Assessment of Greenhouse Gases Emissions from Dairy Cattle Production inThailand

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ภาคการเกษตรนับเป็นภาคส่วนที่มีบทบาทสำคัญในการขับเคลื่อนเศรษฐกิจของประเทศ โดยการปล่อยก๊าซเรือนกระจกจากการผลิตปศุสัตว์ระดับโลกมีค่าประมาณร้อยละ 18 เมื่อเทียบกับภาคส่วนอื่น ถึงแม้ข้อมูลดังกล่าวจะเป็นข้อมูลที่สำคัญ หากแต่ยังขาดการวิจัยเกี่ยวกับการประเมินก๊าซเรือนกระจกจากกิจกรรมที่เกี่ยวข้องในภาค ปศุสัตว์ของประเทศไทย การวิจัยครั้งนี้มีวัตถุประสงค์เพื่อประเมินการปล่อยก๊าซเรือนกระจกจากการผลิตโคนมในจังหวัดสระบุรีและราชบุรี อาศัยการประเมินตามแนวทางและหลักการระดับสากลของ The 2019 Refinement to the 2006 IPCC Guidelines for national greenhouse gas inventories โดยคัดเลือกฟาร์มโคนมทั้งสิ้น 20 แห่ง (n=20) ประกอบด้วย ฟาร์มขนาดเล็ก (n=10) และฟาร์มขนาดกลาง (n=10) เป็นกรณีศึกษาของงานวิจัย ผลการศึกษาพบว่าปริมาณการปล่อยก๊าซเรือนกระจกรวมจากฟาร์มโคนม 20 แห่งมีค่าเท่ากับ 138.83 กิโลกรัมคาร์บอนไดออกไซด์เทียบเท่า (kgCO_2eq) ทั้งนี้ การปล่อยก๊าซมีเทนทั้งจากกระบวนการย่อยอาหารของสัตว์เคี้ยวเอื้อง (Enteric Fermentation) และการจัดการมูลสัตว์พบในสัดส่วนร้อยละ 98 ในขณะที่การปล่อยก๊าซไนตรัสออกไซด์ทั้งทางตรงและทางอ้อมจากการจัดการมูลสัตว์พบเพียงร้อยละ 1-2 นอกจากนี้ ฟาร์มโคนมกรณีศึกษาขนาดเล็กปล่อยก๊าซเรือนกระจกอยู่ในช่วง 3.82 ถึง 16.01 kgCO_2eq (หรือคิดเป็นความเข้มข้นของก๊าซเรือนกระจกเท่ากับ 0.19 – 3.20 กิโลกรัมคาร์บอนไดออกไซด์เทียบเท่าต่อโคนมหนึ่งตัว) ในขณะที่ฟาร์มโคนมกรณีศึกษาขนาดกลางปล่อยก๊าซเรือนกระจกอยู่ในช่วง 2.74 ถึง 4.22 kgCO_2eq (หรือคิดเป็นความเข้มข้นของก๊าซเรือนกระจกเท่ากับ 0.09 – 0.19 กิโลกรัมคาร์บอนไดออกไซด์เทียบเท่าต่อโคนมหนึ่งตัว) การปล่อยก๊าซเรือนกระจกในฟาร์มกรณีศึกษาในจังหวัดราชบุรีมีค่า 3.25 ถึง 16.01 kgCO_2eq ในขณะที่ ฟาร์มกรณีศึกษาในจังหวัดสระบุรีปล่อยก๊าซเรือนกระจกประมาณ 2.74 ถึง 4.07 หรือคิดเป็นความเข้มข้นของก๊าซเรือนกระจกเท่ากับ 0.15 ถึง 3.20 และ 0.09 ถึง 0.21 กิโลกรัมคาร์บอนไดออกไซด์เทียบเท่าต่อโคนมหนึ่งตัว ตามลำดับ เมื่อพิจารณาในส่วนของแหล่งปล่อยพบว่า ฟาร์มโคนมมีการปล่อยก๊าซมีเทนจากกระบวนการย่อยอาหารของสัตว์สูงกว่าการจัดการของเ

สาขาวิชา	การจัดการสารอันตรายและสิ่งแวดล้อม	ลายมือชื่อนิสิต ....
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Thailand's agriculture sector plays a vital role in driving economic growth. Globally, livestock production is estimated to contribute about 18% of greenhouse gas (GHG) emissions. Despite its importance, there is a relative lack of research on GHGs assessment in the livestock sector in Thailand. The aim of this research was to estimate GHGs emissions from dairy cattle production in Saraburi and Ratchaburi provinces of Thailand. The 2019 Refinement to the 2006 IPCC guidelines for national greenhouse gas inventories was applied in this research. Twenty dairy farms (n=20) including both small farms (n=10) and medium farms (n=10) were selected as the case studies. The results revealed that total GHGs emissions from 20 farms were 138.83 kg carbon dioxide equivalent (kg CO_2eq) from all activities. Methane (CH_4) emissions from both enteric fermentation and manure management were accounted for 98%. Nitrous oxide (N_2O) emissions from manure management (both direct and indirect) and from manure applied to soil were only 1%. Small size of farms emitted GHG in the range of 3.82 to16.01 kg CO_2eq (0.19 – 3.20 kgCO_2 eq/head of cattle of GHG emission intensity (ET). Whereas, medium farms contributed GHG range from 2.74 and 4.22 kg CO_2eq (0.09-0.19 kgCO_2 eq/head of cattle of ET) from all activities. Farms in Ratchaburi emitted the emission in the range of 3.25-16.01 kg CO_2eq per cow but farms in Saraburi contributed to total GHGs emission in the range of 2.74 - 4.07 kg CO_2eq. Besides, ET range in Ratchaburi was 0.15-3.20 kg CO_2eq and ET range in Saraburi was 0.09-0.21 kg CO_2eq. By considering emissions activities, CH_4 emission from enteric fermentation is much higher than those from manure management. By considering waste management in a dairy farm, as the manure solid storage system emitted higher emissions than the liquid/slurry system, it is necessary for farm managers and related stakeholders to properly manage the herds and farms to lower methane emissions, especially from manure management practices (i.e., installation of anaerobic digestion, composting, and manure drying practices, etc.). Besides, it is necessary to consider other factors that reduce emissions such as improving feeding quality and keeping good animal husbandry practices.

Field of Study:	Hazardous Substance and Environmental Management	Student's Signature ....
Academic Year:	2022	Advisor's Signature ....
		Co-advisor's Signature ....

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Chapter 1

Introduction

1.1 Problem statement of research

The livestock sector plays a crucial role in the contribution of greenhouse gas (GHGs) emissions (carbon dioxide CO_2, methane CH_4, nitrous oxide N_2O). It is well-known that anthropogenic climate change is the result of the impacts of livestock production. Due to the rapid population around the world, food demand is also higher especially high nutrient products such as milk and meat consumption would be twice in 2050 by comparing in 2000 (FAO,2006). The food supply is increasing to reach one of the sustainable development goals (SDG) called zero hunger, and natural resource conserving is becoming a serious issue such as energy resources, water and GHGs emissions reduction. The agriculture sector is giving benefits to people; on the other hand, it also produces some negative effects on the environment such as GHGs emissions (Williams et al., 2016). The agricultural sector contributes to climate change by emitting GHGs from livestock production particularly in ruminant production; for example, methane (CH_4) emission from enteric fermentation and manure management and nitrous oxide (N_2O) emission from manure management (Elio Roman et al., 2021). According to the environmental protection agency (EPA), only the agricultural sector is about 10–12% of total global anthropogenic greenhouse gas (GHG) emissions (UN-EPA, 2012); in global emissions, 13% of carbon dioxide (CO_2), 44% of methane (CH_4), and 82% of nitrous oxide (N_2O) emissions are produced by anthropogenic activities (IPCC, 2019). In 2006, the FAO report, "Livestock's long show: environmental issues and options", finds that livestock production is contributing to the world environmental problems as a major issue with 18% of anthropogenic GHG emissions.

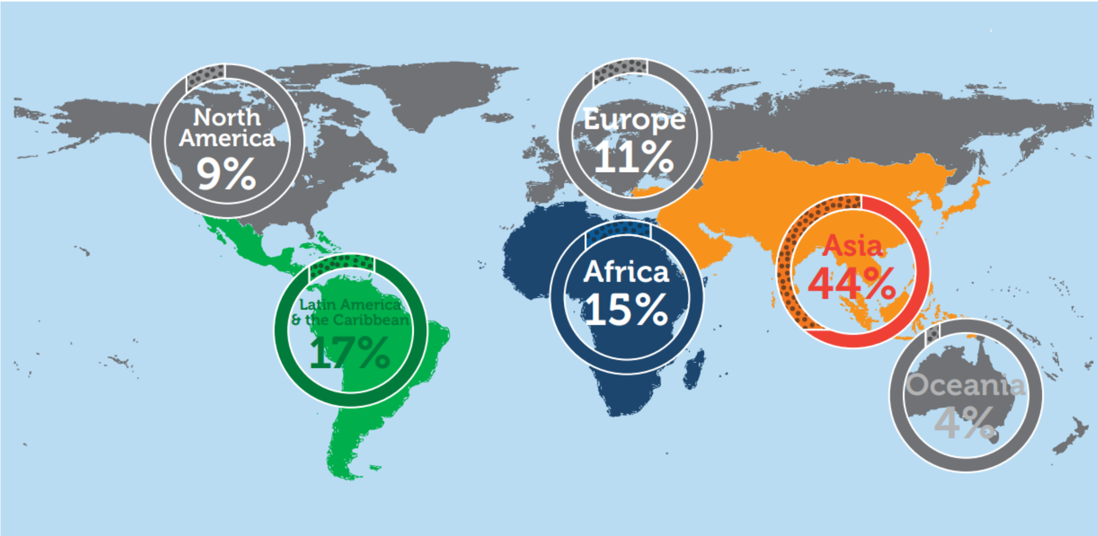

Figure 1 Emissions from agriculture by continent (FAOSTAT, 2016)

Methane is a by-product through burping when microbial fermentation takes place in the rumen or fore-stomach of ruminant which have four-chambered stomach including the rumen, the abomasum, the omasum, the reticulum such as cattle, buffalos. There are many factors affecting methane production in ruminant animals, such as the chemical formation of the carbohydrate, retention time of feed in the rumen, the rate of methanogenesis, manure management, using feed additives to enhance production efficiency (Beauchemin et al., 2009). Although there are various approaches to reduce CH_4 emissions from livestock, feed manipulation is the particular true way of strategy (Bhatta et. al, 2017). Currently, many techniques are widely being used for the measurement of CH_4 from ruminants globally. Moreover, researchers are focusing on feeding strategies as a vital area of research to develop and modify the technologies (Hammond et. al, 2016).

It has been concerned about dairy production in Thailand for 60 years. Due to this, the government determined to a higher support relative to cattle production. National Adaptation Plan (NAP) has been developed to improve climate resilience in 6 significance sectors aiming to increase water security and prevent loss by developing mechanisms and approaches for integrated water resources management and for managing climate risks in water resources (Thailand's updated nationally determined contribution, 2020). Despite the fact that Thailand acquired much support from many organizations around the world for climate change sector improvement, there are still many limitations and gaps such as the factor value in the agricultural sector, providing awareness programs related to climate change (Thailand's Third National Communication, 2018). Furthermore, according to global climate risk index (2019), Thailand is the 13th country in the "extreme risk" category that is vulnerable to future climate change impacts over the next thirty years since it is a developing country and highly vulnerable to the impacts of climate change.

Besides, the Paris Agreement sets a global target which is limiting warm to below 2˚ C and pursuing efforts to limit it to 1.5˚ C (Climate change and the global dairy cattle sector, FAO, 2019). This agreement includes 92 countries including Thailand to achieve the goal by their livestock sector in their nationally determined commitments (Wikes, A, 2017); hence, Thailand focuses on reducing emissions 20-25% by 2030, and will work to reduce emissions a further 20–25 % in 2030 in terms of business as usual (BAU) level (Second Biennial update report of Thailand , 2018).

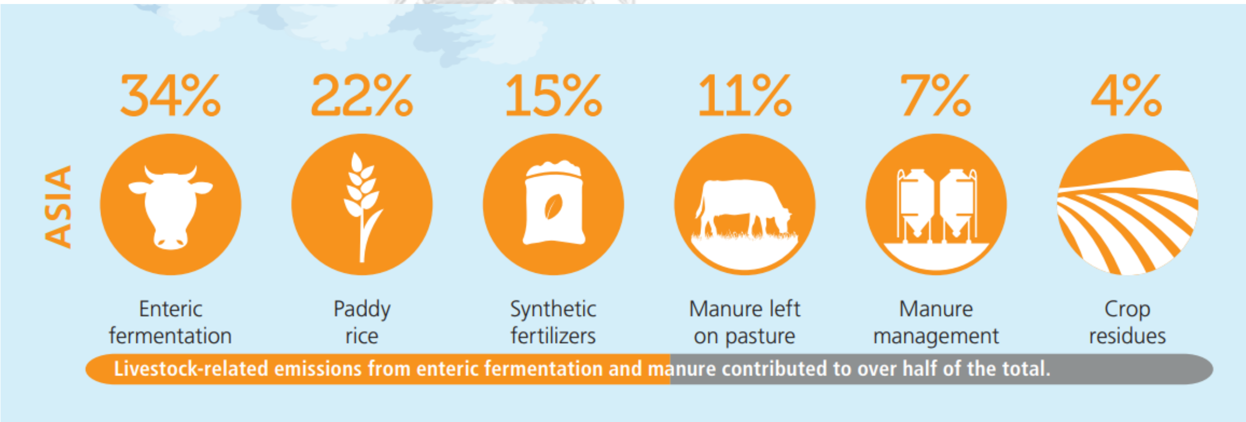

Figure 2 Emissions from agricultural sector (FAO,2016)

Globally, urbanization and increased population increase the meat, milk demand; therefore, the environmental impacts of Livestock are becoming huge and it keeps growing and fast changing. Even though there are many researchers and organization that have been investigating the strategies to reduce the impact of livestock sector on the environment, there are still limitations in the methods and data of environmental sustainability in dairy industry.

Feed intake and other diet factors such as quantity and quality of feed, animal body weight affect methane emissions; however, it changes according to animal species and individual of same species. Hence, it is required that evaluating enteric methane emission in any certain country in a detailed description of the livestock population combined with daily feed consumption and the feed's methane conversion rate (IPCC 2006 guidelines). Since many countries do not have such detailed information, an approach based on standard emission factors is generally used in emission reporting (FAO,2006). In Thailand, waste management depends on farm size and types of livestock. The Department of Livestock Development (DLD) has been trying to lessen community issues due to the issues such as smell form livestock waste, and livestock waste management system have been developed by cattle farms in Thailand, particularly medium to large farms (Eastern Research Group, Inc, 2009). Besides, more researches should be accomplished to find better strategies for GHGs emissions reduction in commercial settings (Byeng R. Min. et al., 2020).

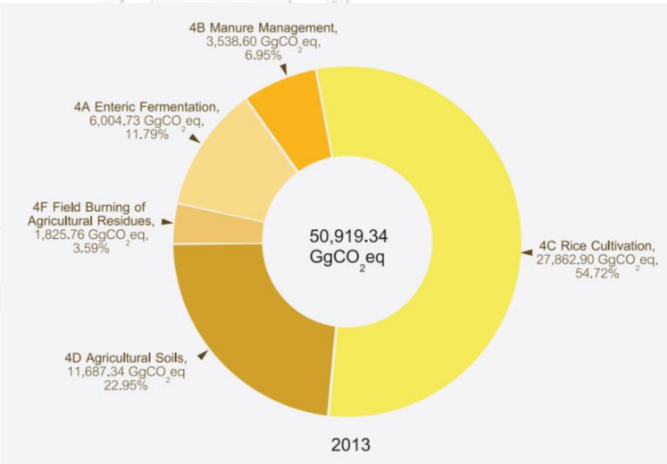

Figure 3 GHGs emissions in the agriculture sector

(Ministry of Natural Resources and Environment, 2013)

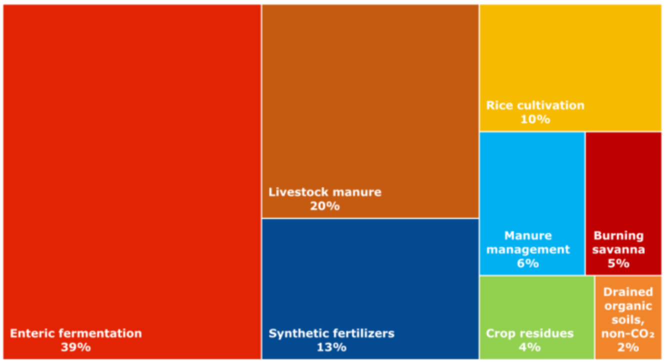

Figure 4 Contribution of livestock activities to total GHGS emissions from agriculture in 2018 (FAOSTAT, 2020)

1.2 Scope of research

Since Thailand is an agriculture-based country, there is no doubt that its livestock production is huge and there are livestock farms around the country. In this study, major emissions from forty dairy farms (twenty small farms and twenty medium farms) in Thailand were investigated to explore how dairy farm management affect GHG emissions. Mainly, this study focused on the following GHG emissions: CH_4 emission from enteric fermentation and manure management, and N_2O emission from manure management in each of the study areas in Thailand.

There are general sources of emissions in dairy production which are mentioned as follows-

1) Producing of grass, crops; for example- providing pastures
2) Enteric Fermentation
3) Manure Management
4) Transportation of milk to the processing area
5) Making by-products such as butter, yogurt, milk powder
6) Packaging
7) Transportation of products to the retail area

1.3 Research objectives

The objectives of this study are as follows.

(1) To estimate total GHGs emissions and identify hotspots of GHGs emissions from the dairy sector in Thailand.

(2) To investigate how farm size affect GHGs emissions from the dairy sector in Thailand.

(3) To propose potential mitigation measures to mitigate GHGs emissions from the livestock sector.

1.4 Hypothesis

GHGs particularly methane (CH_4) and nitrous oxide (N_2O) are emitted mainly from enteric fermentation and manure management in ruminant animals' production. It is assumed that the bigger the farms, the more the GHGs emissions, and the different types of manure management influences the GHGs emissions of dairy cattle production.

1.5 Research questions

(1) What are the hotspots of GHGs emissions from the dairy sector in Thailand?

(2) How does the farm's size affect GHG emissions in dairy cattle production?

(3) How does the manure management in dairy farms impact on GHGs emissions?

(4) What are potential mitigation measures to reduce GHGs emissions in the dairy sector in Thailand?

Chapter 2
Literature Review

2.1 Overview of GHGs emissions from the livestock production

Methane contributes to global warming by about 52 percent in both low-middle income countries and high-income countries while N_2O contributes to around 35 % in developed and developing countries (FAO, 2013). Many studies have mentioned that livestock production has a huge impact on climate change by emitting GHGs (de Vries and de Boer, 2010; Milani et al., 2011).

Enteric fermentation emits CH_4 and manure emit both CH_4 and N_2O in livestock production. Due to the high CH_4 emission from digestive system in ruminants and huge population, ruminants are an significant source of CH_4 in most of the countries (IPCC, 2019). CH_4 which has 25 times more global warming potential than CO_2 is the second most abundant GHGs among the various GHGs (Malyan et al., 2016). The third most abundant GHGs is N_2O (Myhre et al., 2013). Even though N_2O has lower concentration than CH_4 and CO_2 in the atmosphere, it effects on global warming significantly because of its life span is 120 years and it is 265 times higher radiative potential than CO_2 (IPCC,2014 and US-EPA,2021). Moreover, it involves in the ozone depletion significantly (Myhre et al., 2013)

Ruminant animals emit CH_4 per unit of feed consumed, and so, they are the principle origin of emission compared with monogastric animals (US-EPA). The amount of the consumption, nature and condition of feed, environmental temperature, animal size affect enteric methane production (FAO). Legumes, grasses, or mixtures of the two may be fed to dairy cattle. Most of the farmers use legume hay mainly because it contains huge quantities of high-quality proteins and calcium as well as large quantities of vitamins A and D. Since silage provides moist feed during the cold season when cattle are inhibited to dry roughage, enhance the usage of the whole plant without losing much in inclement weather, and can be used as a source of replacement feed during the dry season, it is widely used widely in cattle raising. The principal silage crop is corn, even though satisfactory silage can be made by sorghum. Silage also can be made from alfalfa, various clovers, soybeans, pasture mixtures, and other small grain (Coletti 1963).

Aside from the detrimental effects on climate crisis, CH_4 is also a nutritional loss of energy and CH_4 is emitted by about 10% of ingested energy (Johnson, D.E. et.al 1996). Manure is the main source of GHGs emissions and manure dropped on plains and grasslands is the secondly origin of GHG emissions which is accountable for 7% of farming emissions of CH_4 and N_2O globally (Aguirre-Villegas and Larson, 2017). There are the three major factors which are the manure storage system, the climate, and the composition of manure affecting the quantity of CH_4 emissions (Opio et al., 2013). When feces and urine are stored in fermentation conditions, most of CH_4 emissions can occur, and manure can generate acceptable quantity of CH_4 emissions in tropical regions along the plain area (Montes et al., 2013; Cai et al., 2017).

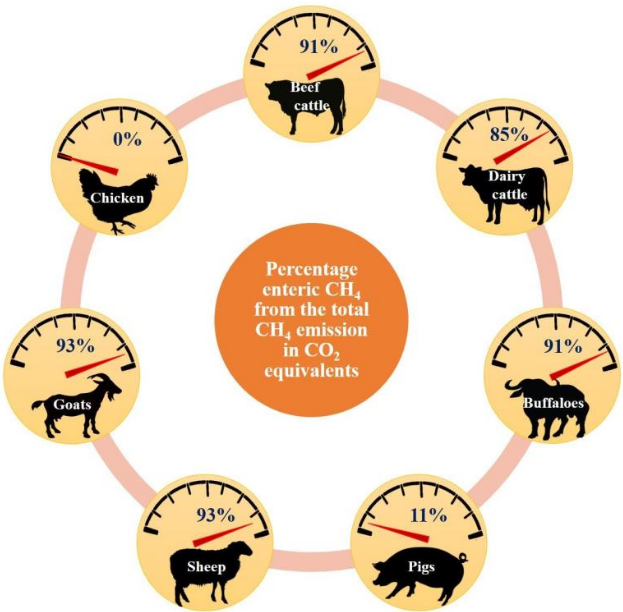

Figure 5 The proportion of enteric methane in the total methane emissions arising from different species (FAO, 2013)

(1) Enteric Fermentation

CH_4 is naturally emitted by the process of the fermentation, where bacteria breaks down organic matter hydrogen (H_2), CO_2 and CH_4 in the rumen, of ingested feed by ruminants. Ruminant animals such as cattle, buffalos have four-chambered stomach which are the rumen, the abomasum, the omasum, the reticulum (Hook, S.E. et. al 2010). Microorganisms in the paunch such as germs, fungi, protozoa brake down the dietary polysaccharides existing in the feedstuffs into simple sugars by their enzymatic activity and finally yield volatile fatty acids (VFA), primarily acetate, propionate, and butyrate (Kumari et.al, 2020). As the fermentation is thermodynamically favorable to microbes, most of the methanogenic bacteria in the large stomach lessen CO_2 by using H_2 ions for CH_4 production (Moss et.al,2000).CH_4 is emitted mainly through via midgut (enteric fermentation) and hindgut fermentation by ruminant animals. Only enteric fermentation produces about 90% of the entire CH_4 production from the ruminants. The microorganisms ferment feedstuffs used up by ruminants through the process of enteric fermentation (Matthews et.al, 2019). The animals get the nutrients from the products that produced from enteric fermentation of feedstuffs to survive (Kumari et.al, 2020).

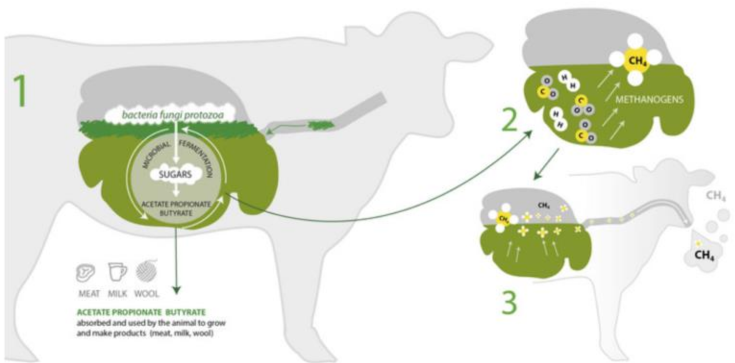

Figure 6 Methane emission from enteric fermentation (FAO, 2017)

(2) Manure Management

When the manure is not properly handled or managed, there are environmental impacts such as GHGs emissions in livestock production, and CH_4 and N_2O are the main emissions of improper manure management in the farms (R.K. Hubbard and R.R. Lowrance ,1998). There are many ways of manure storage system, including uncovered anaerobic lagoon, liquid/slurry, pit storage, solid storage, dry lot, daily spread, anaerobic digestion-biogas, burned for fuel (IPCC, 2019). To have a proper dairy cattle manure management system, cooperating dairy herd size, land availability, geography, weather, types of soil, and fiscal incomes are included in this system. (R.K. Hubbard and R.R. Lowrance ,1998). Furthermore, the waste managing systems in dairy farms significantly influence air emissions of NH_3 which occur after being applied to field, after that the manure managing systems such as parted liquid and solids, straw-covered, raw, then anaerobic digestion. Manure covered by straw has the highest emissions while the emissions decrease with untreated manure and other manure management systems such as separation, aeration (Amon et al., 2006). During the process of manure storing and processing, manure consists of two chemical components that may be changed into CH_4 and Nitrogen (N) which aims to the N_2O emissions (Tracking Climate Change through Livestock, 2013). When manure is stored in tanks or deep lagoons, methane emissions occur. Nitrogen is out in to air by the form of ammonia (NH_3) that transforms into N_2O later throughout the storage and processing of manure, which is called indirect emissions (Tracking Climate Change through Livestock, 2013). The N and carbon amount of the manure influences on the emissions of N_2O during storing (Amon et al.,2006).

The methane emission mainly depends on the quantity of manure production that relies on how much the animal produce waste per animal and the portion of the anaerobic manure decomposition that relies on the manure management. In addition, the amount of CH_4 production significantly depends on the temperature and the retention time of the storage unit (IPCC,2019). The quantity of CH_4 emission from waste depends on the quantity of C, H_2, and O_2 in the waste, manure storing system, food, and bedding main suppliers to total CH_4 production (Place and Mitloehner, 2010).

The Hindgut absorbs 90% of CH_4 and eventually CH_4 is emitted by the ruminants or released with the manure (11%) (Murray et al., 2019). Long term manure storage emits more CH_4 than field application (Amon et al., 2006).

Furthermore, dairy manure has a negative possible impact on the environment when the animal cannot retain nitrogen or secret in the milk which will be excreted in the waste (manure) of the ruminants. (Hristov et al., 2019). N_2 from waste can also cause GHG production by formatting and volatilizing of N_2O. Principally, N_2O is emitted throughout partial microbial denitrification process in which N gas is changed from nitrate for N_2O formation (Place and Mitloehner, 2010). Nitrification produces nitrous oxide in soils. During this process, ammonium oxidizes into nitrate by aerobic microbial oxidation. Then the denitrification process reduces nitrate to nitrogen gas (N_2) by anaerobic microbial reduction. When anthropogenic N inputs or N mineralization occur, N_2O can be emitted by two pathways that are direct and indirect :(i) after ammonia (NH_3) volatilization and nitrogen oxides (NO_x) from managed soils and (ii) following leaching and runoff of N, mainly as NO_3^-, from soils management (IPCC, 2019).

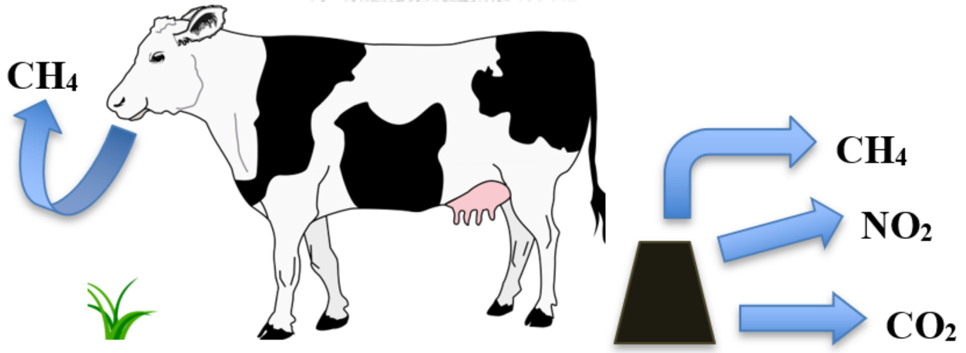

Figure 7 GHGs emissions from manure (Reducing GHGs emissions from cattle production, 2019)

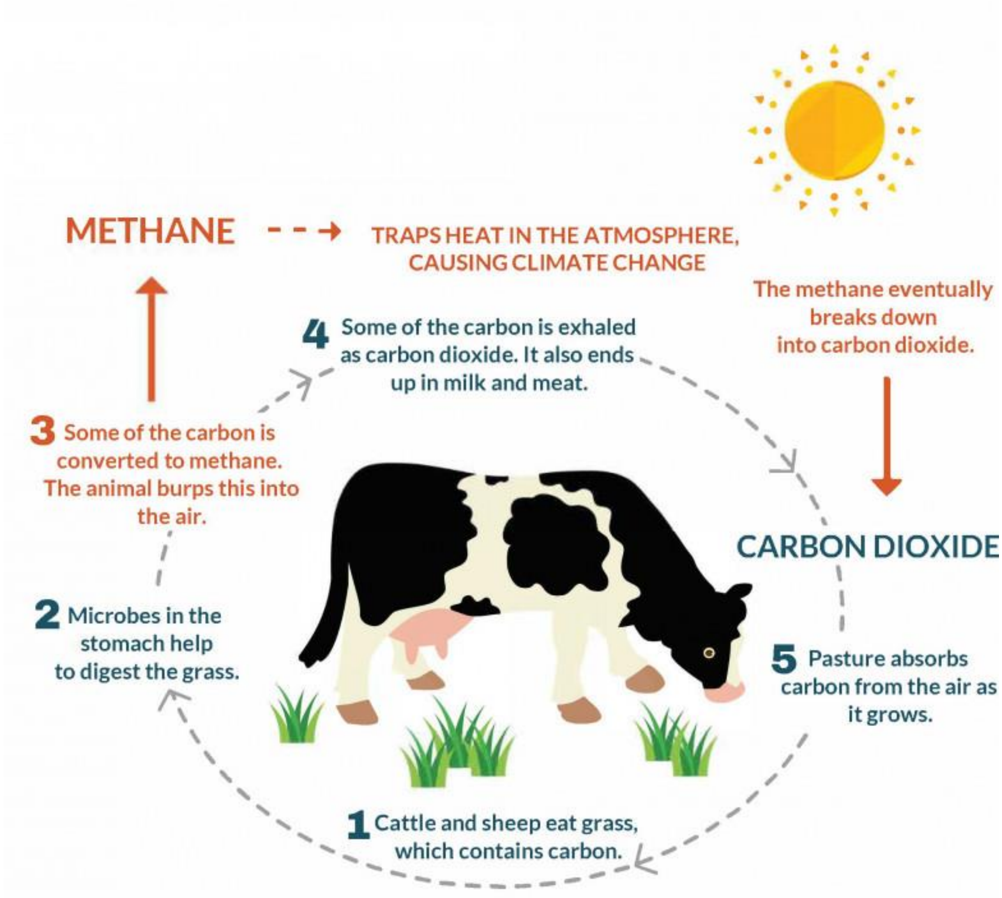

Figure 8 Greenhouse gas emissions from Dairy Cow

(National Institute of Water and Atmospheric Research, New Zealand, 2021)

Enteric fermentation produces about 30 % CH_4 of the entire GHG emissions in farming and around 70 % of all agricultural sources of CH_4. Other actions such as manure management and manure applied to land emit about 10% percent of the total CH_4 emissions, and represent 25 percent of all agricultural sources of methane. (EPA, US). The GHGs emissions from agriculture sector will reach 51.2 $MtCO_2eq$ in 2030 and 63.6 $MtCO_2eq$ in 2050 (Bijay Bahadur Pradhan et. al ,2019).

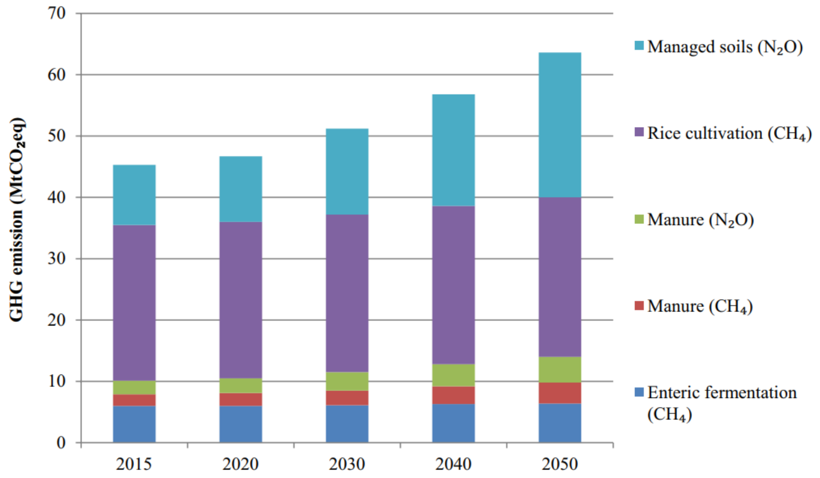

Figure 9 Emissions from the agriculture sector during 2015-2050 (Pradhan et al., 2019)

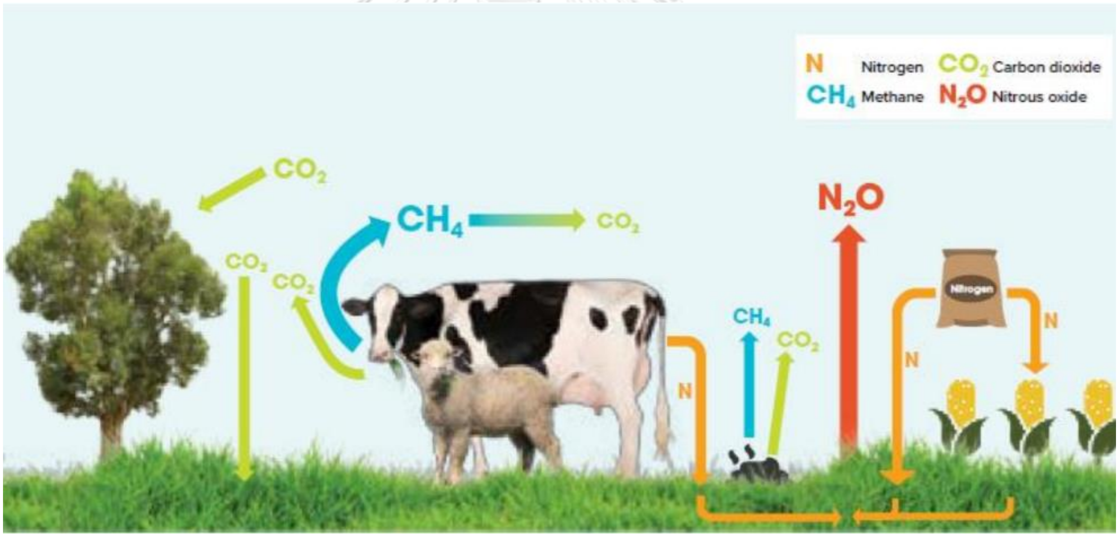

Figure 10 Sources of GHG Emissions on a farm
(Agricultural Greenhouse Gas Research Centre, New Zealand, 2021)

According to growth amount during 2005-2015 annual, dairy cattle are projected to reach at 0.62% annual growth rate during 2015-2050 (Bangkok, office of agricultural economics, 2016).

Table 1 Estimated livestock population during 2015-2050 (thousand heads)

Livestock Type	2015	2020	2030	2040	2050
Cattle (dairy)	510	526	559	595	633
Sheep	49	49	48	46	45
Goats	540	587	756	924	1092
Swine	9887	10,873	13,151	15,906	19,238
Chickens	418,331	490,288	677,284	864,280	1,051,275
Ducks	28,762	36,782	46,282	55,782	65,283

Source: Pradhan et al., 2019

2.2 Previous studies on estimation of GHG from livestock sector

There are four categories for the agricultural emissions: enteric fermentation, manure management, rice cultivation and managed soils (Bijay Bahadur Pradhan et al., 2019). Apart from the GHGs arising from enteric fermentation and manure storage, feed production together with the related soil carbon dioxide and nitrous oxide emissions is another important hot spot for the livestock sector. (Goglio et al., 2018). However, a significant origin of GHG emissions from livestock sector is CH_4, which impacts climate change. To reduce GHG emissions, strategies need to be improved and implemented (Byeng R. Min et al., 2020). Both reducing enteric methane emission from ruminant production and utilizing dietary nutrient are necessary to be able to reach a goal called sustainable livestock production (Waghorn and Hegarty et al., 2011).

Since countries has been changing from low-medium income to high income, protein consumption seems to be an increase per capita as well that should be considered in the prediction. Moreover, livestock products demands is expected to double by 2050 globally (Rojas-Downing et al., 2015). Growing food production will likely cause an increase in GHG emissions, including enteric CH_4 from animals, manure, crop production and cropland with inorganic or organic fertilization, till mitigation practices are implemented. Globally, livestock production contributes up to 10% of total GHG emissions excluding indirect emissions related to other agricultural activities, such as fossil fuels combustion and chemical fertilizers (IPCC, 2013; Gerber et al., 2013).

In Thailand, the energy sector contribution to GHG emission was the highest in 2016, accounting for 71.65% of total GHG emissions, where as the Agriculture, IPPU and Waste sectors emission was 14.72%, 8.90% and 4.73%, individually in Thailand (Mid-century, Long-term Low Greenhouse Gas Emission Development Strategy, Thailand, 2021). In global emissions, this accounts for 13% of carbon dioxide (CO_2), 44% of methane (CH_4), and 82% of nitrous oxide (N_2O) emissions through anthropogenic activities (IPCC, 2019). In late 19th century, the global mean surface temperature has increased to around 0.9˚C mainly by CH_4, CO_2, and other anthropogenic emissions. (IPCC, 2014). In Thailand, it is necessary to implement the relevant measurements or to improve the farms' management as well. In the view of the global movement and condition of the dairy industry in Thailand, further policies support is needed to be developed for sustainability which is required to build on the fundamentals of acceptable farm management. To be able to get the full concept of sustainability, three aspects of sustainability (environmental, social, and economic dimensions) have to be focused and developed (Towards sustainability of the dairy industry in Thailand,2022).

It was estimated that CH_4 emissions from enteric fermentation will gradually increase from 6.0 $MtCO_2eq$ in 2015 to 6.4 $MtCO_2eq$ in 2050 whereas CH_4 emission from manure management would increase from 1.9 $MtCO_2eq$ in 2015 to 3.4 $MtCO_2eq$ in 2050. At the same time, it was estimated that N_2O emissions from manure management would increase by double in 2050; and the emissions from managed soils would increase about 1.4 times in in 2050. The emissions from enteric fermentation would be 10.1% while that of CH_4 and N_2O emissions from manure would be 5.3% and 6.6% correspondingly (Bijay Bahadur Pradhan et.al ,2019).

Hassanat et al., (2017) observed that cows fed brown mid corn silage had similar enteric methane emissions (g/d) as cows fed conventional corn silage (CCS), but dry matter intake (DMI) and milk yield were higher for cows consuming than for cows fed CCS. Consequently, CH_4 production expressed on a DMI or milk production basis was reduced. However, an increase in DMI may result in an increase in volatile solid (VS) excretion, which is associated with higher CH_4 emission of manure (IPCC 2006). As the different kinds of feedstuffs for dairy cattle diets have a significant effect on enteric emissions particularly CH_4, therefore, nutrition and feeding systems and ration ratios have the highest potential for reducing CH_4 emissions, and more energy-dense or more digestible feedstuffs to the animals generate less CH_4 from fermentation process (Knapp et al., 2014). Moreover, the amount of CH_4 emissions from dairy waste can be determined by the amount of carbon, hydrogen, and oxygen present in the waste, manure storage, diet, and bedding suppliers (Place and Mitloehner, 2010).

Developing the production and efficiency of animal production by providing improved nutrients and heredities are the common strategy for methane emissions reduction in livestock production. High energy amount of the animals' feed is absorbed for production (milk, meat, draught power) referred to Greater efficiency so that CH_4 emissions from each product can be diminished (FAO,2006). Diet that has high level of concentrate lessens the energy quantity for CH_4 convertion because of the associated changes in substrate fermentation from fiber to starch and the decline in ruminal pH (Blaxter and Clapperton 1965).

Manure is an emission source for both CH_4 and N_2O, and the amount of emission is linked to environmental circumstances, managing system and the manure composition. Organic matter and nitrogen content of manure are the main compositions of the CH_4 and N_2O, emissions, respectively. Bacteria partially decomposes the organic matter by producing methane and carbon dioxide under anaerobic conditions. When manure is stored in slurry condition in a container, it enhances an anaerobic environment leading to CH_4 emission increasing. Emissions can be increased by long storage periods and warm and wet conditions (EPA, 2010). Conversely, combination of aerobic and anaerobic conditions causes N_2O emission. Hence, once manure is stored as a solid (dung) or deposited on pastures, N_2O production rises when there is no CH_4 emission. N_2O is emitted by nitrification and denitrification processes of the nitrogen involved in manure, in both organic form (e.g., proteins) and in inorganic form as ammonium and ammonia. Nitrification takes place aerobically and ammonium and ammonia are converted to nitrites and then nitrates, while denitrification happens anaerobically by converting nitrates to N_2O and N_2 (Saggar, 2010).

The condition at which manure is managed notably affect CH_4 emission. If the manure is managed properly and removed regularly from the enclosed storing systems, it can lessen CH_4 emission emissions efficiently in temperate climates, but it has to be enough storage capacity in outdoor area (FAO,2006). The growth of bacteria, ambient temperature, humidity, the period of manure storage are the factors that influence on the methane emissions from livestock manure. The quantity of CH_4 produced also relies on the manure energy content, which is set on to a great extent by livestock nutrient. Though, the prospect of high digestibility of feedstuffs offset this impact (USDA, 2004).

As a consequence of a various soil types, as well as manure odors and unpredictable weather conditions in New York, the farmers have exclusive environmental challenges when using manure as the fertilizer. To overcome those challenges, farmers are participating in manure management and treatment technologies to further advance options to optimize nutrient recycling, odor reduction, and environmental management. Though, the technology is expensive that can be limitation for widespread adoption. In Thailand, the Department of Livestock Development (DLD) has been trying to lessen community issues to get better livestock waste management system adopted by livestock farms especially medium farms (Eastern Research Group, Inc, 2009).

Chapter 3
Research Methodology

3.1 Research study design

There are two principal GHGS quantifications methods which are Life Cycle Assessment (LCA) and the Intergovernmental Panel on Climate Change (IPCC). Experts or professional who make decisions can relate two goods and choose the last impact good on the environment based on the LCA results but only on certain impacts. Since LCA assesses the actual world in a simplified model, it depends on assumptions and scenarios. Moreover, the large amount of data is required and if data collection is poor and not enough, there will be losses of accuracy (FiberNet, LCA: Benefits and Limitations,2018). IPCC guideline provide additional methodologies to estimate the GHGs emissions sources and sinks that captivate these gases. Advanced values of some emission factors are improved and provided as well for linking the emission of a GHG for a particular source to the amount of activity that initiates the emission. Many researchers and professionals operated on the 2019 Refinement to develop the overall recommendations or instructions and methods for four parts: energy; industrial processes and product use; agriculture, forestry and other land use; and waste (IPCC,2019).

This research was conducted to evaluate GHGs emissions from the dairy cattle production in Thailand by using 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories model. All data inputs for GHGs quantification were collected by both on-site visits and interviews with the representatives of each farm case study. Moreover, this study also aimed to investigate how the size of the farm and manure management system to realize how these factors affect the GHGs emissions in dairy farms (Figure 10).

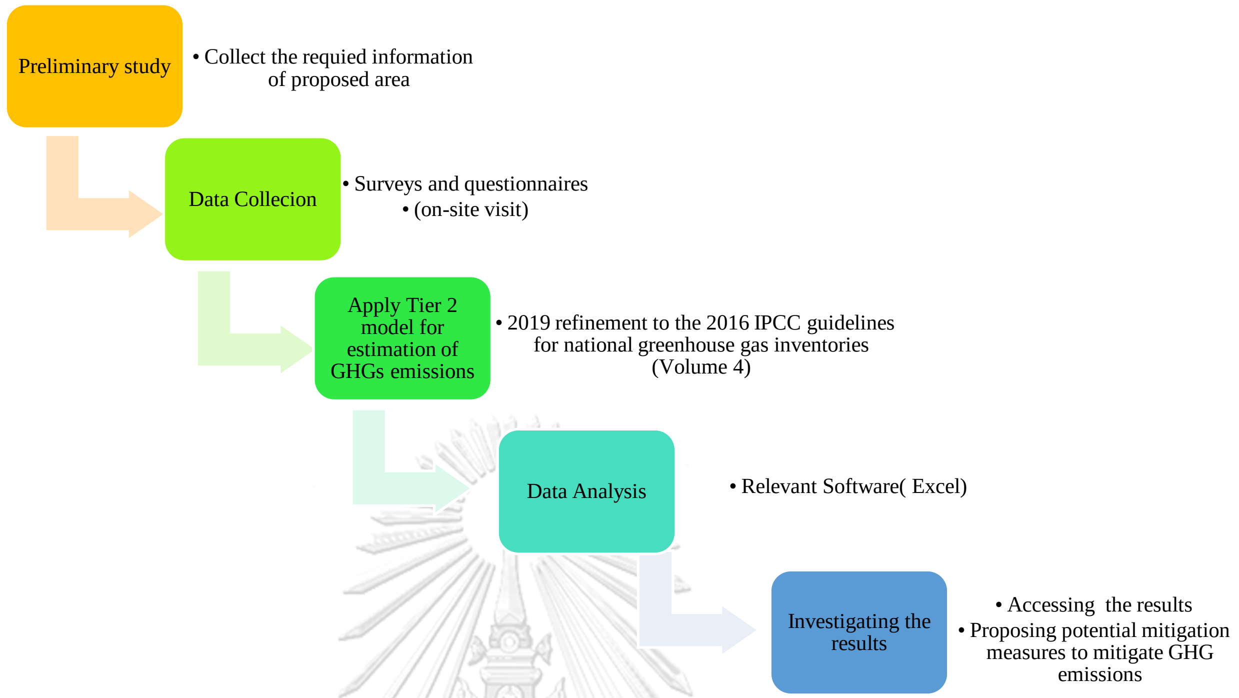

Figure 11 Research Study Design

3.2 Case studies

In 2020, Thailand’s domestic dairy cows can produce raw milk at approximately 3,500 tons daily apart from about 310,000 cows nationwide. The main provinces of raw milk production in Thailand are in Nakhon Ratchasima, Saraburi, Lopburi, Chiang Mai, Ratchaburi and Prachuap Khiri Khan. (Smart Farming for Thai Dairy Producers, Chulalongkorn University, For Sustainable Development ,2019)

Table 2 List of Livestock Production in Main Province areas in Thailand

No.	District	Number of dairy cows	Number of farmers
1.	Ratchaburi	47,143	2,300
2.	Saraburi	155,699	4,521
3.	Nakhon Ratchasima	154,126	4,994
4.	Lopburi	91,603	2,574
5.	Chiang mai	54,645	1,170

Source: National Economic and Social Development Council, Thailand,2021

According to the above-mentioned Table 2, there are highest population of dairy cattle In Saraburiwhere as there are lowest population of dairy cattle in Ratchaburi. Moreover, Thailand's dairy industry has mutual characteristics likewise other countries (Myanmar, Indonesia, Phillipines) in Southeast Asia (Wouters, 2010), such as most of the farms are small, and trade in skim milk powder for dairy products production. There are three major sectors called dairy farms, milk collection places, and milk processing plants in the dairy value chain in Thailand. Therefore, the dairy farms from these two provinces are selected as the case studies to evaluate the comparison of the GHGs emission .The case studies were selected according to the inclusion criteria 1) have to be small or medium cattle farms in Ratchaburi or Saraburi provinces 2) the farms that are willing to participate in this research 3) able to answer all the questions without hesitation. Exclusion criteria includes the cattle farms rather than the dairy cattle farms, the farms locating in other provinces except Saraburi and Ratchaburi, the large cattle farms in Saraburi and Ratchaburi provinces. All the required information was collected by interviewing the responsible person (veterinarian, farm owner or farm operator) from each farm. To carry out the research, the permission was requested by directly contacting (calling) the staff from the farm, informing them all related research information, as well as asking them to consider participating this research and cooperating with the researchers to collect all the required information, allowing visit and interview with assigned staff who are working in the farm. After got approved from the farms, data collection was proceeded by visiting the farms (i.e., interview) according to the date/time and location proposed by the farm staffs.

(1) Ratchaburi province

Ratchaburi province is located in center of Thailand and west of Bangkok, neighboring Myanmar (Burma), and the coordinate is 13°32'24"N and 99°49'12"E. In 2018, the population in this province is 873,518. Ratchaburi covers an area of 5,196 km². There is the biggest agricultural market in the western side of Thailand, so there is also the greatest number of milk cows in the country. It's famous for the Damnoen Saduak floating market, where vendors sell food, handicrafts and souvenirs from traditional wooden boats afloat on khlongs (canals). In Ratchaburi, the average temperature is 27.5°C(81.5°F) annually.

(www.webratchaburi.org).

Figure 12 Thailand Map (dreamstime.com)

Figure 13 Ratchaburi Province (Holiday Travel Reports, 2013)

(2) Saraburi Province

Saraburi is a province in the center of Thailand, northeast of Bangkok. There is the Chao Phraya River valley at the east side of Saraburi, and the coordinate is 14.5270° N, 100.9130° E. Saraburi province covers an area of 848 km^2 forest or 24.2 percent of provincial area. In 2022, the population is approximately 60,809. Saraburi is located in a densely settled rice-growing and cattle-ranching area. The annual average temperature is 28-29°C.

www.websaraburi.org).

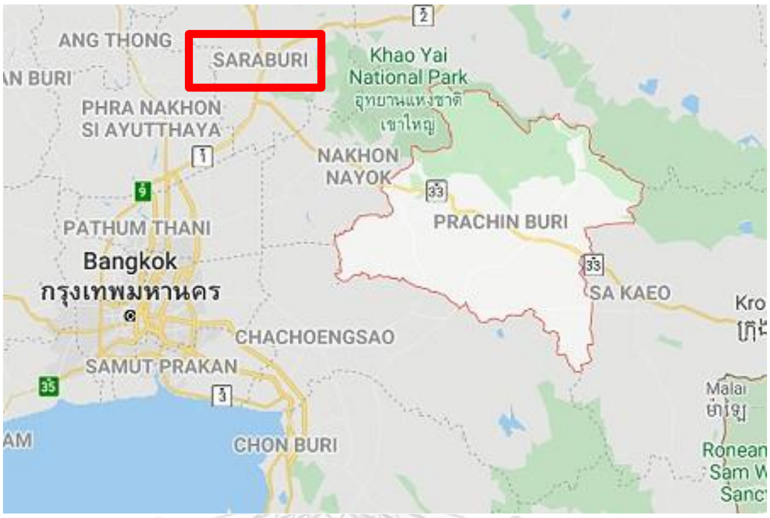

Figure 14 Saraburi Province (Holiday Travel Reports, 2013)

3.3Materials and methods

3.3.1 Estimation of GHGs emissions from the dairy sector

GHG emissions from dairy farm were estimated according to IPCC guidelines from Volume 4: Chapter 10- Emissions from livestock and manure management. The following sources of emissions were accounted and investigated (i) CH_4 enteric fermentation, (ii) CH_4 manure management, (iii) N_2O emissions from manure management, (iv) N_2O emissions from multiple manure management system. All data input for estimating GHGs emissions from the dairy sector in this study are summarized in Table 3.

3.3.1.1 Methane emissions from enteric fermentation

Under this sector, Tier 2 was applied in accordance with the decision tree mentioned in IPCC, 2019. It is also mentioned that Tier 2 is commonly used for the agriculture, Land use, Land use change and forestry and waste sector in Thailand's third national communication (2018), and that report referred Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1997). The main reason why Tier 2 was chosen is that enteric fermentation is one of the main categories in this study.

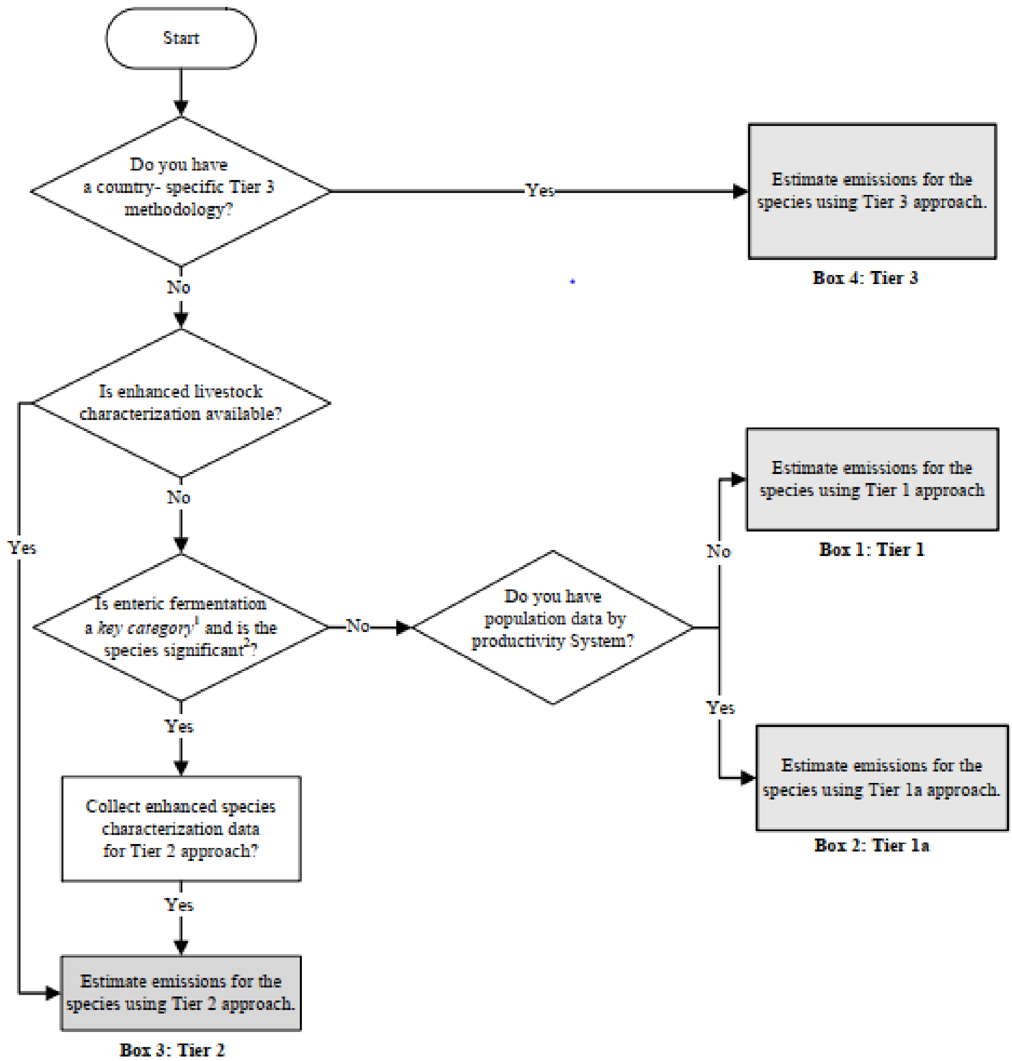

Figure 15 Decision tree for enteric fermentation (IPCC, 2019)

Dairy cow population is generally defined as high-productivity and low-productivity system. High productivity system means that cows are fed by high quality pasture with supplement and the production aims 100% market milk commercial for both national market and or export while in low-productivity system, local roughage and Agri-cultural by-products are used as feedstuffs and the production aims for only local market (IPCC 2019). Milk production depends on whether the cows are the cross bred which are genetically improved or local bred not (FAO et al., 2014). Defining the systems will help to use country-specific value and animal performance among livestock population (IPCC 2019).

Tier 2 emission estimates daily feed intake in terms of gross energy (GE) or dry matter. For Tier2 method, detailed information and the equations is required. Relevant required data and equations to estimate feed intake are mentioned as follows.

(1) Live weigh of animals (Kg) - Weight of a living animal before it is slaughtered for meat
(2) The average live body weight of animals in population (Kg)
(3) The average daily weight gain
(4) Feeding situation - Stall, Pasture, Grazing large areas, Crude protein content in diet
(5) Mature body weight of an adult animal
(6) Fat content in milk (% by weight)
(7) Average daily milk production (Kg/day)
(8) Protein content in milk (%)
(9) Percent of females that give birth in a year in each farm
(10) Dry Matter Intake % (DMI %)

The equations to estimate gross energy (GE) is mentioned as follows.

Net Energy for Maintenance

$$NE_m = Cf_i * (Weight)^{0.75} \quad \text{Eq. (1)}$$

Net Energy for Growth (For cattle and buffalo)

$$NE_g = 22.02.\left(\frac{BW}{C.MW}\right)^{0.75}.WG^{1.097} \quad \text{Eq. (2)}$$

<u>Net Energy for Lactation</u> (For beef cattle, dairy cattle and buffalo)

$$NE_l = Milk*(1.47+0.40*Fat) \qquad \text{Eq.(3)}$$

<u>Net Energy for Pregnancy</u> (For cattle/buffalo and sheep and goat)

$$NE_p = C_{pregnancy}*NE_m \qquad \text{Eq. (4)}$$

<u>Ratio of Net Energy Available in a Diet for Maintenance to Digestible Energy</u>

$$REM = \left[1.123 - (4.092.10^{-3}.DE) + (1.126.10^{-5}.(DE)^2) - (\frac{25.4}{DE})\right] \qquad \text{Eq. (5)}$$

<u>Ratio of Net Energy Available for Growth in a Diet to Digestible Energy Consumed</u>

$$REG = \left[1.164 - (5.16.10^{-3}.DE) + (1.308.10^{-5}.(DE)^2 - (\frac{37.4}{DE})\right] \qquad \text{Eq. (6)}$$

<u>Gross Energy</u>

$$GE = \left[NE_m + NE_a + NE_1 + \frac{NE_p}{REM}\right] + \frac{\left[\frac{NE_g}{REG}\right]}{DE} \qquad \text{Eq. (7)}$$

<u>Methane Emission Factors for Enteric Fermentation from a Livestock Category</u>

$$EF = GE.\left(\frac{Y_m}{100}\right).\frac{365}{55.65} \qquad \text{Eq. (8)}$$

<u>Total emission from livestock enteric fermentation</u>

$$Total\ CH_4\ Enteric = \sum E_{i,p} \qquad \text{Eq. (9)}$$

3.3.1.2 Methane emission from manure management

Manure includes both dung and urine generated by livestock production. Manure decomposes under anaerobic condition throughout the processes of treatment. Manure management affect CH_4 production by the amount of manure produced and storage system. Tier 2 method was applied for estimating CH_4 emissions from manure management according to the following decision tree.

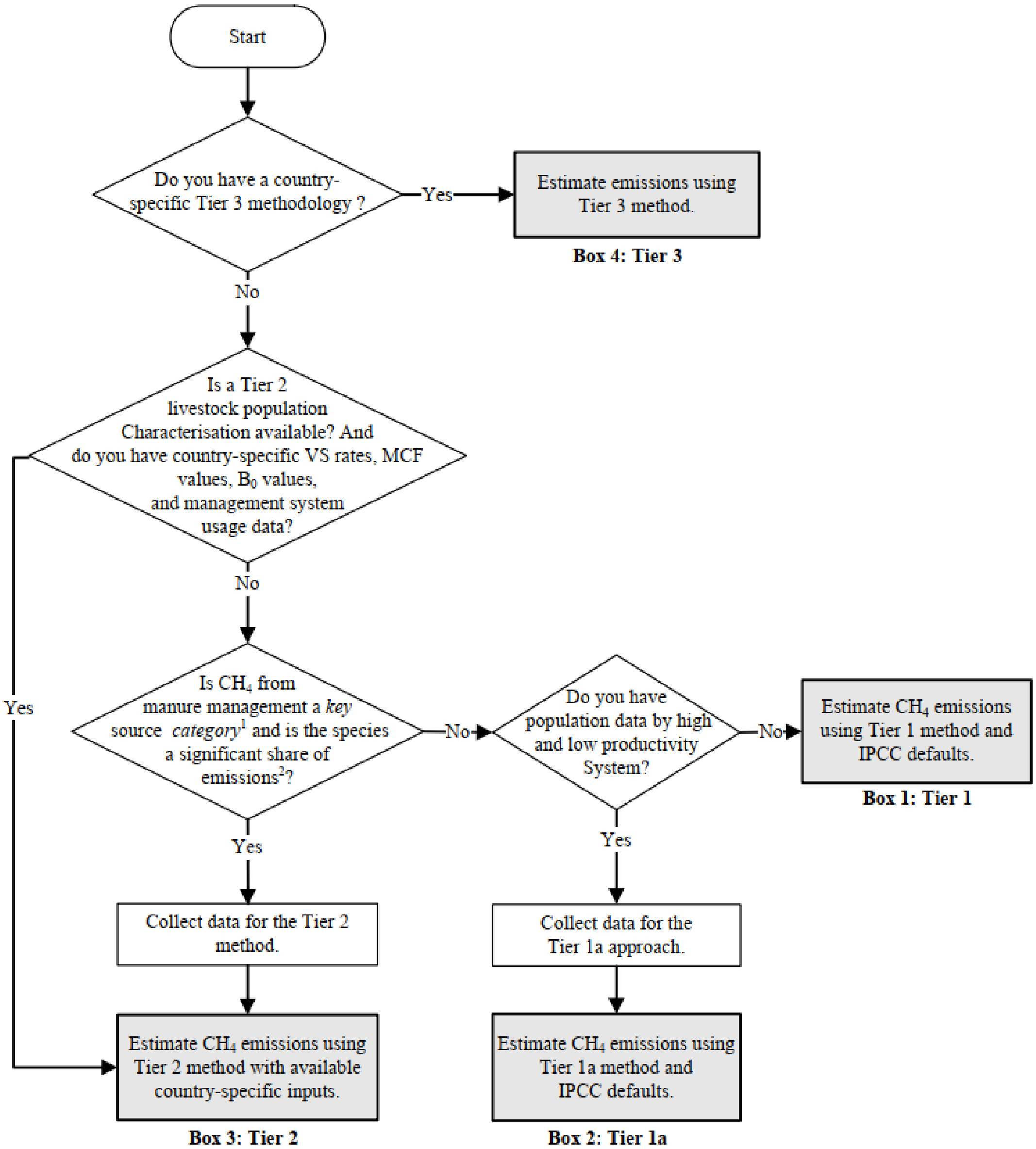

Figure 16 Decision tree for manure management (IPCC,2019)

In Tire 2 method, the following data is required.

(a) Manure Characteristics – amount of volatile solid (VS), the maximum amount of methane production from manure (B_0),

(b) Animal Waste Management System Characteristics - fraction of livestock category T's manure handled using animal waste management system S in climate region k, dimensionless

(c) Methane conversion factors – based on temperature

(d) Manure management system - Uncovered anaerobic lagoon, Liquid/slurry, Pit storage, Solid storage, Dry Lot, Daily spread, Anaerobic digestion-biogas, Burned for fuel

Since above-mentioned fractions are required, if these values are not available in national level, default values for specific sector can be applied to estimate the methane emission from manure management.

The required equations are mentioned as follows:

Annual CH_4 emission factor from manure management

$$EF(T) = (VS_T.365)\left[B_{0(T)}.0.67.\right]\sum\frac{MCF_{S,K}}{100}.AWMS_{T,S,k} \quad \text{Eq. (10)}$$

$$VS = \left[GE.\left(1-\frac{DE}{100}\right)+(UE.GE)\right].\left[(1-\frac{ASH}{18.45})\right] \quad \text{Eq. (11)}$$

3.3.1.3 N_2O emissions from manure management

Nitrous oxide (N_2O) is emitted by both direct and indirect ways from manure management throughout the storing and manure treatment. N_2O emissions was occurred directly by combination of nitrification and denitrification of nitrogen contents in the manure. The oxidation of ammonia nitrogen to nitrate nitrogen called nitrification is a compulsory requirement for N_2O emission from manure storage. Nitrification seems to occur in manure storage providing a sufficient oxygen supply. There is no occurrence under anaerobic conditions. When the denitrification occurs naturally, N_2O and dinitrogen (N_2) are converted from nitrites and nitrates. Indirect emissions occur when volatile nitrogen losses that happen mostly in the forms of ammonia and NO_x. Then, ammonia is highly volatile and easily diffused into the surrounding air (Asman et al. 1998; Monteny & Erisman 1998). Nitrogen losses start at the point of defecation in houses and other animal production areas (e.g., milk parlors) and continuing throughout the on-site storage management and treating methods. When manure in solid storage causes runoff and leaching at outdoor areas, in feedlots and where animals are grazing in pastures. nitrogen losses occur (IPCC, 2019).

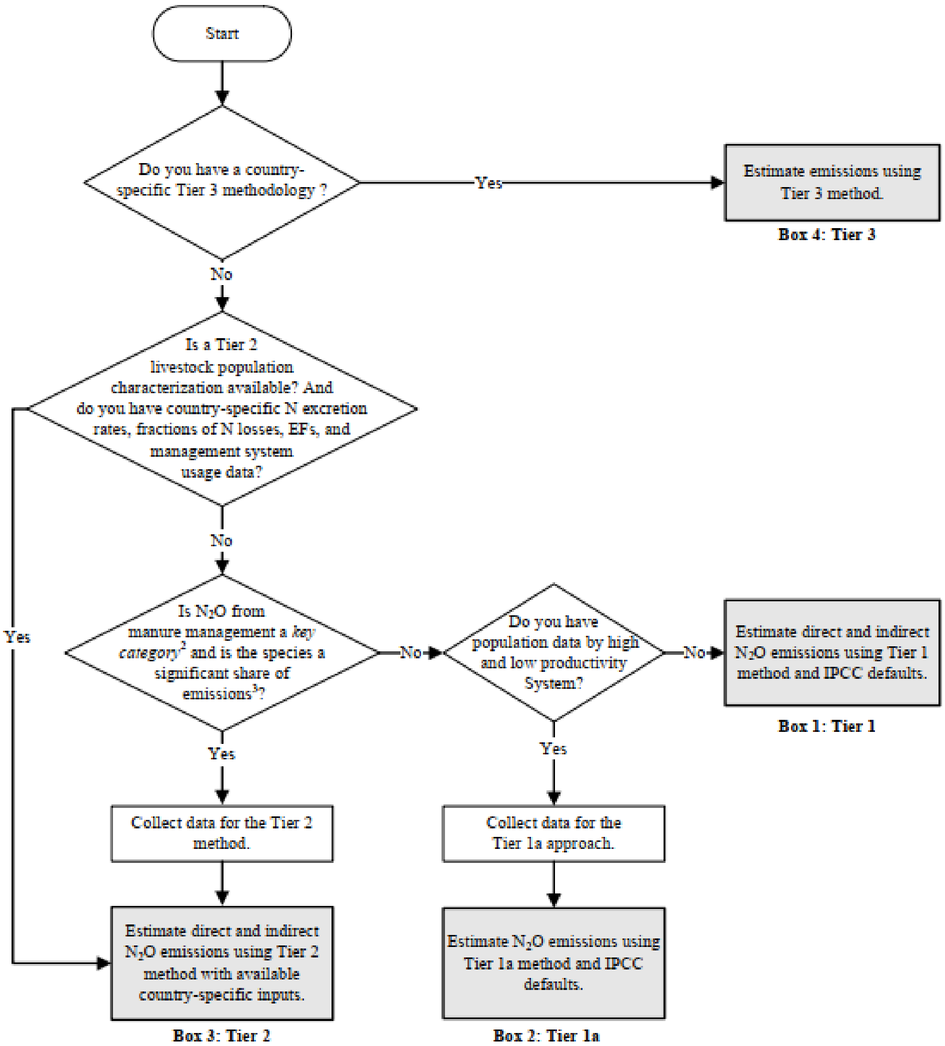

Figure 17 Decision tree of N_2O emission from manure management (IPCC, 2019)

The required equations are mentioned below to estimate direct and indirect N_2O emission from manure management.

Direct N_2O emission from manure management

$$N_2O_{D(mm)} = \left[\sum_{S}\left[\sum_{T,P}\left((N_{(T,P)}.Nex_{(T,P)}.AWMS_{(T,S,P)}\right) + N_{cdg(s)}\right].EF3_{(S)}\right].\frac{44}{28}$$ Eq. (12)

(a) Indirect N_2O emission due to **volatilization** from manure management

$$N_{volatilization-MMS} = \sum_{S}\left[\sum_{T,P}\left[\left(\left(\left(N_{(T,P)}.Nex_{(T,P)}\right).AWMS_{(T,S,P)}\right) +.Frac_{GasMS(T,S)}\right]\right]\right.$$ Eq. (13)

$$N_2O_{G(mm)} = \left(N_{volatilization_{-MMS}}.EF_4\right).\frac{44}{28}$$ Eq. (14)

(b) Indirect N_2O emission due to **leaching** from manure management

$$N_{leaching-MMS} = \sum_{S}\left[\sum_{T,P}\left[\left(\left(N_{(T,P)}.Nex_{(T,P)}.AWMS_{(T,S,P)}\right)\right).Frac_{LeachMS(T,S)}\right]\right]$$ Eq. (15)

$$N_2O_{L(mm)} = \left(N_{leacching-MMS}\ .EF_5\right).\frac{44}{28}$$ Eq. (16)

Annual Average nitrogen excretion rates, $Nex_{(T)}$

Nitrogen intake of cattle

$$N_{intake(T)} = \frac{GE}{18.45} * \left(\frac{\frac{CP\%}{100}}{6.25}\right)$$ Eq. (17)

Nitrogen retention of cattle

$$N_{retention(T)} = \left[Milk.\frac{\left(\frac{Milk\ PR\%}{100}\right)}{6.38} + \right] + \left[WG.\frac{\left[268 - \frac{\left(\frac{7.03.NEg}{WG}\right)}{WG}\right]}{6.25}\right] \qquad \text{Eq. (18)}$$

<u>Annual N excretion rates,</u>

$$Nex_{(T)} = \left(N_{intake(T)} - N_{retention(T)}\right).365 \qquad \text{Eq. (19)}$$

3.3.2 The effect of farms' management on GHGs emissions

There are three dairy system indications of CH_4 emissions namely the milk yield potential, first calving age and the replacement rate in the dairy production. These factors directly effect the population of cows and replacements heifers required for a static amount of milk sales and thus affected enteric CH_4. Developing cattle production efficiency is broadly used for GHGs reduction. When feed concentrate is increased, it can decrease GHG emissions and rises farm production. Nevertheless, there are other many influences for the emissions from the farms, and specific evaluations of each system are necessary for confirmation that increased the amount of dietary concentrate would affect in GHGs emissions reduction (FAO,2016).

3.3.2.1 Relationship between manure management and GHGs emissions

The emissions from manure can be divided as follows;

(a) Emissions from manure storage
(b) Emissions from manure discharged into environment

Although cattle manure is a significant nutrient source for crop growth, if it is applied in extra amount beyond crops and soils acceptable amount or if manure is inappropriately applied, runoff and leaching cause eutrophication of surface water bodies or groundwater contamination (R.K. Hubbard and R.R. Lowrance,1998). Dairy sectors have several storage systems such as solid storage, dry lot, Liquid/slurry, Pit storage system; if there are multiple management system in farm, manure emission factors should be assigned to the main storage system. The fraction values and emission factor depend on the manure storage system (IPCC,2019). There are two mainly manure management system in the case studies area; (a) Pit storage system and (2) Runoff or leaching.

Figure 18 Pit Storage in case studies area (Farm Site)

Figure 19 Runoff or leaching manure system in case studies (Farm Site)

The quantity and portion of manure decomposing anaerobically mainly affect CH_4 emissions. The quantity depends on the production of waste from each animal and the animal's population, and the percentage relies on the manure management system. When manure is managed in tanks, it decays anaerobically and emit a significant amount of CH_4. When manure is stored in stacks or piles or when it is dropped on pastures, it decays under more aerobic conditions and CH_4 emission is reduced (IPCC,2006). Furthermore, if manure N_2 is lost to the atmosphere, it is necessary to estimate the emission from leaching. It was observed that nitrogen loss was about 20% of N excreted from runoff and around 16 % from leaching (Bierman et al.,1999).

To better understand how manure management affects GHGs emissions, both the CH_4 and N_2O emissions resulting from manure management were compared according to the unit of emissions of CO_2 eq. Furthermore, in case of manure is applied as the fertilizer; so, the nitrous oxide emissions is needed to be calculated according to the following equations.

3.3.2.2 N_2O emissions from multiple manure management system

There are many storage systems in dairy sectors such as solid storage, dry lot, Liquid/slurry, Pit storage system; if there are multiple management system in farm, manure emission factors should be focused on the major system. The fraction values and emission factor depend on the manure storage system. In livestock production, almost manure apply to the soils for using in pastures, fuel and construction processing. Therefore, there is necessary to evaluate the emissions for manure application to soils by the next mentioned equations (IPCC,2019).

<u>Total annual N_2O emission from managed soil</u>

$$N_2O_{mm(T)} = N_2O_{D(mm,T)} + N_2O_{G(mm,T)} + N_2O_{L(mm,T)} \quad \text{Eq. (20)}$$

(a) <u>Total annual N_2O emissions from manure nitrogen applied to cultivated soils</u>

$$N_2O_{AM(T)} = N_2O_{D,AM(T)} + N_2O_{I,AM(T)} \quad \text{Eq. (21)}$$

$$N_2O_{D,AM(T)} = F_{AM(T)}.\left[\left(1 - Frac_{AM,Rice}\right).EF_1 + EF_{1FR}\right].\frac{44}{28}$$

$$N_2O_{I,AM(T)} = F_{AM(T)}.\left[Frac_{GASM}.EF_4 + Frac_{LEACH-(H)}.EF_5\right].\frac{44}{28}$$

<u>Total N_2O emission</u>

$$N_2O_{(T)} = N_2O_{mm(T)} + N_2O_{AM(T)} \quad \text{Eq. (22)}$$

3.4 Data collection and interviews

The information mentioned in Table 3 were used to evaluate the GHGs emissions from the case studies. The information are annual value from each farm in 2021. The reference value were also be selected based on these information (No.1-12) because some values are different according to the relevant information; for instance, B_0 value. Moreover, the GHGs emission from farm management was considered in compliance with the rest of the information (No.13-17). All the questions mentioned in Table 3 are the required information for evaluating the GHGs emission from case studies according to 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 4).

Table 3 Summary of the Required Information from Dairy Farm(Annual Data,2021)

No.	Required Information (From Farm)	Details
1.	Productivity System	• High productivity system? (>8500 kg/head/yr) (Grazing on high quality pasture with supplement. Production is 100 % market commercial milk production for national market and or export.) • Medium – 5000-8500 kg/yr • Low productivity system? (<5000 kg/yr) (Using locally produced roughage and agro-industrial by-products. Production is for local market and local consumption.)
2.	Live weigh of animals (Kg)	Weight of a living animal before it is slaughtered for meat

3.	The average live body weight of animals in population (Kg)	-
4.	The average daily weight gain	-
5.	Feeding situation	Stall, Pasture, Grazing large areas, Crude protein content in diet
6.	Mature body weight of an adult animal	Body weight at which skeletal development is complete
7.	Fat content in milk (% by weight)	
8.	Average daily milk production (Kg/day)	
9.	Protein content in milk (%)	-
10.	Percent of females that give birth in a year in each farm	-
11.	DMI %	-
12.	Manure management system	Uncovered anaerobic lagoon, Liquid/slurry, Pit storage, Solid storage, Dry Lot, Daily spread, Anaerobic digestion-biogas, Burned for fuel
13.	How is the manure applied or used after long term storage?	
14.	Are there any mitigation measures or practices to reduce GHGs emissions?	
15.	How do experts manage food and manure not to impact the environment?	
16.	Have there been any public awareness or campaigns on environmental issues related to cattle raising regionally or around the farm area?	
17.	Do the dairy cattle farms have environmental monitoring or reporting scheme?	

3.5 Data analysis

All the emissions results (kg) were converted to CO_2 equivalent according to the global warming potential (GWP) by United Nations Framework Convention on Climate Change (UNFCCC) to be compared (Table 4). All emissions such as the CH_4 emission from enteric fermentation and manure management, and the N_2O emissions from different manure storage systems were compared.

Table 4 Global Warming Potential (GWP)

Greenhouse Gases	Formula	100- year GWP (AR4)
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous Oxide	N_2O	298

Source: UNFCCC,2014

Then, to calculate the emission results , actual data and GHGs emissions, parameter uncertainty analysis was applied according to Good Practice Guidance for Land Use, Land-Use Change and Forestry, IPCC, 2013. As there are two activities involved in this research in GHGs emission, analysis was applied for both activities (enteric fermentation and manure management). Lastly, after the analysis is completed, the results were sent to the relevant case studies farms for data availability.

Table 5 Uncertainty Analysis

Information	Rage of data quality			
Data collecting	X=6 score	Y=3 score	Z= 1 score	
	Systemically and continuously data by on-site/real-time measurement	Collect data by bills, reports or electrical meter	Collect data by estimation	
Score of greenhouse gas emission factor (EF)				
EF	A= 4 score	B=3 score	C= 2 score	D= 1 score
	Direct measurement level	Manufacturing/production level	National-base level	International-base level
Uncertainty = Score of data quality x Score of EF				

Source: Good Practice Guidance for Land Use, Land-Use Change and Forestry, IPCC, 2013

Table 6 Range of Uncertainty Determination

Level	Score	Description
1	1-6	High uncertainty: Poor data quality
2	7-12	Fair uncertainty: Medium data quality

3	13-18	Low uncertainty: Good data quality
4	19-24	Lowest uncertainty: Excellent data quality

Source: Good Practice Guidance for Land Use, Land-Use Change and Forestry, IPCC, 2013

CHAPTER 4
Result and Discussion

4.1 Case studies

The total number of cases in this study was 20 farms including 7 farms located in Saraburi and 13 farms located in Ratchaburi provinces. Both small farms (< 20 cattle) (10 cases) and medium farms (>20 cattle) (10 cases) were focused and considered. In Thailand dairy cows are typically kept on small to medium scale farms with 20-50 animals (Dr Suneerat Aiumlamai, 1998). The farms are classified as the small and medium farms according to the population in each farm. All the farms are low productivity system targeting the local market and provide feeds such as fermented forage and concentrated feed by stall system. All the farms in Saraburi province use liquid/slurry manure management system (Figure 21) while all the farms except one farm in Ratchaburi use solid manure system (Figure 20). Manure in those farms use as fertilizer or being sold. Interestingly, there is no mitigation measurements for emission reduction in all these farms.

Figure 20 Pit Storage in case studies area (Farm Site)

Figure 21 Liquid/slurry manure system in case studies (Farm Site)

4.2 Total GHGs emissions

As mentioned in Chapter 2, the major origin of CH_4 is enteric fermentation where as the main source of N_2O is manure. The value GHGs emissions from enteric fermentation and manure management is shown in Figure 22 and Table 7. The total GHG emissions from all 20 farms were approximately 138.83 kg carbon dioxide equivalent (kg CO_2eq) from all activities. Specifically, total CH_4 emissions from both enteric fermentation and manure management systems was 135.58 kg CO_2eq which is 98% of total emissions. N_2O emissions from–manure management systems were 3.25 kg CO_2eq particularly direct N_2O emission was 1.40 kg CO_2eq while indirect N_2O emission was 0.020 kg CO_2eq.According to the results shown in Table 7 in all activities, CH_4 emission from enteric fermentation is much higher than those from manure management. CH_4 emission from both enteric fermentation and manure management is assumed as the emission amount based on the feeding systems and the type of feedstuffs. N_2O emission from manure management is higher than CH_4 emission from manure management. Moreover, it is known that the manure is applied to the soils in the case studies. Therefore, N_2O emission from manure applied to soil was 1.83 kg CO_2eq which is the highest emission among N_2O emission sources.

Regarding to the size of farm, the total GHG emissions from small farms were in range of 3.82 to16.01 kg CO_2eq (0.19 – 3.20 kgCO_2 eq/head of cattle of GHG emission intensity). Medium size of farms contributed GHG range from 2.74 and 4.22 kg CO_2eq (0.09-0.19 kgCO_2 eq/head of cattle of GHG emission intensity) from all activities. In direct and indirect N_2O emission, the range of emissions was 0 to 0.16 kgCO_2eq.In case of manure applied to soils, N_2O emissions was in the range of 0.01 to 0.19 kg CO_2eq. Further to this, geographically, farm cases located in Ratchaburi were from 3.25 to 16.01 kg CO_2eq and those in Saraburi were from 2.74 to 4.07 kg CO_2eq in all activities.

Table 7 Total GHGs Emissions from Dairy Cattle Farms

No	Farms	Province	Manure management system	Number of cows	CH_4 from Enteric fermentation	CH_4 from Manure management	Direct N_2O emissions	Indirect N_2O emissions	N_2O from manure applied to soil	Total GHGs emission	GHGs Emission Intensity (kgCO_2 eq/head of cattle)
				(kg CO_2eq)							
1	A	Ratchaburi	Solid storage	5	15.62	0.0001	0.16	0.002	0.19	15.97	3.19
2	B	Ratchaburi	Solid storage	6	11.65	0.0001	0.16	0.002	0.19	11.99	2.00
3	C	Ratchaburi	Liquid/slurry	22	3.24	0.0001	0.00	0	0.01	3.25	0.15
4	D	Ratchaburi	Solid storage	5	15.67	0.0001	0.16	0.002	0.19	16.01	3.20
5	E	Ratchaburi	Solid storage	7	10.86	0.0001	0.16	0.002	0.19	11.21	1.60
6	F	Ratchaburi	Solid storage	6	13.57	0.0001	0.16	0.002	0.19	13.91	2.32
7	G	Ratchaburi	Solid storage	9	9.89	0.0001	0.16	0.002	0.19	10.24	1.14
8	H	Ratchaburi	Solid storage	12	5.75	0.0001	0.16	0.002	0.19	6.10	0.51
9	I	Ratchaburi	Solid storage	12	6.85	0.0001	0.16	0.002	0.19	7.19	0.60
10	J	Ratchaburi	Solid storage	12	6.34	0.0001	0.16	0.002	0.19	6.69	0.56
11	K	Ratchaburi	Liquid/slurry	20	3.80	0.0001	0.00	0	0.01	3.82	0.19
12	L	Ratchaburi	Liquid/slurry	22	4.21	0.0001	0.00	0	0.01	4.22	0.19
13	M	Ratchaburi	Liquid/slurry	22	3.70	0.0001	0.00	0	0.01	3.71	0.17
14	N	Saraburi	Liquid/slurry	24	3.76	0.0001	0.00	0	0.01	3.77	0.16
15	O	Saraburi	Liquid/slurry	21	3.33	0.0001	0.00	0	0.01	3.35	0.16
16	P	Saraburi	Liquid/slurry	20	3.50	0.0001	0.00	0	0.01	3.51	0.18
17	Q	Saraburi	Liquid/slurry	19	4.06	0.0001	0.00	0	0.01	4.07	0.21

18	R	Saraburi	Liquid/slurry	22	3.60	0.0001	0.00	0	0.01	3.61	0.16
19	S	Saraburi	Liquid/slurry	30	2.73	0.0001	0.00	0	0.01	2.74	0.09
20	T	Saraburi	Liquid/slurry	22	3.45	0.0001	0.00	0	0.01	3.46	0.16

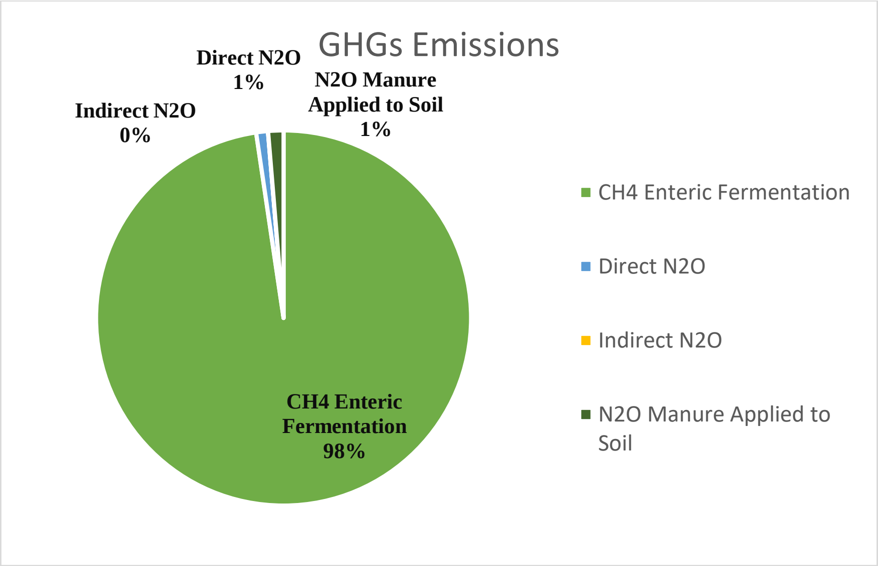

Figure 22 GHGs Emissions by Activities (kg CO_2eq)

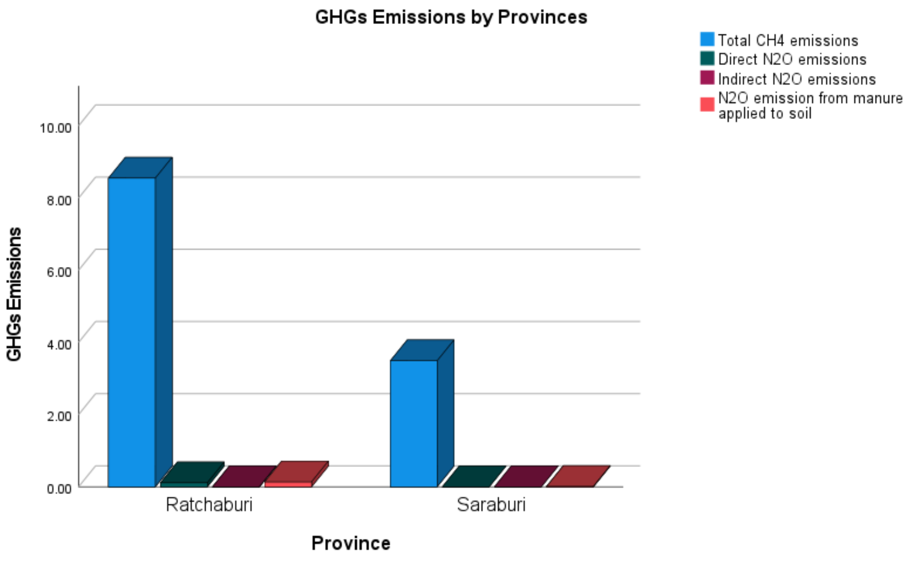

Figure 23 Total GHGs Emissions from Dairy Cattle Farms, by provinces (kg CO_2eq)

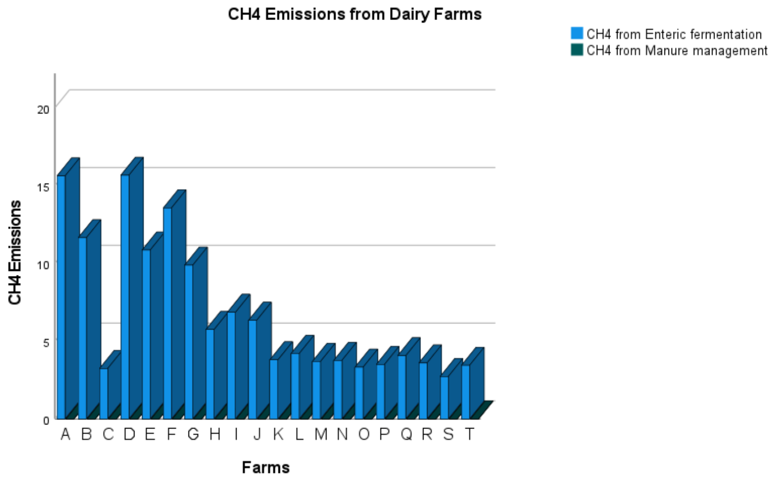

Figure 24 CH_4 Emissions from Dairy Cattle Farms, by emission sources (kg CO_2eq)

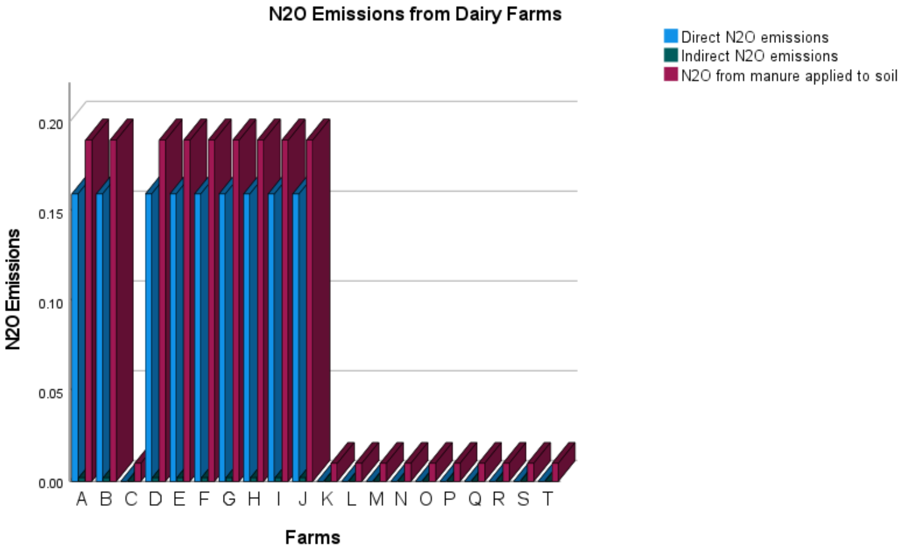

Figure 25 N_2O Emissions from Manure Management in Dairy Cattle Farms (kg CO_2eq)

4.3 CH_4 emissions from enteric fermentation and manure management

According to the results shown in Table 7 in all activities, total CH_4 emission including from both enteric fermentation and manure management was 135.58 kg CO_2eq. As shown in Figure 24, CH_4 emission from enteric fermentation is much higher than those from manure management. While, enteric fermentation emits 99.9% of total CH_4 emission, manure management emits only 0.1% of total CH_4 emission. The amount of

CH_4 emission from both enteric fermentation and manure management is mainly based on the feeding systems and the type of feedstuffs.

4.4 N_2O emissions from manure management system

As shown in Table 7 and Figure 25, total direct N_2O emission was 1.4 kg CO_2eq, total indirect N_2O emission was 0.02 kg CO_2eq, N_2O emission from manure applied to soil was 1.83 kg CO_2eq respectively. N_2O emissions from manure management in solid storage is significantly higher than those in liquid/slurry management (Figure 26 and Table 8). Moreover, the N_2O emissions from the manure applicaiton to soil was 3.15kg CO_2eq in solid storage whereas 0.09 kg CO_2eq in liquid/slurry system, and the emission is the highest among N_2O sources (Figure 26). Solid manure storage emits 97% of total N_2O emission whereas liquid/slurry manure emits 3 % of total N_2O emissions. It means that the manure management system includes as one of the important sources in GHGs emissions. The pits or tanks which used for storage ought to be enclosed for protection the manure from runoff when rainy. Dairy cattle manure has to be considered being a source and have to be applied and utilized carefully eco-friendly (Williams, A.G, et al. 2019). Once the dairy manure is widely used as a resource rather than a waste, it would be cooperative in N_2O emissions reduction. Composting the manure that enhances free of odors and reduce fly problems is highly recommended. As it reduces the volume of manure, it is easier to transport and spread. Besides, it is safer when manure applied to soils because raw manure may contain bacteria contaminating the vegetables and cause human disease. It is also suggested to manage the herd structures to reduce the occurrence of illnesses and vector control that might lessen the gas releasing, to build the pit not to impact on the environmental.

Table 8 N_2O Emissions from Manure Management Systems

No	Farms	Manure management system	Direct N_2O Emission	Indirect N_2O Emission	N_2O from manure applied to soil	Total N_2O emissions
			(kg CO_2eq)			
1	A	Solid storage	0.16	0.002	0.19	0.35
2	B	Solid storage	0.16	0.002	0.19	0.35
3	D	Solid storage	0.16	0.002	0.19	0.35
4	E	Solid storage	0.16	0.002	0.19	0.35
5	F	Solid storage	0.16	0.002	0.19	0.35
6	G	Solid storage	0.16	0.002	0.19	0.35
7	H	Solid storage	0.16	0.002	0.19	0.35
8	I	Solid storage	0.16	0.002	0.19	0.35
9	J	Solid storage	0.16	0.002	0.19	0.35
					Total	3.15
1	K	Liquid/slurry	0	0	0.01	0.01
2	L	Liquid/slurry	0	0	0.01	0.01
3	M	Liquid/slurry	0	0	0.01	0.01
4	N	Liquid/slurry	0	0	0.01	0.01
5	O	Liquid/slurry	0	0	0.01	0.01
6	P	Liquid/slurry	0	0	0.01	0.01
7	Q	Liquid/slurry	0	0	0.01	0.01
8	R	Liquid/slurry	0	0	0.01	0.01
9	C	Liquid/slurry	0	0	0.01	0.09
					Total	

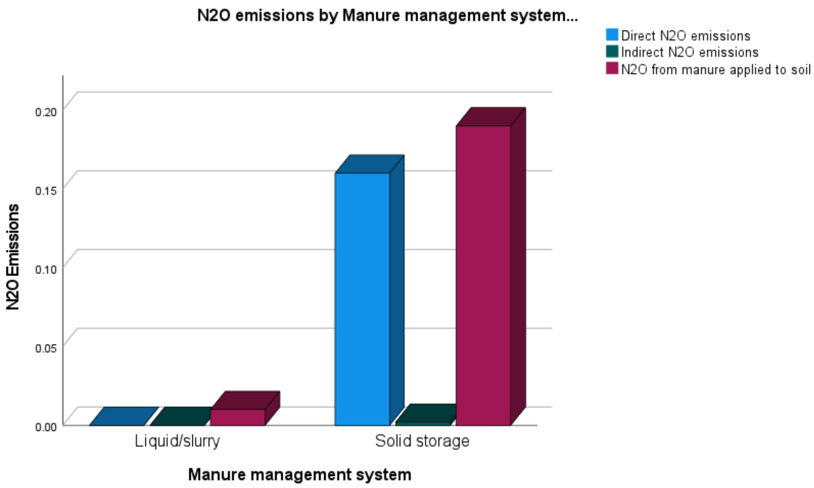

Figure 26 N_2O Emissions from Manure Management (kg CO_2eq)

4.5 Relationship between farms' size and GHGs emissions

As mentioned in Figure 25, there is no direct N_2O emissions from almost all medium farms managing manure in liquid/slurry system because the emission factor (EF) for direct emission is different according to the manure handling system. Hence, it may be assumed that the proper farms' management is the key point in GHGs emission from farms. The GHGs emission intensity (ET) in small farms ranged from 0.19 to 3.20 kg CO_2eq (Table 7 and Figure 27) while those in medium farms ranged from 0.09 to 0.2 kg CO_2eq. Furthermore, ET in Farm D (small farm), Ratchaburi was the highest whereas ET in Farm S (medium farm), Saraburi was the lowest. Moreover, ET range in Ratchaburi was 0.15-3.20 kg CO_2eq and ET range in Saraburi was 0.09-0.21 kg CO_2eq.

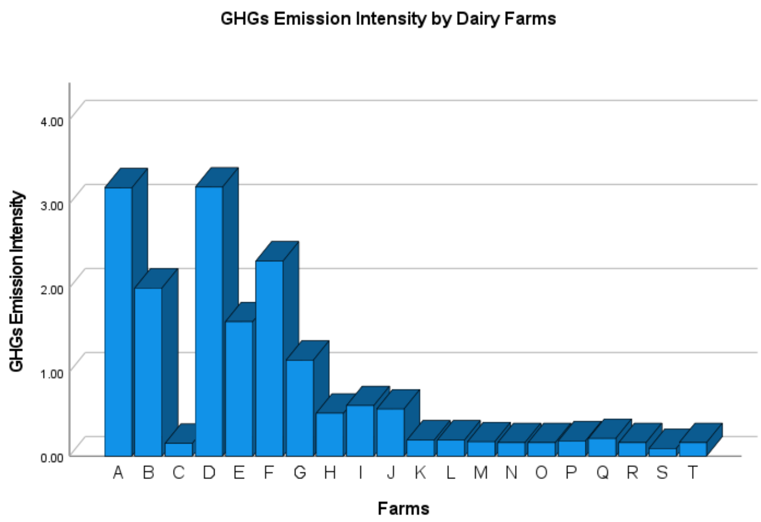

Figure 27 GHGs Emissions Intensity by Dairy Farms (kg CO_2eq)

4.6 Results of interviews

The result data from each case study in this study is mentioned in Table 9. All the production activities are not much different from each other. However, there are different in manure control systems mentioning pit system or slurry system. The small farms use solid storage manure management system whereas the medium farms use liquid/slurry manure system. Therefore, the small farms produce more emissions than the medium emissions based on the manure management systems in the farms. Moreover, stall feeding system is provided, and all the farms provide balanced feeds (same types of fiber and concentrate). Besides, the manure is applied as the fertilizer and being sold. Unexpectedly, it is found that there are no mitigation measurements for emissions reduction such as composting the manure in case of manure applied to soil as the fertilizer in all the farms.

Table 9 Result Data from the Farms

No.	Farms	No. of cows	Manure Management System	Productivity System	Live weigh of animals (Kg)	The average live body weight (Kg)	Feeding situation	Mature body weight	Fat content in milk (% by weight)	Protein content in milk (%)	Percent of females that give birth in a year in each farm	Dry Matter Intake (DMI %)
Ratchaburi Province												
1.	A	5	Solid storage	Low productivity system	500	450	Stall, Concentration feed, Hay, Corn stall	400	3.2	12	2.9	70
2.	B	6	Solid storage	Low productivity system	600	450	Stall, Concentrate feed, corn stall	400	2.6	8	3	60
3.	C	22	Liquid/slurry	Low productivity system	550	450	Hay, Fermented hay, Fermented grass	400	3	9	3	50
4.	D	5	Solid storage	Low productivity system	510	450	Stall, Concentration feed, Hay, Corn stall, pineapple	400	2.6	13	2.9	50
5.	E	7	Solid storage	Low productivity system	610	450	Stall, Concentration feed, Hay, Corn stall	400	2.6	10	2.9	70
6.	F	6	Solid storage	Low productivity system	560	450	Stall, Concentration feed, Hay, Corn stall	400	2.6	13	3.1	50
7.	G	9	Solid storage	Low productivity system	630	450	Stall, Concentration feed, Hay, Corn stall	400	3.2	13	3.1	50
8.	H	12	Solid storage	Low productivity system	520	450	Stall, Concentration feed, Hay, Corn stall, pineapple	400	2.9	9	2.9	50
9.	I	12	Solid storage	Low productivity system	650	450	Stall, Concentration feed, Hay, Corn stall, pineapple	400	2.8	11	3.1	60
10.	J	12	Solid storage	Low productivity system	510	450	Stall, Concentration feed, Hay, Corn stall, pineapple	400	2.7	12	3	70
11.	K	20	Liquid/slurry	Low productivity system	540	450	Hay, Fermented hay, Fermented grass	400	2.9	11	3.1	60

12.	L	22	Liquid/slurry	Low productivity system	640	450	Stall, Concentrate feed, corn stall	400	3.2	14	3	50
13.	M	22	Liquid/slurry	Low productivity system	540	450	Stall, Concentrate feed, corn stall, Fermented grass	400	2.8	13	3.1	60
Saraburi Province												
14.	N	24	Liquid/slurry	Low productivity system	620	450	Stall, Concentrate feed, corn stall	400	3	14	2.9	70
15.	O	21	Liquid/slurry	Low productivity system	530	450	Stall, Concentration feed, Hay, Corn stall, fermented grass	400	3	9	3.1	70
16.	P	20	Liquid/slurry	Low productivity system	510	450	Stall, Concentration feed, Hay, Corn stall, fermented grass	400	2.6	10	2.9	70
17.	Q	19	Liquid/slurry	Low productivity system	510	450	Hay, Fermented hay, Fermented grass	400	2.9	12	3.1	50
18.	R	22	Liquid/slurry	Low productivity system	570	450	Hay, Fermented hay, Fermented grass	400	2.6	12	3	70
19.	S	30	Liquid/slurry	Low productivity system	560	450	Hay, Fermented hay, Fermented grass	400	3.2	12	3.1	60
20.	T	22	Liquid/slurry	Low productivity system	570	450	Hay, Fermented hay, Fermented grass	400	3.1	10	3.1	50
How is the manure applied or used after long term storage? All responses: Fertilizer or sell them												
Are there any mitigation measures or practices to reduce GHGs emissions? All responses: No												
How do experts manage food and manure not to impact the environment? All responses: Fertilizer												
Have there been any public awareness or campaigns on environmental issues related to cattle raising regionally or around the farm area? All responses: No												
Do the dairy cattle farms have environmental monitoring or reporting scheme? All responses: No												

4.7 Uncertainty Analysis of Results

In this study, the uncertainty is attributed to some complicated reasons leading to the emission results. Initially, the data included in this study was moderately limited because of the lack of comprehensive data on the livestock system in selected province. Moreover, the value from the farms such as daily milk production, weigh gain may vary every year. There is no specific national values, which means that the country specific values in this study were applied according to the default values mentioned in IPCC 2019 guidelines (Volume 4).Moreover, we only choose the two provinces (the highest and the lowest population), there would be more appropriate if all top five provinces which produce the milk mainly in Thailand. Particularly, the consideration of emissions from transportation, processing, irrigation and energy consumption were excluded, which would certainly have an influence on the results to some extent.

Therefore, uncertainty analysis was applied according to Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (2015).

Table 10 Uncertainty Analysis

No.	Activity Data	Collecting	Score	EF	Score	Uncertainty
1.	Enteric Fermentation	Questionnaire (on site)	3	International base level	1	3
2.	Manure Management	Questionnaire (on site)	3	International base level	1	3

The uncertainty value is 3 (high uncertainty).

As this study is high uncertainty, to improve the national GHG emission inventories, the data and analysis of GHGs emissions in this study can be used. It would be good contribution to develop the data collecting, to specify the data or country emission factors, particularly the data supplying for high uncertainty.

4.8 Discussion

4.8.1 Hotspots of GHGs emissions

About 65% of the emissions from the cattle industry come from ruminants. In view of activities, there are two main sources of emissions that are feed production and enteric fermentation in ruminant animals, representing 45 and 39 percent of total emissions, correspondingly. Manure management and handling accounts 10 % globally (FAO,2006). According to the result, the enteric emission was the highest among the emissions from all activities. Habtamu Taddele Menghistu (2021) found that In Ethiopia, CH_4 emissions from animal production were the largest, followed by N_2O emissions. (Greenhouse gas emission and mitigation potential from livestock production in the drylands of Northern Ethiopia,2021). Moreover, according to US-EPA 2016, in Brazil, enteric fermentation was responsible for 72% of all CH_4 emissions, accounting for 93% of agricultural emissions. In Thailand, livestock sector contribution to GHG is more than 21.46% which is higher than the global average (14.5%) (Thailand's Third National Communication, 2018). Therefore, the emission from livestock sector should be considered as part of the sectors in emission reduction in Thailand. In addition, there are average to high emission intensities in low-income countries in livestock production because of low animal productivity, low feed quality, knowledge and investments limitation (Zh. Chitchyan. et al, 2017). Similarly, emission intensity from small farms was higher than those from medium farms, and the average is 0.19 – 3.20 kgCO_2 eq/head of cattle of GHG emission intensity in this study. Because of their high emission intensity and low productivity per animal, low- and middle-income countries are categorized. Dairy cattle in developing nations emit between 2 and 9 kg CO_2equivalents per kilogram of fat and protein corrected milk (FPCM), with just a few instances falling below 2 kg CO_2 equivalents per kilogram of FPCM. The average emission intensity is 7.5 kg CO_2-eq/kg FPCM for dairy cattle in sub-Saharan Africa (Reducing dairy emissions in developing countries ,2021).

4.8.2 How farms' management effect on GHGs emission

It was observed that emissions from small farms are more than the emissions from medium farms in this study Smallholders in livestock systems are defined in Africa and Asia by the size of their farms, which typically have animals that produce little, little high-quality feed, and a lot of low-quality feed. (F. Forabosco, Zh. Chitchyan1 & R. Mantovani2,2017). It was discovered that supplying feed with a higher digestibility will boost output while lowering CH_4 and N_2O emissions. These options, meanwhile, go against smallholders' best interests. In accordance with the result, there is negative relationship between farms' size (small and medium farms) and GHGs emissions. While maintaining the same milk yield per cow, it is predicted that improvements in grass silage quality will result in a 10% drop in emission intensities. (Bente A. Åby et al, 2019). The high-quality grass silage quality provides the maximum productivity and the lowest CH_4 emission in the production of both dairy and beef (Randby et al., 2010, 2012). Increased productivity can lower greenhouse gas emissions per kilogram of product, and superior grass silages may be a possible mitigation strategy for enteric CH_4 emission reduction (Bente A. Åby et al , 2019).According to the result data from dairy farms (Table 9), two thirds of the medium farms use fermented grass or fermented hay that can reduce the emissions. Hence, this is one of the considerations for emitting lesser in medium farms in this study.

The microbiological nitrification and denitrification processes release N_2O. Depending on how the manure is managed, the amount of N_2O produced from storage (Jan Broucek,2017). Petersen et al 1998 found that the high porosity of solid manure with a high fiber content encourages aerobic fermentation, which can increase N_2O emissions. Since initial anaerobic process and aerobic reaction are necessary for N_2O production, it was hypothesized a dry, aerobic management system can offer a setting that is more favorable for N_2O production. Furthermore, combination of aerobic and anaerobic areas is necessary for N_2O synthesis. These mixed conditions (both aerobic and anaerobic areas) cannot be occurred in slurry but deep litter. It was found that slurry manures produce significantly lesser N_2O than solid (Philippe and Nicks 2013). Kebreab et al 2006 observed that liquid manure in anaerobic nature lessens N_2O emissions. Likewise, it was observed that solid manure storage emitted more than the slurry manure storage in this study. However, based on the other findings, the results may vary as only the storage system was considered in this study.

Application of manure and fertilizer raises the mineral N content of the soil and increases N_2O emission. (Gerard L et al, 2003). Awais Shakoor et.al ,2020 found that application of manure as an organic fertilizer to soil enhances soil health and agricultural output. as well, additionally, it significantly affects GHG emissions. Similarly, In this investigation, it was discovered that among the N_2O emission sources, manure applied to soil produced the highest levels of N_2O emissions. According to the result in this study, manure applying to soil cause the environmental impact by emitting N_2O emissions. After manure is applied to the soil, considerable nitrogen losses to the air and water can occur. Hence, to reduce N losses, manure should be added to the soil when crops require it and in the amounts they require.. (Horacio Aguirre-Villegas etal, 2017).

4.8.3 Potential mitigation measures to mitigate GHGs emissions from the livestock sector

As mentioned the outcome Table 9, there are no mitigation measurements, monitoring systems and public awareness for GHGs emissions reduction in all case studies. Moreover, the farms apply the manure as the fertilizer without providing any treatment such as composting. Although there are several ways to reduce GHG emissions from cattle, manipulating feed, managing feeding, and managing manure properly is the most effective option (Bhatta, R etal, 2017). However, according to the result data from the farms and the study results, there are mainly four parts, feed and feeding management, manure management, fertilizer management, animal health and husbandry, contributing to GHGs emissions in dairy sector.

Providing alternative forages can reduce GHGs emissions. These alternate forage crops can decrease the ruminal residence time of feeds by increasing voluntary intake, which limits ruminal fermentation and encourages post-ruminal digestion. The alternate forage crops can decrease the ruminal residence time of feeds by increasing voluntary intake, which limits ruminal fermentation and encourages post-ruminal digestion. (FAO,2012). Consuming high-digestibility forages is a typical mitigation strategy for livestock, particularly ruminants, in developing nations. The generation of manure and enteric fermentation are reduced when forages are more digestible, which reduces CH_4 and N_2O emissions. (Hristov et al., 2013a). FAO (2019) mentioned that using proper feeding techniques to match animal and protein content in feed is considered as the one of the options in emissions reduction.

Degradation of natural resources, eutrophication, surface water contamination, nitrate leaching, and GHGs such as NH_3, CH_4 and other harmful gases (Hristov et al., 2013) are caused by unmanaged manure and slurry. Hence, improving manure management system including storage and operation system, using manure waste in biogas systems emissions reduction if it is possible, and converting from raw to composted manures that can significantly enhance GHGs emissions reduction (FAO,2019). Many modern methods of recycling manure waste can be used to lessen the environmental problems caused by conventional methods of managing livestock waste. Biogas technology is widely used in India, China, Germany, Malaysia, Brazil for the advantages. Initial tests of biogas bottling factories in India shown that biogas can be pure up to 98% methane concentration. It is possible to successfully fill CNG cylinders with pure biogas for use as vehicle fuel. (L. M. Sorathiya et;al, 2014).

Additionally, livestock manure included a large amount of the major nutrients (N, P, and K) as well as additional crucial plant nutrients. Providing proper management plays as a key role in emission reduction in the dairy farms. Moreover, the experts in the case study farms use manure as fertilizer. Yet, if manure is applied in huge amount, aternatively, incorrect application of manure can result in groundwater contamination or eutrophication of surface water bodies due to losses from surface runoff and leaching. (Hubbard et al. 1991). It is shown that the emission from manure applied to soil (N_2O) was the highest among N_2O emissions in this study. Hence, it would be great if the farms composting the manure before applied to soils, then it can contribute to emission reduction. Furthermore, it is feasible to reduce N_2O emissions after applying manure to soils by altering animal feed and using the proper manure application techniques. (Gerard L et.al,2003). Besides, FAO 2019 recommended that potential mitigation measurements are required such as reducing manure application rates without any treatment and incorporating the manure into soils by maintaining farm productivity for emission reduction, switching as much as possible from chemical fertilizer to organic fertilizer with a minimal carbon footprint.

Besides, reducing the number of animals (keeping only the finest animals) is another effective mitigation option, and regulatory measures could diminish the advantages of maintaining ineffective animals and encourage the intensification of livestock production. (Udo et al., 2011; Haileslassie et al., 2016). Similarly, it was observed that enhancing the genetic potential of animals through intentional crossbreeding or selection within breeds, and realizing this genetic potential through appropriate nutrition by managing the herd structures to decrease the number of ineffective animals. (FAO, 2019).

4.8.4 Uncertainty Analysis

In general, organizations should not exclude low or high uncertainty emissions sources from their analysis. This study showed that the main sources of the uncertainty are the emission factor values utilized for the CH_4 and N_2O emission factors. Therefore, the uncertainty would be lower if national GHG emissions for the cattle sector's emission components are more accurately calculated. In addition, collecting more primary data from livestock sector especially ruminant animal production would be great contribution to low uncertainty. Therefore, to reduce the uncertainty associated with this issue, it is recommended that country-specific emission factors be created or share regional experience on values derived for livestock production standards that fit the most in their environmental conditions in Thailand.

4.8.5 Limitations of this study and further recommendations for future research

Since this study has some limitations such as excluding detailed feeding ratio of roughage to concentrate, the storage situation in the farms such as closed-type or opened-type, large farms, the emissions from each process in the farms, it is necessary to explore more researches related to those limitations in Thailand. Apart from that, as mentioned already, emission can be reduced by improving genetic potential by deliberate interbreeding or breed selection, and realizing this genetic potential through appropriate nutrition. Hence, more researches evaluating the GHGs emission reduction by improving the genetic selection are needed.

Especially, in Thailand, Department of Livestock Development (2009) recommends that there are knowledge limitations on understanding new technology and acquiring the knowledge for dairy production improvement and profitability in the farmers. To reduce those limitations, dairy producers need to start the initiatives, which include systematic training and ongoing support for production development in a sustainable manner. Furthermore, because it was noted in earlier studies, regular data recording and usage has to be pushed and trained to Thai dairy producers, the farmers thought data recording was expensive and a waste of time because they didn't know how to use it in their dairy operation. By developing that situations, it will have advantage for both individual dairy farmers through improved practices and the whole dairy sector by enhancing regional and national dairy databases for potential use in production, genetic, economic, and social programs (Skorn Koonawootrittriron et;al 2010).

CHAPTER 5
Conclusion

Enteric GHGs emissions was the highest emissions among emission sources. As the enteric fermentation emission is influenced by the feeding management particularly digestibility of feed consumed, improving feeding systems and management will be able to reduce emissions. For instance, feeding fermented feed significantly increase animal performance to digestion that reduce emissions. By improving the feed quality, even many cattle are raised in the farms, the emission especially CH_4 can be reduced. In addition, emissions depend on the manure management as well. Since, there are mainly two management systems of manure, emission was higher in solid manure storage system. Hence, emissions from sources such as manure storage, manure application, housing systems should be reduced. Therefore, bedding material that cannot stimulate emission should be used and applied in solid manure storage. Since N_2O emissions depend on the coverage, for instance, using straw as coverage can reduce emissions, coverage materials (reducing the amount of wind that reaches the manure surface and lowering ammonia volatilization) are important in liquid/slurry manure storage.

According to the results in this study, installing the proper farms management system in the farms would help in emission reduction. Proper farms management includes adjusting feed ratio that means ratio of forage to concentrate ratio is 70:30 (%) for low concentrate and 40:60 (%) for high concentrate. Moreover, the Feed Quality Control Act must be followed while producing feed for dairy animals. Feed containers should be moisture-proof, clean, dry, and in good shape, if not, it can contaminate animals. For manure, store the manure in liquid form if possible. Avoid the bedding materials enhancing emission such as wheat straw, or pine wood chips Manure should be disposed regularly to prevent odor and pathogens to affect residents, neighborhoods or environment. Production management data, such as each dairy cow's history, feed and water intake, farm management, animal health and husbandry, production records, and raw milk quality test results, should also be preserved.

To reach a sustainable production, all sectors should be cooperated such as government, NGOs, farmers, community. The government should pay attention to the livestock sector even if the emission is lesser than the energy sector, and call for organizations and farmers to implement the public awareness about the negative impacts from livestock sector. As my finding observed that enteric fermentation emission was the highest in ruminant animals, it is mainly related to the feeding system (providing the fermented feeds rather than the raw roughage). To implement this, the related government office or NGOs should provide the budge (Loan) plan for farmers if necessary. The farmers should know about the both positive and negative environmental impacts of animals that they are raising.

Lastly, the livestock sector from Thailand contributes about 21.46% This is greater than the average for the world (14.5%) to GHGs emissions because there are no mitigation measurement plans in the dairy farms, in Thailand. Therefore, more research evaluating the GHGs emission reduction by considering each emission from each processing are needed e.g. emission evaluation and recommendations by using different assessment (LCA, Global Livestock Environmental Assessment Model) from high ruminant animal population areas in Thailand. In addition, it is necessary to explore more research about the bedding or coverage materials comparison for a manure storage system (using hay or wood), and feeding different feedstuffs (fermented grass, roughage, soybean) for assessing the emission from ruminant production to know the importance of those factors contribution to GHGs emissions. On top of that, the government should strict about livestock farming by reporting the scheme related to the farms' information, and the campaigns on environmental issues related to livestock raising regionally or nationally.

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APPENDIX

Detailed calculation for GHGs evaluation

REM = Ratio of Net Energy Available in a Diet for Maintenance to Digestible Energy

REG = Ratio of Net Energy Available for Growth in a Diet to Digestible Energy Consume

No.	Net Energy (Maintanance)	Net Energy (Growth)	Net Energy (Lactation)	Net Energy (Pregnancy)	REM	REG	Gross Energy	CH_4 Enteric (Kg)	CH_4 Enteric (CO_2eq /head)	CH_4 manure (Kg)	CH_4 manure (CO_2eq/head)
1.	34.04735	277853.6	33	3.404735	0.53397	0.340842	183.2502	78.12419	15.62484	0.0017	0.000068
2.	39.03636	227485.8	20.08	3.903636	0.53397	0.340842	163.9189	69.88275	11.64713	0.0017	0.000068
3.	36.57025	178091.8	24.03	3.657025	0.53397	0.340842	167.1371	71.25477	3.238853	0.0017	0.000068
4.	34.5568	277853.6	32.63	3.45568	0.53397	0.340842	183.7454	78.33531	15.66706	0.0017	0.000068
5.	39.5233	252558.5	25.1	3.95233	0.53397	0.340842	178.3694	76.04339	10.86334	0.0017	0.000068
6.	37.06781	178091.8	32.63	3.706781	0.53397	0.340842	190.9298	81.39821	13.56637	0.0017	0.000068
7.	40.49126	277853.6	35.75	4.049126	0.53397	0.340842	208.8402	89.03386	9.892651	0.0017	0.000068
8.	35.06375	252558.5	23.67	3.506375	0.53397	0.340842	161.8904	69.01796	5.751497	0.0017	0.000068
9.	41.45156	252558.5	28.49	4.145156	0.53397	0.340842	192.7041	82.15462	6.846218	0.0017	0.000068
10.	34.5568	178091.8	30.6	3.45568	0.53397	0.340842	178.4653	76.08425	6.340354	0.0017	0.000068
11.	36.07042	252558.5	28.93	3.607042	0.53397	0.340842	178.4522	76.07868	3.803934	0.0017	0.000068
12.	40.97235	227485.8	38.5	4.097235	0.53397	0.340842	217.3696	92.67015	4.21228	0.0017	0.000068
13.	36.07042	252558.5	33.67	3.607042	0.53397	0.340842	190.7812	81.33486	3.697039	0.0017	0.000068
14.	40.00826	277853.6	37.38	4.000826	0.53397	0.340842	211.698	90.2522	3.760508	0.0017	0.000068
15.	35.56827	202655.4	24.03	3.556827	0.53397	0.340842	164.2703	70.03257	3.334884	0.0017	0.000068
16.	34.5568	227485.8	25.1	3.45568	0.53397	0.340842	164.1594	69.98531	3.499265	0.0017	0.000068
17.	34.5568	202655.4	31.56	3.45568	0.53397	0.340842	180.9623	77.14879	4.060463	0.0017	0.000068
18.	37.56315	277853.6	30.12	3.756315	0.53397	0.340842	185.8184	79.21909	3.600868	0.0017	0.000068
19.	37.06781	227485.8	33	3.706781	0.53397	0.340842	191.8922	81.8085	2.72695	0.0017	0.000068
20.	37.56315	277853.6	27.1	3.756315	0.53397	0.340842	177.9632	75.87022	3.448646	0.0017	0.000068

Detailed calculation for GHGs evaluation

No.	N_2O Direct (kg)	N_2O Direct (CO2eq/head)	N_2OG	N_2OL	N_2O Indirect	N_2O from manure management (CO_2eq /head)	N_2O from manure applied soil (CO_2eq q/head)
1.	0.7755	0.1551	0.04653	0.002171	0.048701	0.203801	0.189594
2.	0.9306	0.1551	0.04653	0.002171	0.048701	0.203801	0.189594
3.	0	0	0.003545	0	0.003545	0.003545	0.011367
4.	0.7755	0.1551	0.04653	0.002171	0.048701	0.203801	0.189594
5.	1.0857	0.1551	0.04653	0.002171	0.048701	0.203801	0.189594
6.	0.9306	0.1551	0.04653	0.002171	0.048701	0.203801	0.189594
7.	1.3959	0.1551	0.04653	0.002171	0.048701	0.203801	0.189594
8.	1.8612	0.1551	0.04653	0.002171	0.048701	0.203801	0.189594
9.	1.8612	0.1551	0.04653	0.002171	0.048701	0.203801	0.189594
10.	1.8612	0.1551	0.04653	0.002171	0.048701	0.203801	0.189594
11.	0	0	0.003545	0	0.003545	0.003545	0.011367
12.	0	0	0.003545	0	0.003545	0.003545	0.011367
13.	0	0	0.003545	0	0.003545	0.003545	0.011367
14.	0	0	0.003545	0	0.003545	0.003545	0.011367
15.	0	0	0.003545	0	0.003545	0.003545	0.011367
16.	0	0	0.003545	0	0.003545	0.003545	0.011367
17.	0	0	0.003545	0	0.003545	0.003545	0.011367
18.	0	0	0.003545	0	0.003545	0.003545	0.011367
19.	0	0	0.003545	0	0.003545	0.003545	0.011367
20.	0	0	0.003545	0	0.003545	0.003545	0.011367

Activity Coefficients Corresponding to Animal's Feeding Situation

Situation	**Definition**	**C_a**
	Cattle and Buffalo (unit for C_a is dimensionless)	
Stall	Animals are confined to a small area (i.e., tethered, pen, barn) with the result that they expend very little or no energy to acquire feed.	0
Pasture	Animals are confined in areas with sufficient forage requiring modest energy expense to acquire feed.	0.17
Grazing large areas	Animals graze in open range land or hilly terrain and expend significant energy to acquire feed.	0.36

Cattle/Buffalo Methane Conversion Factors (Y_m)

Livestock category	Description	Feed quality Digestibility (DE %) and Neutral Detergent Fibre (NDF, % DMI)	MY, g CH_4 kg DMI^{-1}	Y_m[3]
[1,4]Dairy cows and Buffalo	High-producing cows[5] (>8500 kg/head/yr^{-1})	DE ≥ 70 NDF ≤ 35	19.0	5.7
	High-producing cows[5] (>8500 kg/head/yr^{-1})	DE ≥ 70 NDF ≥ 35	20.0	6.0
	Medium producing cows (5000 – 8500 kg yr^{-1})	DE 63-70 NDF > 37	21.0	6.3
	Low producing cows (<5000 kg yr^{-1})	DE ≤ 62 NDF >38	21.4	6.5

Default Values for VS Excretion Rate

Category of animal	Region																					
	North America	Western Europe	Eastern Europe	Oceania[7]	Latin America			Africa[6]			Middle East[6]			Asia			India sub-continent		
					Mean	High PS[1]	Low PS[1]	Mean	High PS	Low PS	Mean	High PS	Low PS	Mean	High PS	Low PS	Mean	High PS	Low PS
Dairy cattle[4]	9.3	7.5	6.7	6.0	7.9	9.0	7.1	18.2	21.7	15.2	10.7	8.4	11.8	9.0	8.1	9.2	14.1	9.1	16.1
Other cattle[4]	7.6	5.7	7.6	8.7	8.5	8.1	8.6	12.0	10.2	12.7	14.1	10.5	16.8	9.8	6.8	10.8	12.2	13.5	12.0
Buffalo[4]	NA	7.7	6.2	NA	11.2	NE		12.9	NE		9.8	NE		13.5	NE			NE	
Swine[3]	3.3	4.5	4.0	4.0	5.0	3.3	8.3	7.2	4.3	8.7	4.3	3.9	7.2	5.8	4.3	7.1	7.7	5.5	8.7
Finishing	3.9	5.3	4.9	5.6	6.4	4.3	10.0	8.2	5.3	9.4	4.9	4.4	7.8	6.8	5.1	8.1	8.6	6.5	9.5
Breeding	1.8	2.4	2.0	2.1	2.7	1.7	4.8	4.4	2.4	6.0	2.5	2.3	4.6	3.4	2.3	4.3	4.6	3.0	5.5
Poultry[3]	14.5	12.3	12.6	15.4	13.5	13.3	15.7	12.6	12.3	13.0	14.2	14.1	16.5	11.2	10.6	14.3	14.9	14.3	15.7
Hens ±1 yr	9.4	8.6	9.4	8.6	10.1	9.3	14.7	10.2	8.0	11.6	9.0	8.4	15.8	9.3	8.5	12.8	13.2	11.6	14.6
Pullets	5.9	5.3	5.9	6.2	7.6	5.7	18.5	12.0	5.8	16.5	6.8	5.6	18.5	7.5	5.4	17.7	13.2	6.8	18.9
Broilers	16.8	16.1	16.0	18.3	15.6	15.5	17.8	15.9	16.0	15.4	17.7	17.7	17.9	15.7	15.6	17.1	17.7	17.6	18.2
Turkeys[8]	10.3																		
Ducks[8]	7.4																		
Sheep[3]	8.2				8.3														
Goats[5]	9				10.4														
Horses[8]	5.65				7.2														
Mules/ Asses[8]	7.2																		
Camels[8]	11.5																		

Methane Conversion Factors for Manure Management Systems

System[4]		MCFs by climate zone									
		Cool				Temperate		Warm			
		Cool Temperate Moist	**Cool Temperate Dry**	**Boreal Moist**	**Boreal Dry**	**Warm Temperate Moist**	**Warm Temperate Dry**	**Tropical Montane**	**Tropical Wet**	**Tropical Moist**	**Tropical Dry**
Uncovered anaerobic lagoon[7]		60%	67%	50%	49%	73%	76%	76%	80%	80%	80%
Liquid/Slurry, and Pit storage below animal confinements[1]	1 Month	6%	8%	4%	4%	13%	15%	25%	38%	36%	42%
	3 Month[8]	12%	16%	8%	8%	24%	28%	43%	61%	57%	62%
	4 Month[9]	15%	19%	9%	9%	29%	32%	50%	67%	64%	68%
	6 Month[9]	21%	26%	14%	14%	37%	41%	59%	76%	73%	74%
	12 Month[9]	31%	42%	21%	20%	55%	64%	73%	80%	80%	80%
Cattle and Swine deep bedding (cont.)[5]	> 1 month[10]	21%	26%	14%	14%	37%	41%	59%	76%	73%	74%
Cattle and Swine deep bedding	< 1 month[11]	2.75%				6.50%		18%			
Solid storage[6,12]		2.00%				4.00%		5.00%			
Solid storage – Covered/compacted[6, 13]		2.00%				4.00%		5.00%			
Solid storage – Bulking agent addition[6, 14]		0.50%				1.00%		1.50%			
Solid storage – Additives[6, 15]		1.00%				2.00%		2.50%			
Dry lot[16]		1.00%				1.50%		2.00%			
Daily spread[17]		0.10%				0.50%		1.00%			

Table 10.14 (Updated)
Methane Emission Factors by animal category, manure management system and climate zone (g CH_4 kg VS^{-1}) [7]

Livestock species	Productivity Class	Manure Storage System[4]	Cool				Temperate		Warm			
			Cool Temp. Moist	**Cool Temp. Dry**	**Boreal Moist**	**Boreal Dry**	**Warm Temp. Moist**	**Warm Temp. Dry**	**Tropical Montane**	**Tropical Wet**	**Tropical Moist**	**Tropical Dry**
Dairy Cattle	High Productivity	Uncovered anaerobic lagoon	96.5	107.7	80.4	78.8	117.4	122.2	122.2	128.6	128.6	128.6
		Liquid/Slurry, Pit storage > 1 month [5]	33.8	41.8	22.5	22.5	59.5	65.9	94.9	122.2	117.4	119.0
		Solid storage	3.2				6.4		8.0			
		Dry lot	1.6				2.4		3.2			
		Daily spread	0.2				0.8		1.6			
		Anaerobic Digestion - Biogas[8]	3.2				3.7		3.7			
		Burned for fuel	16.1									
	Low Productivity	Uncovered anaerobic lagoon	52.3	58.4	43.6	42.7	63.6	66.2	66.2	69.7	69.7	69.7
		Liquid/Slurry, Pit storage > 1 month [5]	18.3	22.6	12.2	12.2	32.2	35.7	51.4	66.2	63.6	64.5
		Solid storage	1.7				3.5		4.4			
		Dry lot	0.9				1.3		1.7			
		Daily spread	0.1				0.4		0.9			
		Anaerobic Digestion - Biogas[8]	9.2				9.5		9.5			
		Burned for fuel	8.7									

Default Values for B0

TABLE 10.16 (UPDATED)
DEFAULT VALUES FOR MAXIMUM METHANE PRODUCING CAPACITY (B_0) (m^3 CH_4 kg^{-1} VS)

Category of animal [2]	Region					
	North America	Western Europe	Eastern Europe	Oceania	Other Regions[1]	
					High productivity systems	Low productivity systems
Dairy cattle	0.24				0.24	0.13
Non dairy cattle	0.19	0.18	0.17	0.17	0.18	0.13
Buffalo	0.10				0.10	0.10
Swine	0.48	0.45	0.45	0.45	0.45	0.29
Chicken-Layer	0.39				0.39	0.24
Chicken-Broilers	0.36				0.36	0.24
Sheep	0.19				0.19	0.13
Goats	0.18				0.18	0.13
Horses	0.30				0.30	0.26
Mules/ Asses	0.33				0.33	0.26
Camels	0.26				0.26	0.21
All Animals PRP	0.19					

Default Values for AWMS

TABLE 10A.6 (NEW)
ANIMAL WASTE MANAGEMENT SYSTEM (AWMS) REGIONAL AVERAGES FOR CATTLE AND BUFFALO

Animal Category	Climate and System Based Category	AWMS (%)								
		Lagoon	Liquid /Slurry	Solid storage	Drylot	Pasture/ Range/ Paddock	Daily spread	Digester	Burned for fuel	Other
Dairy Cattle	North America	26	24	24	0	15	11	0	0	0
	Western Europe	0	43	29	0	26	2	0	0	0
	Eastern Europe	0	5	74	0	20	1	0	0	0
	Oceania	5	0	0	0	94	1	0	0	0
	East Asia and South-East Asia (Asia)	0	1	21	29	38	0	0	11	0
	South Asia (Indian subcontinent)	0	0	1	49	30	0	0	20	0
	Latin America and the Caribbean	0	0	5	38	57	0	0	0	0
	Near East (Middle East) and North Africa	0	0	14	35	46	0	0	5	0
	Sub-Saharan Africa	0	0	20	29	45	0	0	6	0

Suggested Emissions Inventory Methods for Enteric Fermentation

Livestock	Suggested emissions inventory methods
Dairy Cow	Tier 2[a]/Tier 3
Other Cattle	Tier 2[a]/Tier 3
Buffalo	Tier 1/Tier 2
Sheep	Tier 1/Tier 2
Goats	Tier 1/Tier 2
Camels	Tier 1
Horses	Tier 1
Mules and Asses	Tier 1
Swine	Tier 1
Poultry	Not developed
Other (e.g., Llamas, Alpacas, Deer, Ostrich)	Tier 1

TABLE 10.2 (UPDATED)
REPRESENTATIVE FEED DIGESTIBILITY FOR VARIOUS LIVESTOCK CATEGORIES

Main categories	Class	Digestibility (DE as percent)
Swine[1]	Mature Swine – confinement	70 - 80
	Growing Swine - confinement	80 - 90
	Swine – free range	50 - 70
Cattle and other ruminants	Feedlot animals fed with > 85% concentrate or high-grain diet;	72 - 85
	Pasture / mixed-diet fed animals;	55 - 80
	Animals fed – low quality forage	45 - 55
Poultry[1]	Broiler Chickens –confinement	85 - 93
	Layer Hens – confinement	70 - 80
	Poultry – free range	55 - 90[1]
	Turkeys – confinement	85 - 93
	Geese – confinement	80 - 90

Emission Factors (2019 Refinement to 2016 IPCC guidelines, 2019)

No.	Manure storage system	EF	EF_1	EF_{1FR}	EF_3	EF_4	EF_5	$Frac_{Gas}$	$Frac_{Leach}$	$Frac_{GasMS}$	$Frac_{Leach\_MS}$
1.	Solid	68	0.01	0.004	0.01	0.01	0.007	0.3	0.02	0.3	0.02
2.	Liquid	68	0.01	0.004	0.01	0.01	0.007	0.1	0	0.48	0

Equation explanation

(UE • GE) = urinary energy expressed as fraction of GE. Typically, 0.04GE can be considered urinary energy excretion by most ruminants.
1000 = conversion from g protein to kg protein
18.45= conversion factor for dietary GE per kg of dry matter, MJ kg^{-1}
268 and 7.03 = constants from Equation 3-8 in NRC (1996)
365= number of days in a year
44 / 28= conversion of N_2O-N(mm) emissions to N_2O(mm) emission
55.65 (MJ/kg CH_4) = the energy content of methane
6.25= conversion from kg of dietary protein to kg of dietary N, kg feed protein (kgN^{-1})
6.38=conversion from milk protein to milk N, kg Protein (kg N) $^{-1}$
ASH = the ash content of feed calculated as a fraction of the dry matter feed intake
$AWMS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species, dimensionless
$AWMS_{(T,S,k)}$ = fraction of livestock category T's manure handled using animal waste management system S in climate region k, dimensionless
$AWMS_{(T,S,P)}$ = fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the country, for productivity system P, when applicable, dimensionless
$EF_{3(S)}$ = emission factor for direct N_2O emissions from manure management system S in the country, kg N_2O-N/kg N in manure management system S
$B_{0(T)}$ = maximum methane producing capacity for manure produced by livestock category T, m^3 CH_4 kg^{-1} of VS excreted
0.67 = conversion factor of CH_4 to kilograms CH_4
BW= the average live body weight (BW) of the animals in the population, kg
Ca = a coefficient with a value of 0.8 for females, 1.0 for castrates and 1.2 for bulls (NRC, 1996) *
Cfi = a coefficient which varies for each animal category, MJ day^{-1} Kg $^{-1}$(Cfi=0.386)
CP% = percent crude protein in dry matter for growth stage “i”
$C_{pregnancy}$ = pregnancy coefficient ($C_{pregnancy}$ = 0.10)
DE= digestibility of the feed in percent
DMI = dry mater intake per day during a specific growth stage
E i, p = the emission for the livestock categories and subcategories based on production systems (P)
EF = emission factor, kg CH_4 head-1 yr^{-1}

$EF_{(T)}$ = annual CH_4 emission factor for livestock category, kg CH_4 animal-1 yr^{-1}
EF_4 = emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N_2O -N (kg NH_3-N + NOx-N volatilised)$^{-1}$
EF_5 = emission factor for N_2O emissions from nitrogen leaching and runoff, kg N_2O -N/kg N leached and runoff
Fat= fat content of milk, percent by milk
$FracgasMS_{(T, S)}$ = fraction of managed manure nitrogen for livestock category T that volatilises as NH_3 and NOx in the manure management system
$FracLeachMS_{(T,S)}$ = fraction of managed manure nitrogen for livestock category T that is leached from the manure management system S
GE= gross energy intake, MJ head-1 day^{-1}
$MCF_{(S,k)}$ = methane conversion factors for each manure management system S by climate region k, percent
MILK = milk production, kg animal-1 day-1 (applicable to dairy cows only)
Milk PR% = percent of protein in milk, calculated as [1.9 + 0.4 ● %Fat], where %Fat is an input, assumed to be 4% (applicable to dairy cows only)
MW=the mature body weight of an adult animal individually, mature female, mature males ans steers) in moderate body condition, kg
N $intake_{(T)}$ = the daily N intake per head of animal of species/category T, kg N $animal^{-1}day^{-1}$
$N_{(T,P)}$ = number of head of livestock species/category
$N_2O_{L(mm)}$ = indirect N_2O emissions due to leaching and runoff from Manure Management in the country, kg N_2O yr^{-1}
$N_2O_{D(mm)}$ = direct N_2O emissions from Manure Management in the country, kg N_2O yr^{-1}
$N_2O_{G (mm)}$ = indirect N_2O emissions due to volatilization of N from Manure Management in the country, kg N_2O yr^{-1}
NE_a= net energy for animal activity, MJ day^{-1}
NEg = net energy needed for growth, MJ day-1
Neg= net energy for growth, calculated in livestock characterization, based on current weight, mature weight, rate of weight gain, and IPCC constants, MJ day^{-1}
NEl = net energy for lactation, MJ day-1
NE_l = net energy for lactation, MJ day^{-1}
NEm = net energy required by the animal for maintenance, MJ day^{-1}
NE_m = net energy required by the animal for maintenance, MJ day^{-1}
NEm= net energy required by the animal for maintenance, MJ day^{-1}
NE_p = net energy required for pregnancy, MJ day^{-1}
NE_p = net energy required for pregnancy, MJ day^{-1}
$Nex_{(T)}$ = annual N excretion rates, kg N animal-1 yr-1
$Nex_{(T,P)}$ = annual average N excretion per head of species/category in kg N animal-1 yr^{-1}
$N_{intake(T)}$ = daily N consumed per animal of category T,kg N $animal^{-1}day^{-1}$, per growth stage $^{-1}$
$N_{leaching-MMS}$ = amount of manure nitrogen that is lost due to leaching, kg N yr^{-1}
$N_{leaching-MMS}$ = amount of manure nitrogen that is lost due to leaching, kg N yr^{-1}
$N_{retention(T)}$ = amount of daily N intake by head of animal of species/category T, that is retained by animal of species/category T, kg N animal-1 day^{-1}
$N_{retention(T)}$ = daily N retained per animal of category, kg N $animal^{-1}day^{-1}$

$N_{volatilization-MMS}$ = amount of manure nitrogen that is lost due to volatilisation of NH_3 and NOx, kg N yr^{-1}
P= productivity class, high or low
REG = ratio of net energy available for growth in a diet to digestible energy consumed
DE = digestibility of feed expressed as a fraction of gross energy (digestible energy/gross energy)
REM = ratio of net energy available in a diet for maintenance to digestible energy
Neg= net energy needed for growth, MJ day^{-1}
S= manure management system
T= species/category of livestock
Total CH_4 Enteric = total methane emissions from enteric fermentation, Gg CH_4 yr^{-1}
VS = volatile solid excretion per day on a dry-organic matter basis, kg VS day-1
$VS_{(T)}$ = daily volatile solid excreted for livestock category, kg dry matter $animal^{-1}$ day^{-1}
Weight =live-weight of animal, kg
WG= the average daily weight gain of the animals in the population, kg day-1
Ym= methane conversion factor, per cent of gross energy in feed converted to methane

DATA RECORD FORM

Farm's Name - Researcher-

Province –

Date –

Questions			**Responses**
1.	Productivity System	(a) High productivity system? (>8500 kg/head/yr) (Grazing on high quality pasture with supplement. Production is 100 % market commercial milk production for national market and or export.) (b) Medium – 5000-8500 kg/yr (c) Low productivity system? (<5000 kg/yr) (Using locally produced roughage and agro-industrial by-products. Production is for local market and local consumption.)	
2.	Live weigh of animals (Kg)	Weight of a living animal before it is slaughtered for meat	

3.	The average live body weight of animals in population (Kg)	-	
4.	The average daily weight gain	-	
5.	Feeding situation	Stall, Pasture, Grazing large areas, Crude protein content in diet	
6.	Mature body weight of an adult animal	Body weight at which skeletal development is complete	
7.	Fat content in milk (% by weight)		
8.	Average daily milk production (Kg/day)		
9.	Protein content in milk (%)	-	
10.	Percent of females that give birth in a year in each farm	-	
11.	DMI %	-	
12.	Manure management system	Uncovered anaerobic lagoon, Liquid/slurry, Pit storage, Solid storage, Dry Lot, Daily spread, Anaerobic digestion-biogas, Burned for fuel	
13.	How is the manure applied or used after long term storage?		
	Responses:		
14.	Are there any mitigation measures or practices to reduce GHGs emissions?		
	Responses:		
15.	How do experts manage food and manure not to impact the environment?		
	Responses:		

16.	Have there been any public awareness or campaigns on environmental issues related to cattle raising regionally or around the farm area?
	Responses:
17.	Do the dairy cattle farms have environmental monitoring or reporting scheme?
	Responses:

The Research Ethics Review Committee for Reseach Involving Human Research Participants, Group I, Chulalongkorn University
Chamchuri 1 Building, 2nd Floor, 254 Phayathai Road, Pathumwan, Bangkok 10330 Thailand
Telephone: 02-218-3202, 02-218-3049 Email: eccu@chula.ac.th

COA No. 201/65

Certificate of Approval

Study Title No. 650135 : ASSESSMENT OF GREENHOUSE GASES EMISSIONS FROM DAIRY CATTLE PRODUCTION IN THAILAND

Principal Investigator : Ms. Phoo Pwint Pwint Thu

Place of Proposed Study/institution : Graduate School, Chulalongkorn University

The Research Ethics Review Committee for Research Involving Human Research Participants, Group I, Chulalongkorn University, Thailand, has approved constituted in accordance with Belmont Report 1979, Declaration of Helsinki 2013, Council for International Organizations of Medical Sciences (CIOM) 2016, Standards of Research Ethics Committee (SREC) 2017, and National Policy and guidelines for Human Research 2015.

Signature	**Signature**
(Associate Prof. Prida Tasanapradit)	(Assistant Prof. Dr. Raveenan Mingpakanee)
Chairman	Secretary
Date of Approval : 17 October 2022	**Approval Expire date :** 16 October 2023

The approval documents including:

1. Participant Information Sheet and Consent Form
2. Research proposal
3. Researcher
4. Research instruments/tools

Conditions

The approved investigator must comply with the following conditions:

1. It's unethical to collect data of research participants before the project has been approved by the committee.
2. The research/project activities must end on the approval expired date. To renew the approval, it can be applied one month prior to the expired date with submission of progress report.
3. Strictly conduct the research/project activities as written in the proposal.
4. Using only the documents that bearing the RECCU's seal of approval: research tools, information sheet, consent form, invitation letter for research participation (if applicable).
5. Report to the RECCU for any serious adverse events within 5 working days.
6. Report to the RECCU for any amendment of the research project prior to conduct the research activities.
7. Report to the RECCU for termination of the research project within 2 weeks with reasons.
8. Final report (AF 01-15) and abstract is required for a one year (or less) research/project and report within 30 days after the completion of the research/project.
9. Research project with several phases; approval will be approved phase by phase, progress report and relevant documents for the next phase must be submitted for review.
10. The committee reserves the right to site visit to follow up how the research project being conducted.
11. For external research proposal the dean or head of department oversees how the research being conducted

Digital Certificate

Study Title No. 650135
Date of Approval 17 Oct 2022
Approval Expire date 16 Oct 2023

VITA

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