



Assessment of environmental impacts of broiler farms using different indicators

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Abstract

This study aims to evaluate environmental impacts within farm boundaries in broiler production systems in Turkey. There have been calculated on three-stage assessing environmental impacts: carbon footprint and water footprint. The objectives were evaluated by taking into account 1 kg of chicken meat of the functional unit. Using three different methods (real-time gas concentration, Tier 1 approach, and life cycle assessment) the carbon footprint was evaluated. We obtained an average of 2.9 kg CO₂/functional unit for the carbon footprint using measured gas concentration data. Accordingly, with the Tier 1 method developed by Intergovernmental Panel on Climate Change, it has been shown that 5.1 kg CO₂ equivalent carbon footprint per functional unit occurs in the broiler farms. Based on the life cycle assessment, the emissions were 3 kg CO₂ equivalent per functional unit. The second stage of the study was the determination of water footprints in broiler production systems. The water footprint of farms was evaluated with SimaPro 8.2 software. According to the results, 0.003 m³ water/functional unit was obtained by considering the drinking water and using water amount in the production.

Keywords Carbon footprint · Water footprint · Environmental impacts · Broiler

Introduction

The world population is expected to reach 8.6 billion by 2030, 9.8 billion by 2050, and 11.2 billion by 2100, according to recent estimates by the United Nations (United Nations 2017). The increasing population in recent years, it causes increases in basic vital demands. An essential part of the daily nutrient requirement for balanced and healthy nutrition consists of proteins of animal origin. Poultry products are one of the most consumed animal-derived foods globally. It is estimated that the chicken population in the world will increase by 90% between 2005 and 2050 (Alexandratos and Bruinsma 2012; Cesari et al. 2017).

The chicken meat production in Turkey in 2020 was realized as 2 136 263 tons (TUIK 2021). The number of broiler production facilities in Bursa province is increased parallel to Turkey's broiler production sector's developments. Intensified companies increased their production capacity; more quality, modern and

systematic production chains started to be obtained. Turkey is ranked 10th globally with 342 801 000 whole eggs and broiler chickens (FAO 2017).

Competition in the use of limited resources such as land, water, and energy in livestock enterprises has increased. Emissions generated during all production stages severely impact air, water, and soil ecosystems (De Vries and De Boer 2010). These emissions cause various environmental problems such as eutrophication, acidification, energy use, ozone depletion, terrestrial toxicity, biotic and abiotic degradation in the natural environment (González-García et al. 2014; Leinonen et al. 2014; Cesari et al. 2017). There are studies conducted in different animal species using life cycle analysis to determine and investigate environmental natural resources consumption and environmental impacts during the production process. (Cottle and Cowie, 2016; Ghasempour and Ahmadi, 2016; Kalhor et al., 2016; Kheiralipour et al., 2017; Asem-Hiablie et al. 2019; Ramedani et al., 2019). Unlike other studies, different indicators were used together to determine environmental impacts in this study. In addition, the magnitude of the environmental effects that emerged with different indicators was compared.

The carbon footprint concept has emerged to determine the effects of emissions resulting from anthropogenic activities on global warming. The carbon footprint includes greenhouse gas

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emissions in terms of carbon dioxide equivalents. The International Panel Climate Change (IPCC) has developed Tier 1–2–3 methods to calculate the carbon footprint for a different level of data existence about the animal operations (IPCC 2006).

While water use is essential in every sector, this ratio has a more critical share for agricultural activities. With global water scarcity and food security concerns, the water footprint is an essential sustainability indicator for the agriculture and food sectors (Ridoutt et al., 2010). With intensive agriculture, increased water consumption and subsequent pollution of wastes threaten existing water resources. The concept of water footprint has emerged to determine the effects of water resource consumption and pollution. Hoekstra (2003) and Gerbens-Leenes et al. (2013) stated that the water footprint indicates water use related to consumer products. The water footprint coverage is determined by evaluating water consumption and water pollution.

The cumulative impact of these environmental pollutants derived from broiler houses will be the risk of the future destruction of resources and irreparable damages on the environment. It is crucial to carry out an environmental sustainability assessment to pollute the environment, protect resources, and ensure continuity in production. This study aimed to determine the environmental effects of 1 kg chicken meat production within the boundaries of broiler farms by using different environmental indicators.

Materials and methods

In this study, three broiler houses (House-1 [H1], House-2 [H2], House-3 [H3]) in Bursa, west of Turkey, were selected for the study that calculates environmental impacts. The broiler houses were selected from the Bursa region representing the structural specifications of the existing facilities in Turkey. General characteristics of broiler houses are given in Table 1. The number of birds was significantly different among broiler houses. H3 has the most broiler hens, while H1 has at least broiler hens. The light regime is similar in all houses. After daylight, the lighting system was turned on, and artificial lighting was started until arise sun. Feed formula applied for broilers was changed among monitored broiler houses. H3 uses feed with more protein intake than other broiler houses. Bird densities were 15 bird/m² for H1, 10 bird/m² for H2 and 30 bird/m² for H3.

System boundaries and functional unit of study

The system limits of the study were determined as all activities except the consumption of medicine from the introduction of the chicks and raw material to the exit of the chicken meat from the farm gate. Figure 1 shows the life cycle system limits of poultry meat production. This study determined the system boundaries as gate-to-gate system boundaries in the hen house (the section indicated by the dashed line in Fig. 1).

As a functional unit, 1 kg chicken meat was selected for calculating environmental impacts. Carbon footprint and water footprint have been evaluated consider 1 kg of chicken meat. When the studies on chicken meat production were examined, it was seen that 1 kg chicken meat was taken as a functional unit (Lesschen et al. 2011; González-García et al. 2014; Cesari et al. 2017).

Carbon footprint

The most critical gas emissions from broiler houses are NH₃, N₂O, CH₄, and CO₂. However, N₂O, CH₄, and CO₂ are greenhouse gases and cause global warming. These pollutant gases were included in the estimation of the carbon footprint. The N₂O and CH₄ gas emissions from monitored broiler houses are converted equivalence of CO₂ in calculating the carbon footprint.

While the carbon footprint calculation was carried out with this method, the resulting emissions from the broiler house were examined in two processes: emissions from production auxiliary systems and emissions from production. The emission sources from the auxiliary production systems in the monitored broiler operations; are the emissions from ventilation, cooling, lighting and electricity, and fuel consumption (diesel fuel + coal). Emissions from manure and litter material released from the broiler enterprises examined are included in the emissions from the production process.

Three different carbon footprint calculation methods were used in this study. In the first method, carbon footprints were calculated using measured gas concentrations in monitored broiler houses. In the second method, the Tier approach was used to estimate carbon footprint. The last method determined

Table 1 General characteristics of broiler houses

Broiler Houses	Breeding system	Capacity	Ventilation system	Manure Removal	Direction	Dimension
H1	Litter	10,000	Mechanical	Litter + Manure	North-East	12*34.3*2.45
H2	Litter	12,000	Mechanical + Natural	Litter + manure	North-East	12.5*100*2.9
H3	Litter	24,000	Mechanical	Litter + Manure	East–West	14.4*27.7*2.7



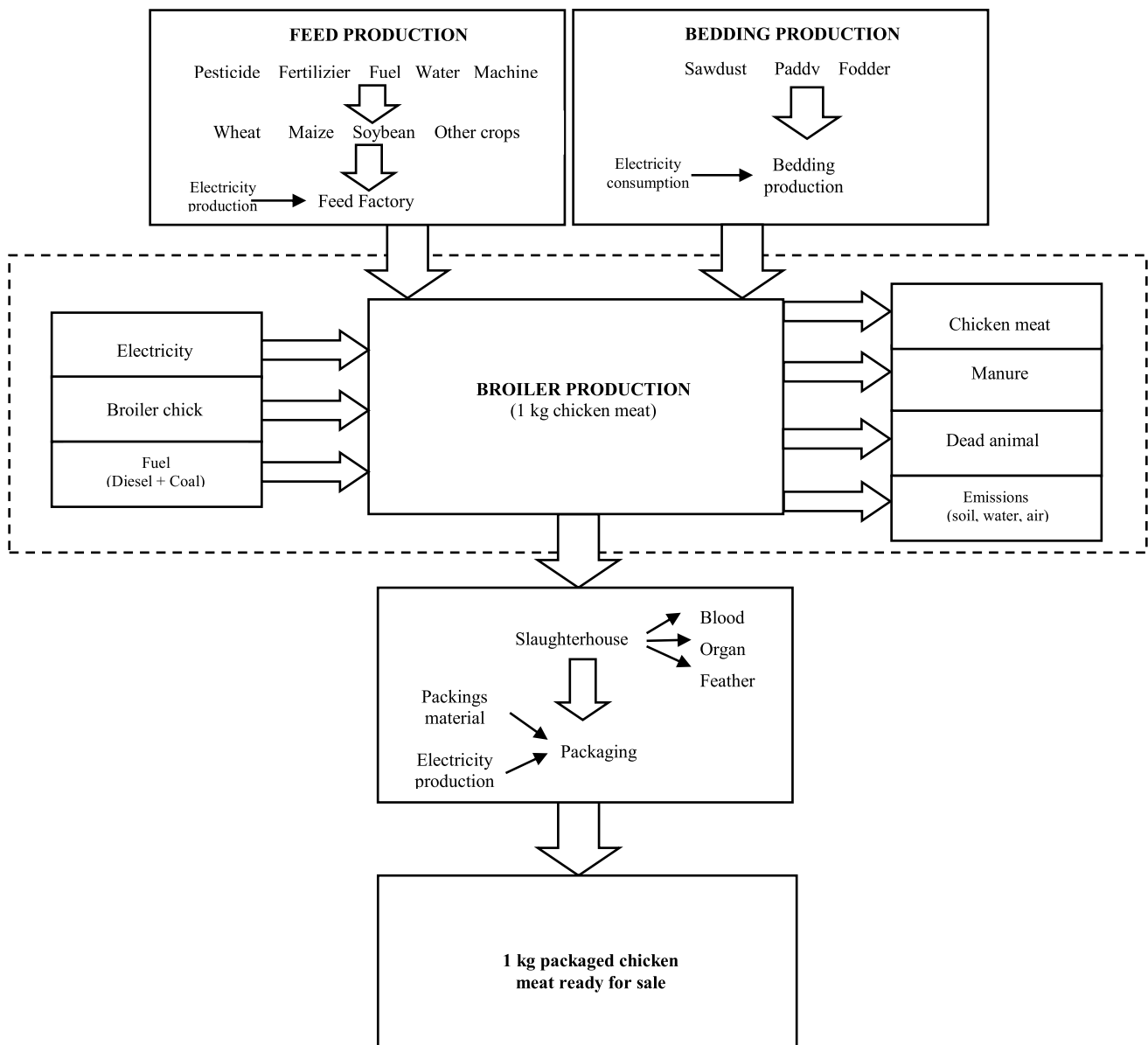


Fig. 1 Production process of chicken meat and system boundary of this study

the carbon footprint using a life cycle assessment based on a functional unit (1 kg chicken meat).

Method 1: real-time gas concentration data

In this method, carbon footprints are calculated using measured greenhouse gas emissions from monitored broiler houses. The greenhouse gas emissions were calculated using the gas concentrations measured in the broiler houses. When greenhouse gas emissions were calculated in this study, CO_2 and CH_4 gas concentration values were used by Kilic (2011) obtained from similar broiler houses. Kilic (2011) measured NH_3 , CO_2 , and CH_4 concentrations using a multi-gas monitor device (Model: Ibrid

MX6, Industrial Scientific Corporation, USA). Electrochemical sensors in multi-gas monitor devices measured three different gas concentrations. The gas concentration measurement was conducted continuously for 24 h every day for one year. The two gas monitor devices were located in the exhaust and inlet in each broiler house. Data logger in the gas monitor device stored all measured data. More detailed information can be found in Kilic (2011). Emission calculation was performed using measured greenhouse gas concentration values. The emission equation is given in Hinz and Linke (1998) was used in Eq. 1. Since N_2O concentrations could not measure in Kilic (2011), emission values were obtained from the studies conducted in the literature (Burns et al. 2008).

$$E = C \cdot Q \quad (1) \quad N_{ex(T)} = N_{rate(T)} \times (TAM/1000) \times 365 \quad (3)$$

where: E = Emission rate (g/h.farm), C_e = Gas concentration (g/m³), Q = Ventilation rate (m³/h.farm).

Method 2: tier approach

The data provided by IPCC were used for enterprise characteristics in this method. Tier equations under different headings in the IPCC report were used for CH₄ gas emissions and N₂O gas emissions from manure management. Since there is no Tier method and emission factor for carbon dioxide emission, an emission factor from a different study (Calvet et al. 2011) was used to calculate CO₂ emission. The equations used to calculate N₂O and CH₄ emissions from manure management are as follows:

N₂O emission equations: The N₂O emission calculation specified by the IPCC consists of two separate phases: direct and indirect emissions. The nitrogen excretion rate required for calculating this emission is given by region and various animal categories. The work area is considered the appropriate region in Eastern Europe in the IPCC 2006 guideline, and appropriate values for broilers are addressed (IPCC 2006).

Equation 2 and Eq. 3 were used to calculate direct N₂O emissions from farm manure management (IPCC 2006). In Eq. 2, $N_{ex(T)}$ was calculated Eq. 3 and found 0.803. EF_3 is came from Table 10.21 in IPCC report in 2006 and is 0.001 kg N₂O-N/kg N for broiler production on litter. For $MS_{(T,S)}$ in Eq. 2, dry manure storage and management was selected in relevant table in IPCC report.

$$N_2OD = \left(\sum_S \left(\sum_T (N(T) \cdot N_{ex(T)} \cdot MS_{(T,S)}) \right) \cdot EF_3(S) \right) \cdot (44/28) \quad (2)$$

where: $N_2OD_{(mm)}$ = direct N₂O emissions from Manure Management in the country, kg N₂O/yr; $N_{(T)}$ = number of head of livestock species/category T in the country; $N_{ex(T)}$ = annual average N excretion per head of species/category T in the country, kg N/ animal.yr; $MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the country, dimensionless; $EF_{3(S)}$ = emission factor for direct N₂O emissions from manure management system S in the country, kg N₂O-N/kg N in manure management system S; S = manure management system; T = species/category of livestock; 44/28 = conversion of (N₂O-N)(mm) emissions to N₂O(mm) emissions; The annual nitrogen excretion per animal required in Eq. 2 was calculated with Eq. 3. $N_{rate(T)}$ was taken 1.1 kgN/1000 animal weight.day from Table 3.6 in IPCC report in 2006.

where: $N_{ex(T)}$ = annual N excretion for livestock category T, kg N/animal.yr; $N_{rate(T)}$ = default N excretion rate, kg N/(1000 kg animal mass).day; $TAM_{(T)}$ = typical animal mass for livestock category T, kg/animal (2 kg per broiler hens in this study).

Indirect N₂O emissions from the enterprises are calculated with Eqs. 4 and Eq. 5 given as follows. EF_4 was taken as 0.01 kg N₂O-N/(kg NH₃-N + NO_x-N volatilized from Table 11–3 in IPCC report in 2006. $N_{volatilization-MMS}$ was calculated using Eq. 5.

$$N_2O_{G(mm)} = (N_{volatilization-MMS} \times EF_4) \times (44/28) \quad (4)$$

where: $N_2O_G(mm)$ = indirect N₂O emissions due to volatilization of N from manure management in the country, kg N₂O/yr; EF_4 = emission factor for N₂O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N₂O-N/(kg NH₃-N + NO_x-N volatilized); 44/28: Conversion of (N₂O-N)(mm) emissions to N₂O(mm) emissions; $N_{volatilization-MMS}$: Amount of manure nitrogen that is lost due to volatility of NH₃ and NO_x (kg N/year).

Since the NH₃ and NO_x found in Eq. 4 are volatile, the amount of nitrogen lost is calculated with Eq. 5. $Frac_{GasMS}$ in equation was taken 40% form broiler houses with litter in IPCC report in 2006.

$$N_{volatilization-MMS} = \left[\sum \left[\sum (N_{(T)} N_{ex(T)} MS_{(TS)}) \right] \left(\frac{Frac_{GasMS}}{100} \right)_{(TS)} \right] \quad (5)$$

where: $N_{volatilization-MMS}$ = amount of manure nitrogen that is lost due to volatilization of NH₃ and NO_x, kg N/yr; $N_{(T)}$ = number of head of livestock species/category T in the country; $N_{ex(T)}$ = annual average N excretion per head of species/category T in the country, kg N/ animal.yr; $MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the country, dimensionless; $Frac_{GasMS}$: Percentage of nitrogen manure managed by animal category based on volatility of NH₃ and NO_x in manure management system (%); $N_{rate(T)}$: Default nitrogen excretion rate (kg N/ (1000 kg animal weight).day).

CH₄ emission equations: CH₄ emissions include CH₄ emission calculations resulting from enteric fermentation and manure management according to the method set by the IPCC. However, since poultry is not ruminant, enteric fermentation is almost non-existent. Therefore the IPCC ignores the calculation of CH₄, which consists of enteric fermentation for poultry. In this part of the study, only CH₄ emissions from manure management were calculated. Equation 6 was used for calculation. $EF_{(T)}$ was taken 0.01 kgCH₄ /animal.year for Bursa, Turkey with 14.6 °C from IPCC report in 2006.



$$CH_{4\text{Manure}} = \sum_{(T)} \frac{(EF(T) * N(T))}{10^6} \quad (6)$$

where: $CH_{4\text{Manure}}$ = CH_4 emissions from manure management, for a defined population, Gg CH_4 /yr; $EF_{(T)}$: Emission factors (kg CH_4 /head.year); $N_{(T)}$ = the number of head of livestock species/category T in the country; T = species/category of livestock.

CO_2 emissions: In this study, the emission factor required for the CO_2 emission from the breathing and litter of broiler chickens were obtained from Calvet et al. (2011). Calvet et al. (2011) reported that a hen (30–33 days old) before slaughter produced 2.60 L of CO_2 per hour per metabolic kilogram weight.

Method 3: life cycle approach

In this method, greenhouse gas emissions from the life cycle of broiler production in the house are used within the system boundaries in chicken meat production (dashed line on Fig. 1). SimaPro 8.2 software was used in the calculations for life cycle assessment. Life cycle assessment is a powerful tool that is prevalently used in the agricultural sector, evaluates the environmental impacts by considering the inputs and outputs in the system, and increases the environmental performance in the production chain (Payandeh et al., 2017).

Water footprint

Water footprints of the broiler operations were determined in gate-to-gate system boundary by SimaPro 8.2 software. In this study, the amount of water consumed in the house was calculated using consumption rates on the water bills of the broiler farms.

Results and discussion

The same inputs and outputs were considered for all methods within the determined system boundaries in the broiler farms. Monitored broiler houses are similar structural specifications but there are differences overall production scale and management practices. Feed formula has little differences among broiler farms and number of broiler in the houses is also different.

Carbon footprints of monitored broiler operations

This study calculated the carbon footprint using data obtained from real-time gas measurements in broiler houses per functional unit. The monitored broiler houses' carbon footprint was obtained 0.11 kg CO_2 eq for H1, 0.17 kg CO_2 eq for H2, and 0.15 kg CO_2 eq for H3.

Figure 2 shows the contribution of the pollutant gas sources to the carbon footprint. Manure in the greenhouse gas (GHG) sources has the highest contribution percentage for the carbon footprint of monitored broiler houses. In addition, it is understood that the least contribution to the carbon footprint is came from electricity consumed for daily works in the broiler houses.

In Fig. 3, daily and annual carbon footprints of broiler houses are given. When the figure is examined, it is seen that the highest carbon footprint belongs to H3.

Carbon Footprint with Tier Approach: By selecting the appropriate parameters for the study, direct emissions resulting from the storage of manure and litter in the monitored broiler houses and indirect N_2O emissions in various ways such as leakage of manure into the soil and from there to water resources, and mixing of volatile organic compounds into the air were calculated by taking the values specified in the IPCC reports.

Overall average direct N_2O emissions from the monitored broiler houses were obtained 0.069 g N_2O / functional unit and 0.0035 g N_2O /chicken.day. The average indirect emissions were calculated as 0.28 g N_2O /kg chicken meat and 0.014 g N_2O /chicken.day. Total N_2O emissions were 0.35 g N_2O /functional unit and 0.017 g N_2O /chicken.day during study period. The direct and indirect N_2O emissions generated by the monitored broiler houses daily and annually basis are given in Fig. 4.

CH_4 emissions from dry manure management of broiler houses are given in Fig. 5. The broiler houses emitted 0.548 g CH_4 /functional unit and calculated to cause 0.0137 g CH_4 gas emission per day for a chicken.

CO_2 emissions from broiler houses were calculated using the CO_2 production rate of the broiler given Calvet et al. (2011). They were stated that the production of 2.6 L CO_2 was realized per 1 kg metabolic weight for the chicken. Considering this value, the CO_2 emission value per broiler was determined as 0.247 kg/day.chicken and 4.935 kg CO_2 per functional unit.

When the carbon footprints of the broiler houses are monitored, a carbon footprint of 0.253 kg CO_2 equivalent per chicken occurs per day, and a 5.051 kg CO_2 equivalent carbon footprint is produced per functional unit. In Fig. 6, the carbon footprint of monitored broiler houses is given based on the day and year.

Carbon Footprint with Life Cycle Approach: In this method, SimaPro software calculated carbon footprint. The software identifies carbon footprints based on the product's life cycle. Carbon footprints per functional unit are included emissions from house, manure, electricity, and fuel consumption. While indirect emissions are generated from energy sources such as electricity, fuel, and coal consumption, direct emissions include broiler hens and manure (Fig. 7). According to life cycle assessment results, carbon footprint per functional unit of H1, H2, H3 were obtained 2.34 kg CO_2 eq, 3.6 kg CO_2 eq, and 3.1 kg CO_2 eq, respectively. The carbon footprint per day was calculated as 0.12 kg CO_2 eq for H1, 0.18 kg CO_2 eq for H2, and 0.16 kg CO_2 eq for H3.



Fig. 2 The contribution of GHG sources to carbon footprint

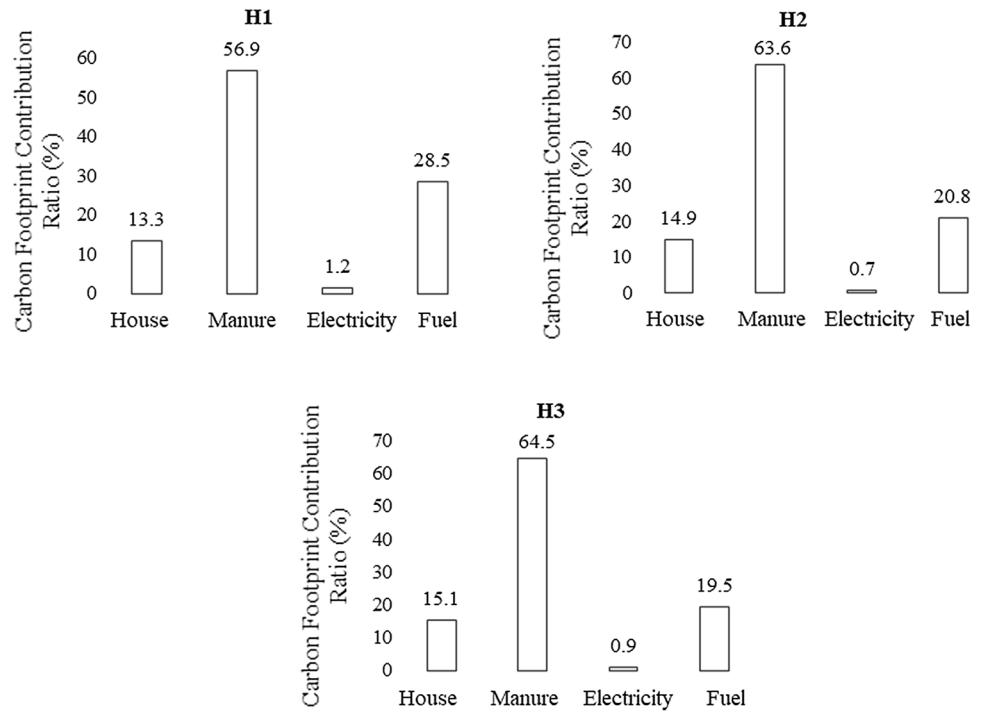
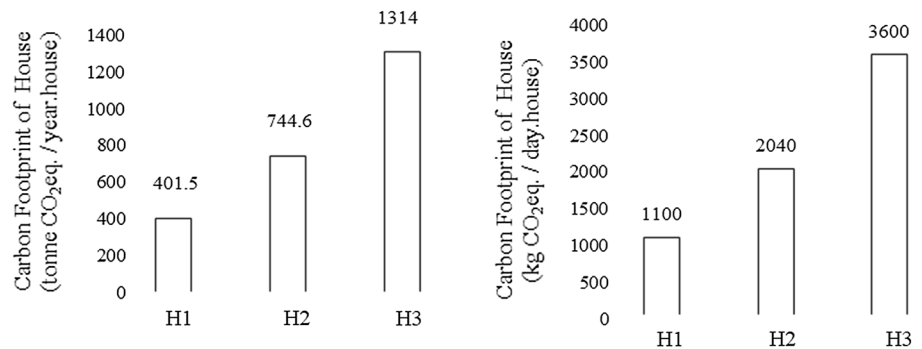


Fig. 3 Carbon footprint of broiler houses based on gas concentrations



The daily and annual carbon footprints of broiler farms were given in Fig. 8. When the figure was examined, it was seen that H3 has the highest carbon footprint.

Ibidhi et al. (2017) investigated the carbon footprint of 1 kg of poultry meat in an industrial poultry farm in Tunisia. Emissions from feed production, manure management, transportation, and operation realized in the slaughterhouse are considered within the system boundaries. At the end of the study, they stated that they have a carbon footprint equivalent to 3 kg CO₂ for 1 kg chicken meat.

Water footprints of monitored broiler farms

The water consumed by the chickens and used in the monitored broiler houses was considered to calculate water footprints. This study evaluated only blue water footprint because it was considered in farms, and city mains water was used. The

average blue water footprint per functional unit was calculated 0.003 m³ or 3 L by using the total amount of water consumed by the chickens and used for cleaning in the house. Based on this value, the blue water footprint per chicken was 0.15 L per day. When the monitored broiler houses' annual and daily blue water footprints were evaluated, it was seen that H3 has the highest water footprint with 1314 m³/year and 3.6 m³/day, respectively (Fig. 9).

Environmental impacts of monitored broiler houses

In this paper, other critical environmental impacts are also presented besides calculating the carbon footprint and water footprint of monitored broiler farms. SimaPro 8.2 software and Eco-invent database enable the determination of the carbon footprint and the environmental impact. According to the



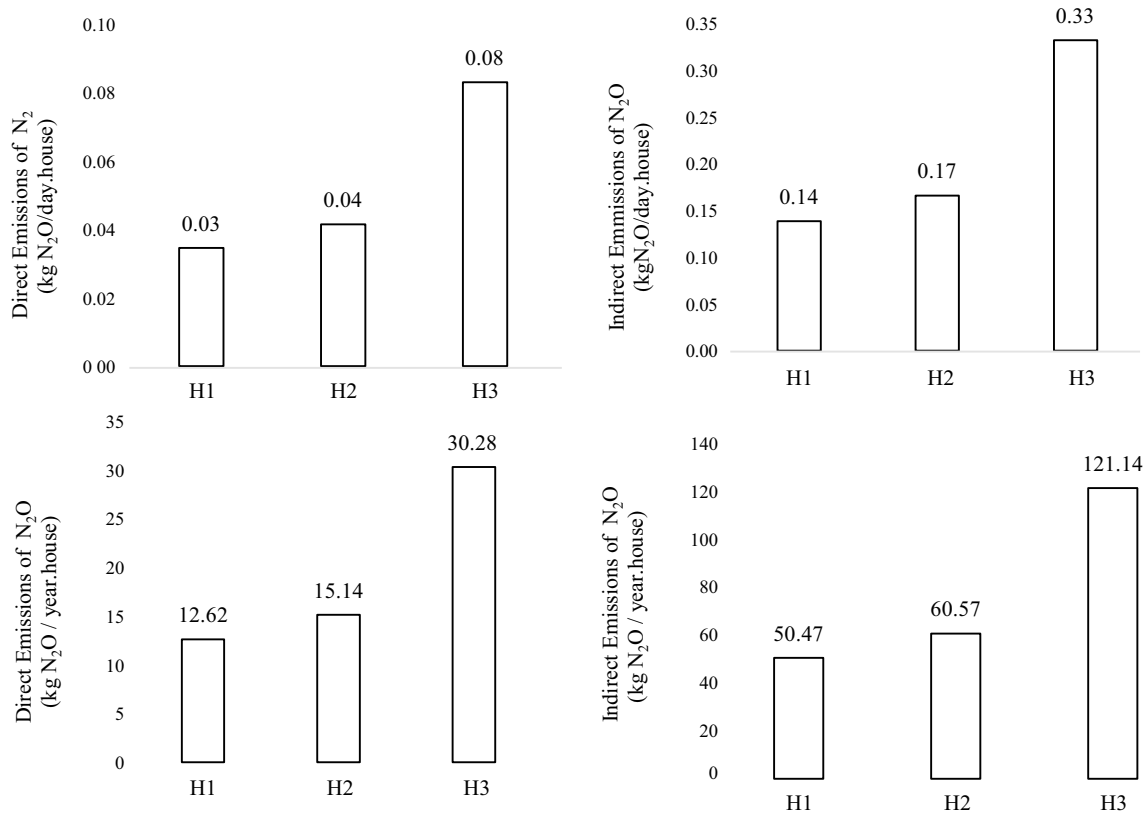


Fig. 4 Direct and indirect N₂O emissions of broiler houses

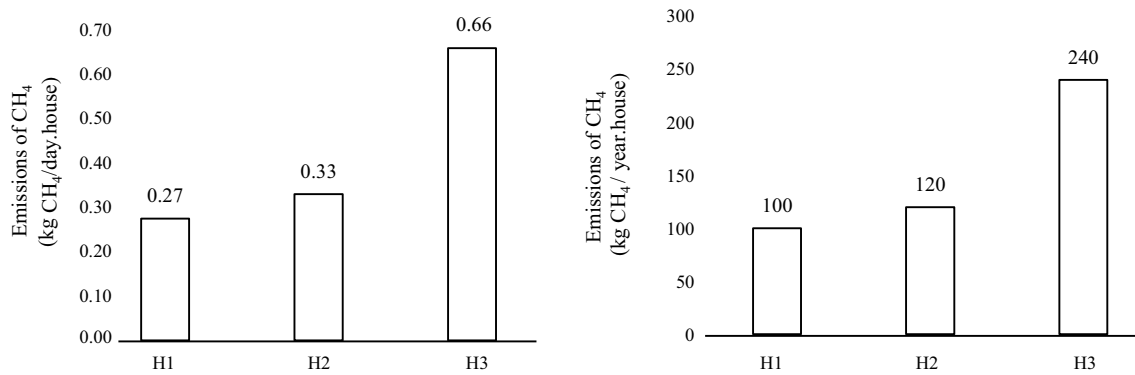


Fig. 5 CH₄ emissions of broiler houses

life cycle assessment results, crucial environmental impact categories for broiler houses were determined as acidification, eutrophication, ozone depletion, photochemical oxidation potential, and human toxicity potential (Table 2).

In monitored H1, human toxicity was the highest environmental impact category with maximum impact potential value (0.0776 kg DCB equivalent/functional unit). The effect of H1 was minimum level on ozone depletion (2.23E-09 kg R11/equivalent unit ozone depletion).

When the environmental impacts of emissions from the H2 operation are examined, it has the highest effect on human toxicity potential with 0.0518 kg DCB equivalent per functional unit. The least effect is 1.49E-09 kg R11 equivalent/functional unit ozone depletion.

The maximum environmental impact in H3 was on the human toxicity potential with 0.078 kg DCB equivalent per functional unit. Minimum effect was 2.23E-09 kg R11 equivalent/functional unit ozone depletion in H3.



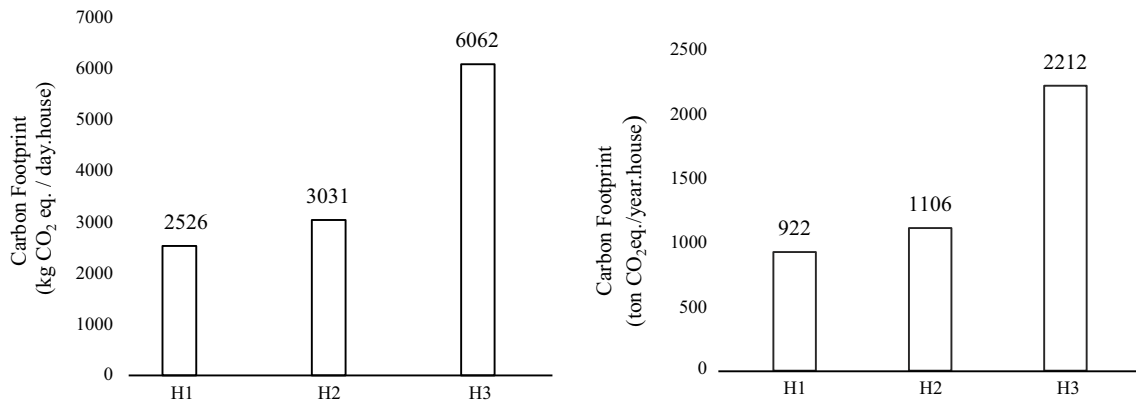


Fig. 6 Carbon footprints of broiler houses according to Tier 1 approach

Fig. 7 Carbon footprints by source of broiler houses

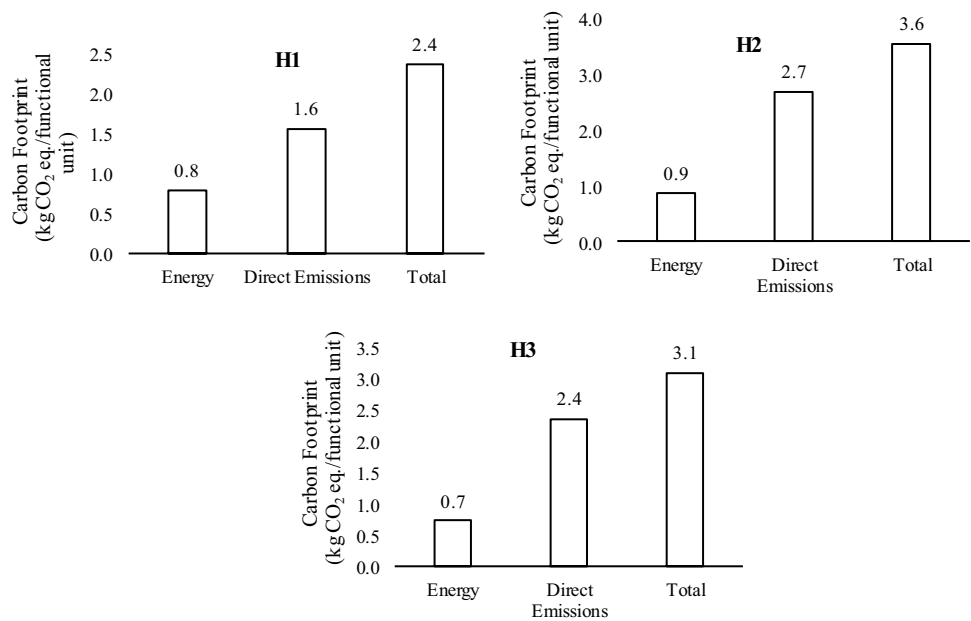
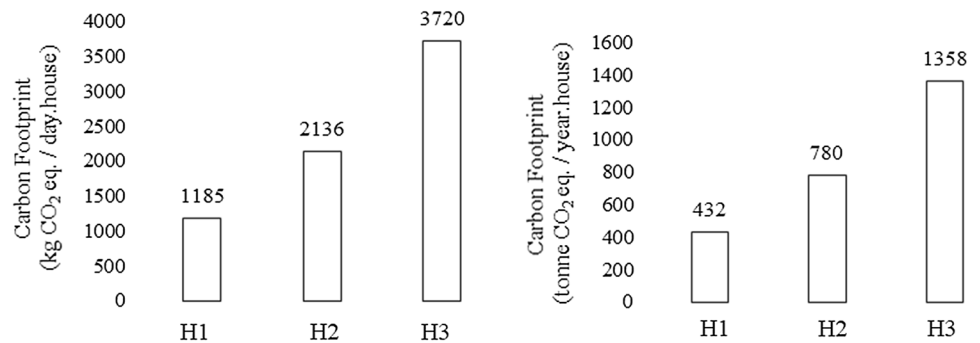


Fig. 8 Carbon footprints of broiler houses



When the results of environmental impact assessments are examined, human toxicity potential observed in all broiler houses. The least significant environmental impact was ozone depletion.

Gonzalez-Garcia et al. (2014) conducted an environmental assessment of chicken meat production throughout the life cycle in Portugal. The functional unit was 1.2 kg packaged meat, widely sold in Portuguese markets considering the

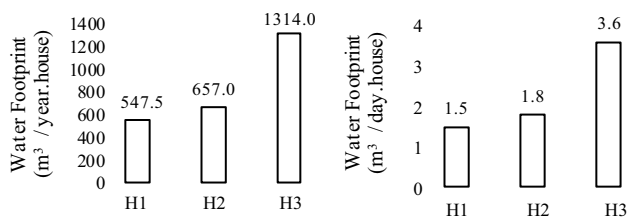


Fig. 9 Water footprints of broiler houses

average live weight of 1.2 kg of chicken for the farms at the farm's boundaries (not including the slaughterhouse). At the end of the study, the global warming potential was calculated as 2.7 kg CO₂ equivalence per functional unit.

The average carbon footprints obtained from all the methods for broiler farms were obtained 3.2 kg CO₂ equivalent for H1, 4.0 kg CO₂ equivalent for H2, and 3.7 kg CO₂ equivalent for H3 per functional unit.

Conclusion

As a result of the study, it was observed that the number of animals in the farms had a significant effect on gas emissions and water consumption. In addition, the increase in electricity and fuel use increases the greenhouse gas emissions to the extent required by chicken welfare in-house.

Since all broiler chickens grown in the farms were the same species, no comparison could be made according to the species. When the monitored broiler houses are evaluated for their dimensional characteristics, the larger house contributes to the water footprint due to the higher amount of water used for consumption of broiler, leakage of water systems, and cleaning of farm office area in the same building.

The carbon footprints of the broiler farms monitored during a year study period were determined by three different methods. As a result of the calculation method with real-time gas concentration measurement data, 2.2, 3.4, and 3.0 kg CO₂ equivalents per functional unit were obtained for the carbon footprint H1, H2, and H3 in total.

The second method was The Tier 1 approach used to determine the carbon footprint of the broiler farms. While using Tier 1 equations for nitrous oxide and methane gases, CO₂ gas was

calculated from a study in the literature. Direct and indirect N₂O emissions from manure management per functional unit were 0.00035 kg, while CH₄ emissions were 0.000548 kg CH₄/functional unit values. CO₂ emissions from chickens were 4.935 kg per functional unit—carbon footprint per functional unit the equivalent of 5.051 kg of CO₂.

According to the life cycle approach method, carbon footprint for H1, H2, H3 is 2.37 kg CO₂ eq, 3.56 kg CO₂ eq and 3.10 kg CO₂ eq per functional unit, respectively.

When the three different methods used in calculating the carbon footprint were compared, the highest carbon footprint value was obtained by the Tier 1 approach. The use of more data and parameters for the Tier 1 method has led to a more excellent reflection of the parameters affecting the carbon footprint on the calculations and the highest carbon footprint value. For other methods, real-time measured gas concentrations and life cycle approach methods have similar results.

In this study, the mean of average carbon footprints of the broiler production in Bursa province was calculated as 845 ton CO₂ equivalent and the carbon footprint of broiler production in the Marmara region one of the seven geographic regions included Bursa city was calculated as 19 497 ton CO₂ equivalent. Turkish Statistical Institute presented broiler chicken number in Turkey as 230 million for the 2018 year. Therefore, using similar methods determined that the carbon footprint of broiler production in overall Turkey was 41 311 tonnes of CO₂ equivalent a day.

The annual water footprints of the monitored broiler houses were calculated 547.5 m³ for H1, 657 m³ for H2, and 1314 m³ for H3. The daily water footprints were 1.5 m³, 1.8 m³, and 3.6 m³ for H1, H2, and H3, respectively. In addition to the calculated water footprint of monitored broiler houses may be shown local water scarcity, waste assimilation capacity, and environmental impacts of water use. The water footprint of monitored broiler farms should be reduced due to Turkey's among water-constrained countries. Rainwater may be an alternative, and it can be used as water for daily works in the broiler houses. Depending on the dimensional characteristics of the monitored broiler houses, it is optimistic that the large roof surface area has sufficient rainwater collection. It is recommended to design rainwater-harvesting systems in the monitored broiler houses, especially in areas with high annual rainfall.

Table 2 Environmental impacts for functional unit in broiler houses

Environmental Impacts	Broiler Houses		
	H1	H2	H3
Acidification Potential (kg SO ₂ eq./f.u.)	4.74E-04	3.16E-04	4.74E-04
Eutrophication Potential (kg PO ₄ eq./f.u.)	6.49E-04	4.33E-04	6.49E-04
Ozone Depletion (kg R11 eq./f.u.)	2.23E-09	1.49E-09	2.23E-09
Photochemical Oxidation Potential (kg C ₂ H ₄ eq./f.u.)	1.88E-05	1.25E-05	1.88E-05
Human Toxicity Potential (kg DCB eq./f.u.)	7.76E-02	5.18E-02	7.76E-02

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Authors' contributions IK designed the research. IK arranged the monitored broiler houses. IK collected data and conducted field measurements. BY analyzed the data. IK and BY wrote the manuscript. All authors read and approved the manuscript. IK reviewed the final manuscript for English language.

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Data availability The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare no conflict of interest.

Consent for publication Not applicable.

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