REFEREED ARTICLE

Selection indices offer potential for New Zealand sheep farmers to reduce greenhouse gas emissions per unit of product

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ABSTRACT

The New Zealand Government is a signatory of the Kyoto Protocol which provides incentive for it to reduce its total greenhouse gas emissions (GHG). The sheep industry is a significant contributor to the total GHG in New Zealand. It also has widespread use of selection index technology which could be a potential GHG mitigation tool. This paper provides an assessment of the potential for New Zealand sheep farmers to reduce GHG using selection indices.

Trait weightings were altered in novel indices to facilitate greater reductions in GHG. These were compared to a conventional farm profit maximising index. Selection of sheep using the farm profit maximising index reduced GHG output in kilograms of carbon dioxide equivalent units (kg CO_2e) per kilogram of lamb carcase weight (kg cwt) by 0.59% of total methane and nitrous oxide emissions *per annum* (pa). Novel 'Dual Purpose Environment' indices (DPE) were developed to provide greater GHG reductions in kg CO_2e/kg cwt. A range of carbon prices were incorporated into the DPE. The study showed 96.6% of the potential farm profit (excluding emissions costs) and 69.8% of potential kg CO_2e/kg cwt improvements could be obtained using a carbon price of NZ$100/tonne CO_2e in the DPE. The corresponding figures for NZ$25/t CO_2e were 99.8% and 56%. The carbon price used in the DPE therefore influenced the trade-off between progress in traits which reduce GHG in kg CO_2e/kg cwt and those that improve farm profitability.

Selection indices are an option for farmers to reduce GHG in kg CO_2e/kg cwt in New Zealand sheep. However, farmers will need to consider the trade-off between improving traits which contribute to farm profit and those that reduce GHG.

KEYWORDS: Mitigation methods; genetic improvement; trait weightings

1. Introduction

Increasing concentrations of GHG in the Earth's atmosphere are a major challenge to humankind. The change in concentrations of GHG has been described as symptomatic of human activities '*stretching Earth's limits*' (Janzen, 2011 p. 785). The rise in GHG concentrations, as well as other waste products produced by human activity may put into jeopardy critical processes to the welfare of the biosphere and therefore the welfare of humankind (Kitzes *et al.*, 2008, Rockström *et al.*, 2009). Fortunately there have been efforts to reduce GHG at a global level (UNFCCC, 1998, UNFCCC, 2010). The Kyoto Protocol for instance was an agreement for signatory countries to measure their GHG and take steps to reduce them to negotiated levels.

Livestock is a significant contributor to global GHG with estimates of up to 51% of total GHG being attributed to this source (Herrero *et al.*, 2011). It has been claimed that livestock is one of the two or three biggest contributors to the most serious environmental problems (Steinfeld *et al.*, 2006). Energy losses through GHG are also significant inefficiencies in ruminant production systems (Eckard *et al.*, 2010). So regardless of their impact on the environment there is economic rationale for aiming to reduce these inefficiencies. Furthermore, any improvement in efficiency of production will enable more food to be produced on Earth's limited land resource. Efforts to improve the production efficiency of the major livestock groups will reduce environmental degradation through land use change (O'Mara, 2011).

A wide range of methods have been suggested as offering potential to mitigate the environmental impact of livestock in GHG terms (Eckard *et al.*, 2010, Moran *et al.*, 2011). However, genetic selection is a particularly feasible option because changes are permanent, cumulative and at relatively low cost (Wall *et al.*, 2010). Reductions in GHG may also occur in concurrence with

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improvements in farm profitability. This can improve the cost effectiveness of the genetic selection relative to other technologies (Moran *et al.*, 2011).

New Zealand is a signatory of the Kyoto Protocol and is relatively dependent on agriculture for its economic welfare. The agriculture sector for example contributed 5% of gross domestic product in the year ending 31 March 2009. Of New Zealand's gross agricultural production, sheep meat and wool contributed NZ$2.61 billion[3] or 11.3% to the total value in the same year (New Zealand Treasury, 2010). New Zealand's commitment to the Kyoto Protocol requires it to reduce its GHG to 1990 levels and take responsibility for any excess emissions (Ministry of Agriculture and Forestry, 2011). Of the total GHG produced by New Zealand in 2009, agriculture contributed 46.5% of New Zealand's total GHG. Methane from sheep alone made up 7.1% of total emissions (Ministry for the Environment, 2011). The potential costs of the agriculture industry exceeding its limit was estimated as being NZ$0.5 billion in the first commitment period (from 2008–2012) (Leslie *et al.*, 2008). The significance of the agriculture sector's contribution to the nation's total GHG therefore lead the New Zealand Government to propose including ruminant emissions in a regulatory framework to place a cost on producers of GHG by 2015. The framework was termed the Emissions Trading Scheme (ETS).

It is expected New Zealand farmers will generally not be the direct participants of the ETS. Rather, it will be the processors of the animal products who will be the participants (a processor point of obligation; (Ministry of Agriculture and Forestry, 2011)). Processors would deduct the costs of GHG from the value of each product. This would be based on New Zealand average emission factors (on a per head and per kilogram of product basis) on behalf of the Government.

The New Zealand sheep industry already has relatively widespread use of selection index technology and clearly has incentives to reduce GHG in order to contribute toward the nation's Kyoto Protocol obligations. This makes it an appropriate case study to assess selection index technology as a potential GHG mitigation tool for ruminants.

An update of the selection index for New Zealand sheep by Byrne *et al.,* (2012) provided an opportunity to incorporate GHG into indices which aimed toward mitigating GHG. No published studies have assessed the implications of including GHG in a wide range of traits in a selection index while taking into account the correlations between traits and the time it takes traits to be expressed. We therefore assessed selection index technology for its potential as a tool to mitigate GHG for the New Zealand sheep industry.

Research questions to answer this include:

- how would the relative weighting of traits differ between indices focussed on farm profit maximisation and indices which incorporate the goal of reducing GHG?;
- how would the genetic progress made in each trait respond to the changes in relative weightings?;
- how would the genetic progress made in each trait relate to GHG emissions?;
- what would be the effect of the novel indices in farm profit terms?

The analysis of genetic progress in this study will be limited to maternal (dual purpose) sheep in New Zealand farm systems for the production of meat and wool.

This introduction will be followed by a literature review which provides background on traditional economic selection indices (Section 2) as well as a review of studies which have assessed the potential implications of selecting for traits to reduce GHG (Section 3). The review will be followed by an explanation of the method we used to develop and assess novel selection indices for the New Zealand sheep industry (Section 4). Then the results (Section 5), discussion (Section 6) and conclusions (Section 7) will be explained.

2. Economic selection indices

Selecting the 'best' animals for breeding can be difficult when trying to take into account a range of traits. Selection indices can simplify the decision farmers make when selecting their 'best' animals. This is achieved by defining the relative weightings for a range of traits so that a fair comparison can be made between animals (Hazel, 1943).

Economic selection indices assign relative weightings to each trait based on how a unit change in the trait impacts on farm profitability. Each trait is generally defined per animal expressing the trait. Geneflow methodology can be used to account for the different timing and frequency of trait expression (McClintock & Cunningham, 1974). The longevity trait for breeding animals for instance will only be expressed once at the end of the life of the breeding animal. In contrast, a growth trait expressed in offspring may be expressed within a relatively short period of time, and by many offspring.

Genetic progress made in each trait is dependent on the relative weightings calculated for each trait. Altering the relative weightings in each trait can result in a re-ranking of individual selection candidates and impact on the overall trait progress made in a breeding programme (Simm, 1998). It is well established in the literature that selection of animals aided by a selection index can improve the production of offspring. Progress made using selection indices tend to range between 1 and 3% in relation to the mean of the trait being selected for (Simm, 1998). Furthermore, genetic progress has been an influential factor in the progress that has been made in livestock yield (Thornton, 2010). There are numerous examples where genetic progress has been made following the use of selection indices. Chickens in Tanzania for example obtained 70 to 81 gram per generation progress in 16 week body weight (Lwelamira & Kifaro, 2010) through genetic selection. European pig breeding programmes were stated by Merks (2000) to have contributed toward annual increases of 20g/day in daily gain and 0.2 piglets/litter in litter size from 1990–1999. Significant improvements in carcase weight and

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[3] In early June 2012, NZ$1 was approximately equivalent to US$0.75, €0.61, and £0.49 (sterling).

fertility traits in New Zealand sheep were also attributed to the use of a selection index (Young & Amer, 2009).

At an industry level genetic progress in traits can vary depending on the flow of information from elite breeders to commercial populations (Wall *et al.*, 2010). Genetic progress made in pig and poultry programmes for instance are generally greater than progress made in sheep and beef cattle breeding programmes. This is because the former industries tend to have fewer and larger seed stock companies in the market (Amer *et al.*, 2007). Nevertheless, genetic progress can bring about change to the economic welfare of farmers (Beard, 1988) with significant returns possible. The combined benefits from 10 years of genetic improvements made in the UK sheep and beef industry for instance was estimated as £110.8 million by Amer *et al.,* (2007). This represented an annual 32% internal rate of return on investment.

Industry incentive to maintain or improve farm profitability through the benefits genetic selection can deliver would partly account for the large number of studies which have developed selection indices across a broad range of species. De Vries (1989) for pigs; Beard (1988) for dairy cattle; McClintock & Cunningham (1974) for beef cattle and Byrne *et al.,* (2012) for sheep are just a few studies where selection indices were developed in order to optimise genetic selection for gains in farm profitability.

As a recent example from the literature Byrne *et al.*, (2012) updated the New Zealand sheep selection index termed the Dual Purpose Overall index (DPO) to reflect the maternal traits ram breeders select for in their maternal sire rams. The objective of the index was to maximise farm profit progress for farmers and is expected to be implemented by the New Zealand sheep industry in the near future. For the New Zealand sheep industry's selection index, farm profit was defined as the gross margin between before tax revenues and before tax costs for a typical sheep farm.

A further recent development in the literature is the uptake of selection index technology for ranking cultivars of perennial ryegrass (*Lolium perenne*) (DairyNZ, 2011, McEvoy *et al.*, 2011). McEvoy *et al.,* (2011) applied a selection index technique similar to that used for developing animal selection indices. They developed a model for an Irish dairy farm system to estimate the profit implications when perennial ryegrass traits changed by one unit. The subsequent ranking of perennial ryegrass cultivars will help optimise cultivar selection for the dairy industry (McEvoy *et al.*, 2011). The literature therefore highlights the flexibility the selection index method has to aid selection decisions across species and farm systems.

3. Selection to reduce GHG in livestock

Selection indices are not limited to just improving animal production and farm profits. Broader societal goals can also be aimed for. Other goals considered for inclusion in selection indices include: animal welfare; species biodiversity; safety of food; health properties of products and the environment (Wall *et al.*, 2010). However, some goals from society have a non-pecuniary aspect to them. This can make it more difficult to assign relative weighting to traits according to the contribution they make toward achieving those goals. Studies from the literature will be limited to the goal of improvements in the environment in relation to GHG as this is the focus of the review.

How reductions in GHG are measured is an important aspect to GHG mitigation through genetic selection methods. Therefore a brief background on ruminant GHG will be explained before studies pertaining to GHG mitigation through genetic selection are reviewed.

There are a range of GHG that contribute to climate change but methane (CH_4) and nitrous oxide (N_2O) are the two most significant from ruminant production systems. In a study of a New Zealand sheep system for instance approximately 90% of the GHG produced were either CH_4 or N_2O (Ledgard *et al.*, 2010). This is because CH_4 is inherently linked to the digestive system of ruminants (Janzen, 2011). Ruminants also excrete nitrogen which can contribute toward N_2O. The quantity of CH_4 or N_2O does not allow a fair comparison of their potential environmental damages to be made. Therefore a standard measure of the radiative forcing effect of a unit mass of each GHG is used (Casey & Holden, 2005). This measure is termed the Global Warming Potential (GWP). The GWP of GHG are calculated relative to carbon dioxide equivalent (CO_2e) values. The GWP of CH_4 for instance is 21 and for N_2O is 210 (Ministry for the Environment, 2010).

Furthermore, to calculate emissions from livestock, GHG emission factors (EF) need to be used. IPCC approved EF are used in order to create a fair and consistent quantification of total GHG between countries. EF can also be used to quantify the potential benefits of agricultural GHG mitigation methods such as how Alcock & Hegarty (2011) examined for sheep in Australia. Ruminant EF are primarily based on the quantity of energy consumed. These energy values can be converted into emissions per kilogram of dry matter consumed (Table 1) as reported in New Zealand's GHG inventory submission to the IPCC.

Although livestock produce GHG, the main aim of livestock systems is generally to produce food or fibre in a profitable manner (Janzen, 2011). However, countries signed up to the Kyoto Protocol also have obligations to take steps to reduce their total GHG. Increasing ruminant production per head could help reduce total GHG if there was a proportionate reduction in number of animals to maintain the same quantity of product. Intensification of agriculture (which genetic selection has contributed toward) has offset some GHG related to land use change (Burney *et al.*, 2010). Similarly, Wall *et al.,* (2010) mentioned improvements in per cow milk yield contributed to reductions in methane in the Canadian dairy industry (10%) and the European Union's agriculture sector (20%) following the reduction in number of cows. However, if the number of ruminants remains unchanged, an increase in per head production can result in higher per animal energy requirements hence higher total GHG. There appears to be a conflict in goals to reduce total GHG when there is selection for ruminants with higher production. A factor to explain why higher ruminant production is being targeted while countries have goals to reduce total GHG is the projected increase in the human population.

Table 1: Methane and nitrous oxide emission factors per kilogram of dry matter intake (kg DMI), based on the Ministry for the Environment (2010)

Class of stock	Grams of CH_4 per kg DMI	Grams of direct N_2O per kg DMI	Grams of indirect N_2O per kg DMI
Lambs (birth to slaughter)	16.8[1]	0.0489	0.0135
Replacement sheep (birth to maturity)	18.9[1]	0.0489	0.0135
Mature sheep	20.9	0.0489	0.0135

[1]Note: Lambs were assumed to not produce methane until they were 8 weeks of age as stated by Clark (2008)

The expected increase in human population will create greater demand for protein. Therefore McAllister *et al.,* (2011) proposed that GHG reductions be targeted per unit of product, termed the Emissions Intensity (EI). This assumed a global human population would continue to consume protein without a massive shift toward a vegetarian diet and that the world placed a priority on matching the increase in demand for food. Alcock & Hegarty (2011) and Beukes *et al.,* (2011) are recent examples of studies which included EI in their analysis. Alcock & Hegarty (2011) measured GHG per kilogram of live weight while Beukes *et al.,* (2011) measured EI per kilogram of milk solids. EI values can allow comparisons between systems and to gain perspective on the relative contribution a GHG mitigation technology might have. Ledgard *et al.,* (2010) for instance reported the most comprehensive calculation of GHG for New Zealand lamb production from the farm to the point of consumption. GHG relating to on-farm CH_4 and N_2O for lamb were estimated as 13.7 kg CO_2e/kg cwt. This was based on 72% of the 19 kg CO_2e/kg cwt total emissions (from farm to consumption) coming from on-farm emissions.

Variation in the production of GHG between ruminants has been long established (eg. Blaxter & Clapperton (1965)), but a focus on using genetic selection to reduce ruminant GHG is a relatively recent development in the literature. There have been an increasing number of studies which use farm system models to estimate the GHG implications of changing ruminant traits.

A New Zealand study of dairy cows by Beukes *et al.*, (2010) estimated beneficial GHG and farm profit impacts of having higher genetic merit cows with improved milk yields (from 390 kg MS/cow pa to 430 kg MS/cow pa). They also suggested the increase in genetic merit could be a contributing technology to help New Zealand meet its Kyoto Protocol commitment. However, the 10–22% reduction in GHG in kg CO_2e/kg milk solids with an improvement in genetic merit did not account for the time lag for the assumed rates of change in production. Nor did it account for the correlations between traits, especially fertility and its effect on overall farm profitability and GHG.

In sheep in Australia, Alcock & Hegarty (2011) estimated reductions in total GHG of up to 18% were possible through 10% changes in a range of traits such as growth and fertility. Cottle *et al.,* (2009) examined what price of carbon was necessary in order for methane production and feed intake to be used as selection criteria in the future breeding programme for Australian merino sheep. In their study a carbon cost of over AU$400/t CO_2e was required to achieve 1% annual reductions in methane. In New Zealand, Cruickshank *et al.*, (2008) estimated up to a 21% reduction in methane output per lamb sold through an increase in fertility. However, the GHG implications of changing one trait in isolation may not necessarily extrapolate to the field. This is because the heritability and genetic correlations between traits will have an influence on what changes in EI can be achieved at a farm level (Alcock & Hegarty, 2011). In particular, Alcock & Hegarty (2011) suggested the GHG benefits could be eroded to an extent by higher emissions from the heavier ewes when there was selection for higher growth rates in lambs.

There are limited published field trials to confirm the modelled studies which have estimated the potential GHG benefits of improving traits in livestock. Most field trials have been in dairy cows. For example field trials in Northern Ireland showed that dairy cattle high in genetic merit (for productive traits) had significantly lower urinary loss of nitrogen, hence lower nitrous oxide emissions per unit of nitrogen intake (Ferris *et al.*, 1999). The high genetic merit cows also had lower methane energy lost in relation to gross energy intake.

The Langhill dairy research herd in Scotland analysed GHG from groups of dairy cows with different selection pressures. This included a group of dairy cows selected for increased milk fat and protein yield (select genetic line) and another selected to be close to the average genetic merit of dairy cows in the UK (control genetic line). Wall *et al.*, (2010) reported the select line of dairy cows produced 21% less methane per unit of milk product in the first lactation compared to control dairy cows. However, it was suggested that body reserves were used to support the additional lactation energy requirements and this could have unfavourable impacts on other 'fitness' traits such as health and longevity. Bell *et al.,* (2011) later concluded that the select line of dairy cows had lower methane per unit of product up until their third lactation, but not over their lifetime. This highlights the complexity of trying to estimate the GHG implications of selecting for certain traits. This is particularly so if the higher production comes at a cost in the form of body reserves which can contribute negatively to health and fertility of livestock (Pryce *et al.*, 1999).

It is therefore important to take into account the interactions between a full range of traits when analysing the effects of selection decisions on GHG at the farm level. Furthermore, the time lag effects of the rates of progress made in each trait need to be accounted for. There has been research on the Welsh sheep industry which has modelled the interactions between traits and time lag effects (Nakielny, C. personal communications, 2011). However, this was based on the current selection objectives to improve farm profits. It did not include analysis of scenarios where the objective was to obtain greater reductions in GHG. The current genetic improvement programme for the Welsh sheep industry was estimated to contribute a modest 0.03% reduction in methane per unit of carcase each year. Estimates of potential GHG reductions when selecting for a range of traits are therefore likely to be lower than when they are calculated as a trait changed in isolation.

To our knowledge no published study has estimated the GHG and economic implications of selecting for a broad range of traits in an index which has a primary objective to reduce GHG. Assessing the implications of indexes which have economic and GHG mitigation objectives for the New Zealand sheep industry will fill this gap in the literature.

4. Method

Approach

The recent development of New Zealand's DPO (Byrne *et al.*, 2012) calculated the energy requirement and economic implications of each trait of significance to the sheep industry. This study developed two GHG selection indices based on the same input assumptions as Byrne *et al.*, (2012). However, the relative trait weightings were different to the DPO as they were calculated to facilitate reductions in two measures of GHG. The Emissions Intensity index (EII) aimed to maximise reductions in terms of GHG/kg lamb cwt to align with the definition of EI described by McAllister *et al.,* (2011). The 'Total GHG' index aimed to maximise reductions in total GHG. GHG were limited to CH_4 and N_2O as these constitute the majority of emissions on a sheep farm in New Zealand (Ledgard *et al.*, 2010).

A third novel index was developed which aimed to facilitate selection of traits which provided a balance between genetic progress in traits that reduced EI and those that contribute positively to farm profitability. This index was termed the 'Dual Purpose Environment' index (DPE).

The aforementioned indices were assessed for their ability to maximise farm profit, reduce EI and reduce total GHG.

Assumptions

Index traits

Table 2 provides a description of the 15 traits used in the DPO described by Byrne *et al.*, (2012). The same traits and their units and definitions were used for the two GHG indices and the DPE.

Farm system assumptions

Sheep production and performance values used in the index models were estimated to reflect the New Zealand industry average. These align to those used by Byrne *et al.*, (2012) in the development of the DPO and are summarised in Table 3. Further assumptions and the sources of information for the estimates are detailed in Byrne *et al.*, (2012). As shown in Table 3 the base NLB was 1.45 lambs born per ewe lambing. Average lamb survival (0.91) was a function of the respective survival rates of each birth ranking (i.e. single, twin, triplet) weighted by the proportion of single, twin, and triplet lambs in the ewe litter. The survival rates (from birth to tailing) for single, twin and triplet lambs were 0.93, 0.88, and 0.60 respectively (Byrne *et al.*, 2012). Similarly, the number of days to slaughter for lambs was weighted by the proportion of each birth ranking of lambs in the ewe litter and their respective growth rates.

Table 2: Objective trait names, description and response units used in the modelling of responses to selection (Byrne *et al.*, 2012).

Name	Trait description	Response unit
NLB	Number of lambs born	Lambs
WWTd	Weaning weight (direct)	kg
WWTm	Weaning weight (maternal)	
CWT	Carcase weight	
LFW	Lamb fleece weight	
HFW	Hogget fleece weight	
EFW	Ewe fleece weight	
FEC1	Faecal egg count	eggs per gramme
FEC2		
AFEC	Adult faecal egg count	
SURd	Lamb survival (direct)	Lambs
SURm	Lamb survival (maternal)	
LeanYield	Carcase lean meat	kg
EweWT	Ewe mature weight	
Longevity	Ewe longevity	Replacement rate

Table 3: Performance parameters which form 'base' farm model assumptions for development of novel indices from Byrne et al., (2012)

Performance parameter	Assumption
Ewe prolificacy, number of lambs born (NLB)	1.45
Average lamb survival (birth to tailing)	0.91
Average lamb survival (tailing to slaughter)	0.98
Average weaning weight, averaged across sexes (kg)	28
Average lamb cwt (kg)	17
Average lamb dressing proportion	0.45
Ewe mature weight (kg)	65
Age at which mature weight reached (years)	2
Replacement rate (proportion of the flock as 2-tooths)	0.25
Average (across birth ranks) days to slaughter for lambs	157

Development of indices

GHG indices

Changes in energy requirements of sheep (in megajoules of metabolisable energy- MJME) for every unit change in traits from the DPO model described by Byrne *et al.*, (2012) were linked to the models which calculated the two GHG indices (EII and Total GHG) and the DPE.

For the GHG indices the change in MJME requirements per unit change in each trait were converted into GHG. To do this, an average pasture energy concentration of 10.4 MJME/kg DM (Litherland *et al.*, 2002) was assumed in the farm system to convert the change in MJME for each trait into a change in kg DM intake.

The change in kg DM intake was then multiplied by the respective EF shown in Table 1 to calculate the total GHG implications for each trait. These GHG values were used for the Total GHG index relative trait values.

In contrast, the EII needed to take into account not only total GHG but also the quantity of lamb cwt produced to formulate an efficiency measure. Appendix A describes the equation used to take GHG efficiency into account when calculating the EI implications of each trait.

As opposed to the trait relative values in the Total GHG index, those in the EII took into account the potential GHG 'dilution' effect of changes in traits. A trait with a GHG dilution effect was defined in this study as a trait which had a proportionately larger change in quantity of product produced for any change in total GHG. Increasing 'fertility' of a ewe may for example increase total GHG through greater energy requirements for the ewe. However, the EI value for the 'fertility' trait may decrease if the additional weight of lambs sent to slaughter dilute the additional total GHG attributed to extra energy requirements.

DPE

The DPE amalgamated both the farm profit economic values from the DPO and the EI values from the EII. EII values were chosen instead of the Total GHG index values as it was assumed EII values would align better to improving traits which contribute to enhanced farm profit. Furthermore, McAllister *et al.*, (2011) suggested EI should be emphasised in production systems in order to reduce GHG while ameliorating food availability problems associated with a growing human population.

The DPO values were in NZ cents/unit change in trait, while EII values were in GHG/kg lamb cwt per unit change in each trait. In order to add the trait values together in a combined DPE, EII values were converted into monetary values. EII values were monetised by multiplying them by carbon prices. This allowed them to be added to the DPO index to create the novel DPE trait values.

There is significant uncertainty in future carbon prices and there is a wide range of estimations for the cost of GHG (Watkiss, 2011). In a review by Watkiss (2011), the mode cost of GHG was US\$2/t CO_2e and the median was US\$14/t CO_2e. When the non peer-reviewed estimates were excluded the mean was US\$50/t CO_2e. However, these estimates may not necessarily reflect the costs a New Zealand sheep farmer may incur in the short term. The Emissions Trading Scheme Review Panel (2011) for instance recommended the New Zealand Government ensure the cost of carbon was kept below NZ\$25/t CO_2e in 2013 using a 'price cap'. Therefore DPE using a wide range of carbon prices were calculated including: NZ\$15; NZ\$25; NZ\$50; NZ\$75 and \$NZ100/t CO_2e and were named the DPE15; DPE25; DPE50; DPE75 and DPE100 (indices) respectively. The NZ\$15/t CO_2e carbon price represented a recent value of tradable carbon emission units in New Zealand's ETS (Point carbon, 2011) while the others provided sensitivity.

Conversion of trait values into trait weights

The trait relative values do not take into account the time it may take for a trait to be expressed on a farm, nor its importance to the industry in general. Therefore these factors needed to be taken into account before annual genetic progress was calculated for the different indices. Discounted genetic expressions (DGE) represent the timing and contribution of a selection candidate's (i.e. usually a ram when using a selection index) genes on farm profits over a 10 year investment period. Industry weighting factors (IWF) represent the proportion of New Zealand's sheep industry the change in the trait is relevant to. Both the DGE and IWF are further explained by Byrne *et al.*, (2012). Equation 1 shows how they were used in order to convert a trait value (i.e. an economic or EII value) into a trait weight.

Equation 1: Conversion of selection index trait values into trait weights:

$$Trait\ weight = Trait\ value \times IWF \times DGE$$

Trait values for all the indices were converted into trait weights before their genetic progress was calculated.

Estimation of genetic progress for each index

Genetic progress made in each trait was calculated for the range of selection indices. Genetic trends were predicted by using a model which followed Dekkers (2007) description of selection index theory and is described in more detail by Sise & Amer (2009). Predictions of the genetic progress made in each trait (in trait units per year) for each of the contrasting indices were calculated, and overall annual rates of genetic progress per lamb born for each index reported. Overall farm profit progress was in units of NZ\$ per lamb born when selecting sheep based on each respective set of index weights.

5. Results

Selection index relative weights

Table 4 provides a comparison of the relative weights in each of the indices. DPE at two carbon prices are included in Table 4 to show the effect of a contrast in carbon prices. Compared to the DPO, the two DPE had greater absolute weightings on the NLB, CWT, SUR and Longevity traits. Increasing the carbon price increased the absolute weights for those traits. NLB for instance was 907 NZ cents higher in the DPE100 compared to the DPE25.

Trait responses

Annual trait responses estimated using relative weights from Table 4 are presented in Table 5. Higher relative weightings for NLB in the two DPE meant more genetic progress was made in this trait compared to when the DPO was used for selection. For example, genetic progress using the DPE100 index was 0.009 extra lambs per annum compared to the DPO index which gave 0.006 extra lambs per annum. Table 5 also highlights the contrast in relative progress made between the EII

Table 4: Relative trait weights for a range of indices

Index	DPO	DPE25	DPE100	EII	Total GHG
Units	NZ cents/lamb born	NZ cents/lamb born at NZ$25/t CO_2e	NZ cents/lamb born at NZ$100/ t CO_2e	kg CO_2e /lamb born	kg CO_2e /lamb born
NLB	1555	1858	2765	121	−118
WWTd	95	92	84	−1	−1
WWTm	84	82	75	−1	−1
CWT	260	274	313	5	1
LFW	182	182	182	0	0
HFW	79	79	79	0	0
EFW	228	228	228	0	0
FEC1	−3	−3	−3	0	0
FEC2	−3	−3	−3	0	0
AFEC	−2	−2	−2	0	0
SURd	6445	7733	11595	515	−160
SURm	5840	7007	10506	467	−145
LeanYield	324	324	324	0	0
EweWT	−104	−113	−141	−4	−4
Longevity	−11381	−11874	−13352	−197	−258

Table 5: Annual trait responses using relative trait weights

Index	DPO	DPE25	DPE100	EII	Total GHG
Trait	Genetic progress made (in trait units pa.)				
NLB	0.006	0.007	0.009	0.013	−0.015
WWTd	0.226	0.215	0.185	−0.009	−0.111
WWTm	0	0	0	0	0
CWT	0.168	0.161	0.141	0.005	−0.088
LFW	0.004	0.004	0.004	0.000	−0.001
HFW	0.028	0.027	0.024	0.003	−0.006
EFW	0.024	0.023	0.021	0.002	−0.006
FEC1	0.240	0.239	0.230	0.105	0.095
FEC2	0.276	0.274	0.264	0.121	0.109
AFEC	0.309	0.307	0.295	0.135	0.122
SURd	0.001	0.001	0.001	0.002	−0.001
SURm	0	0	0	0	0
LeanYield	0.020	0.020	0.019	0.007	0.009
EweWT	0.121	0.113	0.092	−0.030	−0.135
Longevity	0.000	0.000	0.000	0.000	0.000

and Total GHG indices. The EII made more progress in NLB than any other index.

Overall genetic progress

Overall annual progress made (in farm profit and EI terms) is shown in Table 6. Selection using the DPO was estimated to contribute to the highest overall farm profit response with 81.79 NZ cents/ lamb born. Table 6 also indicates that farmers who use the DPO will likely reduce EI by a cumulative 0.081 kg CO_2e/kg lamb CWT reduction each year. This is equivalent to 0.59% of the total on-farm methane and nitrous oxide emissions for lambs estimated by Ledgard *et al.*, (2010).

The EII was estimated to produce the greatest reductions in EI with annual reductions of 0.163 kg CO_2e/kg lamb CWT (or 1.19% of total emissions per kg of lamb cwt). Overall farm profit and EI responses when animals were selected using the two DPE were intermediary between responses from the DPO and the EII.

The Total GHG index was estimated to produce the greatest reductions in total GHG per ewe with a reduction of 0.140 kg CO_2e/breeding ewe. However, selection using the Total GHG index was predicted to facilitate genetic progress which contributed to a reduction in farm profits, equivalent to 47.79 NZ cents/lamb born.

The trade-off in the DPE25, when compared to the DPO was 99.8% of the farm profit progress (achieved by the DPO), and 56% of the potential reductions in EI (using the EII). If the cost of carbon was increased, the trade-off for the DPE100 index was 96.9% of potential farm profit progress while achieving 69.8% of the potential EI reductions (using the EII). Progress in traits that contributed positively to farm profit progress was estimated for the DPE100 with 79.30 NZ cents/ lamb born pa. The DPE100 was also estimated to achieve 0.033 kg CO_2e/kg lamb CWT greater reductions in emissions compared to the DPO.

Figure 1 illustrates the trade-off between farm profit and EI progress made under the full range of indices calculated (apart from the Total GHG index which was excluded due to the scale of its values). The figure graphically illustrates how the DPE across the full range of carbon costs were intermediary in terms of progress (profit and EI) between the DPO and EII. Placing a

Table 6: Overall farm profit and EI progress made using a variety of selection indices

Parameter	Index				
	DPO	DPE25	DPE100	EII	Total GHG
Farm profit response (NZ cents/lamb)	81.79	81.60	79.30	40.42	−47.79
GHG response (kg CO_2e/kg lamb CWT)	−0.081	−0.091	−0.114	−0.163	0.117
GHG response (kg CO_2e/breeding ewe)	0.084	0.089	0.099	0.101	−0.140
Farm profit response relative to DPO index (%)	100.0	99.8	96.9	49.4	−58.4
GHG emission efficiency gains relative to GHG Intensity index (%)	49.9	56.0	69.8	100.0	−72.0
GHG Intensity reduction as % of total lamb GHG[3]	−0.59	−0.67	−0.83	−1.19	0.86

higher cost of carbon in the DPE resulted in lower farm profit progress while the reductions in EI became greater (i.e. more negative).

6. Discussion

The New Zealand Government plans to include agriculture in the ETS. This may bring about a change in the goals farmers base their sheep selection decisions on, to include reducing GHG.

Previous studies have indicated that appropriate genetic selection of animals could contribute significantly to reducing GHG in livestock enterprises (Alcock & Hegarty, 2011, Beukes *et al.*, 2010, Wall *et al.*, 2010). However, these studies calculated the GHG implications of traits in isolation and did not fully account for the sometimes unfavourable correlations between traits or the time lag effect of trait expression.

Two contrasting methods for calculating the GHG implications of traits were used in the two GHG (EII and Total GHG) indices. The EII method aimed to reduce GHG per kg of lamb cwt while the Total GHG index method aimed to reduce total GHG. Selection of sheep using the EII had an opportunity cost of lost genetic gain in traits that contribute toward farm profits. For example the overall farm profit progress using the EII was NZ 41.37 cents per lamb born pa lower than the DPO (which optimised farm profit progress). A better balance between EI and farm profit progress was made using one of the DPE indices. The trade-off between EI and farm profit progress varied depending on the price of carbon used in the DPE. However, across the range of DPE there were greater reductions in EI compared to the DPO with greater progress in traits which contribute toward farm profits than the EII.

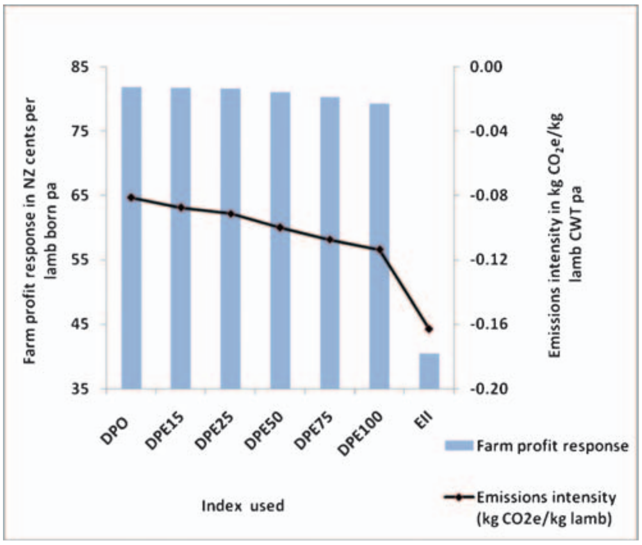

Figure 1: Farm profit and emissions intensity progress estimated using a range of selection indices

The DPE therefore offers a choice for farmers who wish to reduce their EI beyond that achievable using the DPO. It can also achieve farm profit progress greater than the EII. A higher cost of carbon in the DPE placed greater emphasis on traits that improve EI such as NLB. Although reducing EI can also improve farm profitability (as it also selects for efficiency of feed use), there is not a 1.0 correlation between EI and farm profit. Some traits which reduce EI will therefore be emphasised which do not provide optimal farm profit responses. Hence, lower farm profit progress is made as the carbon price in the DPE is increased. Farmers will therefore need to choose their preferred level of trade-off between farm profit and EI progress if they decide to use the DPE.

Reductions in EI through selection index technology can be put into perspective by relating it to total GHG for lamb production. Ledgard *et al.* (2010) reported the most comprehensive calculation of GHG for New Zealand lamb production from the farm to the point of consumption. The range of changes in GHG per unit of lamb product (using the estimate of total lamb GHG by Ledgard *et al.* (2010)) using selection indices ranged from a 0.86% per annum increase using the Total GHG index, to a 1.19% per annum decrease using the EII. Estimates of up to 22% reductions in GHG per unit product were calculated for dairy cattle through trait changes (Beukes *et al.*, 2010). Previous research has generally focussed on estimating the impact of changing traits in isolation to one another. Factors such as the correlated responses when selecting for more than one trait and the time it takes for a unit change in a trait to occur based on the heritability of traits were not taken into account. In contrast, modest (0.03% pa.) rates of reduction in methane intensity were estimated in the Welsh sheep industry (Nakielny, C. personal communications 2011) when more realistic rates of improvement were calculated. Estimates of EI for products can vary depending on the method of calculation and the inherent uncertainty associated with agricultural emission factors. However, these values still allow informative comparisons to be made. Results from New Zealand sheep in this study suggests that a breeding programme selecting for a range of traits may result in small but significant reductions in EI when compared to the overall lamb emissions. Nevertheless, genetic improvement provides permanent changes which cumulate over time (Simm, 1998) and this phenomenon could be exploited to reduce EI using a selection index.

Adoption of selection indices will be a key factor which determines the overall benefit of selection index technology on reducing an industry's GHG. An industry with a relatively high proportion of farmers who currently use a farm profit index will already have the infrastructure and knowledge of using selection indices. This will make it less costly and easier to implement a novel index which aims to provide greater reductions in GHG (such as the DPE). Industries which currently have low rates of adoption of selection indices may have higher costs to overcome to implement a DPE. However, compared to New Zealand, industries with currently low use of selection indices could receive greater marginal EI benefits from implementing either a selection index based on farm profit or one that also incorporates EI. For example, farmers who change from random selection (or selection on physical type characteristics that are not linked to farm profitability) to selection using the DPO would receive 0.59% pa greater reductions in EI. In comparison, farmers who already use the DPO would obtain 0.1% greater marginal reductions in EI if they adopted the DPE25 instead of the DPO. Therefore at an industry level there is greater potential for gains to be made in improving EI by increasing the proportion of farmers who choose to select animals based on a farm profit index (i.e. DPO), rather than alternative inefficient (or random) methods of selecting animals.

Although the New Zealand Government has a desire to reduce total GHG, the selection of sheep using an index with an objective to reduce EI would be desirable. This is because the index which aligns most closely to this goal (the EII) also selects for traits which contribute positively to farm profits. The index which aimed to reduce total GHG (Total GHG index) had selected traits which had a negative impact on farm profits. Farmers who desire improvements in farm profitability and greater reductions in EI are therefore more likely to adopt the EII compared to the Total GHG index.

A complication to the New Zealand situation for the adoption of the DPE is the incentives New Zealand farmers will have to reduce GHG. Under the proposed ETS, farmers may not receive any financial benefit for their reductions in ruminant emissions made at an 'on-farm' level. This is because the processor point of obligation used in the ETS will use New Zealand 'average' GHG emission factors rather than emission factors that alter according to changes made on individual farms.

Sheep selection using a DPE could be a management practice farmers use as evidence to negotiate lower emission factors for their sheep at the processor point of obligation compared to others in the industry. This could reduce a farmer's carbon costs when the ETS comes into effect. Alternatively, the use of a DPE could form part of a quality assurance programme in a 'low-carbon lamb' farmer supplier group. This could lead to innovative marketing strategies to extract greater value for lamb products. So the actual cost of carbon used in the DPE may not necessarily have to reflect the current market price. Farmers may choose to use a higher carbon price in their DPE if they believe they have an ability to counteract the reduction in farm profit progress by extracting benefit from elsewhere.

7. Conclusion

This study indicates there is potential to reduce GHG through the use of a selection index.

Including GHG in an index will result in less farm profit progress in traits compared to the DPO. However, the DPE can be used as a way to concurrently reduce EI and improve farm profit progress with lower opportunity costs than the EII or Total GHG index but greater reductions in EI compared to the DPO.

The trade-off between farm profit progress and reductions in EI using the DPE will depend on the cost of carbon used. Farmers who want to use the DPE may choose a cost of carbon to suit their preferred level of trade-off.

Consultation with the sheep industry could help ascertain farmers preferred level of trade-off between GHG reductions and farm profitability. Aligning farmer expectations with the index that is delivered to them would improve the level of adoption of the DPE. Discussions with farmers may also lead to the development of innovative ideas to capture greater value for their product using this technology in combination with other mitigation strategies.

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Appendix A

Equation to estimate the change in EI (in GHG per kilogram of lamb cwt sold) from a one unit change in a trait (EI value)

$$B\_o\cdot\left(\frac{l(g)}{\Sigma y(g)}-\frac{\Sigma e(g)}{\Sigma y(g)\cdot o(g)}\right)-B\_y\cdot\frac{\Sigma e(g)}{\Sigma y(g)\cdot y(g)}+B\_l\cdot\frac{1}{y(g)}+B\_w\cdot\frac{1}{\Sigma y(g)}={}'Trait\ g'\ GHG_{(Intensity)}\ value\ in\ kg\ CO_2e\ per\ kg\ lamb\ carcass\ sold$$

Whereby:

B_o	is the amount by which the number of offspring per breeding female changes as trait g changes by 1 unit.
B_y	is the amount by which the amount of farm output per offspring changes as trait g changes by 1 unit
B_l	is the amount by which emissions per offspring change as trait g changes by 1 unit
B_w	is the amount the emissions per breeding female changes as trait g changes by 1 unit.

And:

$l(g)$	is the amount of lamb emissions per offspring
$\Sigma y(g)$	is per ewe product output i.e. an increase in emissions per breeding female increases emissions intensity according to the amount of output per breeding female
$\frac{l(g)}{\Sigma y(g)}$	is the offspring emissions per unit of product from a breeding ewe i.e. more emissions per unit of product
$\Sigma e(g)$	is the total lamb and ewe emissions expressed per ewe in the flock
$o(g)$	is the number of offspring per breeding female as a function of trait g
$\frac{\Sigma e(g)}{\Sigma y(g)}$	is the average emissions intensity for the farm
$\frac{\Sigma e(g)}{\Sigma y(g)\cdot o(g)}$	is the average emissions intensity for the farm expressed per offspring from a breeding female i.e. extra offspring with output dilutes emissions intensity
$\frac{\Sigma e(g)}{\Sigma y(g)\cdot y(g)}$	is the average emissions intensity for the farm expressed per unit of output from offspring i.e. extra output per offspring dilutes farm emissions intensity per unit of product
$y(g)$	is the amount of farm output per offspring as a function of trait g i.e. an increase in emission per offspring increases emissions intensity according to the amount of output per offspring