ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

PhD THESIS

Dehouegnon Jerry AGOSSOU

ECOLOGICAL FOOTPRINT OF GRASSLAND-BASED RUMINANT PRODUCTION SYSTEMS IN THE REPUBLIC OF BENIN AND TURKEY'S MEDITERRANEAN REGION

DEPARTMENT OF ANIMAL SCIENCE

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ABSTRACT

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Greenhouse gases (GHG) emissions associated with ruminant (sheep, goats, and cattle) production in the Benin Republic (RB) and the East Mediterranean region of Turkey (EMR) were quantified. The emissions of two GHG, i.e. methane (CH_4) and nitrous oxide (N_2O) were calculated using the Tier 2 method developed by the Intergovernmental Panel for Climate Change (IPCC). The amount of CH_4 was determined using annual animal population and county-specific emission factors (EF) developed. As for N_2O emission, it was estimated using the EF default provided by the IPCC. Over two decades, the GHG emissions in RB increased by 72.79% from 2770.81 Gg CO_2 eq in 1999 to 4787.90 Gg CO_2 eq in 2019. Regarding emissions in the EMR, they were 2540 and 4689 Gg CO_2 eq in 2004 and 2020 respectively, with a yearly growth rate of 4.98%. In terms of animal species, cattle were responsible for the most emissions, representing about 92.11% (4410.19 Gg CO_2 eq) and 66.20% (3104 Gg CO_2eq) of the sector's emissions in RB and the study area in Turkey. Enteric fermentation was the main source of emissions, representing an average of 78.04% (2944.10 Gg CO_2eq) and 60.86% (2151.19 Gg CO_2eq) of total emissions in RB and the study area in Turkey respectively. Manure storage and processing represent 21.96 and 39.14 % of emissions respectively in the RB and the EMR of Turkey.

Key Words: Methane, Nitrous oxide, Ruminant, Enteric fermentation, Manure, Ecological footprint

ÖZ

DOKTORA TEZI

BENİN CUMHURIYETI VE TÜRKİYE'NİN AKDENİZ BÖLGESİNDE MERAYA DAYALI HAYVANSAL ÜRETİM SİSTEMLERİNDE EKOLOJİK AYAK İZİ

Dehouegnon Jerry AGOSSOU

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Bu çalışmada Benin Cumhuriyeti ve Türkiye'nin Doğu Akdeniz bölgesinde yetiştirilen çiftlik hayvanlarının (koyun, keçi ve sığır) üretimi ile ilişkili sera gazları (GHG) emisyonları saptanmıştır. İki sera gazının emisyonu, yani metan (CH_4) ve diazot monoksit (N_2O), Hükümetler Arası İklim Değişikliği Paneli (IPCC) tarafından geliştirilen Tier 2 yöntemi kullanılarak hesaplanmıştır. CH_4, yıllık hayvan popülasyonu ve hesaplanan emisyon faktörleri (EF) kullanılarak hesaplanmıştır. N_2O emisyonuna gelince, IPCC tarafından sağlanan EF varsayılanı kullanılarak tahmin edilmiştir. Son yirmi yıl içinde, Benin Cumhuriyeti'ndeki GHG emisyonları, 1999'da 2770,81 Gg CO_2 eşdeğerinden 2019'da 4787,90 Gg CO_2 eşdeğerine %72,79 artmıştır. Türkiye'nin Doğu Akdeniz bölgesindeki emisyonla ilgili olarak, 2004'te 2540 ve 4689 Gg CO_2 eşdeğeri olduğu ve 2020 yılına kadar, yıllık %4,98 büyüme oranı ile arttığı görülmüştür. Hayvan türleri açısından, Benin Cumhuriyeti'nde ve Türkiye'de çalışma alanında sektör emisyonlarının yaklaşık %92,11'ini (4410,19 Gg CO_2 eşdeğeri) ve %66,20'sini (3104 Gg CO2 eşdeğeri) temsil eden emisyondan sığırların sorumlu olduğu belirlenmiştir. Enterik fermantasyon emisyonun ana kaynağıdır ve Benin Cumhuriyeti ve Türkiyedeki toplam emisyonların ortalama %78,04'ünü (2944,10 Gg CO2 eşdeğeri) ve %60,86'sını (2151,19 Gg CO2 eşdeğeri) oluşturmaktadır.Gübre depolama ve işleme, Benin Cumhuriyeti ve Türkiye'nin Doğu-Akdeniz bölgesinde'de emisyonun sırasıyla %21.96'sını ve %39.14'ünü temsil etmektedir.

Anahtar kelimeler: Metan, Diazot monoksit, Ruminant, Enterik fermantasyon, Gübre, ekolojik ayakizi

EXTENDED SUMMARY

Livestock constitutes an integral component of the Beninese and Turkish agriculture sector, contributes to the livelihoods of the rural population, and provides youth employment. Ruminant rearing, which is one of the largest animal production sectors, adversely affects the climate, exerting an important pressure on natural resources (land and water). Ruminants are a significant source of GHG emissions. Methane (CH_4) and nitrous oxide (N_2O) are two main GHG emitted through enteric fermentation and manure management. Because of the variability in the atmospheric lifespan of gases and their ability to reflect and trap radiant energy, the average global warming potential (GWP) of GHG is expressed in carbon dioxide equivalents (CO_2eq.). CH_4 and N_2O are highly warming GHGs with GWP of 25 and 298 CO_2eq/kg respectively, over a 100-year time horizon. These gases, expressed in CO_2 equivalent (CO_2eq), are accepted as the reporting unit for the carbon footprint. The carbon footprint of livestock products is becoming an important issue for consumers. Therefore, GHG emissions are becoming a concern for producers.

In order to the ruminant production system to be sustainable, it is important to consider key resources, such as land and water, but also the environmental impacts, including GHG emissions and pollution due to the use of inputs. Consequently, a growing interest in understanding the interaction between global warming and ruminant production has risen. Although a significant amount of research has been conducted in this field, there is still limited research regarding the calculation of GHG emissions from ruminant production using country-specific data. The study presents a detailed inventory of GHG emissions from different indigenous and exotic breeds of different ruminant categories estimated using country-specific emission coefficients based on IPCC guidelines. Due to the unavailability of national emission factors (EF) in the Benin Republic, we first developed CH_4 EF for cattle, sheep and goats using the IPCC guideline. To calculate CH_4 emissions in the East Mediterranean area of Turkey, the IPCC default EF was applied to sheep and goats because country-specific EF was not available. For cattle, EF calculated based on country-specific data obtained from the Turkish greenhouse gas inventory 1990-2018 reported by the Turkish Statistical Institute was used. Concerning N2O emissions, in both countries, EF default values were applied.

In the Benin Republic, a national enteric EF of 56.85 kg CH_4 head^{-1} year^{-1} was generated for all cattle, with a range of 34.27 for Lagune to 72.39 kg CH_4 head-1 year^{-1} for Gudali zebu. For sheep and goats, the EF was developed for the West African Dwarf, which represents the most reared breed in the Benin Republic. The Enteric EF of sheep and goats was 3.76 and 2.92 kg CH_4 head^{-1} year^{-1}. The emission intensity developed for CH_4 emissions from manure management was 1.54, 0.16 and 0.12 kg CH_4 head^{-1} year^{-1} for cattle, sheep and goats respectively.

In Turkey, enteric EF in the cattle category was 82.1 and 48.0 kg CH_4 head^{-1} year^{-1} for dairy and non-dairy cattle respectively. In small ruminants, EF was 5 kg/head/year in goats and local sheep, while for Merino sheep it was 6.5 kg CH_4 head^{-1} year^{-1}. Because the emission from manure varied according to climate conditions, manure management system and livestock categories, EF_{manure} ranged between 10 kg CH_4 head^{-1} year^{-1} (in dairy indigenous cattle) and 32 kg CH_4 head^{-1} year^{-1} (in culture cattle). In sheep, the EF value varied between 0.15 and 0.215 kg CH_4 head^{-1} year^{-1}, while in goats it was between 0.11 and 0.17 kg CH_4 head^{-1} year^{-1}.

This assessment indicated that the ruminant subsector is responsible for 3843.97 Gg CO_2eq of CH_4 and 943.93 Gg CO_2eq of N_2O emissions in the Benin Republic. Methane emissions were mainly emitted from enteric fermentation (3740.08 Gg CO_2eq i.e. 97.30%) against (103.89 Gg CO_2eq i.e. 2.70%) for manure management. Direct and indirect N_2O were estimated at 754.11 and 189.82 Gg CO_2eq, accounting for 79.89 and 20.11% respectively. In the study area in Turkey, the GHG emissions were 3538.67 Gg CO_2eq. The GHG profile is dominated by enteric CH_4 (2151.19 Gg CO_2eq.) which accounted for 60.86%. It was followed by N_2O (1468.22 Gg CO_2eq) and $CH_{4manure}$ (406.58 Gg CO_2eq.) contributing to 31.31 and 8.67% of emissions from ruminant production respectively. Despite the increasing trend observed in GHG emissions over the last two decades, significant reductions in GHG emissions can be achieved through intensification of animal production and improved production technologies in the Benin Republic and the use of advanced mitigation practices (such as feed additives, yeast) in modern production systems in Turkey.

GENIŞLETILMIŞ ÖZET

Hayvancılık, Benin ve Türk tarım sektörünün ayrılmaz bir parçasını oluşturmakta, kırsal nüfusun geçimine ve genç istihdamına katkıda bulunmaktadır. En büyük hayvansal üretim sektörlerinden biri olan ruminant yetiştiriciliği, iklimi olumsuz etkilemekte, doğal kaynaklar (toprak ve su) üzerinde önemli bir baskı oluşturmaktadır. Ruminantlar önemli bir sera gazı emisyon kaynağıdır. Metan (CH_4) ve diazot monoksit (N_2O) enterik fermantasyon ve gübre yönetimi yoluyla yayılan iki ana sera gazıdır. Gazların atmosferik ömürlerindeki değişkenlik ve radyan enerjiyi yansıtma ve yakalama yetenekleri nedeniyle, GHG'nin ortalama küresel ısınma potansiyeli (GWP) karbondioksit eşdeğerleri (CO_2eq.) olarak ifade edilir. CH_4 ve N_2O, GWP'si 25 ve 298 CO_2 eşdeğeri /kg ile yüksek oranda ısınan GHG'dir. sırasıyla, 100 yıllık bir zaman ufku üzerinde. CO_2 eşdeğeri (CO_2eq) olarak ifade edilen bu gazlar, karbon ayak izi için raporlama birimi olarak kabul edilir. Hayvancılık ürünlerinin karbon ayak izi tüketiciler için önemli bir konu haline gelmektedir. Bu nedenle, GHG emisyonu üreticiler için de bir endişe kaynağı oluşturmaktadır.

Ruminant üretim sisteminin sürdürülebilir olması için toprak ve su gibi temel kaynakların yanı sıra GHG emisyonu ve girdi kullanımından kaynaklanan kirlilik gibi çevresel etkileri de dikkate almak önemlidir. Sonuç olarak, küresel ısınma ve geviş getiren hayvan üretiminin etkileşimini anlamaya artan ilgi artmıştır. Bu alanda önemli miktarda araştırma yapılmış olmasına rağmen, ruminant üretiminden kaynaklanan sera gazı emisyonunun ülkeye özgü veriler kullanılarak hesaplanmasına yönelik araştırmalar halen sınırlıdır. Çalışma, IPCC yönergelerine dayalı olarak ülkeye özgü emisyon katsayıları kullanılarak tahmin edilen farklı yerli ve egzotik farklı geviş getiren hayvan kategorilerine ait sera gazı emisyonlarının ayrıntılı bir envanterini sunmaktadır. Benin Cumhuriyeti'nde ulusal emisyon faktörlerinin (EF) bulunmaması nedeniyle, ilk olarak IPCC kılavuzunu kullanarak sığır, koyun ve keçiler için CH_4 EF'yi geliştirilmiştir. Türkiye'nin Doğu

Akdeniz bölgesindeki CH_4 emisyonunu hesaplamak için ülkeye özgü EF mevcut olmadığı için koyun ve keçiler için IPCC varsayılan EF uygulanmıştır. Sığırlar için Türkiye İstatistik Kurumu tarafından raporlanan 1990 - 2018 Türkiye sera gazı envanterinden elde edilen ülkeye özgü verilere göre hesaplanan EF kullanılmıştır. N_2O emisyonu ile ilgili olarak, her iki ülkede de EF varsayılan değerleri uygulanmıştır.

Benin Cumhuriyeti'nde, tüm sığırlar için 56.85 kg CH_4 başa^{-1} yıl^{-1} ulusal enterik EF, Lagune için 34.27 ile Gudali zebu için 72.39 kg CH_4 başa^{-1} yıl^{-1} aralığında oluşturulmuştur. Koyun ve keçi için EF, Benin Cumhuriyeti'nde en çok yetiştirilen ırkı temsil eden Batı Afrika Cücesi için geliştirilmiştir. Koyun ve keçinin enterik EF'si 3.76 ve 2.92 kg CH_4 başa^{-1} yıl^{-1} idi. Gübre yönetiminden kaynaklanan CH_4 emisyonu için geliştirilen emisyon yoğunluğu sığır, koyun ve keçiler için sırasıyla 1.54, 0.16 ve 0.12 kg CH_4 başa^{-1} yıl^{-1}'dır.

Türkiye'de sığır kategorisindeki enterik EF, süt ve süt olmayan sığırlar için sırasıyla 82.1 ve 48.0 kg CH_4 başa^{-1} yıl^{-1} idi. Küçükbaşlarda EF keçi ve yerel koyunlarda 5 kg CH_4 başa^{-1} yıl^{-1} iken Merinos koyunlarında; 6.5 kg CH_4 başa^{-1} yıl^{-1} idi. Gübreden kaynaklanan emisyon iklim koşuluna, gübre yönetim sistemine ve canlı hayvan kategorilerine göre değişiklik gösterdiğinden, $EF_{gübre}$ 10 kg CH_4 başa^{-1} yıl^{-1} (süt yerli sığırlarında) ile 32 kg CH_4 başa^{-1} yıl^{-1} (kültür sığırlarında) arasında değişmektedir. EF değeri koyunlarda 0,15 ile 0,215 kg CH_4 başa^{-1} yıl^{-1} arasında değişirken, keçilerde 0,11 ile 0,17 kg CH_4 başa^{-1} yıl^{-1} arasında değişmektedir.

Bu değerlendirme, Benin cumhuriyetinde ruminant alt sektörünün 3843,97 Gg CO_2 eşdeğeri CH_4 ve 943,93 Gg CO_2 eşdeğeri N_2O emisyonundan sorumlu olduğunu göstermiştir. Metan emisyonları esas olarak gübre yönetimi için enterik fermantasyondan (3740.08 Gg CO_2 eşdeğeri yani %97.30) karşı (103.89 Gg CO_2 eşdeğeri yani %2.70) yayılmıştır. Doğrudan ve dolaylı N_2O, sırasıyla %79.89 ve %20.11'e karşılık gelen 754.11 ve 189.82 olarak tahmin edilmiştir. Türkiye'deki çalışma alanında GHG emisyonu 3538.67 Gg CO_2 eşdeğeri GHG profiline, %60.86'ya tekabül eden enterik CH_4 (2151.19 Gg CO_2 eq.) hakimdir. Bunu, geviş getiren hayvan üretiminden kaynaklanan emisyonların sırasıyla %31,31 ve %8,67'sine katkıda bulunan N_2O (1468,22 Gg CO_2 eşdeğeri) ve $CH_{4gübre}$ (406,58 Gg CO_2 eşdeğeri) izledi. Son yirmi yılda sera gazı emisyonunda gözlenen artış eğilimine rağmen, Benin Cumhuriyeti'nde hayvansal üretimin yoğunlaştırılması ve gelişmiş üretim teknolojileri ve modern üretimde gelişmiş azaltma uygulamalarının (yem katkı maddesi, maya gibi) kullanılmasıyla sera gazı emisyonlarında önemli azalma sağlanabilir. Türkiye'de ise hayvansal üretimde sera gazı emisyonunu azaltan bakım besleme uygulamaları ile özellikle atık yönetimi konusunda çevre önceliklerini ön plana alan uygulamalarla emisyon azaltılabilecektir.

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SYMBOLS AND ABBREVIATIONS

CH_4	: Methane
CO_2eq	: Carbon dioxide equivalent
DE	: Feed digestibility
EF	: Emission Factors
EMR	: Eastern Mediterranean Region of Turkey
Eq	: Equation
FAO	: Food and Agriculture Organization
FAOSTAT	: The Food and Agriculture Organization Corporate Statistical Database
GE	: Gross Energy
GDP	: Gross Domestic Product
Gg	: Gigagram
GHG	: Greenhouse gases
GWP	: Global Warming Potential
IPCC	: Intergovernmental Panel for Climate Change
MJ	: Megajoule
N_2O	: Nitrous oxide
kg	: Kilogram
%	: Percentage
RB	: Benin Republic

1. INTRODUCTION

Ruminant production is an important agricultural subsector in both the Benin Republic and Turkey. They dynamically contribute to the efficient use of land, environmental aspects, livelihood and socio-economic development of local communities. In 2018, the population of cattle, sheep and goats was approximately 2.5 million, 1.9 and 1.0 million heads respectively in the Benin Republic, while the cattle and small ruminant (sheep and goats) population were 15.94 and 44.31 million respectively in Turkey (FAOSTAT, 2018). In both countries, extensive production is widely spread and the local breeds are the most reared. However, semi-intensive and intensive dairy or fattening farms (for meat production) have recently emerged in Benin and Turkey, as well (Agossou et al., 2018).

Although ruminant production is an important component of sustainable agricultural economic development, it is one of the major polluters of the environment. Furthermore, ruminant farming requires the use of important natural resources such as rangel-ands and water. This puts considerable pressure on the availability of these resources. The effects of society's actions on the environment, the amount of land area necessary to sustain current levels of resource consumption and waste discharge, is known as the ecological footprint (Folke et al., 1998; Stöglehner, 2003). The most influential component of the Ecological Footprint methodology is the Carbon Footprint (CF) (Pirlo and Carè, 2013). The carbon footprint of livestock products is becoming an important issue for consumers. Therefore, GHG emissions are becoming a concern for producers (Barret et al., 2013).

While several previous studies have largely elucidated the negative effects of climate change (heat stress and water deprivation) on agriculture and livestock, few have addressed the quantitative assessment of GHG emissions and the use of water resources for ruminant production in Benin and Turkey.

The different methods used to measure and estimate the enteric methane emission from ruminants were well reviewed by Storm et al. (2012). Among the measurement methods, the best known are chambers/respiration chambers, the SF6 technique, the in vitro gas production technique, and the newer CO_2 methods. Some models were developed to estimate methane production at the global, national or farm level. These estimation models calculate methane levels based on livestock population, animal categories, feed intake and diet composition. The Intergovernmental Panel on Climate Change (IPCC) issues the common model used to calculate methane emissions from ruminants. However, methods under development, such as the micrometeorological technique, combined feeder and CH_4 analyser, and proxy methods, can determine the amount of methane emitted.

The IPCC developed three different approaches to estimate GHG emissions. These three approaches, known as Tier 1, 2, and 3, depend on the quality of the database established in each country (IPCC, 2006). Tier 1 is the simplest calculation method and Tier 3 is the most complex and data-dependent method (Storm et al., 2012). In most developing countries, Tier I is the most used approach to estimate using default emission factors (EFs) developed to represent the GHG emissions from livestock systems in different geographic regions based on livestock census data and assumptions regarding the systems themselves.

It has been recognised that Tier I estimates have shortcomings, both because they are derived from data from livestock systems in developed economies (‘adjusted’ to fit the conditions of developing countries) and by their nature, as the approach cannot accommodate changes to emissions brought about by changes to livestock production systems. Tier 2 estimates can represent a substantial increase in the precision of CH_4 emissions from livestock because they better define animals, productivity, management, and feed through using actual measurements of these characteristics (Tubiello et al. 2013).

The most important greenhouse gases from animal agriculture are methane and nitrous oxide. Methane, mainly produced by enteric fermentation and manure storage, is a gas that has an effect on global warming 28 times higher than carbon dioxide. Nitrous oxide, arising from manure storage and the use of organic/inorganic fertilizers, is a molecule with a global warming potential 265 times higher than carbon dioxide. The carbon dioxide equivalent is a standard unit used to account for the global warming potential (IPCC, 2013). Thus, the extreme impact of the animal farming sector needs to be taken into account when defining the overall sustainability of a mitigation strategy, which can vary across different livestock systems, species, and climates.

The main objective of this study is to quantify the greenhouse gases emissions and water usage from ruminant (cattle, sheep and goats) production in Turkey and the Benin Republic. Specifically, the study will be conducted:

(i) To calculate methane (CH_4) and nitrogen emissions (N_2O) from enteric fermentation and manure management;
(ii) To explore the possibility of reducing CH_4 and N_2O emissions;
(iii) To propose solutions to help decision-making to take effective mitigation measures in order to promote sustainable production and combat global warming.

2. LITERATURE OVERVIEW

2.1. Ruminant Production in the Benin Republic

2.1.1. Importance Socio-Economic of Ruminant Production in Benin Republic

Livestock production is an important branch of the agricultural sector in the Benin Republic, contributing about 6% of GDP. Livestock is the second most substantial agricultural sub-sector. About 36% of households (predominantly in the North of Benin) are engaged in livestock production, with 87% of households in the Alibori Department and 41% of households in Borgou Department depending on livestock as their main economic activity (FAO; ICRISAT; CIAT. 2018).

Rearing small ruminants is a cultural activity practiced by the vast majority (90%) of the Beninese population. Sheep and goats are mostly kept on family farms with an average of 2 to 10 heads (Hounzangbe-Adote et al., 2011). Apart from the prestige and savings functions, these animals contribute to increasing the income of keepers through the sale of animals and their by-products (skin, milk), and the use of manure for fertilizing farms (Hounzangbe-Adote et al., 2011). Ruminant production plays a crucial role as a source of food (milk and meat) and employment for the population, especially those living in rural areas (Agossou et al., 2018; Agossou et al., 2019).

2.1.2. Ruminant Population and Breeds in Benin Republic

According to data from the Statistical Division of the Food and Agriculture Organisation, the estimated population of cattle, goats and sheep in 2019 was roughly 2.50 million, 1.96 and 0.96 million heads respectively (FAOSTAT, 2018). As shown in Figure 2.1, the Beninese ruminant herd, estimated at 0.92 and 1.81 million heads of cattle and small ruminants in 1989, had increased and reached 2.38 million and 3.36 million heads in 2017. Over the last 30 years, the annual calculated growth rate of the ruminant herd was averagely 3.47, 2.44, and 3.32% in cattle, goats, and sheep respectively. The composition of cattle herds is characterized by a predominance of cows (75% of cows, heifers and calves) (ANOPER, 2014). As they move northward, the density of the cattle and goat population increases proportionally with the altitude. The northern grasslands located at high altitudes are the main hub of ruminant production (Agossou et al., 2018). The Borgou and Alibori departments shelter sixty-three percent of cattle and twenty-nine percent of the small ruminant population.

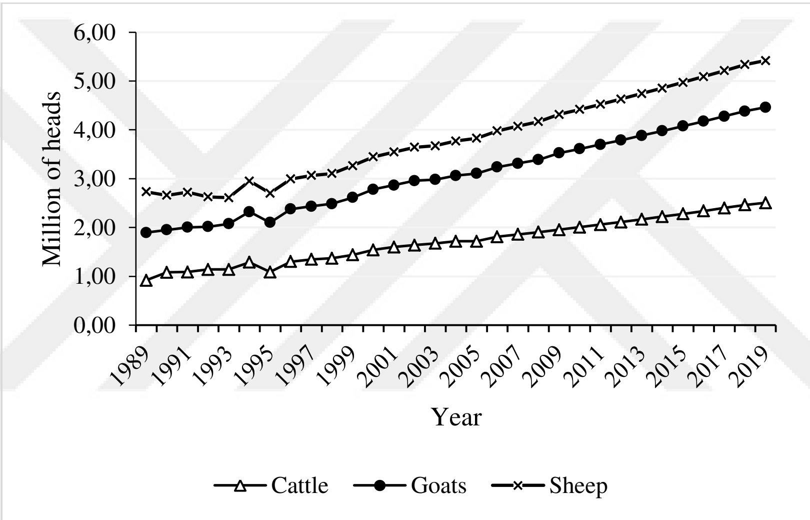


Figure 2.1. Trends in ruminant population in Benin Republic from 1987 to 2017

The variation of climatic factors from one region to another may explain this irregular geographical distribution of the population. These climatic conditions influence the availability of food resources and the pressures of tsetse flies, vectors of trypanosomes (Agossou et al., 2018). It can also be due to the dietary behaviours of consumers, targeted markets, socio-cultural and religious factors (Agossou et al., 2018).

2.1.2.1. Cattle breeds

Cattle mainly comprise 31% of humpless and trypanotolerant breeds, including Borgou, Somba and Lagune; 7.7% of zebus (M'bororo, Azawak, Gudali and White Fulani) and 61.3% of crossbreeds (Alkoiret et al., 2009; Kassa et al., 2016a; Agossou et al., 2018). According to Kassa et al. (2016), the Southern Benin, notably the valley of Ouémè, is predominantly a rearing area for Lagune cattle. This breed represented 3.7% of the national cattle population (Alkoiret and Gbangboche, 2005). Among these local breeds, Borgou cattle are the most widely spread in the country, representing 51% of the total local cattle herd (Fatondji, 2018). The Borgou is a stabilized cross between the short-horned *Bos taurus* of West Africa (Somba or Lagunaire) and the White Fulani (Gbangboche and Alkoiret, 2016). The Borgou cattle breed is mainly used to produce milk and draught power (Worogo et al., 2019). This breed produced more than half of the meat consumed in Benin (Fatondji, 2018; Worogo et al., 2019).

Figure 2.2. Somba cattle in Tanguiéta district (Benin Republic)

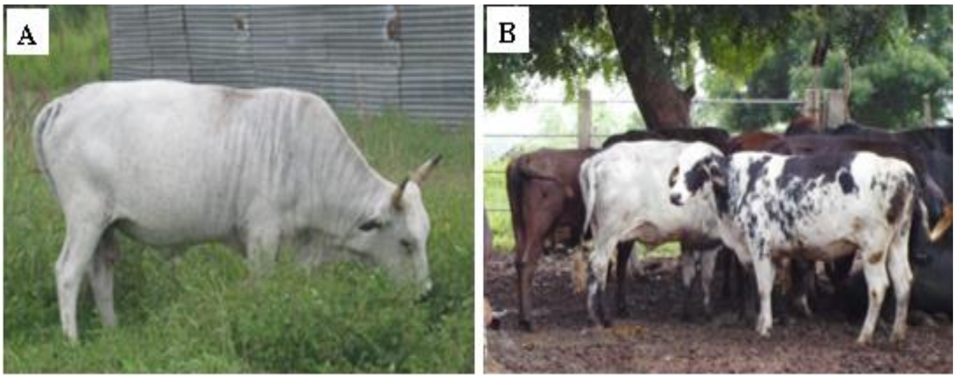


Figure 2.3. (A) Borgou cattle at State Farm of Betecoucou and (B) Girolando cattle kept at the State Farm of Kpinnou

Concerning zebu breeds, i.e. M'bororo, Gudali, and Fulani, Assani (2013) and Fatondji (2018) reported that Gudali is originally from the North-west of Nigeria, mainly the Northeast of the province of Sokoto and surrounding areas located in Cameroon. Native to Northern Nigeria and the northeastern part of Cameroon (Norezzine et al. 2019), the White Fulani zebu is also traditionally kept in Northern Benin. This breed is adapted to the tropical climate characterized by two well-defined seasons – a short rainy season and a long dry season – (Tawah and Rege, 1996; Fatondji, 2018). Local cattle are very well adapted to the adverse climate of the drought region and to the rearing conditions (elevated temperature, feeding and watering restrictions). They can to walk long distances to find out feed and have high resistance to diseases, and parasites (streptothricosis, tick-borne diseases, helminthosis) (Agossou et al., 2019). Their keeping constitutes a means of promoting and increasing the value of the land. However, studies have shown that the low genetic potential, resulting in low milk production (Agossou et al. 2017). Some production performances of these breeds reared in traditional production and semi-intensive conditions are given in table 2.1.

Table 2.1. Some productivity parameters of cattle in Benin Republic

Parameters	**Breeds**				
	Borgou	Lagune	Gudali	Azawak	Girolando
	Reproductive and growth performances				
FR (%)	69.28[a]	58[k]	64.1-91.1[e]	98.39-100[f]	91.18 – 100[g]
PR (%)	83[b]	-	73.0-95.5[e]	45-75[f]	85.29-103.03[g]
MR (%)	4-18[b]	-	-	8-12[f]	6.90[g]
CI (days)	427.2[a]	365 - 455[k]	336[f]	420[f]	468.32[h]
BWm (kg)	18.9[c]	11-12[j]	27.0[e]	23.28[f]	26.79[g]
BWf (kg)	18.5[c]		24.8[e]	21.5[f]	25.96[g]
ADG (g)	235.7[c]	NA	535.6[e]	407-570[f]	600-800[i]
LWm (kg)	200-250[j]	150-200[k]	500-550[f]	350-500[f]	
LWf (kg)		100-150[k]	300-350[f]	250-300[f]	
CY (%)	49.8- 58.1[d]	50[j]	50-52[e]	48-52[f]	
	Dairy performances				
DMY (L)	0.99 -2.5[dh]	0.36[d]	3-5[e]	1.78 [5]	4.77-6.94[dh]
LL (days)	330[d]	180[j]	230[e]	270-300[f]	305[h]
TMY (kg)	256.41[d]	125 – 200[j]	1000-1100[e]	800-1100[f]	2201.17[h]
References	[a]Gbangboché and Alkoiret, 2011; [b]Chabi Toko et al., 2016; [c]Alkoiret et al., 2011; [d]Kassa et al., 2016; [e]Assani, 2013; [f]Oumarou, 2004; [g]Assani et al., 2015; [h]Doko et al., 2012; [i]Toukourou and Senou, 2010; [j]Hestin, 2012 ; [k]Alkoiret and Gbangboche, 2005				

On the other hand, exotic breeds, including Brazilian Girolando, were encountered on some state ranches and private farms. Girolando cattle were introduced to the country through the Livestock Development Project in November 2004. The Girolando cattle producing daily 7.22 ± 0.15 kg of milk are kept mainly in the state and some private farms (Doko et al., 2012; Adambi Boukari et al., 2018). Appropriate breeding programs ensuring the crossing between the local breeds and high productive breeds such as Azawak known for its high lactation performance (4.5 litres/day) have been implemented (Kassa et al., 2016).

2.1.2.2. Sheep and goat breeds in Benin

Small ruminant density and population by the zonal department is given in Figure 2.4.

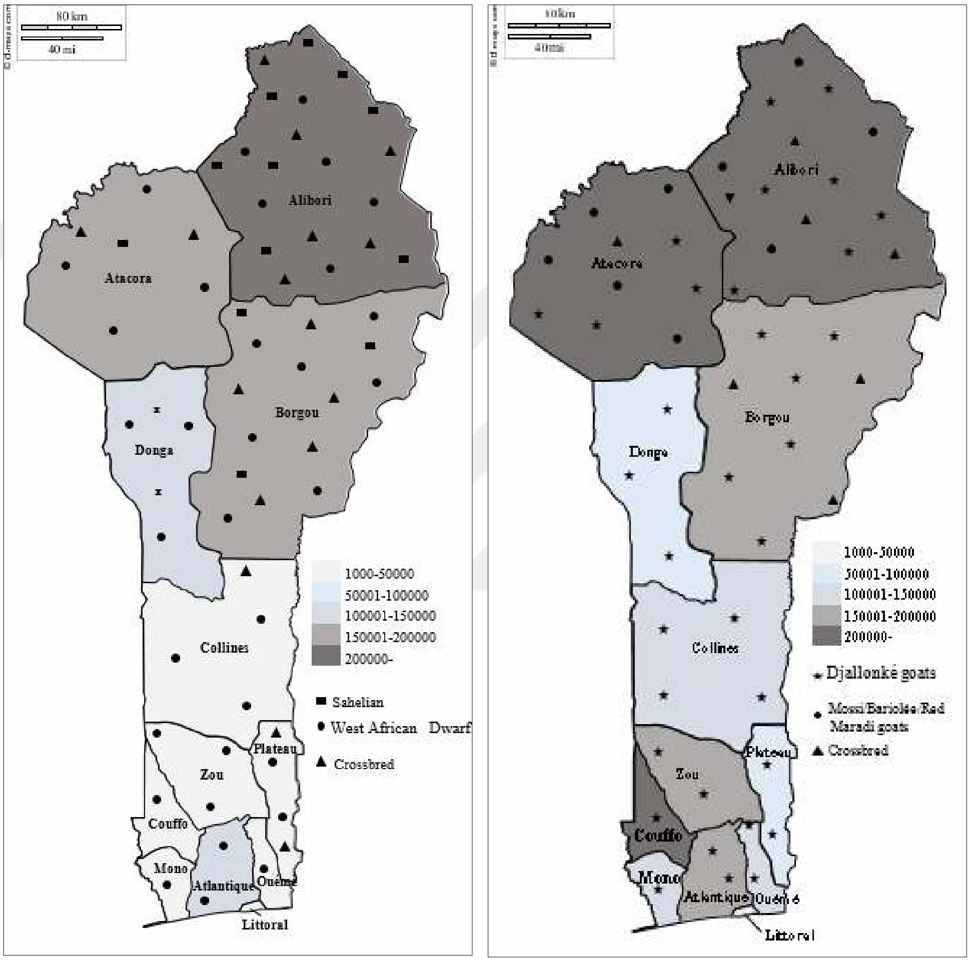


Figure 2.4. Geographical distribution of small ruminant population

As shown in Figure 2.1, sheep and goat populations grew from 1989 to 2019 with an average growth rate of 0.5 and 2.2%, respectively. In Benin, sheep and goats belong for the most part to the Guinean (West African Dwarf) or Djallonké breed, which is originally from Fouta-Djallon. The Djallonké is the most reared breed in Benin. Goats are predominant in the southern zone of the country, while sheep predominate in the northern region (Figure 2.4). However, other breeds include Sahelian sheep (Peulh sheep), Mossi, Bariolée and Red Maradi goats along the Niger River (Karimama and Malanville). Djallonké is mainly found in humid and sub-humid agro-ecological zones characterized by the strong presence of tsetse flies (Figure 2.5). The Sahelian breed is mostly encountered in the extreme north of Benin. These local breeds are very well adapted to the harsh climate and unfavourable keeping conditions (Agossou et al. 2018).

Figure 2.5. Djallonké breeds (A and B) and Sahelian breeds (C and D)

2.1.3. Production systems

Ruminants are mainly reared under the traditional and semi-improved systems. Traditional rearing includes pastoralism and agro-pastoralism systems, while the semi-improved system is characterized by an improvement in the production system, including the management of animals and the organization of production through food, health monitoring, and animal genetics (Worogo et al., 2019).

2.1.3.1. Pastoralism system

It is the most common traditional system practiced by the Peulh and Gando ethnical groups, for whom ruminant (mainly cattle) keeping is a food and income source. The pastoral system is widely developed in the northern and central-northern regions of Benin (Alkoirt et al., 2009; Chabi Toko et al., 2015; Agossou et al., 2017b). Animals are grouped into large herds (averagely 30 ± 15 heads) and are taken every morning by men to natural rangelands for grazing (Alkoirt et al., 2009; Missohou et al., 2016). The quality and grazing capacity of these pastures depend on rainfall, which is the most important limiting factor in grassland growth (Sintondji 1988). In this system, animals are housed in an open pen. The calves are separated from the cows during the night (Alkoirt et al., 2009). Animals may not be supplemented with concentrated feed, clean water, and health care. Most of the time, lactating females produce only in the rainy season. This system is the source of repeated conflicts between pastoralists and farmers because of the damage that herds cause to crops by grazing. This system is actually being turned into a mixed farming system in which producers combine animal production with agriculture, notably the cultivation of cotton and crops (Agossou et al., 2017a).

2.1.3.2. Agropastoral system

An association between crop production and animal rearing characterizes this system. It is the predominant system in the central, southern and West-Atacora regions of the country. Although it is a sedentary production, sometimes farmers practice transhumance on the natural range over short distances. During the cropping season, animals graze on fallow lands and areas of natural vegetation. In the dry season, they are brought back to cultivated areas where they graze in swamps, crop fields (cotton, sorghum, maize, etc.). Additionally, animals are housed under sheds and receive less medical treatment and agro-industrial by-products as a feed complement.

2.1.3.3. Ranching

In these systems, the improvement of the genetic potential of breeds, the production of milk and meat takes place. They are semi intensive farms owned by private (new agro entrepreneurs) or the government. Animal feeding is based on improved pastures, crop residues, industry by-product feedstuffs, and sometimes on cultivated fodder. Unlike other systems, these systems apply improved management practices such as good housing of animals, supplementation of concentrates, appropriate breeding programs, selection of the best reproductive animals, and health monitoring of animals (Agossou et al., 2017b).

2.2. A General Overview of ruminant production in Turkey

2.2.1. Importance of ruminant keeping in Turkey

Historically, livestock and livestock products have played important roles in the Turkish agricultural economy and rural society (GDAR, 2004). In Turkey, the socio-economic and geographical structure make small ruminant production an important profession; it is also a significant source of income in rural regions. 35% of red meat and 12% of milk production is obtained from small ruminants (Ocak et al., 2010).

Sheep and goats' production is very important for the country. These animals convert high fibre and low quality feed sources (straw, stubble, marginal lands, fruit, vegetable and field crop residues, low quality rangelands, etc.) into high value and much-desired milk, milk products, meat and wool (Gürsoy, 2006). Sheep and goat industry constitutes the only alternative to generate income for the subsistence of the people in large areas where good agricultural land and water are scarce (Gürsoy, 2006). Livestock production, in general represents 31% of the total agricultural gross national product (GNP). Of the total livestock production, 17% was from small ruminants, 59.5% from large ruminants and the remaining 23.5% from other species (Gürsoy, 2006).

2.2.2. Breeds and population of ruminant

2.2.2.1. Cattle breeds

Turkey is one of the important countries in terms of livestock population and animal genetic resource diversity among European countries. According to the Food and Agriculture Organization (FAOSTAT, 2018), there were 15.9 million cattle, mainly indigenous breeds, but also exotic breeds and their various crosses.

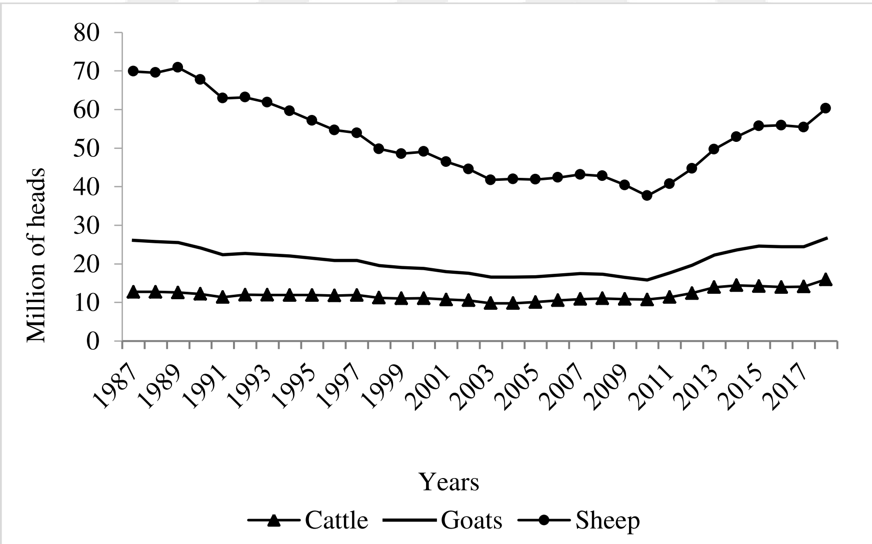
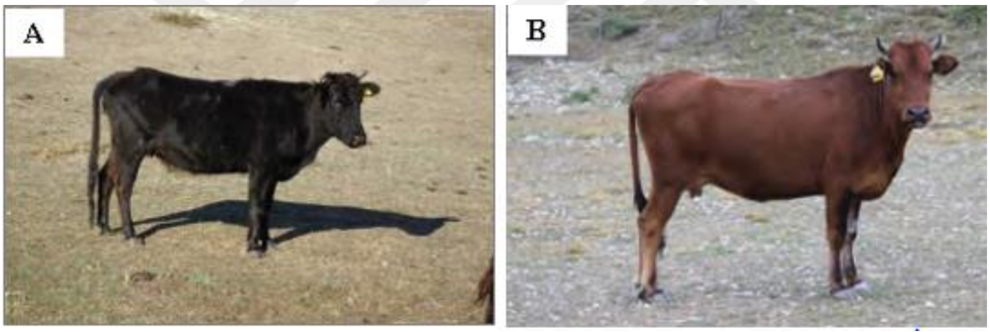
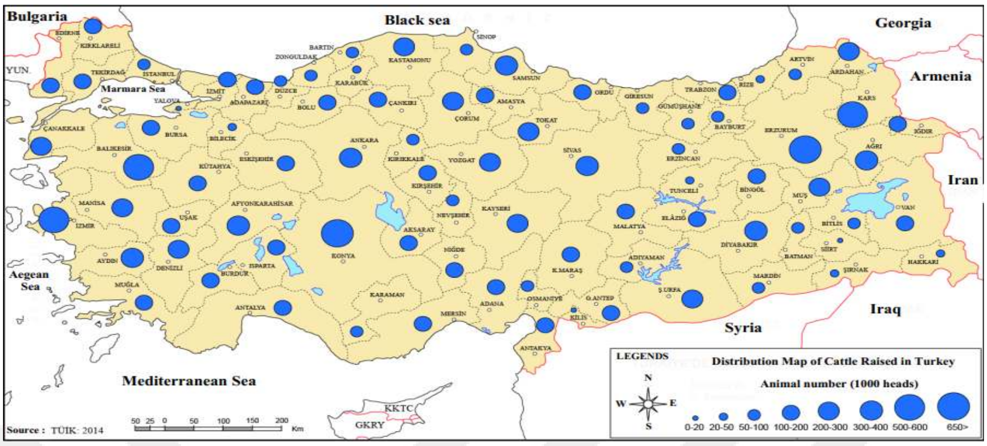


Figure 2.6. Trends in ruminant population in Turkey

The geographical distribution of cattle farms is given in the Figure 2.8. Anatolian Black (Yerli Kara), which is one of the Turkish local breeds, had a high population and was very common in Central Anatolia, due to intensive crossbreeding in recent decades, its population dramatically has declined and become a threatened breed in the region. The Eastern Anatolian Red (Doğu Anadolu Kırmızısı) is a breed of cattle in the Eastern and North-Eastern Anatolia. It has the second largest distribution area after Anatolian Black. Anatolian Grey (Boz Irk) is widespread in the Aegean and Marmara regions. The South Anatolian Red (Güney Anadolu Kırmızısı) extends into the East Mediterranean region and Southeast Anatolia. All these local breeds used to have rather large populations and extension areas, but the number of purebreds has declined and even their populations have come to the threshold level of extinction due to crossbreeding in recent decades (GDAR, 2004).



Source: Yilmaz et al. (2012)
Figure 2.7. Anatolian Black (A) and Eastern Anatolian Red (B)



Source: http://cografyaharita.com

Figure 2.8. Geographical distribution cattle farm across Turkey

Apart from local breeds, exotic breeds are encountered across the country. For instance, Holstein Friesian, Brown Swiss, and Turkish Brown Swiss are wide-spread from west to east. Jersey is especially common in the Black Sea region and Simmental can be seen throughout the country. On the other hand, crossbreeds from local exotic breeds were developed over decades. The Swiss Brown was first crossed with Anatolian Grey and the new crossbred was called Karacabey Brown (Karacabey Esmeri). Later on, a definition was made for the Anatolian Black and Eastern Anatolian Scarlet or Brown, including the crossbreds of them called Turkish Brown Swiss.

Source: Yilmaz et al. (2012)

Figure 2.9. Anatolian Grey (A) and South Anatolian Red (B)

Holstein has been used for crossing with the local breeds in the Marmara and Aegean regions, and Jersey has been used for crossing with native breeds in the Black Sea region. These genetic improvement activities were first initiated by the state and have been well adapted by the breeders. Angus and Hereford were used in crossings to improve the carcass yield of local breeds, but those studies have not been successful.

2.2.2.2. Sheep and goats breeds

Small ruminant production in Turkey is mainly based on extensive systems and the majority of goat breeds in Turkey are multi-type animals (Ocak et al., 2010). With approximately 10.63 million goats and a 33.68 million sheep population, Turkey has attractive breeding systems and genetic diversity (Daskiran and Ayhan, 2014; FAOSTAT, 2018). The well-known Turkish goat breeds are Angora (Mohair), Kilis, Damascus (also known as Shami goat), Hair goat and Honamli goat (Daskiran and Koluman, 2014; Daskiran et al., 2018). The goat population of Turkey is mostly composed of the hair goat (97%) (Anatolian Black) while the rest are different local types. The Hair goat serves multiple purposes (mainly meat and milk), but its productivity is quite low. Goat production is distributed throughout the whole of Turkey (figure 2.12), especially in the mountainous regions of the Mediterranean, South-East Anatolia and South-West Anatolia regions, but production systems are basically extensive and semi-extensive (Daskiran and Koluman, 2014; Daskiran and Ayhan, 2014). In Turkey, exotic breeds, including Saanen, German Fawn Goat, and Toggenburg goats, are also encountered. These breeds are subjected to crossbreeding with native breeds (Günlü and Alaşahan 2010).

Figure 2.10. Damascus (A), Kıl (B), Saanen (C) and Kilis (D) goat

In Turkey, native breeds constitute 97.3% of the total sheep population in Turkey (GDAR, 2004). Fat-tailed sheep represent nearly 90% of this population. The major sheep breeds are Akkaraman and Morkaraman, which make up nearly 65% of the total sheep population (Gürsoy, 2006). Listed as the third largest sheep breed, the Dağlıç sheep is known for its hardiness and adaptation to marginal conditions that are reflected in its small size, low reproductive efficiency, and low milk and wool production (Gürsoy 2006). Akkaraman (White Karaman) is mainly located in Central Anatolia, while Morkaraman and Dağlıç native sheep are widespread in Eastern and Western Anatolia respectively (GDAR, 2004). Ivesi (Awassi) exists in South East Anatolia. There is a considerable population of crossbred fat-tailed sheep resulting from uncontrolled crossbreeding at the boundaries of neighbouring territories where different pure breeds are kept. These crossbred groups are known in Anatolia by local names such as Kamakuyruk, Çandır, Kesber, Gıcık, Herik and Hemşin. Herik and Hemşin are considered as indigenous breeds by many authors (Yalçın, 1986; Özcan, 1990).

Figure 2.11. Akkaraman (A), Dağlıç (B), Morkaraman (C) and Awassi (D) sheep

Regarding the indigenous thin-tailed breeds, they include Kıvırcık encountered in the Aegean and Marmara regions, and Karayaka breed in the Black Sea region. The Gokçeada (Imroz) and Sakız (Chios) are native to the Aegean Islands (Gökçeada-Çanakkale region and coastal parts of the Aegean-Marmara). On the other hand, crossbreeds including the Turkish Merino were derived from two different crossbreeding programs, namely Kıvırcık × German Wool and Meat Merino and Akkaraman × German Wool and Meat Merino (GDAR, 2004; Gürsoy, 2006).

These native breeds are extensively and traditionally reared and are well adapted to the rangelands and marginal/degraded lands of Anatolia. They contribute to the livelihoods of vulnerable and resource-poor farmers living under extremely difficult conditions in the semi-arid areas and highlands (Gürsoy, 2006).

Source: http://cografyaharita.com

Figure 2.12. Geographical distribution of small ruminant production in Turkey

The sheep number progressively declined from 43.7 in 1987 to 21.7 million heads in 2011, a reduction of about 50.2% in 24 years (See figure 2.6). Over the same period of time, the decline in goat populations was more pronounced, with a rate of 61.7%. In 2006, Gürsoy (2006) reported a reduction percent of 58 and 93% in Kıl (hair) and Angora goats, respectively. These trends may lead to serious genetic erosion, particularly in the case of Angora goats. The sheep breeds are Akkaraman, Morkaraman, İvesi, Karayaka Hemşin etc (Daskiran and Ayhan, 2014).

2.2.3. Production systems

Ruminant production systems are determined by climate, soil and pasture conditions, and social and economic factors. Four different major husbandry systems are observed in the Turkish sheep and goat industry: "small household", "settled down village flock", "highland" and the "nomadic" system. Nevertheless, semi-intensive and intensive production systems have been developed over recent years.

2.2.3.1. Small household system

These are family-type farms commonly located in the west and northwest parts of Turkey. In this system, a family has an average of 3-5 sheep, a maximum of 10-15 sheep or goats. Animals are kept to meet the family needs and to contribute to the livelihood by selling the surplus (milk and meat). The animals evaluate waste of plant production, unused lands of the enterprise, and nearby grass.

2.2.3.2. Settled down village flock system

This system can be seen in any part of Turkey. In a village, families can have from 8-10 to 100 sheep. In the early morning, owners release sheep and a village flock is made. This flock is managed by a shepherd and guarded by several shepherd dogs.

2.2.3.3. Highland system

This system is common in the northeast, east and south parts of Turkey. Sheep live in villages during the winter season. At the end of spring, the grass gets dry and it gets hard to find green grass for sheep and lambs. Thus, sheep are taken to highlands at the beginning of summer to get more green grass. After 3 to 5 months, when the weather gets cold sheep are brought back to villages to stay in the cold season.

2.2.3.4. Nomadic system

This system can be seen in the east and southeast of Turkey. In this region, there are some traditional nomadic tribes that have about 100.000-200.000 sheep. Sheep stay and graze during the cold season in the low-levelled plains in the southeast part of Turkey. During the hot season, the grass gets dry and then the nomadic tribes migrate to the east of Turkey. Migration lasts about 1 month.

During the hot season, sheep graze on the high levelled plains of the east part of Turkey. Members of these tribes always live in goat hair tents when they are with the sheep flock.

Figure 2.13. Animal grazing in highland production system

2.2.3.5. Semi-intensive or intensive systems

In Turkey, in line with the changing demands, has begun to be seen lately, especially in the Western Anatolia, Aegean and Marmara regions. Especially in big cities, the increase in demand for goat milk and cheese and the high price of the products have made goat breeding more professional. In this context, establishments consisting of Saanen crossbred goats, especially from the cultural race of foreign goats, have started to be established and a high amount of milk has started to be obtained through quality nutrition and conscious health protection practices. Although the number of such establishments among our total goat enterprises is small, the demand for increasingly increased goat milk and its products has an increasing effect on the number of such enterprises.

2.3. Agricultural carbon in the Benin Republic and Turkey

A carbon footprint is the total amount of GHG caused by a particular organization, activity, product, or person. Livestock have a substantial impact on the world's water, land, and biodiversity resources and contribute significantly to climate change. The livestock sector is a major contributor, emitting an estimated amount of 7.1 gigatonnes CO_2 eq of GHG per annum (FAO, 2016). This represents 14.5 percent of global human-induced GHG emissions (Gerber et al., 2013; Agossou et al., 2017; Nieto et al., 2018). Methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) are the three main GHGs emitted at a farm level.

According to the GHG inventory in Turkey, the total GHG emissions were 496.1 Mt of CO_2eq, including the land use, land use change, and forestry sectors in 2016 (Figure 2.14). GHG emissions from the agricultural sector are mainly the result of the production of agricultural products and associated by-products, as well as livestock. Indeed, in 2016 the total GHG emissions from the agricultural sector was 56.5 Mt CO_2eq, which is 11.4% of total GHG emissions (excluding land use, land use change, and the forestry sector) (MEU, 2018).

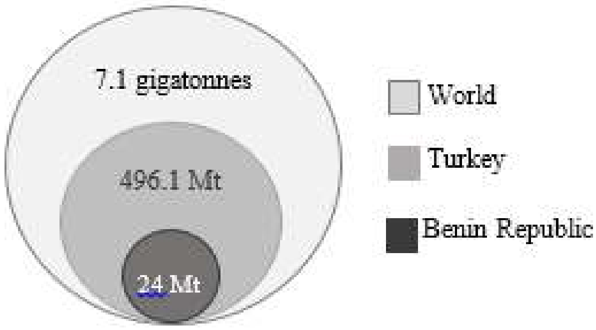


Figure 2.14. Greenhouse gases emissions

The main sources of agricultural emissions are enteric fermentation, agricultural soils, and manure management (Darcan and Silanikove, 2018; MEU, 2018; Koluman et al., 2019). As seen in Figure 2.15., GHG emissions from enteric fermentation were 47.7% of the agriculture sector's GHG emissions. 38.2% was from agricultural soils, 11.2% from manure management, 2.3% was from urea application and 0.7% was from rice cultivation and combustion of agricultural residues in the fields (MEU, 2018). The agriculture sector is responsible for 55.5% of total CH_4 emissions and 77.6% of total N_2O emissions in 2016 (Figure 2.14.). Methane emissions mainly originate from enteric fermentation, while N_2O emissions are released from manure management and agricultural soils. In 2016, methane emissions from enteric fermentation were 26.9 Mt CO_2-eq. The highest portion of CH_4 emissions from enteric fermentation was from cattle (79.4%), followed by sheep (14.7%), goats (4.8%) and other livestock (1.1%) (MEU, 2018). The total emissions from manure management were 6.3 Mt CO_2 eq. This sub sector is responsible for 10.2% of CH_4 and 12.9% of N_2O emissions within the agriculture sector in 2016. As for enteric fermentation, the highest portion of both CH_4 and N_2O emissions within manure management was from cattle.

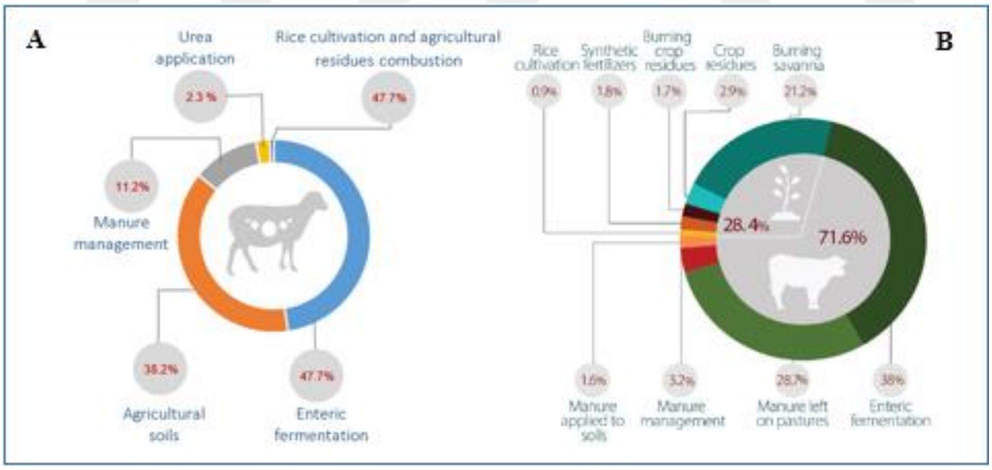


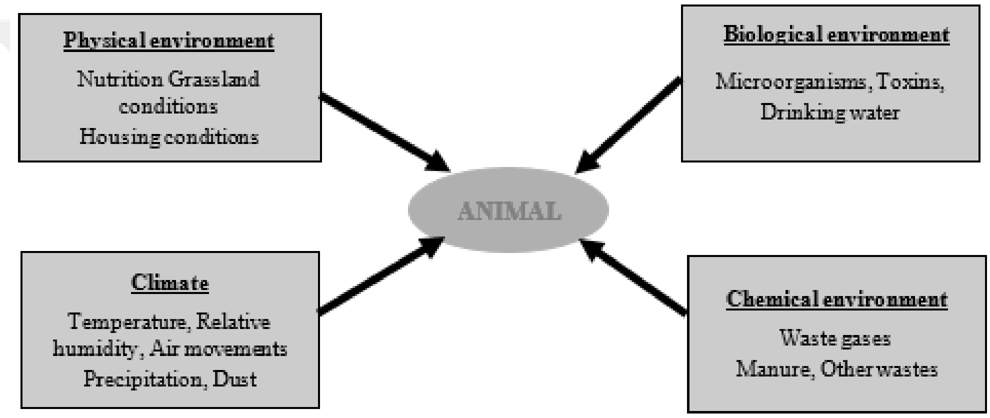
Figure 2.15. Sub-sectorial CH_4 emissions in Turkey (A) and Benin Republic (B) (FAO; ICRISAT; CIAT. 2018)

In Benin, agriculture contributes approximately 20% of GHGs. Within the agriculture sector, livestock production accounts for 71.6% of agricultural GHG emissions, while crop production accounts for 28.4% of emissions. Most livestock emissions are associated with enteric fermentation and manure left on pastures, while crop-related emissions are mostly from the burning of savannahs and, to a lesser extent, with rice cultivation and the burning of crop residues. Although the use of synthetic fertilisers contributes only a small portion of total agricultural emissions (1.8%), some studies have reported that synthetic fertilizers application can be a large contributor within specific farming systems. For example, the application of synthetic fertilizers (particularly nitrogen fertilizers associated with the release of nitrous oxide (N_2O), was estimated to contribute 87% of the total emissions in maize farming at 0.4 tons of CO_2eq. per hectare per season (FAO; ICRISAT; CIAT. 2018).

2.4. Impact of climate change on ruminant production

Climate change is a challenge to the survival of humanity and will become worse in the next century, during which life will be more affected (Mirski et al., 2012). The increase of three main gases – carbon dioxide (CO_2), methane (CH_4) and dinitrous oxide (N_2O) – caused global climate change (Koluman et al., 2019).

The impacts of global warming on farm animals emerge as the physical, biological, chemical environment or direct climate impact (Koluman et al., 2019). The physical environmental conditions appear with possible changes in housing and feeding conditions (Figure 2.16). Indeed, the exposure of animals to extreme climate conditions (too warm or too cold), deprived feeding conditions (low quality and amount of feed) have an impact on animals in terms of meat productivity, milk quality and quantity, and causes a decrease in the lactation period (Darcan and Güney, 2008; Koluman Darcan et al., 2009; Koluman et al., 2016). An increase in body temperature leads to a rise in the uterus temperature, which decreases the fertilization rate limits and embryonic development, aggravating early embryonic fatalities and low reproductive performance (De Rensis et al. 2002) in farm animals. On the other hand, the growth and development of young kids and lambs were also negatively affected under these conditions (Darcan et al., 2007; Darcan and Cankaya, 2008; Koluman Darcan et al., 2009; Ocak et al., 2009; Koluman et al., 2019). Under harsh conditions, ruminants show various metabolic and hormonal responses to adapt to the increased heat load. These adaptive responses include reduced feed intake, increased water intake and changes associated with blood metabolites (Koluman, 2000; Khazanehei et al., 2015).



Adapted from Koluman Darcan et al. (2009)
Figure 2.16. Effects of climate change on animal production

In dairy crossbred goats, Darcan and Güney (2008) reported that under severe heat stress conditions (Thermal Humidity Index=89-96), goats decreased their daily feed intake by up to 18%. In addition, the authors found a negative and significant correlation between feed intake and physiological parameters and milk yield. The decline in feed intake in heat stressed animals contributes to reducing internal heat production by minimizing metabolic processes (Avendano-Reyes et al., 2010).

Climate change is likely to have an impact on the quality and the amount of animal feed, feeding strategies, and seasonal usability of grasslands (Koluman et al., 2019). Drought and floods indirectly affect feed quality and quantity, the availability of drinking water, the increase in epidemic diseases, and the increase in input prices (Koç et al., 2016). The ruminants grazing in natural areas such as meadow-pasture may be directly and further affected by the increasing air temperature, rather than the animals such as sheep and goats. The decrease in yields in natural grazing areas, especially due to drought, may negatively affect the lives of animals due to nutrition and may lead to a decrease in the production of forage plants that need water, such as corn and alfalfa, and an increase in feed prices (Koyuncu, 2017; Koluman et al., 2018).

Benin, as with many African countries, is exposed to the effects of climate change. The country is exposed to both droughts and floods that have a great impact on the country's agricultural production and food security. These changes will exacerbate the already existing challenges. Recent climate projections show both increasing and decreasing trends in rainfall depending on the agro-ecological zones. However, projections indicate that temperatures across the country will continue to increase by 1 to 2°C, exposing smallholder farmers to serious challenges. In the livestock sub-sector, higher temperatures are expected to lead to serious disruption of the physiology of animals, specifically cattle for both milk and meat production. An increase in the incidence of diseases is also expected as increased temperature interacts with changes in humidity and rainfall.

2.5. Quantification methods of GHGs emission from ruminants

The different methods used to measure and estimate the enteric methane emission from ruminants were well reviewed by Storm et al. (2012). Among the measurement methods, the best-known are: chambers/respiration chambers, SF6 technique, in vitro gas production technique, and the newer CO_2 methods. On the other hand, some models have been developed to estimate methane production at the global, national or farm level. These estimation models calculate methane levels based on livestock population, animal categories, feed intake and diet composition. The Intergovernmental Panel on Climate Change (IPCC) issues the common model used to calculate methane emissions from ruminants. However, methods under development, such as the micrometeorological technique, combined feeder and CH_4 analyser, and proxy methods, can determine the amount of methane emitted.

The IPCC developed three different approaches to estimate greenhouse gas emissions. These three approaches, known as Tier 1, 2 and 3, depend on the quality of the database established in each country (Ndung'u et al. 2018). Tier 1 is the simplest calculation method and Tier 3 is the most complex and data-dependent method (Storm et al., 2012).

In most developing countries, Tier I is the most used approach to estimate using default emission factors (EFs) developed to represent the GHG emissions from livestock systems in different geographic regions on the basis of livestock census data and assumptions regarding the systems themselves.

It is known that Tier I estimates have shortcomings, both because they are derived from data from livestock systems in developed economies ('adjusted' to fit the conditions of developing countries) and by their nature, as the approach cannot accommodate changes to emissions brought about by changes to livestock production systems. Tier 2 estimates can represent a substantial increase in the precision of CH_4 emissions from livestock because they better define animals, productivity, management, and feed through using actual measurements of these characteristics (Tubiello et al. 2013).

3. MATERIALS AND METHODS

3.1. Calculation of greenhouse gases emission in Benin republic

Methane (CH_4) and Nitrous Oxide (N_2O) emissions for ruminants (cattle, sheep, and goat) were estimated using the Tier 2 and Tier 1 methods of IPCC (2006) following some steps as outlined in Figure 3.1.

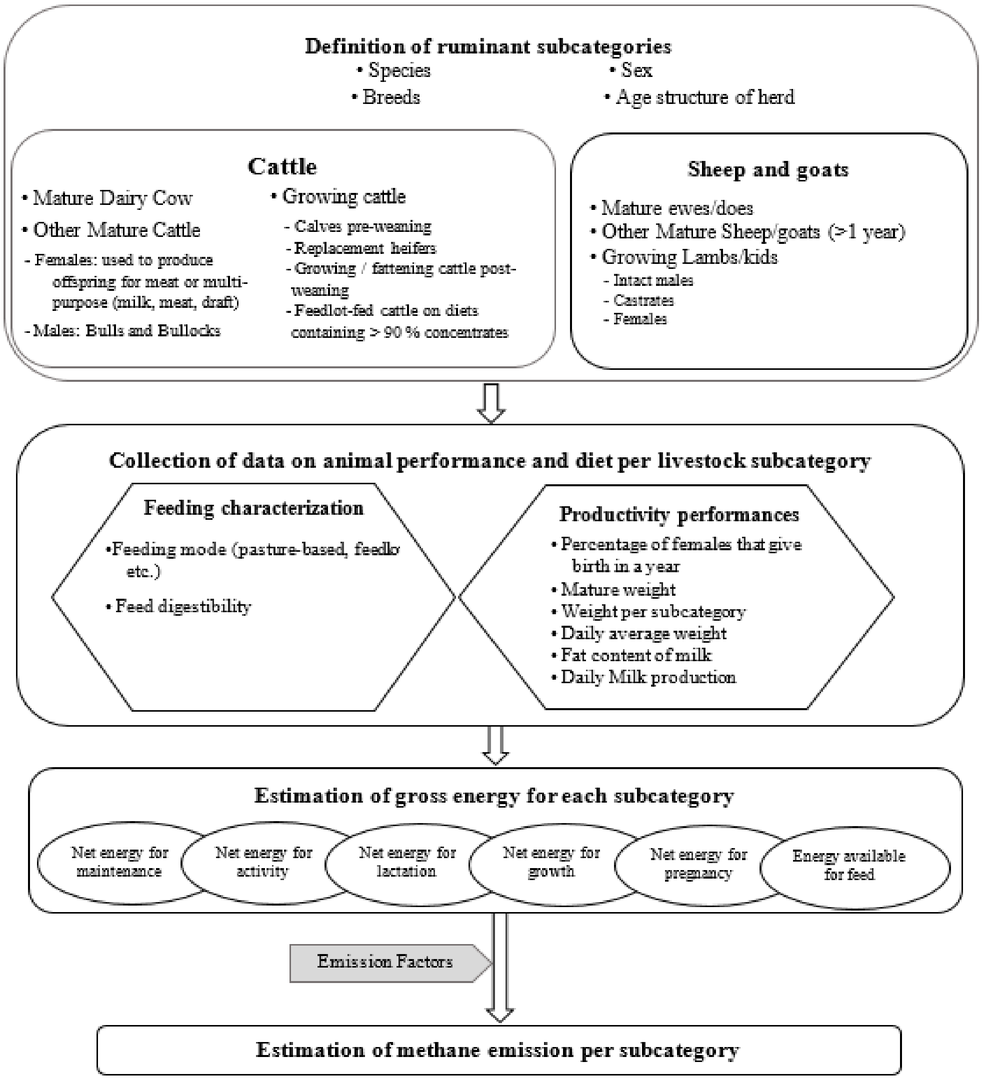


Figure 3.1. Flowchart of GHGs emissions estimation procedure

3.1.1. Country-Specific data source

The data used in this study was compiled from various sources through desk research. These sources included peer-reviewed/published and technical papers, dissertations, project reports published by organizations or research institutions in Benin, reports and data of the Food and Agriculture Organization (FAO) and the guidebook of IPCC (2006). Synthesis of existing research related to ruminant rearing in traditional and improved (research station) production systems was done to gather information on the characteristics of the ruminant population, feeding (diet) and productivity.

In addition, some primary data was collected through a farm survey conducted among 225 agro-pastoral households located in the municipalities of Gogounou, Kalale, and Parakou. The latter are located in the departments of Alibori (10°33'and 10°57' N latitude and 2°15 'and 3°15' E longitude) and Borgou (19°2' N latitude and 2°36' E longitude) respectively (Figure 3.2).

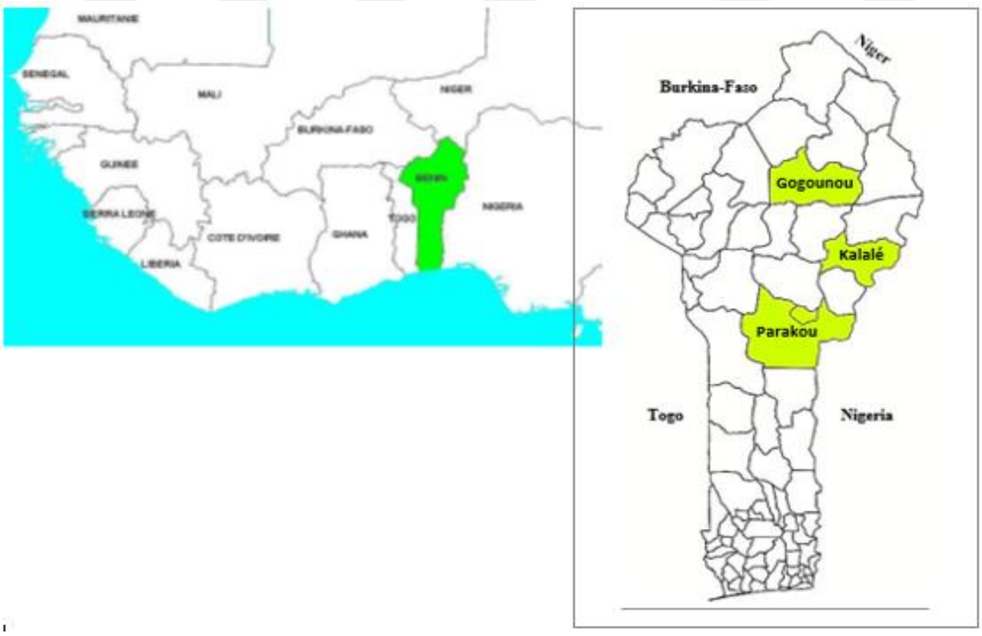


Figure 3.2. Map showing the survey sites

These areas are characterized by a Sudano-Guinean climate with a rainy season (May-October) and a dry season (November-April). The annual rainfall ranges between 1,000 mm and 1,500 mm and the average annual temperature and relative humidity were 28.2±0.6 ° C and 56.4±9% respectively (Alkoiret et al., 2011). Farms were randomly sampled. Using a structured questionnaire, primary data such as the size and structure of the ruminant flock, productivity of livestock, and feeding and management practices were collected. Generated information was used to further the characterization of the feeding pattern and flock population.

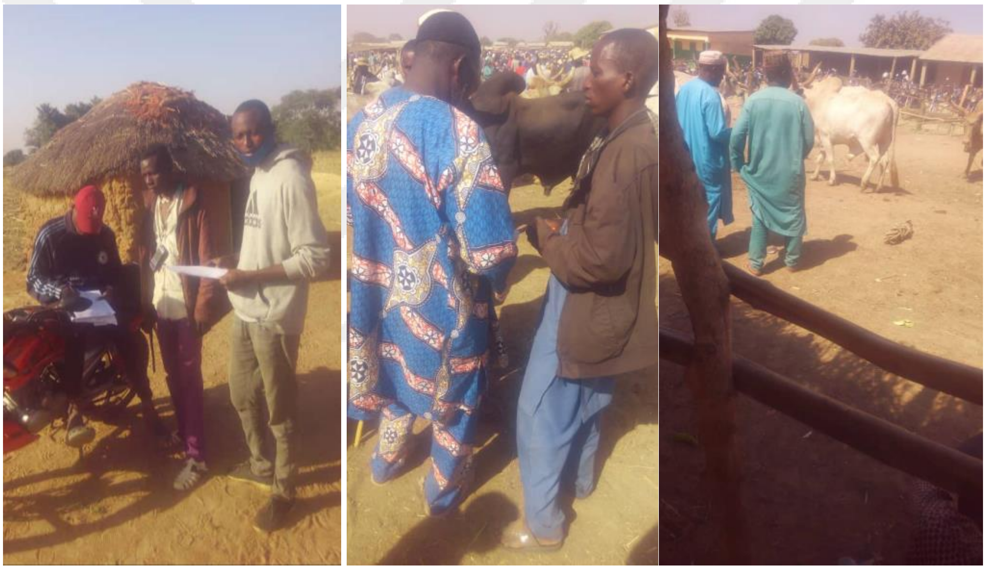


Figure 3.3. Interview with herders

3.1.2. Characterization and categorization of ruminant population

3.1.2.1. Cattle population

Data related to the Beninese population of ruminants (cattle, sheep and goats) from 2005 to 2014 was obtained from the statistics yearbook and data recorded by the Directorate of Livestock Breeding, Ministry of Agriculture, Livestock Keeping and Fishery (Minister de l'Agriculture, l'élevage et de la pêche – MAEP). These data from 1999 to 2003 and from 2015 to 2019 were obtained from the FAO Statistics. The average annual population (AAP) corresponding to each animal species/category was estimated by the following equation:

$$AAPT = \frac{NDAT}{365} \times NAPAT \qquad (Eq. 1)$$

Where NDAT is the number of days alive and NAPAT is the number of animals produced annually of each species/category T (IPCC, 2006).

Cattle populations are classified into two broad subspecies: *Bos taurus* (92.3%) and *Bos indicus* (7.7%) (Gbangboche et al., 2011). In Benin, the breeds used for cattle rearing are very diverse. These are native taurine breeds (Borgou Lagune and Somba), zebu cattle (White Fulani, M'Bororo, Azawak and Gudali), exotic breeds (Girolando), as well as crossbreeds between these different genetic types (Adjou Moumouni, 2006; Worogo et al., 2019). According to Salifou et al. (2012) and Youssao et al. (2016), Borgou cattle represented 51% of the cattle population, while Lagune and Somba accounted for 5% and 3% respectively. Zebu cattle represented 26% of the cattle population (Salifou et al., 2012). Cattle are mainly kept for meat, milk, hides, as well as draught power (Kouazounde et al., 2015).

Using data from the literature (research reports, theses, published papers, and technical articles), cattle productive performances were summarized as given in Table 3.1. It showed that cattle have low dairy and growth performances. For instance, the daily milk yield of Borgou is on average 0.99 l/day (Kassa et al., 2016). Consequently, these breeds cannot be classified among dairy breeds as defined by IPCC (2006).

Based on the information compiled, the cattle population was broadly categorized into weaning, growing and mature animals. Each category is further divided according to sex, age, live weight and average weight gain. The sub-categories of cattle in Benin and the composition of each sub-category in the total population are presented in Table 3.1.

Table 3.1. Demographic parameters and production performances of cattle in Benin Republic

Sub-Categories		CP (%)*	**Breeds**					
			Borgou	Lagune	Somba	White fulani	M'bororo	Gudali
			Average Live Weight (kg)					
Female	BW		18.5 ± 1.7[d]	13.44±0.3[h]	11.4 ± 1.5[a]	23.1 ± 0.4[g]	22.3 ± 3.12[j]	23.69 ± 0.10[i]
	WNG (0-1y)	15.6	99.9 ± 1.6[d]	38[e]	57.3 ± 3.0[b]	129.01 ± 3.5	128.4 ± 17.08[j]	152.42 ± 1.08[i]
	YNG (1-2y)	9.8	141.7 ± 1.8[d]	65[e]	81.3 ± 15.8[a]	231[e]	150[e]	
	YG (2-4 y)	15.2	161.2 ± 2.1[d]	103[e]	118 ± 4.3[b]	309.5 ± 9.2		310.5[k]
	MW (4y +)	30.3		150[c]	183 ± 2.7[b]	340[e]	360-450[e]	404[k]
Male	BW		18.9 ± 1.9[d]	15.37±0.2[h]	12.55 ± 2.4[a]	24.5 ± 0.5[g]	22.4 ± 1.63[j]	24.51 ± 0.10[i]
	WNG (0-1y)	13.4	103.1 ± 1.7[d]	45[e]	63.5 ± 3.0[b]	144.0 ± 4.0	154.4 ± 15.30[j]	166.93 ± 1.13[i]
	YNG (1-2y)	10.9	140.6 ± 1.8[d]	76[e]	81.3 ± 15.88[a]	273[e]	200[e]	222.7[l]
	YG (2-4 y)	2.7	161.2 ± 2.1[d]	110[e]	121 ± 3.6[b]	364.3 ± 13.13		
	MW (4y +)	2.0		200[c]	211 ± 7.9[b]	533[e]	350-500[e]	552.6[k]
					Dairy performances			
DMY (kg)			0.99 -2.5[d, h]	1.5		0.36[d]		3-5[e]
LL (days)			330[d]			180[j]		230[e]
TMY (kg)			256.41[d]			125 – 200[j]		1000-1100[e]
Fat content (%)			5.92±1.04			35.13		
References		[a]Adanléhoussi et al. (2003); [b]Vanvanhossou et al. (2018); [c]Vanvanhossou et al. (2018); [d]Youssao et al. (2000); [e]Joshi et al. (1957); [f]Rege et al. (1993); [g]Olawumi and Salako (2011): [h]Gbangboche et al. (2011); [i]Ebangi et al. (2002), [j]Njoya et al. (1998); [k]Zamba (1989); [l]Obi et al. (1980) ;						

3.1.2.2. Sheep and goat population

Small ruminants are raised in all agro-ecological zones of Benin. The population of small ruminants (goats and sheep) is largely constituted by the West African Dwarf goat and sheep (also known as the Guinean or Djallonké breed). The average weight of the breed ranges between 25 and 30 kg for males, and 20-25 kg for females (Wilson, 1991). In addition, Sahelians and crossbreds (Djallonké x Sahelien) are encountered across the country. Unlike Djallonké, which are small animals (weight is rarely more than 30 kg), Sahelian sheep and goats are large animals weighing 30 to 50 kg (Noudjalbaye, 1989; Sangaré et al., 2005). All these breeds have very low lactogenic potential and milk yield (Gbangboché et al., 2002; Monkotan, 2011); therefore, they cannot be considered as dairy animals. In the current only emissions from Djallonké breeds were taken into account because statistics (data on production and population) were not available for Sahelian breeds.

In the same way as for cattle, small ruminants were divided according to sex, age, live weight, and average weight gain (Table 3.2). The following subcategories were therefore defined: weaning (3-6 months), growing (6-12 months), yearling (1-2 years), young (2-3 years) and mature (more than 3 years).

Table 3.2. Subcategories and body weight of Djallonké sheep and goat

	Sheep		Goat	
Subcategories	Female	Male	Female	Male
BW	1.61[a]	2.09 [a]	1.40[e]	1.41[e]
Weaner (3-6m)	9.50[h]	10.32[h]	5.54[f]	5.84[f]
WNG (6-12m)	13.21[b]	14.37[i]	10.66[g]	12.30[g]
YNG (1-2y)	17.63[i]	20.43[i]	19.38[g]	18.11[g]
YG (2-3y)	20.79[c]	24.87[i]	21.80[g]	25.00[g]
MW (3y +)	23.50[d]	26[d]	25.64[g]	30[f]
Source	[a]Gbangboche et al. (2006); [b]Monkotan et al. (2018) ; Ampong et al. (2019); [c]Gbangboche et al. (2005); [d]Ngere (1983); [e]Peter et al. (2015); [f]Ayizanga et al. (2018); [g]Rade Mbaihinta (1994); [h]Nazinwob (1998), [i]Nianogo (1992)			

3.1.3. Production system and feeding characterization

In Benin, ruminant feeding depends mainly on the production system and environmental conditions (dry or rainy season), the latter determining the availability of fodder. The ruminant production system in Benin can be classified into two major systems: the traditional system and the improved system (ranches). Nearly 99% of cattle are reared in the traditional system (Kouazounde et al., 2015). It combines pastoral (transhumance) and agro-pastoral (mixed crop-livestock system) production systems.

In the pastoral system, herds are fed on natural pasture. Rangelands consist mainly of perennial or annual grasses, which are of good nutritional value only at the beginning of the rainy season; this value deteriorates as the season progresses. In this system, sheep and goats are also associated with cattle herds. It is characterized by a seasonal and cyclical movement (sometimes cross-border) of keepers and herds according to the rainfall regime and availability of feed resources (Agossou et al., 2018). During the dry season, natural pastures are scarce for the first four months of the year and ruminants then feed mainly on woody fodder (Figure 3.4). Only the shallows and edges of watercourses still offer green grass (Agossou, 2014).

Figure 3.4. Scarce pasture during dry season at the municipality of Kalalé

Thus, it is observed during the dry season great mobility of herds and herdsmen within a large geographical area in search of pasture and water. On average, cattle spend 8 h daily feeding. Moving the herd, grazing and water consumption accounted for 20, 75 and 5 percent of the time spent on feeding, respectively. During the dry season, feeding time increased to approximately 10 hours/day (between 8-9 a.m. and 6-7 p.m.) and animals rested and had access to drinking water for one hour (between 12 p.m. and 1 p.m.) (Dehoux and Hounsou-Ve, 1993; Kouazounde et al., 2015).

Regarding the agro-pastoral system, crop production (mostly subsistence farming) is associated with ruminant keeping. Under this system, animals are primarily fed using a combination of grazing on natural rangeland (uncultivated land), and crop fields (maize, cotton, groundnut, and sorghum residues) (Figure 3.5). However, on some private farms, forage crops and agro-industrial by-products are also used to feed animals. The pastures consist of grass and legumes. Grasses, the species of which are eaten at different stages of development, dominate the herbaceous layer. These are *Andropogon*, *Panicum*, *Hyparrhenia*, *Pennisetum*, and *Setaria*.

Ranches (improved systems) are mainly state farms rearing indigenous (Borgou, N'dama) and exotic (Girolando) cattle, as well as sheep (Djallonké). Under this system, animals are reared following improved management practices such as good housing of animals and health monitoring. Furthermore, appropriate breeding programs and selection programs are applied to improve the reproductive and productivity of flocks (Agossou et al., 2017). In these farms, animals are fed both free-grazing on natural and cultivated pastures, and concentrated feed (purchased feed). The concentrate feed is supplied to the following categories of animals (based on physiological stage). Artificial pastures are also used to produce hay which is used during the scarcity period. Crop residues from fields (maize stalks) and artificial meadows of *Brachiaria ruziziensis*, *Aeschynomène hystrix*, *Panicum maximum* C_1, and *Pennisetum purpureum* are used for animal feeding.

Figure 3.5. Cattle grazing in the natural pasture during the rainy season and harvested sorghum field during the dry season

Sheep and goat are mainly reared in the traditional farming system. In urban and peri-urban areas, animals are left to stray to look for food. In rural areas or certain agricultural areas, they roam throughout the dry season and are tied up in the rainy season. Among the Fulani, sheep go to pasture at the same time as the herds of cattle. Natural grazing is abundant in the rainy season and consists of grasses and legumes. In this system, feed supplementation is essentially based on harvest residues and agro-food processing by-products.

3.1.4. Gross energy intake and emission factors calculation

3.1.4.1. Goss energy expenditure calculation

Because traditional rearing was the most widespread system in Benin, and due to a lack of studies (research and censuses), data related to some of the Benin cattle breeds was scarce or not available. As suggested by IPCC protocols (IPCC, 2006), data on animal productivity (reproduction traits, milk yield and composition, live body weight, daily average weight gain) was therefore compiled from research conducted in neighbouring West African countries (Togo, Ghana, Nigeria, Niger, and Burkina-Faso), where these breeds were encountered under similar rearing conditions.

The GE is the daily amount of energy (MJ/day) needed by animals for maintenance and for activities, growth, lactation, work, and pregnancy. It was calculated using the equations as given in Table 3.4.

3.1.4.2. Determination of methane emission factors for enteric fermentation

Once the value of gross energy (GE) is calculated, the methane EF for each sub-category was calculated as follows (IPCC, 2006):

$$\boldsymbol{EF} \quad \left[\frac{\boldsymbol{GE} \bullet \left(\frac{\boldsymbol{Y_m}}{\mathbf{100}}\right)}{\mathbf{55.65}} \bullet \mathbf{365}\right] \quad (\boldsymbol{Equation}\ \mathbf{14})$$

Where:

EF = emission factor, kg CH_4 $head^{-1}$ yr^{-1}

GE = gross energy intake, MJ $head^{-1}$ day^{-1}

Y_m = methane conversion factor, percent of gross energy in feed converted to methane, a value of 7% were applied.

The factor 55.65 (MJ/kg CH_4) is the energy content of methane.

Table 3. 3. Equations used to estimate gross energy in cattle, sheep and goats

<table>
<tr><th rowspan="2">Energy (MJ/day)</th><th colspan="2">Equations (IPCC, 2006)</th></tr>
<tr><th>Cattle</th><th>Sheep and goats</th></tr>
<tr><td>Net energy for maintenance (NEm)</td><td colspan="2">$\boldsymbol{NE_m \quad Cfi \bullet \ (Weight)^{0.75}\ (Eq.2)}$
Where: Cfi = Coefficients for calculating NEm (MJ/day/kg) (See Table A.2. annexes); Weight = live-weight of animal (kg)</td></tr>
<tr><td rowspan="2">Net energy for activity (NEa)</td><td>$\boldsymbol{NE_a \quad C_a \bullet \ NE_m\ (Eq.3)}$</td><td>$\boldsymbol{NE_a \quad C_a \bullet \ Weight\ (Eq.4)}$</td></tr>
<tr><td colspan="2">where
C_a = coefficient corresponding to animal’s feeding situation (activity coefficients for stall feed=0, pasture animal with limited movement=0.17, range grazing animal =0.36);
NEm = net energy for maintenance (MJ/day); Weight = live-weight of animal (kg)</td></tr>
<tr><td>Net Energy for growth (NEg)</td><td>$\boldsymbol{NE_g \quad 22.02 \bullet \left(\frac{BW}{C \bullet MW}\right)^{0.75} \bullet WG^{1.097}\ (Eq.5)}$
Where:
BW = average live body weight of the animals in the population, kg;
C = coefficient with a value of 0.8 for females, 1.0 for castrates and 1.2 for bulls (NRC, 1996);
MW = mature live body weight of an adult animal in moderate body condition (kg); WG = average daily weight gain of animals in the population (kg/day)</td><td>$\boldsymbol{NE_g \quad \frac{WG_{lamb} \bullet (a + 0.5b(BW_i + BW_f))}{365}\ (Eq.6)}$
Where:
WGlamb = the weight gain (BWf – BWi), kg/year
BWi = the live bodyweight at weaning (kg);
BWf = the live bodyweight at 1-year old or at slaughter (LW) if slaughtered prior to 1 year of age, kg
a,b = constants as described in Table A.3. These constants vary by animal species/category</td></tr>
</table>

Net energy for lactation (NEl)	$NE_l \quad Milk \bullet (1.47 + 0.40 \bullet Fat)\ (Eq.7)$ Where: Milk = amount of milk produced, kg of milk/day Fat = fat content of milk, % by weight.	Milk production is unknown: $NE_l \quad \left[\frac{(5 \bullet WG_{wean})}{365}\right] \bullet EV_{milk}\ (Eq.8)$ **WGwean** = weight gain of lamb between birth and weaning (kg) EVmilk = energy required to produce 1 kg of milk (MJ/kg). A default value of 4.6 MJ kg-1 (IPCC, 2006) was used.
Net energy for pregnancy (NEp)	$NE_p \quad C_{pregnancy} \bullet NE_m\ (Eq.9)$ Where: $\mathbf{C_{pregnancy}}$ = pregnancy coefficient (see Table A.4, annexes); **NEm** = net energy for maintenance, MJ/day. When calculating NEp estimate, the portion of the mature females that actually go through gestation in a year were taken into consideration.	
Net energy for work, Oxen (NEwork)	$NE_{work} = 0.10 \bullet NE_m \bullet Hours\ (Eq.10)$ Where: **NEm** = net energy for maintenance, MJ/day; **Hours** = number of hours of work per day	
Ratio of net energy available in a diet for maintenance to digestible energy consumed (REM)	$REM \quad \left[1.123 - (4.092 \bullet 10^{-3} \bullet DE\%) + \left[1..126 \bullet 10^{-5} \bullet (DE\%)^2\right] - \left(\frac{25.4}{DE\%}\right)\right]\ (Eq.11)$ Where: **DE%** = digestible energy expressed as a percentage of gross energy, a value of 55% were used (IPPC, 2006)	
Ratio of net energy available for growth in a diet to digestible energy consumed (REG)	$REG \quad \left[1.164 - (5.160 \bullet 10^{-3} \bullet DE\%) + \left[1..308 \bullet 10^{-5} \bullet (DE\%)^2\right] - \left(\frac{37.4}{DE\%}\right)\right]\ (Euqtaion\ 12)$ Where: **DE%** = digestible energy expressed as a percentage of gross energy, a value of 55% were used (IPPC, 2006)	

Gross energy (GE)	$GE \quad \left[\frac{\left(\frac{NE_m+NE_a+NE_l+NE_{work}+NE_P}{REM}\right)+\left(\frac{NE_g+NE_{Wool}}{REG}\right)}{\frac{DE\%}{100}}\right] \quad (Eq. 13)$ Where: **NEm** = net energy required by the animal for maintenance (MJ day^{-1}) (Equation 2) **NEa** = net energy for animal activity (MJ day^{-1}) (Equation 3 and Equation 4) **NEl** = net energy for lactation (MJ day^{-1}) (Equation 7 and Equation 8) **NEwork** = net energy for work (MJ day^{-1}) (Equation 10) **NEp** = net energy required for pregnancy (MJ day^{-1}) (Equation 9) **REM** = ratio of net energy available in a diet for maintenance to digestible energy consumed (MJ day^{-1}) (Equation 11) **NEg** = net energy needed for growth (MJ day^{-1}) (Equation 5 and Equation 6) **NEwool** = net energy required to produce a year of wool (MJ day^{-1}) **REG** = ratio of net energy available for growth in a diet to digestible energy consumed (MJ day^{-1}) (Equation12) **DE%**= digestible energy expressed as a percentage of gross energy.

3.1.4.3. Determination of methane emission factors for manure management

The amount of methane from manure was estimated using Tier 2. To calculate EF of methane emitted from manure management, we needed volatile solid (VS), the maximum methane producing capacity for manure that is produced by livestock category (Bo); the methane conversion factors for each manure management (MCF) in Benin; and the fraction of the livestock category's manure handled using each manure management system (MS) in Benin.

We calculated the VS based on gross energy intake estimates for each cattle breed and West African Dwarf sheep and goats. As for, the country-specific Bo, MCF, and MS for Benin, data were unavailable. Thus, the default values from the 2006 IPCC GL were used.

- **Manure management system:** Although emissions of CH4 and N2O are influenced by different factors, manure management releases both GHGs. In Benin, manure storage is uncommon because the extensive or traditional rearing system is the most predominant production system. Scavenging sheep and goats excreted and spread most of their manure around and it was not usually collected. In pastoral farming, manure is commonly deposited on pasture and range grazing, and is not managed. In the sedentary system (agro-pastoral), cattle were taken to graze on harvested residues on cropland where they deposited the dung as fertilizer. In addition, in some households, cattle are confined over night, when they deposit their manure in a night paddock. This manure is gathered in an open-place without any special treatment. In some agro-pastoral households, the collected manure is dried and used as fuel.
- **Manure characteristics:** it included the estimation of volatile solids (VS), which are produced in cattle and small ruminant (sheep and goats) manure. Production of manure VS was estimated based on country-specific gross energy intake and feed digestibility used while calculating the enteric CH_4 emission factors. The VS was determined following the formula:

$$\boxed{VS \quad \left[GE * \left(1 - \frac{DE\%}{100}\right) + (UE * GE)\right] * \left[\left(\frac{1 - ASH}{18.45}\right)\right] \ (Eq. 15)}$$

Where:

VS = volatile solid excretion /day on a dry-organic matter basis, kg VS day^{-1}

GE = gross energy intake, MJ day^{-1} (see table 4.6 and table 4.8)

DE% = digestibility of the feed in percent (e.g. 60%)

(UE • GE) = urinary energy expressed as fraction of GE. A value of 0.04 was used for UE as suggested by IPCC (2006).

ASH = the ash content of manure calculated as a fraction of the dry matter feed intake. 0.08 for cattle and (IPCC 200&) and 0,034 for sheep and goat (adapted from Ansah et al., 2018).

18.45 = conversion factor for dietary GE per kg of dry matter (MJ kg-1).

Emission factors of methane emitted from manure management were calculated using the following formula:

$$\boldsymbol{EF_{(T)} \quad (VS_{(T)} \bullet 365) \bullet \left[B_{o(T)} \bullet \frac{0.65}{m^3} \bullet \sum_{S,k} \frac{MCF_{S,k}}{100} \bullet MS_{(T,S,k)}\right] (Eq. 16)}$$

Where:

$EF_{(T)}$ = annual CH_4 emission factor for livestock category T, kg CH_4 animal^{-1} yr^{-1}

$VS_{(T)}$ = daily volatile solid excreted for livestock category T, kg dry matter animal^{-1} day^{-1}

365 = basis for calculating annual VS production, days year^{-1}

$B_{o(T)}$ = maximum CH_4 producing capacity for manure produced by livestock category T, m^3 CH_4 kg^{-1} of VS excreted

0.67 conversion factor of m^3 CH_4 to kilograms CH_4

$MCF_{(S,k)}$ = methane conversion factors for each manure management system S by in Benin k, %. A value of 2% and 10% were plied

$MS_{(T,S,k)}$ = fraction of livestock category T's manure handled using manure management system S in climate region k, dimensionless.

Figure 3.6. Manure deposited on cropland in the district of Kalalé

Figure 3.7. Stack of manure collected from paddock

3.1.5. Calculation of greenhouse gases emission

3.1.5.1. Calculation of methane emission

In the Benin Republic, calculations of methane emissions (enteric and manure) for the year series (1999-2019) were made for each species (cattle, sheep, and goats) and categories (breeds, age, and sex). Emission factors developed in the current study were used for each subcategory. Total methane emission was calculated by multiplying the sub-category emission factor with the number of animals in each sub-category and summing-up sub-categories to arrive at the total emission from each subspecies.

$$\boxed{\boldsymbol{Emissions} \quad \boldsymbol{EF_{(T)}} \bullet \left(\frac{\boldsymbol{N_{(T)}}}{\mathbf{10^6}}\right) \ (\boldsymbol{Eq.}\,\mathbf{17})}$$

Where:

Emissions = CH_4 emissions for a defined population, Gg CH_4 yr^{-1}

$EF_{(T)}$ = emission factor for the defined livestock population, kg CH_4 $head^{-1}$ yr^{-1}

$N_{(T)}$ = the number of head of livestock species/category T in the country T = species/category of livestock

$$\boxed{\boldsymbol{Total\ CH_4} \quad \sum_{\boldsymbol{i}} \boldsymbol{E_i}\ (\boldsymbol{Eq.}\,\mathbf{18})}$$

Where:

Total $CH_{4Enteric}$ = total methane emissions from Enteric Fermentation, Gg CH4 yr^{-1}

E_i = is the emissions for the *i*th livestock categories and subcategories

3.1.5.2. Nitrous oxide emissions calculation method

Using the IPCC 2006 guideline, direct and indirect emissions of N_2O from manure management were calculated for cattle, sheep and goat populations. Direct N_2O emissions were calculated according to the following equation:

$$\boxed{\boldsymbol{N_2O_{D\,(mm)}} \quad \left[\sum_{S}\left[\sum_{T}(\boldsymbol{N_{(T)}} \times \boldsymbol{Nex_{(T)}} \times \boldsymbol{MS_{(T,S)}}\right] \times \boldsymbol{EF_{(s)}}\right] \times \frac{\mathbf{44}}{\mathbf{28}} (\boldsymbol{Eq.\,19})}$$

$$\boldsymbol{Nex_{(T)}} \quad \boldsymbol{Nrate_{(T)}} \times \frac{\boldsymbol{TAM}}{\mathbf{1000}} \times \mathbf{365}$$

where $N_{rate(T)}$ is the default nitrogen excretion rate (kg N.(1000 kg animal mass)/ day), and TAM is the typical animal mass for animal each category (breed). Nex(T) is annual average nitrogen excretion per head of animal species/ category T (kg $N.head^{-1}.year^{-1}$). The values of the Nex(T) for ruminants in Benin Republic are listed in Table 3.4. $EF_{(S)}$ is the default emission factor for direct N_2O emissions from manure management system S (Table 3.4); 44/28 is the conversion of N_2O-N emissions to N_2O emissions.

Table 3.4. Parameters used to calculate nitrous oxide emissions in Benin Republic

Parameters	Cattle					Sheep	Goat
	Borgou	Lagune	Somba	Zebu	Other cattle		
TAM	238.0[a]	140.34[a]	140.47[a]	322.55[a]	173[c]	29.75[a]	24.45[a]
N_{rate}	0.63[b]	0.63[b]	0.63[b]	0.63[b]	0,63[b]	1.17[b]	1.37[b]
Nex	54.73	32.27	32.30	74.17	39.78	12.70	12.23
EF[b]	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Manure management system (%)[b]					
	Daily spread	Dry lot	Pasture/ paddock	Burned for fuel	$Frac_{GasMS}$ (%)
Cattle	1	1	95	3	30
Sheep	95	-	100	-	12
Goat	3	-	100	-	12

a average weight used during gross energy calculation in of animal above 12 months; b: default value from IPCC (2006) guide, .

Indirect N_2O Emissions related to N-Volatilization were calculated using the formula:

$$\boxed{N_2O_{G(mm)} \quad (N_{\text{volatilization}-\text{MMS}} \times EF_{MMS}) \times \frac{44}{28} \; (Eq.20)}$$

Where $N_2O_{G(mm)}$: indirect N_2O emission related to N volatilization during manure management (kg N_2O/year); EF_{MMS}: default emission factor for indirect N_2O and $N_{\text{volatilization–MMS}}$: N losses related to volatilization during manure management in system S and determined according to the following equation,

$$N_{volatilisation-MMS} = \sum_{S}\left[\sum_{T}\left[\left(N_{(T)} \times Nex_{(T)} \times MS_{(T,S)}\right) \times \left(\frac{Frac_{GasMS}}{100}\right)_{(T,S)}\right]\right]$$

Where $Frac_{GasMS}$: percentage (%) of nitrogen for animal species/category T, which volatilizes as NH_3 and NOx in manure management system S.

The emissions of all direct and indirect gases (CH_4 and NO_2) were expressed in Gigagrams (Gg). However, the quantified gases were also converted to Gg CO_2 equivalent (Gg CO_2eq), using their global warming potential, which is 25 for CH_4 and 298 for N_2O.

3.2. Calculation procedure of greenhouse gases in Turkey

The estimation was conducted following three main steps: (i) collection of ruminant population data per subcategories of animals, (ii) estimation of emissions factors for each subgroup or utilization of default emissions factors, and (iii) multiplication of emissions factors by their corresponding populations. The estimation was calculated for cattle (dairy cattle and others), sheep and goats.

3.2.1. Study region and prevailing climate condition

The study was conducted in the Eastern Mediterranean region (province of Adana, Antalya, Burdur, Hatay, Isparta, Mersin, Osmaniye, Kahramanmaraş) of

Turkey. This region is characterized by mild and wet winters and hot and dry summers. Extreme temperatures can reach -8.1°C (in January) and 42 °C (in August) with an average of 9.4°C and 30.10±0.17°C in winter and summer respectively. The air humidity is averagely 65% while the wind speed is 1.1 km/h during the summer period (Koluman et al., 2016). The annual precipitation in the area is 450 mm (Darcan and Cankaya, 2008). The annual average temperature for selected provinces in the region is given in Table 3.6. Therefore, the region was considered as a temperate climate region according to the IPCC guide. The CH_4 and N_2O emissions were estimated regardless of the production system.

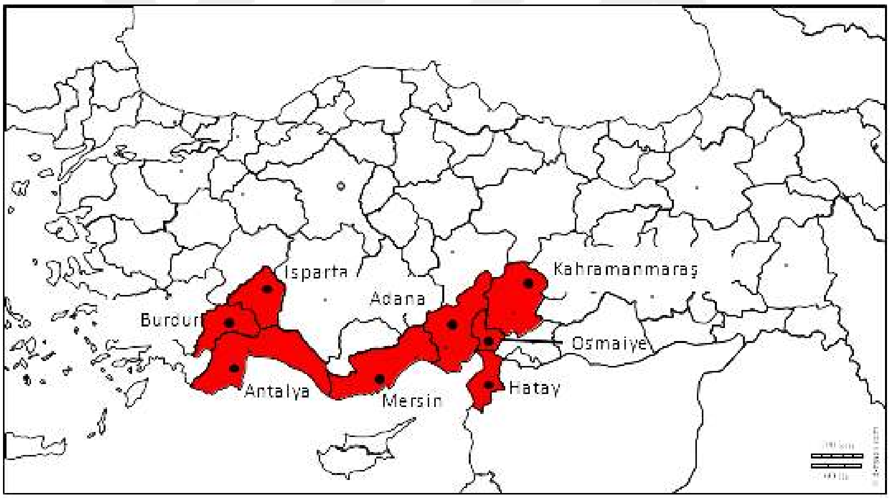


Figure 3.8. The Eastern Mediterranean area of Turkey

3.2.2. Collection of ruminants' population data

The annual population data on cattle, sheep, and goats in the Eastern region of Turkey was collected from the Turkish Statistical Institute (TurkStat, 2021). Table 3.6 shows the regional population data for the year series 2004-2020. Cattle were disaggregated and categorized into dairy and non-dairy categories. Among the dairy cattle category, culture, hybrid and local cattle were then defined as sub-categories. In Turkey, the majority of the ovine population is composed of multipurpose sheep producing meat, milk and wool. Sheep were grouped as Merino and domestic sheep.

3.2.3. Emission factors applied for each category

The emission factors shown in table 3.6 were obtained from the Turkish greenhouse gas inventory 1990-2018 reported by the Turkish Statistical Institute (TurkStat, 2020). To estimate CH4 emissions from enteric fermentation, IPCC default EF values were used for domestic sheep and goats because country-specific EF were not available. For cattle, Tier 2 calculated based on country-specific data was applied (TurkStat, 2020).

Table 3.5. Annual ruminants' population existing in the study region

Year	Dairy cattle			Other cattle	Sheep		Goat
	Culture	Hybrid	Local		Merino	local	
2004	125244	290923	67793	278303	37381	1354784	1550873
2006	170182	310555	54807	312515	80102	1659118	1444320
2008	189504	288160	49856	344077	35847	1402004	1175317
2010	237781	300463	49365	356412	54854	1475324	1760270
2012	352731	352200	55144	464765	90151	2100808	2430350
2014	364748	294699	50094	463974	105079	2465299	2910677
2016	374655	285964	48118	482749	99194	2461454	2800526
2018	481876	258101	45305	601871	143992	2870774	3016494
2020	483477	265522	48183	597850	160983	3182334	3394683

Source: TurkStat (2021)

Table 3.6. Annual temperature and emission factor used to estimate methane emissions

Provinces	Adana	Antalya	Burdur	Hatay	Isparta	K.Maraş	Mersin	Osmaniye
AT (ºC)	19.1	18.6	13.3	18.3	12.2	16.9	19.1	18.4
Manure management CH_4 emission factors (kg CH_4/head/year)*								
CC	32.0	29.5	19.0	29.5	17.5	27.5	32.0	29.5
HC	24.5	22.8	15.0	22.8	13.8	21.3	24.5	22.8
IC	17	16	11	16	10	15	17	16
NDC	1	1	1	1	1	1	1	1
MS	0.150	0.150	0.100	0.150	0.100	0.150	0.150	0.150
LS	0.215	0.215	0.145	0.215	0.145	0.215	0.215	0.215
Goat	0.17	0.17	0.11	0.17	0.11	0.17	0.17	0.17
Enteric Fermentation CH_4 emission factors (kg CH_4/head/year)								
Cattle	Dairy	82.1**						
	Non-dairy	48**						
Sheep	Merinos	6.5*						
	Local	5*						
Goat		5*						

AT: annual temperature calculated on period of 1950-2015 (Ersoy, 2017); CC: Culture cattle; HC: Hybrid cattle; IC: Indigenous cattle; NDC: Non-dairy cattle; MS: Merino sheep; LS: Local sheep; * calculated using Tier 1 method and default of IPCC; **calculated using Tier 2 and country-specific data (TurkStat, 2021)

The merino sheep are also a kind of domestic sheep fed for their wool. The weight of merino sheep is higher compared to domestic sheep and their feeding rate is also higher than domestic ones. For these reasons, the EF for merino sheep is chosen as a higher value compared to domestic sheep. The EF of Merino sheep is taken as an average value (6.5 kg CH_4 head^{-1} year^{-1}) from the IPCC default EF for developing countries (5.0 kg CH_4 head^{-1}year^{-1}) and developed countries (8.0 kg CH_4 head^{-1}year^{-1}). The country's specific typical animal mass values are 50 kg/head and 60 kg/head for domestic sheep and merino sheep, respectively. It is clear that the emissions levels for merino sheep currently calculated are conservative since the approximate EF for merino sheep is 5.73 kg CH_4 head^{-1}year^{-1} obtained by the quotient of the weight figures (60 kg/50kg) raised to the power of 0.75 and then multiplied by the EF for domestic sheep (5.0 kg CH_4 head^{-1} year^{-1}). As stated clearly in the 2006 IPCC Guidelines, this approximate figure can only be used to assess the significance of the emissions from a livestock species. The EF value for merino sheep is clearly higher than the calculated approximate EF value.

3.2.4. Calculation of methane and nitrous oxide emissions

In order to estimate emissions related to cattle, sheep and goat farming in the study area, we used Tier 1 and Tier 2 detailed in the IPCC 2006 guideline. Estimation of CH_4 emissions derived from enteric fermentation and manure was based on the multiplication of the numbers of livestock heads in each category and province by the corresponding emission factors (EFs) given in Table 3.7. EF for enteric fermentation for each subcategory was assumed to be applicable in all provinces. As for the EF from manure, it varies according to the climate conditions in each province and the manure management system. Therefore, provincial CH_4 emissions from manure management were calculated taking into account the corresponding EFs and the existing ruminant population. Equations 17 and 18 were used for estimating livestock methane emissions at a categorical and provincial level.

Regarding the direct and indirect emissions of N_2O from manure management, it was estimated based on the default value as suggested by IPCC (2006). Thus, the values of the $N_{rate(T)}$, TAM, Nex(T), $Frac_{GasMS}$, MS (%) and EF for ruminants in Turkey are presented in table 3.8. Direct N_2O emissions were calculated using equation 19, while indirect emissions were obtained applying equation 20.

Table 3.7. Parameters used to calculate nitrous oxide emissions in Turkey

<table>
<tr><td rowspan="2">Parameters</td><td colspan="3">Cattle</td><td colspan="2">Sheep</td><td rowspan="2">Goat</td></tr>
<tr><td>Dairy</td><td colspan="2">Other</td><td>Merino</td><td>Domestic</td></tr>
<tr><td>TAM</td><td>476.42[a]</td><td colspan="2">299.67[a]</td><td>60[a]</td><td>50[a]</td><td>45[a]</td></tr>
<tr><td>N_{rate}</td><td>0.47[a]</td><td colspan="2">0.34[a]</td><td>1.01[a]</td><td>1.17[a]</td><td>1.37[a]</td></tr>
<tr><td>Nex</td><td>82.47[a]</td><td colspan="2">37.19[a]</td><td>22.12[a]</td><td>21.35[a]</td><td>22.50[a]</td></tr>
<tr><td>EF[c*]</td><td>0.02</td><td colspan="2">0.02</td><td>0.01</td><td>0.01</td><td>0.01</td></tr>
<tr><td></td><td colspan="6">Manure management system (%)</td></tr>
<tr><td></td><td>Liquid system</td><td>Solid storage</td><td>Dry lot</td><td>Pasture/ paddock</td><td>Burned for fuel</td><td>$Frac_{GasMS}$ (%)</td></tr>
<tr><td>Cattle</td><td>10</td><td>50</td><td>6</td><td>30</td><td>4</td><td>30[a] – 45[b]</td></tr>
<tr><td>Sheep</td><td>-</td><td>40</td><td>-</td><td>60</td><td>-</td><td>12</td></tr>
<tr><td>Goat</td><td>-</td><td>10</td><td>10</td><td>80</td><td>-</td><td>12</td></tr>
</table>

a data obtained from the Turkish greenhouse gas inventory 1990 - 2018 (TurkStat, 2020); b average weight used during gross energy calculation in of animal above 12 months; c,d,e: default value from IPCC (2006) guide. * 0.02 was used as EF for dry lot
Distribution of manure management system in Benin and Turkey
a: for dairy cattle, b: for other cattle

3.3. Statistical analysis

Survey data were computerized and analysed using SPSS 25 using descriptive statistics. Qualitative data were presented as frequencies and percentages. Reproductive data were processed and given as mean ± standard error. In addition, a Principal Component Analysis that was carried out in order to obtain a cluster representation of the farms in the form of projections on plans defined by the first factorial axes.

Regarding EF factors and GE in the Benin Republic, they were analyzed separately according to species (cattle, sheep and goats). The analysis was performed using One-way ANOVA methods following the linear statistical model defined as:

$$\boldsymbol{Y_{ij}} \qquad \boldsymbol{\mu + \tau_i + \varepsilon_{l\,j}}$$

Where $\boldsymbol{\mu}$: overall mean; $\boldsymbol{\tau}_i$: is the effect of sub-species, breeds or age-categories.

The GHG emissions in both countries were calculated in Microsoft Excel and results were represented as graphs.

4. RESULTS AND DISCUSSION

4.1. Socio-demographic characteristics

A summary of farmers' socio-demographic characteristics is presented in Table 4.1. All the interviewed keepers were male (100%). In agro-pastoral or pastoral households, the head of the household is the owner of livestock; his sons are his shepherds. His wife or wives process and market milk collected from the herd of cows. Men take care of the animals, the most arduous agricultural work (preparation of fields, manual weeding, harvesting of yam tubers) and harvesting of African locust bean fruits. Women are involved in the processing and sale of milk, the harvesting of shea nuts. During the agricultural production season, they also help men with sowing and harvesting. Livestock ownership by women is clearly subordinate to patrilineality. (Chabi Toko, 2016).

Table 4.1. Demographic characteristics of responding farmers

Parameters		Frequency	Percent (%)
Ethnic group	Peulh	119	52.88
	Gando	52	23.10
	Bariba	47	20.90
	Dendi	7	3.11
Age	> 30 years old	28	12.40
	31-50 years old	154	68.44
	> 50 years old	43	19.10
Level of education	Primary	16	7.10
	Secondary	7	3.10
	University	3	1.30
	Koranic School	38	16.90
	Uneducated	161	71.56
Size of household	4-6	40	17.80
	7-9	94	41.80
	>10	91	40.40
Type of Labour	Family	222	98.67
	Seasonal workforce	3	1.30
Type of system	Sedentary/Agro-pastoral	221	98.22
	Transhumant/Pastoralism	4	1.80

About 12.40% of the respondents were less than 30 years old, 68.44% between 31 and 50 years old, and 19.10% above 50 years old. The distribution of the latter age groupings suggested the active youth population in the study area perceived livestock keeping as a viable source of income and livelihood. The current results demonstrated that the average literacy level of farmers was low. Indeed, 7.10% of the farmers had attained primary school, followed by 3.10% with secondary education. Approximately 1.30% had attained university education, while 71.56% of farmers had no formal education. It was noted that in the study area, 16.90% of farmers received koranic education.

4.2. Ruminant livestock production practices in study area

4.2.1. Cattle herd structure

The surveys were conducted on 4360 heads of cattle. The cattle breeds locally available in the study area were indigenous Zebu and Taurine. The cattle largely reared were Borgou (85.29%) (Figure 4.1). However, in some agro-pastoral households, Zebu Peulh zebu, Yanaka and Gudali were used as reproducers to get crossbreeds (Figure 4.2).

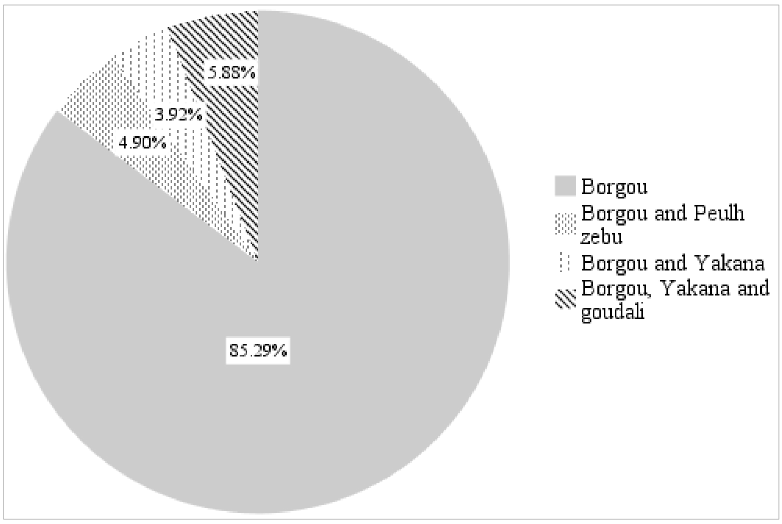


Figure 4.1. Representation of cattle breeds

The herd size ranged between 17 and 92 heads, with an average of 42.75 ± 17.08 heads. As given in table 4.2, the cattle herd mostly consisted of cows (41.79%) and calves (25.28%), while the bull and ox constituted 2.88 and 4.95% respectively. Heifers represented 17.89% of the cattle population. Some breeders in the study area associated with cattle breeding, that of small ruminants. According to Corniaux et al. (2012), herd structure is a relevant indicator for studying the dynamics of the flock. A high percentage of young breeding females is, for example, a pledge of the vitality of a herd, guaranteeing the future of the cattle herd. In addition, the structure of cattle herds reflects the primary objective of the keepers; namely, to live sustainably from their herd. In order to achieve this goal, he must ensure the sustainability of his herd by having a large number of breeding females. The low presence of males in the cattle herd is the consequence of their sale, to solve the money problems, but also, to facilitate the management of the herd. Indeed, the first animals that Peulh sells in his herd are, most of the time, young bulls, followed by old cows. Dehoux and Hounsou-Vè (1993) report that breeders sell young bulls very early on, which are used as draft animals.

Table 4.2. Herd structure in surveyed farms

Categories	Cow	Heifers	Bullock	Bull	Oxen	Calves	Total
Number (Heads)	1821	780	337	125	178	1119	4360
Proportion (%)	**41.77**	**17.89**	**7.73**	**2.87**	**4.08**	**25.67**	**100**

n= number of observation

Figure 4.2. Gudali cattle under traditional production system

4.2.2. Cattle management and feeding practices

Cattle were generally kept in transhumance or agro-pastoral systems. On surveyed farms (100%), cattle were essentially fed natural pasture and harvested fields (Figure 4.3). A shepherd conducted animals to pasture from 7-9 a.m. to 4-6 p.m. On all the farms (100%), the cattle ration contained more than 80% of roughage. The supplementation of cows was carried out by supplying crop residues (cornhusks, millet, sorghum straw, dried cowpeas and groundnut hay). Supplementation of salt, cottonseed and bran (corn, rice) is extremely low. Furthermore, no farm practices group feeding according to categories (cows, heifers, suckling calves etc.), physiological state (pregnant/lactating cows, growing calves etc.). All animals (100%) were fed together and in the same way.

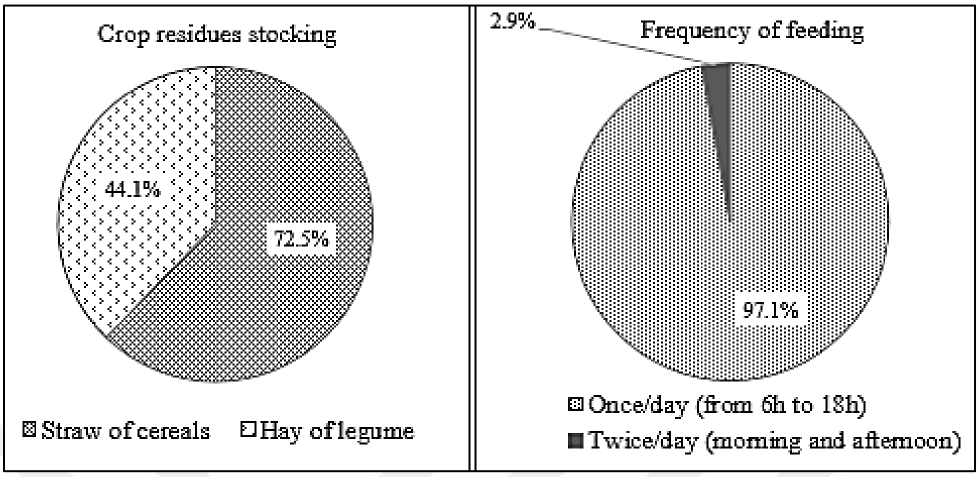


Figure 4.3. Proportion of crop residues stock and feeding frequencies

As for cattle feeding, sheep and goat feeding is greatly dependent on natural grazing. The grasslands consisted largely of Parinari macrophylla and Pennisetum pedicellatum species. However, the animals were supplemented based on local feedstuffs. These feedstuffs can be grouped into:

- Fodder: crop residue including straw, hay (peanuts and beans), sorghum stalks;
- Agro-industrial and traditional residues: cereal bran (millet, maize, rice, sorghum), spent grain (traditional), oilcake (cotton); and by-product from soybean cheese processing;
- Kitchen residues: waste from the kitchen

Throughout the dry season, feeding of sheep and goats in the study area is ensured using harvest residues.

Figure 4.4. Legume and straw from crop-residues stoked for animal feeding during

Figure 4.5. Agri-food by-product (Corn bran and sorghum spent grains from traditional brewery)

Figure 4. 6. Cornhusks and beans hay used to feed sheep and goat during dry seaon

4.2.3. Productivity of cattle herd

4.2.3.1. Reproduction management and reproductive performances

The clustering analysis of productivity data, including herd size, reproduction, and viability variables of studied farms, is indicated in figure 4.7.

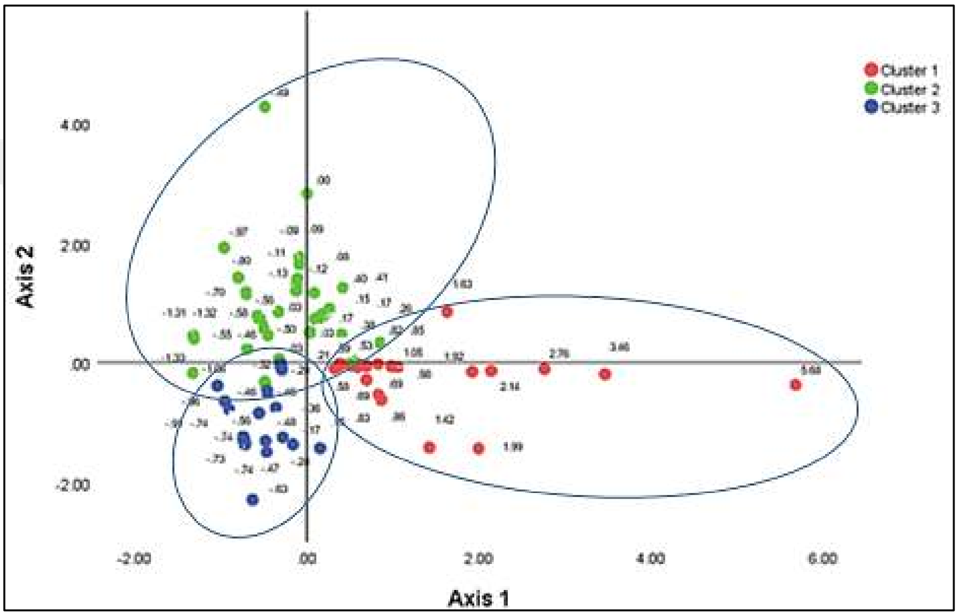


Figure 4.7. Twostep cluster mapping of cattle based on productivity performances

The age at the first mating of cattle (males and females) was between 3 and 5 years. As presented in figure 4.7 and table 4.3, three different types of farms were identified. The flock size and pregnancy rate were not significantly different between clusters. However, significantly different ($P < 0.05$) rates were observed between the types of farms in terms of fertility (calving rate), miscarriage and mortality.

Table 4.3. Reproduction and production parameters according to farm cluster

Parameters		n	Mean	S.D.	S.E.	Sig.
Flock size	Type 1	23	37.57	12.20	2.54	0.25 (NS)
	Type 2	43	44.05	15.29	2.33	
	Type 3	36	44.50	21.11	3.52	
	Total	**102**	**42.75**	**17.08**	**1.69**	
Pregnancy rate (%)	Type 1	23	70.20	3.02	0.63	0.06 (NS)
	Type 2	43	70.92	5.75	0.88	
	Type 3	36	68.47	3.72	0.62	
	Total	**102**	**69.89**	**4.66**	**0.46**	
Miscarriage rate (%)	Type 1	23	20.73	19.76	4.12	0.00 (S)
	Type 2	43	4.44	4.94	0.75	
	Type 3	36	1.79	3.37	0.56	
	Total	**102**	**7.18**	**12.43**	**1.23**	
Fertility rate (%)	Type 1	23	58.05	6.95	1.45	0.00 (S)
	Type 2	43	67.25	8.27	1.26	
	Type 3	36	67.42	4.13	0.69	
	Total	**102**	**65.24**	**7.75**	**0.77**	
Mortality rate (%)	Type 1	23	4.20	6.15	1.28	0.00 (S)
	Type 2	43	12.36	9.41	1.44	
	Type 3	36	4.03	8.57	1.43	
	Total	**102**	**7.58**	**9.35**	**0.93**	

n= Number observations; S.D. = Standard deviation; S.E: Standard Error, S= mean is significantly different at P = 0.05; NS= mean is not significantly different at P = 0.05

The highest pregnancy (70.92%) and mortality (12.36%) rates were observed in the second type of farm, while the lowest miscarriage rate was recorded in the Type 3 farms. As for the fertility rate, the highest (67.42%) was obtained in type 3 and the lowest (58.05%) in type 1. For all studied farms, the overall pregnancy, miscarriage and fertility rates were averagely 69.89 ± 4.66, 7.18 ± 12.43 and 65.24 ± 7.75%. An average mortality rate of 7.58 ± 9.35% was recorded. In general, the reproductive performances of cattle (pregnancy and fertility rate) among agro-pastoralists were poor. These poor reproduction performances of herds were the consequence of poor nutrition, organization of reproduction and animal health monitoring. The fertility rate obtained in the current study is lower than the 70.27 ±

15.23% reported by Alkoiret et al. (2010) in Borgou cow at station. This difference may be explained by various factors, including better animal feeding, good health monitoring, and management of reproduction within the herd.

4.2.3.2. Oxen work

In Benin, the place of animal traction in agricultural households varies according to agro-ecological zones and cropping systems. This form of agricultural mechanization is more adopted in the north-Benin and for various activities, in particular the harness culture and the transport of people and goods. It generates increased income and timesaving for farmers (Gibigaye et al. 2012). The results showed that Borgou was (91.27%) the most used breed (Figure 4.6) for animal traction. Besides the Borgou, some crosses (Borgou x zebu – Peuhl or Gudali zebu) were also used for animal traction, accounting for 8.73% (Figure 4.7). Crossbreeding (Borgou x zebu) is currently increasing because breeders are looking for a larger format for their animals for use in animal traction. Due to their docile character, Borgou are easy to train and handle (Adjou Moumouni, 2006).

Figure 4.8. Borgou oxen used for animal traction

Figure 4.9. Borgou x Peulh Zebu crossbreeds oxen used for animal traction

The average herd size of oxen per agro-pastoral smallholders was 2.91 ± 1.41 heads (a minimum of a pair per household). The minimum age of animals was between 2 and 3 years. Oxen worked for 2-5 hours, an average of 3.25 ± 0.56 hours per day. Usually, animals worked for 3 hours (7 a.m. to 10 a.m) in the morning and 2 hours in the evening (4 p.m. to 6 p.m). Animal traction was mainly used in rainy periods for cultivating fields (ploughing) and transporting crops. Because of its docile character, Borgou is easy to train and handle. The choice of these animals for animal traction is also justified by their size and weight, which can reach 180 to 220 kg at the age of 2 or 3 years. A survey carried out by the ministry of agriculture in 2003 revealed that nearly 80 000 heads of oxen (4% of the cattle population) were used for draft power (Kouazounde et al. 2015). Oxen used for harness culture usually work for 5 years (Hoste et al. 1988). Due to the insufficiency of data on the population, live weight and work activity of crossbred oxen, only the Borgou oxen were taken into account while calculating the energy spent on work as well as the emission factor for oxen.

4.2.4. Small ruminant flock composition

The average flock size of sheep and goats was 18.14 ± 9.67 and 19.29 ± 8.72 respectively. Table 4.4 indicated the composition of the small ruminant flock. It shows that females are numerically more important than males within herds. The sampled sheep population was made up of 391 males (35.32%) and 716 females (64.68%). As for the goat population, it was made up of 822 females (68.73%) against 374 males (31.27%).

Table 4.4. Composition of sheep and goats flock kept in surveyed farms.

Sub-categories	Goats (n = 1196)				Sheep (n = 1107)			
	Male		Female		Male		Female	
	n	%	n	%	n	%	n	%
0-3 m	165	13.80	172	14.38	104	9.39	112	10.12
3-6 m	81	6.77	79	6.61	92	8.31	84	7.59
6-12 m	64	5.35	60	5.02	130	11.74	134	12.10
1-2 y	21	1.76	128	10.70	28	2.53	127	11.47
2-3 y	30	2.51	213	17.81	20	1.81	163	14.72
> 3y	13	1.09	170	14.21	17	1.54	96	8.67
Total	**374**	**31.27**	**822**	**68.73**	**391**	**35.32**	**716**	**64.68**

The predominant type of sheep (95.1%) and goat (100%) in the study zone is the West African Dwarf (Djallonké). However, Sahelian sheep (1.6%) were also encountered. In addition, crossbreeding of both Sahelian and Djallonké types was common (3.3%).

Figure 4. 10. Djallonké sheep under traditional system

4.2.5. Reproductive and productivity traits of sheep and goats

Reproduction parameters are given in table 4.5. Within the traditional farms studied, reproduction was not controlled. No farm (100%) applied an oestrus control method (oestrus synchronization or male effect) (Table 4.5). Females were naturally mated. Males were continuously in the flock, running freely with the females.

About 54.8% and 68.9% of goat and sheep flock had at least one goat or ram. While 24.5% of goat farms and 18% of sheep farms did not have breeding males. The young females were introduced for reproduction according to the needs of the renewal of the flock regardless of their live weight. The information obtained from the breeders revealed that the age at the first birth was between 12 and 15 months.

Table 4.5. Some reproductive indicators in sheep and goats kept in surveyed farms

Parameters	Variables		Goats (n= 62)	Sheep (n= 61)
Age at first mating (%)	< 12 months		91.9	86. 9
	12-18 months		8.1	13.1
Birth frequency (%)	Once/year		87.10	95.08
	Once every 2 years		4.84	1.64
	3 times every 2 years		8.06	3.28
Reproductive performances	Fertility rate		81.37 ± 17.10	96.43 ± 8.72
	Miscarriage rate		6.07 ± 10.26	3.77 ± 8.48
	Birth rate	Simple	40.66 ± 24.98	63.19 ± 17.73
		Double	53.61 ± 21.10	33.90 ± 16.95
		Triplet	8.43 ±13.96	2.90 ± 6.85
	Litter size		1.29 ± 0.55	1.35 ± 0.28
	Mortality rate		24.95 ± 14.18	11.87 ± 13.55

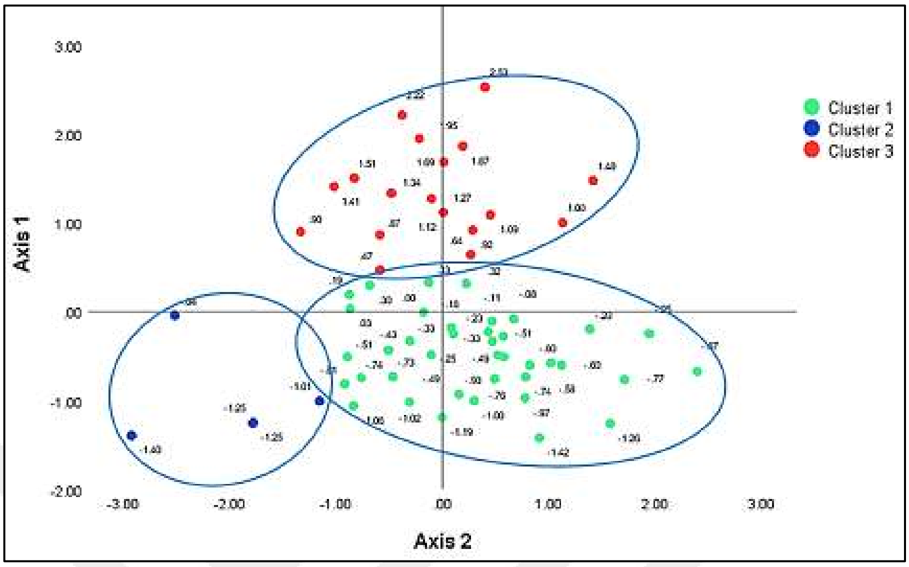


Figure 4.11. Principal components from twostep three-cluster analysis of goat farms

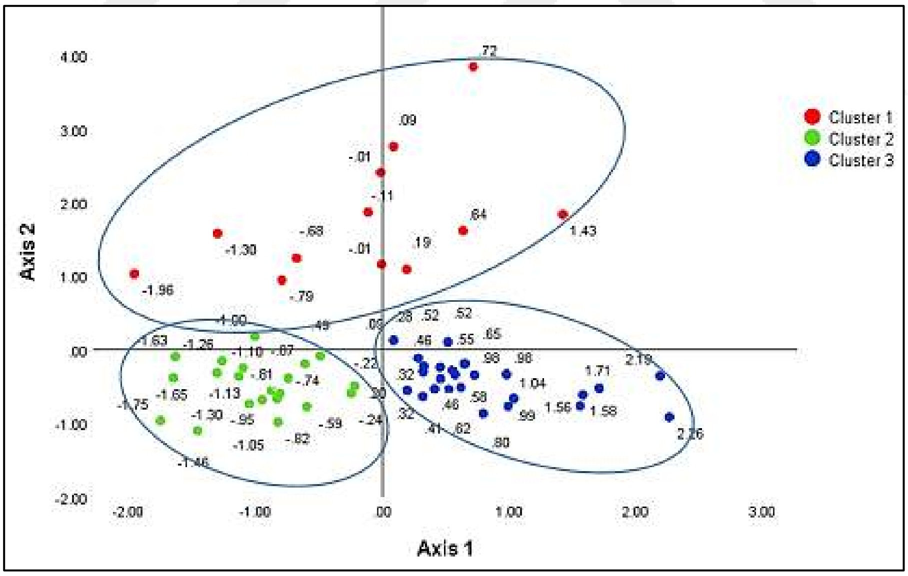


Figure 4.12. Principal components from two-step three-cluster analysis of goat and sheep farms

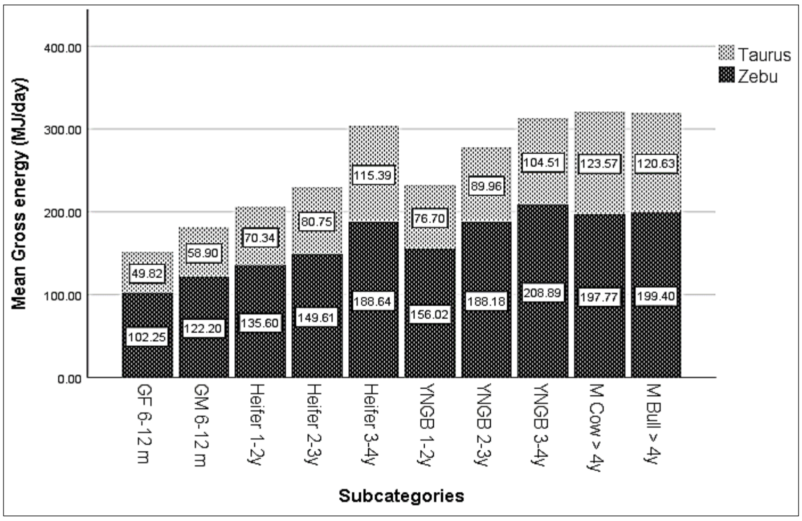
4.3. Country-specific gross energy and emission factors

4.3.1. Gross energy and emission factors for ruminants in Benin Republic

4.3.1.1. Gross energy and Enteric emission factors of cattle

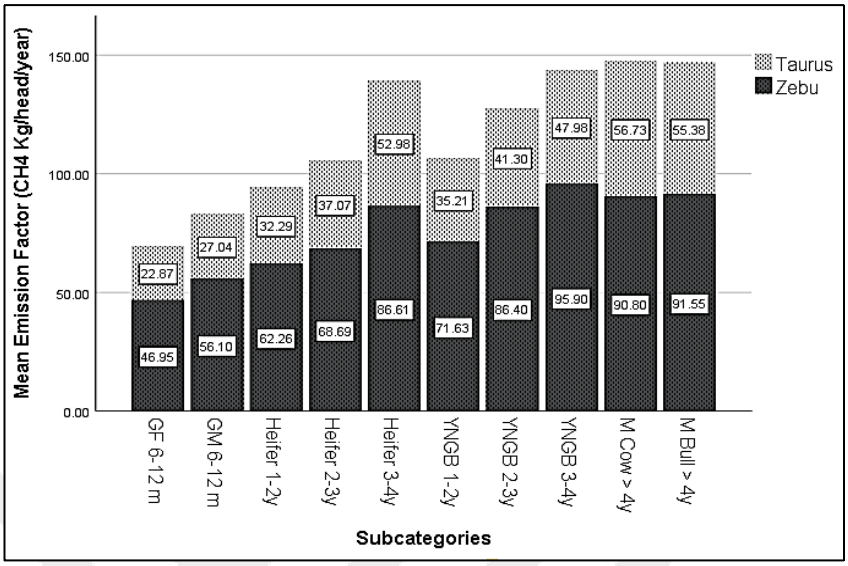
Table 4.6 presents gross energy and emissions factors by breeds and sub-categories. The GE varied within age-subcategories ranging from 71.83 to 168.19, 37.70 to 103.49, 41.38 to 109.39, 116.52 to 221.78, 81.70 to 195.86 and 88.36 to 204.64 MJ/day for Borgou, Lagune, Somba, Gudali, White Fulani, and Azawak cattle, respectively. The GE was averagely 123.83 MJ/day and significantly different within species and breeds ($P < 0.05$). As given in Figure 4.12, zebu (*Bos indicus*) cattle had higher GE than *Bos taurus* (91.92 vs. 156.80 MJ/day). The highest (157.68 MJ/day) and lowest (74.64 MJ/day) GE were recorded in Azawak and Lagune cattle respectively.

A national EF of 56.85kg CH4/head/year was found for all cattle (*Bos indicus* and *Bos taurus*). As with gross energy estimates, EFenteric varied according to subspecies, breeds and subcategories (Table 4.6). The means of EFs (71.99 vs. 41.20 kg CH_4 head^{-1}year^{-1}) of *Bos indicus* were significantly ($P < 0.05$) higher than *Bos taurus* (Figure 4.13).



GF: growing female; GM: growing male; y = year; m = month; NE = not estimated; GE = gross energy (MJ/day); EF = emission factor (kg/head /year); YB = young bull; MC = mature cow

Figure 4.13. Mean of gross energy by subcategories by subspecies



GF: growing female; GM: growing male; y = year; m = month; NE = not estimated; GE = gross energy (MJ/day); EF = emission factor (kg/head /year); YB = young bull; MC = mature cow

Figure 4.14. Mean of emission factors by subcategories by subspecies

In addition. $EF_{enteric}$ differed within breeds. The highest EF was found in Gudali cattle (72.39 kg CH_4 $head^{-1}year^{-1}$), while the lowest came from Lagune (34.27 kg CH_4 $head^{-1}year^{-1}$). Regarding age-categorical emission, $EF_{enteric}$ lowest value was recorded in growing calves (34.91 for females and 41.57 kg CH_4 $head^{-1}year^{-1}$ for males) and highest in mature cows (73.76 kg CH_4 $head^{-1}year^{-1}$) and bulls (73.46 kg CH_4 $head^{-1}year^{-1}$).

Oxen's GE and $EF_{enteric}$ were calculated for Borgou as it was the most used breed for animal traction. The GE and $EF_{enteric}$ estimated for Borgou oxen were 168.19 MJ day^{-1} and 77.22 kg CH_4 $head^{-1}year^{-1}$ respectively (Table 4.6).

The calculated emissions factors for all cattle were compared with published emission factors from some sub-Saharan African countries and the IPCC (2006) default values for Africa (see Table 4.7). The EFs estimated in the current study for humpless Borgou (56.35 vs. 40.2 kg CH_4 $head^{-1}$ $year^{-1}$), Lagune (34.27 vs. 24.8 kg CH_4 $head^{-1}$ $year^{-1}$) and Somba cattle (34.57 vs. 29.5 kg CH_4 $head^{-1}$ $year^{-1}$) were higher than the findings of Kouazounde et al. (2015) in Benin. A similar trend was observed for the current findings when compared to the 30.8 kg CH_4 head^{-1}year^{-1} reported by Ndao et al. (2020) in Ndama cattle. Furthermore, EF for all cattle (56.85 kg CH_4 head^{-1} year^{-1}) was higher than 39.5 kg CH_4 animal^{-1} year^{-1} obtained by Kouazounde et al. (2015) and the default IPCC value of (31 to 49 kg CH_4 head^{-1} year^{-1}). The contradiction of the current results with previous studies and the default EF values of IPCC (2006) was due to differences in productivity (milk yield and composition, average daily weight gain, live weight per subcategory) and feeding characteristics. Moreover, the study of Kouazounde et al. (2015) did not take into account the EFs from zebu cattle (Gudali, White Fulani and Azawak), which represent up to 7.7% of the cattle population in Benin (Alkoiret and Gbangboche, 2005; Gbangboche et al., 2011).

Table 4. 6. Estimated GE and enteric CH_4 EF for cattle breeds and subcategories in Benin Republic

Sub-categories	Borgou		Lagune		Somba		Gudali		White Fulani		Azawak	
	GE	EF	GE	EF	GE	EF	GE	EF	GE	EF	GE	EF
GF 6-12 m	71.83	34.06	37.70	17.31	41.38	19.00	116.52	53.50	81.70	37.51	88.36	40.57
GM 6-12 m	80.14	37.67	47.55	21.83	49.71	22.82	127.12	58.36	96.28	44.21	100.41	46.10
Heifer 1-2y	91.49	43.13	69.10	31.72	54.06	24.82	120.70	55.42	129.85	59.62	139.35	63.98
Heifer 2-3y	109.41	51.32	59.02	27.10	72.95	33.49	140.00	64.28	159.37	73.17	131.48	60.37
Heifer 3-4y	151.65	71.11	95.89	44.03	97.49	44.76	166.18	76.30	189.58	87.04	189.79	87.14
YNGB 1-2y	99.32	46.28	74.20	34.06	60.07	27.58	117.47	53.93	157.75	72.43	160.73	73.79
YNGB 2-3y	120.82	56.13	69.88	32.09	80.84	37.11	160.26	73.58	178.54	81.97	182.68	83.87
YNGB 3-4y	143.80	66.94	91.26	41.90	79.38	36.45	189.42	86.97	195.86	89.92	193.12	88.66
Oxen	168.19	77.22	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
M Cow > 4y	162.98	74.83	98.34	45.15	109.39	50.22	200.69	92.14	187.99	86.31	204.64	93.95
M Bull > 4y	150.66	69.17	103.49	47.51	107.73	49.46	221.78	101.82	190.12	87.29	186.30	85.53
Comparison of GE and EF by breeds (mean ± standard error)												
GE	122.75 ± 10.38^{bc}		74.64 ± 7.08^{adef}		75.30 ± 7.63^{adef}		156.01 ± 11.99^{bc}		156.70 ± 12.99^{bc}		157.68 ± 12.93^{bc}	
EF	56.35 ± 4.76^{bc}		34.27 ± 3.25^{adef}		34.57 ± 3.50^{adef}		71.63 ± 5.50^{bc}		71.94 ± 5.9^{bc}		72.39 ± 5.93^{bc}	

GF: growing female; GM: growing male; y = year; m = month; NE = not estimated; GE = gross energy (MJ/day); EF = emission factor (kg/head per year); YB = young bull; MC = mature cow; a, b, c, d, e, f = the mean difference was significant at 0.05 level.

Table 4.7. Enteric methane EF for cattle from different studies

Study	Region	Breeds	LW (kg)		Average EFs
			MC	MB	
IPCC (2006)	Africa	MCG	200		41
		Bull grazing	275		49
		Young	75		16
		Other Cattle	-		31
Kouazounde et al. (2015)	Benin Republic	Borgou	239.4	275	40.2
		Lagune	157	209	24.8
		Somba	167	173	29.5
Current study	Benin Republic	Borgou	295	330	56.36
		Lagune	160	200	34.27
		Somba	183	211	34.57
		Gudali	404	552.6	71.63
		White fulani	347	450	71.95
		Azawak	350	438	72.40
Ndao et al. (2020)	Senegal	Ndama	223	250	30.8

MCG: mature cow grazing, MC: mature cow; MB: mature bull; LW: live weight (kg); EF: Emission Factors (kg CH4 animal^{-1} year^{-1})

EF calculation using the IPCC (2006) Tier 2 methodology is influenced by variables including live BW, growth rate, feeding practices, gender and productivity (e.g. pregnancy, milk production, work). These factors affect gross energy expenditure, and consequently, enteric CH_4 production. Differences in live BW and grazing systems among breeds of cattle contributed to the variation in estimated $EF_{enteric}$ among cattle breeds and subcategories. The highest EF observed for zebu cattle was attributable to their live body weight, daily average weight gain and dairy productivity, which were higher than those of humpless cattle (Borgou, Somba and Lagune). The greater EF of Borgou cattle compared to that of Lagune and Somba cattle reflected the high-energy needs of Borgou reared under an extensive system to expend to obtain feed to maintain their bodies.

The inconsistency of $EF_{enteric}$ estimated using IPCC Tier-2 methodology was also due to uncertainties associated with the characterization of the cattle population and production. Indeed, the existence of limited data (inaccuracy and unavailability) on productivity performance (milk yield and composition, average daily weight gain, live weight per subcategory) of indigenous cattle breeds in Benin were the major uncertainties limiting the use of IPCC Tier 2 methodology. Besides, few detailed and updated statistics related to cattle population data were available on the actual proportion (percentage) of each cattle breed and for each subcategory among the whole population. To achieve productivity gains (improve milk and meat production), an uncontrolled crossing (uncontrolled reproduction) of local Bos taurus and zebu is done by farmers. As a result, crossbreds are developed, which are considered as a threat to the original genetic resource. For instance, the number of Somba cattle, which was 216,000 heads in 1987, considerably declined to 25,000 heads in 1995, then to 17,000 heads (Chabi China, 2016). Although, these crossbreds are considerable in the cattle population, data on their productivity performance and the population was not available.

4.3.1.2. Gross energy and emission factors of sheep and goats

GE for pre-ruminant lambs and kids (0–3 months) were excluded from $EF_{enteric}$ calculations on the assumption that animals at this age produce negligible emissions (Reed et al. 1990). As presented in table 4.8. GE (9.64 *vs.* 7.35 MJ day^{-1}) and $EF_{enteric}$ (3.76 *vs.* 2.92 kg CH_4 $animal^{-1}$ $year^{-1}$) were higher for sheep than goats. The national $EF_{enteric}$ (kg/CH_4/year) using IPCC Tier-2 was 1.63, 2.29, 4.02, 4.64, 5.92 and 4.44 for lambs (3-6 months), growing (6-12 months), yearlings (1-2 years), young (2-3 years), mature does (> 3 years) and bucks (> 3 years) respectively. In goats, a national emission factor of 1.06, 1.36, 3.15, 3.85, 5.92, 4.44 kg CH_4 $animal^{-1}$ $year^{-1}$ was generated for kids (3-6 months), growing (6-12 months), yearlings (1-2 years), young (2-3 years), mature ewes (> 3 years) and rams (> 3 years) respectively. These $EF_{enteric}$ were lower than the estimates of the Intergovernmental Panel on Climate Change (Tier I) for small ruminants in developing countries. Emission factors are a very critical element to the accuracy of the estimations in the calculations of emissions per animal and could explain some of the variations among results reported in the literature.

Table 4.8. Estimated GE and enteric CH_4 EF for Djallonké goat and sheep

Sub-categories	Goat		Sheep	
	GE	EF	GE	EF
Weaner female 3-6 m	3.53	1.04	5.35	1.58
Weaner male 3-6 m	3.67	1.08	5.70	1.68
Growing female 6-12 m	4.90	1.45	7.44	2.20
Growing male 6-12 m	4.31	1.27	8.08	2.38
Yearling female 1-2 y	6.20	2.64	8.86	3.78
Young female 2-3 y	8.12	3.46	10.10	4.31
Yearling male 1-2 y	8.56	3.65	9.97	4.25
Young male 2-3 y	9.93	4.23	11.66	4.97
Mature female > 3y	13.90	5.92	17.17	7.32
Mature male > 3 y	10.42	4.44	12.07	5.15
Average	**7.35**	**2.92**	**9.64**	**3.76**

4.3.2. Methane emission from manure management

4.3.2.1. Manure methane emission factors for cattle

The volatile solid (VS) calculated based on gross energy intake estimates varied from 1.75 to 4.11, 0.92 to 2.53, 1.01 to 2.67, 2.85 to 5.42, 2 to 4.79, 2.16 to 4.72 kg DM head^{-1} day^{-1} for Borgou, Lagune, Somba, Gudali, Wite Fulani and Azawak respectively (see Table A.6). CH_4 EF_{manure} was higher (1.95 vs. 1.13 kg CH_4 animal^{-1} year^{-1}) in Zebu than in *Bos taurus*. As for $EF_{enteric}$, the highest (1.96 kg CH_4 head^{-1} year^{-1}) and lowest (0.93 CH_4 head^{-1} year^{-1}) EF_{manure} were recorded in Azawak and Lagune cattle respectively) (Table 4.9) The national average CH_4 EF_{manure} in cattle was 1.54 kg CH_4/head/year. The country-specific CH_4 EF_{manure} for cattle was 1.54 times higher than the default EF (1 kg CH_4 head^{-1} year^{-1}). The difference in CH4 EF_{manure} could be attributed to the changes in cattle breeds, live weight, and performance. In addition, this may be attributed to the difference in the type of feeding (forages) also contribute to the variation of VS excretion which resulted in different EF_{manure}, The feed for livestock was low-quality feed or crop residues, which were low in digestibility and high in fibre, resulting in the high excretion of the nutrients that were contained in the manure. The VS of manure from the animal category would vary with diet and other factors, such as straw addition (Dustan, 2002).

Table 4.9. Country-specific emission factors from manure management of cattle

Sub-categories		Borgou	Lagune	Somba	Gudali	White Fulani	Azawak
Female 6-12 m		0.89	0.47	0.51	1.45	1.02	1.10
Male 6-12 m		1.00	0.59	0.62	1.58	1.20	1.25
Heifer 1-2 y		1.14	0.86	0.67	1.50	1.61	1.73
Heifer 2-3 y		1.36	0.73	0.91	1.74	1.98	1.63
Heifer 3-4 y		1.88	1.19	1.21	2.07	2.36	2.36
Bullock 1-2 y		1.23	0.92	0.75	1.46	1.96	2.00
Bullock 2-3 y		1.50	0.87	1.00	1.99	2.22	2.27
Young bull 3-4 y		1.79	1.13	0.99	2.35	2.43	2.40
Oxen		2.09	NE	NE	NE	NE	NE
Mature cow > 4y		2.03	1.22	1.36	2.49	2.34	2.54
Mature bull > 4 y		1.87	1.29	1.34	2.76	2.36	2.32
Average	Breeds	1.53	0.93	0.94	1.94	1.95	1.96
	Subspecies	1.13			1.95		
	All cattle	1.54					

M= months; y = years; NE: not estimated

4.3.2.2. Manure methane emission factors for sheep and goats

The CH_4 EF for sheep and goats are presented in Table 4. 10. Sheep had higher CH_4 EF from manure when compared to goats. Mature does and ewes had the highest CH_4 EF_{manure} across all categories. Weaner lambs and kids had the lowest CH_4 EF_{manure} of 0.09 and 0.05 kg CH_4 head^{-1} year^{-1} respectively. The current EF_{manure} for sheep and goats was 1.25 and 1.83 times higher than the IPCC default value for warm developing regions (0.20 and 0.22 kg CH_4 head^{-1} year^{-1} for sheep and goats respectively). The lower value of EF_{manure} of Djallonké sheep and goats was mainly due to their lower live weights and the poor quality of diets offered to small ruminants in Benin Republic.

Table 4.10. Manure methane emission Factors of Djallonké sheep and goats

Sub-categories	Sheep		Goat	
	VS	EF	VS	EF
Weaner female 3-6 m	0.14	0.09	0.09	0.05
Weaner male 3-6 m	0.15	0.10	0.10	0.06
Growing male 6-12 m	0.20	0.13	0.13	0.08
Growing female 6-12 m	0.21	0.14	0.11	0.07
Yearling female 1-2 y	0.23	0.15	0.16	0.10
Young female 2-3 y	0.27	0.17	0.21	0.14
Yearling male 1-2 y	0.26	0.17	0.23	0.14
Young male 2-3 y	0.31	0.20	0.26	0.17
Mature female > 3y	0.45	0.29	0.37	0.23
Mature male > 3 y	0.32	0.20	0.28	0.18
Average	**0.26**	**0.16**	**0.19**	**0.12**

Comparison with IPCC (2006) default value

	Sheep			Goat		
	ALW	VS	EF	ALW	VS	EF
Current study	25	0.26	0.16	23	0.19	0.12
IPCC (2006) for warm region (≥ 28ºC)	28	0.32	0.2	30	0.35	0.22

ALW: Average live weight of animals (kg); VS: Volatile Solid (/day (kg VS); EF: Emission factors from manure; m: months; y: year

4.4. Greenhouse gases emitted from ruminants kept in Benin

4.4.1. Enteric CH_4 methane emission

Dry matter intake is the main driver of enteric CH_4 emission. The Tier 2 approach is based upon the relationship between dry matter intake and CH_4 enteric production (Pirlo and Carè, 2013). Methane emissions were mainly caused by enteric fermentation (97.30%) against 2.70% for manure management. Emissions from enteric fermentation have shown an increase from 1999 to 2019, changing from 2158.37 to 3740.08 Gg CO_2 eq. The main reason behind this increasing trend in enteric emissions was relative to the growing ruminant population in Benin. Cattle were the major emitters of the emissions from enteric fermentation, with a yearly average of 2797.78 Gg CO_2 eq, accounting for 95.01% (Figure 4.14). This emission was highly from Borgou cattle emissions evaluated at 1234.98 Gg CO_2 eq, accounting for 48.7%. The lowest level of enteric CH_4 was emitted from Somba cattle, (122.74 Gg CO_2 eq, i.e. 18.22%); while the Zebu contributed 4.39 Gg CO_2 eq (0.65%) (Figure 4.15). The highest and lowest emissions from Borgou and Somba were due to the fact that Borgou and Somba owned the greatest and smallest population.

Regarding sheep and goats, they emitted 69 to 114 and 45 to 67 Gg CO_2 eq from 1999 to 2019 respectively. Despite sheep having greater $EF_{enteric}$, their low enteric CH_4 emissions reflected their smaller population when compared to goats (Figure 4.14).

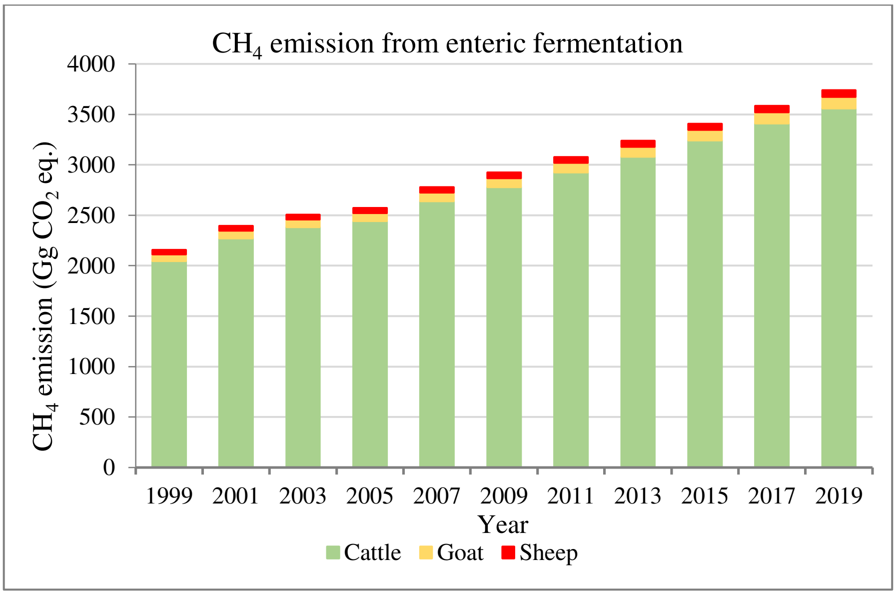


Figure 4.15. Enteric CH_4 emission calculated based on country-specific EFs

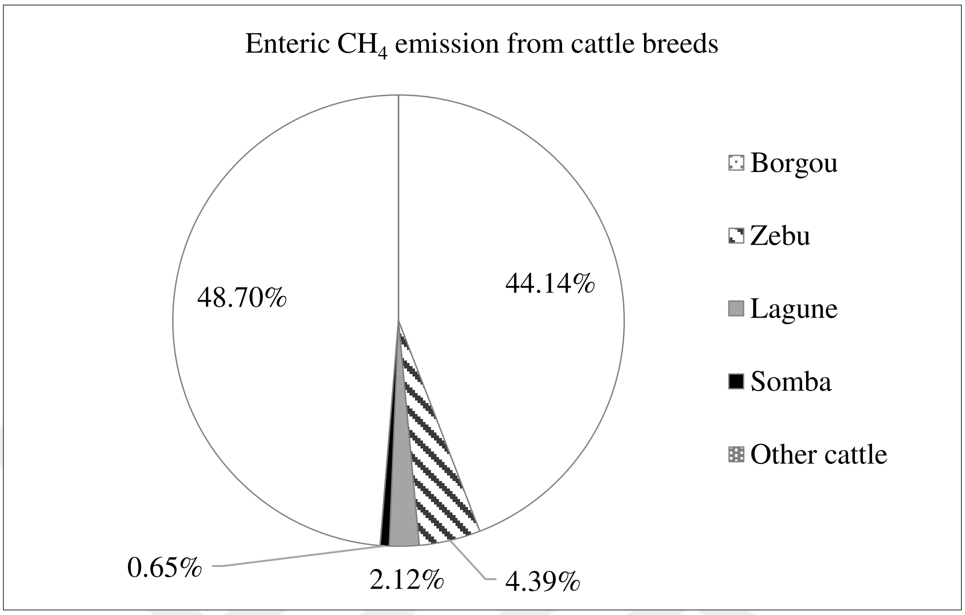


Figure 4.16. Proportion of emission according to cattle breeds

4.4.2. Manure CH_4 methane emission

Manure management CH_4 emissions contributed to 103.89 Gg CO_2 eq., which constituted 2.70% of methane emissions in 2019. The manure CH_4 emissions reported in Figure 4.16 were higher for cattle (96.35 Gg CO_2 eq i.e. 92.75%) than for sheep (2.98 Gg CO_2 eq i.e. 2.87 %) and goats (4.56 Gg CO_2 eq i.e. 4.39%). The emission from manure has shown an increase from 60 Gg CO2 eq in 1999 to 104 Gg CO_2 eq in 2019. The increase was approximately 5.64% on average per year. This increase reflected the growth of the ruminant population in Benin. CH_4 is emitted during the storage and treatment of manure under anaerobic and aerobic conditions. The relatively small amount of manure CH_4 emissions reflected the low management of livestock manure in Benin. Manure is handled as a solid in stacks or it is directly spread on soil and pastureland where it decomposes under aerobic conditions, producing less CH_4.

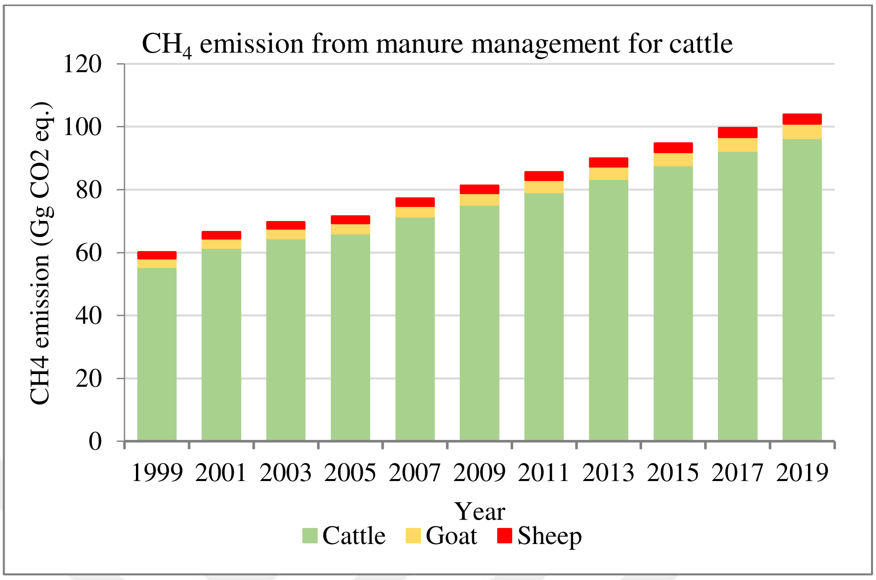


Figure 4.17. Manure CH_4 emission calculated based on country-specific EFs

Manure from livestock consists of a proportion of organic volatile solids, which are fats, carbohydrates, proteins, and other nutrients that act as a source of food and energy for the growth and reproduction of anaerobic bacteria. The acid formers group of bacteria break down the volatile solids in manures into a series of fatty acids in the acid forming stage, and in the next stage, highly specialized methane formers convert the acids to methane gas and carbon dioxide. The methane formers are pH (6.8-7.4) sensitive, strict anaerobes and function best at 95°F (Monteny et al., 2001). These conditions often occur when large numbers of animals are managed in a confined area (for example, dairy farms, beef feedlots, and swine and poultry farms) where manure is stored in large piles or disposed of in lagoons. The main factors affecting methane emission from livestock manure are the amount of manure that is produced and the portion of the manure that decomposes anaerobically.

4.4.3. Nitrous oxide emissions in Benin Republic

Nitrous oxide is produced during the nitrification-denitrification of nitrogen contained in livestock waste (Monteny et al., 2001). The amount of N_2O stood at 943.93 Gg of CO_2 equivalents in 2019. From this emission, direct N_2O amounted to 754.11 Gg CO_2 eq. (79.89%) while indirect N_2O contributed for 189.82 Gg CO_2 eq. (20.11%) (Figure 4.17). This figure marked an overall increase of 41.49% when compared with 1999 (552.33 Gg CO_2 eq), or some 391.60 Gg CO_2 eq. The emissions from cattle manure management were largely higher than small ruminants, contributing to 79.94% and 20.06% respectively in 2019 (Figure 4.16).

Nitrous oxide is currently the leading ozone-depleting substance being emitted (Bracmort, 2010). (Chah and Igbokwe, 2012). The initial nitrification step is important to provide the essential substrate (NO−) for the microbial denitrification processes. There are several other ways of producing N_2O, as nitrifier-denitrification coupled chemical paths are also important. Its production requires an initial aerobic reaction and then an anaerobic process.

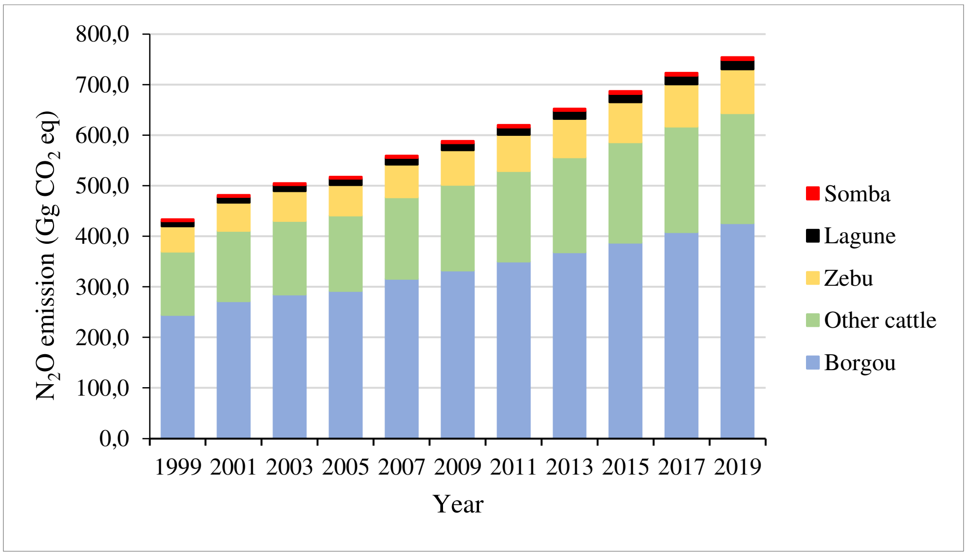


Figure 4.18. Categorical emission of nitrous oxide in Benin Republic

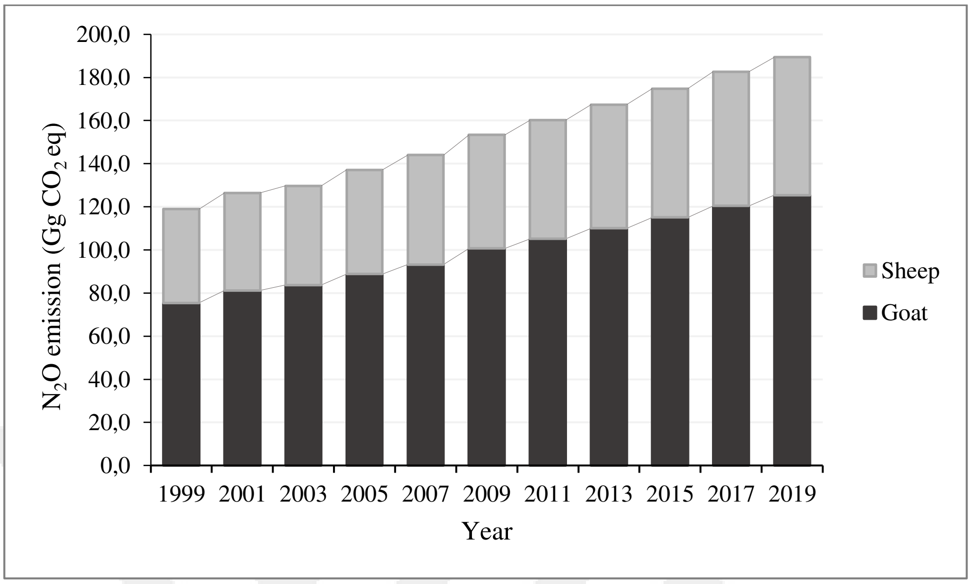


Figure 4.19. Direct and indirect N_2O emission in Benin Republic

Nitrous oxide is formed from nitrogen compounds in feeds or excreta during processes where oxygen is consumed. Dry, aerobic management systems may provide an environment more conducive to N_2O production. The majority of nitrogen in manure is in ammonia (NH_3) form. Nitrification occurs aerobically and converts this ammonia into nitrate. Denitrification occurs anaerobically, and nitrous oxide is one of the intermediate reaction products.

4.4.4. Determinants factors of greenhouse gases emissions in Benin Republic

The summation of GHGs emitted from enteric fermentation (CH_4) and manure management (CH_4 and N_2O) are given in table 4.11. The growing number of ruminants in Benin was identified as the main factor influencing the increase in emission intensity over recent years. In addition, the following factors meaningfully contributed to emissions:

Inadequate nutrition and inefficient reproduction performances: In the Republic of Benin, ruminants are fed on low quality pastures. Ruminant production is essentially traditional (extensive) using natural grassland. Grass species in native pastures are characterized by low yields and low crude protein contents. Generally, ruminants feeding in traditional systems are made up of native pastures that are of poor quality (55% digestibility and crude protein ranging between 18-20 g N/kg dry matter). This has a major influence on reproductive performance and the breeding overhead. The relatively low calving percentages are largely due to seasonal nutrient deficiencies in pastures and the failure to supplement cows during periods of low nutrient intake. Inadequate nutrition results in delayed rebreeding and later calving dates. Improving production efficiency is key to reducing GHG emissions. In Benin Republic, the lack of good management practices for animals in terms of reproduction and feeding; coupled with the non-use of improved pastures, are the key constraints to achieving productivity goals.

Table 4. 11. Greenhouse gas emissions intensity by source category in Gg CO_2 eq.

Year	1999	2007	2015	2019	Absolute change 1999-2019
Total emission	2770.81	3558.38	4364.63	4787.90	2017.09
Enteric fermentation	2158.37	2777.55	3408.05	3740.08	1581.71
Manure management	612.44	780.83	956.58	1047.82	435.37

Large overhead: It is the result of inefficient reproductive through low conception rate combined with the maintenance of a large number of heads in subcategories such as bullock and oxen, accounting for 7.73 and 4.08% (see Table 4.2). Furthermore, breeding stock (cows, bulls, and heifers for replacements) represented about 62.53%. In the traditional production system, the rearing of bullocks and heifers fed on poor natural pasture extends their lifetime (due to the low growth rate) and the period necessary to reach the age for calving. This long keeping of bullocks requires inadequate forage supply and consequently leads to GHG emissions. The reduction of bullock lifetime (finishing periods) through the improvement of keeping practices, especially feeding and health care, can contribute to lower GHG emissions. In the current study, the age at the first calving was between 3-5 years and averaged 4.2 years. Thus, improving heifer growth rate can lower age calving, result in increased production efficiency, and decrease the amount of GHG emissions.

4.5. Greenhouse gases emitted from ruminants in the Eastern Mediterranean area of Turkey

4.5.1. Enteric methane emission

The annual enteric CH_4 calculated as the summation of emissions from different categories of ruminants is given in figure 4.19.

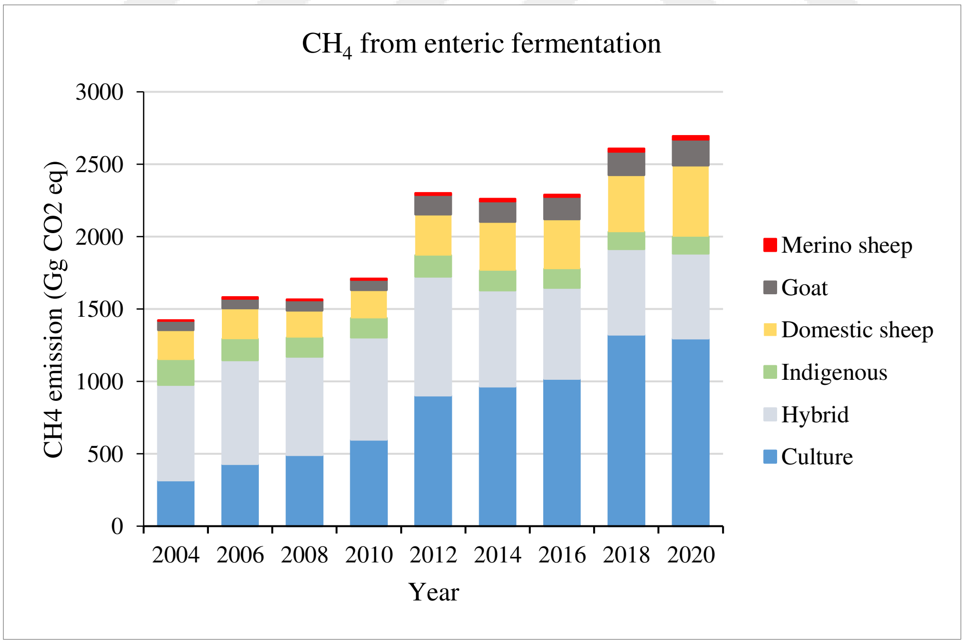


Figure 4.20. Enteric methane emission from ruminant

The total CH_4 emissions from enteric fermentation ranged from 1534.70 Gg CO_2eq (in 2004) to 2816.01 Gg CO_2eq (in 2020), with a yearly average of 2149.73 Gg CO_2 eq. Culture cattle contributed more than any other ruminant category with an average of 815.95 Gg CO_2eq CH_4 per year, accounting for around 37.96 % of the total enteric emissions in the study area (Figure 4.18). It was followed by hybrid cattle, which emitted 672.21 Gg CO_2eq. The lowest emission was recorded in local cattle, at 138.25 Gg CO_2eq. The disparity between categorical emissions was due to the difference between cattle populations coupled with the variance of emission factors. For instance, culture and hybrid cattle own the highest population of these categories (over 310 and 294 thousand) and the highest EF (82 kg CH_4 head^{-1} year^{-1}). Among small ruminants, goats own the highest emissions with around 257.38 Gg CO_2eq, amounting to approximately 11.97 % of the total emissions. This is mainly because of the high annual population, which is above 2.3 million. Despite their relatively lower population (about 2.1 million heads); indigenous sheep emitted 251.28 Gg CO_2eq (5.65 % of total emissions) annually. Sheep emissions were close to goats due to their higher emission intensity, which was 8 kg CH_4 head^{-1}year^{-1}.

4.5.2. Methane emission from manure

Manure management was the second principal CH_4 emission source in livestock. Manure-related CH_4 emissions annually amounted to 316.70 Gg CO_2 eq with an annual growth rate of 8.38%. As seen in figure 4.19, the annual CH_4 from manure strongly increased by 84.08%, from 223.60 (in 2004) to 410.64 Gg CO_2 eq (in 2020).

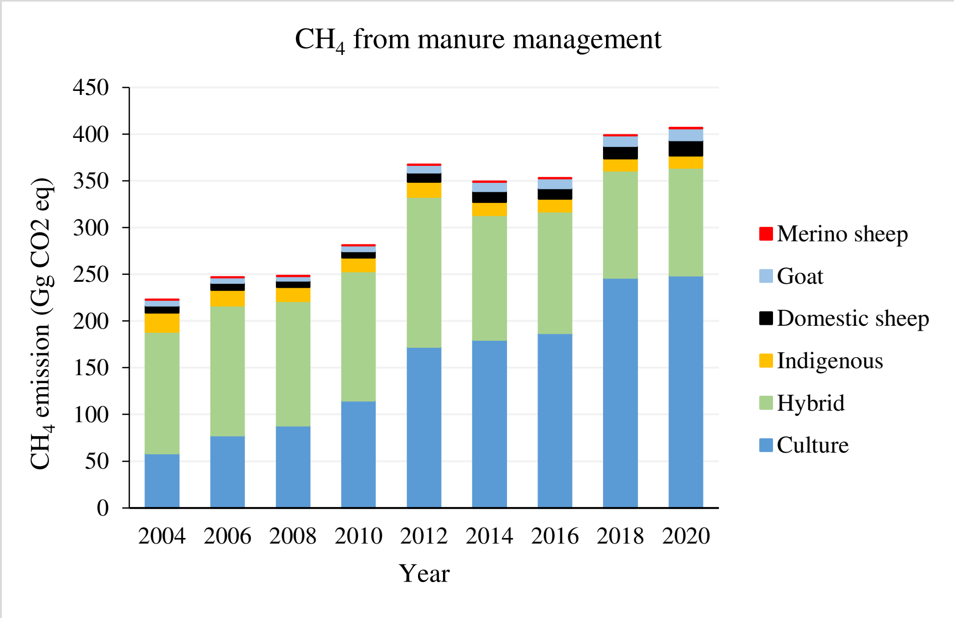


Figure 4. 21. Manure-related CH4 emission from ruminants

Culture, hybrid domestic cattle were responsible for 152.62, 132.75, 15.15 Gg CO_2eq of manure-CH_4 emissions. Domestic sheep and goats emitted 11.96 and 8.48 Gg CO_2eq, contributing to 3.72 and 2.64% of total emissions respectively. The lowest emission was calculated in Merino sheep, which released 0.28 Gg CO_2 eq, accounting for less than 0.1% of total emissions. Animal feeding operations are important sources of undesirable gaseous emissions that affect natural ecosystems and human health (NH_3) and contribute to emissions of non-CO_2 greenhouse gases (CH_4 and N_2O).

4.5.3. Nitrous oxide emissions

Nitrous oxide emissions from manure management vary between the types of the management system used and can also result in indirect emissions due to other forms of nitrogen loss from the systems. The calculation of the nitrogen loss from manure management systems showed that the total nitrous oxide emissions (direct and indirect N_2O), which was 778.06 Gg CO_2eq in 2004, increased to 1468.22 Gg CO_2eq in 2020 with an annual increase rate of 8.74% during the studied period (Figure 4.20).

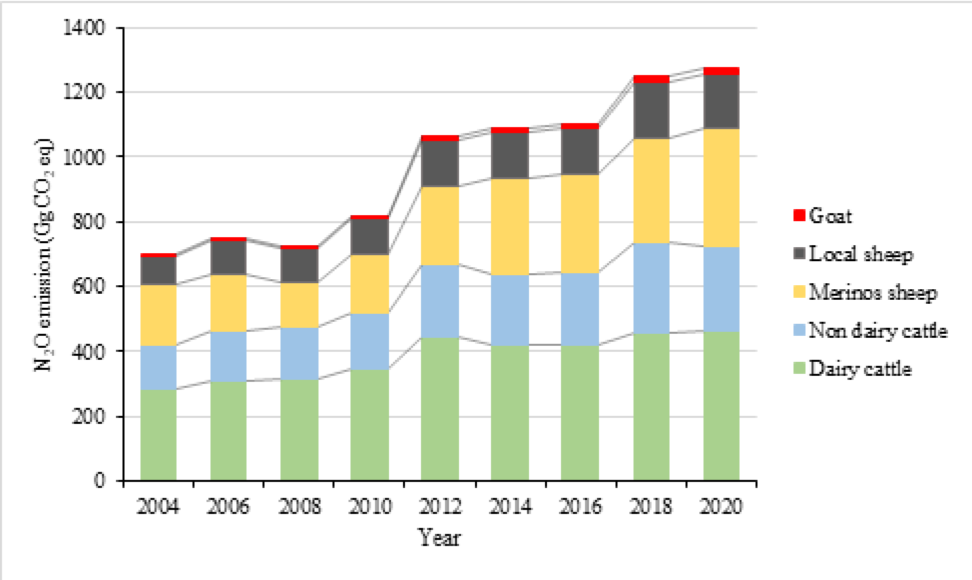


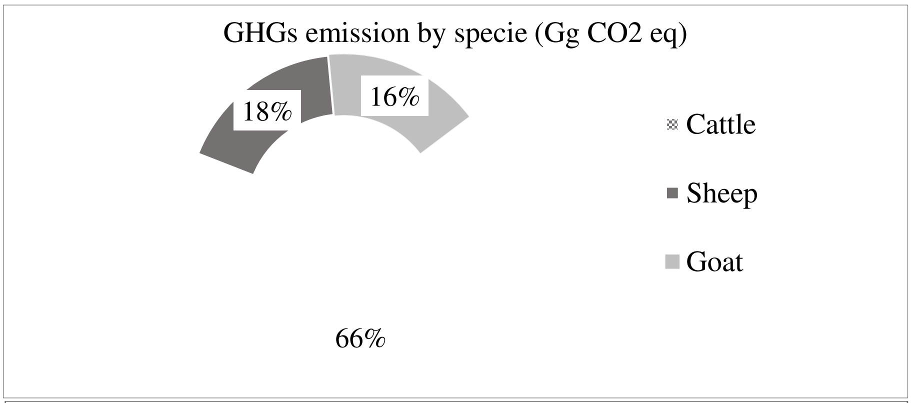
Figure 4.22. Yearly N_2O emission form ruminant reared from the study area in Turkey

The calculation of nitrous emissions showed that the direct and indirect N_2O was 1386.91 and 81.30 Gg CO_2eq in 2020, amounting to 94.46 and 5.54% respectively. Direct N_2O emissions from manure management can occur via combined nitrification (under aerobic conditions) and denitrification (an anaerobic process) of nitrogen contained in the manure. The emission of N_2O from manure during storage and treatment depends on the nitrogen and carbon content of manure, the duration of storage and the type of treatment (Turstat, 2020). In the current study, the direct N_2O emissions from dairy cattle (464.72 Gg CO_2eq) and non-dairy cattle (261.32 Gg CO_2eq,) accounted for 31.65 and 17.80% in 2020. In the same year, the emissions from Merino and local sheep were estimated at 363.23

and 168.52 Gg CO_2eq respectively, while goats emitted 19 Gg CO_2eq. N_2O is an intermediate product of both nitrification and denitrification processes which occur under oxygen-limited conditions during manure storage (Aguerre et al. 2012). The current results demonstrated that N_2O emissions in the study area contributed to 78.42% of GHG emissions from manure management CO_2eq. This emission rate is less than the one reported by TurkStat (2020), which represented 54% of the manure management category. According to the same source, in Turkey, manure-N_2O emissions were the second highest source of all agricultural N_2O emissions after agricultural soils. At the country level, N_2O emissions from manure management accounted for 16.7% of all N_2O emissions in the agriculture sector (Turstat, 2020).

4.5.3. Provincial greenhouse gases emission

In the study area, cattle were the greatest GHG emitters with 3104 Gg CO_2 eq representing 66.19% of total emissions in 2019. They were followed by sheep, which emitted 824 Gg CO_2eq, accounting for 17.58%. Regarding goat emission, it was evaluated at 760 Gg CO_2eq, (16.22%) (Figure 4.21). Concerning the emissions from the studied provinces, in 2019, the greater emitter provinces were Adana, Antalya, and Mersin, amounting to 17%, 16 and 16% respectively. For instance, in 2019, Adana, Antalya and Mersin emitted 541, 518, and 503 Gg CO_2eq of methane respectively. The lowest provincial emissions occurred in Osmaniye, which contributed 6% (Figure 4.21). The reason for this can be directly explained by the number of animals and the amount of manure produced by these animals. Indeed, the higher daily amount of manure (urine and feces) produced by cattle when compared to other animals reflected their great population in Adana, Antalya and Mersin (Table 4.22).



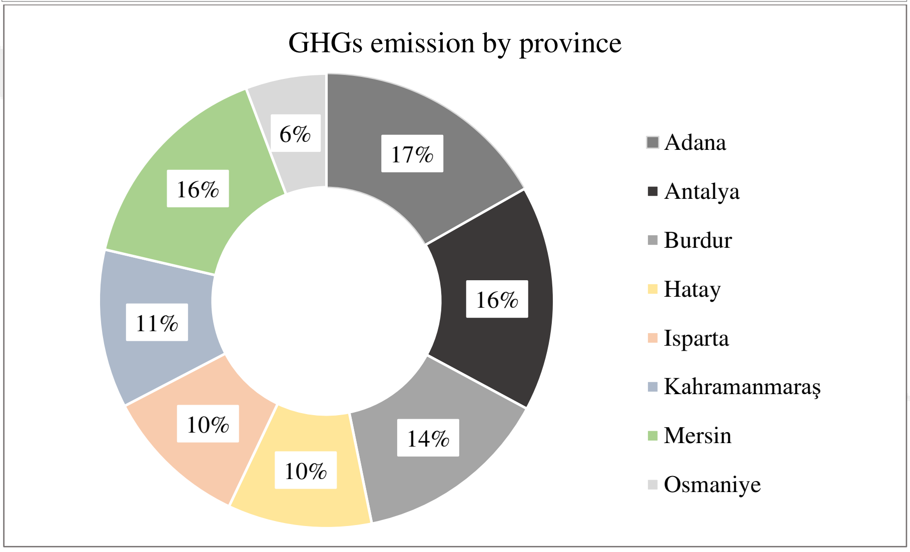


Figure 4.23. Distribution of total CH_4 emission by study location

4.6. Applicable measures and ways to mitigate CH_4 and N_2O emissions

Mitigation approaches have been a focus of research due to the consequences of increasing GHG emissions on climate change and the growing demand for meat products. It emerges that a reduction in greenhouse gas emissions from the livestock sector is possible thanks to the improvement of production practices. These mitigation measures mainly concern increasing animal productivity, improving the quality of animal feed, animal health and herd management, and manure management. The summary of potentials mitigation ways are given in the Table 4.12.

Table 4.12. Summary of potentials mitigation ways

Mitigation ways	Objective and constraint addressed	Mode of action
Increase animal productivity		
Control of reproductive diseases	• Improve health and reproductive performance of breeding animals (Brucellosis, cryptorchidism)	• Enhance animal productivity and reduced CH_4/kg live-weight
Controlled mating – defined breeding season	• Synchronize pasture and supplement availability with the breeding cycle to better manage herd nutrition, cow-calf health, closely monitor breeding and calving • Addresses the mismatch between forage offer and nutritional requirements of the herd	• Reducing wastage (e.g. involuntary culling, empty reproductive cycles) at the herd level and reducing CH_4/kg live-weight
Implementation of a genetic improvement program	• Increase production to meet demand while reducing the number of animals • Addresses the overhead in farms and the low genetic value of local breeds.	• Select the best breeders and animals well performing animal. • Set a database centre at the farm and national level where animal performance (live weight, dairy production etc.) can be recorded and kept.
Improvement of animal feeding		
Strategic supplementation of growing and producing animals	• Accelerate growth and shorten growing and finishing periods of young fattened male. • Accelerate growth and reduce the age at the first mating for replacement females • Increase the dairy production of lactating females • Addresses seasonal energy and protein deficiency	• Optimized supply of concentrate feed to each category of animals (growing, finishing, pregnant and lactating)

Implementation and maintenance of fodder crops	• Ensure that animals have access to high-quality fodder at all times of the year. • Resolve seasonal forage unavailability	• Training of breeders on the installation of artificial rangelands to ensure the continuous feeding of livestock with high quality forage. • Recycling and application of good practice of spreading nitrogen from livestock effluents (doses, periods etc.) contribute to the reduction of environmental losses and the purchase of mineral fertilizers • Growing legumes to reduce the fertilization of forage crops but also to replace part of the nitrogen inputs for feeding the herd • Implantation of hedges and meadows contributes to carbon sequestration and offsetting emissions.
Manure management		
Manure management	• Produce renewable energy to reduce emissions from different levels: building, storage and spreading	• Develop small bio-digesters to promote anaerobic digestion and produce renewable energy (biogas) usable by households. • The use of slurry of biodigesters and excretion for the production of compost.

Adapted from FAO and New Zealand Agricultural Greenhouse Gas Research Centre (2017) and Dollé et al. (2015)

5. CONCLUSION

We reported through this study, the results of the calculation of the emission factors (EF) and GHGs of ruminants for a specific region of humid and dry lands. In this study, two main gases (CH_4 and N_2O) and two sources of emissions (enteric fermentation and manure management) were taken into account. Enteric EF calculated for cattle in Benin Republic (56.85 kg CH_4 animal^{-1} year^{-1}) was higher than the default IPCC value of (31 to 49 kg CH_4 animal^{-1} year^{-1}), while it was 2.92 and 3.76 CH_4 animal^{-1} year^{-1} for goat and sheep respectively. In the Eastern Mediterranean area of Turkey, the enteric EF for dairy cattle, local, non-dairy cattle, Merino sheep, local sheep and goats was 82.1; 48; 6.5; 5 and 5 CH_4 head^{-1} year^{-1} , respectively. A large variation in emission factors among countries and IPCC default values The IPCC default values for Africa was observed. This is primarily due to differences in animal breeds, climate conditions, production systems, feed types and nutrient use efficiency by animals.

The results reflected the increase in greenhouse gas emissions in Benin and Eastern Mediterranean region of Turkey over recent decades. These results showed that the increasing GHGs was parallels that of the constantly animal population. In addition, we have demonstrated cattle especially beef is the major source of emissions from the livestock sector in Benin and the Eastern Mediterranean area of Turkey, contributing approximately 92.11% and 66.20% of the total livestock GHG emissions respectively. These high emissions from cattle were mainly attributed to their high emission factors.

The ruminant subsector is responsible for 3843.97 Gg CO_2eq of CH_4 and 943.93 Gg CO_2eq of N_2O emissions in the Benin Republic. Methane emissions were mainly emitted from enteric fermentation (97.30%) against (2.70%) for manure management. Direct and indirect N_2O were estimated at 754.11 and 189.82 Gg CO_2eq respectively. In the study area in Turkey, the GHG emissions were 3538.67 Gg CO_2eq. With 60.86% of emission, enteric CH_4 dominate the GHG profile. N_2O emission (1468.22 Gg CO_2eq) was the second largest released gas. It was followed by CH4 (406.58 Gg CO_2eq.) from manure management. To cope with the increasing emission of GHG from the ruminant production system, we proposed low-cost mitigation actions. These actions focused on the improvement of animal productivity and management systems, feeding of animals with high quality feed, reduction of lifetime of individual among the herd. Since production systems and rearing conditions change from a region to another, region-specific mitigation measures need to be developed through quantitative research.

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BIOGRAPHY

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ANNEXES

Table A.1. Coefficients for calculating Net Energy for activity (NEa)

Feeding situation	Criteria	Ca
For Cattle (unit for C_a is dimensionless)		
Extensive grazing	Grazing in open range land or hilly grassland and significant expenditure of energy to acquire feed (open grazing in pastoral area and communal grazing found in mixed crop livestock system).	0.36
Stall feeding (dairy and feedlot)	Confinement of animals in a small area as a result they expend very little or no energy to acquire feed (Example; dairy cattle in urban and peri-urban commercial dairy production and feedlot animals).	0.00
Pasture based	Animals are confined in areas with sufficient forage requiring modest energy expense to acquire feed.	0.17
Sheep (unit for C_a = MJ d^{-1} kg^{-1})		
Housed ewes	Animals are confined due to pregnancy in final trimester (50 days).	0.0090
Grazing flat pasture	Animals walk up to 1000 meters per day and expend very little energy to acquire feed.	0.0107
Grazing hilly pasture	Animals walk up to 5,000 meters per day and expend significant energy to acquire feed.	0.0240
Housed fattening lambs	Animals are housed for fattening.	0.0067
IPCC 2006.		

Table A.2. Coefficients for Calculating Net Energy for Maintenance (NEm)

Animal category	Cfi (MJ d^{-1} kg^{-1})	Comments
Cattle/Buffalo (non-lactating cows)	0.322	
Cattle/Buffalo (lactating cows)	0.386	This value is 20% higher for maintenance during lactation
Cattle/Buffalo (bulls)	0.370	This value is 15% higher for maintenance of intact males
Sheep (lamb to 1 year)	0.236	This value can be increased by 15% for intact males
Sheep (older than 1 year)	0.217	This value can be increased by 15% for intact males.
Source: IPCC 2006.		

Table A.3. Constants for Use in calculating Ne_g for Sheep

Animal species/category	a (MJ kg-1)	b (MJ kg-2)
Intact males	2.5	0.35
Castrates	4.4	0.32
Females	2.1	0.45
Source: IPCC 2006.		

Table A.4. Constants for use in calculating NE_p in Eq 9.

Animal category	Cattle	Sheep		
		Single birth	Double birth	Triple birth or more
$C_{pregnancy}$	0.10	0.077	0.126	0.150

Source: IPCC 2006

Table A.6. Manure management CH_4 emission factors by temperature for sheep and goats[a] (kg CH_4 head^{-1} yr^{-1})

Livestock	CH_4 emission factor by average annual temperature (°C)		
	Cool (<15˚C)	Temperate (15 to 25˚C)	Warm (>25˚C)
Sheep			
Developed countries	0.19	0.28	0.37
Developing countries	0.10	0.15	0.20
Goats			
Developed countries	0.13	0.20	0.26
Developing countries	0.11	0.17	0.22

The uncertainty in these emission factors is ±30 %.

Sources: Emission factors developed from: feed intake values and feed digestibilities used to develop the enteric fermentation emission factors (see Annex 10A.1); Except for poultry in developed countries, methane conversion factor (MCF), and maximum methane producing capacity (B_o) values reported in Woodbury and Hashimoto (1993). Poultry for developed countries was subdivided into five categories. Layers (dry) represent layers in a "without bedding" waste management system; layers (wet) represent layers in an anaerobic lagoon waste management system. For layers, volatile solids (VS) are values reported in USDA (1996); typical animal mass values are from ASAE (1999); and B_o values for Layers are values reported by Hill (1982). For broilers and turkeys, B_o values are from Hill (1984); typical animal mass values are from ASAE (1999); and VS values are those reported in USDA (1996). B_o values for ducks were transferred from broilers and turkeys; typical animal mass values are from MWPS-18; and VS values are from USDA, AWMFH. Typical mass of sheep and goats, and VS and B_o values of goats and horses for developed countries updated according to the analysis of GHG inventories of Annex I countries. All manure, with the exception of Layers (wet), is assumed to be managed in dry systems, which is consistent with the manure management system usage reported in Woodbury and Hashimoto (1993).

[a] When selecting a default emission factor, be sure to consult the supporting tables in Annex 10A.2 for the distribution of manure management systems and animal waste characteristics used to estimate emissions. Select an emission factor for a region that most closely matches your own in these characteristics.

[b] Layer operations that manage dry manure.

[c] Layer operations that manage manure as a liquid, such as stored in an anaerobic lagoon.

TABLE A.5
MANURE MANAGEMENT METHANE EMISSION FACTORS BY TEMPERATURE FOR CATTLE, SWINE, AND BUFFALO[a] (KG CH_4 HEAD^{-1} YR^{-1})

Regional characteristics	Species	CH₄ emission factors by average annual temperature (°C)[b]																		
		Cool					Temperate											Warm		
		≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28
Africa: Most livestock manure is managed as a solid on pastures and ranges. A smaller, but significant fraction is burned as fuel.	Dairy Cows	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Other Cattle	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Asia: About half of cattle manure is used for fuel with the remainder managed in dry systems.	Dairy Cows	9	10	10	11	12	13	14	15	16	17	18	20	21	23	24	26	28	31	31
	Other Cattle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Source: See IPCC guide (2006) Annex 10A.2, Tables 10A-4 to 10A-8 for derivation of these emission factors, The uncertainty in these emission factors is ±30 %.

[a] When selecting a default emission factor, be sure to consult the supporting tables in Annex 10A.2 for the distribution of manure management systems and animal waste characteristics used to estimate emissions. Select an emission factor for a region that most closely matches your own in these characteristics.

[b] All temperatures are not necessarily represented within every region. For example, there are no significant warm areas in Eastern or Western Europe. Similarly, there are no significant cool areas in Africa and the Middle East.
Note: Significant buffalo populations do not exist in North America, Oceania, or Africa.

Table A.6. Volatile Solid calculated based on gross energy intake estimates

Sub-categories	Borgou	Lagune	Somba	Gudali	White Fulani	Azawak
FC (6-12 m)	1.75	0.92	1.01	2.85	2.00	2.16
MCA (6-12 m)	1.96	1.16	1.21	3.11	2.35	2.45
Heifer 1-2 y	2.24	1.69	1.32	2.95	3.17	3.40
Heifer 2-3 y	2.67	1.44	1.78	3.42	3.89	3.21
Heifer 3-4 y	3.71	2.34	2.38	4.06	4.63	4.64
Bullock 1-2 y	2.43	1.81	1.47	2.87	3.85	3.93
Bullock 2-3 y	2.95	1.71	1.98	3.92	4.36	4.46
Young bull 3-4 Y	3.51	2.23	1.94	4.63	4.79	4.72
Oxen	4.11	0.00	0.00	0.00	0.00	0.00
MC > 4y	3.98	2.40	2.67	4.90	4.59	5.00
Mature bull > 4 Y	3.68	2.53	2.63	5.42	4.65	4.55
Average	3.00	1.66	1.67	3.47	3.48	3.50

FC: Female calve; MCA: Male calve; MC : Mature cow; MB: Mature bull;