVA. No 243: pp73-82

Thomson, B.C., Muir, P.D. and Smith, N.B. (2004). Litter size, lamb survival, birth and twelve week weight in lambs born to cross-bred ewes. Proceedings of the New Zealand Grassland Association 66:233-237.