

Life cycle energy use, costs, and greenhouse gas emission of broiler farms in different production systems in Iran—a case study of Alborz province

Seyyed Hassan Pishgar-Komleh¹  · Asadollah Akram¹ · Alireza Keyhani¹ · Rosalie van Zelm²

Received: 1 November 2016 / Accepted: 10 May 2017 / Published online: 23 May 2017
© Springer-Verlag Berlin Heidelberg 2017

Abstract In order to achieve sustainable development in agriculture, it is necessary to quantify and compare the energy, economic, and environmental aspects of products. This paper studied the energy, economic, and greenhouse gas (GHG) emission patterns in broiler chicken farms in the Alborz province of Iran. We studied the effect of the broiler farm size as different production systems on the energy, economic, and environmental indices. Energy use efficiency (EUE) and benefit-cost ratio (BCR) were 0.16 and 1.11, respectively. Diesel fuel and feed contributed the most in total energy inputs, while feed and chicks were the most important inputs in economic analysis. GHG

emission calculations showed that production of 1000 birds produces 19.13 t CO_{2-eq} and feed had the highest share in total GHG emission. Total GHG emissions based on different functional units were 8.5 t CO_{2-eq} per t of carcass and 6.83 kg CO_{2-eq} per kg live weight. Results of farm size effect on EUE revealed that large farms had better energy management. For BCR, there was no significant difference between farms. Lower total GHG emissions were reported for large farms, caused by better management of inputs and fewer bird losses. Large farms with more investment had more efficient equipment, resulting in a decrease of the input consumption. In view of our study, it is recommended to support the small-scale broiler industry by providing subsidies to promote the use of high-efficiency equipment. To decrease the amount of energy usage and GHG emissions, replacing heaters (which use diesel fuel) with natural gas heaters can be considered. In addition to the above recommendations, the use of energy saving light bulbs may reduce broiler farm electricity consumption.

Highlights

- We studied the energy, economic, and greenhouse gas (GHG) emission patterns in broiler farms in Alborz province of Iran.
- We studied the effect of the broiler farm size as different production systems on the energy, economic, and environmental indices.
- Energy use efficiency (EUE), GHG emissions, and benefit-cost ratio (BCR) were 0.16, 19.13 t CO_{2-eq} (1000 birds)⁻¹ and 1.11, respectively.
- Results of farm size effect on EUE and GHG emissions revealed that large farms had better energy and environmental management.

Responsible editor: Philippe Garrigues

Electronic supplementary material The online version of this article (doi:10.1007/s11356-017-9255-3) contains supplementary material, which is available to authorized users.

✉ Seyyed Hassan Pishgar-Komleh
hpishgar@ut.ac.ir

¹ Department of Agricultural Machinery, Faculty of Agricultural Engineering and Technology, University of Tehran, P.O. Box 4111, Karaj, Iran

² Department of Environmental Science, Institute for Water and Wetland Research, Radboud University Nijmegen, P.O. Box 9010, 6500 GL Nijmegen, The Netherlands

Keywords Energy · Economic analysis · GHG emissions · Broiler production · Iran

Nomenclature

BCR	Benefit-cost ratio
EP	Energy productivity
EUE	Energy use efficiency
GHG	Greenhouse gas
GR	Gross return
GWP	Global warming potential
LCA	Life cycle assessment
NE	Net energy
NR	Net return

SE	Specific energy
STD	Standard deviation
TPV	Total production value

Introduction

Poultry meat production has been taken into consideration since the red-meat crisis in the world. People have perceived poultry meat as healthier than beef for being lighter and having a lower fat content (Ramirez et al. 2006). Total world chicken meat production in 2012 was 92 million t, from which the USA, China, and Brazil were the main producers, and Iran, with its production of 1.9 million t, was the 7th largest chicken meat producer in the world (FAOSTAT 2012). The total white meat production of Alborz province was reported as 13,000 t (Anonymous 2015). Alborz province is situated 35 km west of Tehran, the most populated city and capital of Iran. In this situation, Alborz province plays an important role in Tehran's food security. Energy as one of the most important inputs for economic growth and human development is used in agricultural production widely. In livestock farming, energy is mostly necessary to implement equipment, heating, cooling, lighting, and many other appliances. Until recently, most in-depth energy analyses for agricultural systems have been focused on energy use of farm crops (e.g., wheat, vegetables, forages) while livestock farming (e.g., dairy cattle, poultry) has been disregarded. The energy analysis is one of the most useful methods for evaluating the potential long-term sustainability for various agricultural practices (Atilgan and Koknaroglu 2006). There are various benefits of improving the energy efficiency, such as helping in the promotion of competitiveness through cost reduction, resulting in minimized energy-related environmental pollution, and therefore positively contributing towards sustainable development (Moore 2010). Since global warming poses one of the major environmental issues now and in the future, greenhouse gas (GHG) emission is the main factor of this challenge. Ruminant animal operations are a source of GHG emissions, although the contributions of poultry activities are far lower (Skunca et al. 2015). These gases include carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) which absorb energy (heat) of specific wavelength bands in the thermal infrared radiation (Xin et al. 2011). Some researchers have done studies on the energy use, economic, and GHG emission pattern of poultry production (Leinonen et al. 2012; Pelletier 2008; González-García et al. 2014; Nielsen et al. 2011; MacLeod et al. 2013; Heidari et al. 2011; Seguin et al. 2011; Kalhor et al. 2016). With respect to the fact that when designing production systems, economic profitability is the main objective, it is essential to perform economic, energy, and environmental assessments together. It gives a better view to policy makers and producers and helps them to better

understand the production system. To the best of our knowledge, energy, economic, and GHG emission assessments have not been studied before on an individual farm level. Initial observation in the research region showed that herd size has a significant effect on input and output variability, and some researchers studied this effect on energy usage in poultry farms (Alaw Qotbi et al. 2011; Atilgan and Koknaroglu 2006). Knowing the effect of farm capacity on the variability of energy, economic, and environmental indices helps to identify the most productive farm capacity. Due to the importance of Alborz province in supplying Tehran's white meat needs and the lack of similar studies, which were focused on all aspects of broiler chicken production, the aim of this study was to investigate the energy use, economic, and GHG emissions pattern in Alborz province of Iran. Moreover, we assessed the effect of farm capacity on the variability of energy, economic, and environmental indices.

Material and methods

Data collection, functional unit, and system boundary

We collected data on broiler chicken from 60 broiler chicken farms in the province of Alborz (35.68 to 36.37° N and 50.23 to 51.43° E) in Iran. To collect data, farmers were asked about the amount of their farm input utilization and output yield during one period of broiler production process (almost 60 days) during the winter season (in 2014). A simple random sampling method was used to find the required sample size (see [Supporting Information file](#)). The most common commercial broiler hybrids in Iran are Arbor Acres, Arian, Cobb, Hubbard, Lohmann, and Ross. Cobb and Lohmann hybrids are the most common hybrids in Alborz province.

The functional unit was 1000 chickens at the farm gate, i.e., the system boundary was from cradle to broiler chicken farm gate. To compare the environmental assessment results with other similar research, we used ton of carcass and kilogram live weight as functional units. To study the effect of farm capacity on energy, economic, and GHG emission indices, farms were classified (based on the frequency of farms) into three groups: small (<16,000 birds which were 19 farms), medium (between 16,000 and 20,000 birds which were 21 farms), and large (>20,000 birds which were 20 farms).

Energy analysis

Table 1 shows the energy equivalents that were used to estimate the energy content of inputs and output. Energy inputs, which were considered in broiler production, were machinery and equipment, diesel fuel, natural gas, electricity, human labor, chick, and feed, while output energy source was broiler chicken meat. Electricity, diesel fuel, chick (1-day-old chicken

Table 1 Energy coefficients of inputs and output

Inputs (unit)	Energy coefficient (MJ unit ⁻¹)	Reference
A. Inputs		
Human labor (h)	1.96	Kitani (1999)
Machinery and equipment		
Electric motor (kg)	64.8	Heidari et al. (2011), Chauhan et al. (2006)
Steel (kg)	62.7	Heidari et al. (2011), Chauhan et al. (2006)
Galvanized iron (kg)	38	Lawson (1996)
Polyethylene (kg)	46.3	Kittle (1993)
Fuels		
Diesel (L)	47.8	Kitani (1999)
Natural gas (m ³)	49.5	Kitani (1999)
Electricity (kW h)	11.21	Pishgar-Komleh et al. (2013)
Feed		
Maize (kg)	7.24	Banaeian and Zangeneh (2011)
Soybean (kg)	10.94	Mousavi-avval et al. (2011)
Wheat (kg)	9.82	Sefeedpari et al. (2013)
Dicalcium phosphate (kg)	10	Alrwis and Francis (2003)
Minerals and vitamins (m ³)	1.59	Sainz (2003)
Fatty acid (kg)	37	Berg et al. (2002)
Chicks (kg)	10.33	Najafi Anari et al. (2008)
B. Output		
Chicken meat (kg)	10.96	

with average weight of 47.5 g), and broiler meat energy content were calculated by multiplying the amount of inputs (or output) and their corresponding energy coefficients (Table 1). The details of calculations for the energy coefficients of machinery and equipment, diesel fuel, natural gas, electricity, and chicken meat can be found in the [Supporting Information file](#). The energy coefficient of feed ingredients is the total energy consumption to produce 1-kg feed. Since the usage of veterinary resources and chemicals were negligible, and reliable energy coefficients were not found for them, veterinary resources and chemicals were not included in the energy analysis. Output energy in Table 1 is the metabolized chicken meat energy. To calculate the metabolized chicken meat energy content, energy-producing constituents of chicken meat in the human body were calculated and multiplied by their corresponding energy contents. Table S2 shows all related values and calculations (see [Supporting Information file](#)).

In order to compare different production systems, various energy indices including energy use efficiency (EUE), energy productivity (EP), specific energy (SE), and net energy (NE) were used (see [Supporting Information file](#)).

Economic analysis

To carry out the economic analysis, the price of all inputs and output was explored. Net return (NR), gross return (GR), and

benefit to cost ratio (BCR) as economic indices were calculated by using Eqs. (1–5) (Pishgar-Komleh et al. 2011):

$$\text{Total production value (TPV)} = \text{Broiler meat yield} \quad (1)$$

$$\left(\text{kg (1000 birds)}^{-1} \right) \times \text{Broiler meat price} \left(\$ \text{kg}^{-1} \right)$$

$$\text{Gross return (GR)} = \text{Total production value} \quad (2)$$

$$\left(\$ (1000)^{-1} \right) - \text{Variable cost of production} \left(\$ (1000)^{-1} \right)$$

$$\text{Net return (NR)} = \text{Total production value} \quad (3)$$

$$\left(\$ (1000)^{-1} \right) - \text{Total production cost} \left(\$ (1000)^{-1} \right)$$

$$\text{Benefit–cost ratio (BCR)} \quad (4)$$

$$= \frac{\text{Total production value} \left(\$ (1000 \text{ birds})^{-1} \right)}{\text{Total production cost} \left(\$ (1000 \text{ birds})^{-1} \right)}$$

$$\text{Economic Productivity (P}_e\text{)} \quad (5)$$

$$= \frac{\text{Broiler meat yield} \left(\text{kg (1000 birds)}^{-1} \right)}{\text{Total production cost} \left(\$ (1000 \text{ birds})^{-1} \right)}$$

GHG emission analysis

To estimate the GHG emissions of broiler chicken production, CO₂, CH₄, and N₂O emissions were calculated and the results were expressed in carbon dioxide equivalents (CO₂-eq). Global warming potentials (GWPs) were used to aggregate the contribution of different relative warming forcing values of GHGs of a product. GWP values of 1, 28, and 265 kgCO₂-eq were used for CO₂, CH₄, and N₂O, respectively (Myhre et al. 2013). The life cycle assessment (LCA) for broiler chicken production begins with the production of crop inputs and passes through the phases of crop production, chick production, and chicken rearing, including all transport phases up to broiler chicken farm gate. The production of chicken houses, buildings, and machineries was included. For buildings and machineries, the amount of steel, aluminum, glass, building, polyethylene, which are used in the construction and equipment were inserted into Simapro software and by using Ecoinvent 3.1 database (Weidema et al. 2013), the amount of production emission was calculated. Inventory data for crop production in Iran was based on Sefeedpari et al. (2013), Banaeian and Zangeneh (2011), and Mousavi-Avval et al. (2011). The grain drying and processing and feed manufacturing were not included. We considered that a portion of the crops is produced for chicken feeding uses chicken manure coming from studied systems. Thus, the chicken manure was not included. Seven main GHG emission sources of broiler production were identified, namely construction and equipment, diesel fuel, natural gas, electricity, feed, chick and chicken rearing emission. We used Ecoinvent 3.1 database to calculate the GHG emissions of diesel fuel, natural gas, and electricity production. Table S3 shows the inventory data of broiler chicken farms in Alborz province (see [Supporting Information file](#)). All emissions related to production, transportation, and application of inputs were calculated by using Ecoinvent 3.1 database.

To calculate all energy and economic indices, Excel spreadsheets were used, and GHG emission calculations were done using SimaPro 8. To find the meaningful differences of values in all three farm size categories, an ANOVA test and Duncan compare mean were performed in SPSS 18 software.

Results and discussion

Energy analysis

Table 2 shows the inputs and output energy contents of broiler chicken farms in Alborz province. The total energy input average was almost 194 GJ per 1000 birds. An amount of 186 GJ was reported in a similar research for broiler chicken farms in Yazd province of Iran (Heidari et al. 2011). This discrepancy can be explained by the colder weather of Alborz in

comparison to Yazd province, which increases the amount of energy usage for heating. Diesel fuel contributed most to the total energy use, i.e., on average 49%, followed by feed (25%), natural gas (22%), and electricity (3%). Diesel fuel, natural gas, and electricity were applied to run the equipment, for heating and ventilation purposes. The same pattern was affirmed by Heidari et al. (2011) and this is in agreement with the results of the research by Alaw Qotbi et al. (2011) and Atilgan and Koknaroglu (2006). In a similar study (Alaw Qotbi et al. 2011), feed was reported as the second most important energy input in the broiler farms. The total average of broiler live weight was 2868 kg (1000 birds)⁻¹ and the corresponding total energy output was approximately 31 GJ (1000 birds)⁻¹. The results of the analysis of the farm size impact on energy consumption showed that total energy input decreases significantly as farm size increases. This reduction can be explained by more efficient energy use for heating (diesel fuel), ventilation, and lighting (electricity) purposes in medium and large farms. This result was in agreement with the results of similar studies (Alaw Qotbi et al. 2011; Atilgan and Koknaroglu 2006). Electricity is consumed in different operations, but lighting is the major use of electricity in poultry industry. It was seen that in small farms, producers use normal light bulbs, while most of the others use energy saving light bulbs. For machinery energy input, an increase of the farm size increases the energy usage. This trend is due to the use of more mechanized production systems in large farms, which increases machinery energy usage and thus decreases human labor energy usage significantly.

Energy indices, consisting of EUE, EP, SE, and NE for broiler chicken production in Alborz province, are presented in Table 3. The EP showed that to produce 1 kg of chicken meat, 67.72 MJ is needed (Table 3). The average EUE was 0.16. The less than unity value of EUE does not show the inefficient use of energy in broiler chicken farms in Alborz province. The EUE index shows that the broiler chicken production is an energy use process. To improve the production in the viewpoint of energy, two major guidelines can be used, including (i) using less energy input and/or (ii) increasing the farm yield (output energy). Various methods for decreasing energy inputs in regard to less diesel fuel, natural gas, and feed diet (i.e., using diets with high fiber and lower protein and lysine) can be suggested. Replacing diesel fuel heaters with ones that burn natural gas is another option, which may decrease the total heating energy consumption. The effect of farm capacity on energy indices showed that large farms with a larger capacity had better EUE than the other groups, due to their lower total energy consumption.

Economic analysis

Table 4 shows the economic analysis of broiler farms in three different farm sizes. Feed accounted for a significant share of

Table 2 Energy analysis in three farm capacities for broiler chicken production in Alborz

Inputs	Energy values in herd size groups (MJ (1000 birds) ⁻¹)			Average (MJ (1000 birds) ⁻¹)	Percentage (%)
	Small (<16,000 birds)	Medium (16,000–20,000 birds)	Large (>20,000 birds)		
A. Inputs					
Human labor	279 ^c	213 ^b	156 ^a	216	<1
Machinery	277 ^a	374 ^b	438 ^b	363	<1
Diesel fuel	100,948 ^b	129,310 ^b	53,475 ^a	94,578	49
Natural gas	51,046	17,505	60,404	42,985	22
Electricity	6813 ^c	4868 ^a	5657 ^b	5779	3
Feed	47,679 ^a	49,620 ^b	49,800 ^b	49,033	25
Chicks	592	573	585	583	<1
Total energy input	207,633 ^b	202,463 ^b	170,514 ^a	193,537	
B. Outputs					
Meat	31,020	31,757	31,183	31,332	100
Total energy output	31,020	31,757	31,183	31,332	

Note: Different letters show significant difference of means at 5% level

the average total cost. Due to the importance and the skyrocket conditions of feed intake of poultry production in Iran, determining the amount of required feed called as optimized diet is of particular importance. After that, chicks (413 \$ (1000 birds)⁻¹) and vaccination (276 \$ (1000 birds)⁻¹) were found to be costly inputs. Despite the high energy consumption in diesel fuel and electricity supply, they had a small share in variable costs, which is due to low price of fossil fuels and the subsidizing policy in Iran. These results are consistent with the findings reported by Heidari et al. (2011). The total costs (sum of variable and fixed costs) were estimated to be 4532 \$ (1000 birds)⁻¹ which is about 24% higher than the estimate reported by Heidari et al. (2011). A significant decrease was observed in the cost per 1000 birds of diesel fuel as the farm size increases. As it can be seen, for major cost inputs such as feed and chick, no significant difference was found among herd size groups.

The economic indices per 1000 birds are given in Table 5. The average gross value was 5031 \$ (1000 birds)⁻¹. The

variation of variable and fixed costs was found to be almost constant as capacity increases. Fixed and variable costs were around 5 and 95% of total costs, respectively. The results revealed that, for all economic indices, there is no significant difference between the herd size groups. The average value for benefit to cost ratio was 1.11. This index was 1.38 in the farms surveyed by Heidari et al. (2011). Colder weather, which increases heating needs and feed cost in Alborz province, are the main reasons of less benefit to cost ratio of our target farms in comparison to Heidari et al. (2011) research results.

GHG emission analysis

Table 6 shows the GHG emissions of broiler farms in Alborz province. The total GHG emission was 19.13 t CO₂-eq per 1000 birds. Feed contributed most to the total GHG emission, i.e., on average 43%, followed by diesel fuel (32%), and natural gas (10%). These findings are similar to Leinonen et al. (2012) research. They found that feed production, processing,

Table 3 Average energy indices in broiler chicken farms in Alborz

Item	Unit	Average values in herd size groups			Average
		Small (<16,000 birds)	Medium (16,000–20,000 birds)	Large (>20,000 birds)	
EUE	–	0.15 ^a	0.16 ^a	0.18 ^b	0.16
EP	kg MJ ⁻¹	0.01 ^a	0.01 ^a	0.02 ^b	0.01
SE	MJ kg ⁻¹	73.36	69.87	59.93	67.72
NEG	MJ (1000 birds) ⁻¹	-176,614	-170,706	-139,331	-162,217

Note: Different letters show significant difference of means at 5% level

Table 4 Economic analysis in three farm capacities for broiler chicken production in Alborz

Inputs	Total values in herd size groups (\$ (1000 birds) ⁻¹)			Average	Percentage (%)
	Small (<16,000 birds)	Medium (16000–20,000 birds)	Large (>20,000 birds)		
A. Inputs					
Variable costs					
Chick	419	405	414	413	9
Human labor	212 ^c	164 ^b	123 ^a	166	4
Diesel fuel	154 ^{ab}	198 ^b	82 ^a	145	3
Natural gas	47	16	56	40	<1
Feed	3146	3274	3286	3236	71
Electricity	17 ^b	12 ^a	14 ^{ab}	14	<1
Water	2 ^b	0.1 ^a	0.53 ^{ab}	0.96	<1
Vaccination	296 ^b	304 ^b	221 ^a	274	6
Chicken bed	39	40	35	38	<1
Fixed cost	209	203	207	206	5
Total costs	4541	4616	4439	4532	
B. Outputs					
Broiler	4917	5033	4942	4964	
Manure	67 ^{ab}	76 ^b	58 ^a	67	
Total income	4983	5109	5001	5031	

Note: Different letters show significant difference of means at 5% level

and transport resulted in greater overall environmental impacts than any other components of broiler chicken production (71 to 72% of GWP). In 2006, Williams et al. (2006) accounted for the environmental burdens and impacts for the UK poultry meat production system and estimated the GWP₁₀₀ value as 4.6 t CO_{2-eq} per t of carcass. In our study, the GWP₁₀₀ value was estimated as 8.50 t CO_{2-eq} per t of carcass. The difference can be explained by the larger amount of material and energy usage and lower output in Alborz province. The broiler chicken production system in Iran is less modern and efficient in comparison to that of Europe. Moreover, our study was carried out during the winter season, and thus, more fuel and feed were used to maintain

the temperature needed for chickens. Katajajuuri et al. (2008) found the total GHG emission of 1.3 kg CO_{2-eq} per kg live weight for chicken meat production in Finland, which was lower than our result (6.83 kg CO_{2-eq} per kg live weight). A comparison of GHG emissions based on herd size showed that as the herd size increases, the GHG emissions decline. The significant difference between large, medium, and small farms was observed in the total GHG, diesel fuel, and electricity emissions (Table 6).

To sum up the study's key findings, we can include feed as the most important input in broiler chicken production in Alborz province. Feed contributed most to total energy consumption, GHG emission, and total cost. As it was seen, in all

Table 5 Economic indices based on three farm capacities for broiler chicken production in Alborz

Item	Unit	Average values in herd size groups			Average
		Small (<16,000 birds)	Medium (16,000–20,000 birds)	Large (>20,000 birds)	
Gross value	\$ (1000 birds) ⁻¹	4983	5109	5001	5031
Variable cost	\$ (1000 birds) ⁻¹	4332	4414	4232	4326
Fixed cost	\$ (1000 birds) ⁻¹	209	203	207	206
Total cost	\$ (1000 birds) ⁻¹	4541	4616	4439	4532
GR	\$ (1000 birds) ⁻¹	651	695	769	705
NR	\$ (1000 birds) ⁻¹	442	492	562	499
BCR	–	1.1	1.11	1.13	1.11

Table 6 GHG emission analysis in three farm capacities for broiler chicken production in Alborz

Inputs	Total emission (t CO ₂ -eq per1000 bird)			Average	Percentage (%)
	Small (<16,000 birds)	Medium (16,000–20,000 birds)	Large (>20,000 birds)		
Equipment	1.654	1.600	1.634	1.629	8
Diesel fuel	6.555 ^{ab}	8.397 ^b	3.472 ^a	6.142	32
Natural gas	2.251	0.772	2.663	1.895	10
Electricity	0.552 ^b	0.394 ^a	0.458 ^{ab}	0.468	2
Feed	8.067	8.395	8.426	8.296	43
Chick	0.518	0.501	0.512	0.518	3
Chicken rearing	0.146	0.146	0.146	0.146	1
Manure	0.049	0.048	0.044	0.049	1
Total	19.791 ^{ab}	20.254 ^b	17.355 ^a	19.133	

herd sizes, there was no significant difference for feed input between different farm sizes, which shows a high consideration of farmers on feed input. Diesel fuel input had the least amount of energy consumption, cost, and GHG emission in large farms. Based on our field observations, a low level of building isolation and applying low efficient heaters are two major reasons for the high consumption of diesel fuel in small farms of Alborz province. Applying old heaters with low efficiency increases the amount of fuel consumption, and this results in more emission. More emission subsequently increases the ventilation needs. As it was observed in the research area, with the increase of the farm size, fuel usage rises up progressively, and in this situation, farmers use more efficient heaters, therefore causing a decrease in fuel consumption in comparison to small farms.

Limitations and uncertainties

Several assumptions were needed to calculate the GHG emission of broiler production leading to some uncertainties. The grain drying and processing and feed manufacturing were not included in GHG emission calculations. Moreover, the chicken manure was not included. We used the Ecoinvent database for emissions of inputs. In some cases, no exact data for Iran were available and we relied on world averages, such as for natural gas, diesel fuel, and construction. Future research would benefit from the application of Iran-specific data for all emissions.

Conclusion

This study shows the energy, economic, and GHG emission flow of broiler chicken farms in Alborz province, Iran. Therewith, comparisons based on different capacities of broiler chicken farms were performed. Based on the results, some

conclusions were drawn, and their corresponding recommendations are as follows:

1. The total average energy input was calculated as 194 GJ (1000 birds)⁻¹, among which diesel fuel, feed, and natural gas had the greatest share. The EP was 67.72 MJ kg⁻¹ in the surveyed area and revealed that to produce 1 kg chicken meat, 67.72 MJ is needed. Results showed that large farms had better energy management, so they had the highest amount of EUE values among other farm categories.
2. The total average cost and income were 4532 and 5031 \$ (1000 birds)⁻¹, respectively. Feed was the most important input in the economic analysis of the present study. BCR was reported as 1.11 and there was no significant difference among broiler chicken herd size groups for BCR.
3. The total GHG emissions based on different functional units were 19.13 t CO₂-eq per 1000 birds, 8.5 t CO₂-eq per t of carcass and 6.83 kg CO₂-eq per kg live weight. Feed had the highest impact on total emission. In large farms, we saw lower amounts of emissions for diesel fuel, electricity, and total emissions.
4. In this study, it was not possible to definitely determine the impact of the improvement or worsening of energy efficiency or GHG emissions as a result of the management changes on broiler yield, or the impact of changes in the inputs use on the yield, but we can posit some likely explanations for the farm-wide patterns observed. It was concluded that energy consumption, and subsequently the GHG emission situation, was better in large farms. A better management of inputs and less bird losses were the reasons of this fact. Large farms with more investment had modern heaters (with higher efficiency), which decreases the diesel fuel and natural gas consumption. It was observed that in almost all the large and medium farms, farmers are experienced in broiler chicken production; therefore, they had better input management and also

less chicken losses. As a result of our study, it is recommended to support small-scale broiler producers by providing subsidies to use high-efficiency equipment. In order to decrease the amount of energy usage and GHG emission, replacing heaters (which use diesel fuel) with natural gas heaters may be considered. Natural gas has lower emission and decreases the amount of ventilation needed in the poultry buildings. It was seen that in small farms, producers use normal light bulbs, while others use energy saving light bulbs. Apart from the other factors (such as ventilation and water pumping), light bulbs have caused small farms to experience higher energy consumption.

References

- Alaw Qotbi A, Najafi S, Ahmadauli O, Rahmatnejad E, Abbasinezhad M (2011) Investigation of poultry housing capacity on energy efficiency of broiler pulletens production in tropical areas. *Afr J Biotechnol* 10(69):15662–15666. doi:10.5897/AJB10.2662
- Alrwis KN, Francis E (2003) Technical, allocative and economic efficiencies of broiler farms in the central region of Saudi Arabia: data envelopment analysis approach. *J Saudi Soc Agric Sci* 1(2):73–99
- Anonymous (2015) Annual agricultural statistics, Ministry of Jihad -e-Agriculture of Iran. <http://www.maj.ir/> (in Persian) (Accessed 22 Dec 2015)
- Atilgan A, Koknaroglu H (2006) Cultural energy analysis on broilers reared in different capacity poultry houses. *Ital J Anim Sci* 5:393–400. doi:10.4081/ijas.2006.393
- Banaeian N, Zangeneh M (2011) Study on energy efficiency in corn production of Iran. *Energy* 36:5394–5402
- Berg MJ, Tymoczko LJ, Stryer L (2002) *Biochemistry*, 5th edn. W.H. Freeman, New York
- Chauhan NS, Mohapatra PKJ, Pandey KP (2006) Improving energy productivity in paddy production through benchmarking—an application of data envelopment analysis. *Energy Convers Manag* 47:1063–1085
- FAOSTAT (2012) Food and Agriculture Organization Statistics. <http://faostat.fao.org/>. (Accessed 22 Dec 2015)
- González-García S, Gomez-Fernández Z, Cláudia Dias A, Feijoo G, Moreira MT, Arrojo L (2014) Life cycle assessment of broiler chicken production: a Portuguese case study. *J Clean Prod* 74:125–134. doi:10.1016/j.jclepro.2014.03.067
- Heidari MD, Omid M, Akram A (2011) Energy efficiency and econometric analysis of broiler production farms. *Energy* 36(11):6536–6541. doi:10.1016/j.energy.2011.09.011
- Kalhor T, Rajabipour A, Akram A, Sharifi M (2016) Environmental impact assessment of chicken meat production using life cycle assessment. *Inf Process Agric* 3:262–271
- Katajajuuri JM, Gronroos J, Usva K (2008) Environmental impacts and related options for improving the chicken meat supply chain. In: *Proceedings of the 6th International Conference on LCA in the Agri-Food Sector*, Zurich, November 12–14, 2008
- Kitani O (1999) CIGR handbook of agricultural engineering, energy and biomass engineering, vol 5. ASAE publication, St Joseph
- Kittle AP (1993) Alternate daily cover materials and subtitle, the selection technique. Rusmar Incorporated, West Chester
- Lawson W (1996) *Building materials energy and the environment: towards ecologically sustainable development*. Royal Australian Institute of Architects, Manuka
- Leinonen I, Williams AG, Wiseman J, Guy J, Kyriazakis I (2012) Predicting the environmental impacts of chicken systems in the United Kingdom through a life cycle assessment: broiler production systems. *Poult Sci* 91:8–25. doi:10.3382/ps.2011-01634
- MacLeod M, Gerber P, Mottet A, Tempio G, Falcucci A, Opio C et al (2013) Greenhouse gas emissions from pig and chicken supply chains—a global life cycle assessment. Food and Agriculture Organization of the United Nations (FAO), Rome
- Moore SR (2010) Energy efficiency in small-scale bio intensive organic onion production in Pennsylvania, USA. *Renewable Agric Food Syst* 25:181–188. doi:10.1017/S1742170510000098
- Mousavi-Avval SH, Rafiee S, Jafari A, Mohammadi A (2011) The functional relationship between energy inputs and yield value of soybean production in Iran. *Int J Green Energy* 8:398–410. doi:10.1080/15435075.2011.557842
- Myhre G, Shindell D, Breon FM, Collins W, Fuglestedt J, Huang J, et al. (2013) Anthropogenic and natural radiative forcing. In: *Climate Change the Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge and New York
- Najafi Anari S, Khademol Hoseini N, Jazayeri K, Mirzade K (2008) Assessing of energy efficiency on broiler farm in the Ahvaz zone. In: *Proceeding of 5th National conference on agriculture machinery and mechanization*. Mashad, Iran. (In Persian)
- Nielsen NI, Jorgensen M, Bahmdorff S (2011) Greenhouse gas emission from the Danish broiler production estimated via LCA methodology. *AgroTech, Institute for Jordbrugs-og FødevarerInnovation, Denmark* http://www.lca-net.com/wp-content/.../110628_vfc_engelsk_vfl_layout_web.pdf/. (Accessed 22 Dec 2015)
- Pelletier N (2008) Environmental performance in the US broiler poultry sector: life cycle energy use and greenhouse gas, ozone depleting, acidifying and eutrophying emissions. *Agric Syst* 98:67–73. doi:10.1016/j.agsy.2008.03.007
- Pishgar-Komleh SH, Sefeedpari P, Rafiee S (2011) Energy and economic analysis of rice production under different farm levels in Guilan province of Iran. *Energy* 36:5824–5831. doi:10.1016/j.energy.2011.08.044
- Pishgar-Komleh SH, Omid M, Heidari MD (2013) On the study of energy use and GHG (greenhouse gas) emissions in greenhouse cucumber production in Yazd province. *Energy* 59:63–71. doi:10.1016/j.energy.2013.07.037
- Ramirez CA, Patel M, Blok K (2006) How much energy to process one pound of meat? A comparison of energy use and specific energy consumption in the meat industry of four European countries. *Energy* 31:2047–2063. doi:10.1016/j.energy.2005.08.007
- Sainz RD (2003) Livestock-environment initiative fossil fuels component: framework for calculation fossil fuel use in livestock systems. <http://www.fao.org/>. (Accessed 22 Dec 2015)
- Sefeedpari P, Ghahderijani M, Pishgar-Komleh SH (2013) Assessment the effect of wheat farm sizes on energy consumption and CO₂ emission. *J Renew Sust Energ* 5:023131. doi:10.1063/1.4800207
- Seguin F, van der Werf H, Bouvarel I, Pottiez E (2011) Environmental analysis of organic broiler production in France and improvement options. In: *proceeding of LCM 2011 conference, the dahlem cube*, Berlin, August 28–31
- Skunca D, Tomasevic I, Djekic I (2015) Environmental performance of the poultry meat chain—LCA approach. *Proc Food Sci* 5:258–261
- Weidema BP, Bauer Ch, Hirschier R, Mutel Ch, Nemecek T, Reinhard J, et al. (2013) The ecoinvent database: overview and methodology, data quality guideline for the ecoinvent database version 3. <http://cdiac.ornl.gov/>. (Accessed 22 Dec 2015)

- Williams AG, Audsley E, Sandars DL (2006) Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main Report. Defra Research Project IS0205. Cranfield University and Defra, Bedford <http://www.silsoe.cranfield.ac.uk> and www.defra.gov.uk/. (Accessed 22 Dec 2015)
- Xin H, Gates RS, Green AR, Mitloehner FM, Moore JPA, Wathes CM (2011) Environmental impacts and sustainability of egg production systems. *Poult Sci* 90(1):263–277. doi:10.3382/ps.2010-00877