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Potential environmental benefits of prospective genetic changes in broiler traits

I. Leinonen*[1], A. G. Williams[†], I. Kyriazakis*

*School of Agriculture, Food and Rural Development, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK

[†] School of Energy, Environment and Agri-Food, Cranfield University, Bedford, MK43 0AL, UK

Corresponding author: Ilkka Leinonen, School of Agriculture, Food and Rural Development, Newcastle University, Agriculture Building, Newcastle upon Tyne, NE1 7RU, UK, Telephone: +44 (0) 191 208 6925, Fax: +44 (0) 191 208 6720, e-mail: ilkka.leinonen@newcastle.ac.uk

Scientific section: Genetics

[1] Corresponding author: ilkka.leinonen@newcastle.ac.uk

ABSTRACT

A system approach-based Life Cycle Assessment (LCA) framework, combined with a simple mechanistic model of bird energy balance was used to predict the potential effects of 15 years prospective broiler breeding on the environmental impacts of the standard UK broiler production system. The year 2014 Ross 308 genotype was used as a baseline, and a future scenario was specified from rates of genetic improvement predicted by the industry. The scenario included changes in the traits of growth rate (reducing the time to reach a target weight 2.05 kg from 34 days to 27 days), body lipid content, carcass yield, mortality and the number of chicks produced by a breeder hen. Diet composition was adjusted in order to accommodate the future nutrient requirements of the birds following the genetic change. The results showed that predicted changes in biological performance due to selective breeding could lead to reduced environmental impacts of the broiler production chain, most notably in the Eutrophication Potential (by 12%), Acidification Potential (by 10%) and Abiotic Resource Use (by 9%) and Global Warming Potential (by 9%). These reductions were mainly caused by the reduced maintenance energy requirement and thus lower feed intake, resulting from the shorter production cycle, together with the increased carcass yield. However, some environmental benefits were limited by the required changes in feed composition (e.g. increased inclusion of soy meal and vegetable oil) as a result of the changes in bird nutrient requirements. This study is the first one aiming to link the mechanistic animal modeling approach to predicted genetic changes in order to produce quantitative estimates of the future environmental impacts of broiler production. Although a more detailed understanding on the mechanisms of the potential changes in bird performance and their consequences on feeding and husbandry would be still be needed, the modeling framework produced in this study provides a starting point for predictions of the effects of prospective genetic progress.

Key words: Broiler, Environmental impact, Genetic changes, Life Cycle Assessment, Selective breeding

INTRODUCTION

Livestock production systems have been considered to have various negative environmental impacts, including nutrient leaching and a significant contribution to global warming (Steinfeld et al., 2006). Amongst different livestock systems, poultry production has been found to be relatively “environmentally friendly” (e.g. Williams 2006; de Vries and de Boer, 2010). However, despite for example relative low greenhouse gas emissions, poultry systems have some features that require special attention in terms of their environmental impacts. These include particularly ammonia emissions to air from housing and manure management, having various harmful effects including contribution to acidification, and nitrate leaching from field spreading of manure, contributing to eutrophication (Sutton et al., 2011; Leinonen et al., 2012a,b). Furthermore, nutrient leaching and emissions to air also occur from production of the feed crops, having a significant contribution to the overall environmental impacts of poultry systems. In order to address all these impacts, a holistic approach to accounting for all burdens occurring during the whole production and consumption cycle would be required, as opposed to simply assessing their “carbon footprint”, which is the only focus of some environmental impacts assessment frameworks (e.g. BSI, 2011).

In earlier studies, various measures aiming to reduce the environmental impacts of poultry production have been assessed through the method of Life Cycle Assessment (LCA), including changes in diets through the use of alternative feed ingredients (Nguyen et al. 2012; Leinonen et al. 2013) or enzymes aiming to improve feed utilization (Oxenboll et al., 2011;

Leinonen and Williams, 2015) and changes in housing and manure management (Leinonen et al., 2014; Williams et al., unpublished data). As the majority of the environmental impacts of poultry production arise from the production and use of feedstuffs and emissions from manure (Leinonen et al., 2012a), any change in feed utilization would be expected to affect the environmental impact of poultry systems, through both the production of feed crop and manure management. One of the major aims of broiler breeding has been to increase the energy efficiency, thus reducing the amount of feed needed to produce a certain amount of broiler meat. Although attempts have been made to assess the consequences of past genetic changes in chickens, (Defra, 2008; Pelletier, 2010) quantitative studies on the environmental effects of predicted future genetic progress have been so far rare. In this study, we aim to apply a system approach-based LCA modeling to assess the changes of environmental impacts of broiler chicken production as a result of selective breeding applying the industry targets for genetic improvement over a 15 year horizon.

MATERIALS AND METHODS

Modeling Approach

The approach taken in the current study was based on systems modeling of agricultural production, as described by Williams et al. (2006, 2007, 2010) and Leinonen et al. (2012a,b). This included structural models of the industry and process-based simulation models that were unified in the systems approach so that changes in one area caused consistent effects elsewhere. This approach was applied to both feed crop and livestock production. The systems modeled in this study included crop production, non-crop nutrient production, feed processing, breeding, broiler production (including farm energy and water use and gaseous emissions from housing), and manure and general waste management. The detailed structure of the broiler production LCA model has been presented earlier by Leinonen et al. (2012a) and the quantification of the uncertainties in the model inputs and outputs is explained in Leinonen et al. (2012a, 2013).

The production system in this study was considered to represent typical UK indoor broiler production as described by Leinonen et al. (2012a). 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 modeled. Transport burdens for importing overseas crops and burdens from processing the feed were also included. For the purpose of this study, a specification was made that all feed crops applied in the broiler diets originated from "mature" agricultural land. Therefore no CO_2 emissions arising from land use changes were included in the calculations, following the suggestions of the carbon footprinting outline PAS 2050 (BSI, 2011). Farm energy consumption for heating, lighting and ventilation was based on average data from typical farms provided by the UK broiler industry (Leinonen et al., 2012a). Information about the type and amount of bedding was also obtained from the industry. Additional data, such as the life cycle inventories of agricultural buildings and machinery came from Williams et al. (2006).

The structural model for the broiler system calculated all of the inputs required to produce the functional unit (1000 kg of expected carcass weight at farm gate: Leinonen et al., 2012a). The model also calculated the outputs, both useful (broilers) and unwanted (e.g. wastes and mortalities). In the model, changes in the proportion of any activity must result in changes to the proportions of others 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 (Williams et al., 2006; Leinonen et al., 2012a).

Energy and mass balance principles for animal growth, production and feed intake were used in the current study to calculate the total consumption of each feed ingredient during the whole production cycle, and to calculate the amounts of main plant nutrients, nitrogen (N), phosphorus (P) and potassium (K) in manure excreted by the birds during the production cycle. The bird energy balance was quantified following Emmans (1994) in order to predict the daily feed intake of a single bird as a function of feed energy content and bird energy requirement. This included requirements for both production (body growth) and maintenance. According to the mass balance principle, the model calculated the N, P and K contents of the manure by subtracting the nutrients retained in the animal body from the total amount of nutrients obtained from the feed. For the purpose of the study, it was assumed that all manure was used for soil improvement as a fertilizer.

In order to model the emissions from the manure, we followed the principles of Audsley et al. (1997) and Williams et al. (2006, 2010), taking a long-term approach to agriculture, for example ensuring that N emissions and uptake from manure are accounted for on an infinite time horizon. Poultry manure is a source of direct gaseous emissions of ammonia (NH_3), nitrous oxide (N_2O) and to a lesser extent methane (CH_4), which occur during housing, storage and land-spreading and were quantified with a separate manure sub-model. Emissions of these gases arising from excreta during housing were calculated following the methods of Williams et al. (2006), which are based on UK national inventories (Chadwick et al., 1999; IPCC, 2006; Misselbrook et al., 2008; Sneddon et al., 2008). Manure management also uses energy and these burdens were debited against the poultry (along with burdens from direct gaseous emissions). In the model, all of the nutrients applied to the soil as manure were accounted for as either crop products or as losses to the environment (Sandars et al., 2003). The benefits of plant nutrients (N, P and K) remaining in soil after land application were credited to poultry by offsetting the need to apply fertilizer to winter wheat as described by Sandars et al. (2003) and Williams et al. (2006).

Environmental Impact Categories

As an output of the LCA model, the resource uses and emissions to the environment were aggregated into environmentally functional groups as follows:

Primary Energy Use. The energy use in broiler production includes for example diesel (e.g. feed production and transport), electricity (e.g. ventilation and lighting) and gas (e.g. heating). All these are quantified in terms of the primary energy needed for extraction and supply of fuels (otherwise known as energy carriers). The primary fuels are coal, natural gas, oil and uranium (nuclear electricity). They are quantified as MJ primary energy which varies from about 1.1 MJ natural gas per MJ available process energy to 3.6 MJ primary energy per MJ of electricity. Data on the origin and proportion of energy carriers in electricity in the UK and overseas came mainly from the European Reference Life Cycle Database (JRC 2013), or were derived from the International Energy Agency. A proportion of electricity is produced by renewable sources such as wind and hydro-power, which account for 3.6% and 8% for UK and European electricity respectively.

Global Warming Potential (GWP 100) 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. 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 fertilization) 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). 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: 1kg NO_3-N and NH_3-N are equivalent to 0.44 and 0.43kg 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 sulfur 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.

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. Land occupation for crops was calculated assuming average yields for UK 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. We applied the method of the Institute of Environmental Sciences at Leiden University, the Netherlands (http://www.leidenuniv.nl/interfac/cml/ssp). The scale is quantified in terms of the mass of the element antimony (Sb).

Modeled Scenarios

The systems LCA model was first used to calculate the environmental impacts for the current (year 2014) Ross 308 genotype, for which the input data was obtained from Aviagen performance objectives (Aviagen, 2014), from UK industry data collected in an earlier study (Leinonen et al., 2012a), and from other recent studies (e.g. Mussini, 2012; Danisman and Gous, 2013). After that, a scenario based on industry targets ("target scenario") for a 15 years cumulative genetic improvement was analyzed with the model. The main biological performance parameters required to run the LCA model and obtained from the industry for the scenario were growth rate (i.e. age to reach the target live weight of 2.05 kg, which, according to the scenario, was reduced from 34 days to 27 days) and carcass yield (i.e. the proportion of eviscerated carcass in relation to the live weight). Due to the changing degree of maturity of the bird at the time of slaughter, the body composition was expected to change (Emmans and Kyriazakis, 2001). The resulting change in lipid content was specified after discussion with the representatives of the breeding industry, and the protein content was calculated based on the body protein:water:ash ratios from Gous et al. (1999), assuming that these would not be changed by genetic selection (Emmans and Kyriazakis, 1995). As a result, in the target scenario the carcass yield was assumed to increase from 71.7% to 73.2% and the body lipid content to decrease from 11% to 8%. As the target live weight did not change in the genetic scenario, a direct consequence of increasing carcass yield was that a smaller number of birds was needed to produce the functional unit of 1000 kg carcass weight. The parameters for growth rate, body composition and carcass yield for the baseline and the target scenario are presented in Table 1.

The protein and energy requirements of the bird for the baseline and the scenario were calculated as follows: first, the total metabolizable energy intake (assumed equal to the bird energy requirement) for the baseline 2.05 kg bird was calculated based on the feed intake and feed metabolizable energy (ME) content reported by the industry (Aviagen, 2014). Then, this total energy (MJ/bird) was distributed to growth and maintenance as follows:

$$ME \ = 50\frac{MJ}{kg} \times Prg + 56\frac{MJ}{kg} \times Lg + \sum c \times Pr_i \qquad (1)$$

where Prg is the total protein growth (kg), Lg the total lipid growth (kg) and $\Sigma c{*}Pr_i$ the total energy requirement for maintenance (MJ) during the growth cycle, where Pr_i is the body protein content (kg) on day i and c (MJ/kg) is a constant describing the bird metabolic rate of maintenance (Emmans, 1997). The constants 50 MJ/kg and 56 MJ/kg describe the total metabolizable energy needed to grow 1 kg of protein and lipid, respectively (including both the chemical energy retained in the body and the heat production associated with increase of the body mass), as estimated by Emmans (1994).

The value of the constant *c* was estimated specifically for the birds applied in this study on the basis of their total energy requirement (ME), obtained directly from baseline performance objectives (Aviagen, 2014), and the baseline body composition. The value of *c* may be expected to be dependent on the physical activity of the bird, which necessarily affects the ME requirement; in this study it was kept unchanged for both the baseline and the target scenario. In theory, changes in genetic traits such as body composition could affect bird activity and consequently maintenance energy requirement. However, according to the industry (Aviagen, personal communication), such changes are not an expected outcome of the current direction of breeding.

For the target scenario, the change in the total energy requirement was then quantified using the industry predictions for the values of Prg, Lg, Pr_i and the (unchanged) constant *c*. As seen in Table 1, there was a reduction of 4.6 MJ in energy requirement for the target scenario compared to the baseline, which was the outcome of reduced maintenance energy requirement as a result of shorter production cycle and the lower energy requirement for growth due to the lower body lipid content.

For the protein requirement, the gross protein use efficiency was calculated based on the baseline feed intake, feed protein content and body composition i.e. the efficiency equals the protein retained in the body (kg) divided by the protein intake (kg) of a single bird. This efficiency value was then used to calculate the protein requirement for the target scenarios with the predicted changes of the growth rate and the body protein content. Currently there is no evidence that the efficiency of protein utilization has changed as a result of selective breeding. Therefore, it was assumed that this trait would remain constant in this genetic scenario. As a direct consequence of the constant protein use efficiency, the increase in the body protein content then slightly increased the overall protein requirement (Table 1).

For the baseline, the total consumption of different feed ingredients (used as an input of the LCA model) was calculated based on typical starter, grower, finisher and withdrawal diets provided by the Industry. For the UK, these are mainly based on wheat and soy bean meal (Leinonen et al., 2012a). Changed consumption of the ingredients for the target scenario was estimated using the predicted changes in bird requirements. This was done as follows: first, the change in the feed intake was calculated using the new energy requirement while keeping the feed energy content unchanged. Second, the protein and the mineral contents for the new diet were estimated based on the changes in feed intake and in bird requirements, (the change of mineral requirement was assumed to be proportional to the change of protein requirement). Third, the new diet was constructed to meet these requirements by changing the proportions of wheat, soy meal, soy oil, pure amino acids and minerals in the diet (assuming that wheat remained the main energy source and soy meal the main protein source, and farmers change the diets following the changing nutrient and energy requirements of the genetically changed birds), while minimizing the economic costs using linear optimization (with the MS Excel Solver Add-In).

In addition to changes in the traits related to growth end energy and protein requirement of a single bird, two other traits, namely broiler mortality and the number of chicks produced per breeder hen were also predicted to change as a result of genetic improvement, and these changes were also included in the LCA model simulations. The baseline and the scenario values for these traits are also presented in Table 1.

The genetic improvement was also expected to change the farm energy consumption as a result of the changes in the length of growth cycle and bird performance. For the baseline, the farm gas and electricity use per bird were provided by the UK industry (Leinonen et al., 2012a). Of the total electricity use, the main part (assumed to be 70%) was used for ventilation, while smaller amounts of electricity were used for lighting (assumed 25%) and feeding (assumed 5%). For the genetic scenarios, the changes in these components were assumed to be proportional to the changes in (1) bird heat production, which was quantified using the bird energy balance model (and reduced in the scenario as a result of increasing energy efficiency), (2) length of the production cycle, and (3) feed intake, respectively. These changes were taken into account in the LCA model runs.

Sensitivity Analysis

In addition to the overall change in the environmental impacts as a result of the genetic change specified by the target scenario, the effects of separate traits were also assessed individually. Since most of the traits in consideration are functionally connected with each other, and because their effects on the overall impact are not additive, it was not possible to directly quantify the effect of each single trait. Instead, a sensitivity analysis was carried out where a change in one trait in turn was excluded from the target scenario (i.e. the baseline value was applied for this trait); then the LCA model was run with this altered scenario and finally the result was compared to the baseline and to the full target scenario. The traits included in the sensitivity analysis were carcass yield, mortality, number of chicks produced by a breeder hen and the body composition (lipid and protein content).

Breakdown of the Environmental Impacts

The results were broken down by the following material (and energy) flow categories (or sub-systems) to demonstrate their relative contribution to the overall impacts and their response to the predicted genetic changes:

1) Feed and water: production of feed crops and additives, feed processing and transport. This category also includes the water consumed during housing.

2) Farm electricity: direct electricity consumption at the farms and hatcheries, not including feed production, processing or transport.

3) Farm gas and oil: direct fuel consumption at the farms and hatcheries, not including feed production, processing or transport.

4) Housing: direct emissions of NH_3, CH_4 and N_2O from housing and burdens from construction of farm buildings and vehicles, not including buildings and vehicles used in feed production, processing and transport of ingredients.

5) Manure and bedding: emissions from manure storage and field spreading and the production of the bedding. This category also includes credits from replacing synthetic fertilizers; does not include direct emissions of NH_3, CH_4 and N_2O from housing.

RESULTS AND DISCUSSION

The changes in bird growth rate (together with the changes in body composition), as predicted by the genetic scenario, had substantial effects both on feed composition and intake. As a result of the reduced growth cycle which reduced the maintenance energy requirement, and to a lesser extent as a result of increasing body protein content of the birds in the target scenario, the feed protein/energy ratio had to be altered to match the new requirements. As a result, the average feed crude protein content had to be increased from 19.8% to 22.9% over the whole production cycle, while keeping the average ME content constant at 13.2 MJ/kg. The main change required in the formulation of the diet to meet these new requirements resulting from the genetic scenario was an increase in the proportion of soy bean meal from an average of 22% up to 31% at the expense of cereals, which resulted in the reduction of wheat from 63% to 53%. This reduction of wheat resulted in a requirement to add more concentrated sources of energy to the feed, and consequently the proportion of vegetable fat in the diet was increased from 2.9% to 4.0%.

The environmental impacts calculated by the LCA model are presented in Tables 2-7 for both the baseline and the target scenario, showing also the results of the sensitivity analysis which highlighted the importance of single genetic traits. The results show that the predicted genetic changes reduced all environmental impacts considered in this study. In most environmental impact categories, relatively large reductions as a result of genetic changes occurred in the "Feed and water" subsystem. This was caused by the reduced ME requirement (and resulting reduced feed intake) due to shorter growing cycle needed to reach the 2.05 kg target weight, and affected also by the changes in the body composition, as decreased body lipid content reduced the energy required for growth. However, the reduced ME requirement as a result of shorter growth cycle and the increased body protein content required a higher protein content in the diet (achieved mainly by higher inclusion of soy) and a more concentrated source of ME (i.e. increased vegetable oil content). These changes affected for example the Primary Energy Use, Global Warming Potential and Land Occupation arising from the feed production, and therefore limited the environmental benefits that could be achieved through the genetic changes. For example, in the category of Land Occupation (consisting mainly of the arable land needed for production of the feed crops), the differences between the baseline and the scenario were only minimal. The reason for this was that although the overall amount of feed needed to produce the functional unit decreased, there was a shift in the diet from high yield feed crops (wheat) towards lower yield crops (soy) as a result of increasing protein requirement of the birds. This also means that relatively more land is needed overseas, as soy is not grown in the UK and the availability of alternative, sustainable protein sources is currently limited in the EU (Leinonen et al, 2013). It is interesting to note that when the change in body composition was excluded from the scenario in the sensitivity analysis, higher reduction in land occupation and primary energy use could actually be achieved compared to the full target scenario, as a result of lower requirement of soy.

Additional reductions of the environmental impacts as a result of genetic changes occurred also in the “Housing” and “Manure and bedding” subsystems. Again, these changes were associated with the reduced length of the production cycle and reduced feed intake of the birds. This considerably reduced the amount of N excreted by the birds, and therefore had a beneficial effect on nitrous oxide (contributing to GWP) and ammonia (contributing to Eutrophication and Acidification Potentials) emissions. Reducing ammonia emissions per se also helps meet internationally agreed targets for reducing emissions of acidifying gases (Leinonen and Williams, 2015). The reduced farm energy consumption as a result of shorter production cycle also had effects on some impact categories, mainly the Primary Energy Use and GWP.

Amongst different traits included in the genetic scenario and assessed in the sensitivity analysis, increased carcass yield affected all environmental impacts uniformly, simply because a smaller number of birds was required to produce the functional unit (1000 kg broiler carcass), reducing directly all the resources needed and emissions arising from the production (Tables 2-7). Reduction in the broiler mortality and number of chicks produced by a breeder hen had only a moderate effect on the changes of environmental impact of the broiler production system, as shown in Tables 2-7. The reason for this is that the broiler mortality was already very low in the baseline, so any further reductions in genetic scenario had a little effect on the environmental impacts. Furthermore, although the number of the breeder hens needed to produce the functional unit decreased in the genetic scenario, the breeder system in general has a relative low contribution to the overall environmental impacts of the broiler production chain (Leinonen et al, 2012a), so again relatively low improvement in the overall environmental performance can be achieved through this trait.

In this study, a holistic, systems-based approach combined with mechanistic animal energy flow modeling was applied to quantify the potential effects of future genetic changes on the environmental impacts of a broiler production system. Earlier studies on this topic have been either conceptual without any quantitative analysis (Pelletier, 2010), or have mainly considered changes that have occurred in the past with only limited predictions for possible future trends (Defra, 2008). In general, a functional process-based approach has only recently been applied in LCA studies on poultry production (e.g. Leinonen 2012a,b), and the current study can be the seen as the first one where such an approach is used for genetic changes in broilers. In earlier studies, for example in the Defra (2008) report, the effect of genetic changes on the animal nutrient requirement (and consequently changes in feed composition) or on their nutrient excretion were not taken into account. Omission of these essential factors may result in either overestimation or underestimation of the predicted changes in the environmental impacts of livestock systems. For example, the consequences of the trend in reducing broiler FCR, achieved by selective breeding, (e.g. Laughlin, 2007) cannot be understood without detailed information on the required changes in the bird diet. Such a trend will have effects on the consumption of different feed crops and on the impacts arising from their cultivation, as shown in this study. On the other hand, the changes in the feed intake and composition have inevitably effects on the amount of nutrients excreted by the birds, which consequently affects the emissions arising from housing and manure management. Mechanistic understanding of this process is likely to produce much more accurate estimates of these emissions than a simplistic use of unchanged emission factors. For example, our results show that there are potentially major effects of genetic changes on the acidification and eutrophication potentials; these are directly affected by reduced N excretion by the birds as a result of reduced ME requirement and consequently reduced protein intake.

Despite its quantitative nature, there are some limitations in the current study that should be kept in mind when interpreting the results. First, only one scenario for the future genetic changes was considered in this study, based on some of the targets/ expectations of the UK broiler breeding industry and concentrating on a single genotype (Ross 308). Alternative broiler genotypes developed for different purposes and production systems exist, and the production systems, including the final weight of the broilers, vary between different countries. This may give rise to different environmental impact outcomes as shown by Leinonen et al (2012a). Therefore, further studies are required where more specific production data collected from different systems and locations will be utilized in connection with the LCA model.

Second, the scenario applied in this study was based on the starting point that the feed provided to the birds does not change any more than what is necessary to meet the changing nutrient requirements. For example, it was assumed that the ME content of the feed (MJ/kg feed) will be kept constant in the scenario. Furthermore, the diet is changed only in terms of the relative proportion of different feed ingredients, i.e. no ingredient is assumed to be completely removed from the feed and no new ingredients are added. Consequently it was assumed that soy remains the main protein source and wheat the main energy source in the broiler feed. In reality, the composition of feed is very much driven by changes in the prices of ingredients, a phenomenon that is very difficult to include in future scenarios (Mackenzie et al, 2013). In addition, novel ingredients may reach the market that would allow manipulations of feed compositions beyond the above confines. Currently there is substantial interest, in the EU at least, on these issues in the context of food security. The advantage of the system-based LCA modeling approach is that it can be readily adapted to any changes in the feeding strategies, providing that Life Cycle Inventory of possible new ingredients is available. Therefore, the modeling framework presented in this study can be also used for evaluation of the effects of different scenarios of future changes in poultry diets (Leinonen et al. 2013).

Third, the analysis is based on the assumption that the metabolic rate of the bird (defined as the maintenance heat production per mass unit of protein per unit of time) does not change as a result of the breeding process. This assumption may not be true if bird activity is also reduced, which would result in further reduction of its ME requirement. Furthermore, in theory, the changes in body composition may not only alter the protein/lipid ratio, but also change the proportion of different types of protein in the body (e.g. Emmans and Kyriazakis, 1995, 1999). Again, this (in theory) might have effects on the rate of metabolic activity and the maintenance energy use. However, such changes are difficult to predict, and currently there is no evidence that they could significantly affect bird energy requirement. In general, there is no literature showing that selective breeding has changed the basic metabolic rate of broilers. For example Geraert et al. (1990) and Buyse et al. (1998) found no significant differences in the rate of maintenance between broiler strains that have been selected for their body composition, growth rate or feed efficiency. Clearly there is a gap in the knowledge concerning the mechanisms of the reduced bird energy requirement as a result of genetic selection. In order to improve the reliability of the predictions of the consequences of the future broiler breeding, better analysis of existing data and new experimental studies are needed to quantify the effects of changes in separate traits (e.g. physical activity, body composition) on the changes of overall energy use of the bird and their environmental consequences.

Fourth, the model used in the predictions assumes that although changes are expected to occur in the housing system in the future, these would only be driven by the genetic change of the birds, including faster growth, reduced heat production and reduced feed intake. However, the energy efficiency of the broiler housing is currently improving (Leinonen et al., 2014), so reduction in the environmental impacts arising from housing can be expected in the future, regardless of the genetic progress of the birds themselves. As in the case of the other systems changes, such as different slaughter weights and feeding strategies discussed above, the systems-based LCA modeling approach can also be used for quantifying the environmental consequences of improved housing conditions, as demonstrated by Leinonen et al. (2014)

In conclusion, the current study demonstrates the applicability of the systems-based modeling approach in predicting effects of future genetic developments in broilers on their environmental impacts. The results suggest that for the genetic scenario investigated here, such effects occur through reduced ME requirement and reduced nutrient excretion, which have a beneficial effect on the environmental performance of broiler production systems.

However, more detailed understanding on the mechanisms behind the altered bird performance in the past and in the future (including possible changes in maintenance, body composition, nutrient utilization and so on) and their consequences on feeding and husbandry would be required in order to evaluate and further develop the modeling framework presented in this study.

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TABLES

Table 1. Final body weight (BW), final age, body protein content, body lipid content, metabolizable energy requirement (MER), protein requirement, carcass yield, mortality and the number of chicks per breeder hen for the baseline and for the target scenario of genetic improvement.

	BW, kg	Final age, days	Body protein, %	Body lipid, %	MER, MJ	Protein requirement, kg	Carcass yield, %	Mortality, %	Chicks per breeder hen
Baseline	2.05	34	17.9	11.0	40.4	0.60	71.7	3.50	144.0
Target scenario	2.05	27	18.4	8.0	35.8	0.62	73.2	2.45	152.5

Table 2. Primary Energy Use (MJ) for the current baseline and for the 'full' target scenario and for scenarios where changes in individual traits are excluded. The absolute and the relative (for the total impact only) changes are shown.

	Feed + water	Electricity	Farm gas + oil	Housing	Manure + bedding	Total	Change relative to baseline
Baseline	11338	2485	5424	188	-752	18683	
Change in 'full' target scenario	-385	-267	-187	-28	36	-831	-4%
-no change in carcass yield	-156	-221	-78	-24	21	-457	-2%
- no change in mortality	-266	-257	-131	-27	27	-654	-4%
- no change in chick production	-325	-252	-168	-26	29	-742	-4%
- no change in body composition	-471	-238	-187	-28	36	-888	-5%

Table 3. Global Warming Potential (GWP 100, kg CO_2 equivalent) for the current baseline and for the full target scenario and for scenarios where changes in individual traits are excluded. The absolute and the relative (for the total impact only) changes are shown.

	Feed + water	Electricity	Farm gas + oil	Housing	Manure + bedding	Total	Change relative to baseline
Baseline	1684	145	370	440	119	2758	
Change in ’full’ target scenario	-104	-15	-13	-91	-15	-238	-9%
-no change in carcass yield	-71	-13	-5	-83	-13	-185	-7%
- no change in mortality	-87	-15	-9	-90	-12	-213	-8%
- no change in chick production	-93	-15	-11	-88	-13	-220	-8%
- no change in body composition	-87	-14	-13	-91	-12	-216	-8%

Table 4. Eutrophication Potential (kg PO_4 equivalent) for the current baseline and for the full target scenario and for scenarios where changes in individual traits are excluded. The absolute and the relative (for the total impact only) changes are shown.

	Feed + water	Electricity	Farm gas + oil	Housing	Manure + bedding	Total	Change relative to baseline
Baseline	8.85	0.00	0.03	1.25	8.67	18.81	
Change in ’full’ target scenario	-1.16	0.00	0.00	-0.12	-0.96	-2.24	-12%
-no change in carcass yield	-1.00	0.00	0.00	-0.10	-0.80	-1.90	-10%
- no change in mortality	-1.08	0.00	0.00	-0.10	-0.75	-1.93	-10%
- no change in chick production	-1.11	0.00	0.00	-0.10	-0.81	-2.03	-11%
- no change in body composition	-0.66	0.00	0.00	-0.10	-0.76	-1.53	-8%

Table 5. Acidification Potential (kg SO_2 equivalent) for the current baseline and for the full target scenario and for scenarios where changes in individual traits are excluded. The absolute and the relative (for the total impact only) changes are shown.

	Feed + water	Electricity	Farm gas + oil	Housing	Manure + bedding	Total	Change relative to baseline
Baseline	9.53	0.49	0.49	6.74	28.68	45.93	
Change in 'full' target scenario	-0.37	-0.06	-0.02	-0.66	-3.42	-4.52	-10%
-no change in carcass yield	-0.18	-0.05	-0.01	-0.53	-2.89	-3.66	-8%
- no change in mortality	-0.27	-0.06	-0.01	-0.53	-2.67	-3.54	-8%
- no change in chick production	-0.32	-0.06	-0.02	-0.52	-2.90	-3.82	-8%
- no change in body composition	-0.41	-0.05	-0.02	-0.55	-2.70	-3.73	-8%

Table 6. Abiotic Resource Use (kg Sb equivalent) for the current baseline and for the full target scenario and for scenarios where changes in individual traits are excluded. The absolute and the relative (for the total impact only) changes are shown.

	Feed + water	Electricity	Farm gas + oil	Housing	Manure + bedding	Total	Change relative to baseline
Baseline	5.73	0.94	2.78	5.36	-0.44	14.37	
Change in 'full' target scenario	-0.29	-0.09	-0.10	-0.90	+0.02	-1.35	-9%
-no change in carcass yield	-0.17	-0.08	-0.04	-0.80	+0.01	-1.08	-8%
- no change in mortality	-0.23	-0.09	-0.07	-0.89	+0.02	-1.26	-9%
- no change in chick production	-0.26	-0.09	-0.09	-0.84	+0.02	-1.25	-9%
- no change in body composition	-0.27	-0.08	-0.10	-0.90	+0.02	-1.33	-9%

Table 7. Land Occupation (ha) for the current baseline and for the full target scenario and for scenarios where changes in individual traits are excluded. The absolute and the relative (for the total impact only) changes are shown.

	Feed + water	Electricity	Farm gas + oil	Housing	Manure + bedding	Total	Change relative to baseline
Baseline	0.48	0.00	0.00	0.00	0.00	0.48	
Change in 'full' target scenario	-0.01	0.00	0.00	0.00	0.00	-0.01	-3%
-no change in carcass yield	0.00	0.00	0.00	0.00	0.00	0.00	-1%
- no change in mortality	-0.01	0.00	0.00	0.00	0.00	-0.01	-2%
- no change in chick production	-0.01	0.00	0.00	0.00	0.00	-0.01	-2%
- no change in body composition	-0.02	0.00	0.00	0.00	0.00	-0.02	-4%