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Environmental impact assessment of chicken meat production using life cycle assessment

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ABSTRACT

The present study was conducted in Varamin city of Tehran province, Iran. The environmental impact of broiler production at farm gate and chicken meat production at slaughterhouse gate per mass-based functional unit in summer and winter seasons were evaluated using life-cycle assessment (LCA) methodology. Environmental impact categories including abiotic depletion potential, acidification potential, eutrophication potential, global warming potential, ozone depletion potential, human toxicity potential, freshwater and marine aquatic ecotoxicity potential, terrestrial ecotoxicity potential, and photochemical oxidation potential were assessed via CML 2 baseline 2000 v2.04/world, 1990 method. According to the results, the global warming potential, acidification and eutrophication for production of 1 ton packed meat were estimated to be 2931.91 kg CO_2-eq, 41.75 kg SO_2-eq and 14.69 kg PO_4-eq, in summer and 5357.61 kg CO_2-eq, 61.9 kg SO_2-eq and 19.34 kg PO_4-eq in winter, respectively. The evaluations revealed that the broiler production stage was the main source of environmental impacts principally due to production and transportation of feed and on-farm emissions in the life cycle of chicken meat production. Broiler production farms, slaughterhouse and transportation account for 56%, 31% and 13% of total energy consumption, respectively.

1. Introduction

The world population is predicted to reach 9.2 billion by 2075 [1] therefore, the agriculture sector will need to enhance efficiencies to feed the world growing population [2]. Production of agricultural inputs such as fertilizers, pesticides and operation of farm machinery produce considerable quantities of emissions [3]. Emissions of agriculture sector are mainly consisted of CH_4 and N_2O, whereas CO_2 emissions are initially from fossil fuels utilization [4]. On the other hand, land use change activities such as deforestation contribute to atmospheric greenhouse gas (GHG) emissions including CO_2 and N_2O [5].

Abbreviations: LCA, life cycle assessment; LCI, life cycle inventory; FU, functional unit; GHG, greenhouse gas; ADP, abiotic depletion potential; AP, acidification potential; EP, eutrophication potential; GWP, global warming potential; ODP, ozone layer depletion potential; HTP, human toxicity potential; FAETP, freshwater aquatic ecotoxicity potential; MAETP, marine aquatic ecotoxicity potential; TETP, terrestrial ecotoxicity potential; PhOP, photochemical oxidation potential; FCR, feed conversion ratio; VS, volatile solids; MCF, methane conversion factor; LW, live weight; BOD, biochemical oxygen demand; COD, chemical oxygen demand

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Livestock production contributes about 18% of all GHG emissions [6]. In the production of food products, about half of GHG emissions are mainly due to agriculture sector [7]. The food industry is one of the largest industries in the world which results in higher energy and resource consumption [8]. The contribution of agro-food to environmental issues such as resource reduction, air emissions and land degradation is significant [9]. Moreover, Boer [10] reported, in developed countries consumers demand food without having a harmful effect on the environment. As a result, evaluating the environmental impact of agro-food products, is paramount to improve the energy and environmental performances of the food sector.

Several methodologies have been applied for environmental impact assessment of livestock production systems [11,12]. Life-cycle assessment (LCA) is the most universal method for evaluating the environmental impacts that overcomes many of the restrictions of the other similar methods [13]. LCA is a holistic and suitable method for assessing the environmental effects of a product throughout its life cycle. LCA was originally developed for assessing the environmental impacts of industrial production and processes, it was later applied to agricultural production systems [14]. Several researches have employed LCA to evaluate environmental impacts of various types of meats [15–20]. In LCA studies on meat, agricultural production made a large contribution to the environmental impacts [21,22]. In other words, environmental burdens of meats are mainly due to the farming systems [23–25]. Pig and poultry farming resulted in lower emissions than beef, sheep and dairy farming and broiler production was more environmentally friendly than other animal production systems [26]. Poultry chain is estimated to produce 0.6 gigatonnes CO_2-equivalent per year [27]. Furthermore, feed requirement of chicken is lower than pork and beef [26,28,29]. Thereby, production of ruminant animals can be replaced by monogastric animals in order to decrease environmental effects [30].

Among different impact categories, carbon footprint has been widely employed for assessing environmental effects [31]. Apart from GHG emission, animal production farms emit ammonia and particulates to the environment [32].

LCA studies on chicken meat production divided into two categories, those that evaluated only to the farm gate [20,33,34] and those that contained slaughter phase [26,35,36]. Williams et al. [26], compared three different systems (conventional, free range and organic). They reported that organic and free-range systems had higher emissions compared to conventional system.

The main objectives of this study were to evaluate environmental impacts of chicken meat production in summer and winter seasons using LCA approach, determine the hotspots that contribute to the environmental effects and energy use, and propose solutions to reduce the environmental load of the chicken meat production in the studied region.

2. Materials and methods

2.1. Site description and data collection

The initial data from 40 broiler producers and one slaughterhouse were collected. The required data were compiled from all of the active broiler farms during summer season. Broiler farms were evaluated again in winter. Broiler production farms in the present study were located in Varamin city of Tehran province, Iran. Fig. 1 shows the location of the Varamin region. The slaughterhouse was located within 20 km of the farms. Varamin region is located within 35° 12′ N latitude and 51° 42′ E longitude. The contribution of Varamin city to produce broiler in Tehran province is significant, therefore this region was selected for study.

2.2. Production system description

In the study area, birds were transported from the hatchery to broiler farm as one-day chickens and after 7–8 weeks they reached a live weight of about 2.6 kg. They were then delivered to the mechanized slaughterhouse. For the production of one ton meat, the slaughterhouse requires more than one ton broiler. The following processes were conducted in the slaughterhouse: weighting, hanging, electrical stunning, manual killing, collection of blood, scalding through a scald tank at a 57 °C temperature and feathers abraded by rotating rubber fingers, foot removal, eviscerating, sterilization, chilling, quality control, grading, weighing and packaging. In this study, waste at slaughterhouse was transported to the meat meal production factory. The conversion of waste to meat meal was not considered in the present study.

2.3. Life cycle assessment methodology

Life-cycle assessment (LCA) is a technique to assess the environmental impacts of a product, process, or activity over its life cycle [37]. The LCA procedure consists of four steps: goal and scope definition, inventory analysis, impact assessment, and interpretation of results [38]. The phases of an LCA are illustrated in Fig. 2.

2.3.1. Goal and scope definition

Goal definition (ISO 14040) is the most important constituent of an LCA study. In this phase, the purpose and limits of the study, system boundaries, functional unit (FU) and assumptions are chosen. The purpose of this study was to evaluate the environmental impacts of chicken meat production. The two different case studies that were investigated for comparative purposes were:

Case 1: Production of chicken meat in summer.
Case 2: Production of chicken meat in winter.

2.3.1.1. System boundary and functional unit. System boundary consists of all processes which contribute in life cycle of product. In LCA studies, system boundaries must be clearly determined. In the present study, the system boundary comprised all inputs from the broiler production in farms (e.g. feed ingredients and detergents production) to the slaughterhouse gate (packed meat). No further environmental impacts after the slaughterhouse were included in this study. It should be noted that machinery and buildings were not considered in the calculations. Fig. 3 shows the schematic flow diagram of the life cycle of chicken meat production and system boundary of this study. As illustrated in Fig. 3, two unit processes (broiler production farms and

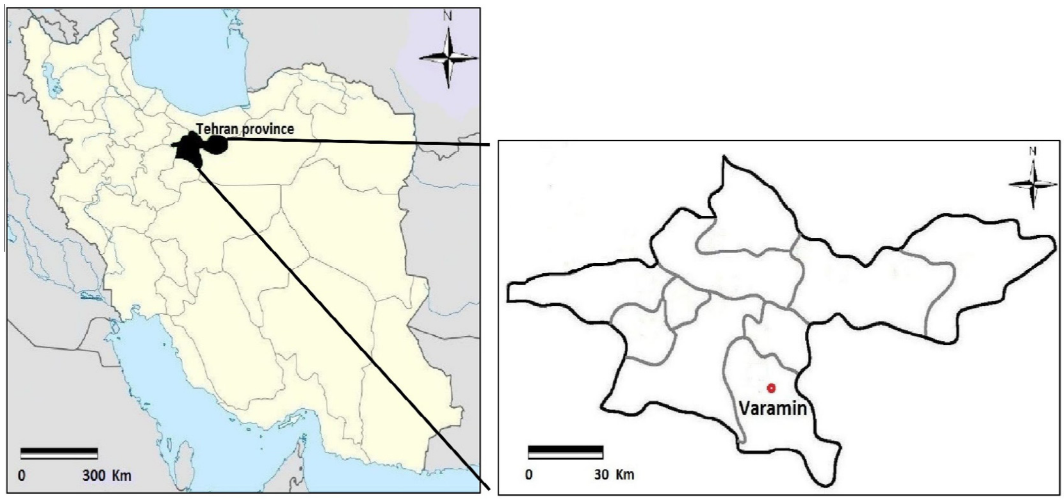

Fig. 1 – Location of the study area in Tehran province, Iran.

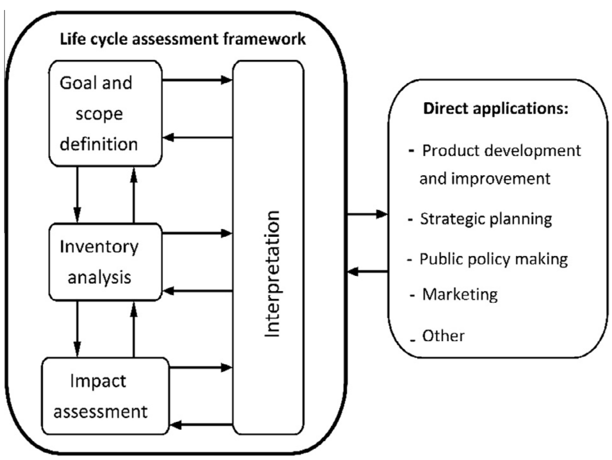

Fig. 2 – Illustration of an LCA stages [38].

slaughterhouse) were evaluated. Black arrows illustrate inputs from outside, green arrows illustrate the conversion steps of chick to packed meat. From each process there are by-products indicated by blue arrows and emissions from each unit process are indicated by red arrows.

FU is utilized as a reference for normalizing inputs and outputs [8]. Mass-based FU is generally used in LCA studies, while other FUs including area, quality adjusted mass and economic value are being applied [37]. For agricultural products, the most common FUs are often based on mass and area [39,40]. In the present study the FU selected is the production of one ton of live weight (LW) at farm gate and one ton of chicken meat at slaughterhouse gate.

2.3.2. *Life cycle inventory (LCI) analysis*

LCI, is the data collection portion of LCA that is the most time consuming phase. It consists of all the flows in (including raw materials, energy (renewable and non- renewable), etc.) and out (products, co-products and emissions) of the production system. For evaluating the environmental impact, all constituents included in the product should be identified [41]. The EcoInvent®2.0 database was applied for several inputs such as (production of feed ingredients, packaging materials and cleaning agents, electricity, transportation, etc.), and data

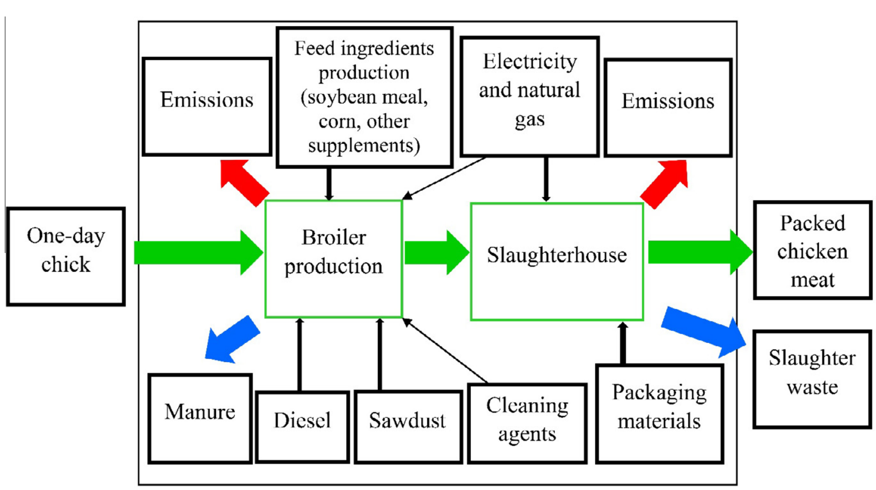

Fig. 3 – System boundary of chicken meat production.

from production farms and slaughterhouse were compiled using questionnaires. The software used for LCI analysis was SimaPro V7.1. In the present study, all inputs and outputs related to chicken meat production are identified and quantified. Table 1 summarizes the inventory data used for broiler production at farm gate for both seasons.

Table 2 presents the LCI of chicken meat production at slaughterhouse. Two common analytical tests (BOD_5 and COD) conducted in the laboratory to determine the gross amount of organic matter in wastewater of slaughterhouse. BOD_5 and COD of wastewater were found to be 68 and 114 mg/L, respectively. BOD_5 and COD values were converted to 344,080 and 576,840 mg per ton packed meat respectively with some unit conversions.

Feed. A wide variety of ingredients such as corn, soybean meal, supplements of minerals, vitamins and amino acids were utilized in broilers feed during a production period. One broiler consumes about five kg feed according to the data from the 40 broiler producers. Production of all ingredients were taken into account. Feed conversion ratio (FCR) was defined as the proportion of food that is converted into animal product. In other words, FCR is the total amount of feed intake divided by the total amount of output product [42].

Electricity. Broiler production farms used electricity for lighting, pumping water from wells, ventilation system and operation of machinery. Mechanical ventilation was used in broiler production to remove moisture released by the birds. In slaughterhouse, electricity is applied mainly for operation of equipment, lighting and pumping water from well.

Fuel. Diesel and natural gas fuels were utilized in heating systems of broiler farms. When the chicks enter the farms the heat necessity is very high and it decreases gradually during growth period. Thirty-seven percent of broiler producers, and the slaughterhouse used natural gas for heating purposes. Emissions from fuels combustion were computed.

Bedding materials. Materials used in broiler sheds include (sawdust, chopped straw, shredded paper, rice hulls, etc.). Sawdust was used as bedding materials in broiler farms of the studied region.

Cleaning agents. Different agents were utilized for cleaning and disinfection of broiler farms before bringing the chicks to the production farms.

Packaging. Plastic and cardboard were used as packaging materials at the slaughterhouse.

Transport. Inputs were assumed to be transported to broiler farms and slaughterhouse by lorry, truck, and delivery van. The commonly used FUs for transportation are one ton kilometer (tkm) for cargo transportation and one passenger kilometer (pkm) for staff and laborers transportation. Transportation was taken into account among all stages. Transport of feed ingredients to broiler production farms was the main contributor to transportation stage.

Table 1 – Life cycle inventory data for broiler production farms.

Inputs	Quantity	
	Summer	Winter
Diesel (L/ton LW)	70.41	591.25
Natural gas (m^3/ton LW)	25.31	191.95
Corn (kg/ton LW)	1343.25	1343.25
Soybean meal (kg/ton LW)	698.61	698.61
Supplements (kg/ton LW)	179.26	179.26
Cleaning agents (kg/ton LW)	1.63	1.63
Electricity (kWh/ton LW)	980.20	664.6
Sawdust (m^3/ton LW)	1.81	2.93
Transport day-old chick (tkm/ton LW)	7.13	7.13
Transport feed (tkm/ton LW)	2021.44	2021.44

Table 2 – Life cycle inventory data for slaughterhouse.

Inputs	Quantity
Natural gas (m^3/ton packed meat)	75.91
Electricity (kWh/ton packed meat)	571.86
Cardboard (kg/ton packed meat)	68.68
Plastic (kg/ton packed meat)	3.66
BOD_5[a] (mg/ton packed meat)	344,080
COD[b] (mg/ton packed meat)	576,840
Transport broiler[c] (tkm/ton packed meat)	26.32
Transport packaging materials (tkm/ton packed meat)	7.16
Transport (laborers and staff) (pkm/ton packed meat)	1660
Slaughterhouse waste (kg/ton packed meat)	315.79

a Biochemical oxygen demand for wastewater.
b Chemical oxygen demand for wastewater.
c Includes transport of broilers from farms to slaughterhouse.

By-product (manure). Direct and indirect emissions of nitrous oxide (N_2O) and methane (CH_4) occur during production and storage of manure in farms and nitrous oxide emissions are mainly due to nitrification of ammonium to nitrate or, uncompleted denitrification of nitrate [2]. The emissions were determined based on guidelines proposed by IPCC [43]. The CH_4 emission was calculated according to the following equation.

$$\text{kg } CH_4/\text{broiler} = VS * Bo * MCF * 0.67 \quad (1)$$

where 'VS' is the volatile solids excreted (kg dry matter/broiler/day), 'Bo' is the methane producing potential from manure (m^3 CH_4/kg VS), 'MCF' is the methane conversion factor that varies with the climate (% of Bo), and '0.67' is the conversion factor of m^3 CH_4 to kg CH_4. An average production period of 55 days was used in the surveyed area. Broiler litter is a valuable by-product, it contains nutrients that can be utilized in field crop production. In this study, manure excreted from broiler was utilized as fertilizer in agricultural land.

2.3.3. *Impact assessment*

Life cycle impact assessment (LCIA) is the stage for calculating the environmental impact on the basis of inventory analysis results [37]. In this phase, the inventory results are converted into impact categories. A variety of impact assessment methods have been used in LCA studies including CML method [44], Eco-indicator 99 [45], Ecological Scarcity 1997 [46], EPS 2000 [47], impact 2002+ [48], etc. In the present study, ten environmental impact categories, have been considered according to CML 2 baseline 2000 v2.04/world. The impact categories considered in this study are listed in Table 3. The LCIA is divided into several compulsory and optional elements. The impact assessment commonly consists of classification, characterization and valuation elements [49].

2.3.4. *Interpretation*

This phase of LCA, interpreting the results of inventory and impact assessment phases. In other words, the life cycle interpretation stage consists of conclusions and recommendations according to the framework of the goal and scope of the study.

3. Results and discussion

3.1. *Environmental impact assessment of chicken meat production in summer*

The absolute values of each impact category for broiler production at farm gate and chicken meat production at slaughterhouse gate in summer are shown in Table 4. It was estimated that the production of one ton of live weight (LW) broilers has an overall impact of 1389.85 kg CO_2-eq for GWP, 29.58 kg SO_2-eq for AP and 11.02 kg PO_4-eq for EP. Fig. 4 depicts the relative contribution of inputs to each impact category at farm gate. Feed (production, transport and processing) and electricity were the main contributors to the total GHG emissions, respectively. In an environmental life cycle assessment of French and Brazilian broiler chicken production by da Silva et al. [50], the contribution of feed-production stage to the environmental impacts of packaged whole-chicken production was significant. In another study, carried out by Bengtsson and Seddon [51], upstream feed production (e.g. soy meal, grains and meat meal) contributed most to the overall impact of the chicken meat supply chain. Pelletier [20], reported that feed production results in generation of GHG emissions ranged from 45% to 82.4%.

In this study, 62.5% of broiler farms used tunnel-ventilation systems. Significant differences in performance between the tunnel-ventilated and conventional houses were found. Birds in the tunnel-ventilated houses weighted more and had a better feed conversion ratio. Moreover, the amount of manure produced is affected by the amount of feed consumption and consequently affected the emissions from housing and field [52]. Decrease in feed consumption per kg broiler produced gives a directly corresponding decrease in the environmental burdens. In the present study, the feed conversion ratio (FCR) is noted to be 2.03. In other words, about 2 kg feed was used per kg live weight at farm gate. According to Cederberg et al. [33], 1.75 kg feed was utilized per kg live weight leaving the house. It is necessary to choose feed produced with low emissions of greenhouse gases. Broiler producers should focus on finding ways to reduce the waste of feed in houses and storage by good monitoring and management. Feed (production, transport and processing) made the largest contribution to all impact categories except

Table 3 – Environmental impact categories and respective measurement units.

Impact category	Acronym	Measurement units
Abiotic depletion potential	ADP	kg Sb eq.
Acidification potential	AP	kg SO_2 eq.
Eutrophication potential	EP	kg PO_4 eq.
Global warming potential[a]	GWP	kg CO_2 eq.
Ozone layer depletion potential	ODP	kg CFC-11 eq.
Human toxicity potential	HTP	kg 1,4-DCB eq.
Freshwater aquatic ecotoxicity potential	FAETP	kg 1,4-DCB eq.
Marine aquatic ecotoxicity potential	MAETP	kg 1,4-DCB eq.
Terrestrial ecotoxicity potential	TETP	kg 1,4-DCB eq.
Photochemical oxidation potential	PhOP	kg C_2H_4 eq.

a Considering 100 years.

Table 4 – Life cycle impact indicators for broiler and chicken meat production in summer.

Impact category	Unit	Per ton of LW	Per ton of packed meat
ADP	kg Sb eq.	14.15	25.97
AP	kg SO_2 eq.	29.58	41.75
EP	kg PO_4 eq.	11.02	14.69
GWP	kg CO_2 eq.	1389.85	2931.91
ODP	kg CFC-11 eq.	0.001	0.001
HTP	kg 1,4-DCB eq.	655.33	996.36
FAETP	kg 1,4-DCB eq.	58.43	98.98
MAETP	kg 1,4-DCB eq.	194,523	316357.2
TETP	kg 1,4-DCB eq.	3.01	4.99
PhOP	kg C_2H_4 eq.	3.22	4.39

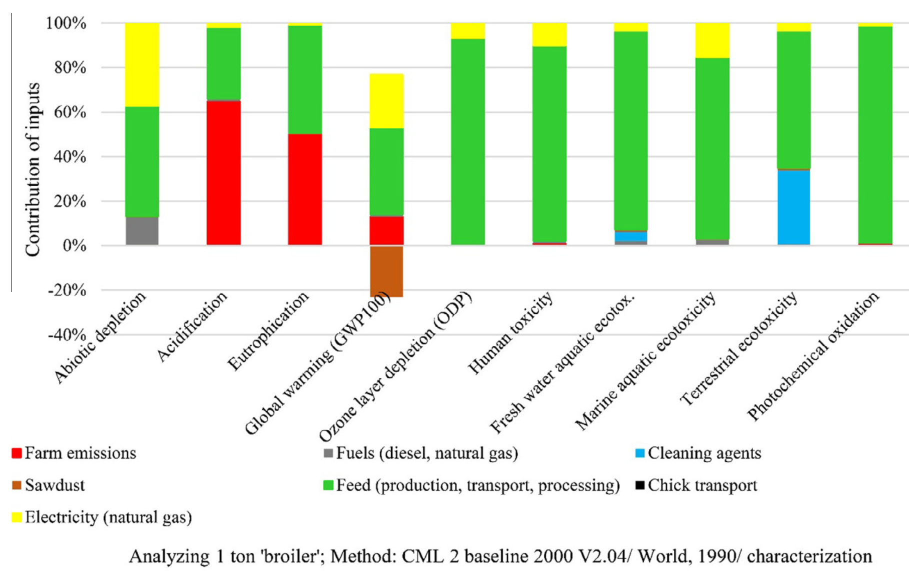

Fig. 4 – Contribution of inputs to impact categories in broiler production at farm gate in summer.

AP and EP. For improving the environmental performance of feed transportation, a large proportion of the feed (agricultural crops) must be grown near the broiler production farms. Likewise, low mortality gives a lower climate impact per kg meat. In this study mortality rate was 12%. Therefore, the higher broiler meat yield resulted in better production systems. On the other hand, installing improved ventilation systems can reduce the consumption of electricity, in summer season. Maintenance and cleaning of fans is very useful for reducing electricity consumption. Ammonia (NH_3) evaporation from manure and SO_2 emission from fossil fuels combustion make a large contribution to the impact category AP. da Silva et al. [50] reported that chicken house emissions made a significant contribution to AP. CH_4 emission from manure can be diminished by anaerobic digestion or improved storage systems [53,54].

The impact category EP is dominated by NO_3 and PO_4 leaching into water and NH_3 emissions into air [52]. Emissions of manure and fossil fuels and chemical fertilizers utilized in soybean cultivation made a large contribution to the EP impact category. In other words, broiler farm emissions made a large contribution to the impact categories AP and EP. In the studied region, decreasing the use of soybean meal in the feeding system leads to lower emissions. The major contributions of cleaning agents and electricity were in TETP and ADP, respectively. As can be seen in Fig. 4 sawdust produced from waste wood improved the environmental performance in terms of GWP.

The contributions of inputs to environmental impact categories of chicken meat production in summer for whole life cycle at slaughterhouse gate are shown in Fig. 5. The contribution of broiler production stage for all impact categories was significant. In a similar study conducted by Gonzalez-Garcia et al. [55], the chicken farm was reported as the main contributor to the environmental impacts. Apart from broiler production phase, the impact categories ADP and GWP were dominated by electricity consumption while in EP, ODP, HTP, FAETP, MAETP, TETP and PhOP, the transportation of inputs was important. The impact categories of different stages are summed to estimate the overall impact categories for the life cycle of one ton packed meat at slaughterhouse gate. As can be seen in Table 4. The GWP, AP and EP for the production of one ton packed meat were calculated as 2931.91 kg CO_2-eq, 41.75 kg SO_2-eq and 14.69 kg PO_4-eq, respectively.

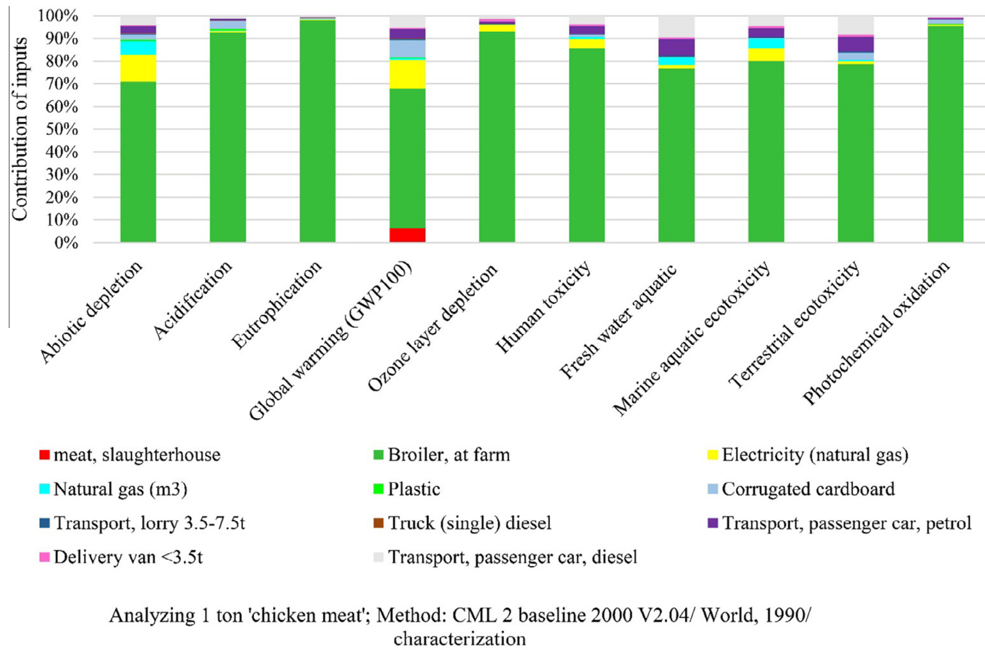

Fig. 5 – Contribution of inputs to impact categories in life cycle of chicken meat at slaughterhouse gate in summer.

Factory sector (including slaughtering, packaging and relative transportation) accounts for 38%, 8% and 3% of total GWP, AP and EP in life cycle of one ton meat production, respectively.

3.2. *Environmental impact assessment of chicken meat production in winter*

The environmental indices for broiler and chicken meat production in winter are summarized in Table 5. The evaluations showed that a larger amount of fossil fuels combustion for heating purposes in winter compared with broiler production farms in summer resulting in greater impact categories such as GWP, AP, EP and ADP. Diesel and natural gas fuels consumption made the largest contribution to ADP. Emissions occurring on the broiler farms to GWP, AP and EP were significant. These emissions are mainly due to fuels combustion for heating the farmhouses. Therefore, the total fuel consumption can differ between different heating options for a farm. Energy resources must be supplied mainly using renewable sources to promote the environmental factors.

The GWP, AP and EP for one ton packed meat production in winter were estimated to 5357.61 kg CO_2-eq, 61.9 kg SO_2-eq and 19.34 kg PO_4-eq, respectively (Table 5).

The study carried out by Pelletier [20], determined that chicken meat production in USA created a total GWP impact of 1.4 kg CO_2-eq per kg live weight at farm gate. Cederberg et al. [33], reported that total GHG emission was 1.35 kg CO_2-eq per kg live weight in Sweden. An LCA of chicken meat production in Canada by Verge et al. [34], showed that total GHG emission was 1 kg CO_2-eq per kg live weight. The differences between studies are mainly due to methodological approach, definition of system boundaries and allocation methods.

The normalization step is used in LCA studies in order to compute the magnitude of category indicator results [56]. Normalization is an optional step in LCIA which describes results of the impact categories [37].

The normalized impact categories are presented in Fig. 6. As can be seen the magnitude of MAETP was greater than the other impact categories in both seasons followed by ADP, AP, EP and GWP.

Table 5 – Impact for each category of broiler and chicken meat production in winter.

Impact category	Unit	Per ton of LW	Per ton of packed meat
ADP	kg Sb eq.	25.33	40.53
AP	kg SO_2 eq.	45.05	61.9
EP	kg PO_4 eq.	14.6	19.34
GWP	kg CO_2 eq.	3252	5357.61
ODP	kg CFC-11 eq.	0.001	0.001
HTP	kg 1,4-DCB eq.	709.63	1067.09
FAETP	kg 1,4-DCB eq.	66.53	109.53
MAETP	kg 1,4-DCB eq.	215987.5	344317.7
TETP	kg 1,4-DCB eq.	3.1	5.1
PhOP	kg C_2H_4 eq.	3.39	4.62

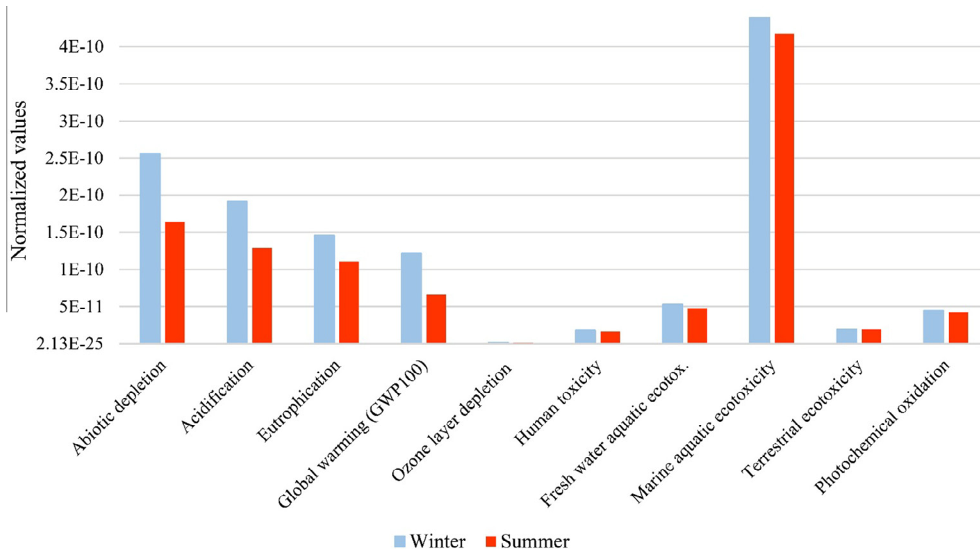

Fig. 6 – Comparison of normalized impact categories for chicken meat production in summer and winter seasons.

3.3. *Energy evaluation of chicken meat production*

Adjusted energy use at farm gate excluding meat processing was calculated as 41.16 GJ per ton live weight in summer. Energy consumption in whole life cycle including slaughter and packaging was estimated as 133.46 GJ per ton packed meat. Total energy use at farm gate in winter was computed as 72.63 GJ per ton live weight. The results demonstrate that the total input energy in broiler production farms in summer is less than that of broiler production farms in winter. The share of total energy consumption in different phases of chicken meat production in summer is shown in Fig. 7. As illustrated in Fig. 7, broiler production farm is by far the greatest contributor with 56% of the energy consumption followed by slaughterhouse phase with 31% and transportation with 13%. In the broiler production phase, feed and fuel were the main important contributors to total energy consumption in summer and winter, respectively. In transportation sector, feed transportation made the largest contribution to energy consumption.

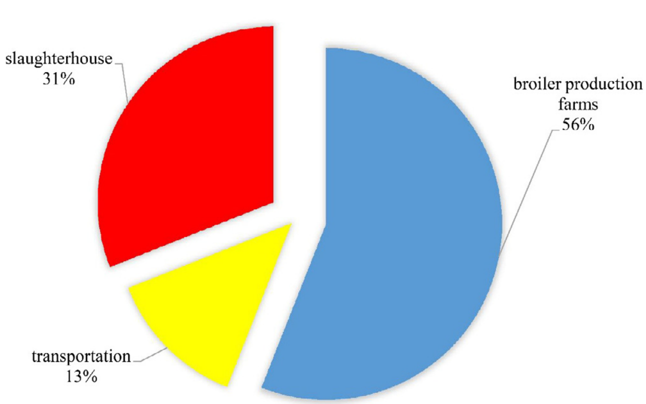

Fig. 7 – Contribution of the energy consumption in different production phases.

4. Conclusions

In the present study, life cycle assessment was utilized to evaluate the environmental impacts of chicken meat production in Varamin city of Tehran province, Iran. GHG emissions arise from several sources within the chicken meat production, primarily associated with use of energy. The results showed that the environmental burdens of chicken meat production in winter were greater than summer season. The results confirm that the broiler production stage is the main contributor in the life cycle of chicken meat in all impact categories. Feed (production, transport and processing) and on-farm emissions were the main factors in environmental impacts. The evaluations showed that the broiler production phase was the most energy intensive process in whole life cycle of meat production.

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