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A Lifecycle Approach to Reducing the Environmental Impacts of Poultry Production

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The environmental burdens of chicken meat and egg production are analysed and reported using environmental life cycle assessment (LCA) to produce life cycle inventories (LCI) of production systems. The functional units were 1 t edible carcass weight and 12,000 eggs (average weight 63 g), both at the farm gate and without any burdens of slaughtering or packaging. The approach uses extensive systems modelling to provide input data for the LCA itself. Working models can be obtained from www.agrilca.org. Burdens are quantified by primary energy and resource use and potentials for causing environmental harm, including global warming (GWP), eutrophication and eutrophication.

The burdens of feed crops and derived products are presented together with the commodities produced by non-organic housed and free range systems as well as by organic production. The main energy, eutrophication and GWP impacts are from feed production, while that for acidification is from ammonia emissions from excreta. The meat finishing or commercial egg laying stages dominate all burdens, with the breeding overheads being relatively small, unlike mammalian stock that is farmed for meat.

The dominance of feed production and the commercial production stage indicates that lifetime feed conversion efficiency is the single most important term in determining the burdens of production. Improvements in genetics and nutritional science as well as husbandry can thus help reduce the environmental burdens.

Keywords: life cycle assessment, meat, eggs, environment, analysis

Introduction

The environmental impacts of agricultural production are coming under increasing scrutiny and poultry production is no exception. Various studies have addressed specific aspects of diffuse emissions and / or energy or resource use (Castellini *et al*., 2006; Ellingsen *et al*., 2006, Wathes *et al*., 1997). In the UK, poultry production above a set size also comes under the Environmental Permitting Regulations (EPR) regulations (EA, 2009). Emissions of pollutants like ammonia are one of the main features under EPR and these also appear in our national ammonia inventory, which is linked with need to achieve reductions in emissions under the Gothenburg protocol. These emissions have been one focus of concern in poultry production, but greenhouse gas (GHG) emissions are considered with increasing interest. These may be direct, *e.g*. burning fossil fuel to heat young birds or as nitrous oxide from litter, but also indirect in origin, which actually dominate. Indirect emissions include those that are embodied, or embedded, in the materials used in poultry production, of which the feed itself dominates.

The analysis of all the inputs and outputs is best achieved using the approach called environmental Life Cycle Assessment (sometimes also called Analysis), or LCA. This is a holistic approach to analysing production systems. There are two main sub-sets of LCA: cradle to gate and cradle to grave. The work described here is cradle to (farm) gate and thus omits the final stages of consumption and disposal of residues. The working models that we have developed can be accessed via www.agrilca.org.

Methods

The methods used conform with the concepts and detail described by the international standards on LCA in the IS0 14040 series. The approach also builds on the work of Audsley *et al*. (1997), who produced approaches for harmonising agricultural LCA. The main difference between our work and that of others is that we have approached agricultural commodity production at a national commodity scale and have used extensive systems modelling to supply the data that are used in the actual analysis. Also, being a cradle to gate approach, the output of our work are life cycle inventories (LCI) of the commodities. Much of what is reported here was developed under a Defra-funded project, IS0205, (Williams, *et al*., 2006) in which more details can be found. Further work was undertaken in a subsequent study for Defra (Williams *et al*., 2009)

OUTLINE OF LCA

The main features of LCA (**Error! Reference source not found.**) help show the main principles of:

- Relating everything to the functional unit
- Tracing all input use back to natural resources in the ground (or land itself)
- Ensuring that intermediate that are manufactured are all included
- Emissions of all diffuse pollutants are accounted for
- Co-products are also accounted for
- There are defined system boundaries, e.g. fields for crop production, which are analysed to a depth of 0.3 m, together with the animal production facilities themselves.

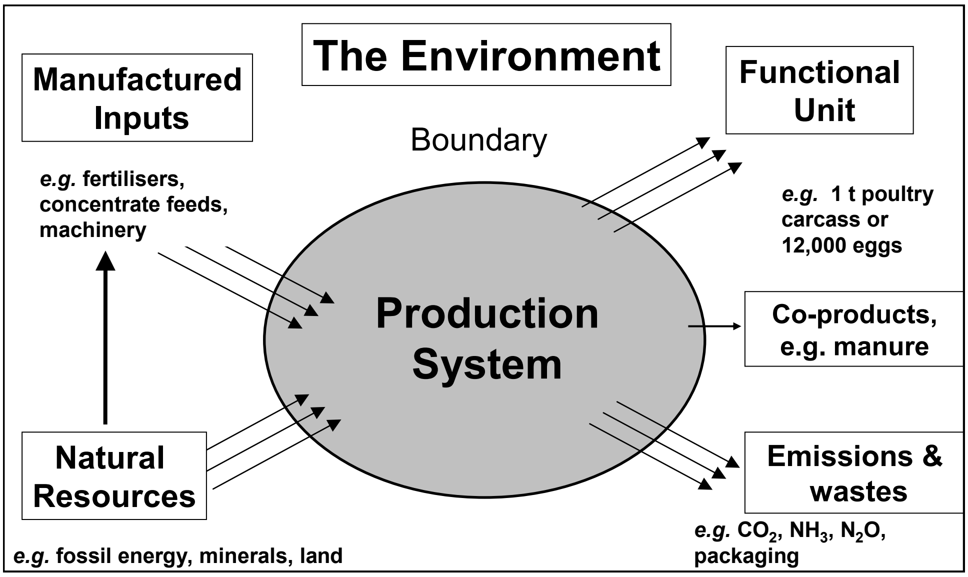

Figure 1 The LCA concept for cradle to gate applications

The functional unit is the main output that is analysed and must be specified with care. It is typically a weight and may be further qualified by qualitative factors or made dependent on locations in space or time. In our original work (Williams *et al*, 2006), the functional unit for poultry meat was 1 t edible carcass weight at the farm gate. Edible carcass weight is the product of liveweight and killing out percentage, but the burdens of slaughtering etc were not included. For eggs, the functional unit is 12,000 eggs with an average weight of 63 g (i.e. 0.75 t).

In agriculture, physical wastes form a small item, but diffuse emissions are the main problem.

STRUCTURAL MODELS

All breeding overheads are included, so that the pyramidal structure of the poultry sectors are included, in a simplified form. Two generations of breeders are included above the generation that hatches broilers for finishing or egg laying.

The industries are defined by sets of systems, each with its own set of production coefficients (such as feed conversion efficiency, longevity, eggs laid per day or liveweight gain). The demand by one part must be met by supply from others. These are all quantified in a set of linear equations that can be solved to meet the specification of different configurations of the industries. So, 12,000 eggs could be supplied by any combination of caged, barn, free range or organic (also free range by definition). Having set the overall supply systems, the structural model calculates all of the intermediates needed (e.g. breeders, pullet rearing) and hence the inputs of feed, housing, direct energy etc.

In egg laying, the main characteristics of the commercial layers and supporting intermediates are given in Table 1 and indicate the higher levels of productivity with caged than free range egg production as well as the higher stocking density and other features.

Table 1. Main characteristics of commercial laying and supporting systems.

	Housed Layers	Barn Eggs	Free Range Layers	Organic Free Range Layers	Layer Breeders	Pullets
Eggs, per layer	295	288	289	262	295	
Weeks	55	55	55	55	52	18
Feed Conversion Ratio	3.04	3.32	3.41	3.76	3.04	5.74 (*)
Feed, kg	45	48	49	49	45	6.6
Mortality	5%	7%	8%	8%	5%	3%
Fans and lighting electricity, MJ/head	11				11	1.9
Propane heat, MJ/head						2.5
Housed area, m^2/yr	0.058	0.12	0.088	0.18	0.058	0.031
Methane kg CH_4/ head	0.033	0.033	0.033	0.033	0.032	0.004
Ammonia, kg N/head	0.13	0.20	0.22	0.22	0.16	0.016
Nitrous Oxide, kg N/head	0.011	0.015	0.015	0.015	0.010	0.003

(*) Based on average lifetime weight of 1.15 kg

The functional unit of 12,000 eggs is met by 40.7 housed layers (or more if other systems). These must be replaced by 42.7 pullets (to allow for mortalities). The pullets arise from 0.40 layer breeders (commercial generation) and these from 0.071 2nd generation breeders and ultimately from 0.00013 pedigree line breeders. It is thus obvious that the final production stage dominates all, closely followed by pullet rearing. The fate of dead chicks and other rejects in the breeding phase has been omitted.

The same pyramidal stature applies to all production systems, although with different coefficients. It has been assumed that all pullet reading and breeding for non-organic production is in all housed facilities and that all breeders are caged. Organic rearing of replacements occurs in parallel certified facilities. At the time of producing the original model, all eggs were laid in non-organic systems and then transferred to organic immediately after hatching.

The requirements for nutrition are built into each system. At present, these are constants derived from average industry values, although we aim to make this more mechanistic. The outputs of N, P and K in manure balance the feed minus offtake in liveweight and / or eggs.

EMISSION FACTORS

The factors for ammonia emissions during housing, ranging and manure management came from the implementation of the UK national ammonia inventory under NARSES (Webb *et al*. 2006). Emissions of methane and nitrous oxide from housing came from the UK 1997 inventories of these gases, which were based whenever possible on UK measurements. Those for manure management came mainly from these sources, but some were replaced by those from the IPCC (2006) when they seemed more appropriate. The emission factors from feed crop production all comply with the methods of IPCC (2006). All individual GHGs are converted to a common scale based on the 100 year Global Warming Potential (GWP) using the IPCC (2006) coefficients and are expressed as CO_2 equivalents (CO_2e).

MANURE MODEL

From the time of excretion, through storage and then to land application, manure emits ammonia, methane and nitrous oxide. Manure management also takes effort, mainly diesel from tractors, fore end loaders and spreaders. These burdens are all debited against poultry production. The fertiliser value in manure is credited back to the birds. This is achieved by calculating the long term crop response to the N in manure and hence comparing this with the avoided burdens of applying N fertiliser in a non-organic crop or producing N via a sacrificial ley in an organic system. It is assumed that the long term replacement of mineral P and K by that in manure has a 100% credit. At present, it is assumed that all manure is applied to agricultural land, although some is actually burned in power stations.

FEED CROPS AND PROCESSING

All crops are analysed on long term basis. This applies especially to the yield responses in non-legumes to N supply and to nitrate leaching. These were calculated using the SUNDIAL crop-soil simulation model from Rothamsted (Smith *et al*., 1996). The feed composition was the best available when the work started but was limited by commercial factors. The diets were thus based on those last published by MAFF in 1993 (Soffe, 1995). Not all crops and by-products that are actually in use are included and proxies for some minor components. In was assumed that all soybeans are imported whole and processed in the UK.

Table 2. Components of diets in the LCA model

	Non-Organic			Organic		
	Broiler starter	**Broiler finisher**	**Layer**	**Broiler starter**	**Broiler finisher**	**Layer**
Feed Beans	11%	16%	10%	11%	16%	10%
Feed Wheat	57%	61%	40%	57%	61%	40%
Maize grain	2.0%	1.0%	1.0%	2.0%	1.0%	4.0%
Maize gluten			3.0%			
Rape meal	6.0%	3.0%				
Barley		1.0%	8.0%		1.0%	8.0%
Soybean meal	22%	16%	11%			
Soybeans (whole)				28%	19%	11%
Feed wheat straw	1.0%	1.0%	6.0%	1.0%	1.0%	6.0%
Wheatfeed			8.0%			8.0%
Limestone	1.4%	1.4%	13%	1.4%	1.4%	13%
Total	100%	100%	100%	100%	100%	100%

The main systematic differences between organic and non-organic diets are the absence of oilseed rape meal and soy meal from organic diets, with whole soy beans being the main organic alternative.

Most feed ingredients are UK grown except for soy and maize. Soy was assumed to come from the Brazil (50%), Argentina (40%) and USA (10%), while all maize was assumed to come from the USA. Most feeds are assumed to be processed in mills with a small proportion mixed on farms. The energy for feed processing is 0.81 GJ/t, mainly as electricity, which is assumed to apply to the ingredients after the main physical separation processes of oil extraction or wheat milling.

The processes of oil extraction and milling wheat produced disparate products with very different physical and nutritional properties. In analysing these processes, burdens must be allocated between the output streams. This could be done on a simple mass basis with, say, oil and meal having equal worth. In some cases, energy or some other property can be used. The most common approach for handling disparate outputs is to use economic allocation, i.e. the burdens are allocated in proportion to the value of the output streams, with the values being applied as close to the point of partition as possible. This is imperfect because the vagaries of markets can introduce apparently arbitrary shift in burdens, but by applying long-term averages, the method reflects the reasons for growing crops. In a simplified example (Figure 2), rapeseed meal and oil are extracted from grain. Without allocation, the burdens of meal and oil would be the same at 7 GJ/t. Applying economic allocation gives these expressions for meal and oil respectively.

Meal: $((0.6 * 100) / (0.4 * 300 + 0.6 * 100)) * (5 + 2) / 0.6 = 3.9$ GJ/t meal

Oil: $((0.4 * 300) / (0.4 * 300 + 0.6 * 100)) * (5 + 2) / 0.4 = 11.7$ GJ/t oil

In economic allocation, the same factors are applied to all burdens.

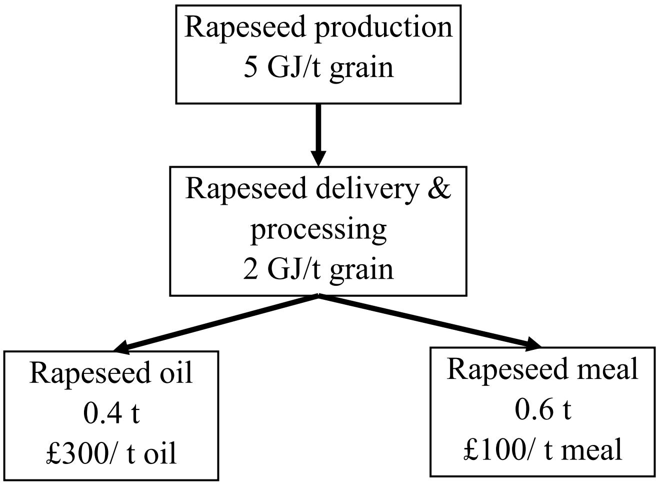

Figure 2 Simplified flow chart for oil and meal extraction from rapeseed

Results

BURDENS OF MAIN FEED INGREDIENTS

The burdens of primary production of the main feed crops, co-products and mixed concentrates (Table 3 to 5 respectively) show a number of features. By-products like wheatfeed have low burdens, because the primary product of milled wheat has a high value and the energy inputs are relatively small. Much more energy is needed to import and process soybeans into meal and the meal has a high value, so that soybean meal has notably higher burdens than soybeans. This also contrasts with rapemeal. The concentrate burdens are generally similar, with the burdens tending to increase with higher protein rations owing to the higher inclusion rate for soy meal. Processing from straights (including soybean and rapeseed meal) accounts for about 22% of energy and 9% of GWP in concentrates.

Table 3 Burdens of producing main feed crops for poultry production

Impacts & resources used per t	**Oilseed Rape**		**Feed Wheat**		**Barley**		**Field Beans**		**Soybeans**		**Maize Grain**	
	Non-Org	Org	Non-Org	Org	Non-Org	Org	Non-Org	Org	Non-Org	Org	Non-Org	Org
Primary Energy used, GJ	5.3	5.2	2.3	2.1	2.4	2.4	2.5	2.4	3.7	3.2	2.2	2.3
Global Warming Potential, t CO_2e	1.0	1.1	0.46	0.41	0.40	0.42	0.51	0.59	0.70	0.82	0.34	0.35
Eutrophication Potential, kg PO_4 Equiv.	8.5	17.4	2.8	8.0	2.5	5.8	5.9	5.6	9.4	9.3	2.5	5.8
Acidification Potential, kg SO_2 Equiv.	7.3	2.6	2.2	1.4	1.9	1.0	2.1	1.5	3.3	2.2	1.3	0.97
Pesticides used, dose ha	0.96	0.00	0.78	0.00	0.63	0.00	1.2	0.00	2.0	0.00	0.74	0.00
Abiotic depletion, kg antimony Equiv.	2.9	2.6	1.4	1.2	1.4	1.3	1.3	1.4	1.9	1.7	1.3	1.2
Land occupation (Grade 3a Equiv.)	0.32	0.91	0.13	0.32	0.17	0.42	0.31	0.34	0.50	0.51	0.14	0.39

Table 4. Burdens of producing major feed ingredients for poultry production

Impacts & resources used per t	**Maize gluten**	**Rapeseed meal**	**Soybean meal**	**Wheatfeed**	**Wheatfeed org.**	**Limestone as rock**
Primary Energy used, GJ	3.9	3.3	7.5	0.74	0.67	0.90
Global Warming Potential, t CO_2e	0.31	0.54	0.96	0.12	0.11	0.49
Eutrophication Potential, kg PO_4 Equiv.	0.99	4.0	9.5	0.61	1.9	0.00
Acidification Potential, kg SO_2 Equiv.	0.86	3.5	7.5	0.58	0.37	0.06
Pesticides used, dose ha	0.29	0.44	2.0	0.17	0.00	0.00
Abiotic depletion, kg antimony Equiv.	1.8	1.7	5.7	0.39	0.34	0.40
Land occupation (Grade 3a Equiv.)	0.06	0.15	0.50	0.03	0.10	0.00

Table 5 Burdens of producing concentrates for poultry production

Impacts & resources used per t	**Layer concs.**	**Layer concs., org.**	**Broiler starter concs.**	**Broiler starter concs., org.**	**Broiler finishing concs.**	**Broiler finishing concs., org.**
Primary Energy used, GJ	3.3	3.3	4.3	3.9	3.9	3.8
Global Warming Potential, t CO_2e	0.51	0.52	0.62	0.63	0.59	0.61
Eutrophication Potential, kg PO_4 Equiv.	3.0	5.7	4.6	7.9	4.4	7.7
Acidification Potential, kg SO_2 Equiv.	2.5	2.0	3.6	2.4	3.3	2.4
Pesticides used, dose ha	0.73	0	1.1	0	1.01	0
Abiotic depletion, kg Sb Equiv.	2.1	2.7	2.8	3.1	2.5	3.1
Land occupation (Grade 3a Equiv.)	0.15	0.28	0.23	0.37	0.21	0.36

BURDENS OF POULTRY MEAT PRODUCTION

Only broiler meat production is addressed here. We considered three main production systems, fully housed broilers, free-range non-organic and organic. The market shares by weight are estimated to be 95%, 4% and 1% respectively. Care must be taken when comparing different commodities because the properties differ and so does the function. Some superficial comparisons between poultry meat and crops are, however, possible. Those per t meat are about an order of magnitude higher for energy and GWP, which is not surprising since the process of animal production is one of concentrating plant nutrients into high quality protein and other nutrients. Eutrophication and acidification potential both increase by about two orders of magnitude. This stems mainly from ammonia emissions that come in turn from unabsorbed protein in manure. The acidification part is caused by the oxidation of ammonia to nitric acid by soil bacteria once it is deposited on land.

The poorer environmental performance of organic poultry meat production is mainly because of the standards that require a longer production period than in the non-organic sector. This results in a lower overall feed conversion ratio. So, even though the burdens of some feeds are lower in burdens, the overall effect is negative.

Table 6 Burdens of chicken meat production by three production systems

	All housed	**Free range**	**Organic**
Primary energy used, GJ	16.0	16.7	18.5
GWP, t CO_2e	2.6	3.0	3.9
Eutrophication potential, kg PO_4 Equiv.	20	25	43
Acidification potential, kg SO_2 Equiv.	37	46	63
Pesticides used, Dose-ha	3.0	3.7	0.3
Abiotic resource use, kg Sb Equiv.	15	16	23
Land (grade 3a), ha	0.61	0.76	1.4

Table 7 Burdens of hen egg production by four systems

	Caged	**Barn**	**Free range**	**Organic**
Primary energy used, GJ	8.4	8.4	8.5	9.5
GWP, t CO_2e	1.5	1.7	1.7	1.8
Eutrophication potential, kg PO_4 Equiv.	12	14	15	21
Acidification potential, kg SO_2 Equiv.	28	32	36	37
Pesticides used, Dose-ha	1.4	1.7	1.8	0.02
Abiotic resource use, kg Sb Equiv.	7.2	8.9	7.6	13
Land (grade 3a), ha	0.3	0.4	0.4	0.7

In both egg and meat production, feed accounts for most energy used and weighted GHG produced, ranging between 67% and 99%. Housed birds used most direct energy (18% to 27%), mainly for ventilation and lighting. Direct gaseous emissions from stock (mainly N_2O) account for 16% to 27% of weighted GHG emissions. When considered from the perspective of functions, the final meat finishing and egg production stages use 86% to 94% of energy and emit 96% to 95% of GHG. Replacement pullets for layers represent about 12% of these burdens and broiler breeders for meat birds represent 4% to 7% of burdens. All other breeding overheads contribute to less than 2% of the total.

This leads to the inescapable observation that feed conversion efficiency in the final production stages completely dominates environmental performance in poultry production. Feed production itself incurs the largest energy and GHG burdens hence the effectiveness of its use is so critical. One exception is acidification potential in which about 80% of emissions are as ammonia from housing, ranging and manure management. This arises ultimately from feed, so again highlighting the need to make very effective use of feed.

Concluding Discussion

Poultry production has developed to be the most resource-efficient meat production system in agriculture. Much of this has been made possible through a combination of improved genetics and nutrition that is helped by the much shorter breeding cycles than with mammals. Also the breeding overheads are much smaller than with mammals. Controlled environment housing is a widespread feature in poultry and despite needing more direct energy than free range systems, our analysis suggests lower burdens than in organic production. The differences are, however, smaller than between species. There are always opportunities for improvements in any production system and this type of analysis is a very useful tool to help the process of improvement. Increasing overall lifetime feed conversion efficiency must be a goal in all systems. For housed birds, direct energy use is still considerable and there must be scope for new generations of systems to be less reliant on fossil fuel.

We have not yet analysed egg-production using the enriched cages that will be come mandatory by 1st January 2012 or the lower intensity meat production systems used by producers for stores such as Waitrose. Bird welfare is a highly contentious subject and, at present, there is no method available for quantifying the lifetime stress of birds going through different systems that can be incorporated in LCA. The development of such a method is highly challenging, but if it were possible, it would help determine whether environmental performance and perceived welfare are in harmony or not.

There are areas in which our analysis is weaker than others, e.g. synthetic amino acids are not included in diets and we only have one generic finishing ration. Industry averages have been assumed for energy use. Burning litter in power stations has not been analysed and it far from being a trivial matter. Some of these will be addressed in a forthcoming Defra and industry funded LINK project.

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