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Holistic analysis of GHG emissions from Irish livestock production systems

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Abstract. *Greenhouse gas (GHG) emissions from livestock production systems arise both directly on farm and indirectly from bought-in product. Ireland is an unusual country with respect to GHG emissions because it has a small human population and a large farm animal population, giving rise to a large per capita emission. Any attempt to manage the emissions from the major sources on farm should be assessed in terms of whether the emissions burden is reduced or simply transferred to another part of the production system. Life cycle assessment (LCA) methodology offers a framework for systems analysis and was applied to livestock production systems to quantify emissions holistically. The average emission calculated for the dairy system was 1.5 kg CO_2 eq. kg ECM. The main contributors were: enteric fermentation (49 %), fertiliser (22 %), concentrates (13%), dung management (11 %) and diesel/electricity (5 %). The average emission recorded for the beef system was 11.9 kg CO_2 kg LW yr^{-1} and for the sheep system was 10.0 kg CO_2 kg LW yr^{-1}. Analysis revealed that the whole system has to be considered in order to identify legitimate reduction strategies, and that having considered the larger emission contributors it is important to examine the smaller ones for amplifying and attenuating effects. The use of LCA methodology for this work has proven advantageous for estimating the potential effects of changing management to attain reductions in GHG emissions from the average dairy, suckler-beef and sheep production systems in Ireland.*

Keywords. Life cycle assessment, Livestock production systems, greenhouse gases, climate change

Introduction

Greenhouse gas (GHG) emissions emanate both directly (on farm) and indirectly (bought-in product) from livestock production systems. Methane emitted by enteric fermentation has been the focus of much research on the reduction of GHG emissions by the livestock industry. Mitigation options that only examine enteric fermentation could potentially result in transfer of the emission rather than its elimination. Reduction strategies must ensure that system attributes such as concentrate feed, inorganic fertiliser, organic waste management and energy are considered.

Ireland is an unusual country with respect to GHG emissions because it has a small human population but a large per capita emission (United Nations Framework Convention on Climate Change, 2002). The total land area of Ireland is 6.9 million hectares, of which, almost 5 million hectares is used for agricultural and forestry purposes. 80% of agricultural land is devoted to grass (silage, hay and pasture), 11% to rough grazing and 9% to crop production. Beef and milk production currently account for 56% of total agricultural output. There are almost 6.5 million cattle. The total number of farms was 141,500 in 2000 (DAFRD, 2005). The Irish agricultural industry contributes just over 2.5 % to GDP from primary production (9 % including agri-sector) (DARD, 2005) and over 30 % of the GHG emissions (Government of Ireland., 2000), therefore there is a necessity to reduce GHG emissions from the sector. Any attempt to modify the emissions from the major sources on farms should be assessed in terms of whether the emissions burden is reduced or simply transferred to another part of the production system (Casey and Holden, 2005a). Emissions must be accounted for holistically when looking at means of emissions reduction. Life cycle assessment (LCA) methodology offers a framework for systems analysis and was applied to livestock production systems to quantify emissions holistically.

Materials and Methods

LCA methodology

Life cycle assessment (LCA) is a holistic tool used to assess the environmental impacts of a system or product from "cradle to grave" (Udo de Haes, 1996*)*. An International Standard (ISO, 1997, 1998) defines LCA methodologies, and to carry out a full LCA it is normal to use a number of impact categories ranging from acidification to energy consumption. LCA methodology is appropriate for agricultural systems because it ensures that consideration has been given to the boundaries of the system under investigation (Audsley et al., 1997; Ceuterick, 1996, 1998; Haas et al., 2001 and Cederberg and Mattsson, 2000). When used with only one impact category the LCA methodology facilitates understanding of a specific aspect of a system (Casey and Holden, 2005a,b; Kramer et al., 1999 and Flessa et al., 2002), and is a useful tool for examining the role of farm intensification on GHG emissions (Casey and Holden, 2005b). In general, to produce a robust LCA those factors that are considered to be very small contributers to the system are ignored (Cederbery and Mattsson, 2000; Casey and Holden, 2005a).

System boundary

The system boundary is defined by the GHG emissions associated with agricultural production from "cradle to farm-gate". The system (Figure 1 dairy, Figure 2 beef) includes the physical limits of the unit and its activities: (i) the emissions associated with the individual ingredients of the concentrate feed production, transport and processing; (ii) emissions associated with N fertiliser production, transportation and application; (iii) emissions associated with livestock and related manure management; (iv) emissions associated with electricity, and diesel for agricultural operations (e.g. fertiliser application, manure application and forage production). As in previous studies emissions associated with the production of medicines, insecticides, machines, buildings and roads are excluded because of lack of data (Cederberg and Mattsson, 2000). Direct N_2O emissions from cattle were excluded from the study as these are known to be negligible (Tiedje, 1988), and CO_2 from enteric fermentation was also excluded because it is generally regarded as recycling from sustainably produced plant matter, and thus makes no net addition to the atmosphere (IPCC, 1993). Geo-political boundaries are not considered as limits to the system (IPCC, 1996b).

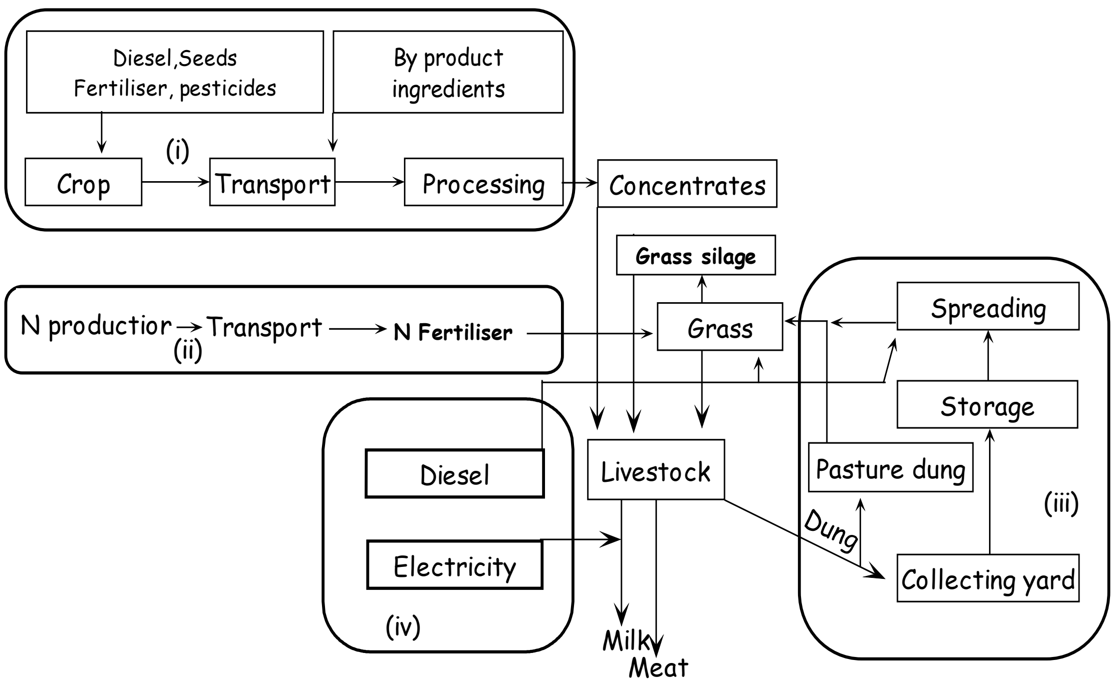

Figure 1. A flowchart of the "cradle to farm-gate" milk production system representing the processes included for describing a typical Irish dairy unit. Where (i) is concentrate feed related, (ii) is fertiliser related, (iii) is manure management related and (iv) relates to electricity and diesel usage. Adapted from Casey and Holden, (2005a).

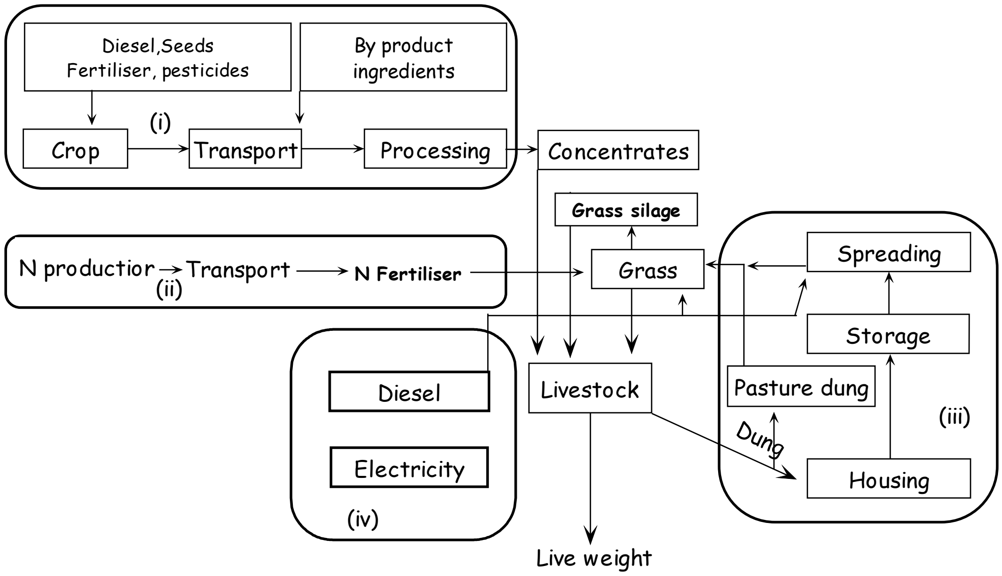

Figure 2. A flowchart of the "cradle to farm-gate" beef and sheep production system representing the processes included for describing a typical Irish suckler-beef unit. Where (i) is concentrate feed related, (ii) is fertiliser related, (iii) is manure management related and (iv) relates to electricity and diesel usage. Adapted from Casey and Holden, (2005c).

National Farm Survey (Heavy *et al.,* 1998; Burke and Roche, 1999, 2000 and 2001; Connolly *et al.,* 2002) data for the years 1997 to 2001 were collated to outline the characteristics of average dairy, beef and sheep production systems.

Functional unit

The functional unit (FU) is an attribute of the product or system and is used as a quantitative scalar for comparison purposes. The FU must be definable and measurable and therefore a system may have a number of possible functions (ISO, 1997). For dairy systems the main product is milk, therefore the FU defined was: *the production of 1 kg of energy corrected milk (ECM) over a time frame of one year*. ECM (kg) was determined as follows:

$$ECM = 0.25*M + 12.2*F + 7.7*P \quad (1)$$

where M is the mass of milk (kg), F is the fat (kg) and P is the protein (kg) (Sjaunja, 1990). Irish milk has an average density of 1.03 kg L^{-1}, and contains on average 3.9 % Fat and 3.2 % Protein (Mc Donagh et al., 1999). This FU encompasses the main product and the natural cycle, driven by lactation periods (Wegener Sleeswijk et al., 1996), and in Ireland is one year. As a mass or volume measure the FU is appropriate for GHG emissions because it is applicable on a global scale (Haas et al., 2000). For the beef and sheep production systems the FU was defined as: *the production of 1 kg of live weight (LW) over one year*.

Impact category

Global warming potential (GWP) was used to determine the contribution of three gases (CO_2, CH_4 and N_2O) to the greenhouse effect. The GWP index is defined as the cumulative radiative forcing effect between the present moment and a selected time in the future caused by a unit mass of gas emitted in the present. The emissions are measured in terms of a reference gas, CO_2 (IPCC, 1996a). The GWP of 1 kg CO_2 is 1, of 1 kg CH_4 is 21, and of 1 kg N_2O is 310 (IPPC, 1996a, assuming a 100-year time horizon). The total greenhouse gas emissions (TGE) (kg CO_2 eq (equivalents)) were determined as:

$$TGE = \Sigma GWP_i \times m_i \qquad (2)$$

where m_i is the mass (in kg) of the emitted gas (Heijungs et al., 1992). The total impact is expressed as kg CO_2 eq per functional unit.

Allocation

All milk production systems generate more than one functional output e.g. milk and meat (from culled cows and calves). Therefore a certain percentage of the emission from the dairy unit has to be allocated to the meat as well as the milk (Cederberg and Stadig, 2002). A number of options are available (ISO, 1998), but three allocation approaches were assessed: (i) no allocation (the milk takes the entire GHG emission), (ii) mass allocation (based on the mass of product leaving the system annually including surplus calves, culled cows and 24 month male animals versus the mass of milk) and (iii) economic allocation based on average milk price 1997-2001 (CSO, 2003) and meat price including subsidies (Heavy et al., 1998; Burke and Roche, 1999, 2000 and 2001; Connolly et al., 2002). Allocation to by-products is not necessary with respect to the FU in the context of the beef and sheep systems because the live weight of animals leaving the production unit will be subject to the production of by-products after post-processing which is outside the system boundary. Mass Allocation into the system from dairy system was considered where relevant, using data from Casey and Holden (2005a).

Emission factors

The emissions from each system were identified with the aid of flow diagrams (Figures 1 and 2). The following table outlines the emission factors selected:

Table 1. Emission factors selected to suit the systems of production adapted from Casey and Holden (2005 b,c and e).

Category	CH_4	CO_2	N_2O
Cows in milk^	85 to 125 kg cow		
Other stock^	45 to 55 kg head		
Suckler-Cows *	Tier 2		
Other stock*	Tier 2		
Ewes §	7.66 to 9.33 kg hd yr^{-1}		
Lambs §	2.19 to 2.66 kg head lifetime		
Fertiliser production	0.0016 to 0.0018 kg kg^{-1}	2.5 to 2.7 kg kg^{-1}	0.012 to 0.014 kg kg^{-1}
Distance input (fert.)	0.013 to 0.014 kg	8.55 to 9.45 kg	0.001 to .0021 kg
Merchant to farm	0.304 to 0.336 kg kg^{-1}	197.4 to 218.1 kg kg^{-1}	0.042 to 0.047 kg kg^{-1}
Fertilizer applied			0.002 to 0.02 kg N^{-1}
Diesel used (kg)	0.00057 to 0.00063 kg	3.38 to 3.73 kg	0.00066 to 0.00073 kg
Electricity (kwh)		0.7 to 0.81 kg	
Manure management			
Storage	0.001 to 0.0063 kg m^3 d^{-1}		0.01 to 0.04 kg N^{-1}
Pasture	0.008 to 0.002 kg cow d^{-1}		0.01 to 0.04 kg N^{-1}
Spreading	0.0014 to 0.0042 kg t^{-1}		0.0041 to 0.012 kg m^{-3}
Other cattle			
Storage	0.001 to 0.0063 kg m^{-3} d^{-1}		0.01 to 0.04 kg N^{-1}
Pasture	0.003 to 0.0003 kg cow d^{-1}		0.01 to 0.04 kg N^{-1}
Spreading	0.0014 to 0.0042 kg t^{-1}		0.0041 to 0.012 kg m^{-3}

^Dairy system only, *Beef system only, § Sheep system only

The justifications and sources for selection of particular emission factors may be viewed on Casey and Holden (2005a to e). The method used for calculating enteric fermentation emissions changed from the dairy to the beef and sheep systems. The method used for estimation in the beef system allowed for more precise quantification using calculations (IPCC, 1996a) combined with nutritional requirements (Casey and Holden, 2005c). With respect to the sheep system a per day emission was adopted (Casey and Holden, 2005e).

Concentrate feed

Concentrate feed is used for energy supplementation in early spring and late summer when grass production cannot fully support the livestock, and throughout the winter period when animals are housed. A method was derived for quantifying the emissions associated with the supply of concentrate feed to the farm-gate. The emission was presented per tonne of feed supplied for all the systems analysed. Different feed mixtures were used for the systems described and in all cases were compiled in consultation with feed suppliers. The data used were subject to allocation (Nielson, pers. comm., 2004) therefore the kg CO_2 eq. contribution does not include components that could be allocated to co-products or waste. The typical diet used for the dairy system is presented on Table 2.

Table 2. Emissions and sources of data to supply 1 t of concentrate feed to the average dairy unit. Percentage contribution to total in brackets. The inclusion rate of individual ingredients is commercially sensitive therefore not detailed at the request of the feed suppliers consulted (adapted from Casey and Holden, 2005a).

Ingredients	**Kg CO_2 eq.**	**Product origin**	**Reference**
Barley	117(10)	Native/UK	Nielsen et al., 2003
Wheat	135(11.5)	Native/UK	Nielsen et al., 2003
Beetpulp	288(25)	German	Brand et al., 1993
Oats	61(5)	U.S	Nielsen et al., 2003
Soya	126(11)	Brazil	Nielsen et al., 2003
Rapeseed	256(22)	U.S.A/Uzbekistan	Nielsen et al., 2003
Mollasses	41(4)	Indian/Pakistan	Kramer and Moll, 1995
Vegetable oil	39(3)	Dutch	Kok et al., 2001
Minerals and Vitamins	No data		No data
Shipping	34(3)		Bos, 1997
Trucking	18(1.5)		Bos, 1997
Processing	42(4)		Nielsen et al., 2003
Total per ton	**1156**		

Results and Discussion

Dairy system

Irish dairy production was summarised by an average dairy unit comprising of 47 milking cows producing 4822 L per cow per 290 days of lactation (equivalent to L yr^{-1}). The cows are fed on grazed grass from mid-March to late October (housed at night at the extremes of the *c*.200 day grazing season) and supplementation is achieved with silage and concentrates (Table 2) up to 819 kg cow yr^{-1} supplied when necessary. Cows are milked for 3 hours per day therefore 12.5 % of the time they are in the yard during the outdoor grazing period. This means 193 days are allocated to grazing and 172 days to housing requiring slurry and manure storage. A period of 870 hours per lactation (year) is spent in the collecting yard, and all cows are dried-off together. Grazed grass is maintained by the application of nitrogen fertiliser at a rate of 175 kg ha^{-1} (Coulter et al., 2002) and a 100 % recycling of organic waste (slurry and manure) is assumed. Grass silage is grown by the unit as conserved forage for the winter period (Casey and Holden, 2005a).

The average emission calculated was 1.50 kg CO_2 eq. kg ECM. The main contributors were: enteric fermentation (49 %), fertiliser (22 %), concentrates (13%), dung management (11 %) and diesel/electricity (5 %) (Casey and Holden, 2005a). Scenario testing indicated that moving towards cows with 20 % greater output per annum could reduce emissions per kg ECM by between 14 and 18 %. Even greater emissions reduction could be achieved by implementing a "slaughter scheme" which would remove excess stock from the unit. This was shown to yield emissions reductions in the order of 28 to 33 % (Casey and Holden, 2005a). However both of these scenarios could have the effect of passing the emission onto the beef sector. As increasing productivity from the dairy sector could see a reduction in the amount of dairy bred beef going to the beef sector there would be a need to increase suckler-beef production to maintain current productivity. The implementation of a "slaughter scheme" could have the same effect.

Ten functioning dairy units in the south of Ireland (where dairying is most profitable) yielded a range of 0.9 to 1.5 kg CO_2 eq. kg ECM yr^{-1} was calculated (Casey and Holden, 2005b). Results indicate that moving towards extensified milk production might give reductions in GHG emissions per kg ECM produced provided efficiency is maintained.

Beef system

In Ireland beef production systems are predominantly grass based. Weather permits 190-240 days grazing with 20 cows producing calves for replacements and beef consumption. It was assumed these calves are weaned at approximately 184 days. The calves are kept outdoors for another 30 days and fed grazed grass and concentrate. The weanlings are then housed for approximately 151 days and fed grass silage and concentrate. The yearlings are fed on grazed grass at turnout for approximately 214 days. During the final winter of 151 days the animals are fed on grass silage and concentrates until they are slaughtered at approximately 730 days and 650 kg live-weight. Animal weight data used for calculations in this study were recorded from a random sample of >1500 animals worth of market data recorded at weekly livestock sales, and then crosschecked with Teagasc (Irish Agriculture and Food Development Authority) data (Drennen, 1999). Grazed grass is maintained by the application of nitrogen fertiliser at a rate of

48 kg ha^{-1} and a 100 % recycling of organic waste (slurry and manure) is assumed (Coulter et al., 2002).

The average emission recorded was 11.9 kg CO_2 kg LW yr^{-1}. The study also concluded that manipulating the diet of the animals (i.e using ingredients of local origin and with low emissions per kg of product) had little effect in reducing the emissions per kg LW. There was however reductions in the order of 12 to 15 % from using a dairy bred animal even with lower productivity, which was assumed in the scenario. This again strengthens the case for an integrated means of production (Casey and Holden, 2005c). The average data were compared to 15 functioning suckler-beef farms in Ireland. Five operating conventionally, five operating within an agri-environmental scheme (AES) (a scheme where specifications limit inorganic fertiliser use, stocking density and special guidelines exist for slurry spreading a general farm management) and five organic producers. The average emission from the conventional units was 13.0 kg CO_2 kg LW yr^{-1}, 12.2 kg (CO_2) kg (LW) yr^{-1} from the AES units and 11.1 kg (CO_2) kg (LW) yr^{-1} from the organic units. The trend showed that moving towards extensified production should give reductions in emissions, but a marked reduction in productivity would be incurred if this approach were adopted to gain emissions reduction.

Sheep system

Irish sheep production was summarised by an average sheep unit comprising of 149 ewes producing on average 1.41 lambs per ewe where 1.28 lambs per ewe are weaned successfully. The replacement rate was set at 5 % in consultation with industry experts. Therefore the stock exported off the unit annually included lambs weaned and culled ewes. The sheep are fed on grazed grass from early-February to late November and supplementation is achieved with silage and concentrates up to 20 kg ewe yr^{-1} supplied when necessary (Flanagan and Kelly, 2002). Lambs are fed a concentrate at grass to increase growth rates particularly after weaning (25 kg lamb yr^{-1}) (Flanagan and Kelly, 2002). The ewes graze with the lambs until weaning at between 70 to 84 days of age. The lambs are then fed separately on concentrate feed and grass until slaughter at between 35 and 40 kg LW yr^{-1} at 160 to 165 days of age. The ewes are managed at grass for approximately 315 days of the year and the remainder is spent indoors in a straw bedded house where they are fed on concentrate and silage. Grazed grass is maintained by the application of nitrogen fertiliser at a rate of 90 kg ha^{-1} (Connolly, 1997) and a 100 % recycling of organic waste (manure) is assumed. Grass silage is grown by the unit as conserved forage for the winter period. The emissions associated with concentrate feed were adapted from Casey and Holden (2005c) and re-formulated according to Flanagan and Kelly, (2002) to suit sheep consumption. The average total emission calculated was 10.0 kg (CO_2) kg (LW) yr^{-1} for Irish sheep production. The study concluded that very little could be done to reduce this emission without reducing stock numbers nationally (Casey and Holden, 2005e).

Conclusion

Analysis should be carried out on a whole system basis to identify legitimate reduction strategies. Analysis of the results indicates that having considered the larger contributors to kg CO_2, it is important to examine the smaller ones for amplifying and attenuating effects. These include concentrate feed, manure management and diesel consumption (Casey and Holden, 2005a). The overall analysis from the national average dairy production situation indicates that moving towards more efficient production would lead to reduction in emissions. This however would have the effect of reducing the productivity of the national beef herd because increasing efficiency in the dairy herd would mean improving both management and animal genetics. This improvement in animal genetics could lead to a reduction in the suitability of animals from the dairy herd crossing over to the beef herd for beef production. Therefore an increase in suckler-cows would occur, which has been the trend for the past number of years in Ireland (McCarty et al., 1996). The work from the case study farms indicates that a move towards fewer cows producing more milk at lower stocking rates is required. Such a move would represent extensification in terms of area but intensification in terms of animal husbandry. The efficiency of the farm is the most important factor in terms of the balance of output per cow and feed supply. Compensating for imbalanced grass supply to feed demand by over feeding concentrates not only erodes profit but also leads to greater CO_2 equivalent emissions. The quality of management *per se* is more important than the intensity of production, but the role of geographical location requires further research, as do the interactions of production viability, economic viability and GHG emissions (Casey and Holden, 2005b).

The use of LCA methodology for this work has proven advantageous for estimating the potential effects of changing management to attain reductions in GHG emissions from the average suckler-beef production situation. The cow phase added a significant amount to emissions and had the greatest impact when eliminated. In terms of dietary management strategies for GHG reduction, the broad range of diet combinations evaluated yielded no major reduction within a grass-dominated system. If a continued increase in specialisation occurs in both the dairy and beef sectors in Ireland (CSO, 2003) it will be difficult to reduce GHG emissions per kg of product.

The most obvious option for GHG reduction in the long term is to integrate production systems, but this may be contrary to EU agricultural policy for the past 50 years. There has been a move towards reducing animal numbers in Europe with the introduction of the new single farm payment scheme. This is estimated to reduce animal numbers by up to 20 % in the short term in Ireland, which will reduce production of beef and increase dependency on imports from South America and Eastern Europe. It is difficult to speculate if this is the best option for European agriculture but it should lead to a reduction in GHG emissions from the agricultural sector in the region, but perhaps not globally. If a system were designed where the cow produced a good supply of milk but also produced a good calf suitable for beef production without having to over compensate for poor genetics with excessive amounts of concentrate feed then an emissions reduction could be attained because a suckler-cow is no longer required which has been demonstrated to contribute to national emissions substantially (Casey and Holden, 2005b).

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