J. BIOL. ENVIRON. SCI.,
2021, 15(43), 1-9

***Original Research Article***

# Determination of Enteric Methane Emissions from Cattle Production by Using Tier-2 Method

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Received: 20.07.2021; Accepted: 09.08.2021; Published Online: 22.09.2021

## ABSTRACT

**Livestock farms are known to be important greenhouse gas producers. Especially in the agriculture sector, the most important source of anthropogenic methane ($CH_4$) emission is ruminant animals. In recent studies of dairy cattle, it is noted that most of the formation of $CH_4$ gas occurs as a result of enteric fermentation. In this study, it was aimed to evaluate the $CH_4$ emissions resulting from enteric fermentation of cattle during the 2004-2020 period in Turkey. The Tier-2 method adopted by the Intergovernmental Panel on Climate Change (IPCC) was used adopted for data generation and calculation of emission factors for the calculation of $CH_4$ emissions for enteric fermentation in cattle. Based on the study results, the required gross energy (GE) value and enteric fermentation emission factors (EF) were calculated according to cattle sub-categories. It has been observed that methane gas emission from cattle as a result of enteric fermentation has followed a fluctuating course in the last 16 years in Turkey. Methane emissions of 541 kT to 907 kT $CH_4$ gas emissions were calculated. Methane emission can be suppressed by changes made in feed rations, added oil and various additives to reduce methane emissions in the rumen. In addition, breeding high yielding species with low methane production is one of the strategies that can reduce methane formation.**

**Keywords: Emissions, Enteric fermentation, IPCC, Methane**

## INTRODUCTION

Agriculture sector is one of the most important factors that affect the generation of methane emissions. Especially ruminant animals that carried out enteric fermentation, produces 21-25% of global anthropogenic methane emissions (Lascano and Cardenas 2010). Cattle are important methane ($CH_4$) sources in Turkey as well as in many countries due to their high population and their ruminant digestive systems. Enteric fermentation contributes to methane emission since cattle have large intestines. The two most important sources of methane in agriculture are enteric fermentation and manure. In ruminant animals, 80% of methane gas is produced during the microbial fermentation of cellulosic feeds in the rumen and 20% as a result of the decomposition of manure (Vergé *et al.* 2009). Yaylı and Kılıç (2020), reported in their study that 86.8% of $CH_4$ emissions from dairy farms in Turkey are caused by enteric fermentation.

The energy of methane gas formed by microbiological fermentation cannot be used by the body and is released to the atmosphere, and the energy taken with the feeds cannot be used by the animal, causing low yield and economic loss (Arslan and Çelebi 2017). In addition, methane is a serious greenhouse gas with a global warming potential that is 28 times greater than carbon dioxide ($CO_2$) (IPCC 2014). Therefore, as $CH_4$ emissions increase, their negative impact on global climate change also increases.

It is observed that the methane emission generated by the enteric fermentation of cattle followed a fluctuating course between 1961 and 2018 in Turkey (FAOSTAT 2021) (Table 1). It has been observed that enteric methane emission occurs in higher amounts in years when the number of animals is higher. With the formation of 589.920 Gg of $CH_4$ gas in 2018, it has been the year with the highest emission in the last 58 years. This is because the increase in the cattle population in 2018. In addition, methane gas, which is a by-product of enteric fermentation in ruminant animals, can vary depending on the age, weight, gender of animals, digestibility, quality and quantity of feed (Popa *et al.* 2016). Digestibility can be used for any nutrient as well as for all feeds. Only the digestibility of the feeds by animals differs. The lower the digestibility of feed in animals, the higher the methane emissions (Yaylı and Kılıç 2020).

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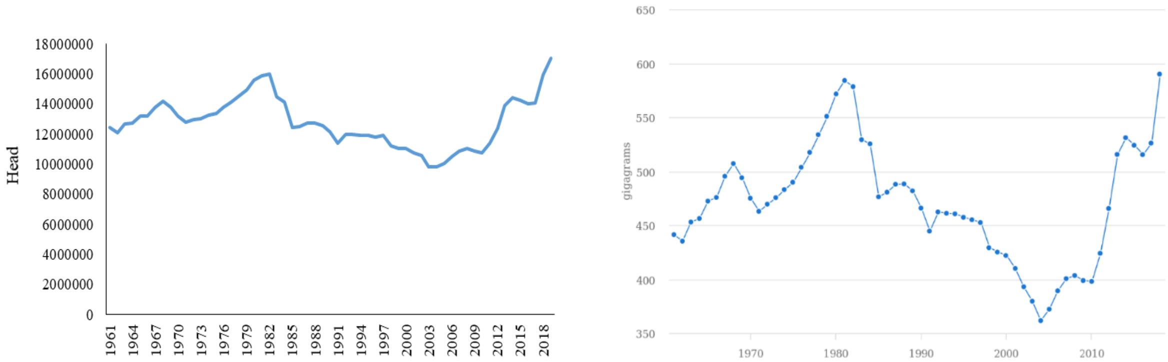


**Figure 1.** Cattle Numbers and Enteric Fermentation $CH_4$ Emissions of Turkey (FAOSTAT 2021).

Unless a technique is developed to measure actual methane emissions from enteric fermentation, estimation can be made based on theoretical estimates derived from research findings (Garnsworthy *et al.* 2012). In calculating methane emissions from enteric fermentation, using Tier methods determined by the Intergovernmental Panel on Climate Change, animal species (cattle, goat sheep, pigs, chickens, etc.) or according to subgroups (dairy cows, beef cattle, etc.) is obtained by multiplying the appropriate emission factors by the national animal population numbers (IPCC 2019). Tier 1-2-3 methods have been developed according to their scope. The Tier-1 method is a basic method in determining the general characterization by using parameters in calculating emissions. The Tier-2 method is a more detailed method that includes detailed information about farm animals and their subcategories and estimates feed intake. The Tier-3 method, on the other hand, is a comprehensive method that develops country-specific methodologies and adopts a measurement-based approach for emission factors.

In this study, the $CH_4$ gas emission resulting from enteric fermentation, in Turkey between 2004-2020, was estimated using the Tier-2 method and reduction strategies were emphasized.

## MATERIALS AND METHODS

It is necessary to collect data such as live weight, milk yield, and live weight gain for animal categories. However, obtaining these data from individual living things is not a realistic approach. These data should be drawn from case studies and, where available, statistical databases (IPCC 2019). In this study, since there is no specific dataset for cattle in Turkey, necessary data were obtained from relevant databases and sources. Cattle numbers in Turkey was obtained from the data provided by Turkish Statistical Institute (TUIK) (TUIK 2021) (Table 1). Because the numbers for the year 2020 for dairy cows were not published, methane emissions from dairy animals in this year could not be calculated.

**Table 1.** Cattle numbers in Turkey between 2004-2020 year by animal categories (head) (TUIK 2021).

| Year | Cattle species sub-category | | |
|---|---|---|---|
| | Lactating cow | Bulls | Cattle/Buffalo |
| **2004** | 3 915 083 | 413 084 | 9 760 162 |
| **2005** | 4 036 302 | 409 764 | 10 221 641 |
| **2006** | 4 224 484 | 450 351 | 10 521 529 |
| **2007** | 4 259 900 | 474 784 | 10 646 674 |
| **2008** | 4 111 683 | 554 337 | 10 391 902 |
| **2009** | 4 165 509 | 495 664 | 10 315 501 |
| **2010** | 4 397 203 | 488 868 | 10 965 658 |
| **2011** | 4 801 360 | 543 350 | 11 940 619 |
| **2012** | 5 478 359 | 619 946 | 13 402 401 |
| **2013** | 5 659 212 | 675 981 | 13 856 867 |
| **2014** | 5 664 131 | 679 193 | 13 666 030 |
| **2015** | 5 598 773 | 666 731 | 13 461 106 |
| **2016** | 5 495 044 | 657 091 | 13 565 137 |
| **2017** | 6 038 545 | 635 889 | 15 469 136 |
| **2018** | 6 413 789 | 750 905 | 16 469 998 |
| **2019** | 3 411 084 | 836 561 | 17 035 770 |
| **2020** | ND* | 958 017 | 17 199 954 |

*No data

The equations used to find the enteric fermentation $CH_4$ emission factor are given in Table 2 as equation (I) and equation (II). When calculating gross energy (GE), the energies an animal needs for its activities and care such as maintenance, activity, lactation, work, pregnancy, growth, (MJ $day^{-1}$) were calculated. The methane conversion factor ($Y_m$) was taken as 6.5% by using equation (II) for the enteric fermentation emission factor (IPCC 2006; Thakuri *et al.* 2020). Total emissions from enteric fermentation were calculated by equation (III).

**Table 2.** Tier-2 equations about $CH_4$ emission derived from enteric fermentation used for cattle for net energy requirements and methane emission factor.

$$GE = \{[(NE_m + NE_a + NE_l + NE_{work} + NE_p) / REM]+[(NE_g) / REG]\} / DE \qquad (I)$$

GE = gross energy (MJ $day^{-1}$)
$NE_m$ = net energy required by the animal for maintenance (MJ $day^{-1}$)
$NE_a$ = net energy for animal activity (MJ $day^{-1}$)
$NE_l$ = net energy for lactation (MJ $day^{-1}$)
$NE_{work}$ = net energy for work (MJ $day^{-1}$)
$NE_p$ = net energy required for pregnancy (MJ $day^{-1}$)
$NE_g$ = net energy needed for growth (MJ $day^{-1}$)
REM = ratio of net energy available in a diet for maintenance to digestible energy
REG = ratio of net energy available for growth in a diet to digestible energy consumed
DE = digestibility of feed expressed as a fraction of gross energy

$$EF=[GE*(Y_m/100)]*365/55.65 \qquad (II)$$

EF = emission factor for enteric fermentation (kg $CH_4$ $head^{-1}$ $yr^{-1}$)
GE = gross energy intake (MJ $day^{-1}$)
$Y_m$ = methane conversion factor, per cent of gross energy in feed converted to methane
The factor 55.65 (MJ kg $CH_4^{-1}$) is the energy content of methane

$$Em = \text{Number of animals} *EF \qquad (III)$$

Em = methane emissions from enteric fermentation (kg $CH_4$ $yr^{-1}$)

Holstein type cattle are generally preferred in dairy cattle breeding in Turkey. In this study, the weight characteristics of cattle were obtained from the relevant standards (Anonymous 2018; Ardıclı et al., 2018;

Anonymous 2020; QMS 2020). It was taken into account that the cattle were raised in the barn and did not spend much energy for feeding. For a typical Holstein-type cattle, daily weight gains should maintain growth rate at an average of 750 g day$^{-1}$ (Wathes *et al.* 2014). Turkey has not show high performance by lagging behind with an average milk yield of 2.513 kg compared to European Union countries according to the latest statistics (EHRC 2009).

## RESULTS AND DISCUSSION

Enteric fermentation $CH_4$ emission factors (EFs) were calculated based on the daily gross energies of cattle and the information using the equation specified in Table 3. Energy required to maintenance for the animal ($NE_m$) is the energy that is not gained or lost to keep the animal in balance. The average $NE_m$ values calculated 52.5, 65.8 and 34 MJ day$^{-1}$ head$^{-1}$ for lactating cow, bulls and cattle/buffalo, respectively. Energy required for animal activity ($NE_a$) is required for animals to access food and water. It is based on the feeding situation rather than the feed characteristics. IPCC guidelines define for cattle the necessary coefficient for net energy for animal activity ($NE_a$) situation in barns, pastures and grazing large areas. Cattle expend significant energy on pasture and grazing large areas to acquire feed and water. On the other hand, animals raised in barns expend very little or no energy. In the IPCC guidelines, the relevant coefficient expends in the barn for cattle and buffalo is specified as 0. Since cattle breeding in the stall were taken into account in this paper, the energy ($NE_a$) spent for daily activities of animals was considered as 0 MJ day$^{-1}$ head$^{-1}$. Net energy required for animal growth ($NE_g$) is the energy required for weight gain in animals (NRC 1996). $Ne_g$ values are 19.3, 18.6 and 20.25 MJ day$^{-1}$ head$^{-1}$ for lactating cow, bulls and cattle/buffalo, respectively. Net energy required for lactation ($NE_l$) is a function of the amount of milk produced in animals and the energy required for lactation (NRC 1989). $NE_l$ values were calculated as 82.5 MJ day$^{-1}$ head$^{-1}$ for all cattle. Lactation energy for calves only is 0 MJ day$^{-1}$ head$^{-1}$. The energy required for work ($NE_{work}$) in animals is the energy that expresses draft for cattle and buffaloes (Ibrahim 1985; Lawrence 1985). $Ne_{work}$ values are 57.8, 72.4 and 37.5 MJ day$^{-1}$ head$^{-1}$ for lactating cow, bulls and cattle/buffalo, respectively. The energy required for pregnancy ($NE_p$) in animals is the energy required for their pregnancy (IPCC 2006). $Ne_p$ values are 5.3, 6.6 and 3.4 MJ day$^{-1}$ head$^{-1}$ for lactating cow, bulls and cattle/buffalo, respectively. Energies required for gross energy could not be calculated since the population data of lactating cows for 2020 has not been published.

**Table 3.** Net energy requirements for maintenance ($NE_m$), activity ($NE_a$), growth ($NE_g$), lactation ($NE_l$), work ($NE_{work}$), and pregnancy ($NE_p$), and daily Gross energy (GE) intake unit for animal category (MJ day$^{-1}$).

| | | $NE_m$ | $NE_a$ | $NE_g$ | $NE_l$ | $NE_{work}$ | $NE_p$ | GE |
|---|---|---|---|---|---|---|---|---|
| **2004** | LC | 205 660 936 | 0 | 75 550 720 | 322 994 348 | 226 227 030 | 20 566 094 | 43 287 711 |
| | B | 27 179 415 | 0 | 7 685 003 | 34 079 430 | 29 897 356 | 2 717 941 | 5 087 093 |
| | C/B | 332 862 091 | 0 | 197 616 185 | 536 808 910 | 366 148 300 | 33 286 209 | 78 602 693 |
| **2005** | LC | 212 028 621 | 0 | 77 889 925 | 332 994 915 | 233 231 483 | 21 202 862 | 44 627 988 |
| | B | 26 960 971 | 0 | 7 623 238 | 33 805 530 | 29 657 068 | 2 696 097 | 5 046 207 |
| | C/B | 348 600 443 | 0 | 206 959 853 | 562 190 255 | 383 460 487 | 34 860 044 | 82 319 178 |
| **2006** | LC | 221 913 899 | 0 | 81 521 338 | 348 519 930 | 244 105 289 | 22 191 390 | 46 708 651 |
| | B | 29 631 447 | 0 | 8 378 317 | 37 153 958 | 32 594 591 | 2 963 145 | 5 546 033 |
| | C/B | 358 827 870 | 0 | 213 031 753 | 578 684 095 | 394 710 657 | 35 882 787 | 84 734 302 |
| **2007** | LC | 223 774 316 | 0 | 82 204 773 | 351 441 750 | 246 151 748 | 22 377 432 | 47 100 233 |
| | B | 31 239 049 | 0 | 8 832 868 | 39 169 680 | 34 362 953 | 3 123 905 | 5 846 923 |
| | C/B | 363 095 834 | 0 | 215 565 592 | 585 567 070 | 399 405 418 | 36 309 583 | 85 742 148 |
| **2008** | LC | 215 988 416 | 0 | 79 344 578 | 339 213 848 | 237 587 257 | 21 598 842 | 45 461 449 |
| | B | 36 473 345 | 0 | 10 312 870 | 45 732 803 | 40 120 679 | 3 647 334 | 6 826 611 |
| | C/B | 354 407 050 | 0 | 210 407 166 | 571 554 610 | 389 847 755 | 35 440 705 | 83 690 361 |
| **2009** | LC | 218 815 918 | 0 | 80 383 277 | 343 654 493 | 240 697 510 | 21 881 592 | 46 056 585 |
| | B | 32 612 876 | 0 | 9 221 319 | 40 892 280 | 35 874 164 | 3 261 288 | 6 104 058 |
| | C/B | 351 801 459 | 0 | 208 860 258 | 567 352 555 | 386 981 605 | 35 180 146 | 83 075 072 |
| **2010** | LC | 230 986 900 | 0 | 84 854 357 | 362 769 248 | 254 085 590 | 23 098 690 | 48 618 345 |
| | B | 32 165 724 | 0 | 9 094 886 | 40 331 610 | 35 382 297 | 3 216 572 | 6 020 366 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | C/B | 373 974 515 | 0 | 222 024 132 | 603 111 190 | 411 371 966 | 37 397 451 | 88 311 060 |
| **2011** | LC | 252 217 435 | 0 | 92 653 515 | 396 112 200 | 277 439 179 | 25 221 744 | 53 086 968 |
| | B | 35 750 440 | 0 | 10 108 468 | 44 826 375 | 39 325 484 | 3 575 044 | 6 691 307 |
| | C/B | 407 224 737 | 0 | 241 764 386 | 656 734 045 | 447 947 211 | 40 722 474 | 96 162 831 |
| **2012** | LC | 287 780 474 | 0 | 105 717 801 | 451 964 618 | 316 558 521 | 28 778 047 | 60 572 311 |
| | B | 40 790 177 | 0 | 11 533 458 | 51 145 545 | 44 869 194 | 4 079 018 | 7 634 580 |
| | C/B | 457 077 579 | 0 | 271 361 413 | 737 132 055 | 502 785 337 | 45 707 758 | 107 935 177 |
| **2013** | LC | 297 280 757 | 0 | 109 207 784 | 466 884 990 | 327 008 833 | 29 728 076 | 62 571 939 |
| | B | 44 477 074 | 0 | 12 575 931 | 55 768 433 | 48 924 782 | 4 447 707 | 8 324 646 |
| | C/B | 472 576 758 | 0 | 280 563 088 | 762 127 685 | 519 834 434 | 47 257 676 | 111 595 183 |
| **2014** | LC | 297 539 154 | 0 | 109 302 708 | 467 290 808 | 327 293 069 | 29 753 915 | 62 626 327 |
| | B | 44 688 412 | 0 | 12 635 687 | 56 033 423 | 49 157 254 | 4 468 841 | 8 364 202 |
| | C/B | 466 068 424 | 0 | 276 699 168 | 751 631 650 | 512 675 266 | 46 606 842 | 110 058 293 |
| **2015** | LC | 294 105 871 | 0 | 108 041 472 | 461 898 773 | 323 516 458 | 29 410 587 | 61 903 686 |
| | B | 43 868 458 | 0 | 12 403 844 | 55 005 308 | 48 255 304 | 4 386 846 | 8 210 733 |
| | C/B | 459 079 663 | 0 | 272 550 026 | 740 360 830 | 504 987 630 | 45 907 966 | 108 407 953 |
| **2016** | LC | 288 656 944 | 0 | 106 039 777 | 453 341 130 | 317 522 638 | 28 865 694 | 60 756 791 |
| | B | 43 234 182 | 0 | 12 224 502 | 54 210 008 | 47 557 600 | 4 323 418 | 8 092 018 |
| | C/B | 462 627 553 | 0 | 274 656 365 | 746 082 535 | 508 890 308 | 46 262 755 | 109 245 759 |
| **2017** | LC | 317 207 277 | 0 | 116 527 905 | 498 179 963 | 348 928 005 | 31 720 728 | 66 766 092 |
| | B | 41 839 168 | 0 | 11 830 061 | 52 460 843 | 46 023 084 | 4 183 917 | 7 830 917 |
| | C/B | 527 561 832 | 0 | 313 207 059 | 850 802 480 | 580 318 016 | 52 756 183 | 124 579 464 |
| **2018** | LC | 336 919 000 | 0 | 123 769 119 | 529 137 593 | 370 610 900 | 33 691 900 | 70 915 035 |
| | B | 49 406 799 | 0 | 13 969 815 | 61 949 663 | 54 347 479 | 4 940 680 | 9 247 329 |
| | C/B | 561 695 387 | 0 | 333 471 736 | 905 849 890 | 617 864 925 | 56 169 539 | 132 639 827 |
| **2019** | LC | 179 185 659 | 0 | 65 824 875 | 281 414 430 | 197 104 225 | 17 918 566 | 37 715 170 |
| | B | 55 042 650 | 0 | 15 563 357 | 69 016 283 | 60 546 916 | 5 504 265 | 10 302 175 |
| | C/B | 580 990 563 | 0 | 344 927 048 | 936 967 350 | 639 089 620 | 58 099 056 | 137 196 227 |
| **2020** | LC | - | - | - | - | - | - | - |
| | B | 63 034 011 | 0 | 17 822 921 | 79 036 403 | 69 337 412 | 6 303 401 | 11 797 895 |
| | C/B | 586 589 920 | 0 | 348 251 319 | 945 997 470 | 645 248 912 | 58 658 992 | 138 518 470 |

LC: Lactating cow, B:Bulls, C/B:Cattle/Buffalo

Methane emission factors by animal categories are 47 kg $CH_4$ year$^{-1}$ head$^{-1}$ for lactating cow (LC) and 52.5 kg $CH_4$ year$^{-1}$ head$^{-1}$ was calculated for bulls (B). In the cattle/buffalo category, emission factors were determined in 24 sub-categories according to the data of TUIK. In the determination of the total emissions, the methane emission calculation was made by using the emission factor obtained for each category. Average emission factor (EF) in the cattle/buffalo category was calculated as 34.3 kg $CH_4$ year$^{-1}$head$^{-1}$. Enteric methane emission rates according to cattle species between 2004-2020 are given in Figure 2. Bulls need the most energy per animal. However, since the group with the highest population is cattle/buffalo, cumulative emissions are mostly generated by this animal subcategory. Enteric methane emission of this group decreased in parallel because it observed that the number of animals decreased by approximately half in 2019 in the lactating cow.

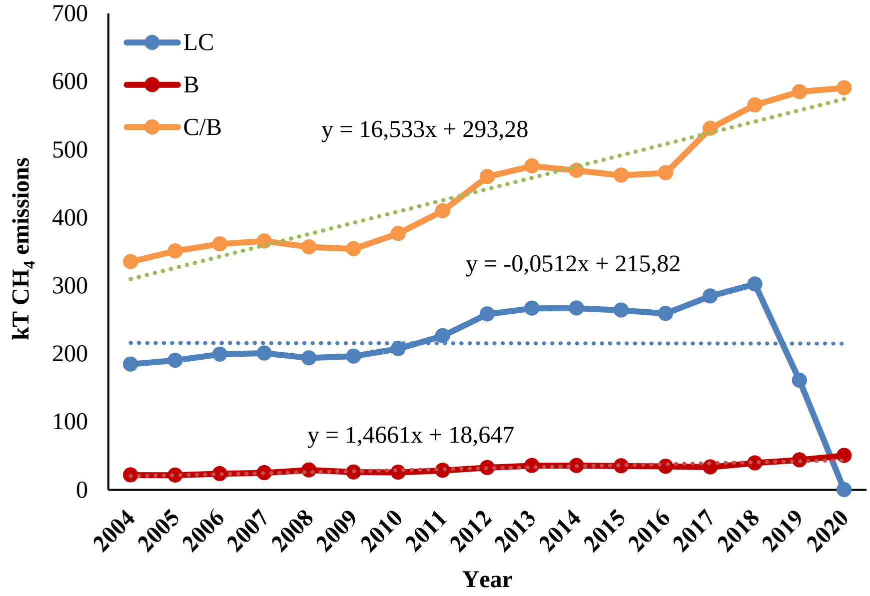


**Figure 2.** Enteric methane emission rates by cattle animal categories in 2004-2020 in Turkey (kT $CH_4$ year$^{-1}$).

Enteric methane emissions from cattle have followed a fluctuating course in the last 20 years in Turkey. (Figure 3). Since lactating cow numbers for 2020 cannot be obtained from the TUIK database, only enteric emissions from the bull and cattle/buffalo categories are indicated for this year. A significant increase is expected in the number of ruminant animals to meet the increasing population food demand and increasing in ruminant animals, which constitute 33% of anthropogenic methane gas emissions, it is predicted that this rate will increase to 70% in the next 20-30 years (Gür and Öztürk 2021).

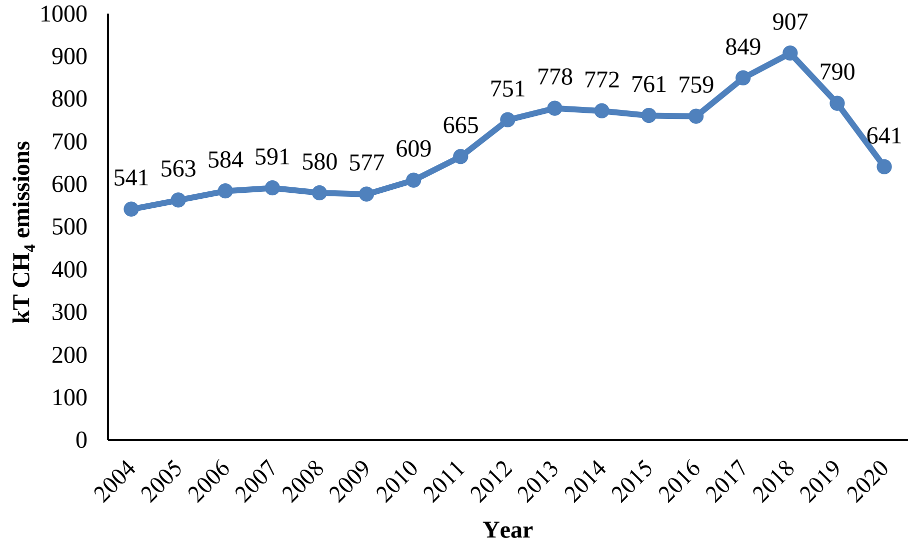


**Figure 3.** Total enteric fermentation methane emissions from cattle in 2004-2020 in Turkey (kT $CH_4$ year$^{-1}$).

Enteric fermentation $CH_4$ emission rates of cattle according to geographical regions of Turkey were also examined for 2019 (Figure 4). Cattle numbers have according to the regions the Mediterranean is 1 363 715 head, the Black Sea is 2 538 371 head, Aegean is 2 838 421 head, Marmara is 2 322 203 head, Eastern Anatolia is 3 824 561 head, Southeastern Anatolia is 1 711 662 head and Central Anatolia is 3 557 442 heads (TUIK, 2021).

According to the evaluations, it is seen that the highest enteric methane emission potential is in the Eastern Anatolia region for three cattle groups. The second highest emission value was obtained in the Central Anatolia region.

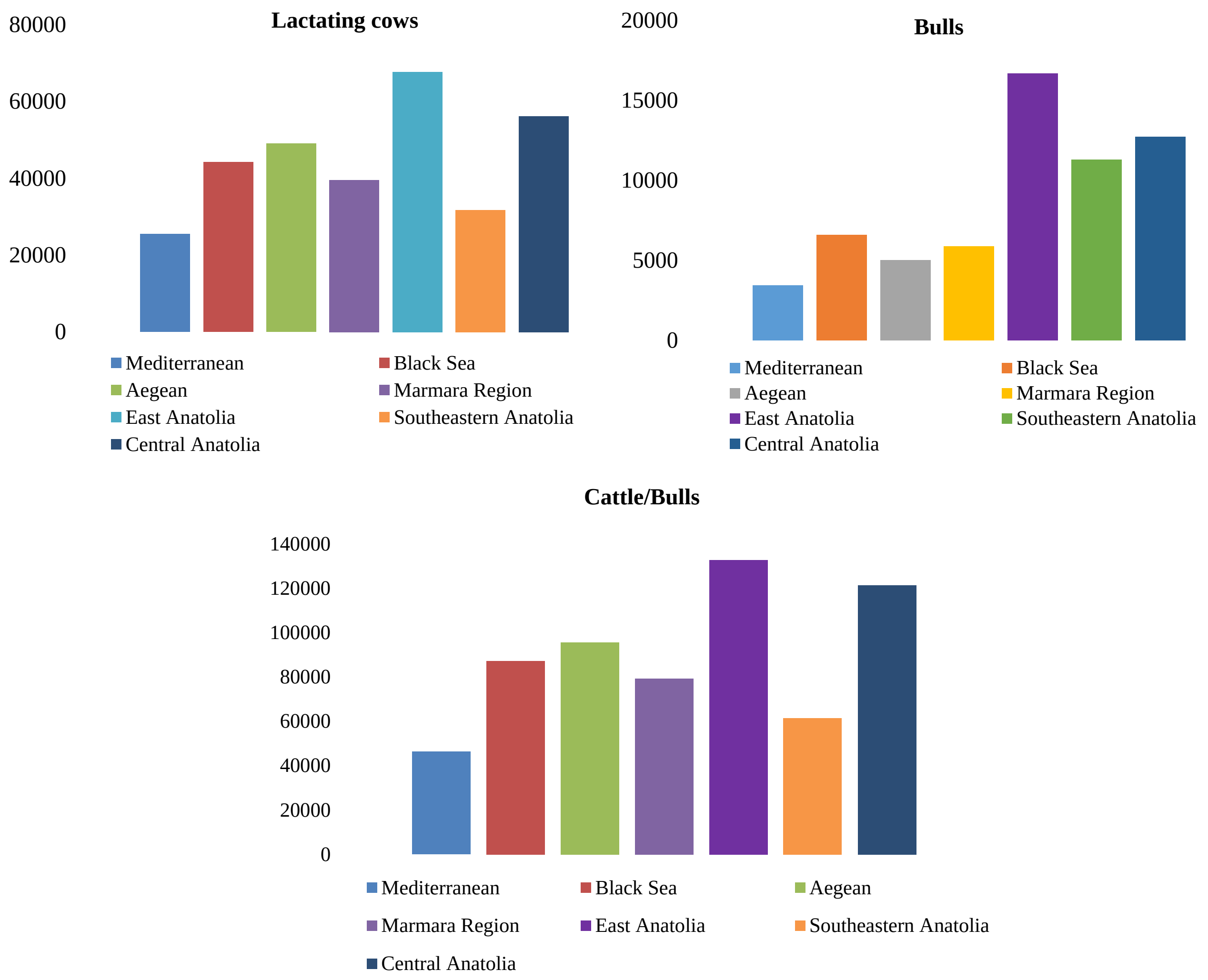


**Figure 4**. Enteric methane emissions by region (ton $CH_4$ $year^{-1}$).

## CONCLUSIONS

In this study, country-specific $CH_4$ EFs for enteric fermentation of cattle was developed using the IPCC Tier 2 methodology and also geographic regions were compared. For calculations, necessary data were obtained from relevant databases and sources, except number of animals. At the end of the study, country-specific $CH_4$ EFs by animal categories are 47 kg $CH_4$ $year^{-1}$ $head^{-1}$ for lactating cow and 52.5 kg $CH_4$ $year^{-1}$ $head^{-1}$ was calculated for bulls. Eastern Anatolia region among geographic regions has the highest enteric methane emissions due to higher number of animal. When we compared our results to other counties in this study, enteric methane emissions calculated for all sub-categories in this study are similar to Asian countries and lower than European countries. Differences in feed formula and feeding can be a reason for this situation. According to the sectoral analysis of greenhouse gas emissions (GHG) published by TURKSTAT in 2019, the agriculture sector, which also includes emissions from animals, ranks second after the energy sector. So, it can be say that the cattle are one of the main sources of GHG emissions in Turkey. But the cattle production contribute to the household economy in rural side and dietary needs in the country. To decrease GHG emissions, enteric methane emissions from cattle should be decreased. Different strategies are considered for methane emissions from enteric fermentation. It has been reported in various studies that changes in feed rations that suppress methane emission reduce the digestibility of the feed and reduce the emission (Haque *et al.* 2001; Akçil and Denek 2013; Güleçyüz and Kılıç 2018). Therefore, using concentrated feed instead of roughage, adding oil or various additives into the feed can suppress the formation of $CH_4$ gas in the rumen. Genetic selection that produces low methane, and increasing productivity by breeding productive species are other reduction strategies that can reduce methane formation.

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