*Pol. J. Environ. Stud. Vol. 26, No. 3 (2017), 1269-1277*
DOI: *10.15244/pjoes/68156*

*Original Research*

# Greenhouse Gas Emissions of One-Day-Old Chick Production

**Phairat Usubharatana, Harnpon Phungrassami***

Excellent Centre of Eco-Energy (ECEE), Department of Chemical Engineering, Faculty of Engineering, Thammasat University, Pathumthani 12120, Thailand

*Received: 7 November 2016*
*Accepted: 29 December 2016*

**Abstract**

We used life cycle assessment (LCA) methodology to assess the environmental impacts of greenhouse gas (GHG) emissions resulting from one-day-old chick production. The system boundary was set from hatching to the farm gate and involved the three main processes as parent farms, chicken feed production, and hatchery processing. The two main objectives were first to accumulate essential data for green supply chain management throughout the three processes of one-day-old chick production, and second, to identify hotspots and find a holistic solution to reduce GHG emissions within the system boundary. Eight combinations of one-day-old chick production were identified. Results determined that GHG emissions varied between 337 and 383 g $CO_2$ eq/day-old chick, depending on the combination. Chicken feed processing caused the highest impact at 45-55% as a result of the protein and energy-rich ingredients in the feed formulas. The replacement of chicken feed ingredients with dried distillers grain with solubles (DDGS), peas, cassava root, and cassava leaves was investigated. The best alternative was cassava root, which reduced GHG emissions between 5% and 6%.

**Keywords**: chicken, greenhouse gas, life cycle assessment

## Introduction

World egg production numbered 1,284 million in 2013, or 68 million tons. The four highest egg-producing countries were China, the United States, Japan, and India, with Thailand producing around 668,000 tons of eggs and 1.37 million tons of broilers as 1.43% of total global output. Thai raw chicken production increased from 154,759 million tons in 2014 to 215,045 million tons by the end of 2015, an increase of 38.9% [1], and Thai annual egg production increased to 1 million tons in 2013 [2].

From the environmental aspects, an increase in egg and chicken meat production requires higher energy, water, chemical consumption, and feed production for chicken husbandry, while more chickens at the slaughterhouses increase solid waste, wastewater,r and gas emissions. Livestock product including chicken meat is consumable and apart from the social pressure pertaining to the surroundings, production affects climate change [3] as food chains have a large negative impact on the environment [4]. Animal husbandry production causes a high amount of greenhouse gas (GHG) emissions [5]. The livestock sector is responsible for 8-18% of global GHG emissions [5-6]. Hence, to reduce this impact and establish sustainable development, an integrated study on the environmental impacts caused throughout the

*e-mail: pharnpon@engr.tu.ac.th

complete chain of the chicken industry was assessed, and workable solutions and strategies were suggested.

Life cycle assessment (LCA) can be used as an assessment methodology to improve management structures and quality monitoring in the food chain. LCA is an essential tool that helps a product development process to achieve the goal of sustainable development [7-8]. LCA is also an effective and widely accepted tool for assessing the environmental impact of a food industry supply chain [9] in compliance with the International Organization for Standardization as ISO14040 [10]. Leinonen et al. opined that LCA was more holistic than the many other methods used to quantify the environmental impacts of a product [11]. Researchers have studied the LCA or carbon footprint of the chicken industry covering egg production in the United States [12], the United Kingdom [11], and the Netherlands [13]. Many also have studied broiler chicken production and analyzed results after slaughterhouse processing in Portugal [14], France [15], the United States [16], and Brazil [17]. However, few studies have focused on the details of chicken feed production in Thailand [18] and Brazil [19]. No in-depth research has examined one-day-old chick production. Thus, this paper concentrates specifically on one-day-old chick production.

Thai broiler husbandry can be classified into four categories:

1. Independent raiser: The farmers or raisers use their own farms and purchase their own chicks without binding conditions or commitments to any chick-producing companies or distributors. Chicken feed and medicines can be procured from any preferential vendors.
2. Contract raiser: The farmers are hired to raise broilers to supply a specific company or dealer. A chicken feed company or dealer invests money in the chicks, feed, and medicine, and provides their cooperative farmers with financial and technical support as well as guidance in farming strategies. When the chickens are mature, the company markets them or sends them to a slaughterhouse. The farmer's income depends on the number or surviving chickens, the amount of feed used, and the weights of the birds.
3. Contract farming: The farmer signs a bilateral contract to buy chicks, feed, and medicine from a particular company which in turn buys the mature chickens back at a mutually agreed price.
4. Corporate farming: The company has complete ownership and operates integrated broiler farming from production to breeding, slaughter, and meat processing.

One-day-old chicks can therefore be raised in a variety of ways. Thus, one-day-old chick production was studied in detail for broilers to provide information concerning efficient green supply chain management of the chicken industry.

The objectives were to identify hotspots of environmental impact of one-day-old chick production and accumulate essential data to establish effective green supply chain management throughout the entire chicken meat production process. For easy understanding, the results were related to global warming potential (GWP) and presented per one-day-old chick before transport to a broiler farm.

## Material and Methods

LCA is a tool used to evaluate the environmental impact of a product considering all the integrated processes of raw material acquisition, manufacturing, distribution, use, and disposal. Following ISO14040 [10], LCA consists of four main parts: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and life cycle interpretation of results. Goal and scope definition, a primary process of LCA, exhibits the objectives, system boundary, and functional unit setting. The second phase, LCI, covers the input and output of inventories within the system boundary such as the amount of raw material and energy used and consequent waste products. LCIA converts these inventories into simpler indicators through problem- and damage-orientation. The problem-oriented method focuses on impact categories, including global warming, ozone depletion, acidification, eutrophication, resource depletion, and toxicity, while the damage-oriented method emphasizes the negative impacts on humans and the ecosystem. Finally, impact assessment analyzes the outcomes and whether they meet the LCA objectives.

### Goal and Scope Definitions

The objectives were (1) to prepare efficient information for green supply chain establishment throughout the entire chicken industry supply chain by initiating a carbon management programme using LCA and (2) to identify hotspots from system observation and suggest ways to streamline the existing system to decrease negative impacts on the receiving environment. LCA methodology requires the specification of a functional reference unit defined as the quantified performance of the production system [20]. Typical functional units used in the chicken industry are 1,000 kg of eggs [11], 1.2 kg of broiler chicken meat [14], or one ton of whole chickens packed and ready for transport to supermarkets [15]. Here, however, the functional unit for the hatchery farm in this study was set as a one-day-old chick at the farm gate ready for transport to broiler farms. One-day-old chicks weigh between 30 and 53 g. The reason for choosing this quantified functional unit was because farmers count their chicks to determine yield records.

The Thai broiler industry is dominated by 12 big corporations that account for more than 90% of the country's total capacity. They control the manufacturing process on an integrated basis, generally called upstream to downstream. Upstream refers to the chick-producing industry and the midstream covers the broiler industry and slaughterhouses. The downstream sector is chicken meat processing. Only the upstream was considered here,

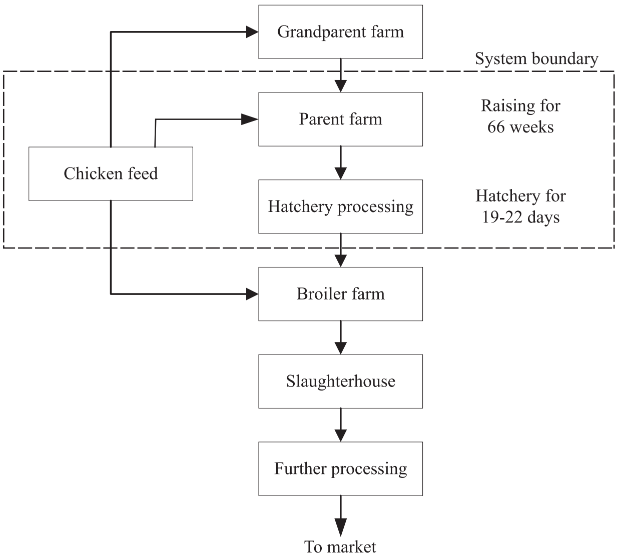


Fig. 1. System boundary.

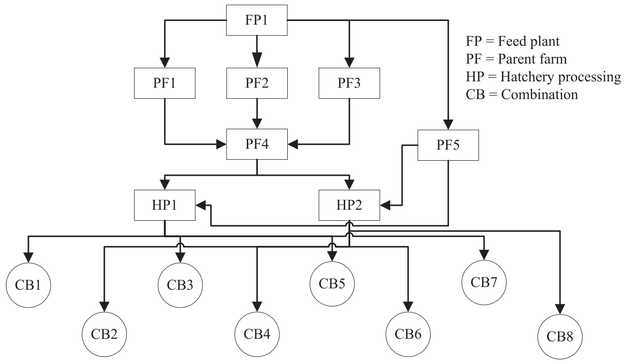


Fig. 2. The relationships between production units and the feasible pattern of GHG emissions.

starting from rearing broiler breeders and incubation to producing one-day-old chicks (Fig. 1).

To rear broiler breeders to maturity, feeding is a mandatory step and primary data was gathered from a chicken feed manufacturing plant. Feed formulas for breeders are different from broilers. During the laying period, one female breeder lays about 160 eggs, which are then transported to the hatchery. Pre-incubation services such as pasteurization and pre-hearing are prepared prior to the hatchery stage, which is controlled under fixed temperature, humidity, and air circulation. The system boundary ends when the chick has hatched out, turned one-day-old, and is ready for transport to a broiler farm.

## Life Cycle Inventory

LCI is the accumulation of input and output related to selected impact categories aligned with the set system boundary. Inventory data for the parent farm to the hatchery processing gate were obtained as both primary and secondary sources. For primary data we selected eight companies: five from parent farms, one from feed production, and two from hatchery processing. Examples of primary data are electricity consumption, water consumption, or chemicals used within the system boundary. Secondary data including chemical production, fertiliser production, electricity, and fuel production were collected from the Thailand National Life Cycle Inventories Database [21] and the life cycle assessment database in the Ecoinvent [22]. The three areas of data accumulation included the parent farms, hatchery processing, and feed production. Fig. 2 presents an overview of the relationships between these production units.

Broiler breeder rearing technically begins with the importation of great-grandparents from abroad to hatch out the next generation of breeders. Importation and rearing of the great-grandparent generation were not included here due to lack of data. The research boundary started when the breeders were fed and raised until they were capable of reproducing and laying eggs that would eventually grow to broilers. Primary data collected in 2011 were obtained from one feed plant, five parent farms, and two hatchery units.

Primary data for feed manufacture were collected throughout 2011 from a feed-producing plant (FP1). The plant produced feeds suitable for both breeders and broilers; however, this was outside the study scope so mass allocation was requisite. Allocation is defined as partitioning the input or output flow of a process or a product system between the product system under study [10]. The broiler breeder feed formulas had different compositions; however, the main ingredients were commonly protein-rich (soybean, baked beans), energy-rich (corn, millet, rice bran, cassava), vitamins (monocalcium phosphate), and other additives. Each formula composition was averaged, and feed raw material transport to the feed plant was also included in the calculation. However, direct land use change from ingredient cultivations was excluded due to lack of available data.

Parent farm Nos. 1, 2, and 3 (PF1, PF2, and PF3) were the primary farm nursing breeders from their early days until 22 weeks, when they were moved to parent farm No. 4 (PF4) until they reached 66 weeks. Parent farm No. 5 (PF5) raised the breeder chicks until they were able to lay eggs, without any relocation. For the parent farm process, all bedding materials, vaccinations, electricity, fuels, chemicals required for proper hygiene, and chicken feed in various formulas and on sequential wastes such as chicken remains to be disposed and wastewater to be treated were prepared for the chicken house. For manure management, $CH_4$ and $N_2O$ values were assessed following the method of Prudencio da Silva et al. [17]. The direct input to and output from the system boundary are shown in Table 1. Vaccination was not taken into account due to the lack of characterization factor information following Gonzalez-Garcia et al. [14]. To fill the data gap, the amount of solid waste at FP1 was assumed to be 0.26 kg per 100 kg of feed [14]. Transportation between parent farms was included in the study.

Eggs from PF4 and PF5 were transported to the hatchery for processing. Inputs such as cardboard paper, electricity, diesel for transportation, and water, and such outputs as chicken shell, wastewater, cardboard, and paper waste were accounted for in the inventory. Primary data were gathered from field surveys and questionnaires provided by the two hatchery processing units (HP1 and HP2). Based on one year of compiled data in 2011, the eggs weighed between 60 and 65 g. All items in the hatchery farms were prepared and strictly controlled. The temperature was conditioned at 37.0-37.7ºC with 60-70% humidity, and egg turning was set at six times a day. After 19-22 days in the hatchery the chicks hatched out. Observations continued for up to one day after birth.

For presentation, the potential ways of GHG emissions of a one-day-old chick were divided into eight patterns (Fig. 2):

- *Combination 1 (CB1)* started from chicken feed acquisition from FP1 to feed breeder chicks in PF1. After turning 22 weeks old, the chicks were relocated to PF4 until they laid eggs, which were then taken to HP1 for processing.
- *Combination 2 (CB2)* started from chicken feed acquisition from FP1 to feed breeder chicks in PF1. After turning 22 weeks old, the chicks were relocated to PF4 until they laid eggs, which were then taken to HP2 for processing.
- *Combination 3 (CB3)* started from chicken feed acquisition from FP1 to feed breeder chicks in PF2. After turning 22 weeks old, the chicks were relocated to PF4 until they laid eggs, which were then taken to HP1 for processing.
- *Combination 4 (CB4)* started from chicken feed acquisition from FP1 to feed breeder chicks in PF2. After turning 22 weeks old, the chicks were relocated to PF4 until they laid eggs, which were then to HP2 for processing.
- *Combination 5 (CB5)* started from chicken feed acquisition from FP1 to feed breeder chicks in PF3. After turning 22 weeks old, the chicks were relocated to PF4 until they laid eggs, which were then taken to HP1 for processing.
- *Combination 6 (CB6)* started from chicken feed acquisition from FP1 to feed breeder chicks in PF3. After turning 22 weeks old, the chicks were relocated

Table 1. Direct input to and output from the product system boundary.

| Input | Unit | FP1* | PF1** | PF2** | PF3** | PF4*** | PF5*** | HP1** | HP2** |
|---|---|---|---|---|---|---|---|---|---|
| Protein-rich ingredient | kg | 20.40 | | | | | | | |
| Energy-rich ingredient | kg | 74.20 | | | | | | | |
| Monocalcium phosphate | kg | 1.52 | | | | | | | |
| Calcium carbonate | kg | 2.25 | | | | | | | |
| Sodium chloride | kg | 0.40 | | | | | | | |
| Vitamins | kg | 1.23 | | | | | | | |
| Energy | MJ | 0.19 | 2,145.28 | 1,234.53 | 2,195.03 | 2.56 | 38.16 | 28.52 | 54.20 |
| Water | $m^3$ | 0.00 | 52.35 | 68.48 | 50.08 | 4.28 | 3.60 | 0.11 | 0.08 |
| Electricity | kWh | 0.19 | 2,724.22 | 3,423.40 | 2,562.17 | 87.13 | 104.70 | 77.99 | 35.84 |
| Chlorine | kg | | 59.75 | 19.14 | 49.11 | 0.78 | 0.37 | 0.08 | 0.12 |
| Feed | kg | | 9,027.08 | 11,928.38 | 9,210.71 | 287.18 | 334.41 | | |
| Bedding material | kg | | 1,481.55 | 1,869.37 | 1,425.85 | 7.03 | 33.35 | | |
| Output | | | | | | | | | |
| Wastewater | $m^3$ | 0.00 | 14.72 | 9.53 | 12.45 | 1.25 | 2.06 | 0.10 | 0.07 |
| Solid waste | kg | 0.26 | 9,694.89 | 10,821.88 | 8,985.84 | 46.89 | 192.14 | 6.31 | 1.65 |
| Dead chicken | kg | | 110.35 | 85.46 | 63.74 | 4.03 | 4.19 | | |
| Egg shell | kg | | | | | | | 3.27 | 3.59 |
| $CO_2$ eq (fuel combustion) | kg | 2.65 | 224.83 | 135.27 | 235.75 | 0.29 | 3.20 | 2.12 | 4.03 |
| $CH_4$ (manure) | kg | | 5.83 | 6.51 | 5.67 | 0.08 | 0.11 | | |
| $N_2O$ (manure) | kg | | 0.11 | 0.12 | 0.10 | 0.00 | 0.00 | | |

FP1= Feed plant, PF1 = Parent farm 1, PF2 = Parent farm 2, PF3 = Parent farm 3, PF4 = Parent farm 4, HP1 = Hatchery unit 1, HP2 = Hatchery unit 2 * per 100 kg; ** per 1,000 chicks; ***per 1,000 eggs to PF4 until they laid eggs, which were then taken to HP2 for processing.

- *Combination 7 (CB7)* started from chicken feed acquisition from FP1 to feed breeder chicks in PF5. After being laid, the eggs were taken to HP1 for processing.
- *Combination 8 (CB8)* started from chicken feed acquisition from FP1 to feed breeder chicks in PF5. After being laid, the eggs were taken to HP2 for processing.

## Life Cycle Impact Assessment

Environmental impacts can be assessed in various categories. Many authors have investigated environmental impacts caused by the chicken industry [12, 14-15, 17, 23-25]. The most common category studied by all these researchers was global warming potential (GWP). However, this study focused only on GWP using IPCC methodology [26]. The selected impact category was calculated in terms of $CO_2$ eq for GWP over 100 years using the problem-oriented approach.

## Results and Discussion

### GHG Emissions Results

Electricity and fuel input per 100 kg of feed production were 0.19 kWh and 0.19 MJ, respectively, or 0.88 MJ in total (Table 1). The main ingredients were energy and protein-rich at a ratio of 74:20. Energy-rich ingredients were mainly corn, rice and rice bran, and protein-rich ingredients such as soybean meal and beans. Tongpool et al. determined that the ratio of energy to protein-rich ingredients was 70:26.6 for broiler feed production only [18]. Information from the parent farms indicated that a female breeder laid between 154 and 161 eggs.

Table 2. GHG emissions (in bold) and contribution (in italics) of one-day-old chicks in the system boundary.

| | CB1 | CB2 | CB3 | CB4 | CB5 | CB6 | CB7 | CB8 |
|---|---|---|---|---|---|---|---|---|
| Production of chicken feed | 194 (55%) | 186 (49%) | 184 (54%) | 176 (48%) | 183 (54%) | 176 (48%) | 174 (51%) | 167 (45%) |
| Protein-rich crop | 21% | 21% | 21% | 21% | 21% | 21% | 21% | 21% |
| Energy-rich crop | 64% | 64% | 64% | 64% | 64% | 64% | 64% | 64% |
| Chemicals and vitamins | 12% | 12% | 12% | 12% | 12% | 12% | 12% | 12% |
| Electricity | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Energy | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% |
| Transportation | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% |
| Others | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Parent farms | 116 (33%) | 112 (29%) | 109 (32%) | 105 (29%) | 110 (33%) | 106 (29%) | 123 (36%) | 119 (32%) |
| Electricity | 75% | 75% | 76% | 76% | 75% | 75% | 66% | 66% |
| Energy | 2% | 2% | 3% | 3% | 2% | 2% | 4% | 4% |
| Bedding material | 11% | 11% | 10% | 10% | 10% | 10% | 17% | 17% |
| Emission from manure | 4% | 4% | 4% | 4% | 4% | 4% | 4% | 4% |
| Dead chickens | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Transportation | 3% | 3% | 1% | 2% | 2% | 2% | 3% | 3% |
| Others | 5% | 5% | 6% | 6% | 6% | 6% | 6% | 6% |
| Hatchery processing | 44 (12%) | 85 (22%) | 44 (13%) | 85 (23%) | 44 (13%) | 85 (23%) | 44 (13%) | 85 (23%) |
| Energy | 10% | 3% | 10% | 3% | 10% | 3% | 10% | 3% |
| Electricity | 49% | 56% | 49% | 56% | 49% | 56% | 49% | 56% |
| Cardboard | 4% | 8% | 4% | 8% | 4% | 8% | 4% | 8% |
| Solid waste, including egg shell | 31% | 32% | 31% | 32% | 31% | 32% | 31% | 32% |
| Transportation | 5% | 1% | 5% | 1% | 5% | 1% | 5% | 1% |
| Others | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Total | 354 | 383 | 337 | 366 | 337 | 367 | 341 | 371 |

CB = Combination

Thus, 334-373 kg of feed was required to produce 1,000 eggs. The electricity consumption varied from 2,562-3,423 kWh/1,000 chicks at the parent farms, indicating the range of efficiency management across properties. Electricity consumption at the hatchery units varied between 36-78 kWh to hatch 1,000 chicks, also reflecting different farm management techniques. Pelletier et al. noted that each farm was implicitly different, probably as a result of the quality of data recording and reporting [12].

Results for GHG emissions within the boundary are presented in Table 2. The percentage contribution is separated by each process of feed production as crop production, chemical processing, and transportation to the feed plant, parent farms, and hatchery units. Feed production resulted in the highest GHG emissions for every combination at 167-194 g $CO_2$ eq/day-old chick, or 45-55% of total GHG emissions. These results concurred with previous research. Despite using a different system boundary, Leinonen et al. [11], Prudencio da Silva et al. [17], and Thevenot et al. [15] concluded that feed production caused the major environmental impact. Energy-rich ingredients were the highest contributors to GHG emissions at 64% of the total feed production, with protein-rich ingredients responsible for 21%. However, the feed production process only slightly impacted GHG emissions.

Parent farms were the second largest source of GHG emissions for the whole life cycle within the system boundary, ranging between 105-123 g $CO_2$ eq/day-old chick or 29-36% of the total, primarily from electricity (66-76%) and bedding material (10-17%). Emissions from manure accounted for only 4% of the total.

Hatchery processing caused the lowest GHG emissions at 12-23%, mostly from electricity consumption and solid waste management at 49-56% and 31-32%, respectively. Transportation generated low GHG emissions.

Overall, the combination of CB3 and CB5 gave the lowest GHG emissions, equivalent to 337 g $CO_2$ eq/day-old chick, whereas CB2 was highest at 383 g $CO_2$ eq/day-old chick, caused by GHG emissions from HP2. The difference between CB3 and CB5 was attributed to the different sources of the 22-week-old breeder chicks from PF2 and PF3, respectively. Comparing PF2 with PF3 from gate to gate gave similar GHG emissions for raising one 22-week-old parent chick at 2.93 and 3.07 kg $CO_2$ eq, respectively. HP1 and HP2 released 44 and 85 g $CO_2$ eq/day-old chicks, respectively, from gate to gate to hatch a one-day-old chick. This was because HP2 used double the electricity consumption of HP1 and also four times more cardboard, which required subsequent disposal. This result compared favorably with other studies using similar system boundaries. Nielsen et al. used estimations based on consequential LCA and reported GHG emissions at 0.52 kg $CO_2$ eq/chick from the hatchery [27]. The emissions factors of soybean meal and corn were specified as 0.450 kg $CO_2$ eq/kg soybean mean and 0.308 kg $CO_2$ eq/kg corn as derived from the Thailand National Life

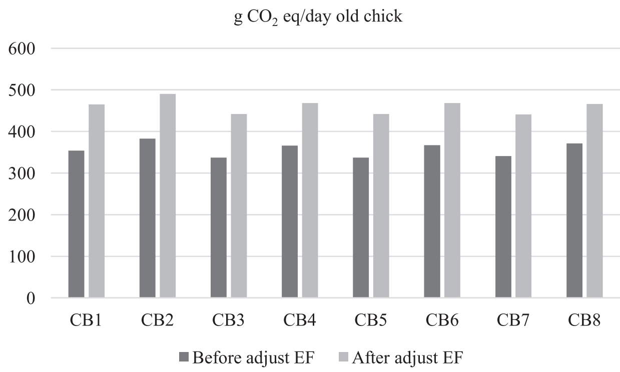


Fig. 3. GHG emissions per one-day-old chicks before and after adjusting the emission factors of soybean meal and corn.

Cycle Inventories Database (MTEC) [21]. Nielsen et al. [27] used 0.738 kg $CO_2$ eq/kg soybean meal and indicated the emission factor from corn at 0.659 kg $CO_2$ eq/kg corn, which was nearly double the MTEC figure. When the emission factors were adjusted to be the same as Nielsen et al. [27], then the GHG emissions changed (Fig. 3). GHG emissions of feed production after adjustment ranged from 441 to 490 g $CO_2$ eq/day-old chick, giving a 26-31% variation and implying that the values of emission factors influenced GHG emissions of chicks.

## Opportunities Identified for Reducing the Environmental Impacts of One-Day-Old Chicks

The largest contribution to environmental impact caused by a one-day-old chick was feed production. Therefore, developing and streamlining the processes and each of the contributions within the system boundary focused mainly on feed production. Corn, soybean meal, and bran extract were the three main sources of environmental impact caused by feed production equivalent to 80% of GHG emissions (Table 3). Corn, soybean meal, and bran

Table 3. Contributions of feed ingredients to GHG emissions.

| Ingredients | Contribution |
|---|---|
| Soybean | 19.15% |
| Baked beans | 2.82% |
| Corn | 41.88% |
| Millet | 0.39% |
| Rice bran | 4.40% |
| Cassava waste | 0.23% |
| Bran extract | 19.03% |
| Monocalcium phosphate | 0.00% |
| Calcium carbonate | 0.01% |
| Sodium chloride | 0.00% |
| Vitamins | 0.00% |

Table 4. GHG emissions for each scenario compared to the base case.

| | CB1 | CB2 | CB3 | CB4 | CB5 | CB6 | CB7 | CB8 |
|---|---|---|---|---|---|---|---|---|
| Base case | 354 | 383 | 337 | 366 | 337 | 367 | 341 | 371 |
| Scenario 1 | 336 (-5%) | 365 (-4%) | 319 (-5%) | 349 (-4%) | 320 (-5%) | 350 (-5%) | 325 (-4%) | 355 (-4%) |
| Scenario 2 | 360 (+7%) | 388 (+6%) | 342 (+7%) | 371 (+6%) | 343 (+7%) | 372 (+6%) | 346 (+6%) | 375 (+6%) |
| Scenario 3 | 347 (-4%) | 376 (-3%) | 330 (-3%) | 360 (-3%) | 331 (-3%) | 360 (-3%) | 335 (-3%) | 365 (-3%) |
| Scenario 4 | 326 (-6%) | 356 (-5%) | 310 (-6%) | 340 (-6%) | 311 (-6%) | 341 (-5%) | 316 (-6%) | 346 (-5%) |

CB = Combination

extract ingredients contributed to GHG emissions in feed production at 42, 19, and 19%, respectively. Therefore, the main focus areas to reduce GHG emissions were corn, soybean meal, and bran extract ingredients.

One protein-rich ingredient in the feed was soybean quantified 16.6% by mass. Baumgartner et al. suggested that grain legumes such as peas and fava beans could be used as a protein source in animal feed instead of soybean to mitigate environmental impacts, as no fertilizers were required in grain legume cultivation [28]. Castell et al. opined that acceptable levels in broiler diets could use up to 200 g/kg [29]. Thus, the first scenario involved totally replacing soybeans with peas. Another interesting protein-rich ingredient as a byproduct of bioethanol production from grains was dried distillers grain with solubles (DDGS) [30-31]. DDGS can be used in broiler diets to replace soybean by up to 15% with no negative effect on growth performance and meat quality [32]. Therefore, the second scenario involved partial replacement of soybean with DDGS at 15%. Cassava leaf contains various essential amino acids in proportions close to soybean meal [33]. Cassava leaf meal can therefore be used at up to 20% as a replacement for soybean meal for both broiler starter and finisher diets, without any deleterious effect on growth and carcass yield [34]. Hence, the third scenario replaced soybean with cassava leaf at 20%.

The main energy-rich ingredient in breeder diets is corn, at 53% by mass. Several researchers have investigated alternative crops to replace corn. Kyawt et al. discovered that up to 40% corn could be substituted by cassava meal to improve laying performance and egg quality [35]. Replacing corn by up to 50% cassava root did not significantly affect the hen-day egg production [36]. Accordingly, the fourth scenario replaced corn with up to 40% cassava root.

Corn and soybean were replaced following each scenario. Results indicated that replacing soybean with DDGS (scenario 2), although comparable in nutritional quality, increased GHG emissions by 6-7% (Table 4) as the addition of DDGS, a co-product from ethanol production, caused high GHG emissions according to the Ecoinvent database [22]. Replacing soybean with peas (scenario 1) reduced GHG by 4-5%, since pea cultivation caused lower GHG emissions [37]. Scenarios 3 and 4 involved soybean meal replacement with cassava root and cassava leaf. Cassava cultivation had a lower influence on GHG emissions than both corn and soybean, thus the total GHG emissions in one-day-old chick production decreased by 3-6% against the base case. Therefore, replacing corn with cassava root was the optimal choice for reducing GHG emissions.

Another influential factor that may hinder these replacement alternatives is price. The poultry industry requires vast quantities of feed to operate and even a small variance in price can result in a huge difference in costs. Spring [31] stated that feed accounted for 50-70% of the total cost of animal production. This study, however, did not consider economic feasibility.

## Conclusions

The GHG emissions of one-day-old chick production were investigated, setting a system boundary as feed production, parent farms, and hatchery processing. The research was conducted on an attributional LCA basis and GHG emissions ranged between 337-383 g $CO_2$ eq/day-old chick. Feed production accounted for the largest contribution at 45-55%. Parent farms were next at 29-36%, and hatchery processing was lowest at 13-23%. In the feed production process, the most prominent causes of high GHG emissions were protein and energy-rich ingredients contributing over 85% of the total (during feed production only). The major factor in parent farms and hatcheries was electricity consumption. The feasibility for reducing GHG emissions was addressed, paying most attention to feed production. Cassava leaves and peas were considered good replacements for soybean, reducing GHG emissions by 3-5%, and replacing corn with cassava root lessened emissions by 5-6%. However, replacing soybean with DDGS increased GHG emissions by 6-7%.

## References

1. Thai Broiler Processing Exporters Association, Thai chicken meat export statistic 2015, Available online: http://www.thaipoultry.org/STATISTIC/tabid/248/Default.aspx., (accessed on 15/06/2016), **2015**.
2. FAOSTAT, Food and agriculture organization of the United Nations, Statistic Division, Available online: http://faostat.fao.org., (accessed on 14/02/2016), **2016**.

3. FRIEL S., DANGOUR A.D., GARNETT T., LOCK K., CHALABI Z., ROBERTS I., BUTLER A., BUTLER C.D., WAAGE J., MCMICHAEL A.J., HAINES A. Public health benefits of strategies to reduce greenhouse-gas emission: food and agriculture. Lancet. **374** (9706), 2022, **2009**.
4. VAN DER GOOT A.J., PELGROM P.J.M., BERGHOUT J.A.M., GEERTS M.E.J., JANKOWIAK L., HARDT N.A., KEIJER J., SCHUTYSER M.A.I., NIKIFORIDIS C.V., BOOM R.M. Concepts for further sustainable production of foods. J Food Eng. **168**, 43, **2016**.
5. GURLUK S., UZEL G., TURAN O. Impacts of cattle and sheep husbandry on global greenhouse gas emissions: a time series analysis for central European countries. Pol J Environ Stud. **24** (1), 94, **2015**.
6. STEINFELD H., GERBER P., WASSENAAR T., CASTEL V., ROSALES M., DE HANN C. Livestock's long shadow: environmental issues and options, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. **2006**.
7. VESHAGH A., OBAGUN A. Survey of sustainable life cycle design and management, Proc. the 14th CIIRP Conference on Life Cycle Engineering 'Advances in Life Cycle Engineering for Sustainable Manufacturing Business', Springer, London, 237, **2007**.
8. INGRAO C., GIUDICE A.L., BACENETTI J., KHANEGHAH A.M., SANT'S ANA A.S., RANA R., SIRACUSA V. Foamy polystyrene trays for fresh-meat packaging: life-cycle inventory data collection and environmental impact assessment. Food Res Int. **76**, 418, **2015**.
9. ROY P., NEI D., ORIKASA T., XU Q., OKADOME H., NAKAMURA N., SHIINA T. A review of life cycle assessment (LCA) on some food products. J Food Eng. **90** (1), 3, **2009**.
10. ISO14040, Environmental management-Life cycle assessment-Principles and framework (ISO14040: 2006), European Standard EN ISO 14040, The International Organization for Standardization, Geneva, Switzerland, **2006**.
11. LEINONEN I., WILLIAMS A.G., WISEMAN J., GUY J., KYRIAZAKIS I. Predicting the environmental impacts of chicken systems in the United Kingdom through a life cycle assessment: egg production systems. Poultry Sci. **91** (1), 26, **2012**.
12. PELLETIER N., IBARBURU M., XIN H. A carbon footprint analysis of egg production and processing supply chains in the Midwestern United States. J Clean Prod. **54**, 108, **2013**.
13. MOLLENHORST H., BERENTSEN P.B., DE BOER I.J. On-farm quantification of sustainability indicators: an application to egg production systems. Brit Poultry Sci. **47** (4), 405, **2006**.
14. GONZALEZ-GARCIA S., GOMEZ-FERNANDEZ Z., DIAS A.C., FEIJOO G., MOREIRA M.T., ARROJA L. Life cycle assessment of broiler chicken production: a Portuguese case study. J Clean Prod. **74**, 125, **2014**.
15. THEVENOT A., AUBIN J., TILLARD E., VAYSSIERES J. Accounting for farm diversity in life cycle assessment studies-the case of poultry production in a tropical island. J Clean Prod. **57**, 280, **2013**.
16. PELLETIER N. Environmental performance in the US broiler poultry sector: life cycle energy use and greenhouse gas, ozone depleting, acidifying and eutrophying emissions. Agr Syst. **98** (2), 67, **2008**.
17. PRUDENCIO DA SILVA V., VAN DER WERF H.M.G., SOARES S.R., CORSON M.S. Environmental impacts of French and Brazilian broiler chicken production scenarios: An LCA approach. J Environ Manage. **133**, 222, **2014**.
18. TONGPOOL R., PHANICHAVALIT N., YUVANIYAMA C., MUNGCHAROEN T. Improvement of the environmental performance of broiler feeds: a study via life cycle assessment. J Clean Prod. **35**, 19, **2012**.
19. FREITAS DE ALVARENGA R.A., PRUDENCIO DA SILVA JUNIOR V., SOARES S.R. Comparison of the ecological footprint and a life cycle assessment method for a case study on Brazilian broiler feed production. J Clean Prod. **28**, 25, **2012**.
20. COLLADO-RUIZ D., OSTAD-AHMAD-GHORABI H. Fuon theory: standardizing functional units for product design. Resour Conserv Recy. **54** (10), 684, **2010**.
21. MTEC. Thai national life cycle inventory database, National Metal and Materials Technology Center National Science and Technology Development Agency of Thailand, Pathumthani, Thailand, **2014**.
22. ECOINVENT CENTRE. Ecoinvent Database Ver.2.2. categories for processes, Ecoinvent Centre, Swiss Centre for Life Cycle Inventories, Zurich, Switzerland, **2010**.
23. BENGTSSON J., SEDDON J. Cradle to retailer or quick service restaurant gate life cycle assessment of chicken products in Australia. J Clean Prod. **41**, 291, **2013**.
24. BOGGIA A., PAOLOTTI L., CASTELLINI C. Environmental impact evaluation of conventional, organic and organic-plus poultry production systems using life cycle assessment. World Poultry Sci J. **66**, 95, **2010**.
25. MACLEOD M., GERBER P., MOTTET A., TEMPIO G., FALCUCCI A., OPIO C., VELLINGA T., HENDERSON B., STEINFELD H. Greenhouse gas emissions from pig and chicken supply chains-a global life cycle assess, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, **2013**.
26. IPCC. Emissions from livestock and manure management, In: Agriculture, Forestry and Other Land Use, Vol. **4**, Intergovernmental Panel on Climate Change, Available online: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html., (accessed on 8/02/2016), **2006**.
27. NIELSEN N.I., JORGENSEN M., BAHRNDORFF S., Greenhouse gas emission from The Danish broiler production estimation via LCA methodology, Knowledge Centre for Agriculture, Denmark, Available online: http://lca-net.com/wp-content/uploads/110628_vfc_engelsk_vfl_layout_web.pdf., (accessed on 24/02/2016), **2011**.
28. BAUMGARTNER D.U., DE BANN L., NEMECK T. European grain legumes-environmental-friendly animal feed: life cycle assessment of pork, chicken meat, egg and milk production. Grain legumes integrated project report. Agroscope Rechenholz-Tanikon Research Station ART. Zurich, Switzerland, **2008**.
29. CASTELL A.G., GUENTER W., IGBASAN F.A. Nutritive value of peas for nonruminant diets. Animal Feed Science and Technology. **60** (3-4), 209, **1996**.
30. NOLL S., FARAHAT M.H. How alternative food ingredients affect poultry dietary electrolyte balance, Agricultural Utilization Research Institute, Minnesota, USA, Available online: http://www.auri.org/assets/2013/01/Alt-Feed-Ingredients-Poultry-Diets.pdf., (accessed on 21/03/2016), **2012**.
31. SPRING P. The challenge of cost effective poultry and animal nutrition: optimizing existing and applying novel concepts. Lohmann Information. **48** (1), 38, **2013**.
32. CHOI H.S., LEE H.L., SHIN M.H., CHEORUN J., LEE S.K., LEE B.D. Nutritive and economic values of corn

distiller's dried grains with solubles in broiler diets. Asian Austral J Anim. **21** (3), 417, **2008**.
33. LIMSILA A., TUNGSAKUL S., SARAWAT P., WATANANONTA W., BOONSING A., PICHITPORN S., HOWELER R.H. Cassava leaf production research in Thailand, Proc. the 7th Regional Workshop held in Bangkok 'Cassava Research and Development in Asia: Exploring New Opportunities for and Ancient Crop', Centro International de Agriculture Tropical, Thailand, 472, **2002**.
34. ABU O.A., OLALERU I.F., OKE T.D., ADEPEGBA V.A., USMAN B. Performance of broiler chicken fed diets containing cassava peel and leaf meals as replacements for maize and soya bean meal. IJST. **4** (4), 172, **2015**.
35. KYAWT Y.Y., TOYAMA H., HTWE W.M., THAIKUA S. Effects of cassava substitute for maize based diets on performance characteristics and egg quality of laying hens. IJPS. **13** (9), 522, **2014**.
36. ANAETO M., ADIGHIBE L.C. Cassava root meal as substitute for maize in layers ration. Rev. Bras. Cienc. Avic. **13** (2), 155, **2011**.
37. KNUDSEN M.T., HERMANSE J.E., OLESEN J.E., TOPP C.F.E., SCHELDE K., ANGELOPOULOS N., RECKLING M. Climate impact of producing more grain legumes in Europe, Proc. the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector 'LCA Food 2014', San Francisco, USA, 645, **2014**.