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LIFE CYCLE ASSESSMENT OF THE ENVIRONMENTAL IMPACT OF BROILER CHICKEN PRODUCTION

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Abstract

The environmental impacts of broiler chicken production are becoming increasingly relevant as the industry grows in importance. A suitable method for assessing the environmental impact of a process is life cycle assessment (ISO 14040:2006).

A life cycle assessment of a broiler chicken farm in Hungary was conducted in this study, which compared the emissions of summer and winter rotations. The environmental burden was represented by five impact categories: acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), ozone depletion potential (ODP) and human toxicity potential (HTP). The study's aim was to compare emissions between summer and winter rotations, as well as to identify and assess the most critical points in broiler chicken production.

The results demonstrated that there is no substantial difference in emissions between winter and summer rotations for AP, EP, and HTP, however values for GWP and ODP impact categories are 10-10% higher in winter months. The higher value is attributable to the increased use of natural gas in the winter. When the critical points were examined, the feed-related processes were the ones that contribute the most to the impact categories.

Key words: life cycle assessment, broiler chicken production, environmental impact

INTRODUCTION

According to the FAO (FAOSTAT, 2020), the world's poultry population is over 23 billion, five times from 50 years ago. Over the last 50 years, poultry meat consumption has increased by an average of 5 % per year, while pork consumption has increased by 3.1 % per year and beef consumption by 1.5 % (Alexandratos and Bruinsma, 2012). Poultry meat consumption per capita increased from 2.88 kg in 1961 to 14.13 kg in 2010, while egg production per capita went from 4.55 kg to 8.92 kg (FAOSTAT, 2020). Consumption for poultry meat is expected to increase by 121 % by 2050, while beef and pork demand would rise by 66 % and 43 %, respectively. This intensive growth is mainly due to the wide range of production systems, as poultry farming produces two main products too, meat and eggs. In addition to these, the poultry sector, such other animal husbandry sector, also produce manure and other organic material, like meat-, bone- and feather meal, or different types of compost, which are recycled back into production

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as a by-product to provide the nutrition needed for crop cultivation (Mézes et al., 2015; Gorliczay et al., 2021).

Today, the majority of poultry meat, approximately 92 %, is produced by intensive broiler chicken farming. In 2018, the United Kingdom, Germany, Poland, Spain, France, Italy and the Netherlands accounted for 62 % of broiler chicken production in the European Union. Maintaining poultry production profitability is a major problem in the sector's modernisation while balancing environmental impact reduction with ever-changing and increasing animal welfare regulations (Bracke et al., 2020).

The main environmental aspects of livestock farming are related to the fact that animals' digestion and metabolize feed and then excreted most of the nutrients in manure. The main environmental aspects of intensive livestock production are related to the natural processes of the animals, i.e. the fact that a very large part of the nutrient content of the feed consumed is excreted in the manure (Gerber et al., 2013; Cappelaere et al., 2021). The composition and quality of manure, followed by its storage and handling, determine the level of emissions from the livestock sector (Grossi et al., 2019).

Aside from the vast volumes of by-products produced, air, soil, surface water, and groundwater emissions must be considered. For identifying the most significant environmental burdens and critical points in a process a life cycle assessment is a technique is a suitable method. As the research approach the ISO14044:2006, "Environmental management. Life cycle assessment" were employed. The aim of the research was to compare and evaluate the emissions between summer and winter rotations and assess the critical points of intensive broiler chicken production. The environmental impacts of broiler breeding itself have been investigated by several authors using life-cycle interpretation methodology, but no data are available for Central and Eastern Europe and Hungary.

MATERIAL AND METHOD

Based on the guidance of Jensen et al., 1997, and ISO 14040:2006, the life cycle assessment should be structured according to the following main steps:

1. Defining the goal and scope and system boundaries;
2. Life cycle inventory analysis;
3. Life cycle impact assessment;
4. Interpretation of results (Fig. 1).

1. Defining the goal and scope and system boundaries: In the first step of life cycle assessment the inputs and outputs required for broiler chicken production were collected separately throughout the summer (April to September) and winter (October to March) rotations. The aim was to identify the environmental critical points for broiler chicken production per 1 t live weight in both summer and winter months.

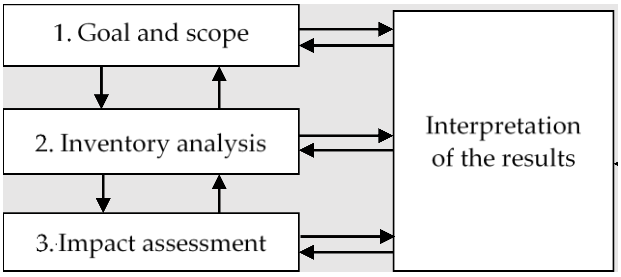

Fig. 1. Steps of life cycle assessment (Jensen et al., 1997; ISO14040:2006)

2. Life cycle inventory analysis: The data was provided by the farm, which is in operation since 2016 and the Single Environmental Permit (SEP) of the respective farm. The farm's technique is a closed-loop, deep-litter intensive housing system. One rotation comprises of a 6-week rearing time followed by a 2-week service period in which cleaning, disinfection, and preparation activities are completed before to the next introduction. This means that in a year can be achieved 6.5 cycles.

Day-old chicks, feed, drinking water, litter, energy for ventilation and feed distribution, and gas for heating are among the input flows involved in intensive broiler chicken production. The amount of water required to clean the poultry house at the end of the rotation was included. Table 1 summarizes the input and output material and energy flows involved in broiler chicken production. Using the available data, the analysis is based on an average of ten winter (October to March) and nine summer (April to September) rotations.

The amount of drinking water, electricity, and natural gas consumed differs the most between winter and summer rotations. Summer rotations used more drinking water and electricity for ventilation, whereas winter rotations used more natural gas to heat the barns. The data were then loaded into the OpenLCA life cycle analysis software, which will be covered in greater depth in the next step. The data from OpenLCA, was then converted to 1 tonne live weight so that it could be compared to literature data.

3. Life cycle impact assessment: The third step of LCA involves processing and evaluating the data collected during the inventory analysis. The impact assessment's goal is to assess and quantify the importance of the environmental consequences and pressures identified in the previous stage.

In practice, life cycle assessments are carried out using software. The OpenLCA software, was utilized, for this analysis because it provides a complete set of material and energy fluxes for all levels of analysis.

Table 1

Input and output flows during broiler chicken production in winter and summer rotations

Input flows	**Winter rotations**	**Summer rotations**
Day-old chick (pcs)	256 000	256 000
Feed (t)	872.6	1169.4
Vitamins (kg)	98.5	128.0
Water (t) (also for drinking water and cleaning)	3 841.5	8 689.4
Litter (t)	24.7	23.9
Electricity (kWh)	39 844.2	66 275.1
Natural gas (m^3)	69 665.0	16 538.8
Output flows		
Main product: chicken for slaughter (pcs)	244 473.1	243 189.7
Chicken for slaughter (t)	619.41	610.57
Manure (t)	102.1	111.5
Technological waste water (t)	102.9	104.0
Emissions to air:		
Ammonia (NH_3) (t)	3.77	3.71
Methane (CH_4) (t)	0.53	0.52
Nitrous oxide (N_2O) (t)	4.04	3.98
Nitrogen oxides (NOx) (t)	0.04	0.04

The study was carried out in the Agribalyse database, which is available for free download and contains a considerable amount of data for all of the essential analysis (Colomb et al., 2015; Koch and Salou, 2020; Asselin-Balençon et al., 2020).

There are several methods to assess the impact of a project. In the United States, for example, the TRACI method is used. In Europe, the EcoIndicator, ReCiPe, ILCD and CML methods are more widely used (Guinée, 2002; Gabathuler, 2006; Kabakian et al., 2015; Lamnatou and Chemisana, 2015). In this study, the CML IA baseline impact assessment method was used, which is internationally accepted and very widely used. The method is in line with international standardisation efforts as it includes goal setting (target and impact area), life cycle inventory (inventory analysis), impact analysis (impact assessment) and evaluation (interpretation of results) (Gabathuler, 2006). The CML IA baseline impact assessment method evaluates the processes and products under consideration based on the 11 most commonly used impact categories of life cycle interpretation (Guinée et al., 2002). In the present study, I assess the environmental impact of broiler chicken production based on 5 impact categories. These impact categories are as follows (Table 2):

Table 2

Applied impact categories

Impact categories	
Acidification potential (AP)	kg SO_2-equivalent
Eutrophication potential (EP)	kg PO_4- equivalent
Global Warming Potential (GWP)	kg CO_2- equivalent
Ozone Depletion Potential (ODP)	kg CFC-11- equivalent
Human Toxicity Potential (HTP)	kg 1,4-DB-egyenérték

The results of the life cycle assessment (Step 4) are detailed in the next chapter.

RESULTS AND DISCUSSION

The environmental impacts of producing 1 tonne live weight of broiler chickens are shown in Table 3. The values for summer and winter are presented separately for each impact category.

Table 3

Results of life cycle assessment of broiler chicken farm

Impact categories	**Summer rotations**	**Winter rotations**
AP (kg SO_2-equivalent)	15.47	15.82
EP (kg PO_4- equivalent)	11.65	11.76
GWP (kg CO_2- equivalent)	2 132	2 374
ODP (kg CFC-11- equivalent)	0.00017	0.00019
HTP (kg 1,4-DB- equivalent)	621.7	639.9

The results reveal that there was no substantial difference between summer and winter rotations' environmental burden for major effect categories, including acidification (AP), eutrophication (EP), and human toxicity potential (HTP). The difference was less than 10 % for these impact categories. The largest differences between the summer and winter rotations were observed for two impact categories, global warming potential (GWP) and ozone depletion potential (ODP). The environmental burden in the GWP and ODP impact categories is 10-10 % higher in winter rotations than in summer rotations. This difference is clearly due to higher natural gas consumption because of heating.

Figure 2 compares which processes contribute the most to environmental burdens within each impact category. Animal feeding, transportation processes, natural gas and electricity consumption, and other processes that have a minimal impact on the environment but cannot be classified into any of the major categories have been grouped into five broad groups. The feed-related operations are the most complexed, extending from the cultivation and processing of feed crops (maize, wheat, soya, rapeseed), to the acquisition and transportation of additional minerals and vitamins, to the final feed mix manufacture in the feed mixing facility. In this case, the transport processes are those other than feeding, which include transporting day-old chicks and feed to the stables. The use of natural gas and electricity in the stables is mostly for temperature control and feed distribution. And other processes are a category that includes operations like waste management or the use of cleaning and disinfection chemicals that have a minor impact on the impact category or only appear in one or two impact categories.

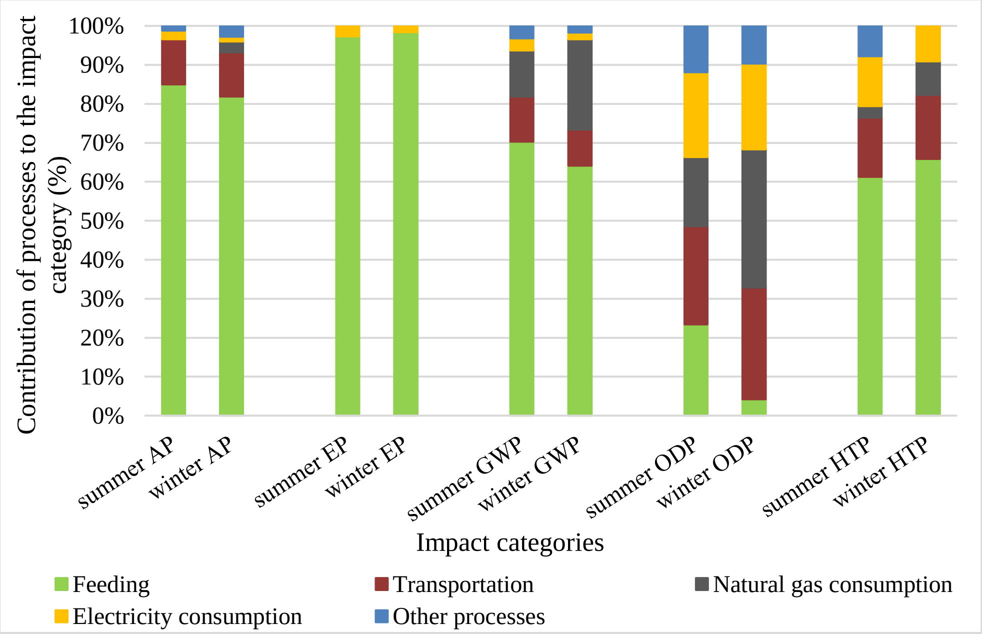

Fig. 2. Contribution of processes to the impact categories

Figure 2 demonstrates that feeding and related processes are responsible for the majority of the impact categories. The life cycle assessment of Da Silva et al., 2014, which looked at a French and a Brazilian broiler chicken farm, backs this conclusion. Another study by Bengtsson and Seddon, 2013, also found that feed production and processing are the biggest contributions to broiler chicken farming's environmental concerns. In his study, Pelletier, 2008, claims that feed production accounts for 45 to 82.4 % of greenhouse gas emissions. González-Garcia et al., 2014, discovered that processes related to feed production and emissions from on-farm activities dominated broiler chicken production.

The contribution of feed-related processes to the environmental load was greater than 80 % for both acidification (AP) and eutrophication potential (EP). Feed-related processes contributed 83 % and 81 % of the 15.47 (summer) and 15.82 (winter) kg SO_2-equivalent, respectively, and transport processes contributed roughly 12 %. The remaining 1 % is accounted for by electricity consumption and other operations in summer rotations, and in winter rotations the 7 % is accounted for by natural gas and electricity consumption and other activities. Several studies have investigated into the AP. The current findings are most similar to Pelletier, 2008, and Martinelli et al., 2020 measurements of 15.8 and 17 kg SO_2-equivalents, respectively. Kalhor et al., 2016, examined the emissions of summer and winter rotations, finding that summer emissions were 29.58 kg SO_2-equivalent and winter emissions were 41.75 kg SO_2-equivalent. The AP was estimated to be between 25.9 and 66.7 kg SO_2-equivalent by several authors (Leinonen et al., 2012; Giannenas et al., 2017; Payandeh et al., 2017; Putman et al., 2017; Lima et al., 2019; Ramedani et al., 2019). The majority of investigations have also discovered that feed-related procedures and outmoded manure management technologies are the main contributors to acidification potential.

Regardless of the summer or winter rotations, the environmental pressure is almost also exclusively represented by processes connected to feeding processes in the case of eutrophication potential (EP). While EP was 11.65 kg PO_4-equivalents in the summer and 15.82 kg PO_4-equivalents in the winter in this study, these two values were 11.02 and 14.69 kg PO_4-equivalents in a similar comparison by Kalhor et al., 2016. In a comparison of French and Brazilian colonies, da Silva et al., 2014, discovered values ranging from 13.8 to 19.3 kg PO_4 equivalents.

Feed-related processes are responsible for over 70% of the estimated global warming potential (GWP) in the summer and 63% in the winter. The remaining emissions are largely associated with natural gas consumption and transportation. The most researched impact category is GWP, which has a wide range of recorded values in CO_2-equivalents. In the current study the summer rotation produced 2132 kg CO_2-equivalent emissions and 2374 kg CO_2-equivalent in the winter rotation. By the various authors results reveal that the GWPs measured have a wide range, between 1226 and 5782 kg CO_2-equivalent (Kalhor et al., 2016; Putman et al., 2017; Payandeh et al., 2017; Lima et al., 2019; Ramedani et al., 2019; Martinelli et al., 2020).

Feeding has a minor impact on the ozone depletion potential (ODP) in the winter (about 4 %), but a considerable impact in the summer (approximately 23 %). Natural gas consumption is the most important factor in the winter, followed by emissions from transportation processes, electricity consumption, and other processes. In the summer, transportation processes contribute about the same as feed-related emissions, followed by electricity and natural gas consumption, and other processes. The ODP values determined by different authors also differ significantly. For all summer and winter rotations, Kalhor et al., 2016, recorded 0.001 kg CFC-11-equivalents, Lima et al., 2019, measured $9.6*10^{-7}$ kg CFC-11-equivalents, and Ramedani et al., 2019), reported 0.00204 kg CFC-11-equivalents.

Animal feeding contributes for around half of the human toxicity potential (HTP), with the other half coming from transportation, electricity consumption, and other processes, such as those associated with farm activities. The current study's summer results of 621.7 kg 1,4-DB-equivalent and winter results of 639.9 kg 1,4-DB-equivalent are the most similar to Kalhor et al., 2016, (655.33 and 996.36 kg 1,4-DB equivalent). Human toxicity potentials of roughly 1080 and 6300 kg 1,4-DB equivalents have been reported by several authors (Lima et al., 2019; Ramedani et al., 2019).

CONCLUSIONS

Based on the results there was no difference in emissions of more than 10 % between summer and winter rotations for most impact categories (AP, EP, HTP). However, due to higher natural gas consumption for heating, the GWP and ODP estimates for the winter rotation were 10-10 % higher.

Based on the results, feed-related processes are the major contributors to environmental consequences in most impact categories. To reduce the environmental impact of this complex feed-related process, the farmers should lessen the usage of fertilizers and pesticides, utilize more modern heavy machinery, and minimize transportation processes as much as possible.

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