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Research Article

Estimation of CH_4 Emissions and Global Warming Potential of Marmara Region Small Livestock Sector with 2019 Refinement IPCC Tier-2 Method

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Abstract: Livestock production is predominantly conducted in intensive farming operations, where large-scale production poses significant challenges related to waste management and environmental pollution. The Marmara Region represents a critical area in Türkiye where intensive animal feeding operations are widely practised. In contrast, goat and sheep farming in Türkiye generally rely on pasture-based or semi-intensive systems. This study aims to estimate methane (CH_4) emissions from small ruminant farming in the Marmara Region over the past 20 years and to assess the resulting carbon footprint to evaluate its impact on global warming. Methane emissions were calculated using the Tier-2 methodology, incorporating the specific characteristics of the region and the general practices of small ruminant farming. Gross energy (GE) and methane emission factors (EF) were derived accordingly. For sheep, the gross energy was calculated as 22.5 MJ head^{-1} year^{-1}, the methane emission factor from enteric fermentation (EF_E) was 9.9 kg CH_4 head^{-1} year^{-1} and methane emissions from manure management (EF_M) amounted to 4.3 kg CH_4 head^{-1}year^{-1}. Similarly, for goats, the GE was determined to be 24.6 MJ head^{-1} year^{-1}, while the EF_E, and EF_M were, 8.9 kg CH_4 head^{-1} year^{-1}, and 4.4 kg CH_4 head^{-1} year^{-1}, respectively. The study found that CH_4 emission rates increased proportionally with the number of animals. To determine the carbon footprint resulting from CH_4 emissions, CO_2-equivalent values established by the Intergovernmental Panel on Climate Change (IPCC) were applied. Consequently, Balıkesir and Çanakkale emerged as the cities with the largest carbon footprints from small ruminant farming within the Marmara Region.

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1. Introduction

The global population is expected to reach 8.5 billion by 2030, increase further to 9.7 billion by 2050, and potentially rise to 10.4 billion by 2100 (UN, 2024). With this population growth, the demand for primary food products will also rise, leading to an increase in inputs for both animal and crop production. The United Nations predicts that crop and animal food production will increase by 70% by 2050 to supply increasing food demand (FAO, 2009; Xu et al., 2021; Siddiqui et al., 2024). The rising demand for animal products in developing countries is referred to as the “animal husbandry revolution” (Thornton, 2015; Rojas-Downing et al., 2017). Animal husbandry is predominantly carried out on intensive farms, where large-scale production results in waste and pollution issues, posing environmental and enterprise challenges.

In the face of various challenges confronting agriculture in the 21st century-such as a decreasing rural workforce, the need for increased food production, the demand for sustainable and efficient methods, and adaptation to climate change-the balance between food security, production efficiency, and environmental protection must be maintained. It is argued that if current climate adaptation efforts aimed at achieving net-zero emissions are not implemented, global warming could reach dangerous levels by 2050, as activities releasing CO_2 emissions surpass sustainable temperature thresholds (Shukla et al., 2022; European Commission, 2023; Scafetta, 2024).

Among anthropogenic activities, the most critical factors contributing to global warming are the combustion of fossil fuels, transportation, industrialization, industrial farming, consumption patterns, and deforestation. Crop production and animal breeding—essential for global food production—are among the most significantly impacted activities by climate change (Dinç et al., 2022; Ayinla et al., 2024). The livestock sector accounts for 14.5% of global greenhouse gas emissions (Gerber et al., 2013; Hur et al., 2023; Raihan, 2024). While the growing importance of global animal husbandry as a source of food input is undeniable, it also substantially increases greenhouse gas emissions, particularly CO_2 (carbon dioxide), CH_4 (methane), and N_2O (nitrous oxide), thereby contributing significantly to global climate change (Yaylı and Kılıç, 2020). The primary sources of CH_4 emissions in animal farming are enteric fermentation and manure management. Enteric CH_4 emissions are particularly high in ruminant animals such as cattle and sheep. In contrast, poultry have simple stomachs and produce minimal CH_4 due to limited microbial fermentation (Dunkley et al., 2015; Yaylı, 2019). Similarly, animals such as horses, donkeys, mules, and pigs generate very low levels of CH_4 in their digestive systems, as they lack rumination and exhibit reduced CH_4 emissions. Additionally, excessive fertilizer application in intensive animal feeding systems leads to nutrient runoff into water bodies, increasing nitrogen and phosphorus levels, which in turn boost algae populations and trigger eutrophication (Eshel, 2014). Moreover, the production of forage crops in intensive systems can result in deforestation, habitat destruction, and biodiversity loss (Thornton, 2015; Williams, 2024).

The Intergovernmental Panel on Climate Change (IPCC) has developed Tier 1, Tier 2 and Tier 3 methodologies for estimating greenhouse gas emissions. The Tier 1 approach involves calculations based on default emission factors and reflects the number of animals. The Tier 2 method uses more detailed, country-specific data, taking into account parameters such as animal characteristics, feed composition, and manure management systems. The Tier 3 method applies when a country-specific methodology is developed, allowing for a highly detailed and precise calculation of emissions.

In Türkiye, the livestock sector is primarily dominated by poultry farming, as well as cattle and sheep breeding, within the scope of food production. The Marmara region stands out as the area where intensive animal feeding units are widely utilized. In the small ruminant category, the number of sheep increased by 3.2% in the first six months of 2024 compared to 2023, reaching 43 394 million heads, while the number of goats increased by 2.6%, reaching 10 571 million heads. Pasture-based and semi-intensive systems are commonly employed for goat and sheep breeding across Türkiye. In Marmara region, sheep and goat breeding in small ruminant farming is predominantly conducted on pastures during warmer periods and in pens during colder seasons.

This study aims to estimate the CH_4 emissions resulting from enteric fermentation and manure management in small livestock farming in the Marmara region over the past twenty years using the Tier-2 method and to assess the global warming potential of these emissions.

2. Material and Methods

2.1. Study area

The Marmara Region is situated between 39º 15' - 42º north latitude and 30º 45' - 26º 45' east longitude in the Northern Hemisphere. Located in the northwest of Türkiye, it is the second smallest region in the country after Southeastern Anatolia (Figure 1). Despite its small size, the region has a high population density, hosting one-third of Türkiye's urban population The Marmara Region does not exhibit a distinct climate type; instead, it has transitional characteristics between the Black Sea, continental, and Mediterranean climates. This climatic diversity supports the cultivation of a wide variety of agricultural products. While the regional economy is predominantly based on industry and trade, the Marmara Region also has the highest proportion of cultivated land. This is facilitated by favorable conditions such as low slopes, fertile soils suitable for agriculture, and the adoption of modern agricultural techniques.

Figure 1. Provincial boundaries of the Marmara Region.

2.2. Animal Data

This study examined sheep and goat populations, which are widely utilized in small ruminant breeding in Türkiye. The Marmara Region demonstrates higher productivity in cattle, sheep, goat, and buffalo breeding compared to other regions (Uzabacı & Üstüner, 2023). Data on the number of sheep and goat in the region for the last two decades were obtained from the Turkish Statistical Institute (TUIK, 2024). Sheep constitute 78.7%, and goats 21.3%, of small ruminant breeding in the region (Tables 1–2). Balıkesir (33%) is the leading province in sheep breeding, while Çanakkale (30%) ranks highest in goat breeding (Figure 2). Over the last 20 years, the total number of sheep in the Marmara Region was 53 392 981, and the number of goats was 14 462 191.

Table 1. Sheep numbers in the Marmara Region between 2004 and 2023

Year	Balıkesir	Bilecik	Bursa	Edirne	Kocaeli	Kırklareli	Sakarya	Tekirdag	Yalova	Canakkale	Istanbul
2004	601 792	47 292	207 302	162 677	38 906	168 061	29 305	105 478	9 964	357 278	51 397
2005	687 400	52 213	233 531	182 834	42 713	176 326	29 295	117 215	13 840	328 919	47 895
2006	694 353	50 471	240 587	183 946	38 055	189 214	30 089	123 964	13 722	319 189	52 846
2007	666 707	49 530	246 090	199 734	38 017	179 779	26 174	127 507	9 379	312 556	74 466
2008	656 525	57 649	215 615	193 896	37 741	184 539	30 731	136 055	8 483	342 767	73 057
2009	607 537	55 785	240 959	185 817	27 679	159 497	27 109	124 877	7 290	347 173	69 321
2010	630 302	55 547	260 740	194 875	43 415	156 578	34 504	132 035	8 947	352 039	72 347
2011	660 787	65 943	280 587	209 615	47 819	164 925	38 807	259 095	14 134	373 155	69 446
2012	695 691	75 145	327 052	205 557	68 431	215 161	47 249	202 259	15 118	400 508	72 623
2013	791 355	77 325	334 892	251 426	72 456	245 155	54 604	180 659	17 361	415 543	74 229
2014	816 290	84 299	356 049	289 453	84 310	316 328	57 541	243 697	19 212	429 076	72 378
2015	792 896	76 427	351 444	288 917	77 104	303 426	53 081	227 771	20 340	442 621	100 255
2016	796 947	81 347	330 549	279 403	75 767	224 926	43 333	240 088	19 126	469 725	95 091
2017	984 381	97 109	392 466	275 480	78 355	259 008	46 015	255 052	21 350	458 250	110 858
2018	1 006 072	112 324	440 595	293 658	75 340	294 197	49 848	249 056	24 834	475 409	117 543
2019	1 112 323	137 988	494 594	299 256	81 973	276 161	56 203	257 249	23 193	489 443	133 022
2020	1 299 936	142 863	504 467	322 342	97 435	341 345	67 709	271 356	27 911	541 692	143 933
2021	1 495 379	156 577	512 040	357 976	96 292	349 248	75 062	315 020	33 082	592 111	151 556
2022	1 272 236	148 163	520 022	357 794	103 601	339 036	79 464	307 050	26 692	577 047	155 537
2023	1 183 486	132 997	519 221	307 009	105 619	306 075	76 416	290 976	25 986	570 799	141 050

Table 2. Goat numbers in the Marmara Region between 2004 and 2023

Year	Balıkesir	Bilecik	Bursa	Edirne	Kocaeli	Kırklareli	Sakarya	Tekirdag	Yalova	Canakkale	Istanbul
2004	142 836	27 443	56 467	35 420	13 223	46 747	4 332	43 034	2 612	163 335	6 733
2005	148 832	27 987	60 068	39 565	11 297	51 687	9 332	44 252	2 475	166 819	5 552
2006	150 659	24 486	63 207	41 268	11 817	51 644	5 595	48 121	2 240	182 920	5 544
2007	154 717	24 135	64 602	39 521	10 404	43 396	10 554	41 825	1 589	206 241	7 391
2008	160 914	25 978	54 612	40 507	11 299	53 945	8 184	45 044	2 184	215 553	8 524
2009	141 842	25 650	52 855	37 528	7 856	42 055	6 919	43 533	1 826	195 813	10 178
2010	160 963	34 742	69 097	39 928	13 186	42 618	9 844	45 859	3 906	198 861	11 170
2011	164 745	41 506	95 944	41 433	15 965	48 666	12 030	48 589	4 082	204 206	12 200
2012	187 668	42 205	96 916	44 678	20 616	68 394	14 865	60 926	3 895	218 898	12 921
2013	202 338	42 955	107 121	54 121	24 835	76 633	20 130	56 881	4 653	227 131	14 221
2014	212 058	52 064	109 296	61 377	26 594	97 838	19 361	65 540	5 977	232 034	15 771
2015	207 334	41 093	107 379	57 717	25 653	95 490	18 128	60 257	6 169	237 228	15 666
2016	194 574	45 463	111 310	55 602	25 238	60 982	16 359	62 311	5 918	246 750	16 228
2017	188 518	43 028	80 001	55 218	25 151	61 932	16 230	55 824	4 007	238 592	21 914
2018	183 782	42 867	82 603	54 889	23 340	67 374	15 393	53 050	3 126	234 408	19 367
2019	171 635	49 964	84 931	56 054	24 981	56 978	16 972	51 824	3 046	226 106	16 942
2020	187 456	49 951	82 778	55 630	23 942	66 195	19 904	50 020	4 338	242 972	22 393
2021	189 650	45 889	80 050	60 380	22 536	62 914	19 431	49 951	6 003	258 355	22 113
2022	162 060	42 107	76 609	62 045	22 908	61 706	18 857	43 493	3 391	248 043	22 799
2023	143 630	40 482	73 454	57 846	20 031	61 703	17 294	48 607	3 645	229 011	21 549

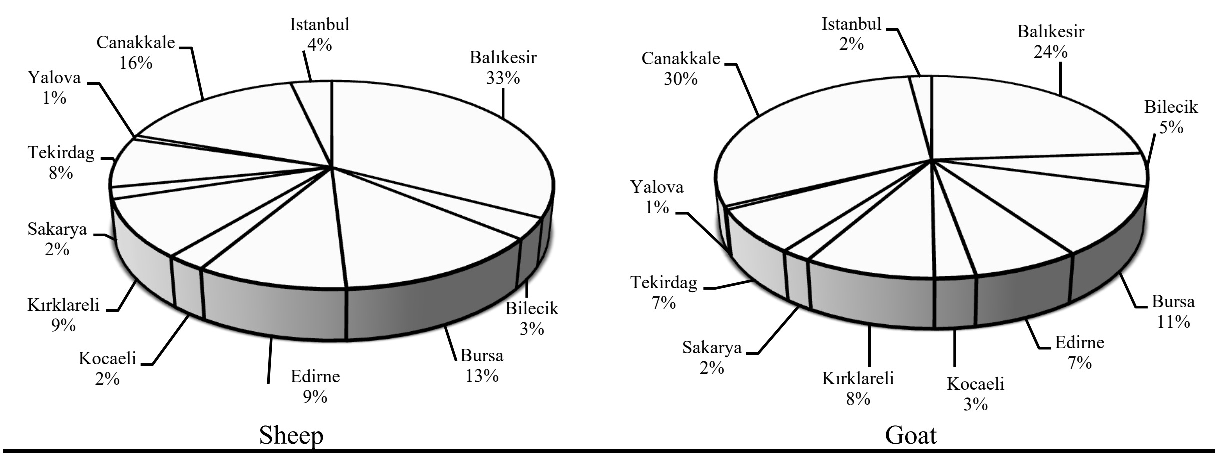

Figure 2. Small ruminant distribution by province in the Marmara Region.

2.3. CH_4 emissions from livestock and manure management: Tier-2 methodology

In this study, enteric CH_4 emission from small ruminants in the Marmara region is estimated based on the IPCC Tier 2 method. The Tier-2 method offers a more detailed and comprehensive approach, taking into account local characteristics, manure management systems, and regional variations in animal species, in contrast to the Tier-1 method, which solely considers the number of animals. Equation 1-9 presents the Tier-2 equations utilized to calculate the total energy required for the metabolic functions of animals.

The equations used in calculating CH_4 emissions from enteric fermentation and manure management resulting from the rumination of small ruminants are provided in Equation 10-12. In determining these emissions, the general manure systems of the region, along with the characteristics of the waste, were taken into account.

Certain coefficients have been established by the International Panel on Climate Change (IPCC) to evaluate the impact of agricultural animal husbandry on global climate change. To assess this impact, the IPCC has determined the CO_2 equivalence of CH_4 gas to be 25 kg over 100 years (IPCC, 2006).

$$NE_m = Cf_i * [Weight]^{0.75} \quad (1)$$

NE_m=Net energy required for maintenance (MJ day^{-1})
C_{fi} =a coefficient that varies according to each animal category (MJ day^{-1} kg^{-1})
Weight = live-weight of animal (kg)

$$NE_a = C_a * Weight \tag{2}$$

NE_a = Net energy for animal activity (MJ day^{-1})
C_a = coefficient corresponding to the nutritional status of the animal (MJ day^{-1} kg^{-1})
NE_m=Net energy required for maintenance (MJ day^{-1})

$$NE_g = [WG_{lamb/kid}*[a+0.5b(BW_i+BW_f)]/365 \tag{3}$$

NE_g = Net energy for growth (MJ day^{-1})
$WG_{lamb/kid}$ = the weight gain (BW_f-BW_i)(kg $year^{-1}$)
BW_f = Live body weight at 1 year of age or live weight at the time of slaughter if slaughtered before 1 year of age (kg)
BW_i=Live body weight at the time of weaning (kg)
a,b = constants for use in calculating NE_g

$$NE_l = [(5*WG_{weam})/365]* EV_{milk} \tag{4}$$

NE_l = Net energy for lactation for sheep (MJ day^{-1})
WG_{weam} = the weight gain of the lamb between birth and weaning (kg)
EV_{milk} = the energy required to produce 1 kg of milk (MJ kg^{-1})

$$NE_{wool} = [EV_{wool}* Pr_{wool}]/365 \tag{5}$$

NE_{wool} = Net energy to produce wool for sheep and goats (MJ day^{-1})
EV_{wool} = the energy value of each kg of wool produced (MJ kg^{-1})
Pr_{wool} = annual wool production per sheep (kg $year^{-1}$)

$$NE_P = C_{pregnancy}*NE_m \tag{6}$$

NE_p = net energy required for pregnancy (MJ day^{-1})
$C_{pregnancy}$ = pregnancy coefficient

$$REM = [1.123–(4.092*10^{-3}*DE) + (1.126*10^{-5}*DE^2) – (25.4/ DE)] \tag{7}$$

REM = The ratio of net energy available in a diet for maintenance to digestible energy consumed
DE = digestibility of feed expressed as a fraction of gross energy

$$REG = [1.164–(5.16*10^{-3}*DE)+[1.308*10^{-5}*DE^2] –(37.4/DE)] \tag{8}$$

REG = The ratio of net energy available for growth in a diet to digestible energy consumed

$$GE = [(NE_m+NE_a+NE_l+NE_p)/REM) + (NE_g + NE_{wool})/REG] / DE \tag{9}$$

GE = Gross energy (MJ day^{-1})

$$EF_E= [GE*(Y_m/100)*365]/55.65 \tag{10}$$

EF_E = CH_4 emission factor from enteric fermentation (kg CH_4 $head^{-1}year^{-1}$)
Y_m = Percentage of gross energy in feed converted to methane

$$EF_M= (VS*365)[B_o*0.67* \sum \frac{MCF}{100} * AWMS] \tag{11}$$

EF_M = CH_4 emission factor from manure management (kg CH_4 $head^{-1}$ $year^{-1}$)
VS = Volatile solid excretion rates (kg dry matter $head^{-1}$ day^{-1})

B_o = maximum methane producing capacity of manure produced in animals according to their categories (m^3 CH_4 kg^{-1} of VS excreted)
0.67 = conversion factor of m^3 CH_4 to kilograms CH_4
MCF = Methane conversion factors for manure management systems (%)
AWMS = Animal manure management system according to climate zone, dimensionless

$$VS = [GE*(1-(DE/100)+(UE*GE)]*[(1-Ash)/18.45] \quad (12)$$

VS = Volatile solid excretion rates (kg VS day^{-1})
UE = Urine energy expressed as a fraction of GE
Ash = Ash content of feed
18.45 = conversion factor for dietary GE per kg of dry matter (MJ kg^{-1}).

2.4. Statistical Analysis

SPSS 29.0.2 software was used to evaluate differences in the calculated data. A one-way analysis of variance (ANOVA) was conducted at the $p < 0.05$ significance level, and Tukey's Honestly Significant Difference (HSD) test was employed for post hoc comparisons.

3. Results and Discussions

In this study, the characteristic features of the most commonly bred sheep and goat breeds in Türkiye were taken into consideration. For goats, the Hair and Saanen breeds are the most widely raised (Atac et al., 2014). In the Marmara Region, the predominant sheep breed is Kıvırcık, followed by Merino and Akkaraman (Taşkın & Kandemir, 2022). For the calculation of CH_4 emissions from small ruminant farming in the region, some coefficients were adopted from the IPCC report, while others were obtained from region-specific studies in the literature.

Equation 9 was used to calculate the total daily energy requirements (GE) of sheep and goats. The total energy requirement for small ruminants is calculated by considering the net energy requirements (NE_m, Ne_a, NE_l, NE_p, NE_g, NE_{wool}) and the digestibility of energy in feed (REM, REG) properties. Equations 1-6 were used to determine gross energy requirements. Equations 7-8 were used to calculate the energy obtained from feed. For the characteristic features of the animal species included in the equations, the goat breed commonly raised in the region, the Hair goat and the Saanen breed, and the sheep breed, the Kıvırcık sheep, were considered. There are some coefficients belonging to the animals in the Tier-2 equations. If these coefficients are not available or not determined specifically for the region, the coefficients determined by the IPCC can be used. Since there are no coefficients specific to Türkiye or the Marmara region, the coefficients in the equations were taken from the IPCC report.

The CH_4 emission factor from enteric fermentation was estimated using Equation 10 and the CH_4 emission factor from manure management was estimated using Equation 11. The conversion factor (Y_m), which expresses the percentage of conversion of gross energy in feed into methane affecting the CH_4 emission factors from enteric fermentation for sheep and goats, was taken from the IPCC guide as 6.7 for sheep and 5.5 for goats. In the calculation of CH_4 emissions from manure management, the relevant coefficients are selected according to the management system by taking into account the climate characteristics of the region and the system in which the manure is managed. As a result of the calculations, the enteric CH_4 emission factor of a sheep per year was determined as 9.9 kg CH_4 and that of a goat as 8.9 kg CH_4 (Table 3).

Table 3. Metabolic energy requirements and methane emission factors for sheep and goats

	GE (MJ $head^{-1}year^{-1}$)	EF_E (kg CH_4 $head^{-1}year^{-1}$)	EF_M (kg CH_4 $head^{-1}year^{-1}$)
Sheep	22.5	9.9	4.3
Goat	24.6	8.9	4.4

In determining CH_4 emissions from manure, both manure and management system characteristics are considered. Manure characteristics include the amount of volatile solids (VS) and the maximum amount of CH_4 that can be produced from the manure (B_0). Ideally, published data from national sources should be used for average VS values. However, since this data is not available, it was calculated with Equation 12, considering the feed characteristics used in the relevant livestock farming in the region. Due to the unavailability of country- and region-specific data, the B_0 value was taken as the default value provided in the IPCC guide.

In selecting factors related to manure characteristics and management systems for the Marmara region, the region was evaluated in the context of Eastern Europe. In this region, manure is typically found in pastures for part of the year, making it impossible to accumulate. During colder seasons, animals are kept in shelters. When determining the Methane Conversion Factor (MCF), the weighted average of these two systems was used. Pasture management and solid storage were considered the basis for the system. CH_4 emission factors were calculated using the relevant data in based on Equation 11. The annual CH_4 emission factor from manure (EF_M) for sheep was calculated to be 4.3 kg CH_4, while for goats, it was calculated as 4.4 kg CH_4 (Table 3). The emission factors for both sheep and goats are similar to those determined for developed countries. Although Türkiye is a developing country, the Marmara region is the most developed region in the country in many respects. More advanced and modern methods are applied in livestock farming compared to other regions. Therefore, it is assumed that the emission factors in this region are higher.

By applying the same emission factors for sheep and goats across all provinces in the Marmara Region, the CH_4 emission rates from sheep and goat breeding over the past 20 years are presented in Tables 4–7 for each province. CH_4 emission rates have increased in direct proportion to the number of animals. Total CH_4 emissions calculated for the Marmara Region are 950 527 tons. The total CH_4 emissions generated solely by sheep amount to 758,180 tons, while emissions from goats account for 192 347 tons. Sheep account for 79.8% of the total CH_4 emissions, while goats contribute 20.2%. Of the total CH_4 emissions from small ruminant farming, 69.2% comes from enteric fermentation, while 30.8% is generated through manure management.

Significant differences were found between cities in enteric methane emissions and methane emissions from manure from small ruminants ($p < 0.05$). However, no significant differences were observed between cities in CH_4 emissions from sheep and goats over the years ($p > 0.05$).

Table 4. Annual enteric CH_4 emissions from sheep in the Marmara Region over the last 20 years (tons year^{-1})

Year	Balıkesir	Bilecik	Bursa	Edirne	Kocaeli	Kırklareli	Sakarya	Tekirdag	Yalova	Canakkale	Istanbul
2004	5 958	468	2 052	1 611	385	1 664	290	1 044	99	3 537	509
2005	6 805	517	2 312	1 810	423	1 746	290	1 160	137	3 256	474
2006	6 874	500	2 382	1 821	377	1 873	298	1 227	136	3 160	523
2007	6 600	490	2 436	1 977	376	1 780	259	1 262	93	3 094	737
2008	6 500	571	2 135	1 920	374	1 827	304	1 347	84	3 393	723
2009	6 015	552	2 385	1 840	274	1 579	268	1 236	72	3 437	686
2010	6 240	550	2 581	1 929	430	1 550	342	1 307	89	3 485	716
2011	6 542	653	2 778	2 075	473	1 633	384	2 565	140	3 694	688
2012	6 887	744	3 238	2 035	677	2 130	468	2 002	150	3 965	719
2013	7 834	766	3 315	2 489	717	2 427	541	1 789	172	4 114	735
2014	8 081	835	3 525	2 866	835	3 132	570	2 413	190	4 248	717
2015	7 850	757	3 479	2 860	763	3 004	526	2 255	201	4 382	993
2016	7 890	805	3 272	2 766	750	2 227	429	2 377	189	4 650	941
2017	9 745	961	3 885	2 727	776	2 564	456	2 525	211	4 537	1 097
2018	9 960	1 112	4 362	2 907	746	2 913	493	2 466	246	4 707	1 164
2019	11 012	1 366	4 896	2 963	812	2 734	556	2 547	230	4 845	1 317
2020	12 869	1 414	4 994	3 191	965	3 379	670	2 686	276	5 363	1 425
2021	14804	1550	5069	3544	953	3458	743	3119	328	5862	1500
2022	12595	1467	5148	3542	1026	3356	787	3040	264	5713	1540
2023	11 717	1 317	5 140	3 039	1 046	3 030	757	2 881	257	5 651	1 396
TOTAL	172 779	17 394	69 387	49 912	13 177	48 005	9 430	41 248	3 564	85 093	18 601

Table 5. Annual enteric CH_4 emissions from goat in the Marmara Region over the last 20 years (tons year^{-1})

Year	Balıkesir	Bilecik	Bursa	Edirne	Kocaeli	Kirklareli	Sakarya	Tekirdag	Yalova	Canakkale	Istanbul
2004	1 271	244	503	315	118	416	39	383	23	1 454	60
2005	1 325	249	535	352	101	460	83	394	22	1 485	49
2006	1 341	218	563	367	105	460	50	428	20	1 628	49
2007	1 377	215	575	352	93	386	94	372	14	1 836	66
2008	1 432	231	486	361	101	480	73	401	19	1 918	76
2009	1 262	228	470	334	70	374	62	387	16	1 743	91
2010	1 433	309	615	355	117	379	88	408	35	1 770	99
2011	1 466	369	854	369	142	433	107	432	36	1 817	109
2012	1 670	376	863	398	183	609	132	542	35	1 948	115
2013	1 801	382	953	482	221	682	179	506	41	2 021	127
2014	1 887	463	973	546	237	871	172	583	53	2 065	140
2015	1 845	366	956	514	228	850	161	536	55	2 111	139
2016	1 732	405	991	495	225	543	146	555	53	2 196	144
2017	1 678	383	712	491	224	551	144	497	36	2 123	195
2018	1 636	382	735	489	208	600	137	472	28	2 086	172
2019	1 528	445	756	499	222	507	151	461	27	2 012	151
2020	1 668	445	737	495	213	589	177	445	39	2 162	199
2021	1 688	408	712	537	201	560	173	445	53	2 299	197
2022	1 442	375	682	552	204	549	168	387	30	2 208	203
2023	1 278	360	654	515	178	549	154	433	32	2 038	192
TOTAL	30 760	6 853	14 323	8 817	3 390	10 848	2 489	9 069	668	38 922	2 574

Table 6. CH_4 emissions from sheep manure management in the Marmara Region over the last 20 years (tons year^{-1})

Year	Balıkesir	Bilecik	Bursa	Edirne	Kocaeli	Kirklareli	Sakarya	Tekirdag	Yalova	Canakkale	Istanbul
2004	2 588	203	891	700	167	723	126	454	43	1 536	221
2005	2 956	225	1 004	786	184	758	126	504	60	1 414	206
2006	2 986	217	1 035	791	164	814	129	533	59	1 373	227
2007	2 867	213	1 058	859	163	773	113	548	40	1 344	320
2008	2 823	248	927	834	162	794	132	585	36	1 474	314
2009	2 612	240	1 036	799	119	686	117	537	31	1 493	298
2010	2 710	239	1 121	838	187	673	148	568	38	1 514	311
2011	2 841	284	1 207	901	206	709	167	1 114	61	1 605	299
2012	2 991	323	1 406	884	294	925	203	870	65	1 722	312
2013	3 403	332	1 440	1 081	312	1 054	235	777	75	1 787	319
2014	3 510	362	1 531	1 245	363	1 360	247	1 048	83	1 845	311
2015	3 409	329	1 511	1 242	332	1 305	228	979	87	1 903	431
2016	3 427	350	1 421	1 201	326	967	186	1 032	82	2 020	409
2017	4 233	418	1 688	1 185	337	1 114	198	1 097	92	1 970	477
2018	4 326	483	1 895	1 263	324	1 265	214	1 071	107	2 044	505
2019	4 783	593	2 127	1 287	352	1 187	242	1 106	100	2 105	572
2020	5 590	614	2 169	1 386	419	1 468	291	1 167	120	2 329	619
2021	6 430	673	2 202	1 539	414	1 502	323	1 355	142	2 546	652
2022	5 471	637	2 236	1 539	445	1 458	342	1 320	115	2 481	669
2023	5 089	572	2 233	1 320	454	1 316	329	1 251	112	2 454	607
TOTAL	75 045	7 555	30 138	21 679	5 723	20 851	4 096	17 916	1 548	36 960	8 079

Table 7. CH_4 emissions from goat manure management in the Marmara Region over the last 20 years (tons year^{-1})

Year	Balıkesir	Bilecik	Bursa	Edirne	Kocaeli	Kırklareli	Sakarya	Tekirdag	Yalova	Canakkale	Istanbul
2004	628	121	248	156	58	206	19	189	11	719	30
2005	655	123	264	174	50	227	41	195	11	734	24
2006	663	108	278	182	52	227	25	212	10	805	24
2007	681	106	284	174	46	191	46	184	7	907	33
2008	708	114	240	178	50	237	36	198	10	948	38
2009	624	113	233	165	35	185	30	192	8	862	45
2010	708	153	304	176	58	188	43	202	17	875	49
2011	725	183	422	182	70	214	53	214	18	899	54
2012	826	186	426	197	91	301	65	268	17	963	57
2013	890	189	471	238	109	337	89	250	20	999	63
2014	933	229	481	270	117	430	85	288	26	1 021	69
2015	912	181	472	254	113	420	80	265	27	1 044	69
2016	856	200	490	245	111	268	72	274	26	1 086	71
2017	829	189	352	243	111	273	71	246	18	1 050	96
2018	809	189	363	242	103	296	68	233	14	1 031	85
2019	755	220	374	247	110	251	75	228	13	995	75
2020	825	220	364	245	105	291	88	220	19	1 069	99
2021	834	202	352	266	99	277	85	220	26	1 137	97
2022	713	185	337	273	101	272	83	191	15	1 091	100
2023	632	178	323	255	88	271	76	214	16	1 008	95
TOTAL	15207	3388	7081	4359	1676	5363	1231	4483	330	19242	1272

The value determined by the IPCC was used to calculate the carbon footprint resulting from CH_4 emissions in small livestock farming. The cities with the most significant impact on global warming potential, in terms of CO_2 equivalent emissions, are Çanakkale, Balıkesir, and Bursa (Figure 3).

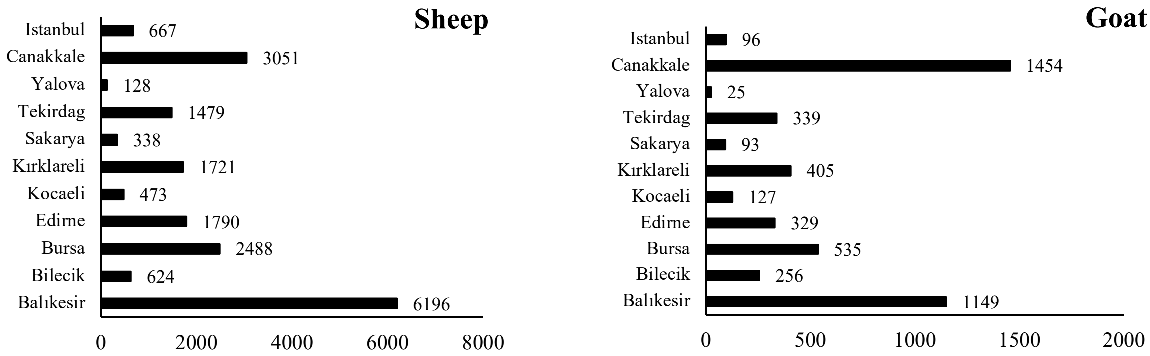

Figure 3. CO_2 equivalent of CH_4 emissions (kilotons of CO_2) by city in the Marmara Region.

The CO_2 equivalence of CH_4 emissions over the last twenty years is considerable. When examining global warming potential on a CO_2 equivalence basis, an increase was observed in 2021, followed by a downward trend in the last two years (Figure 4). The increase in emissions in 2021 was primarily due to the rise in the number of animals that year. There is a positive correlation between the carbon footprint and the number of animals. Particularly in the breeding of lower-yield species, attempts to meet production demands by increasing animal numbers result in a higher carbon footprint.

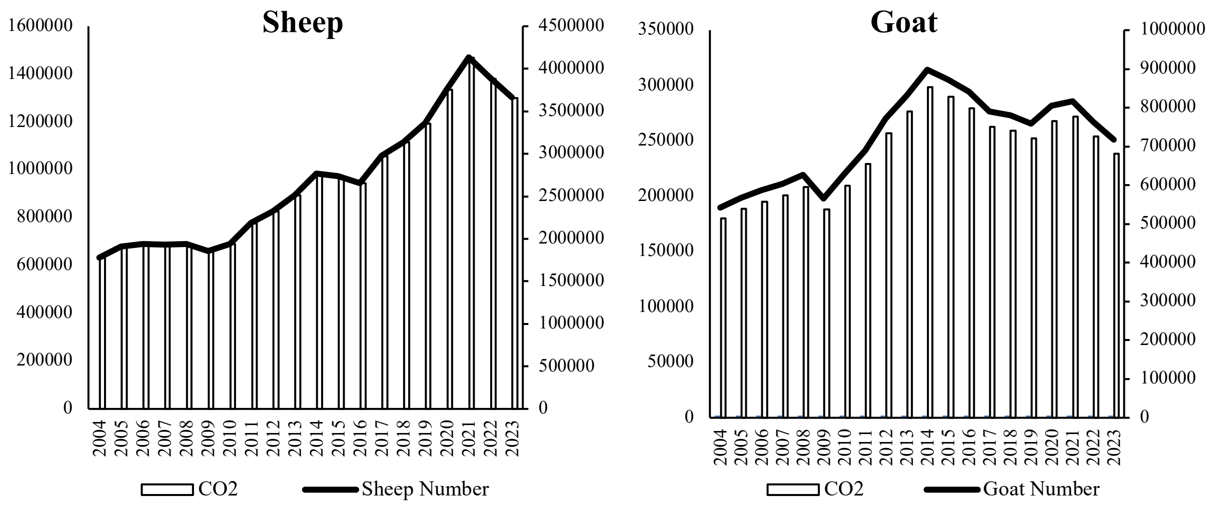

Figure 4. Small ruminants' CO_2 emissions footprint in the last 20 years (tonnes).

Conclusion

This study reveals the potential of CH_4 emissions originating from small livestock farming in the Marmara region over the last 20 years and the size of the resulting carbon footprint. According to the study results, 69.2% of CH_4 emissions from small livestock farming consist of enteric CH_4, while 30.8% come from manure management. Additionally, 79.8% of total CH_4 emissions originate from sheep, while 20.2% come from goats. Significant differences ($p < 0.05$) were identified between cities in terms of enteric CH_4 emissions from sheep and goat farming, as well as CH_4 emissions from manure. However, when emissions were evaluated over the years, no significant differences were observed ($p > 0.05$). The carbon footprint of all CH_4 emissions from sheep farming is approximately 19 Mt CO_2 equivalent, whereas goat farming has a CO_2 footprint of approximately 5 Mt CO_2 equivalent. While the carbon footprints from emissions showed significant differences between cities ($p < 0.05$), no significant differences were observed across years ($p > 0.05$).

This study considered general characteristics, such as manure management and the breeds used in sheep farming, representing the Marmara region in calculating CH_4 emissions using the Tier-2 method. However, future studies should conduct more field research and create a national inventory by considering the characteristics that vary from region to region. More comprehensive policies can be developed for the sector, and more stringent measures can be taken within the scope of climate change adaptation for producers and the country.

Ethical Statement

Ethical approval is not required for this study because no direct measurements were made on animals.

Conflict of Interest

All authors declare that there is no conflict of interest related to this article.

Author Contributions

The authors declare that they have contributed equally to the article. All authors declare that they have seen/read and approved the final version of the article ready for publication.

References

Atac, F. E., & Burcu, H. (2014). The importance of hair goats in Turkey. J*ournal of Agricultural Science and Technology*, *4*(4), 364-369.

Ayinla, R. A., Alao, O., Adesoji, S., Ayinla, R. A., & Olawuyi, S. O. (2024). Perceived effects of climate change on farm income: Insights from smallholder arable crops farmers in south-west Nigeria. *Yuzuncu Yil University Journal of Agricultural Sciences*, *34*(4), 608-620. https://doi.org/10.29133/yyutbd.1501494

Dinç, S. Ö., Künili, İ. E., & Çolakoğlu, F. (2022). Impact of climate change process on sustainable and safe food production. *Journal of Agricultural Faculty of Bursa Uludag University, 36*(2), 447-460. https://doi.org/10.20479/bursauludagziraat.994886

Dunkley, C. S., Fairchild, B. D., Ritz, C. W., Kiepper, B. H., & Lacy, M.P. (2015). Carbon footprint of poultry production farms in South Georgia: A case study. *Poultry Science Association, 24*, 73-79. https://doi.org/10.3382/japr/pfu005

Eshel, G., Shepon, A., Makov, T., & Milo, R. (2014). Land, irrigation water, greenhouse gas, and reactive nitrogen burdens of meat, eggs, and dairy production in the United States. *Proceedings of the National Academy of Sciences*, *111*(33), 11996-12001. https://doi.org/10.1073/pnas.1402183111

European Commission, (2023). *2050 long-term strategy.* https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en . Access date: 25.09.2024.

FAO, (2009). *Global agriculture towards 2050.* https://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf . Access date: 03.09.2024.

Gerber, P. J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., & Tempio, G. (2013). *Tackling Climate Change Through Livestock: A Global Assessment of Emissions and Mitigation Opportunities.* FAO, Rome.

Hur, S. J., Kim, J. M., Yim, D. G., Yoon, Y., Lee, S. S., & Jo, C. (2023). Impact of livestock industry on climate change: Case study in South Korea—A review. *Animal Bioscience*, *37*(3), 405. https://doi.org/10.5713/ab.23.0256

IPCC, (2006). *Guidelines for national Greenhouse Gas Inventories.* https://www.ipccnggip.iges.or.jp/public/ 2006gl/ . Access date: 07.10.2024

Raihan, A. (2024). The interrelationship amid carbon emissions, tourism, economy, and energy use in Brazil. *Carbon Research*, *3*(1), 11. https://doi.org/10.1007/s44246-024-00147-8

Rojas-Downing, M. M., Nejadhashemi, A. P., Harrigan, T., & Woznicki, S. A. (2017). Climate change and livestock: Impacts, adaptation, and mitigation. *Climate risk management, 16,* 145-163. https://doi.org/10.1016/j.crm.2017.02.001

Scafetta, N. (2024). Impacts and risks of "realistic" global warming projections for the 21st century. *Geoscience Frontiers, 15*(2), 101774. https://doi.org/10.1016/j.gsf.2023.101774

Shukla, P., Skea, J., Reisinger, A., Slade, R., Fradera, R., Pathak, M., Khourdajie, A., Belkacemi, M., van Diemen, R., Hasija, A., Lisboa, G., Luz, S., Malley, J., McCollum, D., Some, S., (eds.), P.V. (2022). *IPCC, 2022: Climate Change 2022: Mitigation of Climate Change.* Cambridge University Press.

Siddiqui, S. A., Gadge, A. S., Hasan, M., Rahayu, T., Povetkin, S. N., Fernando, I., & Castro-Muñoz, R. (2024). Future opportunities for products derived from black soldier fly (BSF) treatment as animal feed and fertilizer-A systematic review. *Environment, Development and Sustainability*, *26*(12)*,* 30273-30354. https://doi.org/10.1007/s10668-024-04673-8

Taşkın, T., & Kandemir, Ç. (2022). Marmara bölgesinde yerli ve kültür koyun ırklarının mevcut durumu. *Doğanın Sesi, 5*(9), 17-33.

Thornton, P. K., Boone, R. B., & Ramírez Villegas, J. (2015). Climate change impacts on livestock. CCAFS Working Paper.

TUIK, (2024). *Livestock Statistics.* Access date: 3.10.2024.

UN, (2024). United Nations, Population. www.un.org. Access date: 19.03.2024

Uzabacı, E., & Üstüner, H. (2023). Investigation of small ruminant and cattle livestock in the Marmara Region by simple correspondence analysis. *Harran University Journal of the Faculty of Veterinary Medicine, 12*(2)*,* 209-215. https://doi.org/10.31196/huvfd.1364289

Williams, J. (2024). Contribution of livestock farming to environmental pollution in China. *Journal of Animal Health, 4*(1), 43-53. https://doi.org/10.47604/jah.2510

Xu, X., Sharma, P., Shu, S., Lin, T. S., Ciais, P., Tubiello, F. N., Smith, P., Campbell, N., & Jain, A. K. (2021). Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods. *Nature Food, 2*(9), 724-732.

Yaylı, B. (2019). *Calculation of Carbon And Water Footprints of Three Broiler Operations in Bursa Region And Determination Of Their Environmental Sustainabilities* (Master's thesis, Bursa Uludag University (Türkiye)).

Yaylı, B., & Kılıç, I. (2020). Estimation of global warming potential by Tier-1 method of dairy cattle farms. *International Journal of Biosystems Engineering, 1*(2), 79-86.