GREENHOUSE GAS FOOTPRINTING USING OVERSEER®
– 'THE WHOLE PICTURE'

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Abstract
The inputs into OVERSEER® Nutrient Budgets (*Overseer*) allow farm-specific greenhouse gas (GHG) emissions to be estimated. Since development of the original model, international Life Cycle Assessment (LCA) standards have been developed for reporting greenhouse or carbon footprints (e.g. PAS 2050) and increasingly, data on GHG for a unit of product (kg milk solids, kg meat, and kg wool) are required. *Overseer* required GHG footprint reports to cover on-farm-specific emissions and to provide carbon footprint of products from the 'cradle-to-farm-gate'.

Greenhouse gas emissions, converted to CO_2 equivalents on a 100-year basis, include methane, nitrous oxide, carbon dioxide and embodied GHG associated with inputs (fuel, electricity, fertilisers, supplements, chemicals, etc.) used on the farm and off-farm components such replacement animals grazed off-farm. Embodied GHG are determined using an LCA approach following PAS 2050 guidelines using a mix of national average data and farm-specific data. The GHG can be estimated with no additional inputs to the model, using defaults; alternatively, the user can input key information such as fuel and electricity use, transport distances, and fertiliser application methods. Changes in soil or plant carbon stocks are not included in the model.

The design of the model means that emissions can be allocated to individual animal types and then used to produce two distinct GHG footprints reports based on either area or product. Animals, supplements, and effluent can be moved between farms. Procedures were adopted to ensure that area footprints can be additive across farms.

The animal-based GHG are allocated to give product (e.g. milk, meat, wool, velvet) footprints to the farm gate. In undertaking this analysis, emissions associated with breeding animals are allocated to output products (milk, wool or velvet), meat production and to breeding animals for meat production. This allows the possibility of total product emissions for meat to be built up from contributing farms.

Introduction
The inputs into OVERSEER® Nutrient Budgets (*Overseer*) allow farm-specific greenhouse gas emissions (GHG) to be estimated (Wheeler et al, 2008). Since development of the original model, international Life Cycle Assessment (LCA) standards have been developed for reporting GHG or carbon footprints (e.g. PAS 2050 (BSI 2008)) and increasingly, GHG for a unit of product (kg milk solids, kg meat, and kg wool) are required.

Product emissions are a LCA of emissions associated with the production of a product to a specified point. As *Overseer* is a farm scale model, GHG emissions need to be estimated using LCA to cover the 'cradle-to-farm-gate', accounting for all direct and embodied GHG emissions up to the point that the product is ready to leave the farm for processing. Thus it does not include transport to the processing plant, or any emissions associated with processing or transport of the product to market.

Overseer is an integrated model that allows multiple animals systems as well as supplement removal, horticultural and cropping systems on the one farm. Some inputs are not necessarily applied for use by a single animal enterprise or product. For example, N fertiliser may be applied to a block used by sheep and beef animals, with associated products of wool, sheep meat, and beef meat. Thus, a robust system was required to allocate the individual sources of GHG emissions (e.g. methane, nitrous oxide, embodied emission for fertiliser) to a product.

This paper describes the methods used to allocate total farm GHG emissions to a product footprint and to calculate the farm emissions on an area basis. As GHG and energy emissions are closely aligned, the same principals are also used to develop energy reports. The energy reports are not covered specifically in this paper.

Estimated GHG emissions

Individual source emissions are estimated. These include enteric and faecal methane emissions determined using a metabolic intake model to estimate DMI and faecal DM, and New Zealand National GHG Inventory emission factors (Ministry of the Environment 2010). Nitrous oxide emissions are estimated using site specific data to estimate leaching and ammonia volatilisation and using national inventory emission factors. The on farm carbon dioxide emissions from fertiliser and lime are based on their composition (IPCC 2006). Refrigerant emissions are based on LCA analysis of refrigeration use in New Zealand.

Detailed studies estimating carbon footprint of dairy (Basset-Mens et al. 2009; Ledgard et al. 2010) red meat (Ledgard et al. 2009a, b, 2010; Lieffering et al. 2010), fertiliser (Ledgard and Boyes 2008; Ledgard et al. 2011) and electricity fuel and transport (Nebel 2008) have been produced using LCA and meeting PAS 2050 (BSI 2008) or ISO 14046 recommendations. Data from these studies were used in developing equations and data embodied GHG emissions for “imported” inputs used on farm such as fuel, electricity, fertilisers, supplements, chemicals, plastics, and off-farm components.

Embodied emissions for supplements are based on rate supplied by the user and typical LCA based emissions for growing the supplement as the source of the supplement is not always known when purchased. Farm specific information (e.g. transport, application methods) are used when available. A similar process is used for fertilizer but using LCA for fertiliser manufacturing (Ledgard et al., these Proceedings). The model allows users to either enter specific data or default fuel or electricity use and transport distances are used. A national average emission factor for fuel or electricity is used. For other inputs, embodied emissions were estimate using an LCA approach based on national average data, converted to a per animal, per stock unit or per ha basis, and the result multiplied by the farm number of animals, stock unit or area as appropriate.

Off-farm components are also included in whole-system product emissions. Thus for replacement animals grazed off-farm or winter grazing off of animals, the embodied GHG emissions for pasture grown and transport costs in both directions are included. The off-farm animal-related GHG emissions are also included.

All emissions are converted to kg CO_2 equivalents on a 100-year basis.

It should be noted that changes in soil or plant carbon stocks are not included in the model.

Product carbon footprint

Within farm systems, meat can be an output of a deliberate meat production system (e.g. breeding or trading system) or a by-product from a product stream (e.g. cull cows from a dairy system where the primary product of concern is milk). The final meat product may be the result of operations of one or more farms (see Figure 1). The embodied emission for a weaned animal used for live weight gain can vary between farms. Thus, a calf from a dairy farm may have fewer emissions associated with its birth than a calf from a beef system because it is a by-product of the milking system. Although the model requests information on the final fate of animals, this is not always known when animals are sold.

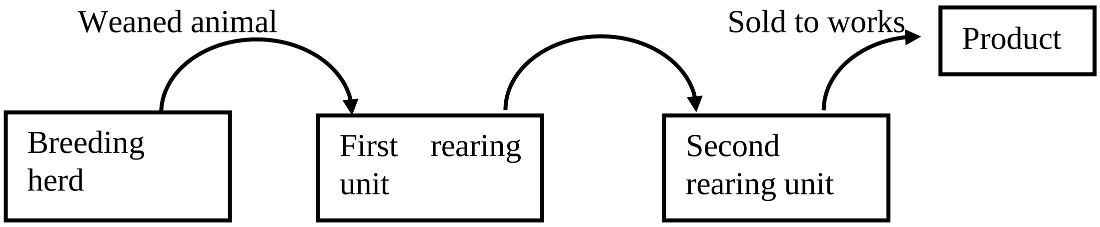

Figure 1. Flow pathway of GHG emissions between farms for meat product

Therefore, the approach to estimate total GHG emissions for a meat product was to estimate emissions associated with live weight gain for each farm, and to estimate emissions associated with the rearing of animals in a breeding herd that are used for meat production (breeding herd non-replacement animals). To achieve this required dividing GHG emissions from each animal enterprise (dairy, sheep, beef, deer) into the emissions from two basic management systems, trading and breeding. A trading system is where the primary purpose of the operation is live weight gain, ultimately for sale as meat. Within a trading mob, there are two product streams, namely non-meat products (e.g. wool, velvet or antler) or live weight gain (lwg). A breeding system consists of a mob of mature animals producing offspring to weaning. Weaned non-replacement animals from a breeding herd are treated as trading animals. Dairy systems are considered to be breeding systems. The breeding herd has three product streams, namely non-meat product (milk, wool, velvet), meat (cull animals), and animals used in the trading system. Farms can have both types of animals. Thus, typically dairy systems only have a breeding mob, while sheep and beef farms typically have breeding and trading systems, although some intensive systems may have trading system only.

Individual sources of emissions are distributed to each farm enterprise (dairy, sheep, beef, deer, dairy goats, supplements removed, horticultural, and cropping). Emissions such as methane are calculated on an animal basis. Emissions from imported products used on a block basis, such as fertiliser, are distributed to each animal enterprise in proportion to the total block pasture DM consumed by each animal enterprise. Animal types that supplements are fed to are identified by the user. Most other embodied costs can be directly associated with an animal enterprise.

Next, emissions for each animal enterprise are divided into the two basic management systems, namely breeding and trading (see Figure 2). The emissions for each animal enterprise are then split between breeding and trading systems based on total ME intakes for animals in each system. This is estimated from input data.

Last, emissions for each management system are allocated to non-meat products (Figure 2). For breeding systems, the remaining emissions are then allocated between animals raised for use in a live weight rearing system (non-replacement animals) and live weight sold (culled animals).

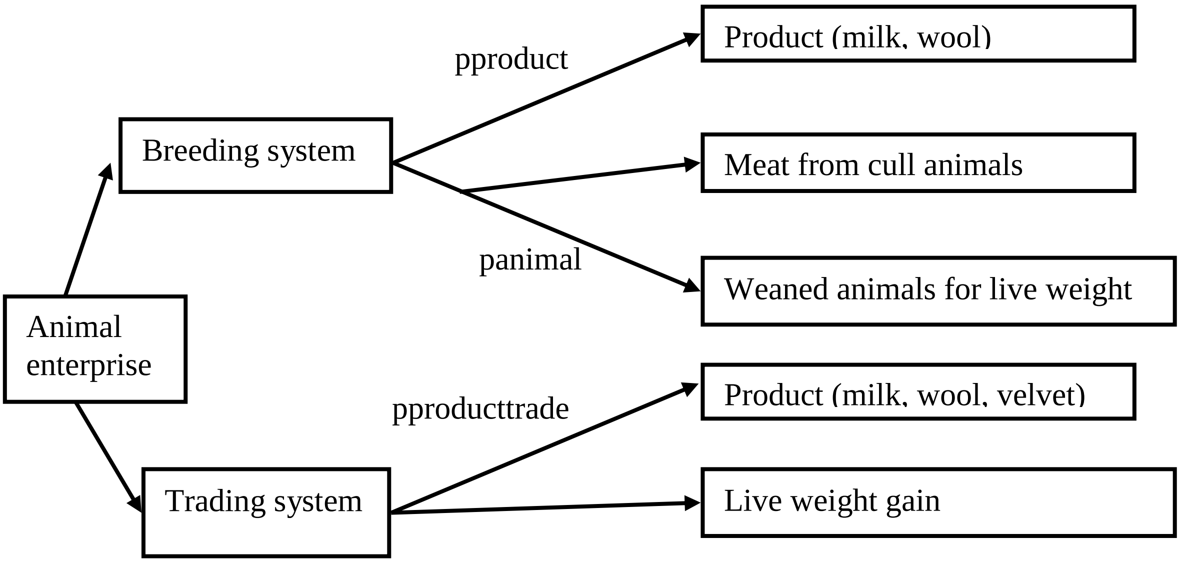

Figure 2. Flow path for the allocation of GHG emissions to products

To achieve the allocation illustrated in Figure 2 requires estimation of the fraction of emissions allocated to non-meat products (product allocation, or pproduct and pproducttrade in Figure 2) and the fraction of the remaining emissions allocated to animals raised for use in a live weight rearing system (reared animal allocation, or panimal in Figure 2).

<u>Product allocation</u>

LCA standards recommend that emissions be allocated to products using system expansion, biophysical allocation, or economic allocation (ISO 14046). System expansion was not applicable to a farm system model such as *Overseer* as the information to apply it is not available at the farm scale.

For dairy animals, product ratio can be entered by the user, or a default is based on biophysical allocation (IDF, 2010). Thus:

$$\text{pproduct} = 1 - 5.7717 * R$$

where R is the ratio of live weight of all animals sold (calves, cull cows) and fat protein corrected milk (FPCM), where

$$\text{FPCM} = \text{milkyield} * 0.1226 * \text{fat\%} + 0.0776 * \text{true\_protein\%} + 0.2534$$

where milk yield is in kg milk, and fat% and true_protein% are the fat and protein contents of the milk respectively.

For beef, product allocation is zero because there are no co-products produced inside the farm gate.

For other animal types, product allocation is based on economic allocation as there was no biophysical method for estimating product allocation. Using a price based allocation implies that the allocation may change over time if the relative prices of products change. Based on international guidelines, a five or ten year average is used to remove yearly fluctuations.

For sheep, the user can enter a product allocation, which is defined as income from wool divided by total income from sheep, or a default product allocation based on economic allocation is calculated. Given that mutton and lamb have different prices, and that the model already differentiates between sheep < 1 year and > 1 year, the following economic approach is used to estimate the default allocation to product:

$$\text{pproduct} = \text{income\_wool} / (\text{income\_wool} + \text{income\_lamb} + \text{income\_mutton})$$

where income_wool, income_lamb and income_mutton are estimated incomes from wool, lamb live weight gain and live weight gain from mature (cull) animals. The income for wool was estimated as:

$$\text{income\_wool} = (\text{RSUlamb} * \text{woolrate} * \text{pricelambswool}) + (\text{RSUmutton} * \text{woolrate} * \text{priceotherwool})$$

where RSUlamb is revised stock units of <= 1 year old animals, RSUmutton is the revised stock units of >1 year old animals. RSU (revised stock units) was estimated as total ME requirements divided by 6000 MJ ME/RSU (Woodford and Nicol 2004). Woolrate (wool growth rate per RSU) are 10-year means from Beef + Lamb NZ (2010), with values of 4.83, 4.46 and 5.10 kg wool/RSU for merino, corriedale and perendale, and crossbreed respectively. Priceotherwool ($per kg wool) are 10-year means from Meat and Wool (2010), with values of 6.78, 3.20 and 2.30 $/kg wool for merino, corriedale and perendale, and crossbreed respectively.

The income for live weight gain for lambs was estimated as:

$$\text{income\_lamb} = \text{pricelambmeat} * \text{lwgsoldlambs}$$

where the pricelambmeat was based on the average price for lambs (66$/head, Meat and Wool 2010) and an average weight of lambs at selling ot 17.5 kg (Meat and Wool 2010), and lwgsoldlamb is the live weight gain from animals <= 1 year.

The income from live weight gain for mutton (animals > 1 year) was estimated as:

$$\text{income\_mutton} = \text{pricemuttonmeat} * \text{lwgsoldmutton}$$

where pricemuttonmeat was estimated as being 60% that if lambs lwgsoldmutton is the live weight gain from animals > 1 year.

The proportion of gross revenue for sheep derived from wool averaged 0.17 on intensive farms, averaged 0.22 on breeding farms, and was 0.29 on South Island hill country, and 0.59 on South Island high country (MAF 2008). This suggests that the product allocation may differ between breeding and trading systems, and hence was estimated separately.

For female deer, product allocation is zero as there are no co-products. For male deer, if antler/velvet is removed, the user can entered a product allocation or a default economic allocation is estimated as:

$$\text{pproduct} = \text{income\_velvet} / (\text{income\_velvet} + \text{income\_meat})$$

$$\text{income\_velvet} = 70 * (\text{velvet} + \text{antler})$$

where income_velvet was based on a average price over 5 years of 70 $/kg, and velvet and antler (kg sold) are prodvided by the user, and income_meat is based on average price of $4.50 per kg and the estimated live weight gain from male animals sold.

Note that emissions for deer are split between male and female, and product ratio only applies to male deer emissions. Thus, deer enterprise emissions are split into male and female emissions based on the ME requirements and the generic approach above applied to each fraction.

Reared animal allocation

Reared animal allocation is the ratio of non-product breeding emissions that is allocated to animals raised for a live weight gain system – the non-replacement animals at weaning. The remainder is allocated to meat from animals sold from the breeding system (culls). The allocation is based on live weight gain, with a similar approach used for each animal enterprise. Thus:

panimal = lwg_weaned / (lwg_weaned + lwg_culled)

where lwg_weaned is the weight of animals weaned, and lwg_culled in the weight of mature animals culled. These were estimated as:

lwg_weaned = n_breeding * weanweight * (1 – replacement_rate)

lwg_culled = n_breeding * matureweight * replacement_rate

where n_breeding is the number of animals in the breeding mob, weanweight is the weaning weight (kg/animal) for a animal enterprise, matureweight is the weight of a mature animal (kg/animal) and replacement_rate is the proportion of breeding animals replaced (culled) each year.

It is assumed that live weight gain is a measure of the biophysical requirements to achieve that live weight. This could be further refined by including a factor to take account of the composition of the live weight gain.

The formula would typically give reared animal allocation of 0.15- 0.25 for dairy systems, or using typical product allocation in the IDF guide for milk would give 85.6% dairy emissions allocated to milk, 2.9% allocated to animals for live weight gain systems and 11.5% to cull meat.

In beef systems, this would typically give 40-50% of emissions allocated to animals used for live weight gain and 50-60% to cull meat.

Product emissions

Given the above, emissions can be allocated to product streams for breeding systems as:

eCO2ProductBreed = eCO2BreedEmission * pproduct

eCO2AnimalBreed = eCO2BreedEmission * (1 – pproduct) * panimal

eCO2MeatBreed = eCO2BreedEmission * (1 – pproduct) * (1 – panimal)

where eCO2BreedEmission is the total emissions allocated to a breeding system for a given animal enterprise, and pproduct (product allocation) and panimal (reared animal allocation) are defined in previous sections.

In addition, GHG emissions can be allocated to product streams for trading systems as:

eCO2ProductTrade = eCO2TradeEmission * pproductTrade

eCO2MeatTrade = eCO2TradeEmission * (1 – pproductTrade)

where eCO2TradeEmission is the total emissions allocated to a trading system for a given animal enterprise and pproductTrade (product allocation) is defined in a previous section.

The reported product emissions for each animal enterprise (kg CO2 equivalents/kg product) are then estimated as:

eCO2Product = (eCO2ProductBreed + eCO2ProductTrade) / kg product

where product is the weight of either milk solids, wool, velvet or antler sold off-farm. The GHG emissions for raising an animal to weaning (kg CO_2 equivalents/animal) are estimated as:

eCO2AnimalRaise = eCO2AnimalBreed / number_trade

where number_trade is the number of animals from the breeding system that end up as trading animals either on or off farm, and is estimated as:

numbertrade= n_brreeding * birth_rate * (1 – replacement_rate)

where n_breeding is the number of mature breeding animals, birth_rate is the lambing, calving or fawning rate, and replacement_rate is the proportion of breeding animals that are replaced each year. The estimated GHG emissions for live weight gain (kg CO_2 equivalents/kg live weight gain per year) are estimated separately for the breeding and trading systems as:

eCO2MeatBreed = eCO2meatBreed / lwg_Breed

eCO2Meattrade = eCO2meatTrade / lwg_trade

where lwg_Breed is the live weight gain (kg/year) associated with breeding animals, including replacements (in effect is live weight sold as culls) and lwg_trade is the total farm live weight gain of animals in the trading management system.

Live weight sold

The emissions for live weight sold to works (the source of the meat product) for a trading system is the sum of emissions to produce a young animal to weaning, and of live weight gain emissions associated with live weight reared on 1 or more farms. Thus:

eCO2liveweightformeat = totalCO2 / slaughterwt

where slaughterwt is the live weight at slaughter (kg/animal), and totalCO2 (kg CO_2 equivalents) is estimated as:

totalCO2 = eCO2AnimalRaise + ∑(eCO2Meattrade * lwg)

where eCO2AnimalRaise is the emissions for a breeding herd from the farm animals are born on or a default value (kg CO2 equivalents /animal), eCO2Meattrade is the emisisons for a gain in liveweight on a given farm (kg CO2 equivalents /kg live weight change), and lwg is the change in liveweight on a given farm (kg/animal).

On-farm GHG emissions

The on-farm GHG emissions are the embodied emissions associated with activity on that farm. It is essentially the sum of the emissions from each source divided by total farm area, except that:

- embodied emissions for DM production associated with wintering off or grazing of replacements are not included as these occur on another farm.
- transport costs for winter off and grazing off are in one direction (to the farm) to ensure that there is no double accounting between farms.

- supplements removed are given the same emissions factors as supplements brought in of the same type.

In practice, GHG emissions are summed up in categories to make displaying of results easier to manage.

Summary

The GHG module within OVERSEER® nutrient budgets has been updated so that GHG emissions can be estimated with no additional inputs to the model using defaults. Alternatively, the user can input key farm specific-information such as fuel and electricity use, transport distances, and fertiliser application methods. Thus, the reported GHG emissions can be more farm-specific. These emissions are then allocated so the product carbon footprint can be produced.

The model generates product carbon footprints that are consistent with average values from LCA analysis but are more farm specific. When comparing these results with LCA analysis, it should be noted that the model gives product carbon footprint estimates to the farm gate whereas LCA analyses usually aim to cover the whole life cycle, and thus may include manufacturing emissions, transport to market and consumption.

The updated module will be included in the next release of OVERSEER® nutrient budgets.

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