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Comparing the environmental impacts of UK turkey production systems using analytical error propagation in uncertainty analysis

Ilkka Leinonen [a, *], Adrian G. Williams [b], Ilias Kyriazakis [a]

[a] School of Agriculture, Food and Rural Development, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK
[b] School of Energy, Environment and Agri-Food, Cranfield University, Bedford, MK43 0AL, UK

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ABSTRACT

The aim of this study was to (1) quantify the environmental impact of UK turkey systems and (2) develop a methodology for analytical uncertainty analysis, as currently error propagation methods for such analyses of environmental impacts of agricultural commodities rely on time consuming Monte-Carlo approaches. The turkey systems considered were: 1) Stags (males) with controlled ventilation, 2) Hens (females) with controlled ventilation, 3) Stags with natural ventilation, and 4) Hens with natural ventilation, all being the main UK turkey production systems. An LCA modelling framework, based on a system approach and mechanistic sub-models was applied to assess several environmental impact categories, expressed per unit of live weight, and their associated uncertainties. For the first time, detailed production data and their variations from the industry, including slaughter age and weight, feed composition and consumption, mortality, and farm energy use, were used as input. The statistical significance of the differences between the systems was analysed using an analytical “top–down” method for uncertainty analysis, developed in this study. The results show that there were only small, mainly non-significant differences in impacts between the systems, affected mainly by their feed conversion ratio and slaughter weight, both of which were generally higher in the stag systems than the hen systems. A significant difference ($P < 0.05$) between the systems was found only in Acidification Potential, for which the stag system with controlled ventilation had a higher impact (88 ± 4.5 kg SO_2 equivalent per 1000 kg live weight at farm gate) than the hen system with natural ventilation (72 ± 6.3 kg SO_2 equivalent). For the other impacts, the average Primary Energy Use varied from 18,000 to 21,600 MJ, Global Warming Potential from 4000 to 4600 kg CO_2 equivalent and Eutrophication Potential from 26 to 31 kg PO_4^{3-} equivalent per 1000 kg live weight at farm gate, depending on the system (without any statistically significant differences). As a central outcome of this study, the development of the novel uncertainty analysis method makes it possible to precisely quantify the overall uncertainties of outputs of complex systems models, without the need for time-consuming Monte Carlo simulations, thus allowing statistical comparisons between different systems and scenarios.

1. Introduction

According to Defra (2011), UK turkey production in 2010 was 162 thousand tons carcass weight, which is over 10% of total UK poultry meat production; in several European Union countries turkey production is even higher (FAO, 2011). Despite the importance of turkey systems and their potential contribution to the overall environmental consequences of livestock production, quantifying environmental impacts of turkey production has so far gained little attention in agricultural research. The only study aiming to analyse systematically the environmental impacts of UK turkey production was carried out by Williams et al. (2006). In that study, however, only generic UK data were used, without detailed information on potential differences between separate production systems. To quantify the current impacts of the main turkey systems and find ways to decrease them, detailed production data from primary producers is required; these should be combined with systemic assessment methods. Amongst such methods, Life Cycle Assessment (LCA) is becoming generally preferred in agricultural production, since it accounts for all environmental burdens occurring during the production cycle, starting from raw material extraction through to the end products (BSI, 2006). Unlike some

* Corresponding author. Tel.: +44 (0)191 208 6925.
E-mail address: ilkka.leinonen@newcastle.ac.uk (I. Leinonen).

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other methods for environmental impact assessment (e.g. BSI, 2011), LCA is not limited to carbon footprinting only. Instead, it uses several indicators of environmental impacts, including resource use and potential for causing harm to ecosystems and humans, for example, global warming from greenhouse gas emissions, eutrophication from nitrate and phosphate leaching, and acidification, e.g. as a result of ammonia emissions, which are considered to be one of the major environmental problems of large-scale poultry systems, in particular. In poultry production, LCA modelling has been previously used, for example, to quantify environmental impacts of different meat and egg production systems (Williams et al., 2006; Mollenhorst et al., 2006; Katajajuuri, 2008; Usva et al., 2009; Pelletier, 2008, 2014; Boggia et al., 2010; Xin et al., 2011; Leinonen et al., 2012a, 2012b, 2014a; Taylor et al., 2014) or to evaluate system changes such as how modifying feed composition may decrease impacts of these systems (Nguyen et al., 2012; Dekker et al., 2013; Leinonen et al., 2013, 2014a; Arroyo et al., 2013).

To compare different systems that produce the same commodity, a method to quantify uncertainty in their environmental impacts is required (Leinonen et al., 2012a). Such a method was developed as an essential part of a systems-based LCA modelling framework aimed at quantifying environmental impacts of poultry systems (Leinonen et al., 2012a, 2012b). In these studies, uncertainty was quantified using Monte Carlo simulation, which is an approach used commonly in LCA and in commercial software, such as SimaPro (PRé, 2013). However, this approach requires considerable computing power, is time consuming, and yields only approximations as output, the accuracy of which depends on the number of Monte Carlo iterations used. Therefore, there is a need for a more straightforward, preferably analytical, method for quantifying uncertainty in agricultural LCA studies.

The aim of the current study was to apply the LCA method “from cradle to gate” to quantify and compare environmental burdens of the four main turkey production systems in the UK. A complementary aim was to develop a novel analytical method for uncertainty analysis which would allow precise quantification of system uncertainties without time consuming Monte Carlo simulations.

2. Methods

2.1. Systems approach and life cycle inventory data

The general approach followed in the current study was systems modelling of production. This included structural models of the industry describing relationships between activities of turkey production (including brooding and finishing of male and female turkeys, growing the parent stock, feed crop production, etc.), process models and simulation models (e.g. mechanistic sub-models for crop production and manure management) that were unified in the systems approach so that changes in one area caused consistent interactions elsewhere. This approach was applied to both feed crop and animal production. The systems modelled in this study included crop production, non-crop nutrient production, feed processing, turkey breeding (i.e. growing the parent stock), turkey brooding (i.e. growing young birds) and finishing and manure and general waste management, following the overall principles presented by Williams et al. (2006) and Leinonen et al. (2012a, 2012b). The outline of the turkey LCA model is presented in Fig. 1.

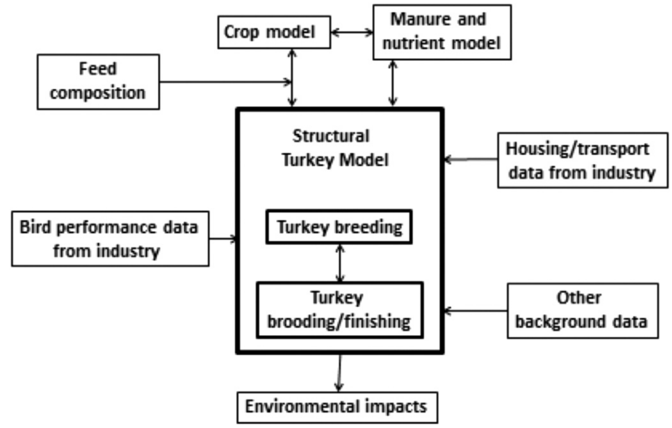

Fig. 1. Structure of the turkey LCA model as used in this study.

The production systems in this study represent typical mainstream UK turkey production, namely 1) Stags (males) with controlled ventilation, 2) Hens (females) with controlled ventilation, 3) Stags with natural ventilation, and 4) Hens with natural ventilation. Farm energy consumption for heating, lighting, ventilation and feeding was based on average data from typical farms provided by the main UK turkey production companies (see Acknowledgements). Information about the type and amount of bedding and other materials used was also obtained from the industry. It was assumed that all turkey manure was used for soil improvement as a fertiliser, which is a common practice in UK poultry production. In practice, some litter is burned in power stations, but this option was not considered here, as the aim was to compare on-farm environmental performance between the production systems. Bird performance and production data, including the length of the production cycle, stocking density, final weight, feed intake and mortality came from actual farm data provided by the industry. The main production figures for different systems are presented in Table 1. Additional data, such as life cycle inventories (LCIs) of agricultural buildings and machinery, came from Williams et al. (2006). Baseline diets representative of those used in the UK for each system were constructed using information provided by the turkey industry. Separate phase-fed diets were applied to stag systems and hen systems, and details of the diet formulation are presented in the Supplementary Material. Typical system-specific feeding programs were also provided, and the consumption of separate phase diets was quantified based on them (see Supplementary Material for bird ages at different phases). Environmental impacts arising from feed production were calculated based on the relative proportion of each ingredient in the overall diet and its LCI data.

2.2. The models

The structural model of turkey systems calculated all of the inputs required to produce the functional unit (1000 kg of live weight at the farm gate and ready for slaughter). These inputs consisted of feed, farm energy and other resources for all stages of the production chain (including, for example, brooding and finishing of turkeys and production of a required number of parent birds) and took into account bird performance and mortality rates. It also calculated outputs, such as the amount of turkey live weight produced, manure produced and waste and emissions to the environment in general. Changes in the proportion of any activity resulted in changes in the proportions of others to keep producing the desired amount of output. For example, production of certain amount of live weight of turkeys required a certain number of poults (taking mortality into account), which in turn required a certain number of parent birds and so on. Establishing how much of each activity was required was found by solving linear equations that described the relationships that linked the activities together.