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Evaluation of the energy equations used by the National Enteric Methane Inventory

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Executive Summary

The equations used by the National Enteric Methane Inventory (NEMI) and described by Pickering (2011) to predict the energy requirements of farmed ruminants were reviewed and assessed for their applicability to New Zealand conditions.

The review evaluated individual factorial components of ME_{total} for dairy and beef cattle, sheep and deer and identified potential areas of improvement for individual equations and their parameters according to species, breed and physiological state.

1. Maintenance energy requirements (ME_m)

The general equation adopted by the NEMI for $\mathbf{ME_m}$ is in accordance with all contemporary (modern) models for predicting maintenance energy requirements with the following exceptions:

a) **$\mathbf{ME_{basal}}$ in cattle.** The NEMI adopts a K value of 1.4 to predict ME_{basal} for both dairy and beef cattle after CSIRO (2007). However, the literature concerning maintenance energy requirements in cattle provides evidence that there are breed differences in ME_m between dairy and "British" beef breeds which support the adoption of K values of 1.3 for "British" beef cattle breeds and 1.5 for dairy breeds as adopted by Nicol & Brookes (2007). In addition it would be appropriate to use the dairy breed K value (1.5) for beef cattle of dairy origin.

   The consequences would be a 7% decrease in ME_{basal} for beef cattle breeds and a 7% increase in ME_{basal} for dairy cattle breeds compared to the current NEMI model using K = 1.4.

b) **$\mathbf{ME_m}$ in deer**. The NEMI equations for deer maintenance requirements do not account for differences in requirements between stags and hinds according to the generally accepted principle that maintenance requirements of intact males are 15% higher than females and castrates. Compared to the CSIRO (2007) equations, the NEMI approach does not account for age/weight relationships for maintenance requirements.

   It is recommended that the NEMI adopts the CSIRO (2007) general equations as used for cattle and sheep as adopted by Nicol & Brookes (2007) using a K value of 1.4. The consequence would be an approximate 18-25% reduction in ME_m for deer (dependent on age, weight and gender) compared to the current NEMI deer equations.

This review recommends that the current BASAL equation for cattle and sheep (NEMI equation 3; Pickering, 2011) is modified as follows, and is applied also to deer:

$$BASAL\ (MJ/d) = K \times S \times (0.28W^{0.75} \times \exp(-0.03A))/k_m \qquad \text{[new NEMI equation 3]}$$

Where:

K	= 1.0 for sheep
	= 1.3 for cattle of "British" beef breed origin (e.g. Angus, Hereford)
	= 1.5 for beef and dairy cattle of dairy breed origin (e.g. Friesian, Holstein)
	= 1.4 for deer
S	= 1.0 for females and castrates, and 1.15 for entire males

W	= Liveweight (kg) (excluding conceptus)
A	= Age in years, with a maximum of 6
k_m	= net efficiency of use of ME for maintenance

2. Energy requirements for grazing and activity (ME_{graze})

The equation adopted by the NEMI for $\mathbf{ME_{graze}}$ is at variance with all contemporary (modern) models for predicting additional energy requirements associated with grazing and activity.

a) **$\mathbf{ME_{graze}}$ in cattle and sheep.** The NEMI adopts an outdated equation from SCA (1990) which accounts for terrain (flat, undulating or steep) but does not account specifically for distance walked (or climbed) by livestock. It is recommended that the NEMI adopt the more recent equation of Nicol & Brookes (2007) for ME_{graze} + ME_{move} + $ME_{activity}$ to assess more precisely the activity costs of grazing, including distance walked and the nature of the terrain.

b) **$\mathbf{ME_{graze}}$ terrain assumptions in cattle and sheep.** The NEMI assumes all dairy cattle are farmed on flat terrain. This is not appropriate in today's farming situation where dairy conversions are occurring increasingly on undulating terrain. Similarly the NEMI assumes all beef cattle and sheep are farmed on undulating terrain. This may be inappropriate for high production beef finishing systems on flat land and high country sheep farms. It is recommended that terrain assumptions for dairy, beef and sheep are reviewed and validated, especially if the NEMI develops into a regional or individual farm model.

c) **Deer $\mathbf{ME_{graze}}$.** The NEMI equations do not consider separately the energy requirements of grazing or activity for deer as they are "assumed" to be included in the current NEMI calculation for ME_m. This review recommends the adoption of the factorial approach of CSIRO (2007) and Nicol & Brookes (2007) to improve precision of calculating deer ME_m requirements. Therefore it will be necessary to assess separately the additional energy requirements of grazing and activity of deer in addition to ME_{basal}. It is recommended that the NEMI adopts the Nicol & Brookes (2007) equations as for cattle and sheep.

This review recommends that the current $\mathbf{ME_{graze}}$ equation for cattle and sheep (NEMI equation 10; Pickering, 2011) is replaced by the following, and applied also to deer:

Additional ME expenditure of grazing = ME_{graze} + ME_{move} + $ME_{activity}$ where:

$\mathbf{ME_{graze}}$ = W x [(C.DMI(0.9-DMD))]/k_m (after CSIR0, 2007)

Where:

C	= 0.02 (sheep and deer <100kg) or 0.0025 (cattle and deer >100kg)
DMI	= dry matter intake from pasture
DMD	= digestibility of the dry matter (calculated as ME/DM)/15.088)
W	= liveweight (kg)

k_m = efficiency of use of ME for maintenance

$\mathbf{ME_{move}}$ = 0.0026 × W × S × (TSR/SD)/(0.057 × PM + 0.16)/k_m (after CSIRO, 2007)

Where:

W = liveweight (kg)

S = slope (1.0, 1.5, 2.0 for flat, easy and steep respectively)

TSR/SD = relative stocking rate (1 for sheep, and beef cattle, 0.07 for dairy cattle) - threshold stocking rate ÷ current stocking density

PM = pasture mass (t/DM/ha)

$\mathbf{ME_{activity}}$ = W x [0.0026 × Hkm) + (0.028 × Vkm)]/km

Where:

W = liveweight (kg)

Hkm = horizontal km walked

Vkm = vertical km climbed

3. Energy requirements for pregnancy/gestation (ME_c)

The equations adopted by the NEMI for $\mathbf{ME_c}$ in cattle and sheep are consistent with those used in all current models. Deer equations are not:

a) **Deer $\mathbf{ME_c}$.** The NEMI approach, using a 'trimester factor", does not adequately account for the exponential growth of the conceptus from gestation to parturition and consequently overestimates ME_c compared with Nicol & Brookes (2007) and NRC (2007). It is recommended that the NEMI adopts the Nicol & Brookes (2007) equation.

This review recommends that the current $\mathbf{ME_c}$ equation for deer (NEMI equation 23; Pickering, 2011) is replaced by the following:

$\mathbf{ME_c}$ = (BWT/8) × (-0.5424 + 0.3346 (exp(0.0217t)))/k_c (after Nicol & Brookes, 2007)

Where:

BWT = calf birth weight (kg) (BWT/8 = adjusted for SRW calf weight of 8kg)

t = days after conception

k_c = 0.133

4. Energy requirements for lactation (ME_l)

The equations adopted by the NEMI for **ME_l** are consistent with those used in all current models with the following exceptions:

a) **ME_l for dairy and beef cattle and sheep.** ME requirements for lactation are sensitive to changes in lactation length and the energy value of milk. It is recommended that these are reviewed and validated as they may change over time.

b) **Deer ME_l.** The NEMI adopts appropriate equations for deer ME_l but the values used for net energy content of milk (evl), milk yield and lactation length are at variance with recent information from Landete-Callistejos et al (2000, 2003) and NRC (2007). It is recommended that the NEMI adopts the evl, milk yield and lactation lengths according to Landete-Callistejos et al (2000, 2003).

This review recommends that in the current ME_l equation for deer (NEMI equation 21; Pickering, 2011) the milk yield and composition parameters are modified as follows:

ME_l (MJ ME/d) = $Y \times evl/k_l$ [NEMI equation 21]

Where:

Y = milk yield (kg/d) - based on a total annual milk yield of 147 litres, and a lactation length of 105 days (after Landete-Callistejos *et al.*, 2000, 2003)

evl = energy value of milk

= 7.2 MJ/kg (after Landete-Callistejos *et al.*, 2000, 2003)

k_l = efficiency of use of ME for lactation = 0.64 (from Moe *et al.*, 1971)

5. Energy requirements for liveweight change (ME_g)

The equations adopted by the NEMI for **ME_g** for cattle and sheep are consistent with those used for both non-lactating and lactating animals in all current models with the following exceptions:

a) **ME_g in lactating dairy and beef cattle**. The equations adopted by the NEMI for ME_g for growing lactating cattle and lactating cattle losing weight are different to other contemporary New Zealand models which use the same equations as for non-lactating animals. However, they are in accordance with CSIRO (2007) which concludes that changes in energy reserves of lactating animals may be more accurately assessed from their condition score rather than live weight change. No changes to the current NEMI equations for growing lactating cattle and lactating cattle losing weight are proposed.

However, the NEMI assumes a fixed condition score of 6 for all dairy and beef animals at all stages. It is recommended that this assumption is validated for both dairy and beef cattle as a 1 point change in condition score (to 7 or 5) changes ME_g supplied by tissue catabolism in lactating animals losing weight by approximately 9%.

b) **Deer ME_g.** The NEMI equations do not take into consideration the potential change in composition of gain (fat and protein) with age. It is recommended that the NEMI adopts the CSIRO (2007) equation as applied by Nicol & Brookes (2007).

This review recommends that the current ME_g equation for deer (NEMI equation 19 and 20; Pickering, 2011) is replaced by NEMI equation 7 as used for cattle and sheep:

$$\mathbf{ME_g}\ (\text{MJME/day}) = ((6.7 + R) + (20.3 - R)/[1 + \exp(-6(P - 0.4))]/k_g) \times LWG$$

Where:

R	= adjustment for rate of gain or loss = $[EBG/(4 \times SRW^{0.75})]-1$
EBG	= empty body gain = 0.92 × (LWG × 1000) for LWT in kg/d
SRW	= the standard reference weight in kg.
P	= current live weight/SRW (maximum value of 1)
LWG	= live weight gain in kg per day
k_g	= 0.042 × pasture ME content + 0.006

Introduction

The basis of the Computerised National Enteric Methane Inventory (hereafter abbreviated to NEMI) is the prediction of annual ME requirements, and therefore dry matter intake, of average animals achieving average levels of production within defined New Zealand production systems.

The NEMI predicts ME intake using a factorial approach which separately estimates and then sums the daily ME requirements for maintenance, liveweight change, lactation and conception.

The basic factorial model (after Nicol & Brookes, 2007) is:

Total ME requirement

= ME for maintenance + ME for liveweight gain + ME for pregnancy + ME for lactation

- ME for maintenance is dependent on species, liveweight, age, sex and production level
- ME for liveweight change is dependent on rate of gain and composition of gain
- ME for pregnancy is dependent on litter size, birth weight and stage of pregnancy
- ME for lactation is dependent on milk yield and milk composition

For cattle (beef and dairy) and sheep, the NEMI estimates ME requirements using equations that are largely based on those of CSIRO (2007) with some modifications from AFRC (1993) and other sources. For deer, equations derived from Fennessy *et al.* (1981) are used.

Since the publication of the most recent standards relevant to Australian and New Zealand conditions (CSIRO, 2007) modified methods for calculating ME requirements of ruminants have been published which have relevance to this review. They are Nicol & Brookes (2007), Freer (2009) and Freer *et al.* (2010). In these publications, calculation methods are still based largely on the equations proposed by CSIRO (2007) but include important changes to some key parameters and constants.

CSIRO (2007) does not include equations for deer. In the NEMI, alternative methods derived from New Zealand research (Fennessy *et al*., 1981) have been used. However, Nicol & Brookes (2007) have applied the CSIRO (2007) factorial approach to deer with appropriate modifications to key parameters and constants. A similar approach has been adopted by Wheeler *et al.* (2008; pers comm).

This review assesses the relevance and accuracy of the current NEMI equations used to predict energy requirements for the NEMI. The NEMI equations (as described by Pickering, 2011) are compared with those of with those of CSIRO (2007), Nicol & Brookes (2007), Freer (2009), Freer *et al.* (2010) and any other data relevant to New Zealand livestock classes and production systems. This includes identifying, where possible, the source/derivation of the equations and parameters to evaluate their relevance to New Zealand conditions and current knowledge of ruminant nutrition.

Where approaches to calculating ME requirements differ between publications, the different approaches to calculating individual factorial components of ME_{total} are compared to estimate the potential impact on energy requirements and methane production.

Recommendations are provided on the adequacy of the NEMI equations and specific areas for improved accuracy are identified.

This review discusses and evaluates the NEMI equations described by Pickering (2011) beginning with a description of the general equations for maintenance ME requirements, followed by a species by species comparison of ME predictions (dairy, beef, sheep and deer).

NEMI general equations for prediction of energy requirements for cattle and sheep

The NEMI (Pickering, 2011) uses the same general equations for dairy cattle, beef cattle and sheep with some minor variations according to species and physiological state. For all stock classes (defined by species, age and physiological state) the total energy requirement of an animal (ME_{total}) is calculated using the general equation:

$$ME_{total} = ME_{basal} + 1.1 \times (ME_g + ME_c + ME_l) + ME_{graze} - z_l$$

Where:

ME_{basal}	= ME requirements to maintain animal liveweight
ME_g	= ME requirements for liveweight change (gain or loss)
ME_c	= ME requirements of the conceptus (pregnancy/gestation)
ME_l	= ME requirements for lactation
ME_{graze}	= ME requirements for grazing and associated activity
z_l	= a correction for ME intake derived from milk in young animals

Individual terms are applied as appropriate to the age and physiological state of a particular animal.

The general equation for maintenance energy requirements (ME_m).

The NEMI general energy equation for maintenance ME requirements in cattle and sheep is based on CSIRO (2007). This generalised equation was derived by Corbett *et al.* (1987) after revision of a basic equation defining fasting heat production (FHP) originally devised by Graham *et al.* (1974). The generalised equation adopted by CSIRO (2007) is:

$$ME_m \text{ (MJ/d)} = K.S.M.(0.28W^{0.75} \times \exp(-0.03A))/k_m + 0.1 \times ME_p + E_{graze}/k_m + E_{cold}$$

[NEMI equation 1; CSIRO equation 1.19.]

Where:

K	= 1.0 for sheep and 1.2 for *Bos indicus*, 1.4 for *Bos taurus* breeds, or intermediate values for crosses between these types
S	= 1.0 for females and castrates and 1.15 for entire males (rams, bulls)
M	= 1 + (0.23 x proportion of DE from milk)
W	= Liveweight (kg) (excluding conceptus and, for sheep, the fleece)
A	= Age in years, with a maximum value of 6
k_m	= net efficiency of use of ME for maintenance = 0.02 M/D + 0.5
ME_p	= the amount of ME (MJ) being used directly for production (milk production, conception/gestation, and live weight gain)

E_{graze} = additional energy expenditure (MJ) of a grazing animal compared with a similar housed animal

E_{cold} = additional energy expenditure (MJ) when the ambient temperature is below the animal's lower critical temperature

BASAL ME requirements

In the NEMI (Pickering, 2011) the first part of the CSIRO (2007) general equation for ME_m is separated out and defined as BASAL (or ME_{basal}), which is the baseline ME requirement for a non-lactating, non-pregnant, non-moving (stall-fed) animal and is defined as:

$$BASAL\ (MJ/d) = (K \times S \times (0.28W^{0.75}) \times \exp(-0.03A))/k_m$$

[NEMI equation 3]

The total ME requirement for an animal is, therefore, the sum of ME_m and ME_p so the equation for ME_{total} then becomes

$$ME_{total} = BASAL + 1.1 \times ME_p + ME_{graze}$$ [NEMI equation 2]

Where:

BASAL = metabolisable energy requirements to maintain animal weight (MJ/d)

ME_p = the amount of ME (MJ/d) being used directly for production (milk production, conception/gestation and liveweight gain)

ME_{graze} = additional energy expenditure (MJ/d) of a grazing animal compared with a similar housed animal

The parameter $1.1 \times ME_p$ acknowledges the generally accepted principle that ME_m varies directly with feed intake and is accounted for by a 10% increment on the ME required for production, also acknowledged above as $0.1 \times ME_p$ in the CSIRO (2007) general equation.

The NEMI uses the same BASAL equation for sheep, beef cattle and dairy cattle with parameters variable according to the species and physiological state as described above in the general equations for ME_m.

Derivation of terms in the general equation for ME_m and ME_{basal}

K - species/genotype scalar

The NEMI adopts K values of 1.0 for sheep and 1.4 for *Bos taurus* breeds as specified by CSIRO (2007).

These values are derived from Frisch & Vercoe (1977, 1984) and indicate that, in predicting ME_m, the coefficient on metabolic liveweight for *Bos taurus* is 1.4× that of sheep and 1.2× for *Bos indicus* cattle. Frisch & Vercoe (1977, 1984) measured fasting metabolic rate of Hereford × Shorthorn (HS; *B. taurus*), Brahman (*B. indicus*) and Brahman × HS fed lucerne or low-quality tropical pasture hay.

Dairy breeds or their crosses were not observed in these studies. In the CSIRO (2007) general equation for ME_m no distinction is made between dairy and beef cattle breeds.

The application and relevance of these K values to beef and dairy cattle in the NEMI are discussed further below.

S - gender scalar

CSIRO (2007) cites S values of 1.0 for females and castrates and 1.15 for entire males (for both sheep and cattle). These figures are derived from Graham (1968) and ARC (1980).

This 15% increment on fasting heat production is a convenient average based on separate sheep and cattle studies.

Sheep

ARC (1980) cites the studies of Graham (1968) and Rattray *et al.* (1973) which showed no difference in the fasting metabolism of ewes and wether sheep. Graham (1968) also noted that the mean fasting metabolism of rams was approximately 18% higher than ewes and wethers of the same breed. Joshi (1973) found the mean fasting metabolism of 14 rams aged 2 to 5 years was 12% higher than predicted for ewes. In conclusion, the ARC (1980) proposed “that until more information is available the fasting metabolism of the intact male [sheep] is taken to be 15% higher than that of the castrate.”

Cattle

ARC (1980) cited the studies of Webster *et al.* (1976) and Vercoe (1970) which indicated that maintenance requirements of bulls are approximately 20% and 16% greater than those of castrates, respectively. In conclusion ARC (1980) proposed “that until more information is available the 15% higher fasting metabolism adopted for intact male sheep has been taken to apply to cattle.” This was later confirmed in AFRC (1993). This 15% increment for intact male sheep and cattle has been accepted without further modification in all subsequent applications to sheep and cattle ME_m calculations including CSIRO (2007) and Nicol & Brookes (2007). Sahlu *et al.* (2004) indicated that the 15% increment is also appropriate for goats.

Deer

Nicol & Brookes (2007) also applied the general equation for ME_m to deer including a 15% increment for intact males. However, NRC (2007) suggested that for cervids, this may be too simplistic due to “major differences in timing and amplitude [which] exist in seasonal body gains made by males and females.” Deer equations are considered separately below.

M - proportion of ME obtained from milk

The CSIRO (2007) general equation follows the convention of ARC (1980) and AFRC (1993) that the fasting heat production of lambs on milk is 23% higher than lambs of the same weight on dry diets (Graham *et al.*1974). The NEMI excludes this factor from the equation in favour of a milk adjustment factor applied specifically to calculations applied to young animals (discussed separately below).

W - liveweight

It is universally accepted in the literature that fasting metabolism and ME_m of ruminants is related not to liveweight but to metabolic liveweight expressed as $W^{0.75}$. It is also universally accepted that this function is applicable to sheep, beef cattle, dairy cattle and deer (and goats).

The CSIRO (2007) general equation uses a basal metabolism weight scalar of $0.28W^{0.75}$ for sheep and cattle when ME intake is not known and $0.26W^{0.75}$ when ME intake is known. The former is adopted by the NEMI, Nicol & Brookes (2007) and Freer, (2009) and the latter by Freer *et al.* (2010) in the GRAZPLAN model (developed from the equations of CSIRO, 2007).

Note that Freer (2009), in the *ME Requirement* spreadsheet[1], combines the genotype/species scalar (K) with the liveweight scalar (0.28) into a single constant for cattle:

Cattle (*Bos taurus*)	$= 0.39W^{0.75}$	(where K=1.4)
Cattle (*Bos indicus*)	$= 0.34W^{0.75}$	(where K=1.2)

Similarly, Freer et al. (2010) in the GRAZPLAN model combines the genotype/species scalar (K) with the liveweight scalar (0.26; as ME intake is known) into a single constant for cattle:

Cattle (*Bos taurus*)	$= 0.36W^{0.75}$	(where K=1.285
Cattle (*Bos indicus*)	$= 0.31W^{0.75}$	(where K=1.192)

A - age

The age scalar (expressed in years) acknowledges that fasting heat production decreases with age at about 8% per year in the young animal with the rate falling to zero at about 6 years of age (Blaxter, 1962; Graham *et al.*1974) by which time it is about 0.84 of the original. Freer (2009) in the *ME requirement* spreadsheet and GRAZPLAN program, both developed from CSIRO (2007), expresses age with more precision in days. The term then becomes exp(-0.00008A) with a maximum value of 0.84 (age 6 years - expressed in days) for both sheep and cattle. There is no practical difference in the calculations other than from rounding.

k_m - net efficiency of use of ME for maintenance

CSIRO (2007) adopted the ARC (1980) 'preferred' values for k_m in association with the general equation for ME_m for sheep, cattle and goats. These values, for diets with an average GE content of 18.4 MJ/kg DM were adopted by CSIRO (2007):

for milk diets k_m	= 0.85 and
for all other diets k_m	= 0.02 x M/D + 0.5, where
M/D	= ME concentration of the feed DM (MJ ME/kg DM).

The CSIRO (2007) generalised ME_m equation (CSIRO equation 1.19) was derived in such a way by Corbett *et al.* (1987) that consideration of effect of feeding level on k_m is not necessary. The same equation is also used by Freer *et al.* (2010) in the latest GRAZPLAN model.

[1] Downloadable from CSIRO: http://www.pi.csiro.au/grazplan/supporting.htm

CSIRO (2007) states that it is generally inadvisable to use fixed values for k_m due to the wide variation in diet quality encountered in Australia [and New Zealand]. Therefore, a k_m based on M/D as described above is desirable.

ME_p - ME requirement for production

ME_p is the sum of ME requirements for productive metabolism including liveweight gain, wool growth, milk production during lactation and growth of conceptus tissues during gestation.

In the CSIRO (2007) and NEMI general equation for $ME_{m,}$ the term $0.1ME_p$ acknowledges the increase in maintenance metabolism resulting from increases in protein turnover and consequent energy costs associated with increased rates of protein synthesis for these productive processes. This term was also derived by Corbett *et al.* (1987) after Graham *et al.* (1974).

In the NEMI (and Nicol & Brookes, 2007), the 0.1 ME_p term is considered separately from ME_m in the BASAL equation. The individual factorial components of ME_p for each species are discussed later.

ME_{graze} - ME requirement for grazing and activity

ME_{graze} is the additional metabolisable energy expenditure of grazing animals compared to similar housed animals - basically a reflection of muscular activity in grazing (standing, walking, prehension, chewing and rumination).

There are three relevant documented approaches to calculating ME_{graze} - CSIRO (2007), SCA (1990) as used by the NEMI, and Nicol & Brookes (2007). They all account for the energy cost of prehension, chewing and rumination in a similar way and are based on equations from ARC (1980). However, they vary in their approach to accounting for the energy associated with walking and activity associated with grazing. These are discussed in detail below for cattle, sheep and deer.

E_{cold} - ME requirement to alleviate cold stress

E_{cold}, the additional ME required to alleviate cold stress (CSIRO, 2007) is regarded as irrelevant to the New Zealand farm situation.

Freer *et al*. (2010) in the GRAZPLAN model included factors/equations to account for “chilling” (Freer *et al.*, 2010, equation 100). Similarly, models originating in the northern hemisphere (e.g. Fox *et al.* (2004, CNCPS model) contain factors/equations to account for heat and cold stress.

Nicol & Brookes (2007) and Pickering (2011) stated that environmental temperatures below the lower critical temperature are unlikely to be experienced in New Zealand except for relatively short periods (hours) on a few occasions during the year (Sykes, 1982). Sise *et al.* (2011, HOOFPRINT model) also ignores E_{cold} as unimportant to New Zealand conditions citing Holmes & Sykes (1984).

Cattle energy predictions

Nicol & Brookes (2007) state that the requirements of dairy and beef cattle are usually considered separately, because small differences in the background assumptions mainly around seasonal management decisions, result in small differences between equivalent figures for dairy and beef cattle.

The NEMI uses the same general equation for both dairy and beef cattle:

$ME_{total} = BASAL + 1.1 \times ME_p + ME_{graze}$ [NEMI equation 2]

Where:

BASAL = ME requirements to maintain animal weight (MJ/d)

ME_p = ME requirements used directly for milk production, conception/gestation and liveweight gain (MJ/d)

ME_{graze} = additional energy expenditure of a grazing animal compared with a similar housed animal (MJ/d)

Cattle BASAL (ME_{basal})

The NEMI uses the BASAL energy equation derived from the CSIRO (2007) general equation for both dairy and beef cattle:

$BASAL\ (MJ/d) = K \times S \times (0.28W^{0.75} \times \exp(-0.03A))/k_m$ [NEMI equation 3]

Where:

K = 1.4 for both dairy and beef cattle

S = 1.0 for cows and steer and 1.15 for entire bulls

W = Liveweight (kg) (excluding conceptus)

A = Age in years, with a maximum of 6

k_m = net efficiency of use of ME for maintenance = 0.02 M/D + 0.5

The adoption of this equation and parameters for predicting ME_{basal} is consistent with several New Zealand and Australian published models to calculate sheep and cattle maintenance energy requirements (Wheeler *et al.*, 2008 (OVERSEER model); Freer, 2009 (*ME Requirement* spreadsheet model); Freer *et al.*, 2010 (GRAZPLAN model); Sise *et al.*, 2011 (HOOFPRINT model). All use K values of 1.4 for both beef and dairy cattle.

Nicol & Brookes (2007) also used the same CSIRO (2007) general equation but specified different K values of 1.3 for beef cattle and 1.5 for dairy cattle implying a difference in maintenance energy requirements for beef and dairy breeds. These revised cattle coefficients appear to originate from (NRC, 2000) for beef cattle and (NRC, 2001) for dairy cattle.

It is appropriate here to briefly review the literature on breed effects on maintenance requirements in cattle.

Breed effects on maintenance requirements in cattle

All current New Zealand and Australian approaches to calculating ME requirements for cattle (based on CSIRO, 2007), with the exception of Nicol & Brookes (2007), do not distinguish between beef and dairy cattle breeds and apply the same general equation and parameters to both beef and dairy cattle. However in general the literature seems to recognise a breed effect on cattle maintenance requirements. North American models for calculating cattle ME_m requirements (based on NRC, 2000, 2001) apply breed multiplier factors which recognise higher maintenance requirement in dairy and dual-purpose breeds (e.g. Ayrshire, Brown Swiss, Braunvieh, Friesian, Holstein, Simmental,) compared to “British” beef breeds (e.g. Angus, Hereford).

ARC (1980) reviewed a number of calorimetric trials and though statistical analysis found no clear-cut difference in fasting metabolism which might be attributed to breed, ARC (1980) concluded that “*it is probable that such breed differences exist*”. ARC (1980) went on to describe studies which suggested differences between beef and dairy breeds. Ritzman & Benedict (1938) reported a 9% greater fasting heat production (FHP) in dairy compared to beef animals. Blaxter & Wainman (1966) reported Ayrshire (dairy) cattle had 19% higher FHP than beef bullocks, with intermediate values for Ayrshire×beef crosses. In three comparative slaughter trials Garrett (1971) found Holsteins bullocks had higher maintenance costs than Herefords (5%, 11% and 13% respectively). ARC (1980) concluded with the statement *“undoubtedly, as more data accrue, these differences will be established with precision and so explain the variation associated with the* [then] *present mean estimate of fasting metabolism.”*

Consequently, ARC (1980) and AFRC (1993) specified only one equation for cattle FHP regardless of breed:

$$\text{FHP (MJ/d)} = \text{C1}\{0.53(\text{W}/1.08)^{0.67}\}$$ [AFRC, 1993; equation 40]

Where:

C1 = 1.15 for bulls and 1.0 for other cattle

The factor of 1.08 converts liveweight to fasted body weight (ARC, 1980)

NRC (2000) stated that in cattle, “*maintenance energy expenditures vary with body weight, breed or genotype, sex, age, season, temperature, physiological state and previous nutrition*”, and reviewed a considerable number of studies referring to breed differences in maintenance energy requirements.

Most of the studies reviewed observed differences in maintenance energy requirements between or among breeds compared and NRC (2000) concluded that *“considerable variation exists in maintenance requirements among cattle germplasm resources”*. However, because of the diversity of breeds, methodologies, conditions, etc., direct comparisons between studies were not useful.

Consequently, NRC (2000) selected studies in which British beef breeds or British beef breed crosses were compared with other breeds or breed crosses and expressed the results as relative values. NRC (2000) concluded with the following generalizations based on the reviewed studies:

- In growing cattle, *Bos indicus* breeds of cattle (e.g. Africander, Barzona, Brahman, Sahiwal) require about 10% less energy than beef breeds of *Bos taurus* cattle (e.g. Angus, Hereford, Shorthorn, Charolais, Limousin) for maintenance, with crossbreds being intermediate.
- Dairy or dual-purpose breeds of *Bos taurus* cattle (e.g. Ayrshire, Brown Swiss, Braunvieh, Friesian, Holstein, Simmental) apparently require about 20% more energy for maintenance than beef breeds, with crosses being intermediate.
- Data involving straight bred, mature cows are more limited. However, available data with straight breds combined with those of crossbreds, indicate that relative differences between breeds in mature cows is similar to that observed in growing animals. This may be generalized further to indicate, in both adult and growing cattle, that a positive relationship exists between maintenance requirement and genetic potential for measures of productivity (for example, rate of growth or milk production; Webster *et al.*, 1977; Taylor *et al.*, 1986; Ferrell and Jenkins, 1987; Montano-Bermudez *et al.*, 1990).

Appendix 1 presents a detailed list of the references and reported differences in maintenance energy requirements of beef and dairy cattle breeds, which were reviewed by ARC (1980), AFRC (1993), NRC (2000, 2001), CSIRO (2007) as referred to above.

NRC (2000, 2001) specified breed differences in their recommendations for net energy requirements for maintenance. NRC (2000) specified the net energy requirements for maintenance in 'British' beef cattle breeds as:

For beef breeds:

NE_m = 0.077 Mcal/kg $EBW^{0.75}$ (EBW = 0.85 × liveweight; NRC 2001)
= 0.065 Mcal/kg $LWT^{0.75}$ (as converted by NRC, 2001)

NRC (2001) applied a breed adjustment factor of 1.2 for Holstein and Jersey cattle which, when adjusted to a liveweight basis meant that:

For dairy breeds:

NE_m = 0.080 Mcal/kg $LWT^{0.75}$

When corrected for 0.28 × $LWT^{0.75}$, $exp^{-0.03A}$ and converted to MJ ME as expressed in CSIRO (2007) and the NEMI general equation for ME_m, the corresponding K values are approximately (depending on age) 1.22 for beef breeds and 1.49 for dairy breeds[2].

[2] Age of beef and dairy animal = 4 as specified in the NEMI (Pickering, 2011); k_m = 0.71

NRC (2000, 2001) stated that the NE_m values include a 10% activity allowance to account for normal voluntary activity of cows that would be housed in dry-lot or free-stall systems. Note that estimation of K is sensitive to age with a change from 4 to 3 years increasing K, and therefore ME_{basal}, by approximately 3%.

More recently, Fox *et al.*, (2004) and Tylutki *et al*. (2008) applied modified NE_m values from NRC (2000, 2001) to their CNCPS model. The figures adopted are slightly different to those quoted in NRC (2000, 2001) as the breed effect multiplier for dairy breeds is 1.12 (Fox *et al.*, 1992) and NE_m is calculated on shrunk body weight (SBW = 0.96 × full live weight) rather than EBW. These modified NE_m values and their corresponding estimates for K values are presented in Table 1.

Table 1: NE_m values from Fox *et al.* (2004) and Tylutki *et al*. (2008) and estimated K values for "British" beef and dairy breeds

Breed Type	NE_m (Mcal/kg $SBW^{0.75}$)	Estimated K†
British beef breeds (B. taurus) e.g. Angus, Hereford	0.070	1.32
Dairy breeds (B. taurus) e.g. Friesian, Holstein, Jersey	0.078	1.48

†Estimated using age = 4 for both beef and dairy animal as specified in the NEMI (Pickering, 2011); km = 0.71

The data from NRC (2000, 2001), Fox *et al*. (1992, 2004) and Tylutki *et al*. (2008) appear to support Nicol & Brookes (2007) distinction between beef and dairy breeds by adopting K values of 1.3 and 1.5 for beef and dairy cattle respectively in calculating ME_{basal}.

The adoption by the NEMI of Nicol & Brookes (2007) K values of 1.3 for beef breeds and 1.5 for dairy breeds would appear to offer greater precision in calculating maintenance energy requirements of beef and dairy cattle, particularly if the NEMI is applied on a regional or on-farm basis in which the breed composition of herds will vary with location.

Furthermore, in the NEMI, it appears necessary to account for breed type within beef cattle systems as beef cattle of dairy origin will have higher maintenance requirements than traditional British beef breeds.

Currently, it is not possible to identify accurately the breed composition of New Zealand's national (or regional) beef herds, though the newly introduced National Animal Identification and Tracing (NAIT) system may offer an opportunity to collect such data in the future.

Compared to the differential K values adopted by Nicol & Brookes (2007), the 'standard' K value of 1.4 for *Bos taurus* breeds specified by CSIRO (2007) and used in various contemporary cattle maintenance models, appears to be an appropriate and convenient average across all cattle types. However, this assumes that beef and dairy breeds are represented in equal proportions in the national (or regional) cattle populations. This is not currently the case in New Zealand, particularly among beef herds which are sourced from both beef breeds and dairy breeds.

For beef herds, until more accurate data on breed composition is available, a practical approach to accounting for breed and improving the precision of ME requirements calculated by the NEMI may be to estimate the proportions of beef breed and dairy breed calves sourced by the beef industry and to apply the Nicol & Brookes (2007) K factors accordingly.

The consequences of adopting Nicol & Brookes (2007) K values in the NEMI would be a 7% decrease in ME_{basal} for beef cattle breeds and a 7% increase in ME_{basal} for dairy cattle breeds.

Tables comparing the effect of variation of K on ME_{basal} predictions for beef and dairy cattle breeds are presented in Appendix 2 and Appendix 3.

Conclusions and recommendations for Cattle ME_{basal}

The equations adopted by the NEMI for ME_{basal} in dairy and beef cattle are in accordance with all contemporary (modern) models for predicting maintenance energy requirements.

However, it is recommended that:

- For Beef breeds ME_{basal} the NEMI adopts a K value of 1.3, and
- For Dairy breeds ME_{basal} the NEMI adopts a K value of 1.5

For dairy breeds used in the beef industry the K value for dairy breed maintenance (1.5) is recommended.

Until accurate data on the breed composition the national beef herd is available it is recommended that the differential K values be applied to beef herds according to the proportions of beef breed and dairy breed calves sourced into the industry.

Cattle ME_l - Energy requirements for milk production (lactation)

The NEMI takes its ME_l equations from AFRC (1993) as the CSIRO (2007) equations refer to milk components not routinely measured in New Zealand. The same equations are applied to both dairy and beef cattle.

ME_l is predicted from the net energy content of milk (evl) and milk yield according to the following equations:

evl MJ/kg = net energy content of milk (energy value of milk)

$= 0.376 \times F + 0.209 \times P + 0.948$

[NEMI equation 4, AFRC equation 54]

Where:

F = milk fat percentage

P = milk protein percentage

ME_l (MJ ME/d) = Y x evl/k_l [NEMI equation 5, AFRC equation 56]

Where:

Y = milk yield (kg/d)

= national milk yield × milk yield monthly proportion/number of days in month

evl = net energy content of milk

k_l = 0.019 × pasture ME content + 0.42

These equations were validated for New Zealand conditions by Pickering (2011) by reference to US studies by Grainger *et al.* (1983) and New Zealand specific data.

The same equations were also applied by Nicol & Brookes (2007) to dairy cattle and by Sise *et al*. (2001) for both dairy and beef cattle. However, for beef cows (also ewes and hinds) Nicol & Brookes (2007) calculated ME requirements during lactation for dams and their offspring based on the net energy requirements for calf growth and assumptions on the proportions of energy supplied by pasture and milk.

The current factorial approach adopted by the NEMI relies on relevant up-to-date values for evl and milk yield for both dairy and beef cattle. This information is readily available for dairy cows, though values applied in the NEMI should be reviewed and updated as they are likely to change over time.

The NEMI does not cite sources for beef cow milk yield (824kg/annum over approximately 180 days) used in the model. Values for milk protein and fat percentages are derived from New Zealand dairy statistics.

Gregory *et al.* (1992) estimated 200-day milk yield beef cows by the ‘weigh-nurse-weigh’ method to be 1258 and 1694 kg for Hereford and Angus cows respectively. Similarly, from Meyer *et al*. (1994) 200-day milk yield for Australian Hereford cows was estimated at 1234 kg. Grings *et al.* (2008) reported mean 190-day milk yield of Angus, Hereford and Angus×Hereford cows of 1074-1199 kg (mean of all breeds). Compared at similar lactation length the NEMI value appears to underestimate of beef cow milk production (915 kg over 200 days).

It is recommended that milk yield value for beef cows is reviewed and validated in the NEMI.

Conclusions and recommendations for ME_l in dairy and beef cattle

The equation adopted by the NEMI for ME_l for both dairy and beef cattle are in accordance with contemporary (modern) New Zealand models for predicting energy requirements for lactation.

It is recommended that values for milk yield and composition in both dairy and beef cows are reviewed and validated as these are likely to change over time.

Cattle ME_c - Energy requirements for conception/gestation

The NEMI equations for calculating ME_c are based on the those of ARC (1980), confirmed by AFRC (1993) and adapted by CSIRO (2007) and describe the accretion of net energy and nutrients during foetal and conceptus growth.

The only difference between the equations of AFRC (1993) and CSIRO (2007) is that the CSIRO (2007) equations are expressed as functions of natural logarithms (ln or $\log_e$) compared to $\log_{10}$ in AFRC (1993).

These equations predict the net energy retention of the gravid uterus on a specified day of pregnancy (t) and reflect the exponential increase in NE_c from conception to parturition. Total NE_c retention over the whole pregnancy is the sum of individual daily NE_c from conception to parturition.

For clarity, the NEMI/AFRC (1993) and CSIRO (2007) equations are described in full below.

The NEMI takes its equations directly from AFRC (1993) for both dairy and beef cattle:

$$ME_c\ (\text{MJ ME/day}) = 0.025 \times W_c \times (E_t \times 0.0201 \times \exp(-0.0000576 \times t))/k_c$$

[NEMI equation 6; AFRC equations 70, 71]

Where:

- W_c = calf birthweight (assumed in NEMI to be 9% of dam weight adjusted annually: see note below †).
- E_t = $10^{(151.665-151.64\times\exp(-0.0000576\times t))}$ = total energy retention of the gravid foetus (ARC, 1980)
- t = days from conception.
- k_c = 0.13 (ARC, 1990)

† AFRC (1993) calculates calf birth weight as:

$$W_c\ (\text{kg}) = (W_m^{0.73} - 28.89)/2.064$$

[AFRC equation 72 - after Roy, 1980]

Where:

W_m = mature bodyweight of the dam

Muir *et al.* (2008) identified that using a figure of 9% of cow bodyweight may over estimate dairy heifer birth weights. Using the NEMI assumption the calf liveweight from a 450kg cow would be 40.5 kg. Assuming a mature body weight of 550kg (Nicol & Brookes, 2007) the AFRC (1990) method calculates calf liveweight to be 34.8kg. However, it is unlikely that discrepancies in calf liveweight will have much impact on national methane output.

CSIRO (2007) refined the AFRC (1993) equations to create general equations to predict the daily gain in net energy content of the gravid uterus in both cattle and sheep:

dY/dt (MJ NE/kg) = B C exp(-Ct) Y [CSIRO, 2007: equation 1.26]

Where:

Y (MJ) = net energy content of the gravid foetus

= SBW exp(A - B (exp(-Ct)) [CSIRO, 2007: equation 1.25]

SBW = expected birth weight of the foetus/standard weight (=40kg)

t = days after conception

A, B and C are parameters from Table 2 reproduced from CSIRO (2007: Table 1.9). These values were derived by CSIRO (2007) from ARC (1980).

Table 2: Parameters for calculation of ME_c in sheep and cattle

Parameter	A	B	C
Sheep (MJ)	7.64	11.46	6.43×10^{-3}
Cattle (MJ)	349.22	11.46	5.76×10^{-3}

Nicol & Brookes (2007) adopts CSIRO (2007) equation 1.26 as described above.

Freer (2009) and Freer *et al.* (2010) adopt a more complex equation adapted from CSIRO (2007) which is scaled for foetus number, animal size and body condition of the foetus:

ME_c = (BW×4.11×1.8×343.5×0.0164/285)×exp(0.0164×(1-t/285)

+343.5×(1-exp(0.0164×(1-t/285))))/0.133

[Freer *et al.*, 2010; Equation 63]

Where:

BW = birth weight

t = days of gestation

Conclusions and recommendations for ME_c in dairy and beef cattle

The equations adopted by the NEMI for ME_c for both dairy and beef cattle are in accordance with contemporary (modern) New Zealand models for predicting energy requirements for pregnancy and lactation.

It is recommended that the method for determining calf weight used in the calculations are reviewed for relevance.

Cattle ME_g - ME requirements for change in liveweight

The NEMI adopts two separate equations for ME_g in cattle, one for non-lactating cattle, and a second for growing lactating animals and for lactating animals losing weight.

1) In non-lactating animals

The NEMI calculates ME requirements for liveweight gain in non-lactating dairy and beef based on an equation from CSIRO (2007):

$$EBG\ (MJ/kg) = (a + cR) + (b - cR) / [1 + \exp(-6(Z-0.4))]$$

[CSIRO (2007) Equation 1.30]

Where:

a, b and c are derived from CSIRO (2007; Table 1.11) and are reproduced in Table 3

R = adjustment for rate of gain or loss = $[EBC/(4 \times SRW^{0.75})]-1$

EBC = 0.92 × LWG in g/d

SRW = the standard reference weight in kg.

Z = current live weight /SRW (maximum value of 1)

CSIRO (2007) states that "this equation is applicable to all breeds of sheep and cattle including *Bos indicus* with the exception that coefficient b differs for some large, lean breeds of cattle (e.g. Charolais, Chianina, Blonde d'Aquitaine, Limousin, Maine Anjou and Simmental)".

Table 3. Parameters for predicting the energy content of empty body gain in immature animals (CSIRO, 2007)

	All animals		All animals except large lean breeds	Large lean breeds	Crosses involving large lean breeds
Coefficient	a	c	b	b	b
Total energy content of empty body gain (MJ/kg)	6.7	1.0	20.3	16.5	18.4

In the NEMI the equation becomes:

ME_g (MJME/day) = ((6.7 + R) + (20.3 - R)/[1 + exp(-6(P - 0.4))]/k_g) × LWG

[NEMI equation 7]

Where:

R = adjustment for rate of gain or loss = [EBG/(4 × $SRW^{0.75}$)]-1

EBG = empty body gain

= 0.92 × (LWG × 1000) for LWT in kg/d

SRW = the standard reference weight in kg.

P = current live weight (NEMI, Appendix 1)/SRW (maximum value of 1)

LWG = live weight gain in kg per day

k_g = 0.042 × pasture ME content + 0.006

k_g factor 0.006 is derived by CSIRO (2007) from AFRC (1993)

[CSIRO (2007) equation 1.35]

Nicol & Brookes (2007), Freer (2009) and Sise *et al.* (2011) also adopt the CSIRO (2007) equation though Freer (2009) modifies the equation further to inclusion an additional term F which accounts for potential liveweight loss.

ME_g (MJ/kg) = (LWG/1000) × (((6.7 + R) + (20.3 – R)/(1 + exp(-6(P-0.4))))/(1.09 × F))

Freer (2009) applies this equation to both cattle and sheep.

Nicol & Brookes (2007) applies the same equation (CSIRO, 2007) to calculate ME_g in sheep, cattle and deer, for both dry and lactating animals. This is discussed further in the relevant species sections below.

However, the NEMI approach to calculating ME_g in non-lactating dairy and beef cattle is consistent with other contemporary models used in New Zealand and Australia.

2) In growing lactating animals

To calculate ME_g in growing lactating animals the NEMI adopts an equation derived from SCA (1990), after Hulme *et al.* (1986) based on regressions relating body energy changes to live weight change:

ME_g (MJ ME/day) = (neclw × LWG)/k_g

[NEMI equation 8; SCA (1990) equation 1.37]

Where

neclw	= net energy content of liveweight
	= 10.1 + 2.47 × CS
cs	= condition score (NEMI specifies CS = 6; heavy moderate condition[†])
LWG	= live weight gain in kg per day
k_g	= 0.95 × k_l
k_l	= The efficiency of use of ME for milk production
	= 0.019 × pasture ME content + 0.42 (ARC, 1980; CSIRO, 2007)

[†] *as defined in SCA (1990)*

This approach is consistent with CSIRO (2007) which suggests that changes in energy reserves of lactating animals may be more accurately assessed from their condition score rather than live weight change (as calculated for non-lactating animals [NEMI equation 7]). This is because lactating animals may lose condition score (reflecting changes in tissue mass) without changing liveweight due to increases in body water content during lactation.

CSIRO (2007) equations are slightly different to those of SCA (1990) as the coefficients are derived from regressions relating energy changes to *empty body gain* rather than liveweight change as for SCA (1990):

For dairy cattle:

neclw (MJ/kg EBG) = 21.4 + 1.24 × CS (8 unit range)

[CSIRO (2007) equation 1.32A]

For beef cattle:

neclw (MJ/kg EBG) = 20.8 + 2.07 × CS (5 unit range)

[CSIRO (2007) equation 1.32A]

Nicol & Brookes (2007) and Sise *et al.* (2011) do not use this condition score approach to calculate ME_g in lactating cattle. Instead they apply the same equation as used for non-lactating animals described above [NEMI equation 7], though k_g (efficiency of use of ME for liveweight gain) is modified to account for the efficiency of use of ME for lactation:

For ME_g in lactating animals:

$k_g = 0.95 \times k_l$ (ARC, 1980)

Where:

$k_l = (ME/DM \times 0.02) + 0.4$ (CSIRO, 2007)

The NEMI approach to calculating ME_g in lactating animals is different to that of Nicol & Brookes (2007) or Sise *et al.* (2011). However, the NEMI approach is consistent with CSIRO (2007) which suggests that changes in energy reserves of lactating animals may be more accurately assessed from their condition score rather than live weight change.

Nevertheless, predicted values for ME_g for lactating cattle are similar for each of the three methods (NEMI/SCA (1990) [NEMI equation 8], CSIRO (2007) equation or the Nicol & Brookes (2007) approach using NEMI equation 7.

ME_g values for lactating cattle predicted by the different methods NEMI (Pickering, 2011), CSIRO (2007) and Nicol & Brookes (2007) are compared in Appendix 4.

The NEMI assumes a fixed condition score of 6 for all animals at all stages of lactation for both dairy and beef cattle. Changing the condition score by 1 point up (to 7) or down (to 5) changes ME_g by approximately 9%. ME_g values in lactating cattle as predicted by NEMI (Pickering, 2011), for different body condition scores are presented in Appendix 5.

Therefore, it is recommended that the condition score used in the NEMI be reviewed for relevance, and its applicability to both dairy and beef cattle.

3) In lactating animals losing weight

The NEMI uses the same equation as for lactating animals gaining weight with a correction factor of 0.84 to account for the efficiency of utilisation of body energy for milk secretion (ARC, 1980). NEMI equation 8 then becomes:

ME_g (MJME/day) = $(neclw \times 0.84 \times LWG)/k_l$ [NEMI equation 9]

CSIRO (2007) cites Searle *et al*. (1972) and Blaxter *et al*. (1982) which concluded that the composition an energy value of liveweight loss in sheep and cattle is similar to that of its liveweight gain. Therefore, it is reasonable to calculate the energy provided to animals from catabolism of tissues in the same way as to calculate the energy content of gain by ‘reverse use’ of the gain equations.

As for growing lactating animals, the NEMI assumes a fixed condition score of 6 for all animals at all stages of lactation for both dairy and beef cattle. Similarly, changing the condition score by 1 point up (to 7) or down (to 5) changes ME_g supplied by tissue catabolism in lactating animals losing weight by approximately 9%.

As for calculation of ME_g in growing lactating animals, it is recommended that the condition score used in the NEMI be reviewed for relevance, and its applicability to both dairy and beef cattle.

Conclusions and recommendations for ME_g in dairy and beef cattle

The equations adopted by the NEMI for ME_g for non-lactating dairy and beef cattle are in accordance with contemporary (modern) New Zealand models for predicting energy requirements for liveweight gain.

The equations adopted by the NEMI for ME_g for growing lactating cattle and lactating cattle losing weight are different to other contemporary New Zealand models. However, they are in accordance with CSIRO (2007) which concludes that changes in energy reserves of lactating animals may be more accurately assessed from their condition score rather than live weight change.

It is recommended that the condition score value of 6 applied to equations for ME_g in both lactating dairy and beef cattle is reviewed to confirm relevance for both cattle types.

Cattle ME_{graze} - Additional energy requirements for grazing and activity

The NEMI applies an equation derived from SCA (1990; equation 1.24) to calculate ME_{graze}:

$$ME_{graze} = [((C \times DMI(0.9 - DMD)) + 0.05 \times (T/(GF+3)))W]/k_m$$

[NEMI equation 10; SCA (1990) equation 1.24]

Where:

- C = 0.006 for cattle (in comparison to 0.05 for sheep)
- DMI = dry matter intake from pasture, (specified as 10kg/d in Pickering (2011)
- DMD = digestibility of the dry matter (decimal)
- T = terrain takes values which range from 1.0 to 2.0 as terrain varies from level to steep [1.0 for dairy (level); 1.5 for beef (undulating)]
- GF = availability of green forage (tDM/ha) - assumed to be 3.5 for dairy
- W = liveweight (kg)
- k_m = efficiency of use of ME for maintenance (0.02 x pasture ME content +0.5)

SCA (1990) defines the first term in the equation as the additional net energy expenditure in eating (MJ/kg W) incurred by grazing compared with housed animals. It assumes that the energy expended in ruminating a given quantity and quality (DMD) of feed does not differ between grazing and housed animals. (The values for the coefficient C imply that the relative intakes of DMI (kg/hr) from pasture are in the ration 1:8 respectively, for cattle and sheep).

The second term defines the net energy expenditure of walking which decreases as the availability of green forage increases and animals walk correspondingly shorter distances to find feed. This is also influenced by terrain and the NEMI assumes that dairy cattle are farmed on level terrain whilst beef cattle are farmed on undulating terrain with a corresponding increase in energy expenditure. This assumption may no longer be valid as dairy farm conversions now often include a component of undulating terrain. Similarly high producing beef finishing systems may involve grazing on highly productive flat terrain. It is recommended that the NEMI terrain assumptions for dairy and beef cattle should be reviewed, especially if the NEMI develops into a regional or individual farm model.

Sise *et al*. (2011) adopted the SCA (1990) equation in the commercial *Hoofprint* model.

CSIRO (2007) modified the SCA (1990) equation to cover the particular range of activities experienced in Australian grazing situations including housed animals, strip grazing, animals walking long distances to pastures or water (e.g. dairy cows walking to and from the dairy shed) and animals grazing steep hilly country. The CSIRO (2007) equation is also used by Freer *et al.* (2010) in the GRAZPLAN model:

$$ME_{graze}\ (MJ\ ME/d) = [C \times DMI(0.9 - DMD) + 0.0026 \times H]W/k_m$$

[CSIRO (2007) equation 1.22]

Where:

H	= horizontal equivalent of distance walked) (km)
	= T[min(1,SR/SD)/(0.057GF + 0.16) + M]

And:

C	= 0.02 (sheep, goats) or 0.0025 (cattle)
DMI	= dry matter intake from pasture, excluding supplementary DM
DMD	= digestibility of the dry matter (decimal)
GF	= availability of green forage (tDM/ha when cut to ground level)
M	= total distance walked each day from pasture to milking shed (km)
SD	= threshold for grazing density (animals/ha): 40 (sheep) or 5 (cattle)
SR	= current grazing density (animals/ha)
T	takes values the range from 1.0 to 2.0 a terrain varies from level to steep.
W	= liveweight (kg)
k_m	= efficiency of use of ME for maintenance

The first term is the same as that specified by SCA (1990) and used in the NEMI.

The second term defining the net energy expenditure for walking is modified to include a factor M which accounts for situations where animals may need to walk considerable distances to access feed or water. In Australia this is relevant to range grazing at very low stocking rates. In New Zealand situations this is particularly relevant to dairy cattle which may walk long distances to and from the dairy shed – this is additional activity which is not associated with grazing. CSIRO (2007) also contains a factor which considered grazing density (SR/SD) and the coefficient C has been modified compared to SCA (1990).

This equation is adopted by Freer *et al.* (2010) in the GRAZPLAN model. Freer (2009), in the *ME Required* spreadsheet model, accounts for the energy associated with grazing as a simple, user defined increment on maintenance requirements (default 15%).

Nicol & Brookes (2007) adopted a similar approach to CSIRO (2007) but consider separately the calculations for energy costs of grazing activity (ME_{graze}), walking associated with grazing (ME_{move}) and other (walking) activity costs ($ME_{activity}$). Note that some terms have been translated from the original (Nicol & Brookes, 2007) for consistency with other authors:

$ME_{graze} = W \times [(C.DMI(0.9-DMD))]/k_m$ (after CSIR0, 2007)

Where:

C	= 0.02 (sheep and deer <100kg) or 0.0025 (cattle and deer >100kg)
DMI	= dry matter intake from pasture
DMD	= digestibility of the dry matter (calculated as ME/DM)/15.088)
W	= liveweight (kg)
k_m	= efficiency of use of ME for maintenance

$ME_{move} = 0.0026 \times W \times S \times (TSR/SD)/(0.057 \times PM + 0.16)/k_m$ (after CSIRO, 2007)

Where:

W	= liveweight (kg)
S	= slope (1.0, 1.5, 2.0 for flat, easy and steep respectively)
TSR/SD	= relative stocking rate (1 for sheep, and beef cattle, 0.07 for dairy cattle) - threshold stocking rate ÷ current stocking density
PM	= pasture mass (t/DM/ha)

This is in agreement with Freer *et al.* (2010) – GRAZPLAN model – with a specific assumption of TSR/SD values but differs in approach from the NEMI (Pickering, 2011).

$ME_{activity} = W \times [0.0026 \times Hkm)+(0.028 \times Vkm)]/km$

Where:

W	= liveweight (kg)
Hkm	= horizontal km walked

Vkm = vertical km climbed

These activity values are taken from CSIRO (2007) which states that for animals which need to walk considerable distances for access feed or water (e.g. dairy cattle) "*E_{graze} should then be increased by 0.0026 MJ/kg W for each extra km (horizontal) and 0.028 MJ/kg W per km (vertical component)*".

Regardless of which equation is used to calculate ME_{graze}, the calculations require DMI as an input. Since the NEMI is used to predict DMI, Pickering (2011) states that "*an iterative routine was developed which "guessed" an initial DMI for use in E_{GRAZE} and then repeated the calculation with an updated DMI obtained from the calculated total energy requirements divided by the energy concentration of the diet. This iterative process was repeated until the DMI was stable: this usually took four to six iterations.*"

In calculating E_{graze} Sise *et al*. (2011) estimated DMI from the equation:

DMI = $0.52 \times LWT^{0.75}$ (after Rattray *et al.*, 2007)

Comparison of methods for predicting ME_{graze} for cattle

The methods for calculating ME_{graze} for cattle discussed above, i.e. the approach adopted by the NEMI after SCA (1990) and that adopted by CSIRO (2007) and Nicol & Brookes (2007) were compared for dairy cows (Table 4) and beef cows (Table 5). Liveweight, production and activity assumptions from Nicol & Brookes (2007) were used as a baseline for the comparison.

Table 4. Comparison of ME requirements for grazing and activity (MEgraze) of adult dairy cows using the equations of the NEMI/SCA (1990), CSIRO (2007) and Nicol & Brookes (2007)

Adult Dairy Cows	Liveweight (kg)			
	300	400	500	600
	MJ ME/cow/day			
ME_{basal}†	40.5	49.5	56.4	62.7
ME_{graze} (flat terrain)				
NEMI/SCA (1990)	3.80	5.07	6.33	7.59
CSIRO (2007)	5.83	7.77	9.72	11.66
Nicol & Brookes (2007)$^{\Phi}$	5.21	6.95	8.69	10.43

† K= 1.5 after Nicol & Brookes (2007)

Liveweight, production and activity assumptions from (Nicol & Brookes 2007)

Lactating cows walking 2km each day to and from the dairy shed.

$^{\Phi}$ Refer to the discussion below on the influence of relative stocking density for dairy cows in this calculation

Table 5. Comparison of ME requirements for grazing and activity (ME_{graze}) of beef cows using the equations of the NEMI/SCA (1990), CSIRO (2007) and Nicol & Brookes (2007)

Beef cows	Liveweight (kg)			
	300	400	500	600
	MJ ME/cow/day			
ME_{basal}†	31.8	39.5	46.7	53.5
ME_{graze} (undulating terrain)				
NEMI/SCA (1990)	6.34	8.46	10.57	12.68
CSIRO (2007)	8.36	11.15	13.94	16.72
Nicol & Brookes (2007)	10.89	14.53	18.16	21.79

† K= 1.3 after Nicol & Brookes (2007)

Liveweight, production and activity assumptions from (Nicol & Brookes 2007)

The NEMI/SCA (1990) appears to underestimate ME_{graze} in comparison to the more recent equations of CSIRO (2007) and Nicol & Brookes (2007). These equations both include specific terms for "horizontal distance walked" and, in Nicol & Brookes (2007), an additional term for "vertical distance climbed". The figures presented in Tables 4 and 5 show ME_{graze} for dairy cows on flat terrain and for beef cows on undulating terrain as assumed in the NEMI. Additional comparisons for dairy cattle on flat and undulating terrain and beef cattle on flat, undulating and steep country are presented in Appendix 6 and Appendix 7 respectively.

These comparisons indicate that terrain and walking distance has a potentially large influence on ME_{graze}. Predictions of ME_{graze} for dairy cows including 'walking' activity (after CSIRO, 2007) were between 20 and 25% compared to those calculated by the current NEMI approach. Similarly, for beef cattle grazing on steep terrain ME_{graze} could be further increased by 20 to 25% compared to grazing on undulating terrain.

The influence of relative stocking rate in Nicol & Brookes (2007) equations

One anomaly between ME_{graze} predictions for dairy and beef cows using the Nicol & Brookes (2007) equations is the term for relative stocking rate of 1 for beef cows and 0.07 for dairy cows. As a result the ME_{graze} predications for dairy cattle are smaller than those for CSIRO (2007). The reasoning for the application of the relative stocking rate of 0.07 in Nicol & Brookes (2007) is not clear. This may be a typographical error. If the term is changed to 0.7 for dairy cows the ME_{graze} figures become 7.34, 9.79, 12.24 and 14.69 respectively.

The sensitivity of cattle ME requirements to terrain (flat, undulating and steep) indicates that the values assumed by the NEMI (i.e. flat terrain for dairy cattle and undulating terrain for beef cattle) should be validated. The influence of terrain and walking activity on ME_{graze} and total ME requirements may become important if the NEMI is used on a regional or individual farm basis.

Conclusions and recommendations for ME_{graze} for dairy and beef cattle

The NEMI adopts an outdated equation to account for dairy and beef cattle ME_{graze}.

For dairy cattle ME_{graze} in the NEMI assumes all cattle are farmed on flat terrain. This may not be appropriate where dairy farms often now have a component of undulating terrain.

Similarly for beef cattle ME_{graze} the NEMI assumes all beef cattle are farmed on undulating terrain. This may be inappropriate for high production beef finishing systems on flat land.

It is recommended that the NEMI adopt the updated CSIRO (2007) equation for ME_{graze} or that of Nicol & Brookes (2007) for $ME_{graze} + ME_{move} + ME_{activity}$ to assess more accurately the activity costs of grazing, including distance walked and the nature of the terrain.

It is recommended that terrain assumptions for dairy and beef cattle should be reviewed, especially if the NEMI develops into a regional or individual farm model.

Cattle z_l - Energy adjustment for milk diet in rising 1 year olds

The CSIRO (2007) general equation for maintenance energy requirements (ME_m) accounts for the energy received in milk fed animals with the general equation as follows:

$$ME_m \text{ (MJ/d)} = [K.S.\mathbf{M}.(0.28W^{0.75} \times \exp(-0.03A))]/k_m + 0.1ME_p + (ME_{graze}/k_m) + E_{cold}$$

[NEMI equation 1; CSIRO equation 1.19]

Where:

M = 1 + (0.23 x proportion of DE from milk)

The NEMI adjusts the ME_{total} requirements separately for each appropriate stock class using by subtracting an adjustment factor z_l.

z_l for dairy replacement calves

It is assumed that rising 1 year old dairy replacements are fed milk or milk powder in their first 2 months and, therefore, receive all their energy from these products.

Therefore, for the first two months of life:

$$z_l \text{ (MJ ME/day)} = (Z_{mp} / d) \times (evl/k_l)$$

[NEMI equation 11]

Where:

Z_{mp} = milk (from milk powder) fed to calves

= 200 (kg)

d = number of days of lactation (61 days)

evl = net energy content of milk

= 0.376 × F + 0.209 × P + 0.948 (MJ ME/kg, after AFRC, 1993)

F = milk fat percentage

P = milk protein percentage

k_l = The efficiency of use of ME for milk production

= 0.019 × Pasture ME content + 0.42

The term Z_{mp} is the amount of milk fed to a calf during these two months. The NEMI assumes that for the dairy industry in New Zealand this generally comes from milk powder.

From 3 months of age onwards $z_l = 0$

z_l for beef calves

It is assumed that rising 1 year old beef animals are fed milk and milk powder in their first 6 months and therefore receive part of their energy requirement from these products.

For the first 6 months of life the following equation is used to determine the variable z_l:

z_l (MJ ME/day) = (Z / d) × (evl/k_l)

Where:

Z = milk fed to calves

= (0.67 × Y) + (0.33 × Z_{mp})

Y = milk yield (kg) × calving percentage (specified as 0.85)

Z_{mp} = milk fed to calves from milk powder

= 200 (kg)

d = length of lactation (182 days)

evl = net energy content of milk

= 0.376 × F + 0.209 × P + 0.948 (MJ ME/kg, after AFRC, 1993)

F = milk fat percentage

P = milk protein percentage

k_l = The efficiency of use of ME for milk production

= 0.019 × Pasture ME content + 0.42

From 7 months of age onwards $z_l = 0$

Nicol & Brookes (2007), Freer (2009), and Sise *et al.* (2011) do not make separate adjustments for milk diets in unweaned beef animals. Sise *et al.* (2011) accounts for this using the M coefficient in the CSIRO (2007) general ME_m equation. Nicol & Brookes (2007) and Freer (2009) account for this in the calculation of total ME_l requirements of cows and their calves.

The NEMI is the only model which accounts for the ME requirements of milk fed young stock ‘in arrears’.

Muir *et al.* (2008) recommended that the amounts and proportions of fresh milk and milk replacer fed to calves in both dairy and beef systems be reviewed to reflect changing rearing practices.

Conclusions and recommendations for z_l in dairy and beef cattle

The NEMI adopts a unique approach to calculating an ME ‘discount’ for predicting methane output.

It is recommended the amounts and proportions of fresh milk and milk replacer fed to calves in both dairy and beef systems be reviewed to reflect changing rearing practices.

Sheep energy predictions

The NEMI calculates ME requirements for sheep using the same equations as for cattle with changes to key parameters reflecting species and physiological state.

The NEMI uses the same general equation for sheep as for cattle:

$ME_{total} = BASAL + 1.1 \times ME_p + ME_{graze}$ [NEMI equation 2]

Where:

BASAL = ME requirements to maintain animal weight (MJ/d)

ME_p = ME requirements used directly for milk production, conception/gestation and liveweight gain (MJ/d)

ME_{graze} = additional energy expenditure of a grazing animal compared with a similar housed animal (MJ/d)

Sheep ME_{basal}

The NEMI uses the BASAL energy equation derived from the CSIRO (2007) general equation as for cattle:

$BASAL\ (MJ/d) = K \times S \times (0.28W^{0.75} \times \exp(-0.03A))/k_m$

[NEMI equation 3]

Where:

K = 1.0 for sheep

S = 1.0 for ewes and wethers and 1.15 for entire rams

W = Liveweight (kg) (excluding conceptus)

A = Age in years, with a maximum of 6

k_m = net efficiency of use of ME for maintenance = 0.02 M/D + 0.5

The adoption of this equation for predicting ME_{basal} is consistent with all recent published models to calculate sheep maintenance energy requirements (Cannas *et al.*, 2004 (CNCPS-S model); Wheeler *et al.*, 2008 (OVERSEER model); Freer, 2009 (*ME Requirement* spreadsheet model); Freer *et al.*, 2010 (GRAZPLAN model); Sise *et al.*, 2011 (*Hoofprint* model).

Conclusions and recommendations for Sheep ME_{basal}

The equation adopted by the NEMI for ME_{basal} in sheep are in accordance with all contemporary (modern) models for predicting maintenance energy requirements.

Sheep ME_l - Energy requirements for milk production (lactation)

The NEMI takes its equations for sheep ME_l from CSIRO (2007) and is based on milk fat content:

ME_l (MJ ME/d) = $Y \times evl/k_l$ [NEMI equation 14]

Where:

evl = net energy content of milk

= $0.328 \times F + 0.0025\ D + 2.203$ [CSIRO (2007) equation 1.41]

and:

F = milk fat %

d = number of days of lactation (NEMI assumes 122 days)

Y = y × lambing percentage

y = daily milk yield (kg/d)

k_l = 0.019 × pasture ME content + 0.42

Milk fat percentage is set at 8% (after CSIRO, 2007) and annual milk yield at 103 kg.

The milk fat percentage is in general agreement with Muir *et al.* (2000) who reported an average milk fat percentage of 9% in well fed East Friesian×Romney, Finn×Romney and Romney ewes over 15 weeks of lactation (107 days). During this study milk yield in Romney ewes, assessed by machine milking and using oxytocin, averaged 1.5 litres/d; equating to a total yield of approximately 150 litres over lactation. This is considerably higher than the annual milk yield used by the NEMI and suggests that this figure should be reviewed and validated from current production data. Similarly, the NEMI value for 122 days lactation may need to be validated from current production data.

The term Y= y × lambing percentage assumes a linear relationship between milk yield and number of lambs suckled. This is relevant at lambing percentages close to 100%. However, in some highly productive flocks considerably higher lambing percentages are achieved (e.g. approaching 200%) and this this assumption may need to be validated (Muir *et al.*, 2000), particularly if the NEMI is developed for use on a regional or individual farm basis.

The NEMI is the only contemporary model which calculates sheep lactation requirements separately. Nicol & Brookes (2007), Freer *et al.* (2009) and Sise *et al.* (2011) calculate the additional pasture ME requirements of the suckling mother, adjusted for litter size, to estimate the total amount of energy available for maintenance and growth of each suckling offspring. This accounts for the efficiency of conversion of ME in the dam's tissues into milk and the conversion of net energy content of milk into offspring maintenance and growth.

Conclusions and recommendations for Sheep ME_l

The NEMI appears to be the only contemporary model to calculate ME_l separately, based on milk yield and gross energy content of milk. However, the equation adopted by the NEMI produces results consistent with those produced by CSIRO (2007).

It is recommended that values used for sheep lactation length, milk yield and milk fat should be reviewed, monitored and adjusted as performance improves in the future, though this is likely to have little impact on overall annual methane output for sheep.

Sheep ME_c - Energy requirements for conception/gestation

As for cattle, the NEMI equations for sheep ME_c are based on the those of ARC (1980), confirmed by AFRC (1993) and adapted by CSIRO (2007) which describe the accretion of net energy and nutrients during foetal and conceptus growth.

The only difference between the equations of AFRC (1993) and CSIRO (2007) is that the CSIRO (2007) equations are expressed as functions of natural logarithms (ln or $\log_e$) compared to $\log_{10}$ in AFRC (1993). Nicol & Brookes (2007), Freer (2009) and Sise *et al.* (2011) adopted the CSIRO (2007) for calculating ME_c for sheep.

The general form of the NEMI equation is the same as that used for cattle though parameters are adapted specifically for sheep:

$$ME_g \text{ (MJ/day)} = 0.25 \times W_l \times (E_t \times 0.07372 \times \exp(-0.00643 \times t))/k_c$$

[NEMI equation 13; AFRC equations 73, 74]

Where:

W_l = lamb birth weight (9% of dam weight)

E_t $=10^{(3.322-4.979\times\exp(-0.00643*t))}$

t = number of days pregnant.

The NEMI assumes that lamb birthweight = ewe liveweight × 0.09 × lambing percentage. When the average lambing percentage is above 100%, the lamb birth weight is increased by the same percentage.

Conclusions and recommendations for ME_c in sheep

The equations adopted by the NEMI for ME_c for sheep are in accordance with contemporary (modern) New Zealand models for predicting energy requirements for pregnancy and lactation.

It is recommended that the assumption for determining lamb birth weight (9% of ewe weight) used in the calculations is reviewed for relevance.

Sheep ME_g - ME requirements for change in liveweight

The NEMI calculates ME requirements for liveweight gain in growing sheep (both non-lactating and lactating animals) using the same general equation (CSIRO, 2007) as that for non-lactating cattle (NEMI equation 7). Specific sheep parameters are applied. The NEMI assumes no weight change in adult ewes.

All contemporary models used in New Zealand and Australia apply the same equation and parameters for ME_g in sheep (Nicol & Brookes, 2007; Wheeler *et al.,* 2008; Freer, 2009; Freer *et al.*, 2010; Sise *et al.*, 2011).

Conclusions and recommendations for ME_g in sheep

The equations adopted by the NEMI for ME_g in sheep are in accordance with all contemporary (modern) New Zealand models for predicting energy requirements for liveweight change.

Sheep ME_{graze} – Additional energy requirements for grazing and activity

The NEMI applies the same equation as for cattle to calculate sheep ME_{graze}:

$$ME_{graze} = [((C \times DMI(0.9 - DMD)) + (0.05 \times T/(GF+3)))W]/k_m$$

[NEMI equation 10; SCA (1990) equation 1.24]

Where:

C = 0.05 for sheep

DMI = dry matter intake from pasture, (specified as 10kg/d in Pickering (2011)

DMD = digestibility of the dry matter (decimal)

T = terrain takes values the range from 1.0 to 2.0 as terrain varies from level to steep (1.5 for sheep: undulating)

GF = availability of green forage (tDM/ha) - assumed to be 3.5 – as for dairy

W = liveweight (kg)

k_m = efficiency of use of ME for maintenance (0.02 x pasture ME content +0.5)

Sise *et al*. (2011) adopted this equation for sheep in the commercial *Hoofprint* model.

Freer *et al.* (2010) in the GRAZPLAN model adopts the CSIRO (2007) described earlier for cattle (CSIRO, 2007; equation 1.22 – refer page 27). Freer (2009), in the *ME Required* spreadsheet model, accounts for the energy associated with grazing as a simple, user defined increment on maintenance requirements (default 15%)

Nicol & Brookes (2007) used the same approach in sheep as for cattle and considered separately the calculations for energy costs of grazing activity (ME_{graze}), walking associated with grazing (ME_{move}) and other (walking) activity costs ($ME_{activity}$).

Comparison of methods for predicting ME_{graze} for sheep

The method for calculating ME_{graze} for sheep (i.e. the approach adopted by the NEMI/SCA (1990) has been compared (Table 6) with that adopted by CSIRO (2007) and Nicol & Brookes (2007). Liveweight, production and activity assumptions from Nicol & Brookes (2007) were used as a baseline for the comparison.

Table 6. Comparison of ME requirements for grazing and activity (ME_{graze}) of sheep using the equations of the NEMI/SCA (1990), CSIRO (2007) and Nicol & Brookes (2007)

	Liveweight (kg)				
	40	50	60	70	80
	MJ ME/ewe/day				
ME_{basal}	5.6	6.6	7.5	8.5	9.4
ME_{graze} (undulating terrain)					
NEMI/SCA (1990)	0.95	1.18	1.42	1.65	1.89
CSIRO (2007)	1.12	1.40	1.67	1.95	2.23
Nicol & Brookes (2007)	1.36	1.71	2.05	2.39	2.73

Liveweight, production and activity assumptions from Nicol & Brookes (2007)

As for cattle, the NEMI/SCA (1990) appears to underestimate ME_{graze} in comparison to the more recent equations of CSIRO (2007) and Nicol & Brookes (2007). These equations both include specific terms for "horizontal distance walked" and in Nicol & Brookes (2007) an additional term for "vertical distance climbed". Values for energy expenditure for horizontal and vertical movement are taken from ARC (1980). The figures presented here show ME_{graze} for ewes on undulating terrain as specified in the NEMI. Additional comparisons for flat and steep hill country are presented in Appendix 8. These indicate ewe maintenance requirements could be up to 25% greater on steep compared to flat country due to increased ME_{graze}. Compared to the NEMI equations, the CSIRO

(2007) and Nicol & Brookes (2007) approaches include a specific term for horizontal distance walked, and Nicol & Brookes (2007) an additional term for vertical distance climbed.

The apparent sensitivity of sheep ME_{graze} to terrain (flat, undulating and steep) and potential influence on ME_m, indicates that the terrain value assumed by the NEMI (i.e. sheep grazed on undulating terrain) may need to be validated from current national sheep population data. The influence of terrain and walking activity on ME_{graze} and total ME requirements may become significant if the NEMI is used on a regional or individual farm basis.

Conclusions and recommendations for ME_{graze} for sheep

The NEMI adopts an outdated equation to account for sheep ME_{graze} which does not adequately account for potentially large influences on maintenance requirements of activity associated with grazing, especially on hill country.

For sheep ME_{graze} the NEMI assumes all sheep are farmed on undulating terrain. This may change as national or regional livestock populations change over time.

It is recommended that the NEMI adopt the updated CSIRO (2007) equation for ME_{graze} to that of Nicol & Brookes (2007) for ME_{graze} + ME_{move} + $ME_{activity}$ to more accurately account for the activity costs of grazing, including distance walked and terrain.

It is also recommended that terrain assumptions for sheep should be reviewed and defined, especially if the NEMI develops into a regional or individual farm model.

Sheep z_l - Energy adjustment for milk diet in rising 1 year olds

The NEMI adopts the same procedure as for cattle to adjust for the energy received from milk by a value of z_l.

Therefore for months 3-6 (September to December) i.e. for the first three months of a lamb’s life:

z_l (MJ ME/day) = (Z / d) × (evl/k_l) [NEMI equation 17]

Where:

Z	= milk yield	
	= 103 (kg)	
d	= number of days of lactation (122 days)	
evl	= = gross energy content of milk	
	= 0.328 × F + 0.0025 D + 2.203	[CSIRO (2007) equation 1.41]
F	= milk fat percentage	

D = day of lactation

k_l = The efficiency of use of ME for milk production

= 0.019 × Pasture ME content + 0.42

As discussed for ME_l, the values assumed for milk yield (103kg) and lactation length (122 days) should be reviewed and validated as they are at variance with those reported by Muir *et al.* (2000).

Nicol & Brookes (2007), Freer (2009), and Sise *et al.* (2011) do not make separate adjustments for milk diets in unweaned animals. Sise *et al.* (2011) accounts for this using the M coefficient in the CSIRO (2007) general ME_m equation. Nicol & Brookes (2007) and Freer (2009) account for this in the calculation of total ME_l requirements of ewes and their lambs.

The NEMI is the only model which accounts for the ME requirements of milk fed young stock 'in arrears'.

Conclusions and recommendation for z_l for sheep

The NEMI adopts a unique approach to calculating an ME 'discount' for predicting methane output.

As with ME_l it is recommended that sheep milk yield and milk fat percentage should be validated and adjusted as sheep performance improves, though this is likely to have little impact on overall annual methane output for sheep in the short term.

Sheep ME_w - ME requirements for wool growth in sheep

The NEMI adopts the equation for ME_w from CSIRO (2007):

$$ME_w = (MJ/d) = 0.13\ (Fl - 6)$$

[NEMI equation 16; CSIRO (2007) equation 1.38]

Where:

Fl_{adult} = (fl ×1000)/365 for sheep>1 year old

Fl_{lamb} = ((fl × 1000)/365)/2 for sheep<1 year old

f_l = greasy fleece weight (kg per head)

Only growth in excess of 6g/d contributes to E_w. It is assumed that that the 6g/d is part of maintenance (CSIRO, 2007)

Wool growth is ignored by Nicol & Brookes (2007) and Freer (2009). Freer (2009) uses only shorn live weights. CSIRO (2007) states that *"this amount of ME will be small in absolute terms and in* *relation to the total ME intake that would sustain a high fleece growth rate…and in practical feeding an ME allowance for wool could be ignored.”*

Conclusions and recommendations for ME_{wool} for sheep

The NEMI adopts an equation for ME_{wool} which is in accordance with CSIRO (2007).

Other contemporary models ignore wool growth as it is a very small proportion of individual animal ME_{total}. However, over the national flock annually, the methane consequences could be important.

Deer energy predictions

The energy equations for deer have been considered separately from cattle and sheep as the approach adopted by the NEMI (Pickering 2011) differs considerably from cattle and sheep.

CSIRO (2007) does not provide factorial energy calculations for deer so the NEMI uses New Zealand specific studies to generate equations. The equations described in Pickering (2011) are based largely on the studies of Fennessy *et al*. (1981) and Suttie *et al*. (1987), with modifications according to Mulley & Flesch (2001) and Kay (1985).

The general equation for ME_{total} in deer is:

$$ME_{total} = ME_m + ME_g + ME_c + ME_l – z_l$$

Where:

ME_m	= ME requirements for maintenance
ME_g	= ME requirements for liveweight change (gain or loss)
ME_c	= ME requirements of the pregnancy/gestation
ME_l	= ME requirements for lactation
z_l	= a correction for ME intake derived from milk in young animals

Individual terms are applied as appropriate to the age and physiological state of a particular animal.

Note that compared to the general ME_{total} equation for sheep and cattle [NEMI equation 2] the deer equation excludes ME_{graze} as a separate term. ME_{graze} is ‘assumed’ in the equation for ME_m (described below).

Deer ME_m - energy requirements for maintenance

For deer, the NEMI does not calculate ME_m as the sum of ME_{basal} and ME_{graze} in the same way as for cattle and sheep [NEMI equation 2] (refer to page 10). Instead it adopts an equation based on Fennessy *et al*. (1981)

$$ME_m \text{ (MJ ME/d)} = C \times (W^{0.75}) \qquad \text{[NEMI equation 18]}$$

Where:

C	= 0.7 (coefficient determined from Fennessy *et al*., 1981)
W	= liveweight of deer (kg)

The coefficient (C = 0.7) is an average of data derived from stags (60-110kg) fed indoors (C = 0.52) and stags (113-140kg) outdoors (C = 0.85). These data concurred with calorimetric data from Simpson *et al*. (1978), Suttie *et al*. (1987) and Semiadai *et al*. (1998).

NRC (2007) reviewed ME_m requirements of cervids. These are summarised in Table 7.

The 'average' coefficient (C = 0.7) adopted by the NEMI is in general agreement with the data presented by NRC (2007), though Jiang & Hudson (1992) and Wairimu *et al*. (1992) reported even higher ME_m requirements of wapiti stags and hinds on summer pasture (up to 0.94 MJ/kg $W^{0.75}$).

Table 7. A review of ME_m requirements of deer (NRC, 2007)

Stock class	ME requirements for Maintenance (MJ/kg BW $^{0.75}$)	Source
Suckling or pre-weaned		
Penned	0.485*	*Based on goat data NRC (2007)
Field-maternally raised	0.962†	†White & Luick (1984)
Growing (weaning to 1.5 years of age)		
Winter (red deer calves)	0.452	Simpson *et al*. (1978a,b)
Mature		
Winter (red deer hinds and stags)	0.515, 0.612 respectively	Brockway & Maloiy, (1968), Fennessy *et al.* (1981), Kay & Staines, (1981), Suttie *et al.* (1987)
Winter (elk/wapiti hinds and stags)	0.573, 0.510 respectively	Jiang & Hudson (1992), Haigh & Hudson (1993)
Growing (weaning to 1.5 years of age)		
Summer (red deer)	0.502	Simpson *et al*. (1978b)
Summer (yearling hind & stags)	0.937, 0.879 respectively	Jiang & Hudson, 1992; Wairimu *et al.* 1992)
Mature		
Summer (red deer stags and hinds)	0.849	Fennessy *et al*. (1981) (*May include components of* ME_g)

From the NRC (2007) data it would appear that on a $W^{0.75}$ basis, ME_m requirements of red deer (*Cervus elaphus*) and wapiti/elk (also *Cervus elaphus*) are similar, which is to be expected since they are essentially the same species. Therefore, the higher ME_m calculated by Jiang & Hudson (1992) is likely to reflect higher energy requirements for grazing (an E_{graze} component) not accounted for in data based on indoor fed animals.

Nicol & Brookes (2007) calculated ME_m requirements for deer using the CSIRO (2007) general equation as used by the NEMI for cattle and sheep (NEMI equations 1 and 2).

The equation used by Nicol & Brookes (2007) to calculate ME_{basal} follows CSIRO (2007):

$$ME_{basal}\ (MJ/d) = K \times S \times (0.28W^{0.75} \times \exp(-0.03A))/k_m \qquad \text{[NEMI equation 3]}$$

Where:

K	= 1.4 for deer
S	= 1.0 for females and castrates and 1.15 for stags
W	= Liveweight (kg)
A	= Age in years
k_m	= net efficiency of use of ME for maintenance = 0.02 × M/D + 0.5.

K values for deer

Wheeler (pers. comm.) also reviewed reported C values (ME requirements for maintenance: MJ/kg $BW^{0.75}$) for deer and estimated corresponding K values appropriate for application in the CSIRO (2007) general equation for ME_m. The estimated K values ranged from 1.3 to 1.5. Using the mean value of C = 0.7 (Fennessy *et al.*, 1981) as used in the NEMI, K is estimated to 1.7. Therefore, the NEMI, using K = 1.4, is expected to estimate energy requirements approximately 18% higher than Nicol & Brookes (2007).

Maintenance energy requirements of stags and hinds

Another difference between the NEMI (using C=0.7) and the methods of Nicol & Brookes (2007) and Wheeler *et al.*, (pers. comm; 2011) is that the NEMI does not account for differences in maintenance ME requirement of entire males (stags) and females (hinds), caused by differences in body composition (protein:fat ratio). This principle appears to be firmly established in the literature on ME requirements of ruminants and is generally reflected in a 15% increment in ME_m for males over females.

This may be further complicated by extreme seasonal changes in body composition in stags and hinds during the year. However, mature stags make up a relatively small part of the deer population and, on annual basis, this seasonality is not likely to greatly affect overall estimates of annual ME intake in the NEMI.

Energy costs of grazing and activity

The NEMI equations based on Fennessy *et al*., (1981) and the extended data source of NRC (2007) imply that the energy cost of grazing (E_{graze}) is included in the calculations for ME_m. However, Nicol & Brookes (2007) accounts for the energy cost of grazing separately using the formula:

$$ME_m = ME_{basal} + ME_{graze} + ME_{move} + ME_{activity}$$

The equations for ME_{graze}, ME_{move} and $ME_{activity}$ are the same as those described above for cattle.

Comparison of methods for predicting ME_m for deer

The methods for calculating ME_m for deer, i.e. the approach adopted by the NEMI after Fennessy *et al*. (1981) and that adopted by Nicol & Brookes (2007) after CSIRO (2007), were compared (Table 8). Liveweight and production information from Nicol & Brookes (2007) was used as a baseline for the comparison.

Table 8. Comparison of ME requirements for maintenance (ME_m) of adult deer, using the equations of the NEMI/Fennessy (1987) and Nicol & Brookes (2007)

	Liveweight (kg)					
Class	100	120	140	200	300	400
	MJ ME/hind or stag/day					
After NEMI/Fennessy et al (1987) C = 0.7						
Hind	22.1	25.4	28.5	37.2	50.5	62.6
Stag	22.1	25.4	28.5	37.2	50.5	62.6
After Nicol & Brookes (2007) K=1.4						
Hind	19.7	22.9	26.1	35.5	50.9	66.4
Stag	22.6	25.8	29.0	38.6	53.9	70.2

Note that in the NEMI calculations there is no distinction between stags and hinds. Using the Nicol & Brookes (2007) approach ME_m requirements of stags are between 6% and 12% higher than hinds, with greater difference at lower liveweights.

In the Nicol & Brookes (2007) calculations energy costs associated with grazing and activity are accounted for separately. These are shown in Appendix 9 along with Nicol & Brookes (2007) published ME_m requirements for deer.

The calculated results in the table above are similar to those published by Nicol & Brookes (2007), though the value for the 300kg stag is 20% higher than stated by Nicol & Brookes (2007). This may reflect a typographical error in Nicol & Brookes (2007).

There appears to be little practical difference between the results of the NEMI and Nicol & Brookes (2007) for calculating ME_m for deer, particularly within the lower/middle liveweight range. However, should the NEMI be applied on a regional or individual farm basis, the Nicol & Brookes (2007) approach is able to account for differences energy costs of grazing due to variations in farm type and pasture quality. These may vary from 14-29% of the overall ME_m (for flat country), 16-32% (easy hill country) and 19-35% (steep/hard hill country) across the liveweight range of Nicol & Brookes (2007) – see Appendix 9.

Conclusions and recommendations for Deer ME_m

For deer ME_{basal} the current NEMI equations do not account for differences in maintenance energy requirements between stags and hinds according to the generally accepted principle that maintenance requirements of intact males are 15% higher than females and castrates. Also, compared to the CSIRO (2007) equations, the NEMI approach does not account for age/weight relationships for maintenance requirements.

Similarly, compared to the CSIRO (2007) equations, the NEMI approach does not account for variations in energy costs associated with grazing and activity due to variations in regional farm topography.

It is recommended that the NEMI adopts the CSIRO (2007) equation with K = 1.4.

Deer ME_g - energy requirements for liveweight gain

For deer ME_g the equations used in the NEMI are:

Hinds ME_g = 56 MJ ME/kg liveweight gain. [NEMI equation 19]

Stags ME_g = 37 MJ ME/kg liveweight gain. [NEMI equation 20]

In the NEMI (Pickering 2007) the ME_g equations for hinds and stages are both attributed to Fennessy *et al.* (1981) when in fact the stag equation is derived from Fennessy *et al.* (1981) and the hind data from Suttie *et al*. (1987). Suttie *et al*. (1987) reported the first actual measurement of ME requirements of red deer hinds.

NRC (2007) summarised a number of studies which reported values for ME_g in cervids (converted from kcal/g to MJ/kg average daily liveweight gain). These are summarised in Table 9.

Table 9. Review of ME_g requirements of deer (NRC, 2007)

Stock class	ME requirements for liveweight gain (MJ/kg ADG)	Source
Suckling		
Free range reindeer	22.3	White & Luick (1984)
Growing (Wapiti)		
Weaned	19.7	Jiang & Hudson, 1992
Yearling hinds	38.5	Jiang & Hudson, 1992
Yearling males	33.5	Wairimu *et al*. 1992
Mature		

Red deer hinds	54.8	Fennessy *et al*. 1981

In contrast, Nicol & Brookes (2007) calculated ME_g requirements for deer using the equations derived from CSIRO (2007) which predict the net energy content of live weight gain. These are the same equations used in the NEMI to calculate ME_g in non-lactating cattle and sheep:

$$EBG\ (MJ/kg) = (a + cR) + (b – cR) / [1 + \exp(-6(Z-0.4))]$$

[CSIRO (2007) Equation 1.30]

Where:

a, b and c are derived from CSIRO (2007: Table 1.11) - refer to Table 3, page 23

a = 6.7

b = 1.0

c = 20.3

R = adjustment for rate of gain or loss = $[EBC/(4 \times SRW^{0.75})]-1$

EBC = 0.92 × LWG in g/d

SRW = the standard reference weight in kg.

Z = current live weight /SRW (maximum value of 1)

Comparison of methods for predicting ME_g for deer

The methods for calculating ME_g for deer discussed above, i.e. the approach adopted by the NEMI after Fennessy *et al*. (1981) and that adopted by Nicol & Brookes (2007) after CSIRO (2007) were compared (Tables 10 and 11). Liveweight and production information from Nicol & Brookes (2007) was used as a baseline for the comparison. ME_g requirements for deer as published by Nicol and Brookes are presented in Appendix 10.

The ME_g requirements (MJ ME/kg liveweight gain) used in NEMI (Pickering, 2011), and NRC (2007) are in general agreement. However, compared to the results of Nicol & Brookes (2007) the equations adopted NEMI do not appear to account for change in composition of gain (fat and protein) with increased liveweight. The NEMI approach appears to overestimate ME_g for smaller animals and underestimate ME_g for larger animals compared to Nicol & Brookes (2007). It is worth noting that at the heavy end, there are very few (if any) mature elk currently being farmed. The difference between the NEMI prediction and Nicol & Brooks (2007) decreases as animals approach mature live weight.

Table 10. Metabolisable energy requirements for liveweight gain (ME_g) in deer, calculated using the NEMI equations (Pickering (2011), after Fennessy *et al*. (1987).

Class	Sire type	Mature liveweight	Liveweight (kg)				
			40	60	80	100	120
			MJ ME/100g liveweight gain				
Hinds	Red	100	5.6	5.6	5.6	5.6	5.6
	Hybrid	120	5.6	5.6	5.6	5.6	5.6

	Elk	300	5.6	5.6	5.6	5.6	5.6
Stags	Red	250	3.7	3.7	3.7	3.7	3.7
	Hybrid	300	3.7	3.7	3.7	3.7	3.7
	Elk	400	3.7	3.7	3.7	3.7	3.7

Note that the NEMI (Pickering, 2011) method does not consider deer genotype (mature liveweight) or individual deer liveweight. Data are duplicated here for clarity during comparisons between tables.

Table 11. Metabolisable energy requirements for liveweight gain (ME_g) in deer, calculated using the equations of Nicol & Brookes (2007) after CSIRO (2007)

Class	Sire type	Mature liveweight	Liveweight (kg)				
			40	60	80	100	120
			MJ ME/100g liveweight gain				
Hinds	Red	100	3.6	4.8	5.5	5.7	5.8
	Hybrid	120	3.2	4.3	5.1	5.5	5.7
	Elk	300	2.1	2.4	2.7	3.1	3.6
Stags	Red	250	2.2	2.6	3.0	3.6	4.1
	Hybrid	300	2.1	2.4	2.7	3.1	3.6
	Elk	400	1.9	2.1	2.3	2.6	2.9

Conclusions and recommendations for Deer ME_g

For deer ME_g the NEMI equations do not take into consideration the potential change in composition of gain (fat and protein) with age.

It is recommended that the NEMI adopts the CSIRO (2007) equation for ME_g in deer as applied by Nicol & Brookes (2007).

Deer ME_c - energy requirements for conception/gestation

The NEMI (Pickering, 2011) adopts the equations of Fennessy *et al*. (1981) for ME_c and adjusts for pregnancy by applying a ‘trimester factor’ to hind liveweight, adapted from recommendations of Mulley & Flesch (2001):

ME_c (MJ ME/d) = C x TF x $W^{0.75}$ [NEMI equation 23]

Where:

C	= 0.7 (as for deer ME_m)
TF	= trimester factor (10% for May, Jun; 20% for Jul; 30% for Aug, Sep; 60% for Oct, Nov)
W	= maternal liveweight.

Total ME_c requirement for gestation is the sum of daily ME_c requirements for each day of pregnancy (Appendix 11).

This approach differs considerably from other published methods of calculating ME_c in ruminants which base calculations of ME_c on calf birth weight.

The CSIRO (2007) equations used for ME_c in cattle and sheep in the NEMI appear not to have been applied to deer. CSIRO (2007) did not cite specific relevant coefficients for deer, and none have yet been identified in the published literature.

However, Nicol & Brookes (2007) calculated ME_c using the equation:

$$ME_c = (BWT/8) \times (-0.5424 + 0.3346 (\exp(0.0217t)))/k_c$$

Where:

BWT	= calf birth weight (kg) (BWT/8 = adjusted for SRW calf weight of 8kg)
t	= days after conception
k_c	= 0.133

In contrast to the ME_c equation adopted by CSIRO (2007) and the NEMI (Pickering, 2011) for cattle and sheep, Nicol & Brookes (2007) predict *cumulative* ME_c from conception to a specified day of gestation. From these data the ME requirement for any particular day of gestation and total ME requirements for pregnancy can be calculated (Appendix 12). The source of this equation is yet to be identified.

NRC (2007) generated equations to estimate NE_{preg} (net energy retention in the gravid uterus) in cervids at day ‘t’ during the second half of gestation (100-230 days depending on species) based on gravid body composition data in a number of studies. The equations (and data sources) are:

$$NE_{preg}\ t\ (kcal/d) = LBW \times Yt$$

Where:

t = day of gestation

LBW = parturition birth weight (kg)

$\ln Yt = -1.6198 + 0.0226 \times X$ for red deer (after Adam et al. 1988a,b)

$$\text{Ln } Yt = -1.7938 + 0.0193 \times X \quad \text{for wapiti/elk (after Robbins \& Moen, 1975)}$$

Where:

Y = energy retention (kcal/d) per kg foetus produced

X = day of gestation

As in Nicol & Brookes (2007) these equations reflect the exponential increase in NE_{preg} from conception to parturition (Appendix 13).

However, the NRC (2007) equations predict NE_{preg} for a particular day of pregnancy (t or X). Total NE_{preg} over the whole pregnancy is the sum of individual daily requirements from conception to parturition.

Comparison of methods for predicting ME_c for deer

The methods for calculating ME_c for deer discussed above, i.e. those adopted by the NEMI after Fennessy *et al*. (1981), Nicol & Brookes (2007) and NRC (2007) were compared (Table 12). Liveweight and production information from Nicol & Brookes (2007) was used as a baseline for the comparison. ME_c requirements for deer as published by Nicol and Brookes (2007; Table 22) are presented in Appendix 12.

Table 12. Total metabolisable energy requirements for pregnancy (ME_c) in deer, calculated using the equations of NEMI/Fennessy *et al*. (1981), Nicol & Brookes (2007) and NRC (2007).

Calf birth weight (kg)	Total ME requirements for pregnancy (MJ ME)		
	NEMI/(Fennessy *et al*., 1981)	Nicol & Brookes (2007)	NRC (2007)
8	1316	436	439
10	1316	545	549
12	1316	654	659

The results of ME_c predictions using the methods of Nicol & Brookes (2007) and (NRC (2007), though based on different approaches, agree closely both in terms of daily ME_c requirement and total ME_c requirement from conception to pregnancy (see also Appendix 12 and 13).

However, the results of calculations using the NEMI equations agree with neither Nicol & Brookes (2007) nor NRC (2007).

The discrepancy appears to be because the NEMI method does not adequately account for the exponential increase in ME_c during pregnancy (see Appendix 11). The NEMI relationship between day-of-pregnancy and daily ME_c is largely linear. Therefore, it overestimates daily ME_c requirements in mid pregnancy and underestimates near the end of pregnancy, resulting in a considerable overestimate of total ME requirements.

It is clear that due to the exponential relationship between ME_c and day of gestation (t), the length of gestation has a large influence on individual daily ME_c requirements near the end of pregnancy. For example, extending overall gestation length by 4 days from 234-238 days increased *daily* ME requirements by 1.2 MJ ME (≈10%) for a hind with a 12kg calf. However, this would be a small increment on the total ME requirements for pregnancy. However, it is important to validate an appropriate gestation length for deer for use in the model.

The NEMI model also fails to account for variation in ME_c requirements with calf birth weight. In the Nicol & Brookes (2007) and NRC (2007) models there was difference in ME_c of approximately 30% between a 12kg and an 8 kg calf.

Conclusions and recommendations for Deer ME_c

For deer ME_c the current NEMI equations do not agree with other accepted models. It appears that this is because the NEMI equation, using a 'trimester factor", does not adequately reflect the exponential relationship between day-of-pregnancy and daily ME requirements of the conceptus and appears to considerably overestimate ME_c requirements.

It is recommended that the NEMI adopts the exponential function based on calf birth weight as used by Nicol & Brookes (2007).

It is also recommended that the length of gestation applied to the equation is validated.

Deer ME_l - energy requirements for lactation

Both NEMI (Pickering, 2011) and NRC (2007) calculate ME_l based on the gross energy content of deer milk (evl) and milk yield (Y):

ME_l (MJ ME/d) = Y × evl/k_l [NEMI equation 21]

Where:

Y	= milk yield (kg/d)
	= annual milk yield x milk yield monthly proportion/number of days in month
evl	= energy value of milk
	= 5.25 MJ/kg
k_l	= 0.64 (from Moe *et al*., 1971)

Milk yield and lactation length

Pickering (2011) cites Mulley & Flesch (2001) as the origin of the value for annual milk yield (242 kg) used in the NEMI.

The annual milk yield used by the NEMI (242 kg) is in general agreement with the data of Landete-Callistejos *et al.* (2000) who reported total milk yield of 224.1 ± 21.1 litres in captive Iberian red deer (*Cervus elaphus hispanicus*) and average daily yield of 0.91 ± 0.06 l/d though this was recorded over a 34 week period, longer than the natural lactation period. However, Landete-Callistejos *et al.* (2000) also reported milk production for a standard period of 105 days was 147 ± 13.1 l (approximately the length of the lactation period in Iberian red deer in natural conditions), which may be regarded as the amount of milk available for calf growth during a standard lactation. NEMI uses 121 days as the length of lactation.

Landete-Callistejos *et al.* (2000) also cited lactation volumes and duration from three other studies. These are summarised in Table 12.

Table 13. Milk yield data and sources cited by Landete-Callistejos *et al*. (2000)

Source	Deer breed	Total milk yield (litres)	Lactation length (days)
Arman et al. (1974)	Scottish red	136.2	150
Loudon & Kay (1984)	Red deer	171	100
Robbins *et al*. (1987)	Wapiti	240	Not stated
Landete-Callistejos *et al*. (2000)	Iberian red	147	105
NEMI (Pickering, 2011)	Red deer	242	103

Taking into consideration minor errors associated with comparing milk yield in kg and litres and the potential effect of liveweight of dams (from red to wapiti× to wapiti) in the data in the table above, it appears that the value of 242 kg per dam used in the NEMI could be an overestimate of annual milk production for a 4 month lactation across the national herd.

Therefore, the value for milk yield for red deer used in the NEMI should be reviewed taking into consideration variation in the period of lactation measured in these studies.

Nicol & Brookes (2007) does not calculate ME_l *per se*, but "*ME requirements of hinds plus fawns during lactation*" which includes milk production from the dam and also the ME_m requirements of the fawn to weaning (including pasture ME).

Energy value of milk

The NEMI (Pickering 2011) cites Kay (1985) as the origin of the energy value of red deer milk (5.25 MJ ME/kg) used in NEMI equation 22. This is based on Kay's statement that "in the early days of lactation (10-50 days) a hind on good pasture produces about 2kg milk daily, supplying about 10.5 MJ/day" after Loudon & Kay (1984).

Landete-Callistejos *et al.* (2003) identified an equation to predict gross energy content of milk energy from Iberian (*C. elaphus hispanicus*) and Scottish (*C. elaphus scoticus*) red deer. Since there was no difference between Iberian and Scottish red deer it would seem reasonable that the equation could be applied to New Zealand red deer:

E_{cal} (kcal/g fresh milk) = 0.345 + 8.339F + 5.407P

Where:

F = milk fat content (g/ml)

P = milk protein content (g/ml)

Note: E_{cal} is expressed in g whereas milk F and P are expressed in ml – as cited in Landete-Callistejos *et al*. (2003)

Landete-Callistejos *et al.* (2000) reported the following milk fat and protein compositions for Iberian red deer:

F = 11.5% = 0.115 g/ml (assuming the density of milk = 1 g/ml)

P = 7.6% = 0.076 g/ml

Using this milk composition data and the equation from Landete-Callistejos *et al.* (2003):

E_{cal} = 1.71 kcal/g fresh milk = 7.2 MJ/kg

However, in Landete-Callistejos *et al.* (2003) mean caloric value for milk was reported as

E_{cal} = 1.41 ± 0.01kcal/g = 5.9 MJ/kg

Note that in the Clark (2003) version of NEMI:

E_l = 8.2 MJ per litre milk (no source cited)

NRC (2007) calculates the energy value of milk for cervids using the equation:

$Q = 4.24 - 0.6202 \times \text{Ln } Y_m$

Where:

Y_m = daily milk yield (ml/kg $W^{0.75}$)

Using this equation and the deer liveweight input data from the NEMI (NEMI Appendix14)

Q (= evl) was calculated to be 7.29 MJ/litre fresh milk.

Published values for gross energy content of cervid milk are summarised in Table 14.

Table 14. Published values for gross energy content of cervid milk

Gross energy content	Source
5.25 MJ/kg	Adopted by NEMI (Pickering, 2011)
5.9 MJ/kg	Measured caloric value quoted by Landete-Callistejos *et al.* (2003)
7.2 MJ/kg	Calculated using milk composition from Landete-Callistejos *et al.* (2000) and equation from Landete-Callistejos *et al.* (2003)
7.29 MJ/litre	NRC (2007)
8.25 MJ/kg	Value stated by Clark (2008) – source not cited.

In light of these data, it would appear that the evl used in the NEMI (5.25 MJ ME/kg) may be an underestimate. It is recommended that this figure be reviewed in the NEMI.

It appears that the approach for predicting ME_l for deer using milk yield and evl is the most appropriate method provided that an appropriate value for these factors is confirmed.

It is clear that the current values used by the NEMI are at the extreme high end of the current published values for milk yield and the extreme low end of the data for evl (Appendix 14).

Conclusions and recommendations for Deer ME_l

For deer ME_l the NEMI adopts appropriate equations but the values for evl and milk yield are at variance with recent information Landete-Callistejos *et al.* (2000, 2003), NRC (2007).

It is **recommended** that the NEMI adopts the evl and lactation lengths according to Landete-Callistejos *et al.* (2000, 2003).

Deer z_l - Energy adjustment for milk diet

The NEMI methane adjustment for milk fed deer calves follows the same procedure as for sheep and cattle using the basic equation:

z_l (MJ ME/day) = (Z/ d) × (evl/k_l) [NEMI equation 22]

Where:

Z	= milk yield
d	= number of days of lactation (121 days)
evl	= as above 5.25 (MJ ME/kg)
k_l	= 0.64 (Moe et al. 1971)

The methane adjustment should be reviewed following the discussion in the previous section on the relevance of current values for milk composition and evl.

Conclusions and recommendations for z_l in deer

The NEMI adopts a unique approach to calculating an ME 'discount' for predicting methane output.

The values adopted by the NEMI for evl and milk yield in deer are at variance with recent information Landete-Callistejos *et al.* (2000, 2003), NRC (2007).

It is recommended that the NEMI adopts the evl and lactation lengths according to Landete-Callistejos *et al.* (2000, 2003).

Deer ME_{velvet} - energy requirements for velvet production

ME_{velvet} = 0.75 MJ ME/d NEMI (Pickering 2011)

No data source or reference is provided.

Fennessy *et al*. (1981) calculated the total ME requirement for velvet antler growth to be 0.5 MJ ME/d over 100 days for a stag producing 2.4kg of velvet antlers.

CSIRO (2007) states the energy requirement for antler growth is 21 kcal/kg $W^{0.75}$ (0.0879 MJ/kg $W^{0.75}$ (no source cited).

Using the CSIRO (2007) figures above, energy requirements for antler growth for a mature stag weighing 200 kg (Drew 1993) over 100 days would be approximately 0.47MJ/day.

This is in general agreement with Fennessy *et al.* (1981) but is significantly less than the value adopted by NEMI (Pickering 2011).

The NEMI uses a figure of 3kg velvet antler yield per stag per year.

Compared with ME_{total} in stags, ME_{velvet} is quite small and any change this figure in the energy calculations is unlikely to make a significant difference to methane emissions until further information is available.

Conclusions and recommendations for ME_{velvet} in deer

The NEMI value for ME_{velvet} appears to overestimate ME_{velvet} compared with data from Fennessy *et al.* (1981) and CSIRO (2007).

It is recommended that the NEMI uses a value of 0.5 MJME for ME_{velvet}.

Implications for the NEMI of changes to ME_{total}

This review has evaluated individual factorial components of ME_{total} for dairy and beef cattle, sheep and deer and has identified potential areas of improvement for individual equations.

This final section briefly explores the potential effects of recommended changes to the NEMI equations in terms of total metabolisable energy requirements (ME_{total}).

Calculations using the current NEMI equations are compared with the alternative equations recommended by this review. Since it is not possible to evaluate all the permutations of species and physiological state, four 'typical' animals, one from each species group, are compared. Assumptions are stated.

The following tables present results for the individual factorial components and total ME requirements together with an indication of the magnitude of difference between the two methods.

Differences between current equations and parameters and proposed alternatives are briefly summarised:

Dairy cattle and beef cattle of dairy breed origin

Table 15. Comparison of ME requirements for a 'typical' dairy cow as calculated by the current NEMI equations (Pickering, 2011) and those recommended in this review.

Assumptions: 600 kg adult cow (4yr old), mid-lactation (day 92), single calf, 60 days into gestation, 0.5kg/d liveweight gain, grazing flat terrain, walking 2km/day to and from dairy shed.

Method	ME_{basal}	ME_{g}	ME_{l}	ME_{c}	ME_{graze}	ME_{move}	$ME_{activity}$	ME_{total}
NEMI	58.5	20.9	74.2	1.4	12.8	6.4	-	183.8
Alternative	62.7	26.4	74.2	1.4	5.3	0.4†	4.3	185.0
Difference	7.2%	26.5%	0%	0%		-47.5%		0.6%

NEMI: current equations (Pickering 2011) K=1.4

Alternative: after Nicol & Brookes (2007); CSIRO (2007) K=1.5

For dairy cattle ME_{basal} the NEMI adopts a K value of 1.4. The alternative method here predicts ME_{basal} using k = 1.5 (Nicol & Brookes, 2007) for both dairy cattle and beef cattle of dairy breed origin.

The NEMI adopts an outdated equation to account for liveweight change (increase and decrease) in lactating cows.

NEMI calculates ME_{graze} (and ME_{move}) with different coefficients and older equations compared to CSIRO (2007).

†Note very low ME_{move} in alternative method – due to very high stocking rate factor adopted by Nicol & Brookes (2007).

Recommendations:

- To predict ME_{basal} NEMI adopts K = 1.5
- To predict ME_g for lactating cows NEMI adopts the CSIRO (2007) equation rather than the SCA (1990) equation.
- To account for energy costs of grazing and activity, the NEMI adopts the more precise method of Nicol & Brookes (2007); CSIRO (2007) to allow for variation in energy costs associated with grazing on varying terrain.

Beef cattle of "british" beef breed origin

Table 16. Comparison of ME requirements for a 'typical' beef cow as calculated by the current NEMI equations (Pickering, 2011) and those recommended in this review.

Assumptions: 500 kg adult cow (2yr old), mid-lactation (day 92), single calf, 60 days into gestation, 0.5kg/d liveweight gain, grazing undulating terrain.

Method	ME_{basal}	ME_g	ME_l	ME_c	ME_{graze}	ME_{move}	$ME_{activity}$	ME_{total}
NEMI	55.0	20.9	24.3	0.6	9.1	8.0	-	122.5
Alternative	51.1	26.5	24.3	0.6	3.8	10	3.8	125.3
Difference	-7.1%	27.1%	0%	0%		2.8%		2.3%

NEMI: current equations (Pickering 2011) K=1.4

Alternative: after Nicol & Brookes (2007); CSIRO (2007) K=1.3

For beef cattle ME_{basal} the NEMI adopts a K value of 1.4. The alternative method here predicts ME_{basal} for beef cows of "British" beef breed origin using K = 1.3 (Nicol & Brookes, 2007).

ME_{basal} for beef cattle of dairy origin would be calculated using K= 1.5 as in Table 15.

The NEMI adopts an outdated equation to account for liveweight change (increase and decrease) in lactating cows.

NEMI calculates ME_{graze} (and ME_{move}) with different coefficients and older equations compared to CSIRO (2007).

Recommendations:

- To predict $ME_{basal,}$ for beef cattle of “British” beef breed origin NEMI adopts K = 1.3
- To predict $ME_{basal,}$ for beef cattle of dairy breed origin NEMI adopts K = 1.5
- To predict ME_g for lactating cows, NEMI adopts the CSIRO (2007) equation for rather than the SCA (1990) equation.
- To account for energy costs of grazing and activity, NEMI adopts the more precise method of Nicol & Brookes (2007); CSIRO (2007) to allow for variation in energy costs associated with grazing on varying terrain.

Sheep

Table 17. Comparison of ME requirements for a ‘typical’ ewe as calculated by the current NEMI equations (Pickering, 2011) and those recommended in this review.

Assumptions: 60 kg adult ewe, mid-lactation (day 60), single lamb, no liveweight gain, grazing undulating terrain.

Method	ME_{basal}	ME_g	ME_l	ME_c	ME_{graze}	ME_{move}	$ME_{activity}$	ME_{total}
NEMI	7.5	0	6.8	-	2.43	0.96	-	17.43
Alternative	7.5	0	6.8	-	0.59	1.3	0.5	17.39
Difference	0%	0%	0%			-1.7%		-0.2%

NEMI: current equations (Pickering 2011)

Alternative: after Nicol & Brookes (2007); CSIRO (2007)

Current sheep equations are consistent with contemporary models except for the calculation of energy costs of grazing. NEMI calculates ME_{graze} (and ME_{move}) with different coefficients and older equations compared to CSIRO (2007).

Recommendation:

- To account for energy costs of grazing and activity NEMI adopts the more precise method of Nicol & Brookes (2007); CSIRO (2007) to allow for variation in energy costs associated with grazing on varying terrain.

Deer

Table 18. Comparison of ME requirements for a ‘typical’ hind as calculated by the current NEMI equations (Pickering, 2011) and those recommended in this review.

Assumptions: 120 kg adult hind (2yr old), mid-lactation (day 60), single calf, 0.1kg/d liveweight gain, grazing flat terrain.

Method	ME_{basal}	ME_g	ME_l	ME_c	ME_{graze}	ME_{move}	$ME_{activity}$	ME_{total}
NEMI	25.4	5.6	16.3	-	-	-	-	49.5
Alternative	18.9	5.2	15.0	-	0.8	2.5	0.9	45.3
Difference	-25.5%	-7.1%	-7.9%	-		-		-8.4%

NEMI: current equations (Pickering 2011)

Alternative: after Nicol & Brookes (2007); CSIRO (2007) K=1.4

For deer ME_{basal} the NEMI, the NEMI approach does not account for age/weight relationships for maintenance requirements compared to the CSIRO (2007) equations. The alternative method here predicts ME_{basal} using the CSIRO (2007) equations with K=1.4 (after Nicol & Brookes, 2007).

For Deer ME_g the NEMI equations do not take into consideration the potential change in composition of gain (fat and protein) with age.

For Deer ME_l the NEMI adopts appropriate equations but the values for evl and milk yield are at variance with recent information Landete-Callistejos *et al.* (200, 2003), NRC (2007).

The NEMI does not account adequately for energy costs of grazing or activity

.

Recommendations:

- To predict ME_{basal} NEMI adopts the CSIRO (2007) equations for $_l$ with K = 1.4 after Nicol & Brookes (2007)
- To predict ME_g the NEMI adopts the CSIRO (2007) equation.
- To predict ME_l the NEMI adopts the evl and lactation lengths according to Landete-Callistejos *et al.* (200, 2003).
- To account for energy costs of grazing and activity the NEMI adopts the equations of CSIRO (2007) for ME_{graze}, ME_{move} and $ME_{activity}$

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Appendices

Appendix 1: Breed differences in maintenance energy requirements for beef and dairy cattle, as reviewed by ARC (1980), AFRC (1993), NRC (2000, 2001) and CSIRO (2007)

Source	Breed difference reported
Andersen (1980) *Cited by NRC (2000)*	Simmental (high mature body weight as for dairy breeds) had 6% higher maintenance requirements compared to Herefords
ARC (1993)	Discusses “safety margins” for feed allowances to avoid “underfeeding”. ARC (1993) summarises thus: *Beef cattle:* a 5% allowance in addition to requirements reduces the proportion of underfed cattle by 10%. *Dairy cattle:* ARC (1980) ME requirements are 10% too low on average. A 10% margin reduces the proportion of underfed cattle by 30%. Since ARC (1993) uses the same FHP equation for all cattle (AFRC, 1993; equation 40) this supports the notion of a practical difference between FHP in dairy and beef cattle.
Blaxter & Wainman (1966) *Cited by ARC (1980) and NRC (2000)*	Ayrshire (dairy type) steers had 20 % higher FHP (kcal/BW0.75) than Angus (beef type) type steers and 6 % higher than crosses of those breeds. (by calorimetry)
Brody (1945) *Cited by NRC (2000)*	Observed slightly higher requirements by Holstein cows than Jersey cows.
Byers (1982), Andersen (1980). *Cited by NRC (2000)*	Estimates of maintenance requirements similar in Limousin, Angus, Hereford, and Charolais
Byers(1982) *Cited by NRC (2000)*	Simmental had 3% higher maintenance requirements compared to Herefords
Chestnutt *et al.* (1975) *Cited by NRC (2000)*	Maintenance requirements of Friesian estimated to be 20% higher than Friesian×Hereford and 14% greater than Angus steers
Frisch & Vercoe (1977, 1984) *Cited by CSIRO (2007)*	The appropriate coefficient on metabolic liveweight for Bos taurus cattle is 1.4× that for sheep (no distinction made between dairy and beef breeds). Note that in these two papers this coefficient is for Brahman, Hereford × Shorthorn (HS) and Brahman × HS Dairy cattle breeds or their crosses were not observed
Garrett (1971) *Cited by ARC (1980) and NRC (2000)*	In three separate comparative slaughter trials Holstein had higher maintenance costs than Hereford steers, individual trial differences being 5%, 13% and 11%.

Source	Breed difference reported
Jenkins & Ferrell (1983) and Ferrell & Jenkins (1984a,b,c) *Cited by NRC (2000)*	ME requirement for energy stasis of mature, non-lactating crossbred Jersey, Simmental, and Charolais sired cows (from Angus or Hereford dams) was 112, 123, and 99 % that of Angus-Hereford (130 kcal/BW0.75) cross cows.
Jenkins & Ferrell (1984b), Ferrell & Jenkins (1985a), Stetter *et al.* (1989). *Cited by NRC (2000)*	Feed required for weight or energy stasis in young bulls and heifers was 19% greater in Simmental than Hereford. (Simmental is regarded as a high mature liveweight breed as for dairy breeds)
Lemenager *et al.* (1980) *Cited by NRC (2000)*	Energy needs of Simmental×Hereford cows was approx. 25 % higher than Hereford cows during gestation, whereas Angus×Hereford and Charolais×Hereford required about 5% and 7 % more than Herefords respectively.
NRC (2007)	NRC (2007) cited NRC (2000, 2001) in concluding that “selection for milk production has yielded a greater maintenance energy requirement for dairy vs. beef cattle breeds”.
Old & Garrett (1987), Andersen (1980) *Cited by NRC (2000)*	Maintenance requirements of Charolais and Hereford similar
Ritzman & Benedict (1938) *Cited by ARC (1980) and NRC (2000)*	Dairy animals have 9% higher metabolism than beef animals. No difference between energy required by Jersey and Holstein cows
Ritzman & Benedict (1938) *Cited by NRC (2000)*	No difference between energy required by Jersey and Holstein cows
Robelin & Geay (1976), Vermorel *et al.* (1976), Geay et al. (1980), Vermorel *et al.* (1982) *Cited by NRC (2000)*	Estimates of maintenance requirements in growing Friesian cattle average approximately 13 % higher (5 to 20 present) than for Charolais
Solis *et al.* (1988) *Cited by NRC (2000)*	Estimates of ME required for energy stasis were 104, 96, 96, 112, and 106 kcal/BW0.75/day for ½ Angus, ½ Brahman, ½ Hereford, ½ Holstein, and ½ Jersey cows, respectively.
Taylor & Young (1968), Taylor *et al.* (1986) *Cited by NRC (2000)*	Energy required for long-term weight equilibrium of British Friesian, Jersey, and Ayrshire cows was 20% higher than that of Angus and Hereford cows. Energy required by Dexter cows was 9 % higher than the average of Angus and Hereford cows
Thompson *et al.* (1983) *Cited by NRC (2000)*	ME required for energy stasis was 9% higher in Angus×Holstein than in Angus×Hereford cows

Source	Breed difference reported
Truscott *et al.* (1983) *Cited by NRC (2000)*	Maintenance estimates were 7% higher for Friesian than Hereford steers
Webster *et al.* (1976, 1982) *Cited by NRC (2000)*	Predicted basal metabolism rates of Friesian cattle to be greater than Angus (10%), Hereford (31%), or Friesian×Hereford (8%).
Wurgler & Bickel (1985) *Cited by NRC (2000)*	no consistent difference in estimates of maintenance requirements among Angus×Braunvieh, Braunvieh, or Friesian steers

Appendix 2: Beef cow ME_{basal} requirements, calculated using the NEMI BASAL equation (Pickering 2011) as derived from CSIRO (2007), using K = 1.3 and 1.4

	Liveweight (kg)*			
	300	400	500	600
K†	ME_{basal} MJ ME/cow/day			
1.3	31.8	39.5	46.7	53.5
1.4	34.3	4.25	50.2	57.6
% difference 1.4 →1.3	-7.1%			

† K= 1.3 after Nicol & Brookes (2007); K=1.4 after CSIRO (2007) and Freer (2009)

** Liveweight data from Nicol & Brookes (2007)*

Average Age = 5 years: M/D = 10.5 MJ ME/kgDM (after Nicol & Brookes 2007)

Appendix 3: Dairy cow ME_{basal} requirements, calculated using the NEMI BASAL equation (Pickering 2011) as derived from CSIRO (2007), using K = 1.4 and 1.5.

Replacement heifers	Liveweight (kg)*						
	100	150	200	250	300	350	400
K†	ME_{basal} MJ ME/cow/day						
1.4	16.2	22.0	27.3	32.2	37.0	41.5	45.9
1.5	17.4	23.5	29.2	34.5	39.6	44.5	49.1
% difference 1.4 →1.5	+7.1%						

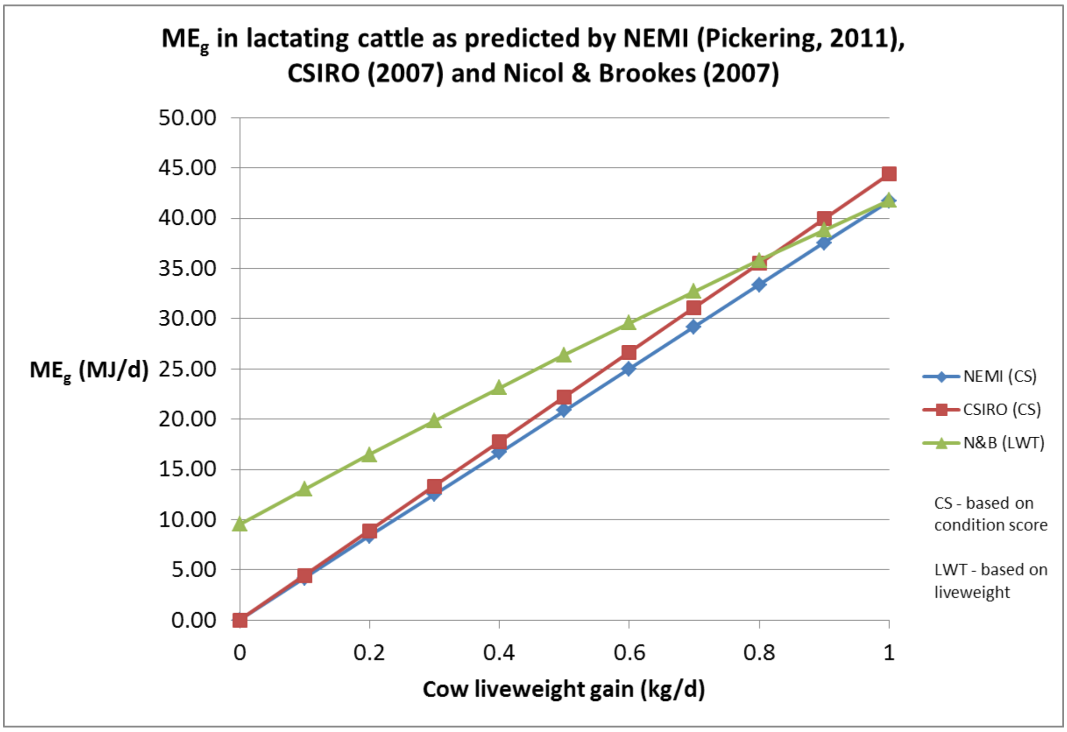
Adult cows	Liveweight (kg)*						
	300	350	400	450	500	550	600
K†	ME_{basal} MJ ME/cow/day						
1.4	34.8	39.1	43.2	47.2	51.1	54.8	58.5
1.5	37.3	41.5	46.3	50.5	54.7	58.8	62.7
% difference 1.4 →1.5	+7.1%						

† K= 1.5 after Nicol & Brookes (2007); K=1.4 after CSIRO (2007) and Freer (2009)

** Liveweight data from Nicol & Brookes (2007)*

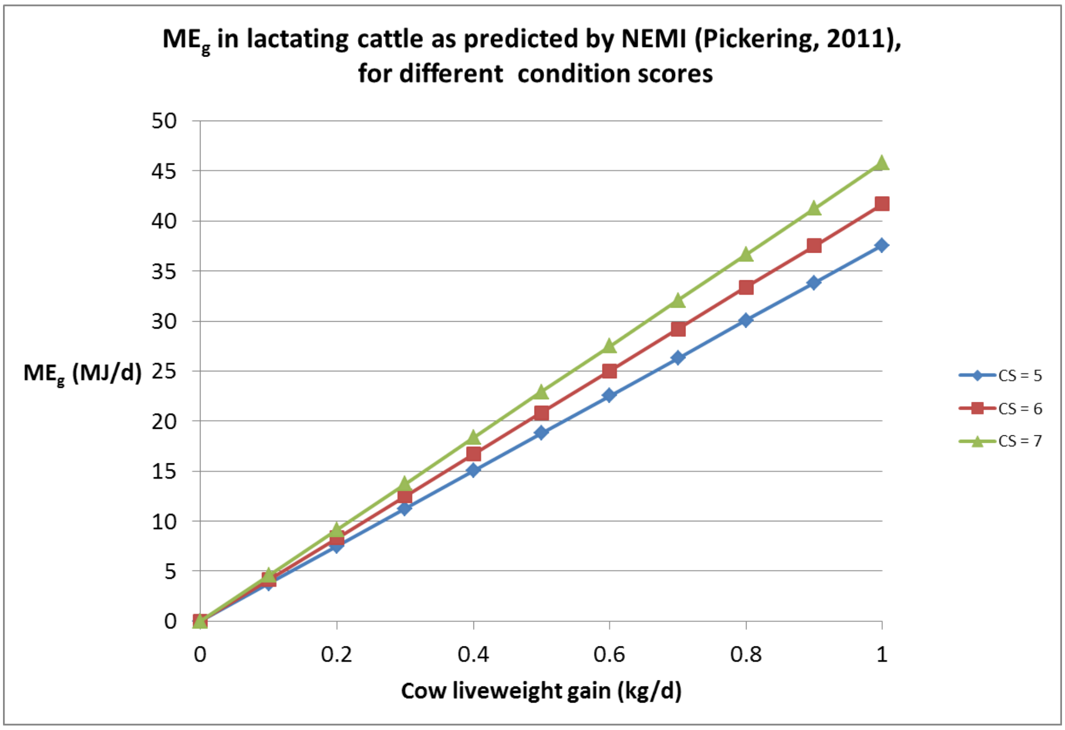
Age = 2 years (heifers) Age = 5 years (adult cows: M/D = 10.5 MJ ME/kgDM (after Nicol & Brookes 2007)

Appendix 4: ME_g in lactating cattle as predicted by NEMI (Pickering, 2011), CSIRO (2007) and Nicol & Brookes (2007)



These data were calculated for a 600kg cow with a CS of 6

Appendix 5: ME_g in lactating cattle as predicted by NEMI (Pickering, 2011), for different body condition scores



Appendix 6: Comparison of ME requirements for grazing and activity (ME_{graze}) of adult dairy cows using the equations of the NEMI (Pickering, 2011), CSIRO (2007) and Nicol & Brookes (2007)

Adult Dairy Cows	Liveweight (kg)			
	300	400	500	600
	MJ ME/cow/day			
ME_{basal} †	40.5	49.5	56.4	62.7
ME_{graze} (flat terrain)				
NEMI/SCA (1990)	3.80	5.07	6.33	7.59
CSIRO (2007)	5.83	7.77	9.72	11.66
Nicol & Brookes (2007) Φ	5.09	6.78	8.48	10.18
ME_{graze} (undulating terrain)				
NEMI/SCA (1990)	5.70	7.59	9.49	11.38
CSIRO (2007)	8.75	11.66	14.57	17.49
Nicol & Brookes (2007) Φ	5.21	6.95	8.69	10.43

† K= 1.5 after Nicol & Brookes (2007)

Liveweight, production and activity assumptions from (Nicol & Brookes 2007)

Lactating cows walking 2km each day to and from the dairy shed.

Φ Refer to the discussion on relative stocking density for dairy cows

Appendix 7: Comparison of ME requirements for grazing and activity (ME_{graze}) of beef cows using the equations of the NEMI (Pickering, 2011), CSIRO (2007) and Nicol & Brookes (2007)

Beef Cows	Liveweight (kg)			
	300	400	500	600
	MJ ME/cow/day			
ME_{basal}[†]	31.8	39.5	46.7	53.5
ME_{graze} (flat terrain)				
NEMI/SCA (1990)	4.07	5.42	6.78	8.13
CSIRO (2007)	4.74	6.31	7.89	9.47
Nicol & Brookes (2007)	6.28	8.38	10.47	12.57
ME_{graze} (undulating terrain)				
NEMI/SCA (1990)	6.34	8.46	10.57	12.68
CSIRO (2007)	8.36	11.15	13.94	16.72
Nicol & Brookes (2007)	10.89	14.53	18.16	21.79
ME_{graze} (steep terrain)				
NEMI/SCA (1990)	8.81	11.74	14.68	17.61
CSIRO (2007)	14.02	18.69	23.36	28.03
Nicol & Brookes (2007)	16.38	21.84	27.30	32.76

[†] K= 1.3 after Nicol & Brookes (2007)

Liveweight, production and activity assumptions from (Nicol & Brookes 2007)

Appendix 8: Comparison of ME requirements for grazing and activity (ME_{graze}) of sheep using the equations of the NEMI (Pickering, 2011), CSIRO (2007) and Nicol & Brookes (2007)

	Liveweight (kg)				
	40	50	60	70	80
	MJ ME/ewe/day				
ME_{basal}	5.6	6.6	7.5	8.5	9.4
MEgraze (flat terrain)					
NEMI/SCA (1990)	0.59	0.74	0.89	1.03	1.18
CSIRO (2007)	0.63	0.79	0.95	1.11	1.26
Nicol & Brookes (2007)	0.80	1.00	1.19	1.39	1.59
MEgraze (undulating terrain)					
NEMI/SCA (1990)	0.95	1.18	1.42	1.65	1.89
CSIRO (2007)	1.12	1.40	1.67	1.95	2.23
Nicol & Brookes (2007)	1.36	1.71	2.05	2.39	2.73
MEgraze (steep terrain)					
NEMI/SCA (1990)	1.35	1.68	2.02	2.35	2.69
CSIRO (2007)	1.87	2.34	2.81	3.27	3.74
Nicol & Brookes (2007)	2.06	2.57	3.09	3.60	4.11

Liveweight, production and activity assumptions from Nicol & Brookes (2007)

The NEMI/SCA (1990) appears to underestimate ME_{graze} in comparison to the more recent equations of CSIRO (2007) and Nicol & Brookes (2007). These equations both include specific terms for "horizontal distance walked" and in Nicol & Brookes (2007) an additional term for "vertical distance climbed".

Appendix 9: Metabolisable energy requirements for maintenance (ME_m) of adult deer

ME_m for adult deer as published by Nicol & Brookes (2007; Table 21)

Class	Liveweight (kg)					
	100	120	140	200	300	400
	MJ ME/hind or stag/day					
Hind	20.0	25.0	30.0			
Stag			33.0	35.0	40.0	65.0

From this data Nicol & Brookes (2007) calculated that these ME requirements for maintenance for adult deer range from 0.62-0.72 MJ ME/kg $W^{0.75}$.

Calculated metabolisable energy requirements for maintenance (ME_m) of adult deer, using the equations of Pickering (2011), after Fennessy et al (1987) where C = 0.7

Class	Liveweight (kg)					
	100	120	140	200	300	400
	MJ ME/hind or stag/day					
Hind	22.1	25.4	28.5	37.2	50.5	62.6
Stag	22.1	25.4	28.5	37.2	50.5	62.6

Note that in the NEMI and Fennessy et al. (1987) calculations there is no distinction between stags and hinds.

Data are duplicated here for clarity during comparisons between tables.

Calculated metabolisable energy requirements for maintenance (ME_m) of adult deer, using the equations of Nicol & Brookes (2007), after CSIRO (2007)

Class		Liveweight (kg)					
		100	120	140	200	300	400
		MJ ME/hind or stag/day					
Hind	ME_{basal}	16.0	18.3	20.5	26.8	36.4	45.1
	ME_{graze}	0.9	1.2	1.6	2.9	6.0	9.9
	ME_{move}	2.1	2.5	2.9	4.2	6.3	8.4
	$ME_{activity}$	0.8	0.9	1.1	1.5	2.3	3.0
	ME_m	19.7	22.9	26.1	35.5	50.9	66.4
Stag	ME_{basal}	18.9	21.2	23.4	29.9	39.4	48.9
	ME_{graze}	0.9	1.2	1.6	2.9	6.0	9.9

ME_{move}	2.1	2.5	2.9	4.2	6.3	8.4
$ME_{activity}$	0.8	0.9	1.1	1.5	2.3	3.0
ME_m	22.6	25.8	29.0	38.6	53.9	70.2

Appendix 10: The metabolisable energy requirements for liveweight gain (ME_g) in deer

ME_g for adult deer as published by Nicol & Brookes (2007; Table 25)

Class	Sire type	Mature liveweight	Liveweight (kg)				
			40	60	80	100	120
			MJ ME/100g liveweight gain				
Hinds	Red	100	4.0	5.0			
	Hybrid	120	3.5	4.5	5.5	6.0	
	Elk	300		2.5	3.0	3.5	4.0
Stags	Red	250	2.5	3.0	3.5	4.0	5.0
	Hybrid	300		2.5	3.0	3.5	4.0
	Elk	400			2.5	3.0	3.5

Metabolisable energy requirements for liveweight gain (ME_g) in deer, calculated using the NEMI equations (Pickering (2011), after Fennessy *et al.* (1987).

Class	Sire type	Mature liveweight	Liveweight (kg)				
			40	60	80	100	120
			MJ ME/100g liveweight gain				
Hinds	Red	100	5.6	5.6	5.6	5.6	5.6
	Hybrid	120	5.6	5.6	5.6	5.6	5.6
	Elk	300	5.6	5.6	5.6	5.6	5.6
Stags	Red	250	3.7	3.7	3.7	3.7	3.7
	Hybrid	300	3.7	3.7	3.7	3.7	3.7
	Elk	400	3.7	3.7	3.7	3.7	3.7

Note that the NEMI (Pickering, 2011) method does not consider deer genotype (mature liveweight) or individual deer liveweight. Data are duplicated here for clarity during comparisons between tables.

Metabolisable energy requirements for liveweight gain (ME_g) in deer, calculated using the equations of Nicol & Brookes (2007) after CSIRO (2007)

Class	Sire type	Mature liveweight	Liveweight (kg)				
			40	60	80	100	120
			MJ ME/100g liveweight gain				
Hinds	Red	100	3.6	4.8	5.5	5.7	5.8

	Hybrid	120	3.2	4.3	5.1	5.5	5.7
	Elk	300	2.1	2.4	2.7	3.1	3.6
Stags	Red	250	2.2	2.6	3.0	3.6	4.1
	Hybrid	300	2.1	2.4	2.7	3.1	3.6
	Elk	400	1.9	2.1	2.3	2.6	2.9

Appendix 11: Metabolisable energy requirements for pregnancy (ME_c) in hinds calculated using the equations of Pickering (2011), after Fennessy et al (1987).

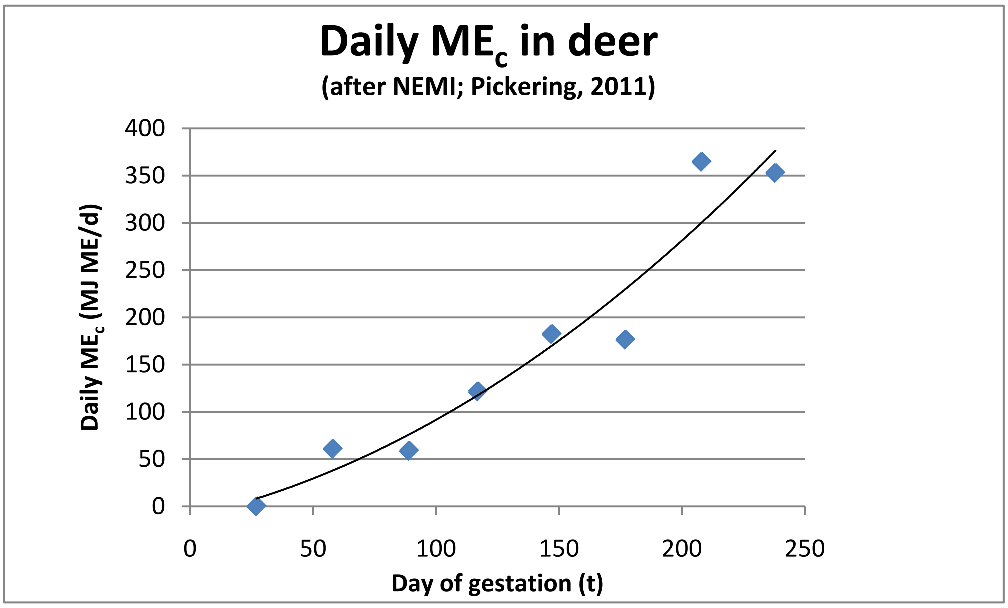
Month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Day of gestation	27	58	89	117	147	177	208	238
TF	0	0.1	0.1	0.2	0.3	0.3	0.6	0.6
Hind LWT (kg)	85	85	85	85	85	85	85	85
ME (MJ/d)	0.0	2.0	2.0	3.9	5.9	5.9	11.8	11.8
ME (MJ/month)	0	61	59	121	182	176	364	353

Total ME_c over pregnancy = Σ ME (MJ/month) = 1317 MJ

Trimester factors are taken from Pickering (2011; Table 6)

Day of gestation is taken from Pickering (2011; Appendix 5). These are not used in the calculation but provide a reference for comparison with other tables.

The relationship between daily ME_c requirements and day of gestation as calculated using the equations of Pickering (2011), after Fennessy et al (1987).



Appendix 12: Metabolisable energy requirements for pregnancy (ME_c) in deer, calculated using the equations of Nicol & Brookes (2007).

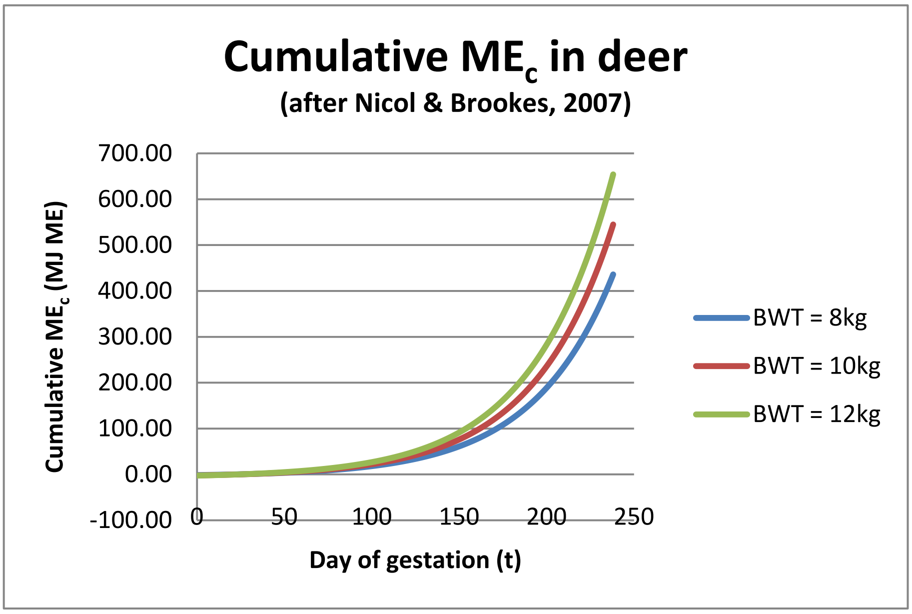
Calf birth weight (kg)	Weeks before calving				Total for pregnancy
	-6	-4	-2	0	
	MJ ME/hind/day				MJ ME
8	3.8	5.1	7.0	9.4	436.0
10	4.7	6.4	8.7	11.8	545.0
12	5.7	7.7	10.5	14.2	654.0

The metabolisable energy requirements for pregnancy (ME_c) in hinds (in addition to maintenance requirement) as published by Nicol & Brookes (2007; Table 22)

Calf birth weight (kg)	Weeks before calving				Total for pregnancy
	-6	-4	-2	0	
	MJ ME/hind/day				MJ ME
8	3.5	5.0	7.0	9.0	440.0
10	4.5	6.5	9.0	11.5	550.0
12	5.5	7.5	10.5	13.5	660.0

The relationship between cumulative ME_c requirements and day of gestation as calculated using the equations of Nicol & Brookes (2007).

The graph demonstrates the exponential increase in *cumulative* ME_c requirements from conception to parturition. The data points (y-value) at the far right of each curve equal the Total ME_c for pregnancy in the table above.



Appendix 13: Metabolisable energy requirements for pregnancy (ME_c) in deer, calculated using the equations of NRC (2007).

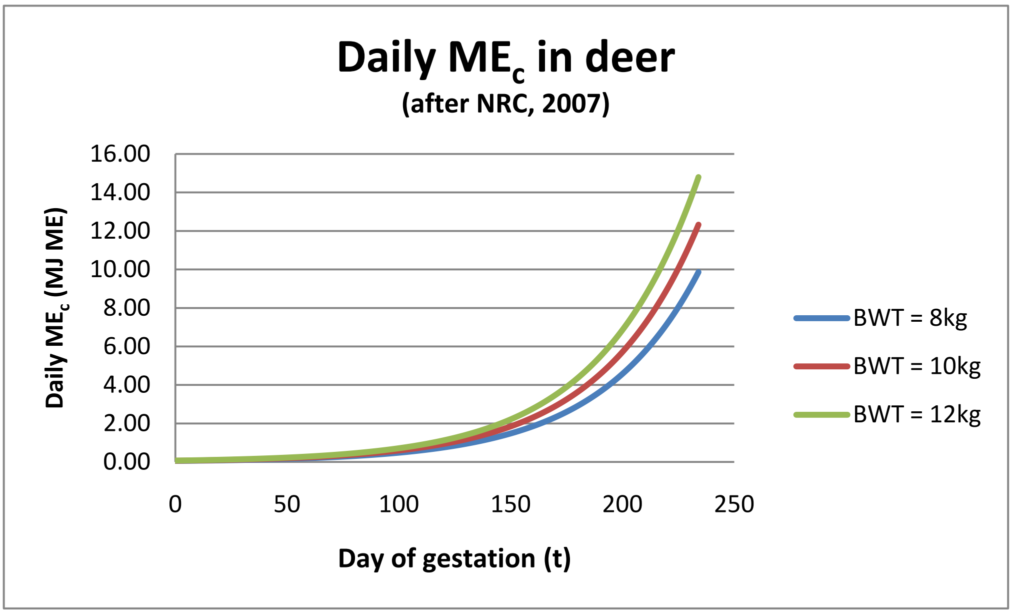
Calf birth weight (kg)	Weeks before calving				Total for pregnancy
	-6	-4	-2	0	
	MJ ME/hind/day				MJ ME
8	3.82	5.24	7.19	9.86	439.0
10	4.77	6.55	8.99	12.33	549.0
12	5.73	7.86	10.78	14.80	659.0

These data agree closely with those of Nicol & Brookes (2007) – see Appendix 12.

The relationship between daily ME_c requirements and day of gestation as calculated using the equations of NRC (2007).

In common with Nicol & Brookes (2007) these data reflect exponential increase in *daily* ME_c requirements from conception to parturition. The data points at the far right of each curve equal the daily ME_c for pregnancy at parturition (0 weeks before calving).

Total ME_c over the whole pregnancy is the sum of individual daily requirements from conception to parturition.



Appendix 14. Metabolisable energy requirements for lactation (ME_l) in deer.

Milk yield data and sources cited by Landete-Callistejos *et al*. (2000)

Source	Deer breed	Total milk yield (litres)	Lactation length (days)
Arman *et al*. (1974)	Scottish red	136.2	150
Loudon & Kay (1984)	Red deer	171	100
Robbins *et al.* (1987)	Wapiti	240	Not stated
Landete-Callistejos *et al.* (2000)	Iberian red	147	105
NEMI (Pickering, 2011)	Red deer	242	103

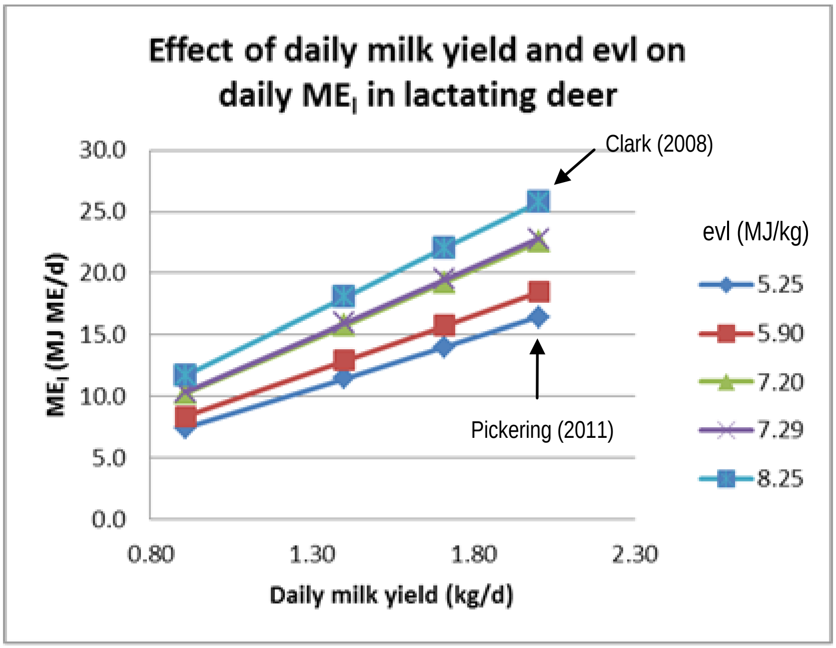
Published values for gross energy content of cervid milk

Gross energy content	Source
5.25 MJ/kg	Adopted by NEMI (Pickering, 2011)
5.9 MJ/kg	Measured caloric value quoted by Landete-Callistejos *et al.* (2003)
7.2 MJ/kg	Calculated using milk composition from Landete-Callistejos *et al.* (2000) and equation from Landete-Callistejos *et al.* (2003)
7.29 MJ/litre	NRC (2007)
8.25 MJ/kg	Value stated by Clark (2008) – source not cited.

The effect of daily milk yield and evl on daily ME_l using published values listed above.

Daily milk yield was plotted rather than annual milk yield to take account of the different lactation lengths measured in the studies.

The upper and lower lines correspond to the extreme values for evl in the NEMI of 5.25 MJ/kg



(Pickering, 2011) and 8.25 MJ/kg (Clark, 2008).