Greenhouse gas emissions and other environmental impacts and related improvement options of broiler production chain

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Abstract: *In this study, a supply web integrated Life Cycle Assessment was used to assess the environmental impacts, including greenhouse gas emissions, of a certain honey-marinated and sliced broiler fillet. The environmental impact assessment was based on actual production network processes in Finland between the years 2003 and 2005. All essential production stages from parent stock and production of farming inputs to product distribution and sales in retail stores were included. The assessment consisted of primary energy consumption and also direct and indirect emissions to the air and freshwaters. The environmental impacts were assessed in the form of climate change potential, aquatic eutrophication, acidification and photochemical ozone formation.*
Considering the primary energy consumption in the production network, feed production and broiler housing accounted together 41 per cent of all primary energy consumed.
In terms of global warming potential, carbon dioxide was the most influencing gas creating 59 per cent of all the impacts of the category. Carbon dioxide (CO_2) emissions were evenly distributed throughout the production network correlating with the energy consumption. Broiler chicken production and feeding accounted for 65 per cent of the total global warming potential. This result was not only influenced by the carbon dioxide emissions from energy consumption but also by the nitrous oxide emissions (N_2O) from the fertilizer production and use as well as in nitrous oxide and methane (CH_4) that are evaporated in broiler chicken manure handling.
The environmental impacts caused by the broiler chicken production network were also illustrated with the Finnish 'Eco-Benchmark', which describes the environmental impacts related to average Finnish consumption. Crop production for broiler chicken was clearly the most influential part (41 %) in the production network when the total environmental impacts were concerned due to nitrogen and phosphorus run-off and leaching.
Although the farming related processes in the production chain had a significant impact on the environmental impacts created, the shared responsibility in the overall environmental performance of the product has to be recognised widely in the production network. There is a need for common vision and proactive actions in cooperation within the entire production network to find new solutions and to influence on the collaboration in the primary production.

Keywords: *life cycle assessment, supply web integrated LCA, poultry, broiler chicken, environmental impacts*

Introduction

European Commission has adopted a Green Paper on Integrated Product Policy (IPP) in 2001. IPP seeks to minimise environmental impacts by looking at all phases of a products' life-cycle and taking action where it is most effective. In 2002 at United Nations Johannesburg Conference the question about sustainable production and consumption was taken into the Plan of Implementation of the World Summit on Sustainable Development. In 2005 Finland launched its own national programme to promote sustainable consumption and production.

Consumption of food consists of one-third of environmental impacts of consumption (Nissinen et al. 2007). In Finland the consumption of broiler meat is increasing. In this study, Life Cycle Assessment was used to assess the GHG-emissions and other environmental impacts of a certain honey-marinated and sliced broiler fillet.

The aim of the study was both to increase the knowledge on the GHG-emissions and other environmental burdens of the production of the broiler meat, and also find out the contribution of the different production phases on the emissions and energy consumption in the system. The other target of this approach was to recognize the potential measures to improve the environmental performance of Finnish broiler chicken production, particularly for the HK Ruokatalo Kariniemi brand production chain.

Product integrated sustainability and environmental management are essential elements both to improve competitiveness of agricultural products and also reduce their GHG-emissions in the modern business world and value chain. Supply web integrated Life Cycle Assessment (LCA) was applied to the assessment of environmental impacts of agricultural products and foods of national importance in Finland.

In this study an effort was made to get the different parties involved in the supply webs to learn more about product oriented environmental management in this certain production chain and respective assessment of environmental impacts, and related benefits, i.e. learning by doing. This gives a real possibility to seek continuous improvements in the supply chains.

Materials and methods

Supply web integrated LCA-method

Life Cycle Assessment (LCA) according to ISO 14040/2006 standard is a « compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle » (ISO 14040, 2006).

Supply web integrated LCA-method is built on the ideology of industrial ecology, the technique of life cycle assessment and the organisation and business management methods of supply chain management. This combination aims at to direct the focus on the real operations and, through this, better quality and applicability of the results in for example designing improvement options. Principles and benefits of production chain - supply web - integrated LCA are more widely presented and discussed by Poikkimäki and Virtanen (2003).

Scope

The functional unit (FU) of this supply web integrated Life Cycle Assessment was 1000 kg honey-marinated and sliced broiler chicken fillet produced and packed by HK Ruokatalo and bought by consumers in retail shops.

The environmental impact assessment was based on actual production network processes in Finland between the years 2003 and 2005.

Production chain processes consisted of all essential production stages:

- rearing of young breeders and cockerels,
- production and transportation of the eggs,
- hatchery and transportation of the chicks,
- feeds production for young breeders and cockerels, breeders and broilers,
- production of fertilizers and lime,
- production of peat litter,
- farming of broilers,
- transporting broilers to the processing plant,
- slaughtering and final meat product production,
- main consumer product package and other packaging materials,
- cultivation of turnip rape,
- production of turnip rape oil and marinade and
- products delivery in Finland and storage and selling at the retail stores.

The assessment consisted of primary energy consumption, direct and indirect emissions to the air, land use, amount of landfill waste as well as by-products and their applications. In addition, direct and indirect emissions to freshwaters were assessed. The environmental impacts were assessed in the form of climate change potential, aquatic eutrophication, acidification and photochemical ozone formation.

LCA Inventory Analysis and Impact Assessment

Data for the system models were acquired from the field where it was possible. The central data on the current supply webs were based on empirical investigation of the real processes. Hence, data from industrial processes came from Finnish plants producing and processing raw materials and products needed in the systems. Also the data from Finnish field cultivation came mainly from national databases in which the data was collected directly from the farms producing fodder grain and also from the broiler farms which produce part of their fodder at their own fields.

Average Finnish grid electricity data from the year 2004 was used for electricity. Main sources of energy were fossil fuels 51 %, nuclear 42 %, wood 9 % and hydro 6 % (Statistics Finland, 2004). Local energy production, like steam and heat, was taken as it currently appeared in the systems.

Cultivation

According to the feed use records of the broiler farms one broiler chicken consumes 2,4 kg of feed during it's life time, averagely. Besides that, in preliminary phases of production chain, i.e. in parent stock rearing feed is consumed too but in smaller amounts. Broiler feed is divided between concentrated feed and farms' own feed (cereals). Concentrated feed is divided between different feed types according to the feeding phases. For both main feed types the key feed raw materials were cereals (wheat, barley and oats). In concentrated feeds also soy was included.

Cereals produced in the broiler farm (farm's own feed) and average Finnish crop farms (cereals for concentrated feed) were considered separately due to differences in farming practices including use of fertilisers and soil soluble phosphorus concentrations between these farm types. Data were acquired from the grain survey of the fodder producing company and from the farming records of the broiler farms except the data of machinery works - where main data sources were the work norms of the Work Efficiency Institute (Peltonen and Vanhala, 1992) and the Unit Emissions of Machinery Calculation System developed by the VTT Technical Research Centre of Finland.

Production and emissions data for soy production were obtained from Cederberg (1998), Cederberg and Darelius (2000), Kulay and Silva (2005) and Miller and Theis (2006).

Besides cereals also turnip rape production was considered. Data source was ProAgria Agricultural Data Processing Centre ML Ltd (unpublished database) in which cultivation data is collected directly from Finnish farmers. Turnip rape oil is the main component of the broiler meat marinade.

Emissions to air and water from agriculture

Atmospheric N_2O-emissions from the soil as well as the emissions from agricultural lime were calculated using the IPCC emission factors (IPCC, 2000). The national emission factor for ammonia emission from mineral fertilizers is 0.5 % (placement fertilization with NPK fertilizers) which was used. Ammonia emissions from manure applied on soil were assessed based on international studies.

A regression model based on field trials was used to assess nitrogen leaching from the fields (Salo. & Turtola 2006). In the model, nitrogen leaching is predicted by annual nitrogen balance, ΔN (formula 1) (Salo, 2005. Personal communication).

$$\text{N leaching (kg/ha/a)} = 5 + 0.16\Delta N \text{ (kg/ha)} \qquad (1)$$

Phosphorus leaching – including both dissolved reactive phosphorus (DRP) and particulate P (PP) - was calculated based on method of Ekholm et al. (2005). Phosphorus leaching depends strongly on soil total and soluble P concentration and on amount of erosion and, thus, is not as directly affected by fertilization level as in the case of nitrogen. For broiler farms the phosphorus emissions were somewhat higher than for crop farms due to the higher soil soluble phosphorus concentrations.

Fertilizer and lime production

The consumption of primary energy and natural resources and emissions to air and water in fertilizer production process was collected from the fertilizer producer Kemira Growhow. Most of the data were collected in 2002 but it was updated in 2005. However, the reliability of the data was heterogeneous, and that is why one representative fertilizer (nitrogen content of 20 %) ecoprofile was formed. Most of the environmental effects in fertilizer production chain were caused by production of nitrogen acid.

The consumption of primary energy and natural resources and emissions to air and water in lime production process was based on the notification of the lime producer Nordkalk. Transportation (including the usage of the primary energy and emissions to air) and also the plastic sacks used for packaging of fertilizers were included in the calculations.

Industrial feed production

Most of the feed used for broilers and breeders is processed industrially from cereals and soy. Use of electricity, heat and raw material mix and related production outputs including air emission and side-stream amounts for broiler and parent stock feed production was acquisited directly from the industrial feed production site.

The industrial oil extraction and production of the soy meal was defined based on similar production statistics from soy meal producer. In the soy meal process also soybean oil is produced and respective allocation between oil and meal was done according to the international stock prices in 2006 of products.

Rearing of broilers

Broiler production chain consist of parent stock, hatching, rearing of broilers, slaughtering and processing broiler meat. The data was collected from the real operators of this chain.

Rearing of young breeders and cockerels as well as production of eggs takes place in separate broiler houses. Feed, water and litter consumption data and output data were obtained from the data records of HK Ruokatalo. Electricity and heat consumption in young breeders and cockerels production was estimated based on consumption data in broiler houses. Data concerning egg production was completed by data from five egg producer farms, collected with a questionnaire.

In hatching the actual production process was the main data source. Material flow data (eggs, chicks and waste material) and energy consumption data were based on data records of HK Ruokatalo. This information was validated and completed during the project using the company's own follow-up data.

Broiler house process data in 2004 was acquisited mainly from the bookkeeping (which originates from bookkeeping of broiler houses) of HK Ruokatalo concerning feed, water and litter consumption in broiler houses and number of carcass during the process. These data were completed by the questionnaire sent to a group of broiler producers. Data of the consumption of electricity and fuels in broiler houses was acquired by this questionnaire. Also information about manure handling practices was collected. Answers were caught from 16 producers and the data was verified and validated together with the producers by phone and visiting the farms.

Heat consumption of broiler houses was on average 4,7 MJ/carcass weight kg according to the questionnaire data. However the data of heat consumption in broiler houses had a wide range, and it was validated by a theoretical model of a heat consumption in a broiler house for 15 000 broiler chickens.

The transportation of young breeders and cockerels, eggs, chicks and broilers was included and modeled using the real distances and the types of transport equipment used for this purpose.

Ammonia emission estimate in broiler houses

Ammonia emissions assessment was performed by two different ways: 1) using national and international studies (e.g. Arnold et al. 2006) on ammonia evaporation during broiler rearing and during manure storing, and 2) subtracting the amount of manure nitrogen of stored manure from the fresh manure nitrogen obtained from feeding nutrient balance calculations, where the data were obtained from farms (feeding, feed nitrogen content, number of broilers produced), from MTT Agrifood Research Finland (data on nitrogen content of birds) and from national manure analysis. Manure management data were achieved directly from farms and by expert interviews. According to the manure use records of broiler farms, 65% of manure is submitted to Biolan Ltd, a manufacturer of biological fertilizers, for further processing, and the rest is used as a fertilizer directly on broiler farms or on crop farms in the neighborhood.

The first mentioned way resulted ammonia emission factor 0.15 kg NH3/animal place/year for animal rearing phase. For the whole manure management chain the emission factor 0.18 was achieved. These values were used in the NH_3-emission calculations.

Slaughtering and processing plant of broilers

Material flow data (raw materials, products and by-products) of slaughtering and processing plant was collected using the follow-up data of HK Ruokatalo. This data was validated and completed by measurement data and comparing different documentations of the plant.

The amount of energy and water consumption and waste water was measured for the whole plant. We wanted to find out the energy consumption of the honey-marinated and sliced broiler chicken fillet and specified this data by splitting the plant into smaller processes. The consumption of heat and electricity was measured where ever it was possible. In some processes it was defined theoretically or, in some cases, estimated by the experts of HK Ruokatalo.

Water consumption data was based on follow-up data of the plant concerning the amount of water used in products. Washing water consumption in different processes was estimated using e. g. the documentation of cleaners' working methods. Air emissions of heat production was based on the plants own announcement.

HK Ruokatalo broiler processing plant produces both boneless products and products with the bones like chicken wings. All the allocations between the products were done using the amount of meat of the product, not the mass of the products. Using this principle the different types of products were treated equally.

The transportation of broiler chickens to the slaughtering house was included and modeled using the real distances between the broiler houses and the slaughtering house and the types of transport equipment used for this purpose.

Marinade production

Use of electricity, heat and raw material mix and related production outputs including air emission and side-stream amounts for industrial oil extraction and refining was acquisited directly from the industrial vegetable oil production site. In the turnip rape oil process also turnip rape meal is produced and respective allocation between oil and meal was done according to the international stock prices in 2006 of products.

Package production

Package production data was acquired directly from industrial package producer. Material consumption, side stream materials and heat and electricity consumption data was based on data records of the actual body. In inventory analysis concerning packaging material production, data from Plastics Europe (2006) was used.

Product logistics and retail

Consumer products were assumed to be delivered over Finland according to the current regional market shares. Emissions of product deliveries were modeled using realistic delivery routes with initial loading, retail stops, and final discharge of return load each. Logistics was modeled in collaboration with Finnish logistics company, including retail product losses. The data for retail refrigeration was drawn using nominal electricity consumption of the refrigeration device and assessed average product throughputs of the cold stores.

Impact assessment

The impact categories were climate change, aquatic eutrophication, acidification and tropospheric ozone formation. In characterization the site-dependent characterization factors were used for aquatic eutrophication and acidification (Seppälä et al 2006). For climate change the IPCC 2000 factors were used and for tropospheric ozone formation the factors described in Hauschild et al (2004) were used.

Results

Climate change and primary energy demand

According to the LCA results, broiler chicken housing and related fodder production created the majority of the GHG-emissions. Fodder production, especially crop cultivation phases, for broiler chickens accounted for 25% of the primary energy consumed in the production network, followed by the refrigeration in retail stores (20%) and broiler chicken housing (16%), respectively. In terms of global warming potential, production of fodder accounted for 36% of the total impact, and broiler housing 29%. This result was not only influenced by the emissions from energy consumption but also by the nitrous oxide emissions from the fertiliser production and use, as well as in nitrous oxide and methane that are evaporated in broiler chicken manure handling. Nevertheless, carbon dioxide was still the most influencing greenhouse gas in the climate change potential creating 59% of all the impacts of the category. Carbon dioxide emissions were evenly distributed throughout the production chain correlating with the energy consumption. The contribution of retail for climate change was 9% (Figure 1).

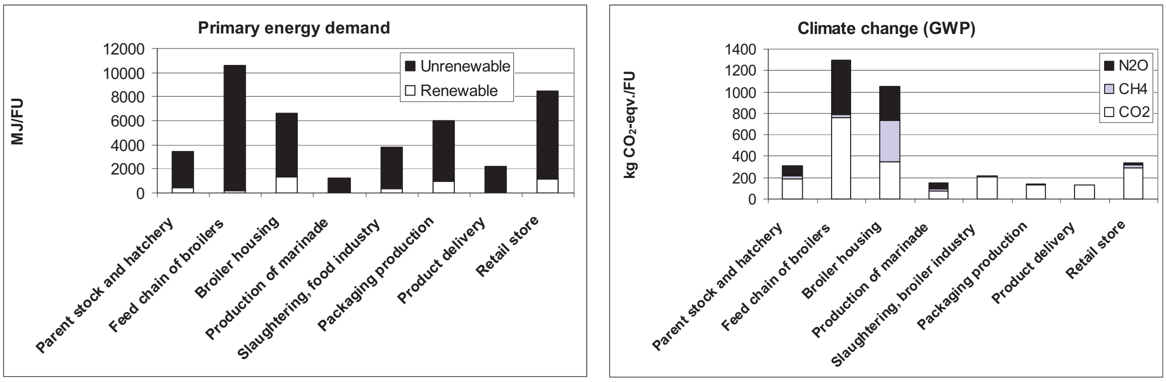
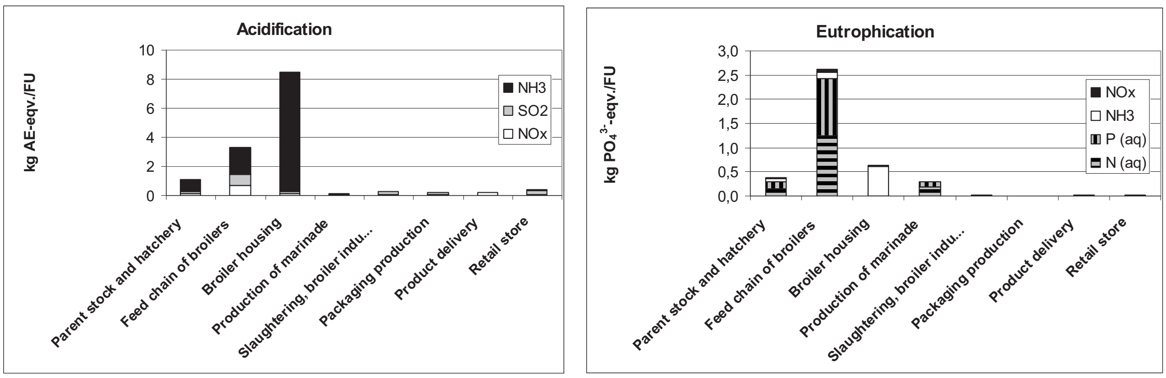


Figure 1. Primary energy demand and climate change impact by life cycle phases in the broiler chicken production network (1000 kg product as FU).

Other environmental impacts

Broiler chicken housing and corresponding fodder production accounted for over 80% of all eutrophication and acidification impacts created by the entire production network. This was especially due to the crop cultivation needed for broiler chicken fodders, which had the biggest contribution to the nutrient run-off and leaching, as well as ammonia evaporation from manure (Figure 2). However, these nutrient run-off emissions have high uncertainties in the inventory results due to their non-point character. The contribution of the parent stock and related fodder production and hatching, was in all impact categories from 8 to 9 per cent. The share of the marinade in the final product is much higher than its corresponding environmental impacts. Relatively largest contribution of the marinade (turnip rape oil) was in eutrophication, with 4% of the total impact in the category.



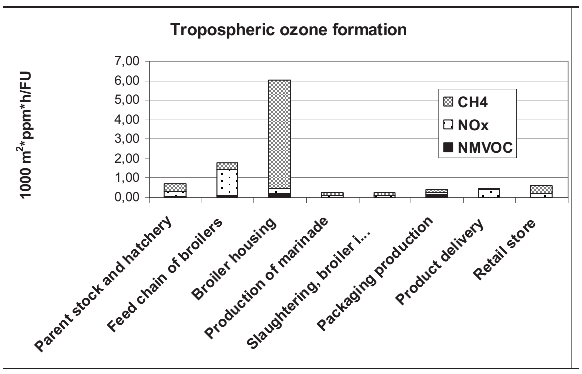


Figure 2. Acidification, eutrophication and trophospheric ozone formation impact by life cycle phases in the broiler chicken production network (1000 kg product as FU).

Results illustrated with the Finnish Eco-Benchmark

The environmental impacts caused by the broiler chicken production network were also illustrated as total environmental impacts with method Finnish Eco-Benchmark (Figure 3). Eco-Benchmark takes into account five important environmental impacts (consumption of primary energy, global warming, acidification, eutrophication and trophospheric ozone formation), which were weighted according to their importance. The scale is based on the per capita daily total environmental impacts of Finland, which are set at 100. In addition, five products are placed on the Eco-Benchmark (ruler), serving as additional benchmarks alongside the scale itself. The Eco-Benchmark is described and discussed in Nissinen et al (2006) in more detail.

The most important phases in whole production chain are production of broiler feeds and rearing of broilers. Together these phases incured 80 % of all environmental impacts. Packaging, product delivery and retail stores incured 10 % of total environmental impacts and 10 % is incured by the remaining phases.

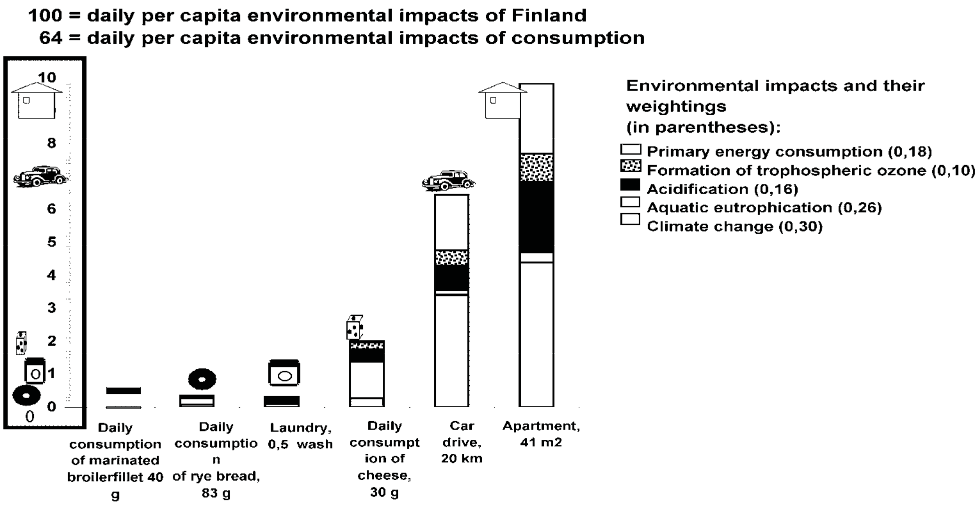


Figure 3. Sliced and marinated broiler fillet (daily consumption 40 g) is compared to Eco-Benchmark products to illustrate the magnitude of its environmental impacts.

Improvement options

To find out what kind of measures could be taken to improve the eco-efficiency of the production chain, some scenarios were defined together with the parties of the chain. Environmental impacts of these scenarios were calculated.

Farm grain and industrial fodder

Broiler producers used about 4 % grain from the farm of their own together with the industrially produced fodder, but this share was assumed to be growing. We calculated environmental impacts in five different feeding scenarios (Figure 4). In “common feed scenario” 100 % of the fodder was industrially produced and in the four other scenarios the share of the farmers grain is altering (10 %, 20 %, 30 % and 40 %, the rest is industrially produced fodder). In the last scenario 40 % of the farmers own grain is used plus this grain is not dried but stored in airproof tank.

As a result, using more grain from their own fields, the broiler producer is able to decrease the consumption of primary energy and global warming as the need for transportation and feed processing is getting smaller. Using gas-proof tank for storing cereals, and avoiding the cereal drying, it is possible to save even more energy and diminish greenhouse gas emissions.

However, the more grain from their own fields the broiler producers use, the bigger is the total eutrophication impact. The soluble phosphorous in the soil was remarkably higher in the broiler farms than in cereal producing farms due to the long-term use of broiler manure as a fertilizer. As the share of the farms own grain raised over 20 %, there was an assumption made that the theoretical field area of the farm is not enough any more and the grain is acquired from surrounding farms. In addition soy is a remarkable part of the industrial feeds and the eutrophication impact of its cultivation in Brazil is smaller than impact of cereal cultivation in Finland.

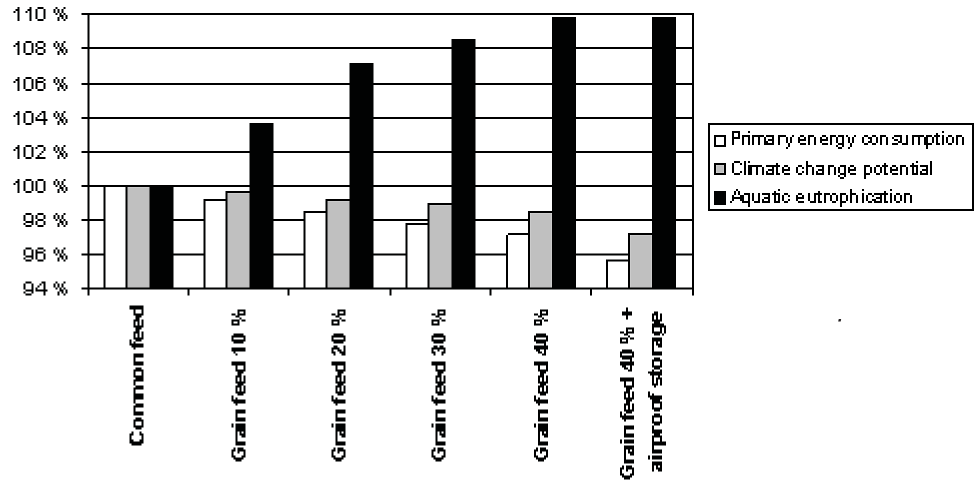


Figure 4. Change in primary energy consumption, climate change potential and aquatic eutrophication when the share of farms grain is altering and in the last scenario also airproof tank is used for un-dried grain

Heat recovery and alternative fuels in broiler houses

Broiler houses consume a lot of energy as the air conditioning has to be adequate to keep air proper for the birds in terms of air quality and temperature. At the same time broilers produce more heat as their growth goes along. There is a great potential to save energy with heat recovery but dust content of outgoing air, treatment of condense water and possible hygienic problems cause technical barriers. That is why as low as 10 % efficiency of heat recovery was used in this scenario.

As a result, more than 1/3 savings in heating energy consumption in broiler houses was achieved with this kind of heat recovery and respectively 35 % reduction in green house gas emissions (Figure 5).

Most of the broiler houses were heated by light fuel oil in 2004 but also wood chips and pellets were used. The share of these renewable energy sources was increasing and in “alternative fuel” scenario we investigated a broiler house heated 50 % by wood chips and 50 % by wood pellets. With these fuels 70 % of green house gas emissions from broiler houses could be cut and even 6 % reduction could be achieved in whole sliced and marinated broiler fillet production chain. However, this scenario would incur 7 % increase in trophospere ozone formation, due to increased air emissions in heating by wood chips and wood pellets (Figure 6).

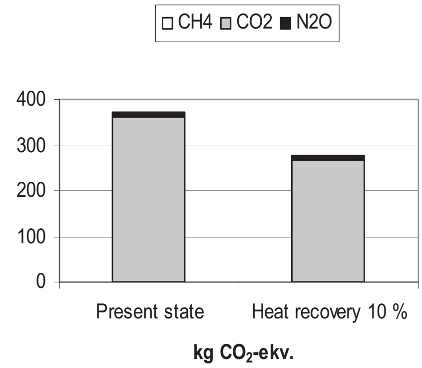


Figure 5. Change in global change potential caused by energy consumption n in broiler houses at present state and with heat recovery.

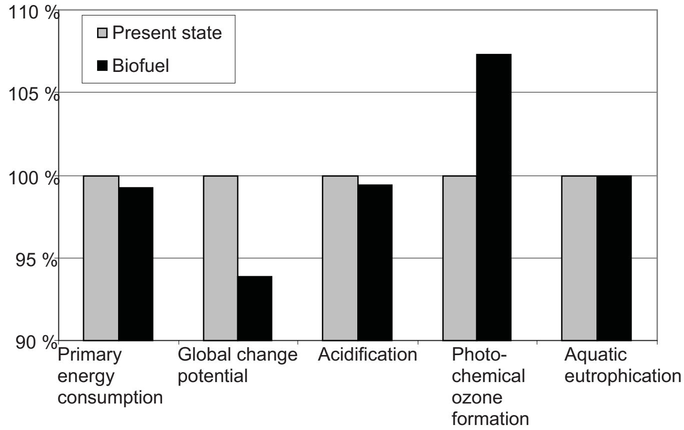


Figure 6. Change in environmental impacts in "alternative fuel" scenario carried into effect in broiler houses (broilerhouse heating 50 % by wood chips and 50 % by wood pellets). Changes in impacts are presented as relative changes (value 100 given to present state).

Discussion and conclusion

It is widely known that the control of processes and releases is much more complicated in crop cultivation than in industry, which is due to the field and climate conditions of agriculture. This is also the reason why crop production for broiler chicken was clearly the most influential part (41 %) in the production network when the total anvironmental impacts were concerned. The most significant environmental burdens from agriculture were those of nitrogen and phosphorus run-off and leaching (33 %).

Using industrially produced feeds seemed to incur less run-off and leaching as using the cereals cultivated in broiler farms. This is due to the high rates of broiler manure which is used as a fertilizer in broiler farms. One way to improve this situation is not only to spread the manure more efficiently to neighbourhood farmrs but also to investigate the possibilities to industrially treat the manure. At the same time all the means to decrease the environmental impacts in agriculture should be brought into play.

It is easier to reduce emissions in broiler houses than in fields where the emissions are from non-point sources. At best the emissions could be reduced inhibiting their formation. In this case the quality of litter is in important role. The litter has also a significant role in the health of the broilers. Ammonia emissions could also be decreased reducing them in out-going air together with dust. In our scenario study the heat recovery proved to be efficient way to decrease greenhouse gas emissions, but the problem with these equipments is their high investment costs. Decreasing the environmental impacts of the broiler houses should be reviewed as a whole, taking air-conditioning, circumstantial factors and heating into account.

Although the farming and broiler production related processes in the production chain had a significant impact on the environmental impacts created, the shared responsibility in the overall environmental performance of the product has to be recognised widely in the production network. There is a need for common vision and proactive actions in cooperation within the entire production network to find new solutions and to influence on the collaboration in the primary production.

Life cycle assessment enables the parties of production chain to study their processes and their impacts. The broiler production chain is directed in details from chicks production to product packaging and this gives a good possibility to develop the whole process. Production network integrated Life Cycle Assessment gave participants new views of cooperation and the focus of development work.

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