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RESEARCH PAPER

Estimation of enteric and manure-derived methane emissions in sheep and goats in Ankara Province

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Abstract

Since livestock account for most of Türkiye's agricultural greenhouse gas emissions, strategies for estimating livestock emissions must be developed. Methane emissions per animal category were estimated in this study using the Intergovernmental Panel on Climate Change (IPCC) Tier 2 method for enteric and manure methane (CH_4) emissions in two sheep breeds (Akkaraman and Anatolian Merino) and three goat breeds (Hairy, Angora, Saanen) raised in Ankara province, Türkiye. Average enteric CH_4 emission factor (EF) was 9.61 kg CH_4 head^{-1} yr^{-1}, with the highest value of 10.86 kg CH_4 head^{-1} yr^{-1} in Hairy goats, and lowest 8.55 kg CH_4 head^{-1} yr^{-1} in Anatolian Merino. Estimated gross energy (GE) was highest in Hairy goats (30.10 MJ head^{-1} day^{-1}), and lowest in Anatolian Merino (21.73 MJ head^{-1} day^{-1}). Average dry matter intake (DMI) was 1.40 kg DM head^{-1} day^{-1}. The total average volatile solids (VS) excretion was estimated at 0.95 kg DM head^{-1} yr^{-1}, and the average methane emission factor (EF) for animal manure was 0.46 kg CH_4 head^{-1} yr^{-1}. Total mean VS estimate was twice as much as the IPCC default values, and the CH_4 EF for animal manure was higher than the IPCC default values. The current study's estimates will be helpful in the creation of the national methane inventory. In case more detailed data are collected to improve population data, subcategories may be expanded, and subgroups may vary by region.

Introduction

The average temperature on Earth's surface has increased by 0.6 °C since the beginning of the industrial era, and this increase is projected to reach an additional 1.4-5.8 °C by the year 2100 (FAO, 2006). The Kyoto Protocol has set a limit for countries worldwide to reduce their emissions by 8-10% of the 1990 emissions as a milestone (FAO, 2006). One powerful greenhouse gas (GHG) that causes global warming is methane (CH_4). The main causes of CH_4 emissions from animals are enteric fermentation and manure management. Approximately 18% of greenhouse gas emissions in the world are attributed to the livestock

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sector (Steinfeld et al., 2006; EPA, 2023). An estimated 2.2 billion tons of CO_2 equivalent are released by livestock each year, making up over 80% of agricultural CH_4 emissions and 35% of all anthropogenic CH_4 emissions (Soren et al., 2017). In Türkiye, inventories of methane emissions from enteric fermentation and manure management have been reported by TÜİK, (2018) following the methodology of Intergovernmental Panel on Climate Change (IPCC, 2006). In total, 37% of methane emissions originate from livestock farming (FAO, 2006). In Türkiye's agricultural sector, methane (CH_4) emissions originating from enteric fermentation account for approximately 48%, while those from manure management contribute 11.2% (TUIK, 2018). Hydrogen generation, a crucial step before methane is formed in the rumen, is enhanced by high concentrations of structural carbohydrates. High acetic and butyric acid production increases hydrogen generation, whereas non-structural carbohydrates, such as starch and sugars, reduce hydrogen formation (Aguilera and Molina-Alcaide, 2021). Including alternative roughages (Blepharis scindica herbage) in the diet of ewes could be a promising approach to reduce enteric methane emissions up to 49.3%, from 14.9 to 6.9 kg CH_4 head^{-1} yr^{-1} in Malpura ewes (Bhatt et al., 2021). The addition of olive cake (Aguilera and Molina-Alcaide, 2021), soybean oil (Lima et al., 2019), selected tropical tree leaves supplementation (Malik et al., 2017) reduces enteric CH_4 emissions in sheep.

Most of the nutrients required by sheep are obtained from grazing resources, as they are primarily raised on rangelands. Improving the nutritive value of feeds may significantly improve flock productivity and feed efficiency, and decrease enteric methane emissions (Hristov et al., 2013; Johnson and Johnson, 1995). Dry matter intake (DMI) is the major determinant of enteric CH_4 production and, consequently, the most important variable for predicting enteric CH_4 production in sheep (Aguilera and Molina-Alcaide, 2021). The methane production potential (B_0), also referred to as the maximum methane production capacity, of manure varies depending on the animal species and diet (IPCC, 2019 ref). The methane conversion factor (MCF) defines the proportion of B_o obtained. Theoretically, the MCF varies between 0-100%. Temperature and retention time are important in the calculation of MCF. Manure in liquid form, in hot conditions and kept for a long time, produces more methane. In such manure management systems, the MCF varies between 65-80%. Dry manure has an MCF of about 1% under cold conditions. In the Tier 2 system, the average MCF should be calculated according to the manure management system for each climate zone. The MCF is then multiplied by VS and B_o. The assumed MCFs for each manure management system were developed from previous studies; the inclusion of additional studies on methane production under various management scenarios may increase the accuracy of these factors (IPCC, 2019).

The selection of greenhouse gas estimation method depends on factors such as emission sources, research objectives, desired accuracy, and availability of financial resources (Bhatta et al., 2007). Direct measurements are not always possible, especially when estimations apply to large areas such as regions, countries, or even continents. Indirect methods are preferred for large areas. Inventories, equations, and mathematical models allow the estimation of greenhouse gas emissions when considering large numbers of animals and farms (Storm et al., 2012). IPCC guidelines (IPCC, 2006) are accepted as standard methods for emission estimation for each production sector. The IPCC method offers three levels of analysis, called Tier 1, Tier 2 and Tier 3. The choice of Tier depends on the availability of the information requested for the calculations and the size of the system considered. Estimations referring to large areas such as continents and nations are usually carried out by applying Tier 1 and Tier 2. Tier 3 is usually applied to limited areas or even to single entities such as industries or farms. Given the high variability in ruminant production systems (due to breeds, production direction, geographical and environmental conditions, available feeds, management, etc.), a simplified approach should be sufficient for initial estimates in most countries (Zervas and Tsiplakou, 2012).

In this study, the Tier 2 method recommended by the IPCC, (2019) was applied to estimate enteric and manure-derived CH_4 emissions in two sheep breeds (Akkaraman and Anatolian Merino) and three goat breeds (Hairy, Mohair, and Saanen) commonly raised in Ankara Province in Türkiye.

Materials and Methods

Field study

The enterprises were determined according to the density, diversity, and production systems of livestock operations in the districts of Ankara Province. A total of 25 sheep and goat enterprises were visited across the province of Ankara. Average values were obtained from data collected through surveys and on-site observations, scientific publications, and information provided by the Ministry and breeder associations.

Methodology

The method for estimating gross energy (GE) consumption for animal categories is given below.

GE = [(NEm+NEa+NEl+NEp) / REM) + (NEg+NEw) / REG)] / DE

Explanation of the terms in the model;

GE: Gross energy, (MJ $head^{-1}$ day^{-1}),
NEm: net energy for maintenance, (MJ $head^{-1}$ day^{-1}),
NEa: net energy for activity, (MJ $head^{-1}$ day^{-1}),
NEl: net energy for lactation, (MJ $head^{-1}$ day^{-1}),
NEp: net energy for pregnancy, (MJ $head^{-1}$ day^{-1}),
NEg: net energy for growth, (MJ $head^{-1}$ day^{-1}),
NEw: net energy for wool/mohair, (MJ $head^{-1}$ day^{-1}),
DE: digestible energy fraction of GE (DE/GE %)

The method for estimating emission factors (EF) for animal categories is given below.

EF = [GE * (Y*m*/100) *365] / 55.65 (kg CH_4 $head^{-1}$ yr^{-1})

Explanation of the terms in the model;

EF: Emission factor (kg CH_4 $head^{-1}$ yr^{-1}),
Ym = methane conversion factor (%)

Estimating dry matter intake (DMI)

Dry matter intake (DMI) was estimated by dividing the gross energy (GE) requirement of each animal subcategory by the assumed dietary energy density (18.45 MJ kg^{-1} DM), following IPCC (2019).

Manure characteristics

The two main factors—volatile solids (VS) and the maximum methane production capacity (B_0)—have a significant effect on methane emissions. Reference B_0 values of 0.19 for sheep and 0.18 for goats were obtained from the IPCC (2019) guidelines. In this study, IPCC default values were used for methane conversion factor (MCF), in which MCF values for dry storage and pasture systems ranged from 0.47% to 4.0%, depending on the climate zone.

The method to estimate manure-derived emission factors (EF) for each animal category is given below.

EF(T) = (VS(T) x 365) x [Bo(T) x 0,67 kg m^{-3} x ∑ S,k MCFS, k / 100 x MS(T, S, k)]

Explanation of the terms in the model;

$EF_{(T)}$ = emission factor of animal manure for animal category *(T)*, (kg CH_4 $head^{-1}$ yr^{-1}),
$VS_{(T)}$ = volatile solid excretion of animal category *(T)* (kg CH_4 $head^{-1}$ day^{-1}),
$B_{o\ (T)}$ = maximum CH_4 producing capacity for each category,
0.67 = conversion factor from m^3 CH_4 to kg CH_4,
$MCF_{S,\ k}$ = methane conversion factor for manure management system *(S)*, %,
MS (T, S, k) = animal waste management system.

Climate class

Ankara has a Mediterranean climate according to the Köppen–Geiger climate classification, with hot, dry summers and cold winters. Recent observations indicate that the annual average precipitation is 387 mm, indicating a semi-arid climate over the long term (Danandeh et al., 2020). The average number of rainy days is 104, with an mean maximum temperature of 17.8 °C, an mean minimum temperature of 6.3 °C, and a mean annual temperature of 11.9 °C (Arslan and Bağdatlı, 2021).

Results and Discussion

The activity data for sheep and goats, along with the estimated GE, DMI, and enteric EF values, are presented in Table 1. The average live weight (LW) was 49.7 kg $head^{-1}$ for the breeds studied. Average lactation milk yield (LMY) was 133.4 kg per lactation, and fiber (wool/mohair) production averaged 2.73 kg $head^{-1}$ yr^{-1}. The mean enteric EF was 9.61 kg CH_4 $head^{-1}$ yr^{-1}, with

Table 1. Activity data and estimated GE, DMI, and enteric CH_4 emission factors for sheep and goat breeds

Breed	LW	LMY	Wool/mohair	Litter size	GE	DMI	EF
Akkaraman	51.08	78.77	2.25	1.18	23.68	1.28	9.32
Anatolian Merino	52.08	76.00	3.25	1.40	21.73	1.18	8.55
Angora goat	43.30	73.25	2.67	1.13	25.06	1.36	9.04
Hairy goat	50.65	115.50	-	1.15	30.10	1.63	10.86
Saanen goat	51.38	323.67	-	1.60	28.55	1.55	10.30
Mean	49.7	133.4	2.73	1.29	25.82	1.40	9.61

LW: live weight (kg $head^{-1}$), LMY: lactation milk yield, GE: gross energy (MJ $head^{-1}$ day^{-1}), DMI: dry matter intake (kg DM $head^{-1}$ day^{-1}), EF: enteric emission factor (kg CH_4 $head^{-1}$ yr^{-1})

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the highest value of 10.86 kg CH_4 head^{-1} yr^{-1} in Hairy goats and the lowest value of 8.55 kg CH_4 head^{-1} yr^{-1} in Anatolian Merino sheep. Estimated GE was highest in Hairy goats (30.10 MJ head^{-1} day^{-1}) and and lowest in Anatolian Merino sheep (21.73 MJ head^{-1} day^{-1}). Average DMI was 1.40 kg DM head^{-1} day^{-1}.

Table 2 shows the average VS excretion and the CH_4 emission factor (EF) for animal manure in comparison with the IPCC default values. The mean VS estimate was twice as much as the IPCC default values, and the CH_4 EF for animal manure was also higher than the IPCC default value. The total average VS excretion was estimated at 0.95 kg DM head^{-1} day^{-1}, and the average CH_4 EF for animal manure was 0.46 kg CH_4 head^{-1} yr^{-1}.

Table 2. Estimated values and IPCC default factors for volatile solids (VS) and CH_4 emission factors from animal manure

Breed	VS	EF	PCC	
			VS	EF
Akkaraman	0,83	0,45	0,42	0,39
Anatolian Merino	0,82	0,36	0,43	0,34
Angora goat	0,88	0,32	0,39	0,22
Hairy goat	1,06	0,38	0,46	0,35
Saanen goat	1,15	0,77	0,46	0,46
Mean	0,95	0,46	0,43	0,35

VS: volatile solids (kg DM head^{-1} day^{-1}), EF: emission factor (kg CH_4 head^{-1} yr^{-1})

The activity data of the studied breeds were selected from peer-reviewed journals. Therefore, breed-specific phenotypes were collected through a review of published articles. Published data were used for Akkaraman sheep (Dellal et al., 2002; Dağ et al., 2000; Şireli, 1996; Gürsoy, 2006; Altın, 2001; Esen and Özbey, 2002; Kahraman and Yüceer, 2020; Aşkan and Aygün, 2020; Çolakoğlu and Özbeyaz, 1999; Özmen et al., 2015), for Anatolian Merino (Boztepe, 2013; Tuncer and Cengiz, 2018; Aktaş et al., 2016), for Angora goat (Vatansever and Akçapınar, 2006; Erol, 2012, 2014, 2017; Yertürk and Odabaşoğlu, 2007), for Hairy goat (Koyuncu, 1990; Şam et al., 2024; Erten and Yılmaz, 2013; Erişir and Gürdoğan, 2004), and for Saanen goat (Bolacali and Kucuk, 2012; Tölü et al., 2009, 2010; Ceyhan and Karadağ, 2009; Peşmen, 2005; Aktaş et al., 2012). After the review, the GE, DMI and EF for enteric fermentation were estimated. For example, the IPCC (2019) default live-weight values for sheep and goats are 40 and 36 kg, respectively. In this study, LW values were determined based on values reported in the literature (Table 1). The LW values of the sheep and goat breeds were higher than the IPCC (2019) default values.

According to the IPCC (2019), Tier 1 enteric CH_4 EF values were reported as the IPCC (2019) as 9 and 5 kg CH_4 head^{-1} yr^{-1} for high (40 kg LW) and low (31 kg LW) production systems, respectively. Methane EF values were reported as 12.5 and 0.22 kg CH_4 head^{-1} yr^{-1} for enteric and manure emissions, respectively, in grazing sheep in Australia (Bell et al., 2012). The enteric CH_4 EF was reported as 6.68 kg CH_4 head^{-1} yr^{-1} for sheep with an LW of 48.7 kg (Patra et al., 2016). Patra and Lalhriatpuii (2016), who aimed to explain methane emissions based on diet dynamics through 42 scientific studies conducted on goats, reported enteric methane emissions of 14.3 g head^{-1} day^{-1} (equivalent to 5.2 kg CH_4 head^{-1} yr^{-1}). Zhou et al. (2007) reported average enteric methane emissions for sheep and goats as 5.34 and 4.62 kg CH_4 head^{-1} yr^{-1} under Chinese national conditions. In this study, the mean GE, DMI, and enteric EF were 25.82 MJ head^{-1} day^{-1}, 1.40 kg DM head^{-1} day^{-1}, and 9.61 kg CH_4 head^{-1} yr^{-1}, respectively.

Two experiments with twelve rams of the autochthonous Segureña breed (initial average body weight, BW) 40.2 ± 0.75 kg were conducted. GE was 18.8 MJ kg^{-1} DM, and GE intake was 12.09 MJ day^{-1} (Aguilera and Molina-Alcaide, 2021). GE intake ranged from 20 to 23 MJ day^{-1} with 74% GE digestibility under Australian pasture conditions (Bell et al., 2012). GE intake was estimated at 16.3 MJ day^{-1} (Patra et al., 2016). Dry matter intake was 1.06 kg DM head^{-1} day^{-1}, and DM digestibility ranged between 65% and 72% in Malpura ewes (LW: 35 kg) (Bhatt et al., 2021). DMI ranged from 1.22 to 1.28 kg DM head^{-1} day^{-1} in Santa Inês crossbred intact male sheep in Brazil (Lima et al., 2019). In this study, the lowest GE estimate was 21.73 MJ head^{-1} day^{-1}.

Moeletsi and Tongwane (2015) reported VS excretion under South African conditions as 0.40 and 0.30 kg VS head^{-1} day^{-1} for sheep and goats, respectively. Zhou et al. (2007) reported average manure methane emissions of 0.10 and 0.13 kg CH_4 head^{-1} yr^{-1} for sheep and goats, respectively. In this study, the mean VS estimate was twice as much as the

IPCC default values, and the manure CH_4 EF was also higher than the IPCC default values (Table 2). However, most of the EF values from animal manure were only slightly higher than the IPCC defaults. The IPCC (2019) report presented regional averages for animal waste management systems (AWMS) of 54% and 46% for sheep and goats, respectively, and 9% and 91% for landfills and pastures, respectively. In this study, solid storage and pasture AWMS differed among the studied breeds. The combined results of the experimental data and this study indicated higher VS output and higher EF values under the studied manure management systems.

There is a need to develop methods that are globally recognized and applicable in Türkiye to reduce greenhouse gas emissions. For example, the use of specific feed additives in animal diets can reduce emissions originating from enteric fermentation. More importantly, high-quality feeds can substantially decrease emissions. The use of high-yielding breeds or intensive livestock production systems results in lower greenhouse gas emissions compared with extensive or pasture-based systems. Breeds with high productivity and feed efficiency produce greater output per animal, which in turn reduces natural resource use and CH_4 emissions. In Türkiye, raising high-yielding breeds and their crossbreds under appropriate feeding conditions is considered one of the most important strategies for mitigating greenhouse gas emissions.

The choice of a greenhouse gas estimation method depends on several factors. Indirect methods, such as inventories, equations, and mathematical models, enable the estimation of greenhouse gas emissions when large numbers of animals and farms are considered (Storm et al., 2012). The IPCC offers three analytical levels—Tier 1, Tier 2, and Tier 3—as standard emission estimation approaches for each production system or animal category. The choice of Tier depends on the availability of the data required for calculations and the scale of the system under consideration. Given the high variability present in ruminant production systems, a simplified approach may be sufficient for initial estimates in Türkiye.

Conclusions

The current study's estimates will be useful in developing the national methane inventory. If more detailed data are collected to improve population statistics, additional subcategories may be added, or existing subgroups may differ among regions. There may be uncertainties or assumptions with limited empirical support in the existing population and performance data. Therefore, the inventory framework used in this study can serve as a tool for continuous estimation and for updating data management systems. Performance data directly influence the estimation of gross energy (GE), dry matter intake (DMI), and volatile solids (VS), serving as fundamental parameters in livestock subcategory assessments. Consequently, the estimation of national enteric methane emissions by livestock subcategory should be conducted in accordance with the Tier 2 methodology.

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Author Contribution

M.Y.: Project Administration, Conceptualization, Investigation, Methodology, Software, Resources, Data Curation, Writing-Original Draft Preparation, Visualization, Supervision. **A.E.:** Investigation, Methodology, Software, Writing – Review & Editing. **M.F.Y. and V.D.:** Investigation, Formal Analysis. **E.K. and S.B.:** Investigation, Methodology, Formal Analysis. **E.Ü.:** Investigation, Methodology, Software. **M.İ.C. and R.S.:** Investigation, Methodology.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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