Environmental impacts of poultry production when using poultry manure as a fuel on broiler farms

Project report for bhsl, April 2013

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Summary

The on-farm utilisation of poultry manure as a fuel for heating or as a fuel for combined heat and power generation (CHP) is a new use for the material. Currently, the predominant use of poultry manure is for land spreading as a fertiliser. The environmental impacts related to the fertilizer use of poultry manure include acidification and eutrophication as a result of ammonia emissions and nitrate leaching, so alternative manure management strategies may be advantageous in reducing these impacts.

This study applied the Life Cycle Assessment (LCA) method to compare the environmental impacts of three scenarios for broiler manure management: the baseline fertilizer use and the use of the manure as a fuel to generate either heating or both heating and electricity. The data provided by bhsl for the analyses included the amount of manure used as a fuel, reductions in the use of liquid petroleum gas (LPG), trace combustion gases released, electricity used for running the bhsl energy system, electricity generated by the combined heat and power system (CHP), additional electricity to increase ventilation and optimise the environment for birds, changes in bird performance and the nutrient content of the ash for land application.

The results showed that on-site use of poultry manure as a fuel was generally beneficial in terms of the environmental impacts. According to the data, the LPG use was reduced by 89 - 95%, and the analysis showed reductions in eutrophication potential by 26 - 32% and reductions in acidification potential by 31 - 40%. The study focused on the Life Cycle Assessment (LCA) and did not include benefits such as energy security advantages or cost reductions and new income streams.

1. Objectives

The aim of the project was to evaluate the environmental impacts of poultry production when using poultry manure as a fuel on the same broiler production sites. The scenarios with manure being used as a fuel included the generation of heating, and the generation of both heating and electricity, i.e. using combined heat and power (CHP). The environmental impacts of broiler production applying the bhsl energy systems were compared to the impacts of the scenario where all manure was used as a fertilizer.

2. Method

A method called environmental Life Cycle Assessment (LCA) was used to quantify the environmental impacts of the broiler production with different scenarios of manure management. LCA evaluates the scenarios systematically to account for all inputs and outputs that cross a specified system boundary and relates these to the useful outputs. In this study, the functional unit (FU) was set as 1000 kg of expected edible broiler carcass (i.e. excluding feathers, heads, necks, feet and internal organs), and the modelled system was defined as “from cradle to farm gate”. The LCA-systems model used in the analyses was developed originally at Cranfield University (Williams et al. 2006) and subsequently developed further in a partnership with Newcastle University (Leinonen et al. 2012).

2.1. Scenarios

The three different scenarios for manure management considered in this study were the following:

1) Fertilizer use scenario (Baseline). In this scenario, all manure was assumed to be used as fertilizer (with credits given for the value of N, P and K in manure). With this application, the manure has both environmental credit (replacement of synthetic fertilizers in crop production), and environmental burden (emissions to water and atmosphere and energy use from manure management).

2) Heat only scenario. In this scenario, it was assumed that part of the manure is used as a fuel to produce heat and the remaining is used as fertilizer (as in the Scenario 1 above). The heat offsets the need for fossil fuel, in this case LPG. Also, the ash from the bhsl energy system is used as fertilizer with only P and K as valued plant nutrients.

3) Combined heat and power scenario (CHP). In this scenario, it was assumed that all the manure is used as a fuel to produce heat and electricity. Some electricity may be exported and so displaces the need to generate it elsewhere. The ash from the bhsl energy system is used as fertilizer with only P and K as valued plant nutrients.

In the system comparison, the factors affecting the environmental impacts of different scenarios included the following:

- The reduction of the use of fossil fuels in heating of the broiler house
- The reduction of the use of fossil fuels in the generation of electricity
- The electricity requirement for running the bhsl energy system
- The energy requirement for additional ventilation
- Trace gas emissions from combustion
- Changing transport burdens
- Changes in the use of synthetic fertilizers
- Changing emissions from manure storage and from the field
- Long-term changes in soil carbon storage
- Possible change in the performance of the birds

2.2. Data

All the data related to the energy use in the farm-level heat production and heat + electricity production systems were based on the model calculations provided by bhsl. These included the annual totals of the following, calculated for an 11-year period (2000-2010):

- The total amount of manure* produced and the amount used as a fuel per year
- LPG and electricity use for the baseline system
- The amount of LPG used and the amount avoided when using the bhsl systems
- Electricity use, including the electricity requirement for running the system
- The amount of electricity and heat produced by the bhsl systems

* Note that manure includes both bedding and excreta

Additional data, also provided by bhsl included the following:

- The amount of ash produced per unit of manure used as a fuel
- The plant nutrient concentration of ash
- Total quantities of trace combustion gases released (NOx, SO_2, CO)
- Weight and main constituents of the equipment

In addition, data on bird performance (including body weight, feed conversion ratio and mortality) were provided by bhsl. These data were collected from three farms applying the bhsl heating system and included several production cycles before and after installing the bhsl system. Before the bhsl heating system was installed, direct gas heating was used in the farms included in the data.

All the activity data related to the broiler production chain that were not directly provided by bhsl was obtained from the earlier study by Leinonen et al. (2012) and included, for example, the composition of the diets used in standard indoor broiler production and the description of the breeding system. These data were assumed to be applicable for all scenarios considered in this study.

In all the scenarios considered in this study, it was assumed that the farm consisted of 12 broiler houses with the overall crop size of 378,000 birds. In the Fertilizer use scenario (baseline), the final age of the birds was assumed to be 36 days, the final weight 2059 g and the feed conversion ratio 1.72 kg/kg. For the other scenarios, the bird performance was adjusted based on the provided data as described below.

2.3. The LCA-systems model

The structural model for the broiler production system calculated all of the inputs required to produce the functional unit 1000 kg of expected edible carcass weight, allowing for breeding overheads, mortalities and productivity levels. It also calculated the outputs, both useful (broilers) and unwanted (e.g. mortalities). Changes in the proportion of any activity resulted in changes to the proportions of others in order to keep producing the desired amount of output. Establishing how much of each activity was required was found by solving linear equations that described the relationships that linked the activities together.

The environmental impacts of the production, processing and transport broiler feed were calculated in the model by using generalized broiler and breeder diets representative to those used in the UK poultry industry (Leinonen et al. 2012). A separate sub-model for arable production was used to quantify the environmental impacts of the main feed ingredients, with main features as in Williams et al. (2010). All major crops used for production of poultry feed were modelled. For the crops partly or wholly produced overseas (soya, sunflower, palm oil), the production was modelled as closely as possible using local techniques, and transport burdens for importing were also included. The greenhouse gas emissions arising from land use change were taken into account according to the principles of the carbon footprinting method PAS 2050 (BSI 2011).

A separate sub-model was used for the manure in the nutrient cycle. In the model, the main nutrients that are applied to the soil in manure are accounted for as either crop products or as losses to the environment. The benefits of N, P and K remaining in soil after land application of manure are credited to poultry by offsetting the need to apply fertilizers to winter wheat as described by Sandars et al. (2003) and implemented by Williams et al. (2006).

2.4. Offsetting electricity

Exported electricity is offset against the marginal supply, which is assumed to be a combined cycle gas turbine (CCGT) that operates with a requirement for 2 MJ net energy natural gas per MJ electricity produced. The net electricity generated is reduced to allow for the expected transmission and distribution losses in the grid. This includes stepping voltages up and down as well as losses in cables etc. and the value was derived from UK Digest of Energy Statistics for 2012 (https://www.gov.uk/government/publications/digest-of-united-kingdom-energy-statistics-2012-internet-content-only) using the average of the last three years of data (2009-2011), i.e. 8.3%.

2.5. Manure production and fertilizer use

Based on the data provided, it was assumed in the model that each bird produced 0.82 kg dry weight of excreta in its 36 day life. The baseline manure contained 59% DM and that from the system using manure as a fuel contained 68% DM. Hence, each bird produced 1.29 or 1.11 kg litter, respectively, on a fresh weight basis.

The manure not used as a fuel was assumed to be applied to agricultural land to fertilise winter wheat and the net burdens were derived from the Cranfield manure model in which the N increases yield and offsets the need to ammonium nitrate fertiliser and the P and K offset the need for manufactured fertiliser. These were credited to the livestock produced and direct emissions of unwanted trace gases and the energy for manure management were debited against the livestock.

The ash when using manure as a fuel was assumed to be used for agriculture in a way that is compatible with good agricultural practice. It can be expected that there is interest in using the ash as fertilizer as it is pathogen and odour free and it has higher bulk density than manure, making the economics of transporting it more attractive.

Furthermore, the following assumptions were also made:

- The ash contains no N
- The P and K are valued as if they were of the same value as the P and K single super-phosphate and potassium chloride respectively.
- It is assumed that ash is transported 15 km to land for application
- Other constituents are ignored, having very little value.

2.6. Potential ammonia emissions

The concentrations of free ammonia that could be expected in manure were calculated from the total ammoniacal concentration, the pH and the dissociation constant. The analyses were based on the litter sample data provided by bhsl. Because of the non-significant variation in pH, there was also no significant difference between the systems.

With the drier litter when using manure as a fuel, there should be less microbial activity than in the baseline system. This should lead to reduced ammonia production from uric acid in the litter. On the other hand, the rate of volatilisation of ammonia from litter, leading to emissions from the house, is increased by air speed. So, the higher ventilation rates for optimum ventilation would act against the lower rate of production of ammonia. The magnitude of each process determines the net effect on ammonia emissions. A detailed analysis of actual ammonia emissions from the bhsl demonstration site is underway in a separate study. Without actual experimental data, no conclusive statement can be made at this time.

2.7. CO_2 from using manure as a fuel

We assume that most CO_2 when using manure as a fuel is in a short term cycle and so should not be included in the combustion emissions. However, there is a need to account for the carbon that would be lost from soil if manure was no longer used as a fertiliser. This was derived by using the RothC soil carbon model and a simulation was conducted using a manure applicant rate of 1 t ha per year. This was continued until in steady state and then applications stopped and the loss of soil carbon was calculated after 20 years. This is the pragmatic time period used in PAS 2050. This resulted in 29% of applied carbon being retained, and this amount must be assumed to be emitted when there is no fertilizer use of the manure. The carbon content of manure was estimated to be 0.26 t C/[t FW], so using 1 t of it as a fuel results in 75 kg carbon being lost per t FW or 75*44/12, i.e. 265 kg CO_2/[t FW].

2.8. Effect of production system on bird performance

The effect of the bhsl heating system together with other factors (farm effect, breed, age of birds, genetic trend) on the Feed Conversion Ratio (FCR) of broilers was evaluated with a General Linear Model using the Minitab statistical software. The following model was used in connection of bird performance data provided by bhsl (data from three farms from years 2008-2012):

$$FCR = System + Farm + a * day + b * age + c * Ross\% + d + \varepsilon \quad (1)$$

Where "FCR" is the feed conversion ratio (kg/kg), "System" is the effect of the heating system (Control or bhsl), "Farm" is the effect of farm (Farm1, Farm3 or Farm4), covariate "day" is the running number of the day, representing here the possible genetic progress, covariate "age" is the final age (days) of the birds (here a linear relationship between FRC and age is assumed), covariate "Ross%" is the proportion of the birds of the Ross breed (0-1, the remaining birds represent the Hubbard breed), "a", "b" and "c" are coefficients, "d" is constant and "ε" is the error.

Similarly, the relationship between the heating system and the growth rate of the birds was analysed with a General Linear Model. The following model was used:

$$GR = System + Farm + a * day + b * Ross\% + c + \varepsilon \quad (2)$$

Where “GR” is the growth rate (g/day), “System” is the effect of the heating system (Control or bhsl), “Farm” is the effect of farm (Farm1, Farm3 or Farm4), covariate “day” is the running number of the day, representing the possible genetic progress, covariate “Ross%” is the proportion of the birds of the Ross breed (0-1, the remaining birds represent the Hubbard breed), “a”, and ”b” are coefficients, “c” is constant and “ε” is the error.

2.9. Functional groups of environmental impacts

The output of the LCA-systems model was the emissions to the environment in different scenarios. The emissions were aggregated into environmentally functional groups as follows:

Global Warming Potential (GWP) is a measure of the greenhouse gas emissions to the atmosphere, and was calculated here using a timescale of 100 years. The main sources of GWP are carbon dioxide (CO_2) from fossil fuel and land use changes, nitrous oxide (N_2O) and methane (CH_4). GWP was quantified as CO_2 equivalent: with a 100 year timescale 1 kg CH_4 and N_2O are equivalent to 25 and 298 kg CO_2 respectively (IPCC, 2007). The sum of GWP per functional unit is also known as the “carbon footprint”.

Eutrophication Potential (EP) is used to assess the over-supply (or unnatural fertilisation) of nutrients as a result of nutrients reaching water systems by leaching, run-off or atmospheric deposition. EP was calculated using the method of the Institute of Environmental Sciences (CML) at Leiden University (http://www.leidenuniv.nl/interfac/cml/ssp/index.html). The main sources are nitrate (NO_3^-) and phosphate (PO_4^{3-}) leaching to water and ammonia (NH_3) emissions to air. EP was quantified in terms of phosphate equivalents: 1 kg NO_3-N and NH_3-N are equivalent to 0.44 and 0.43 kg PO_4^{3-}, respectively.

Acidification Potential (AP) is mainly an indicator of potential reduction of soil pH (and causing damage to some building materials, like limestone). AP was also calculated using the method of the Institute of Environmental Sciences (CML) at Leiden University The main source is ammonia emissions, together with sulphur dioxide (SO_2) from fossil fuel combustion. AP was quantified in terms of SO_2 equivalents: 1 kg NH_3-N is equivalent to 2.3 kg SO_2.

Primary Energy Use was quantified in terms of the primary energy needed for extraction and supply of energy carriers, including gas, oil, coal, nuclear and renewable.

Land Occupation describes the area of the land required to produce a unit of the product. In the case of poultry production, this mainly consists of the arable land for producing crops for feed, and it was calculated assuming average yields for Grade 3a land (Bibby and Mackney 1969).

Abiotic Resource Use describes the use of non-renewable raw materials, such as fossil fuels and minerals. The use of disparate abiotic resources was aggregated by scaling them in relation to the scarcity of each resource using the method of the Institute of Environmental Sciences (CML) at Leiden University (http://www.leidenuniv.nl/interfac/cml/ssp/index.html). The scale is quantified in terms of the mass of the element antimony (Sb).

2.10. Model runs

The LCA-systems model was run separately for each year included in the bhsl data (from 2000 to 2010), in order to demonstrate the potential year-to-year variation in the results. These runs were used to derive the mean, minimum and maximum values that are presented. The "minimum" was set for the year 2002 in which the minimum amount of LPG was used and the "maximum" was for the year 2010 in which the maximum amount of LPG was used.

3. Results

3.1. Changes in energy use

The farm energy use figures, based on the bhsl model, are presented in Table 1. These figures show that both the bhsl systems considerably reduced the LPG use. In the CHP system, more LPG was used than in the heat only scenario because less manure was used to produce heat and all the remaining manure was used for electricity generation. In the heat only scenario, there was an increase in the electricity use compared to the baseline as a result of increased ventilation requirements.

Table 1. Annual farm energy use in the baseline and the bhsl systems as calculated by the bhsl model.

	Total LPG UK Shortfall, litres (and reduction compared to the baseline)	Total electricity used, MWh	Electricity exported, MWh
Baseline	**485,000**	**582**	**0**
bhsl heat only (mean)	**25,793 (-95%)**	**1,183**	**0**
bhsl heat only (min)	*1,497*	*1,212*	*0*
bhsl heat only (max)	*46,764*	*1,148*	*0*
bhsl CHP (mean)	**51,605 (-89%)**	**0**	**254**
bhsl CHP (min)	*18,236*	*0*	*244*
bhsl CHP (max)	*87,060*	*0*	*265*

3.2. Overall environmental impacts

The environmental impacts of all three systems are presented in Table 2. The results are expressed per functional unit (1000 kg expected edible broiler carcass), and they show the mean values for the 11 year period included in the calculations, as well as years with minimum and maximum LPG use (2002 and 2010, respectively).

Table 2. The environmental impacts of different manure management scenarios per 1000 kg expected edible broiler carcass.

	Baseline	bhsl heat only			bhsl CHP		
		mean	min	max	**mean**	min	max
Primary Energy used, GJ	**22.6**	**21.4**	*21.3*	*21.4*	**19.5**	*19.3*	*19.8*
Global Warming Potential, t CO_2 equivalent	**4.05**	**4.04**	*4.04*	*4.04*	**3.97**	*3.95*	*3.99*
Eutrophication Potential, kg PO_4^{3-} equivalent	**17.0**	**12.5**	*12.4*	*12.6*	**11.5**	*11.5*	*11.5*
Acidification Potential, kg SO_2 equivalent	**29.9**	**20.6**	*20.5*	*20.8*	**17.8**	*17.8*	*17.8*
Abiotic resource use, kg antimony equivalent	**16.5**	**15.5**	*15.4*	*15.5*	**15.0**	*14.8*	*15.1*
Land occupation, ha	**0.529**	**0.548**	*0.549*	*0.548*	**0.554**	*0.554*	*0.554*

4. Discussion

The results show that generally there are environmental benefits from using manure as a fuel on a farm compared to the fertilizer use scenario, as the environmental impacts were reduced in most of the main categories. The main reductions occurred in the categories of Eutrophication Potential and Acidification Potential. This is a result of considerable reductions of ammonia emissions and, to a lesser extent, nitrate leaching when the manure is used as a fuel instead of as a fertilizer.

The main benefits of the bhsl system are in reducing ammonia emissions from manure management (storage and land application), rather than from housing itself. The differences between pH or the proportion of total ammoniacal nitrogen (TAN) that is present in the ammonia form (which is potentially volatilised) was not statistically significant. Hence, no differences in emissions from housing could be assumed based on the litter samples provided. However, bhsl has a separate study underway to measure the actual ammonia emissions from a poultry house on the bhsl demonstration site to provide additional data for such analyses.

The balance between avoiding LPG use and using manure as a fertilizer is relatively fine for energy use and greenhouse gas emissions (Global Warming Potential). In general, when using manure as a fuel, the farm LPG use could be considerably reduced (by 89 - 95%), which also reduced the greenhouse gas emissions. On the other hand, there was a need for extra electricity to run the plant, pump hot water to houses and deliver greater ventilation levels in the broiler house when the bhsl system was used. Furthermore, using manure as a fuel also reduced the soil carbon storage compared to the fertilizer use scenario, and this also reduced the potential GWP benefits.

The differences in bird performance had only a minor effect on the environmental impacts in different systems. Furthermore, it should be noted that possible reasons for the differences in performance were not considered in this study.

We have modelled the system as closely as possible to represent the bhsl data. The analysis has been done in good faith, based on a combination of real activity data and modelled inputs from bhsl. We cannot guarantee that users of the equipment will actually derive the same benefits as were quantified by the LCA.

5. References

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