INITIATIVE FOR CLIMATE ACTION TRANSPARENCY PROJECT: SET UP OF SECTORAL MRV SYSTEMS FOR THE AGRICULTURE SECTOR

Fiji Agriculture Livestock Emissions

Guidance Document & User Manual

DISCLAIMER

PREPARED UNDER

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1. Introduction

The National Greenhouse Gas Inventory (NGGI) is compiled using the 2006 IPCC Guidelines for NGGI that has been divided into 5 volumes. This guidance document focuses primarily on Volume 4. Agriculture, Forestry and Other Land Uses (AFOLU), looking particularly at Enteric Fermentation and Manure Management as key category[1] sources for methane (CH_4) and nitrous oxide (N_2O) emission from the agriculture sector in Fiji.

There are three different methodologies[2] that are used to determine the GHG emissions from enteric fermentation and manure management; Tier 1, Tier 2 and Tier 3. The pros and cons of each methodology are discussed in Table 1.

Table 1: IPCC Inventory Tier Structure

Tier Level	Pros	Cons
Tier 1	• Basic • Require minimum information regarding activity data. • Use default values provided in the 2006 IPCC Guidelines for NGGI.	• Does not capture country specific national circumstances. • Potentially have large uncertainties.
Tier 2	• Use country and region specific emission factors. • Has reduced uncertainty compared to Tier 1.	• Is more complex, thus requires detailed activity data.
Tier 3	• Detailed country specific modelling. • Has the ability to test mitigation strategies using simulations. • Potentially low uncertainties.	• Model calibration/ validation may lack diversity. • It is considerably difficult to collect high resolution spatial data.

[1] Prominent source or sink for GHG's [2] "Good Practice" is to use advanced methodologies (Tier 2 or Tier 3) for Key Categories (depending on data availability for the specific country)
https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf

2. Emissions from Livestock and Manure Management

2.1. Methane Emissions from Enteric Fermentation

Herbivores produce methane as a by–product of enteric fermentation where food is broken down in the digestive system of animals by micro–organisms. The amount of CH_4 emitted depends on:

- Digestive tract
- Age
- Weight of the animal
- Quality and quantity of feed consumed by the animal.

NOTE: ruminant animal (cattle, buffalo, sheep, goats, deer, camels) produce more CH_4 compared to non–ruminants (horses, mules/asses, swine) due to the presence of rumen (a chamber in the fore – part of the digestive tract that allows for intensive microbial fermentation of the food intake, particularly cellulose).

2.1.1 Choice of Methodology

The choice of methodology is influenced by the availability of country - specific data for key category species. The appropriate method for the determination of CH_4 emissions from enteric fermentation can be selected using the flowchart below:

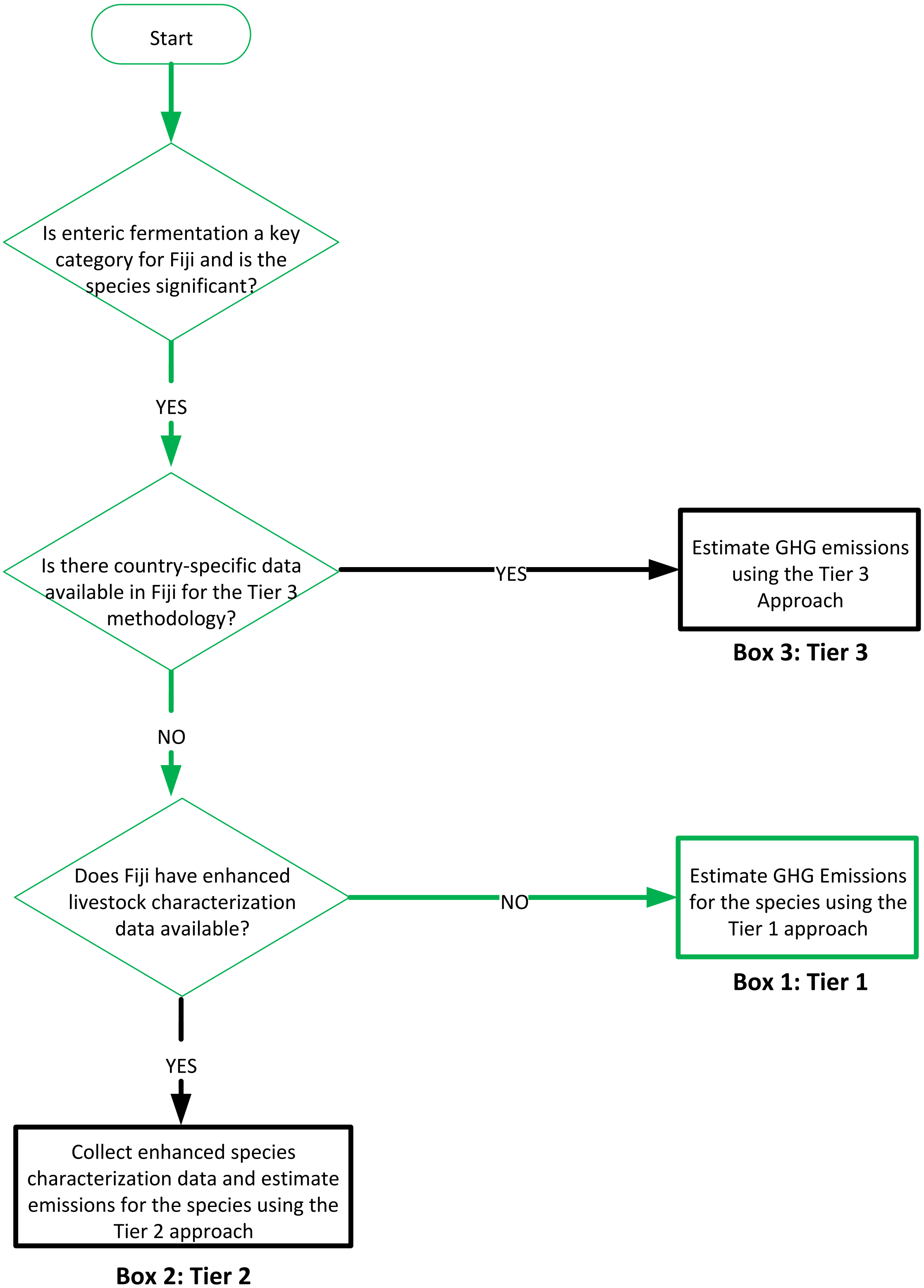


Fig.1: Fiji – Specific decision tree for methane emissions from enteric fermentation

The decision tree provided in the 2006 IPCC Guidelines for NGGI for CH_4 emissions from enteric fermentation was redesigned using the country – specific information available for Fiji in Fig.1 with the decision pathway highlighted in green. Given that methane emission from enteric fermentation is a key category with a significant livestock population in Fiji, the emissions must be included in the NGGI. The Tier 1 approach is generally used for non – key categories whereas Tier 2 and Tier 3 approaches are used for key categories. However, if enhanced characterisation data or country specific information (such as emission factors) are unavailable, the Tier 1 approach can be used for a key category. Moreover, when the emission estimates for enteric fermentation are derived by extrapolation from the main livestock category, it should be considered as a Tier 1 method as well. Therefore, the Tier 1 approach will be applied to estimate CH_4 emissions from enteric fermentation using default values from the 2006 IPCC guidelines.

2.1.2 Steps for Estimating CH_4 Emission from Enteric Fermentation – Tier 1 Method

As illustrated in the decision tree for CH_4 emissions from enteric fermentation, the Tier 1 approach is most applicable for Fiji due to the lack of country specific data. When estimating emissions, the generic equation that is used to calculate GHG emissions is:

$$\boldsymbol{GHG\ Emissions = Activity\ Data \times Emission\ Factors}$$

Where:

Activity Data: magnitude of human activity (number of animals, fertilizer applied, etc).

Emission Factor: coefficients for the emissions or removals per unit of activity data.

The generic equation is further simplified to estimate the CH_4 emissions from enteric fermentation. Prior to emission estimation, a number of steps must be followed to ensure correct data and default values are chosen for calculation. These steps are discussed as follows:

Step 1: Divide the livestock population into subgroups and characterise them as per Section 10.2. For the Tier 1 approach, the basic characterisation method is used for livestock population and it is a good practice to collect the following livestock characterisation data to support the emission estimates:

a. *Livestock Species Characterisation:* develop a complete list of all livestock population that have a default emission factor available as per the IPCC guidelines (e.g., dairy cows, other cows, swine, horses, sheep, goat, poultry, etc.). If more detailed category data is available for Fiji, these can be further classified to sub–categories (breeding swine, market swine, broilers, layers, ducks, other poultry, etc.).

b. *Animal population:* For the Tier one approach, readily available animal population data is needed to estimate the emissions. The Annual Average Population (AAP) must be used to take into consideration the production cycle and seasonal influences on the population numbers. For static animals (dairy cows, breeding swine, layers), the AAP may be equivalent to the one –time annual animal inventory data. However, the AAP for growing population (meat animals such as beef cattle, turkey, market swine) would require more evaluation as these populations are alive only for a portion of the year. Animals should be included in the populations regardless of whether it was slaughtered for human consumption or died due to natural causes. The equation below can be used to calculate the AAP:

c.

$$AAP = Days\_alive \bullet \left(\frac{NAPA}{365}\right)$$

Where:
AAP = Average annual population (number per year)
NAPA = number of animals produced annually

Source: Equation 10.1 from Chapter 10 of the 2006 IPCC Guideline for NGGI.

The accurate recording and reporting of livestock species characterisation and animal population should be the responsibility of the Director Animal Health and Production. The Director must delegate the task of identifying the respective livestock categories as per IPCC guidelines and total population headcount to the respective officers within the Animal Health and Production department, while providing guidance and supervision.

Example

Broiler chicken are typically grown for 60 days before slaughter. If the operation grew 60,000 broilers over a period of one year, calculate the AAP.

The equation for this example would be:

$$AAP = Days\_alive \bullet \left(\frac{NAPA}{365}\right)$$

$$AAP = 60 \times \left(\frac{60000}{365}\right)$$

$$\underline{\boldsymbol{AAP = 9863\ Broilers}}$$

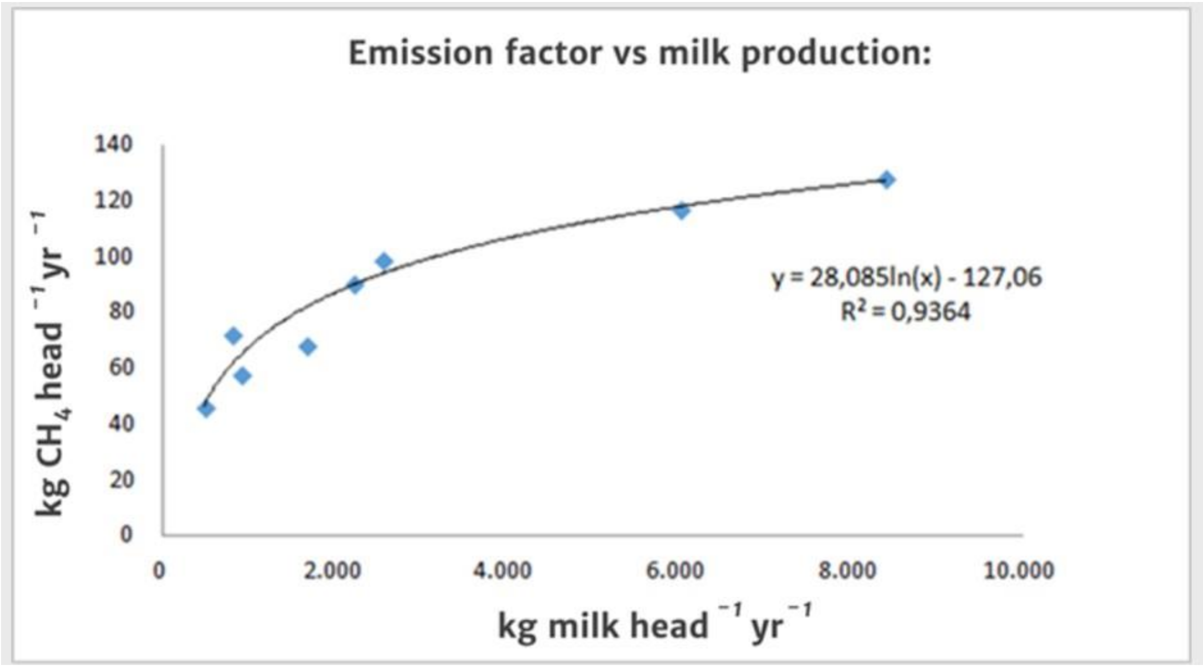
NOTE: if official or national data is not available, use reliable data from other sources (e.g., Food and Agriculture Organization Corporate Statistical Database (FAOSTAT), interpolation, extrapolation, surrogate data, seek expert advice from people in the industry and check whether the numbers look realistic or not (adjust if necessary).

Step 2: Estimate the emission factors for each subgroup in terms of kg CH_4 animal^{-1} yr^{-1}. For the Tier 1 method, the default emission factors are presented for each of the recommended population groups. The default emission factors have been drawn from previous studies and are organised by region for ease of use (refer to Table 10.11 from Chapter 10 of the 2006 IPCC Guideline for NGGI for the default emission factors. These default emission factors have been estimated using the data available in Annex 10A.1 in Chapter 10 of the 2006 IPCC Guideline for NGGI). Table 10.11 only represents the default emission factors for cattle (dairy and other cattle) and Table 10.10 shows default emission factors from enteric fermentation for the other animal species.

IMPORTANT: When selecting emission factors from Table 10.10 and 10.11 of the 2006 IPCC Guideline for NGGI, identify the region that is most applicable to the country being evaluated. Scrutinise the tabulations in Annex 10A.1 to ensure that the underlying animal characteristics such as weight, growth rate and milk production used to develop the emission factors are similar to the conditions in the country. The data collected on the average annual milk production by dairy cows is a good proxy to help select the dairy cow emission factor. If necessary, interpolate between dairy cow emission factors shown in Table 10.11 using the data collected on average annual milk production per head for Fiji.

Example:

For Fiji, the default emission factor for dairy cattle that can be identified form Table 10.11 as 100 kg CH_4 $head^{-1}yr^{-1}$. However, this value is applicable if the dairy cattle have an average milk production of 2200 kg $head^{-1}$ $yr^{-1.}$ According to FAOSTAT, the annual milk production is 1200 kg $head^{-1}$ yr^{-1}. Using the milk production data from Table 10.11 (refer to column on Comments), it can be interpolated to determine the emission factor at 1200 kg $head^{-1}$ yr^{-1}.



Using the equation $y = 28.085 \ln(x) - 127.06$, the adjusted Emission Factor (EF) is 72. The readjusted EF is in line with that of Latin America (Table 10.11) and also indicated that milk production in Fiji is 2.2 kg milk day^{-1} as opposed to 6.0 kg milk day^{-1}. Adjustment of the emission factor allows the eradication of over or under estimation of methane emission for the purpose of the NGGI.

STEP 3: Calculate the total emission by using the selected emission factors and multiplying it to the associated animal production (Equation 10.19) and, finally, sum the values to get the total emissions (Equation 10.20).

NOTE: the IPCC provides worksheets in MS Excel spreadsheet to assist users of the guidelines for estimating GHG emissions for NGGIs.

EQUATION 10.19
ENTERIC FERMENTATION EMISSIONS FROM A LIVESTOCK CATEGORY

$$Emissions = EF_{(T)} \bullet \left(\frac{N_{(T)}}{10^6} \right)$$

Where:

Emissions = methane emissions from Enteric Fermentation, Gg CH_4 yr^{-1}

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

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

T = species/category of livestock

EQUATION 10.20
TOTAL EMISSIONS FROM LIVESTOCK ENTERIC FERMENTATION

$$\text{Total } CH_{4\,Enteric} = \sum_i E_i$$

Where:

Total $CH_{4_{Enteric}}$ = total methane emissions from Enteric Fermentation, Gg CH_4 yr^{-1}

E_i = is the emissions for the i^{th} livestock categories and subcategories

Example 1

Using the data provided below, calculate the total methane emission for dairy and beef cattle. Conduct the calculations using the emission factor stated in Table 10.11 and the readjusted value for comparison.

There are 309000 cows where 50% are dairy cattle and 50% are beef cattle. Assume that the beef cattle have a life span of more than a year.

Solution

Sector	**Agriculture, Forestry and Other Land Use**				
Category	**Methane Emissions from Enteric Fermentation and Manure Management**				
Category code	**3A1 and 3A2**				
Sheet	**1 of 1**				
Equation	**Equation 10.19**		**Eq. 10.19 and 10.20**	**Using re - adjusted values**	
Species/Livestock category	Number of animals	Emission factor for Enteric Fermentation	CH_4 emissions from Enteric Fermentation	Emission factor for Enteric Fermentation	CH_4 emissions from Enteric Fermentation
	(head)	(Kg $head^{-1}$ yr^{-1})	(Gg CH_4 yr^{-1})	(Kg $head^{-1}$ yr^{-1})	(Gg CH_4 yr^{-1})
		Tables 10.10 and 10.11	$CH_{4\ Enteric} = N_{(T)} * EF_{(T)} * 10^{-6}$	Tables 10.10 and 10.11	$CH_{4\ Enteric} = N_{(T)} * EF_{(T)} * 10^{-6}$
T	**$N_{(T)}$**	**$EF_{(T)}$**	**$CH_{4\ Enteric}$**	**$EF_{(T)}$**	**$CH_{4\ Manure}$**
Dairy Cattle	154500	100	15.45	72	11.124
Beef Cattle	154500	60	9.27	60	9.270
Total Emission			24.72		20.394

The total emission would be overestimated by 4.33 Gg CH_4 yr^{-1}.

NOTE: Using country specific data that may be available allows accurate estimate of the methane emissions. The emission factor for beef cattle is not readjusted and is for the Oceania region.

Example 2

Using the information provided below, determine the total methane emissions. Also incorporate the adjusted emissions from the earlier example.

There are a total of 11268 sheep, 250500 goats, 46000 Horses and 145700 swine (50% breeding and 50% for market with a lifespan of 6 months before slaughter).

Solution

Sector	**Agriculture, Forestry and Other Land Use**		
Category	**Methane Emissions from Enteric Fermentation**		
Category code	**3A1 and 3A2**		
Sheet	**1 of 1**		
Equation	**Equation 10.19**		**Eq. 10.19 and 10.20**
Species/Livestock category	Number of animals	Emission factor for Enteric Fermentation	CH_4 emissions from Enteric Fermentation
	(head)	(Kg head^{-1} yr^{-1})	(Gg CH_4 yr^{-1})
		Tables 10.10 and 10.11	$CH_{4\ Enteric} = N_{(T)} * EF_{(T)} * 10^{-6}$
T	**$N_{(T)}$**	**$EF_{(T)}$**	**$CH_{4\ Enteric}$**
Dairy Cattle	154500	72	11.124
Beef Cattle	154500	60	9.270
Sheep	11268	5	0.056
Goats	250500	5	1.253
Horses	46000	18	0.828
Swine (breeding)	72850	1	0.073
Swine (Market)	36425	1	0.036
Total Emissions			**22.640**

NOTE: For swine, the AAP has to be calculated for those that are bred for market and are slaughtered within 6 months. The avian population, such as poultry and ducks, are given but it is not used to calculate emission for enteric fermentation but is used in manure management calculations.

2.2. Methane Emissions from Manure Management

In addition to enteric fermentation, CH_4 is also produced during the storage and treatment of manure [2] as well as from manure that has been deposited on pasture during grazing. The decomposition of manure under anaerobic[3] conditions, during storage and treatment, leads to the production of CH_4. Such conditions occur more readily when large numbers of animals are managed in a confined area (e.g., dairy farms, feedlots and swine and poultry farms) and where manure is deposited into a liquid – based manure management system [4](MMS).

The main factors affecting CH_4 emissions include the:

- Amount of manure produced by livestock – depends on the rate of waste production per animal and the number of animals (per each category or sub- category.
- Feed composition.
- Portion of manure that decomposes anaerobically – depends on the MMS.

What is impact of MMS's on CH_4 production?

a. When manure is stored or treated as a liquid[6], it decomposes anaerobically and produces a significant amount of CH_4.
b. When manure is stored or treated as a solid or when deposited on pastures and rangelands, it tends to decompose under aerobic conditions, thus, producing less CH_4.
c. Temperature, pH and retention time affect the amount of CH_4 production – increase in temperature and low pH (acidic condition) provides favourable conditions for anaerobic micro – organisms to decompose manure and produce high amounts of CH_4.
d. Chemical composition – high nitrogen content in the manure promotes anaerobic conditions. this is also influenced by the feed composition.

NOTE: emissions from the burning of dung for fuel are reported under "Energy" or under "Waste" if it is burned without energy recovery. However, biomass energy from cow dungs is not relevant to Fiji.

2.2.1. Choice of Methodology

There are three tiers that can be used to estimate CH_4 emissions from livestock manure management. The guidance provided in the figure below form Chapter 10 of the 2006 IPCC Guidelines on NGGI can be used to determine the appropriate method.

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[2] includes both dung and urine, i.e. he solid and liquid waste produced by livestock.
[3] Absence of oxygen
[4] The definition for the different MMS can be found in Table 10.18 of the 2006 IPCC Guidelines for NGGI. [6]
In lagoons, ponds, tanks or pits.

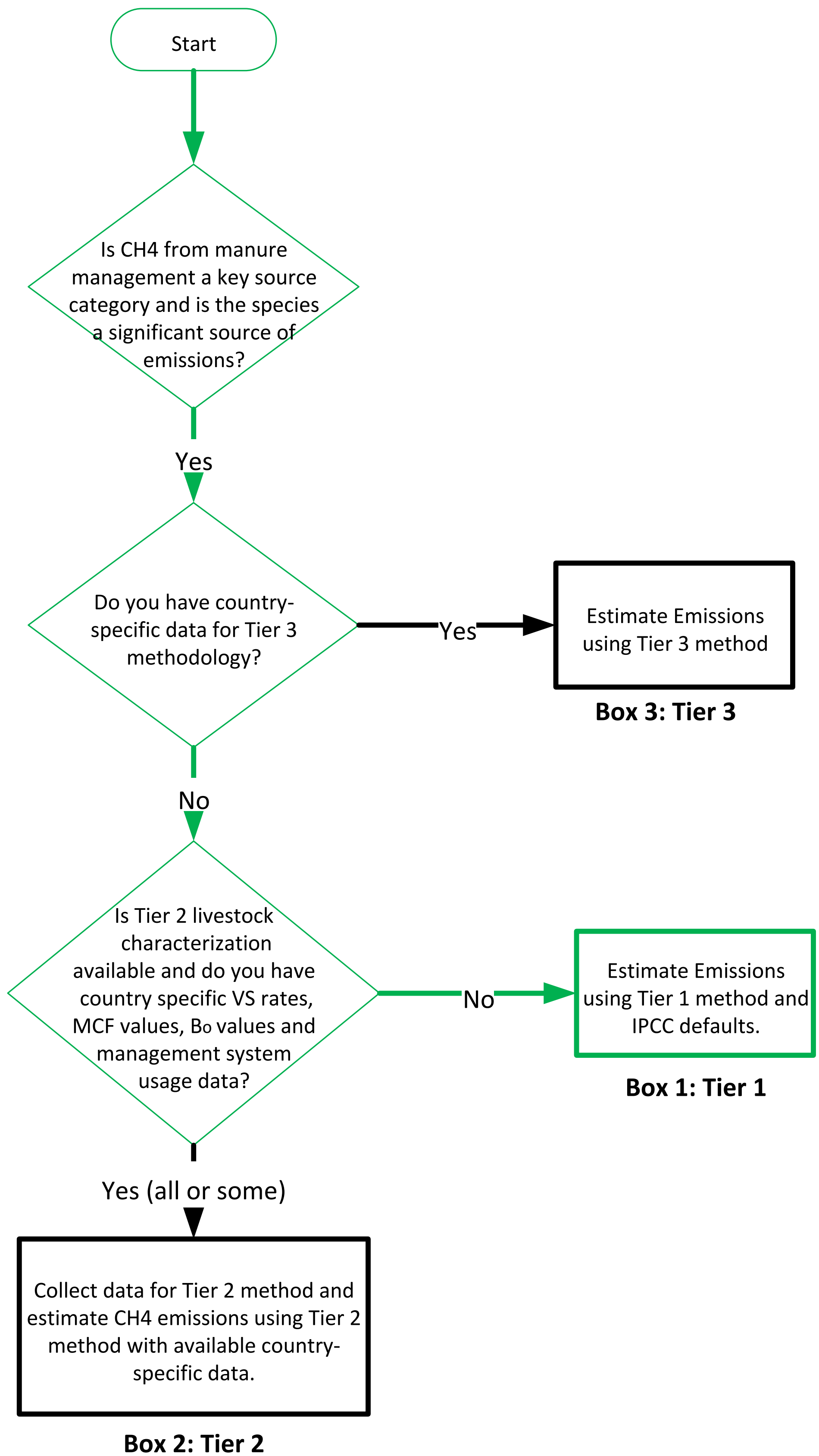

Start
Is CH4 from manure management a key source category and is the species a significant source of emissions?
Yes
Do you have country-specific data for Tier 3 methodology?
Yes
Estimate Emissions using Tier 3 method
Box 3: Tier 3
No
Is Tier 2 livestock characterization available and do you have country specific VS rates, MCF values, Bo values and management system usage data?
No
Estimate Emissions using Tier 1 method and IPCC defaults.
Box 1: Tier 1
Yes (all or some)
Collect data for Tier 2 method and estimate CH4 emissions using Tier 2 method with available country-specific data.
Box 2: Tier 2

Fig.2: Fiji – Specific decision tree for methane emissions from manure management

Source: https://www.ipccnggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf, pg. 10.36

For a country like Fiji, the Tier 1 method is most applicable. It is a simplified method that only requires livestock population data by animal species/ category and climate region or temperature, in combination with IPCC default emission factors, to estimate emission. Considering some emissions from MMS are highly temperature dependent, it is good practice to estimate the average temperature associated with the locations where manure is managed.

2.2.2. Steps for Estimating Methane Emissions from Manure Management – Tier Method

Step 1: Collect population data for the livestock and divide them into sub – categories as per Section 10.2. and section 2.1.2. of this document. The accurate recording and reporting of livestock species characterisation and animal population should be the responsibility of the Director Animal Health and Production. The Director must delegate the task of identifying the respective livestock categories as per IPCC guidelines and total population headcount to the respective officers within the Animal Health and Production department, while providing guidance and supervision.

Step 2: Use the default values or the country specific emissions factors (if available) for each livestock category and/or subcategory in kg CH_4 animal^{-1} yr^{-1}. Since temperature plays a key role in decomposition and production of CH_4, the emission factors by average temperature are presented in Tables 10.14, 10.15 and 10.16 for each of the recommended population subcategories. The underlying assumptions that were used to estimate the default emission factors for the different regions and the average mean temperature are detailed in Table 10A – 4 through to Table 10A – 9 of 2006 IPCC Guidelines on NGGI.

NOTE: Countries using a Tier 1 method to estimate methane emissions from manure management should review the regional variables in these tables to identify the region that most closely matches their animal operations and use the default emission factors for that region.

STEP 3: Calculate the CH_4 emissions for each livestock sub – category from manure management using Eq. 10.22 and the sum to find the total emissions.

EQUATION 10.22
CH_4 EMISSIONS FROM MANURE MANAGEMENT

$$CH_{4\,Manure} = \sum_{(T)} \frac{\left(EF_{(T)} \bullet N_{(T)}\right)}{10^6}$$

Where:

$CH_{4Manure}$ = CH_4 emissions from manure management, for a defined population, Gg CH_4 yr^{-1}

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

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

T = species/category of livestock

Example

Use the information provided below to determine the total CH_4 emissions from manure management.

a. There are 309000 cattle were 50% are dairy cattle and 50% are beef cattle.
b. There are a total of 11268 sheep, 250500 goats, 46000 Horses and 145700 swine (50% breeding and 50% for market with a lifespan of 6 months before slaughter).
c. There are 5097000 chicken where 2000000 are layers (dry system for manure) and 3097000 broilers that are alive for 47 days.
d. The population data provided is for a developing country located in the Oceania region with an average annual temperature of 26°C.

Solution

Sector	**Agriculture, Forestry and Other Land Use**		
Category	**Methane Emissions from Enteric Fermentation and Manure Management**		
Category code	**3A1 and 3A2**		
Sheet	**1 of 1**		
Equation	**Equation 10.19**	**Equation 10.22**	
Species/Livestock category	Number of animals	Emission factor for Manure Management	CH_4 emissions from Manure Management
	(head)	(Kg head^{-1} yr^{-1})	(Gg CH_4 yr^{-1})
		Tables 10.14 - 10.16	$CH_{4\ Manure} = N_{(T)} * EF_{(T)} * 10^{-6}$
T	**$N_{(T)}$**	**$EF_{(T)}$**	**$CH_{4\ Manure}$**
Dairy Cows	154500	31	4.790
Beef Cattle	154,500	2	0.309
Sheep	11,268	0.2	0.002
Goats	250500	0.22	0.055
Horses	46,000	2.19	0.101
Swine - Breeding	72,850	24	1.748
Swine - Market	36,425	13	0.474
Chickens - layers	2,000,000	0.02	0.040
Chickens - Broilers	398,792	0.02	0.008
Total			7.580

NOTE: you will need to determine the AAP for Market Swine and Broiler Chicken.

2.3.Nitrous Oxide Emissions from Manure Management

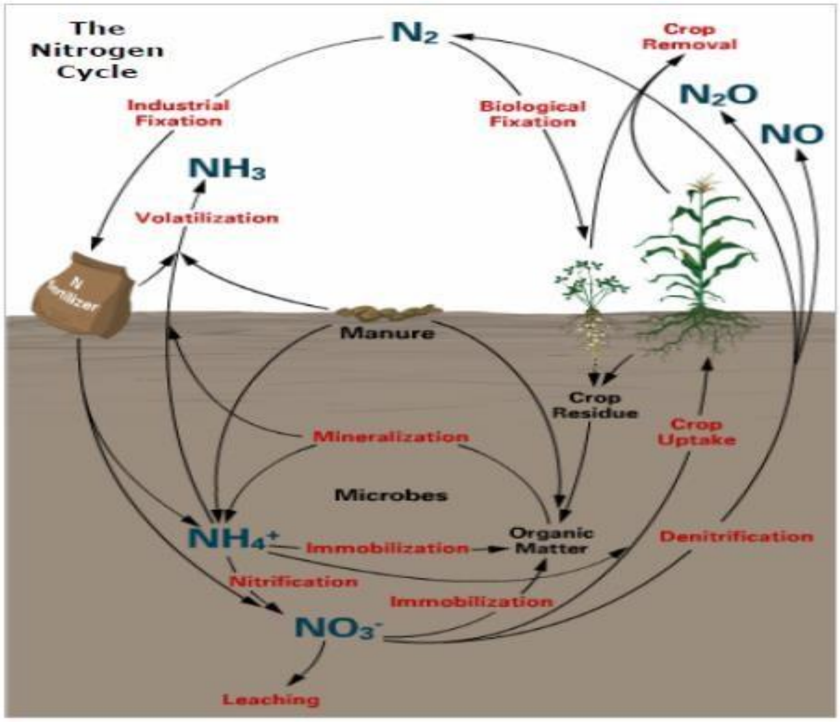
Nitrous oxide, N_2O, is produced directly and indirectly during storage and treatment of livestock manure before it is used as organic fertilizer, feed, fuel or construction purposes. The N_2O emissions generated by manure in the system 'pasture, range, and paddock' occur directly and indirectly from the soil and are therefore reported under the category 'N_2O Emissions from Managed Soils'. The emissions associated with the burning of dung for fuel are to be reported under 'Fuel Combustion' (Energy), or under 'Waste Combustion' (Waste) if burned without energy recovery.

Direct N_2O Emissions: arise from the manure as a by-product of nitrogen (N) transformations during nitrification and denitrification (Biological processes that continuously change the form in which nitrogen is present in the soil leading to the release of N_2O). The direct emission of N_2O during storage and treatment of manure depends on:

- Nitrogen and carbon content of the manure.
- Duration of storage
- Type of treatment – aerobic conditions (solid storage and treatment) lead to nitrification whereas anaerobic conditions (liquid storage and treatment) lead to denitrification.
- pH and moisture – increasing acidity, nitrate concentration and moisture leads to an increase in the ratio of N_2O: N_2

In summary, the production and emission of N_2O from managed manures requires the presence of either nitrites or nitrates in an anaerobic environment preceded by aerobic conditions necessary for the formation of these oxidized forms of nitrogen. In addition, conditions preventing reduction of N_2O to N_2, such as a low pH or limited moisture, must be present.

Indirect N_2O Emissions: occur when N, that is converted to other gases such as ammonia and nitrogen oxides (NO_x) (volatile N losses) or lost via leaching, is later converted to N_2O. The fraction of excreted organic nitrogen that is mineralized to ammonia during manure collection and storage depends primarily on time, and to a lesser degree temperature. Simple forms of organic nitrogen are rapidly mineralized to ammonia, which is highly volatile and easily diffused into the surrounding air. Nitrogen losses begin at the point of excretion in houses and other animal production areas (e.g., milk parlours) and continue through on-site management in storage and treatment systems (i.e., manure management systems). Nitrogen is also lost through runoff and leaching into soils from the solid storage of manure at outdoor areas, in feedlots and where animals are grazing in pastures. Pasture losses are considered separately under Agriculture Soils: N_2O Emissions from Managed Soils, as are emissions of nitrogen compounds from grazing livestock.

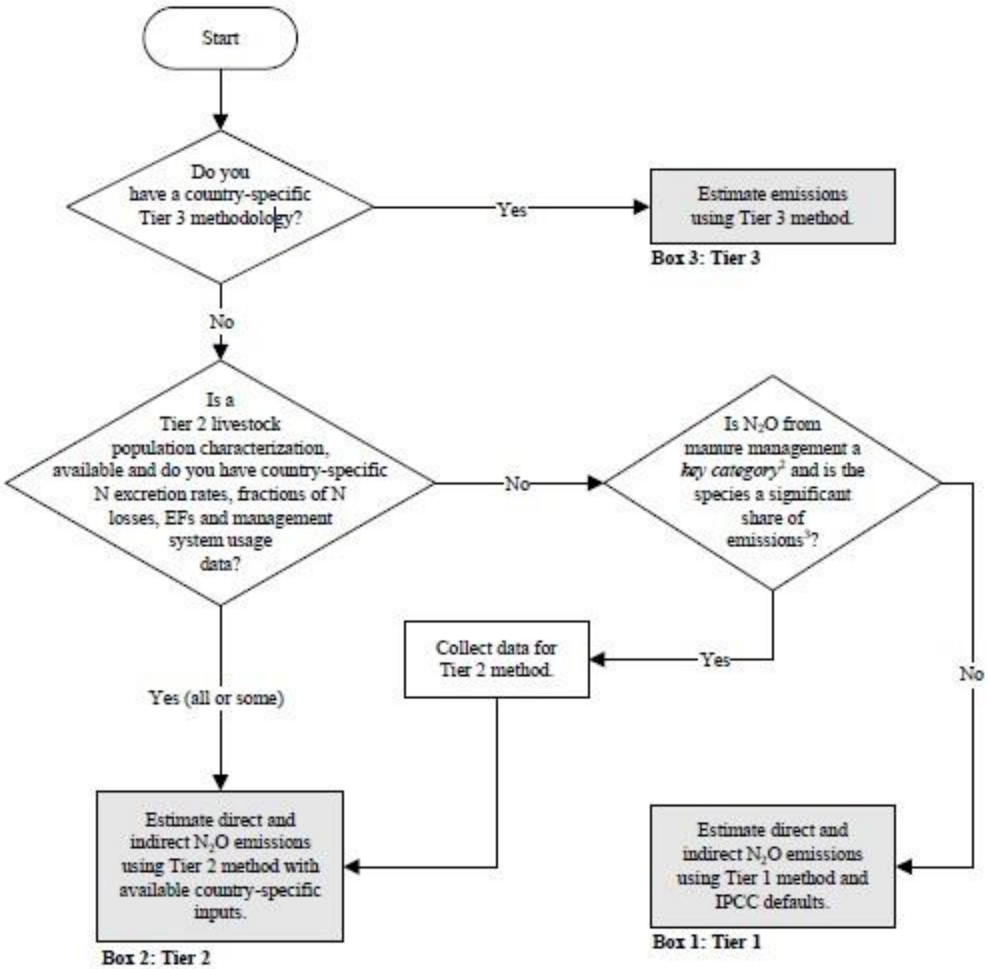


The Nitrogen Cycle

2.3.1. Choice of Methodology

The level of detail and methods chosen for estimating N_2O emissions from manure management systems will depend upon national circumstances and the decision tree in Figure 10.4 describes good practice in choosing a method accordingly.

Figure 10.4 Decision tree for N_2O emissions from Manure Management (Note 1)



Note:
1: N_2O emissions from manure management systems include both direct and indirect sources
2: See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.
3: As a rule of thumb, a livestock species would be significant if it accounts for 25-30% or more of emissions from the source category.

For a country like Fiji, the Tier 1 method is most applicable as N2O from manure management is not a key source category. The Tier 1 method is applied using IPCC default N_2O emission factors (Table 10.21), default nitrogen excretion data (Table 10.19), and default manure management system data (see Annex 10A.2, Tables 10A-4 to 10A-8 for default management system allocations).

2.3.2. Steps for Estimating Direct Nitrous Oxide Emissions from Manure Management – Tier 1 Method

Step 1: Collect population data for the livestock and divide them into sub – categories as per Section 10.2. and section 2.1.2. of this document.

Step 2: Using the default values for daily N excretion rate from Table 10.19 (kg N (1000 kg animal mass)$^{-1}$ day^{-1}) for the geographical region of interest and Eq. 10.30, determine the default values for **annual** average nitrogen excretion rate per head ($Nex_{(T)}$) for each defined livestock sub –category.

EQUATION 10.30
ANNUAL N EXCRETION RATES

$$Nex_{(T)} = N_{rate(T)} \bullet \frac{TAM}{1000} \bullet 365$$

Where:

$Nex_{(T)}$ = annual N excretion for livestock category T, kg N animal^{-1} yr^{-1}

$N_{rate(T)}$ = default N excretion rate, kg N (1000 kg animal mass)$^{-1}$ day^{-1} (see Table 10.19)

$TAM_{(T)}$ = typical animal mass for livestock category T, kg animal^{-1}

NOTE: Default TAM values are provided in Tables 10A-4 to 10A-9 in Annex 10A.2. However, it is preferable to collect country-specific TAM values due to the sensitivity of nitrogen excretion rates to different weight categories. For example, market swine may vary from nursery pigs weighing less than 30 kilograms to finished pigs that weigh over 90 kilograms. By constructing animal population groups that reflect the various growth stages of market pigs, countries will be better able to estimate the total nitrogen excreted by their swine population.

This data is not currently available as per the discussions with officials from MoA. Such data can be collated annually should there be sufficient staffing within the relevant departments within MoA. Currently, the total annual population headcount is only conducted for census reporting, while annual reporting is only carried out for livestock on supervised farms. To have a more categorised reporting for livestock characteristics (weight at different stages, total animal headcount, etc.), the Director Animal Health and Production needs to identify staffing gaps and appoint more livestock officers (where necessary) to collate the necessary national data for annual reporting.

Step 3: Determine the default values for the fraction of total annual nitrogen excretion for each livestock sub – category that is managed in each MMS ($MS_{(T, S)}$) from Tables 10A-4 to 10A-8.

Step 4: Determine the default N_2O emission factors for each MMS for each livestock sub – category from Table 10.21.

Step 5: Calculate the N_2O emissions for each livestock sub – category from each MMS using Eq. 10.25 followed by calculating the sum of the overall manure management systems.

EQUATION 10.25
DIRECT N_2O EMISSIONS FROM MANURE MANAGEMENT

$$N_2O_{D(mm)} = \left[\sum_S \left[\sum_T \left(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)} \right) \right] \bullet EF_{3(S)} \right] \bullet \frac{44}{28}$$

Where:

$N_2O_{D(mm)}$ = direct N_2O emissions from Manure Management in the country, kg N_2O yr^{-1}

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

$Nex_{(T)}$ = annual average N excretion per head of species/category *T* in the country, kg N $animal^{-1}$ yr^{-1}

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, 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*

S = manure management system

T = species/category of livestock

44/28 = conversion of $(N_2O\text{-}N)_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions

NOTE: In some cases, manure nitrogen may be managed in several types of manure management systems. For example, manure flushed from a dairy free stall barn to an anaerobic lagoon may first pass through a solid separation unit where some of the manure nitrogen is removed and managed as a solid. Therefore, it is important to carefully consider the fraction of manure nitrogen that is managed in each type of system.

Example

Country A is a developing country in Oceania whose primary livestock production include dairy cattle, swine, and poultry, with some non-dairy cattle and sheep. The average annual temperature of Country A is 24^oC.

Dairy cattle are predominantly pasture grazing with 5% of their time in the milking shed. Manure from the milking shed is collected and spread daily onto pasture. Dairy cows average about 400kg in weight and produce on average 2.2 kg of milk per day, which equates to 800 kg milk per year.

All **non-dairy cattle and sheep** are 100% pasture grazed. Other than that, there is no other information available for non-dairy cattle and sheep.

Twenty-five percent of the **swine population** are kept for breeding purposes, while the remainder are grown for 6 months before being slaughtered. The breeding population are 50% pasture grazed and 50% in crates where their manure is collected and managed in dry lot. Market swine spend 50% of their time in crates and 50% of their time on pasture. Manure from the crates is managed mainly in dry lot MMS (80%) and small proportion in solid storage systems (20%). Breeding swine weight on average is 172kg and market swine are 47kg.

Population Data:

Cattle: 1,682,690 dairy cattle and 397,901 other cattle.

Sheep: 248,319

Swine: 652,864

For the year 2015, calculate the direct nitrous oxide from manure management for Country A.

Solution

Using the information provided, determine the MMS that was used for each animal subcategory. This can be represented as in the table below.

	Solid storage	Dry lot	Daily Spread	PR&P	Total
Dairy Cows	0	0	**5**	**95**	100
Other Cattle	0	0	0	**100**	100
Sheep	0	0	0	**100**	100
Swine – Breeding	0	**50**	0	**50**	100
Swine – Market	**10**	**40**	0	**50**	100

Determine the total head count for each animal subcategory

Cattle: 1,682,690 dairy cattle and 397,901 other cattle.

Sheep: 248,319

Swine: Breeding Swine: 25% of total swine population – 163,216

Market Swine: 75% of total swine population – 489,648. Remember that market swine is not alive for the whole year. Therefore, the AAP will need to be calculated. The market swine head count now becomes 244,824.

Determine the $N_{rate(T)}$, $MS_{(T, S)}$ and $EF_{3(s)}$ form Tables 10.19, Tables 10A4 – A8 and Table 10.21, respectively.

Note that according to Table 10.21, N_2O emissions from Pasture/ Range/ Paddock are reported under Managed Agricultural Soils. Also, daily spread has an emission factor of zero, thus, making the emissions zero as well.

Therefore, the emissions will only need to be determined for solid storage and dry lot.

Sector		**Agriculture, Forestry and Other Land Use**								
Category		**Manure Management: Direct N_2O Emissions from Manure Management Systems**								
Category code		**3A2**								
Sheet		**1 of 1**								
Equation		**Eq. 10.25**	**Equation 10.30**			**Equation 10.25**				
Manure Management System (MMS)[1]	Species/ Livestock category	Number of animals	Default N excretion rate	Typical animal mass for livestock	Annual N excretion per head of species/livestock	Fraction of total annual nitrogen excretion	Total nitrogen excretion for the MMS [4]	Emission factor for direct N_2O-N emissions from MMS	Annual direct N_2O emissions from Manure Management	
		(head)	[kg N (1000 kg animal)$^{-1}$ day^{-1}]	(kg)	(Kg N animal^{-1} year^{-1})	(-)	(Kg N yr^{-1})	[kg N_2O-N (Kg N in MMS)$^{-1}$]	kg N_2O yr^{-1}	Gg N_2O yr^{-2}
			Table 10.19	Table s 10A-4 to 10A-9	$Nex_{(T)} = N_{rate(T)} * TAM * 10^{-3} * 365$	Tables A4-A8	$NE_{MMS} = N_{(T)} * Nex_{(T)} * MS_{(T,S)}$	Table 10.21	$N_2O_{(mm)} = NE_{MMS} * EF_{3(S)} * 44/28$	$N_2O_D (mm) = N_2O_{D(mm)} * 10^{-6}$
S	**T**	**$N_{(T)}$**	**$N_{rate(T)}$**	**TAM**	**$Nex_{(T)}$**	**$MS_{(T,S)}$**	**NE_{MMS}**	**$EF_{3(S)}$**	**$N_2O_{D(mm)}$**	
Solid Storage	Swine - Market	244,824	0.53	47	9.09215	0.03	66,779.30	0.005	524.6944682	0.000525
Total										0.000525

[1] The calculations must be done by Manure Management System, and for each management system, the relevant species/livestock category (ies) must be selected. For the Manure Management Systems, see Table 10.18.

[2] Specify livestock categories as needed using additional lines (e.g., llamas, alpacas, reindeers, rabbits, fur-bearing animals etc.) [3] Country-specific values are preferred to directly enter into this column. If these are not available, use default values of $N_{rate(T)}$ and TAM to calculate this variable.

[4] This value will be input to worksheet in Indirect N_2O emissions from Manure Management (see category 3C6).

Sector		**Agriculture, Forestry and Other Land Use**								
Category		**Manure Management: Direct N_2O Emissions from Manure Management Systems**								
Category code		**3A2**								
Sheet		**1 of 1**								
Equation		**Eq. 10.25**	**Equation 10.30**			**Equation 10.25**				
Manure Management System (MMS)[1]	Species/Livestock category	Number of animals	Default N excretion rate	Typical animal mass for livestock category	Annual N excretion per head of species/livestock category[3]	Fraction of total annual nitrogen excretion managed in MMS for each species/livestock	Total nitrogen excretion for the MMS [4]	Emission factor for direct N_2O-N emissions from	Annual direct N_2O emissions from Manure Management	
		(head)	[kg N (1000 kg animal)$^{-1}$ day^{-1}]	(kg)	(Kg N animal^{-1} year^{-1})	(-)	(Kg N yr^{-1})	[kg N_2O-N (Kg N in MMS)$^{-1}$]	kg N_2O yr^{-1}	Gg N_2O yr^{-2}
			Table 10.19	Table s 10A-4 to 10A-9	$Nex_{(T)} = N_{rate(T)} * TAM * 10^{-3} * 365$	Tables A4A8	$NE_{MMS} = N_{(T)} * Nex_{(T)} * MS_{(T,S)}$	Table 10.21	$N_2O_{(mm)} = NE_{MMS} * EF_{3(S)} * 44/28$	N_2O_D (mm) $N_2O_{D(mm)} * 10^{-6}$
S	**T**	**$N_{(T)}$**	**$N_{rate(T)}$**	**TAM**	**$Nex_{(T)}$**	**$MS_{(T,S)}$**	**NE_{MMS}**	**$EF_{3(S)}$**	**$N_2O_{D (mm)}$**	
Dry Lot	Swine - Breeding	163,216	0.46	172	28.8788	0.15	4.33182	0.02	0.136142914	1.36E-07
	Swine - Market	244,824	0.53	47	9.09215	0.15	1.3638225	0.02	0.042862993	4.29E-08
Total									0.179005907	1.79E-07

[1] The calculations must be done by Manure Management System, and for each management system, the relevant species/livestock category (ies) must be selected. For the Manure Management Systems, see Table 10.18.

[2] Specify livestock categories as needed using additional lines (e.g., llamas, alpacas, reindeers, rabbits, fur-bearing animals etc.) [3] Country-specific values are preferred to directly enter into this column. If these are not available, use default values of $N_{rate(T)}$ and TAM to calculate this variable.

[4] This value will be input to worksheet in Indirect N_2O emissions from Manure Management (see category 3C6).

3. User Manual for Calculating GHG Emissions from Livestock in Fiji

In order to determine the GHG inventory to capture emissions from enteric fermentation and manure management systems, activity data for the different livestock categories need to be collected and validated for use. The three main sources of activity data that were analysed for validation were from the Ministry of Agriculture (MoA) Officials, Fiji National Agriculture Census Reports (1991, 1999, 2009 & 2020) and FAOSTAT and were used to generate the data time series from 1995 – 2020. As there were significant activity data gap for the years from 1990 – 1994 for key categories such as horses, goats and poultry, expert judgement was made and it was decided that the time series would be from 1995 – 2020, representing a 25 – year emissions trend for the inventory.

This section outlines the steps that can be taken to generate the time series data from the three sources and to determine the GHG emissions from enteric fermentation and manure management for the different livestock categories in Fiji. It also describes the steps taken to select the default emission factors from the 2006 IPCC Guidelines for NGGI for the Tier 1 Approach.

3.1. Activity Data Time Series

The key livestock categories that are used to determine the GHG emissions from consists of cattle (dairy and other cattle), swine, chicken, goat, horses, sheep and ducks. Upon sourcing the population count from FAOSTAT and Ministry of Agriculture for the National Data, the data must be analysed for discrepancies and data gaps to for validation.

For the purpose of this project, it was deduced that there were various discrepancies in the population count for the different years and the National Data received from MoA were only for the years from 2009 – 2019. Also, the data trend for the population count from FAOSTAT was erratic and the numbers did not follow a standard population trend. Therefore, using expert judgement, the Fiji National Agriculture Census Report for the years 1991, 1995, 2009 and 2020 for the population count were extrapolated and interpolated (depending on the livestock species) to determine the population count for the years 1995 – 2020 for dairy cattle, other cattle, swine and goat. The census data that was used are outlined in the Table 2 below:

Table 2: Fiji Agriculture Census Data for Cattle, Swine and Goat

Livestock Species	Year			
	1991	**1999**	**2009**	**2020**
Dairy Cattle[5]	36805	22583	22533	49650
Other Cattle	243416	262104	91616	70041
Swine	90850	92251	73698	58420
Goat	187235	251765	101196	143853

(Source: Fiji National Agriculture Census Report for 1991, 1999, 2009 & 2020).

It is also important to note that the national data provided by MoA are only for supervised farms and does not take into consideration subsistence or non-supervised farms. Thus, extrapolating or interpolating the census data allows experts to get a more realistic annual population count for the different livestock species. The following figure is a representation of the animal population time series data ranging from the year 1995 – 2020.

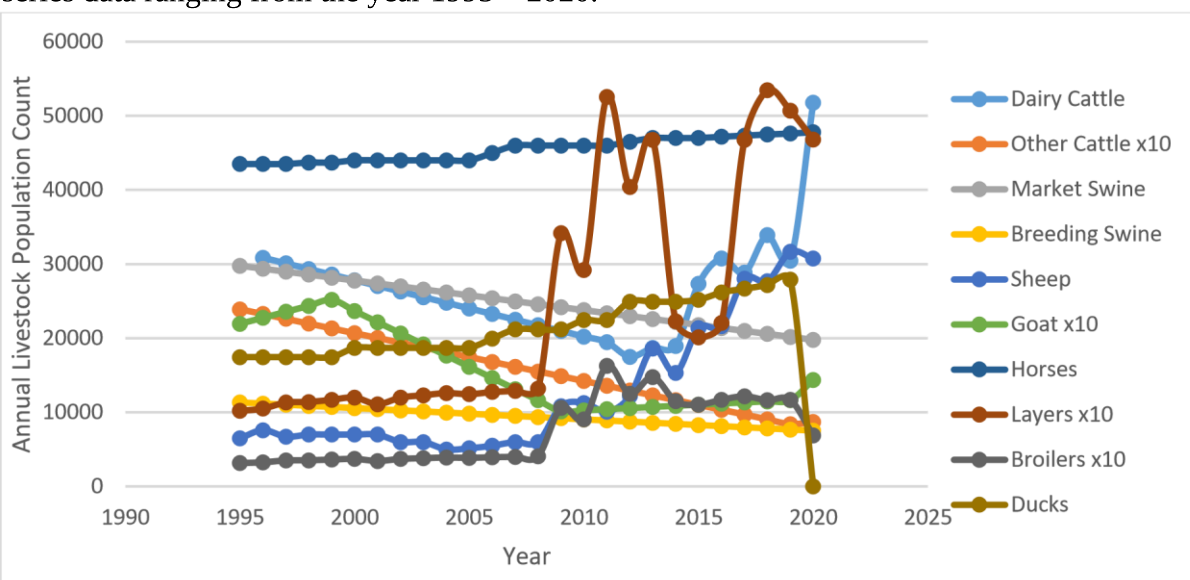


Fig. 1: Annual livestock population trend for the years 1995-2020.

[5] Commercialized dairy sector based on grazing. Growing amount of feedlot feeding with grains. Dairy cows are a small part of the population.

The activity data time series for the different livestock species was determined using the following approach:

a. Dairy Cattle

The national dairy cattle population count was made available for the years 2011 – 2020 by MoA while the population count for the years 1995 – 2010 were unavailable. In this case, the National Agriculture Census data was used and extrapolated using liner regression to calculate the dairy cattle population count. This is represented in the figure below:

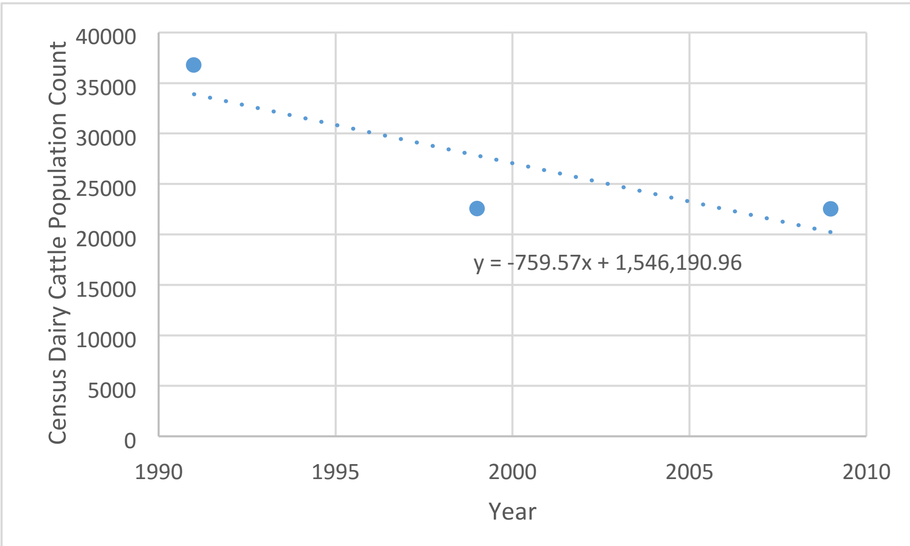


Fig.2: Linear Regression to determine the annual population count for dairy cattle from 19952010.

Using the equation $y = -759.57x + 1{,}546{,}190.96$ the annual dairy cattle population count for the years 1995-2010 were calculated and recorded in the activity data time series. Furthermore, given that dairy cattle are defined as cattle that used for commercial purposes and are subjected to a specific diet, the census data was not used for the 2020 annual dairy cattle population data as it also includes those that are from unsupervised or subsistence. Thus, the annual dairy cattle population for 2020 was taken from the national data provided by MoA; having an annual population count of 32620. This value was subtracted from the census data and added to the "other cattle" livestock category $(49650 - 32620 = 17030\ dairy\ cattle\ for\ subsistence\ farming)$.

b. Other Cattle

The national data provided by MoA for "other cattle" only consisted of those that were grazed for commercial purposes or from supervised farms; mainly for meat production (beef cattle). It did not take into account the cattle that were grazed in unsupervised farms. The census data provided the annual population count for total cattle and dairy cattle grazed in Fiji in 1991, 1999 and 2009. This was used to determine the total "other cattle" population by subtracting the dairy cattle population from the total cattle population. This method was not used for the year 2020 as the total cattle headcount was not provided in the census. For the year 2020, the remaining subsistence dairy cattle headcount from the 2020 census were added to the 2020 census data for beef cattle to get the holistic “other cattle” head count $(70041 + 17030 = 87071)$. Thereafter, the census data for “other cattle” was extrapolated to determine the linear regression and calculate the annual “other cattle” population for the years 1995 – 2019 and is represented in the figure below.

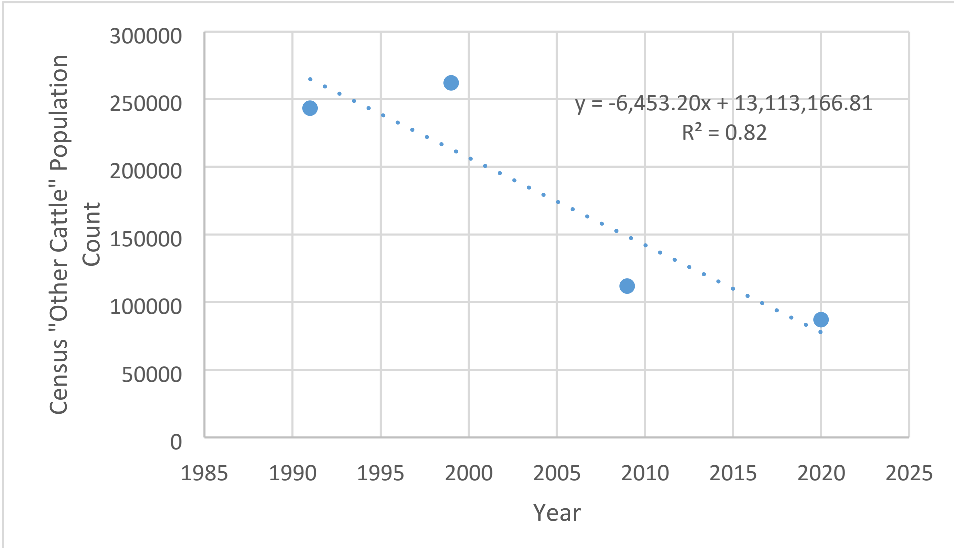


Fig.3: Linear Regression to determine the annual population count for “other cattle” from 19952019

Using the equation $y = -6{,}453.20x + 13{,}113{,}166.81$, the annual “other cattle” population count for the years 1995-2019 were calculated and recorded in the activity data time series. **c. Swine**

The National Data provided by MoA for the annual swine population count was only for the years 2009 – 2019 from supervised farms. Since the data was not inclusive of the swine population from unsupervised, it did not provide appropriate headcount for the holistic GHG emissions from swine. Therefore, the census data was extrapolated a linear regression was used to calculate the total annual swine population count for the years 1995-2020. This is represented in the figure below.

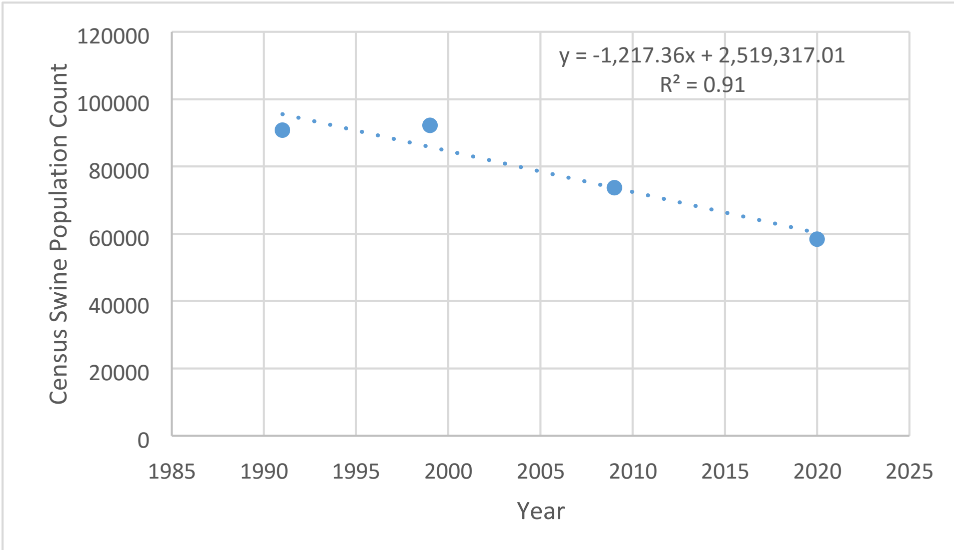


Fig.4: Linear Regression to determine the annual population count for swine from 1995-2020.

Using the equation $y = -1,217.36x + 2,519,317.01$, the annual swine population count for the years 1995-2020 was calculated and recorded in the activity data time series. However, this livestock category must be further disaggregated into breeding and market swine as the lifespan for each sub-category is different. The disaggregated annual swine population data was not available within the MoA, FAOSTAT or in the census reports. Upon consultation with the officials from the livestock department within the MoA, it was deduced that 87.5% of the total swine population was raised for market while 12.5% were for breeding. This information was used to disaggregate the swine population data into breeding and market sub-categories and recorded in the activity data time series.

Additionally, as mentioned under the guidance section, the GHG emissions using the IPCC guidelines for Tier 1 requires activity data (animal headcount) for a species that is grazed for an entire annual cycle. Therefore, for market swine, the AAP needs to be calculated to readjust the annual market swine population. The life span for market swine as per the livestock officials from MoA is 137 days (~4.5 months). This information was used to readjust the total market swine population count and was recorded in the activity data time series.

d. Goat

Similar to the other livestock categories, the national data provided by MoA cannot be used to estimate GHG emissions from goats as it only takes into consideration the goat population grazed in supervised farms. Therefore, the census data was used to determine the total annual goat population headcount for the years 1995-2020. However, extrapolation of the data and the linear regression approach cannot be used for goats as it did not show a linear trend. Therefore, the census data was interpolated to determine the annual goat population count. The annual population count and the census data are illustrated in the figure below.

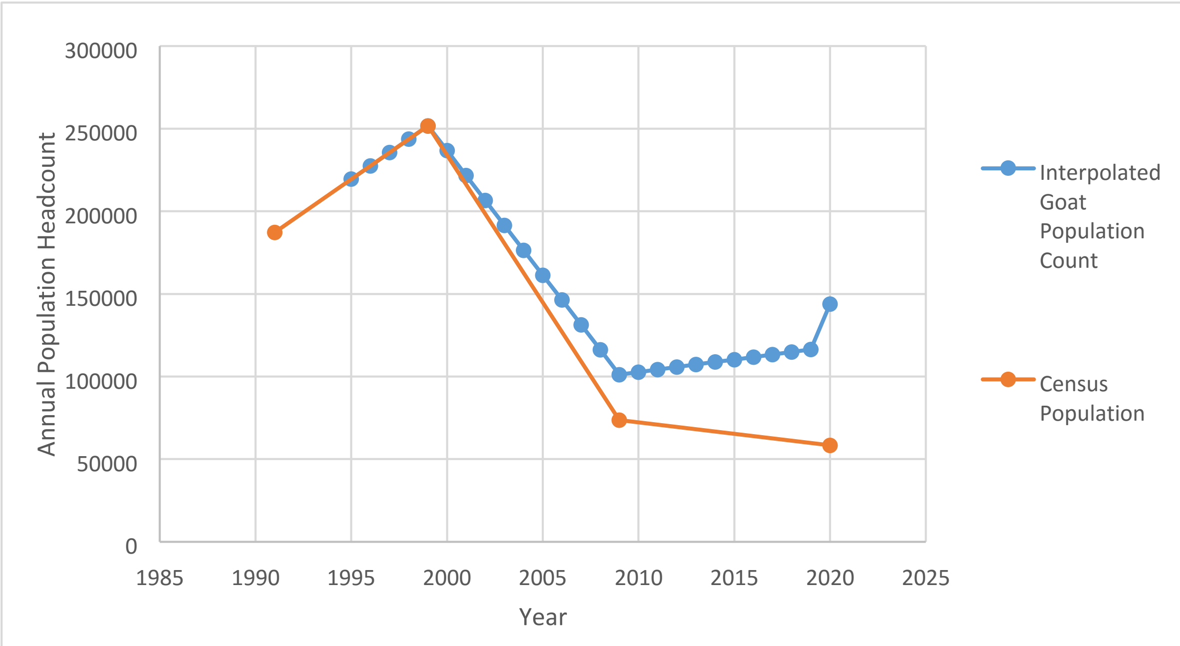


Fig. 5: Comparison between census and interpolated goat population count.

The interpolated population data was used to calculate the GHG emissions from goat as per the IPCC guidelines for the Tier 1 approach.

e. Horses

The total annual population count for horses is not recoded by MoA, nor is it reported in the agriculture census report for Fiji. Therefore, the population data for this animal category was retrieved directly from FAOSTAT for the years 1995 – 2019. The population data for 2020 was not available on the FAOSTAT database, therefore, the horse population count from 2015 – 2019 was plotted to find a linear regression and extrapolated to calculate the population count for 2020. This is illustrated in the figure below.

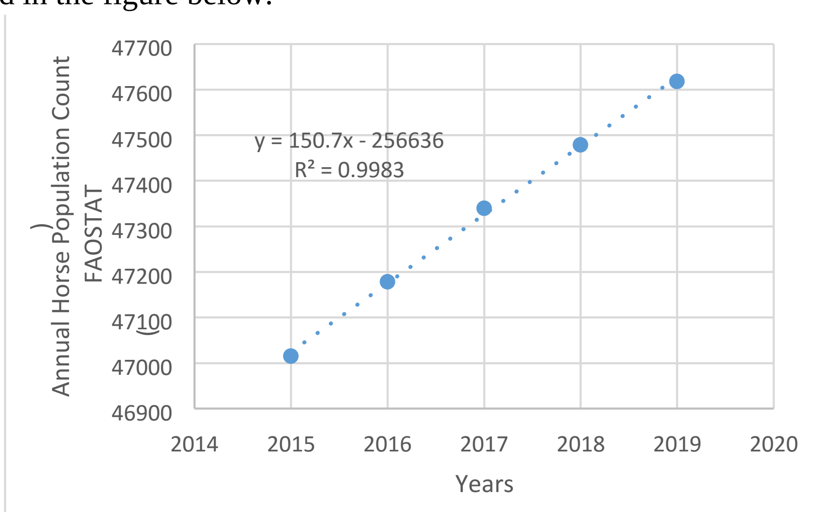


Fig.6. Linear Regression to determine the annual population count for horses in 2020.

The equation $150.7x - 256636$ was used to calculate the total horse population count for the year 2020 and was recorded in the activity data time series.

f. Sheep

The total annual sheep population count sourced from MoA was limited to the years 2009-2020. Since the national census data did not report the sheep population count, this activity data was sourced from the FAOSTAT database for the years 1994 – 2008 and was recorded in the activity data time series.

g. Chicken

This livestock category has to be disaggregated into layers and broilers as the lifespan for each sub-category is different. The disaggregated population numbers for layers were available for the years 2013-2020 while the broiler annual population count was available for the years 2009-2020. This data was sourced from the MoA. However, there still remained data gaps for the remaining years from 1995-2008 for broilers and 1995-2021 for layers. In addition, upon comparison between the total chicken population count and the disaggregated population count, it was deduced that layers made up ~97% of the total chicken population while ~3% are broilers. Using this ratio and the total annual chicken population count from FAOSTAT, the disaggregated population count was calculated and reported in the activity data time series.

Additionally, as mentioned under the guidance section, the GHG emissions using the IPCC guidelines for Tier 1 requires activity data (animal headcount) for a species that is grazed for an entire annual cycle. Therefore, for broilers, the AAP needs to be calculate to readjust the annual broiler chicken population. The life span for broiler chicken as per the livestock officials from MoA is 35 days. This information was used to readjust the total broiler chicken population count and was recorded in the activity data time series.

h. Ducks

The total annual duck population count sourced from MoA was limited to the years 2013-2020. Since the national census data did not report the duck population count, this activity data was sourced from the FAOSTAT database for the years 1994 – 2012. However, a comparison between the national data and the FAOSTAT data showed significant discrepancies between the two data sets. Therefore, the FAOSTAT data was reported in the activity data time series for the years 1995 – 2019.

3.2.Calculation of GHG Emissions from Enteric Fermentation & Manure Management.

The three categories for which the GHG emissions were calculated for were:

1. CH_4 from Enteric Fermentation.
2. CH_4 from manure management systems.
3. N_2O from Manure Management Systems

In order to calculate the emissions, the default emission factors for each of the categories were selected from the 2006 IPCC Guidelines for NGGI upon expert judgement and analysing national circumstances. The steps which were involved in this process are outlined in this section for the respective categories.

3.2.1. Emission factors - CH_4 from Enteric Fermentation

a. Dairy Cattle

The default emission factor for CH_4 emissions from Enteric Fermentation is reported in Table 10.11. Guiding information provided in the table for Enteric Fermentation EF for cattle states that "values represent averages within region, where applicable the use of more specific regional milk production data is encouraged" (Dong , et al., 2006). Upon analysis Table 10.11, it was deduced that the EF for dairy cattle in Oceania is on the basis that cattle have an average milk production of 2,200 kg head^{-1} yr^{-1}. Upon comparison of the national data with the FAOSTAT data for average milk production in Fiji, it was deduced that there were inconsistencies in the values reported, especially since the national data only took into consideration milk production form large commercial farms. Therefore, the FAOSTAT data was used and reported in the activity data time series from 1995-2019. The milk production data for the years 2015-2019 were extrapolated to calculate the average milk production for the year 2020. This is also illustrated in the figure below.

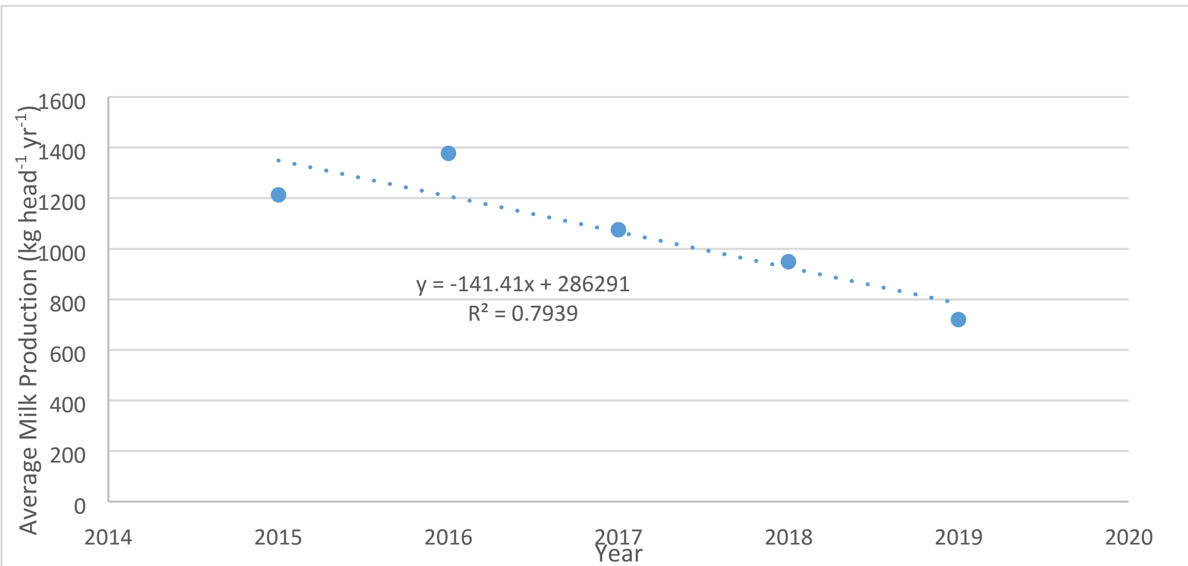


Fig. 7. Average annual milk production (kg head^{-1} yr^{-1}) data from FAOSTAT for the years 20152020

In addition, the default EF values reported were determined using the Tier 2 approach and the information represented in Table 10 A.1 and 10 A.2. Given that Fiji is located in Oceania, the Tier 2 data used to determine the EF were not consistent with the FAOSTAT data. Table 10.11 also indicates that an EF of 90 kg CH_4 head^{-1} yr^{-1} for Oceania was deduced on the assumption that dairy cattle have an average milk production of 2,200 kg head^{-1} yr^{-1}. However, this is not applicable for Fiji as the annual milk production data is much lower than 2,200 kg head^{-1} yr^{-1}. Since Table 10.11 provides the EF at for different regions at varying milk production rates, this information can be used to readjust the EF for Fiji based on the local annual milk production data provided by FAOSTAT. The following steps can be followed to readjust the EF for Fiji:

1. Plot a graph of Default EF vs. Average Annual Milk Production (from Table 10.11) to find the linear regression as illustrated in the figure below:

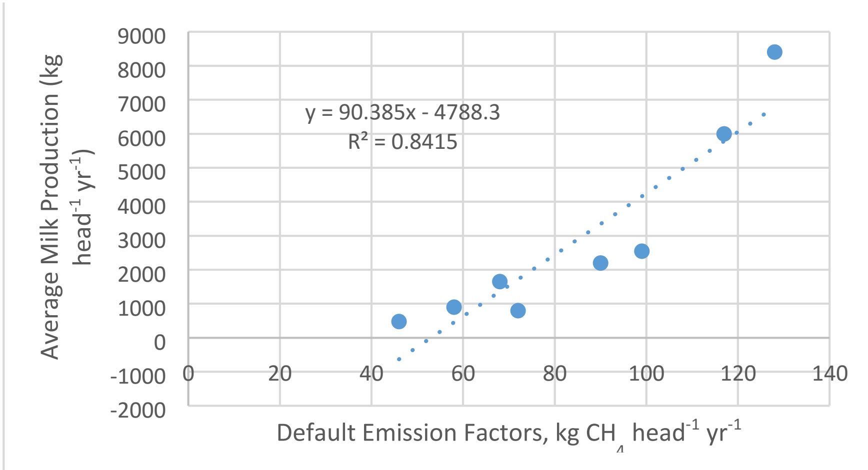


Fig. 8. Readjustment of the default emission factor using the information from Table 10.11.

2. Using the equation $y = 90.385x - 4788.3$, find the readjusted EF for the years 1995-2020 and record in the activity data time series. The readjusted EFs are illustrated in the figure below.

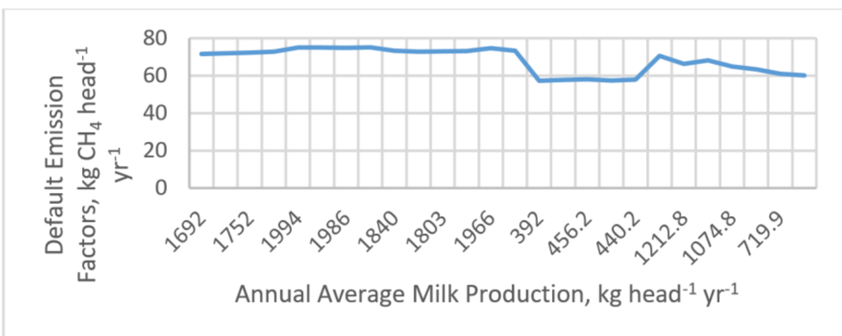


Fig. 9. Readjusted EF for the respective annual average milk production from dairy cattle in Fiji.

b. Other Cattle

The default emission factor for other cattle is derived based on animal characteristics (such as liveweight) and feed intake. Since this information was not available, the default EF of 60 kg CH_4 head^{-1} yr^{-1} for Oceania from Table 10.11 was used for "other cattle" to calculate its total CH_4 emissions from 1995 – 2020.

c. Goats, Sheep, Horses & Swine

The default emission factors for goats, horses, sheep and swine were selected from Table 10.10 of the 2006 IPCC Guidelines for NGGI. The table has different EF's for developed and developing countries as the EF's are deduced based on animal characteristics and feed. Therefore, the EF's from the "developing Countries" column is most appropriate for Fiji (also because Fiji is considered a developing country). The following table outlines the respective EF's chosen to calculate the CH_4 emissions from goats, sheep, horses and swine for the years 1995- 2020.

Table 3: Enteric Fermentation Default EF's for the Tier 1 Method, *kg CH_4 head^{-1}yr^{-1}*

Livestock	Default EF *kg CH_4 head^{-1}yr^{-1}*
Goat	5
Sheep	5
Horse	18
Swine	1

3.2.1.1.Calculation for CH_4 Emissions from Enteric Fermentation

The following equations are used to calculate the total CH_4 emissions from enteric fermentation for each livestock category for the years 1995-2020:

Enteric Fermentation Emissions from Each Livestock

$$Emissions = EF_{(T)} \cdot \left(\frac{N_{(T)}}{10^6}\right)$$

Where:

Emissions= CH_4 emissions from Enteric Fermentation, Gg CH_4 yr^{-1}

$EF_{(T)}$= emission factor for the defined livestock population, kg CH4 head^{-1} yr^{-1}

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

T = species/category of livestock

Total Emissions from Livestock Enteric Fermentation

$$Total\ CH_{4\,Enteric} = \sum_i E_i$$

Where:

Total $CH_{4Enteric}$=total methane emissions from Enteric Fermentation, GgCH_4 yr^{-1}

E_i = is the emissions for the i^{th} livestock categories and subcategories

The total CH_4 emissions from enteric fermentation was calculated and reported in the time series for the years 1995-2020 for Fiji.

3.2.2. Emission Factors – CH_4 from Manure Management

An important characteristic to be considered when determining EF for CH_4 emissions from manure management is the ***average annual temperature*** as it plays a key role in decomposition and production of CH_4. The average annual temperature for Fiji for the years 1995 – 2020 was sourced from the Fiji Meteorological Services through MoA and was reported to be ***26°C***. Using this information and the default EFs provided in Table 10.14 for Cattle and Swine (for the respective regions) and Table 10.15 for sheep, goats, horses and poultry, the following EFs were deduced for Fiji:

Table 4: Manure Management CH_4 EFs by Temperature for Cattle and Swine in Fiji

Regional Characteristic	Livestock	EF at 26°C *kg CH_4 head^{-1} yr^{-1}*
Oceania: Most cattle manure is managed as a solid on pastures and ranges, except dairy cows where there is some usage of lagoons. About half of the swine manure is managed in anaerobic lagoons.	Dairy Cattle	31
	Other Cattle	2
	Market Swine	13
	Breeding Swine	24

(Source: (Dong , et al., 2006))

Table 5: Manure Management CH_4 EFs by Temperature for Sheep, Goat, Horse and Poultry in Fiji

Livestock	Developing Country EF at 26°C *kg CH_4 head^{-1} yr^{-1}*
Sheep	0.2
Goats	0.22
Horses	2.19
Poultry	0.02

(Source: (Dong , et al., 2006))

The EF's noted in Tables 4 & 5 were used to calculate the total CH_4 emissions from manure management for the key livestock categories from 1995-2020.

3.2.2.1.Calculation for CH_4 Emissions from Manure Management

The following equations are used to calculate the total CH_4 emissions from enteric fermentation for each livestock category for the years 1995-2020:

CH_4 Emissions from Manure Management

$$CH_{4\,Manure} = \sum_T \frac{(EF_{(T)} \cdot N_{(T)})}{10^6}$$

Where:

$CH_{4Manure}$ = CH_4 emissions from manure management, for a defined population, Gg CH_4 yr^{-1}

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

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

The total CH_4 emissions from manure management was calculated and reported in the time series for the years 1995-2020 for Fiji.

3.2.3. Emission Factor and Key Parameters – N_2O Emission from Manure Management

Steps to calculate direct N_2O emissions from Manure Management Systems (MMS)

Step 1: Collection of Activity Data

Population Data: Could be sourced from the national agriculture animal census reports and a timeline data series could be prepared through linear regression or official data from MoA could be obtained. This is discussed in detail in Section 3.1

Usage of Manure Management System

This activity data was aggregated from calculating the number of animal population in commercial farms, semi-commercial and household subsistence farming. According to expert judgement only manure from intensive commercial and semi commercials farms were managed whereas household/subsistence farming manure was left on pasture/range/paddock except for swine reared for subsistence farming whereby manure was managed in a pit storage below animal confinement (See Table 6 below).

Table 6: <u>Manure Management Systems used for the different category of animals in Fiji</u>

Animal category	% use of Manure Management System (MMS)						
	Pasture/ Range/ Paddock	Daily Spread	Pit Storage below confinement	Dry lots	Uncovered anaerobic Lagoon	Manure with litter	Manure without litter
Dairy Cattle	96	4	0	0	0	0	0
Other Cattle	100	0	0	0	0	0	0

Sheep	100	0	0	0	0	0	0
Goats	100	0	0	0	0	0	0
Horses	100	0	0	0	0	0	0
Swine -Market	0	0	50	30	20	0	0
Swine-Breeding	0	0	50	30	20	0	0
Poultry - Broilers	20	0	0	0	0	80	0
Poultry - Layers	20	0	0	0	0	0	80

From Table 6 it is apparent that the Pasture/range/paddock MMS has an emission factor of zero and is actually considered in Direct N_2O emissions from managed soil and is not calculated under agriculture. The emission factor for daily spread and uncovered anaerobic lagoon is also zero and therefore would result in zero direct N_2O emissions and therefore not included in the calculation. Given the MMS usage data provided by Animal Health and Production Division of Ministry of Agriculture the Direct N_2O emissions were calculated for Swine (Market and Breeding) and Poultry (Broilers and Layers).

Typical Animal Mass (TAM)

The average life weight data for Cattle (dairy and other cattle), Swine (Market and Breeding) sheep, goat and Poultry (Broilers and Layers) are given in the table below

Table 7: Animal Average Live Weight for Key Categories

Animal Category	Animal Average Live weight (Kg)
Dairy Cattle	270
Other Cattle	350
Swine- Market	70
Swine - Breeding	115
Sheep	33
Goat	28
Poultry- Broilers	2.0
Poultry - Layers[8]	1.3

(Source of data: Ministry of Agriculture, 2021)

Step 2: Calculation of Annual N excretion per head of species/livestock category (kg N animal^{-1} yr^{-1})

To enable calculation of annual N excretion rate per head of species/livestock category, default excretion rate, $N_{rate\ (T)}$, (kg N (1000 kg animal)$^{-1}$ day^{-1}) given in table below was used: **Table 8: Default Excretion Rate**, $\mathbf{N_{rate\ (T)}}$

Livestock category	N_{rate}
Swine – Market	0.53
Swine - Breeding	0.46
Poultry - Layers	0.82
Poultry - Broilers	1.10

(Source: Extracted from Table 10.19)

The above $Nrate_{(T)}$ and TAM data provided by MoA will be used in equation 10.30 to calculate $Nex_{(T)}$ as follows:

EQUATION 10.30
ANNUAL N EXCRETION RATES

$$Nex_{(T)} = N_{rate(T)} \bullet \frac{TAM}{1000} \bullet 365$$

Where:

$Nex_{(T)}$ = annual N excretion for livestock category *T*, kg N animal^{-1} yr^{-1}

$N_{rate(T)}$ = default N excretion rate, kg N (1000 kg animal mass)$^{-1}$ day^{-1} (see Table 10.19)

$TAM_{(T)}$ = typical animal mass for livestock category *T*, kg animal^{-1}

Step 3: Determine the fraction of total annual nitrogen excretion for each livestock sub – category that is managed in each MMS ($MS_{(T, S)}$) from Table 6. For example, market swine uses 50% Pit storage below confinement, 30% drylots, 20% uncovered anaerobic lagoon and this equates to 0.5, 0.3 and 0.2 fractions respectively for each MMS used.

Step 4: Determine the default N_2O emission factors for each MMS for each livestock sub – category from Table 10.21. According to Table 6 only following MMSs were used and its respective N_2O emission factors that should be used is given below:

Table 9: Default Emission Factors for MMS's

MMS	Emission factor (Kg N-N_2O Kg Nitrogen Excreted
Dry lot	0.02
Pit Storage below animal confinement	0.002
Poultry manure with litter	0.001

Poultry manure without Litter	0.001

Step 5: Calculate the N_2O emissions for each livestock sub – category from each MMS using Eq. 10.25 (given below) followed by calculating the sum of the overall manure management systems.

EQUATION 10.25
DIRECT N_2O EMISSIONS FROM MANURE MANAGEMENT

$$N_2O_{D(mm)} = \left[\sum_S \left[\sum_T \left(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)} \right) \right] \bullet EF_{3(S)} \right] \bullet \frac{44}{28}$$

Where:

$N_2O_{D(mm)}$ = direct N_2O emissions from Manure Management in the country, kg N_2O yr^{-1}

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

$Nex_{(T)}$ = annual average N excretion per head of species/category *T* in the country, kg N $animal^{-1}$ yr^{-1}

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, 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*

S = manure management system

T = species/category of livestock

44/28 = conversion of $(N_2O\text{-}N)_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions

4. Current Status of GHG Emissions in Fiji

The calculation of GHG emissions from enteric fermentation and manure management for the years 1995-2020 was carried out using national activity data specific to Fiji as well as form the FAOSTAT database. The country specific parameters such as temperature, manure management systems, annual average dairy milk production, etc. were also important factors that were useful in deducing the appropriate default values to apply the Tier 1 approach. Moreover, the current status of Fiji's GHG emissions as per the time series from 1995-2020 is illustrated in the figures below:

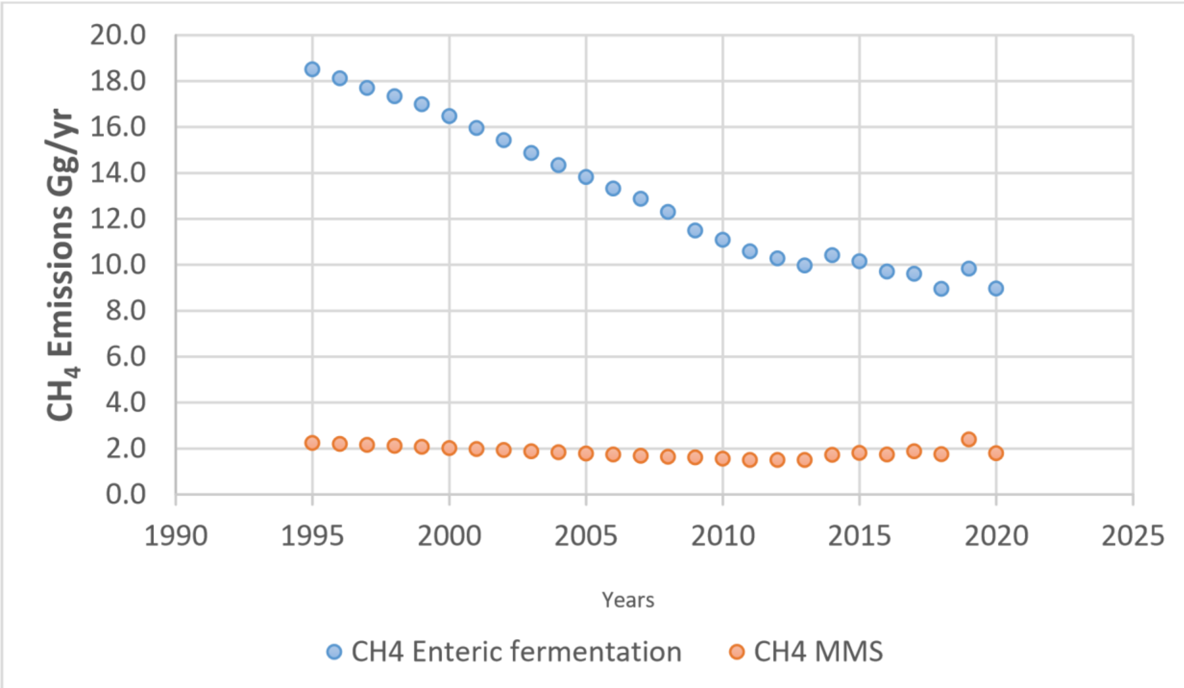


Fig.10. CH_4 Emissions from Enteric Fermentation and Manure Management from 1995 – 2020.

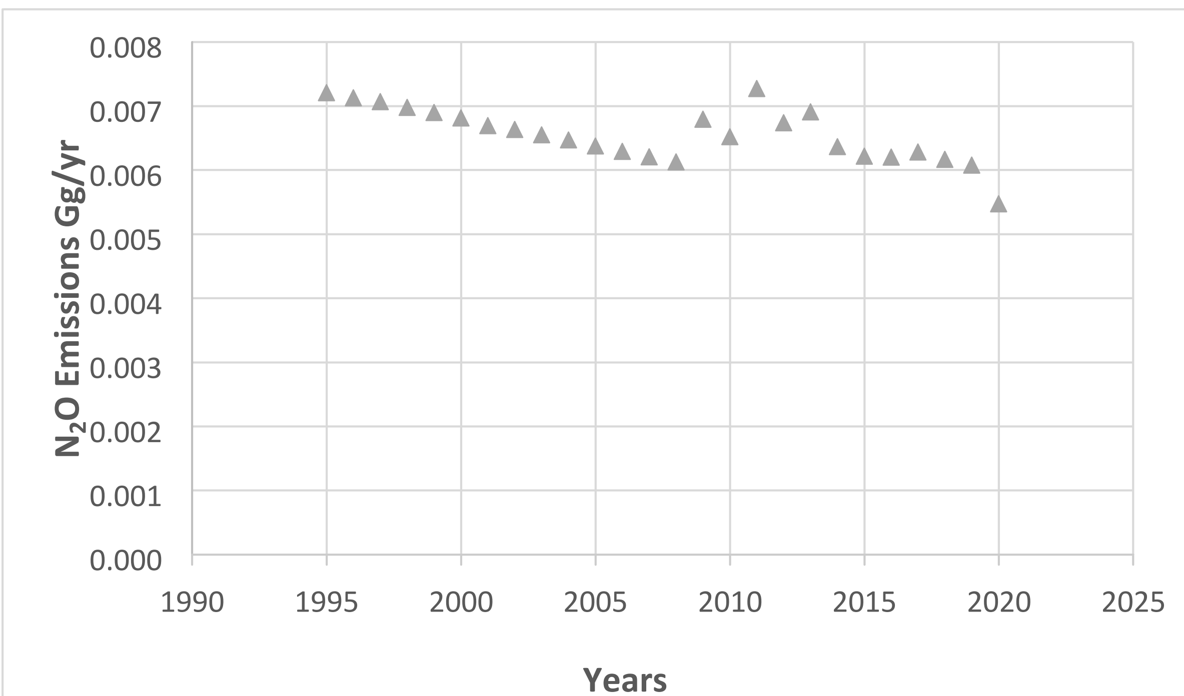


Fig.11. N_2O Emissions from Manure Management from 1995 – 2020.

The total GHG emissions from enteric fermentation and manure management is in the range of 227 – 438 Gg/yr CO_2 eq. from 1995 – 2020. Table 9 suggest that the total emissions from enteric fermentation and manure management is steadily declining and is about 52% of 1995 level. Two main reasons for the observed decline are due to declining population number for other cattle, and the declining re-adjusted EF for dairy cows based on annual milk production. The main contributory factor is declining other cattle population data, and this could emanate from actual loss of animals due to diseases or incorrect capturing of data.

Table 10: Annual GHG Emissions Time Series Data from 1995 - 2020

Year	CH4 Emissions Enteric Fermentation		CH4 Emissions MMS		Direct $N_2$0 Emission MMS		Total GHG emissions
	CH4 emission (Gg yr^{-1})	CO2 eq (Gg yr^{-1})	CH4 emission (Gg yr^{-1})	CO2 eq (Gg yr^{-1})	N_2O emission (Gg yr^{-1})	CO2 eq (Gg yr^{-1})	CO_2 eq (Gg/yr)
1995	18.5	388.9	2.2	47.2	0.007	2.2	438
1996	18.1	380.6	2.2	46.3	0.007	2.2	429
1997	17.7	372.0	2.2	45.4	0.007	2.2	420
1998	17.3	364.3	2.1	44.5	0.007	2.2	411
1999	17.0	357.0	2.1	43.6	0.007	2.1	403
2000	16.5	346.2	2.0	42.6	0.007	2.1	391
2001	16.0	335.3	2.0	41.6	0.007	2.1	379
2002	15.4	324.2	1.9	40.6	0.007	2.1	367
2003	14.9	312.3	1.9	39.5	0.007	2.0	354
2004	14.3	301.3	1.8	38.5	0.006	2.0	342
2005	13.8	290.4	1.8	37.5	0.006	2.0	330
2006	13.3	279.9	1.7	36.5	0.006	2.0	318
2007	12.9	270.4	1.7	35.6	0.006	1.9	308
2008	12.3	258.6	1.6	34.5	0.006	1.9	295
2009	11.5	241.4	1.6	34.0	0.007	2.1	277
2010	11.1	233.0	1.6	32.9	0.007	2.0	268
2011	10.6	222.5	1.5	31.6	0.007	2.3	256
2012	10.3	216.0	1.5	31.8	0.007	2.1	250
2013	10.0	209.6	1.5	31.8	0.007	2.1	243
2014	10.4	218.9	1.7	36.4	0.006	2.0	257
2015	10.2	213.4	1.8	38.1	0.006	1.9	253
2016	9.7	204.1	1.7	36.5	0.006	1.9	242
2017	9.6	201.9	1.9	39.5	0.006	1.9	243
2018	9.0	188.0	1.8	36.9	0.006	1.9	227
2019	9.8	206.5	2.4	50.3	0.006	1.9	259
2020	9.0	188.4	1.8	37.7	0.005	1.7	228

Figure 12 illustrates the individual contributions of sub-sectors to the total GHG emissions estimated from enteric fermentation and manure management. It shows clearly that methane emissions from enteric fermentation dominates the total GHG emissions by 86.6% followed by methane emissions from manure management (12.7%) and then direct N_2O emissions from manure management (0.7%). From the historic data it can inferred that enteric fermentation is the key category source in the agricultural sector and improvements in data activity and estimation process needs to be more robust.

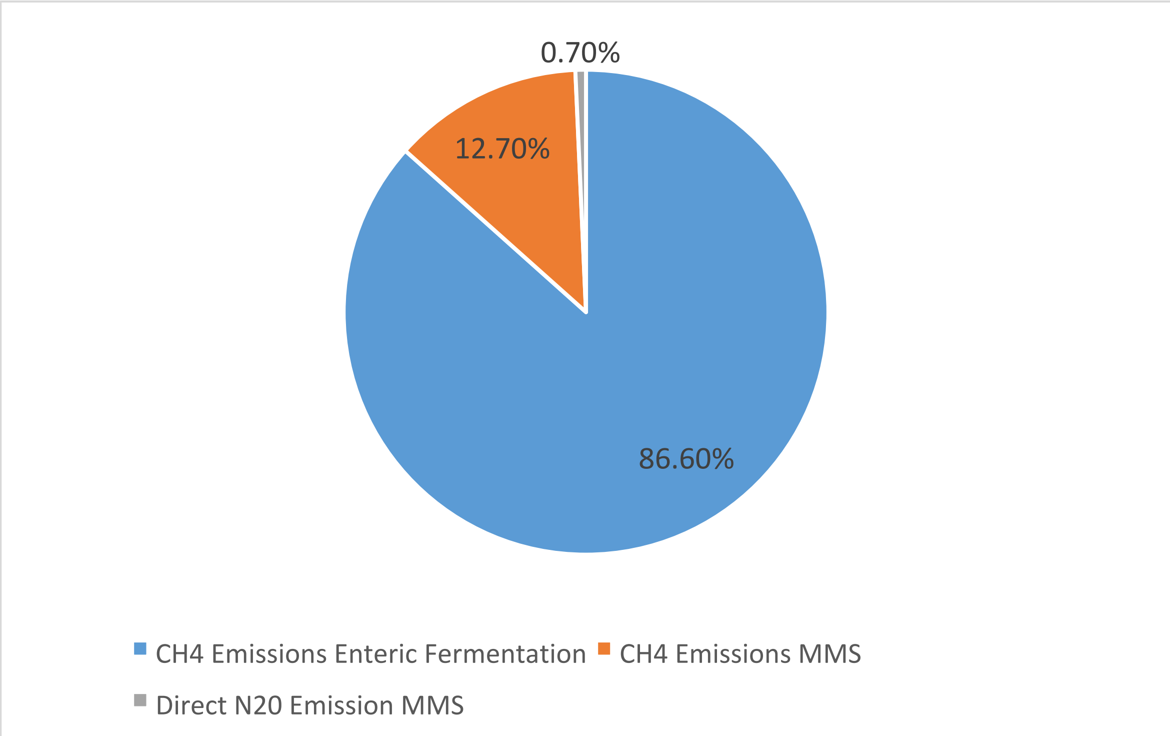


Fig. 12. Sub-sectoral contribution in percentage to the total GHG emissions reported in CO_2 eq.

5. Recommendations for Improvement

Correct capturing and recording of animal population is very critical for a more robust GHGI for agricultural emissions. The FAOSTAT database could not be reconciled with the national animal survey, hence animal population data was estimated (linear regression or interpolation) using the national census data. There should be a dedicated section within the Ministry of Agriculture to generate database on animal population and data should be disaggregated in a format to enable GHG calculations. For example the data needs to be segregated into Dairy cattle, other cattle, breeding swine and marketing swine, Poultry- layers and Poultry – broilers. Also data should be collected for all farms rather than just supervised farms.

- Data on live weight, milk production should be noted so that EF could be corrected and a more appropriate EF could be used.
- The methane emissions from enteric fermentation is significant and is classified as a key source category for Fiji. In future the ruminant animal population is going to increase and perhaps Fiji should look into Tier 2 methodology for CH_4 emissions from enteric fermentation.
- For emissions from manure management it is critical to know the % usage of a particular manure management system, data needs to be captured correctly that reflects the nationwide practice. This data has been very poorly recorded to date.

6. Checklist

Methane Emission from Enteric Fermentation

	The following steps must be followed to collect data and calculate emissions from enteric fermentation:	**Status**	**Task completed by:**
1	Identify the approach as per the 2006 IPCC guidelines for National Greenhouse Gas Inventory to calculate CH_4 emissions from enteric fermentation. Also refer to the Decision tree for guidance. ☐Tier 1 ☐Tier 2 ☐Tier3		
2	Identify the key livestock categories for which the emissions need to be calculated for based on national data.		
3	Liaise with relevant stakeholders and list the total population headcount for all key livestock categories for the last 20 years (you can go back even further if the data is available). ☐Dairy Cattle ☐Other Cattle ☐Swine (further disaggregate into breeding and market swine) ☐Sheep ☐Goats ☐Horses *Key stakeholder is the Ministry of Agriculture, Fiji.		
4	For each livestock category, document: ☐lifespan, years ☐average annual live-weight, kg ☐feed intake, kg Also, for dairy cattle, document: ☐average annual milk production per head.		

5	Using the livestock category data in 7 and Table10.10, Table 10.11, Table 10A. 1 and Table 10A.2, select the default emission factor for each livestock category. ☐Dairy Cattle ☐Other Cattle ☐Swine (further disaggregate into breeding and market swine) ☐Sheep ☐Goats ☐Horses		
6	Calculate the Average Annual Population for all livestock that have a lifespan of less than one annual cycle.		
7	Calculate the total methane emissions from enteric fermentation using Equation 10.19 & 10.20 and the IPCC Workbook.		
8	Review the livestock data collection method, especially to see whether the livestock sub-species data were collected and aggregated (or disaggregated) correctly.		
9	Compare the data with those from previous years to ensure that the data is reasonable and consistent with the expected trend.		
10	Document the data collection method(s), identify potential areas of bias and comment on the representativeness of the data. If population modelling is used (extrapolation, interpolation, etc.), document this process as well for each livestock category. In cases where activity data was not available directly from databases, document the information and assumptions that were used to determine the activity data.		
11	List the source used to collect all activity data.		

Methane Emission from Manure Management

	The following steps must be followed to collect data and calculate emissions from manure management:	**Status**	**Task completed by:**
1	Identify the approach as per the 2006 IPCC guidelines for National Greenhouse Gas Inventory to calculate CH_4 emissions from manure management. Also refer to the Decision tree for guidance. ☐Tier 1 ☐Tier 2 ☐Tier3		
2	Identify the key livestock categories for which the emissions need to be calculated for based on national data.		
3	Liaise with relevant stakeholders and list the total population headcount for all key livestock categories for the last 20 years (you can go back even further if the data is available). ☐Dairy Cattle ☐Other Cattle ☐Swine (further disaggregate into breeding and market swine)		
	☐Sheep ☐Goats ☐Horses ☐Poultry (further disaggregated into layers and broilers) *Key stakeholder is the Ministry of Agriculture, Fiji.		
4	For each livestock category, document: ☐lifespan, years ☐average annual live-weight, kg ☐feed intake, kg		
5	Document the average annual temperature (°C) for all the years as per the time series. *key source is the Fiji Meteorological Services.		
6	Using the information from 4 & 5 with reference to and Table10.14, Table 10.15, Table 10A.2 and Table 10A.4 – Table 10A.8, select the default emission factor for each livestock category. ☐Dairy Cattle ☐Other Cattle ☐Swine (further disaggregate into breeding and market swine) ☐Sheep ☐Goats ☐Horses ☐Poultry (further disaggregated into layers and broilers)		
7	Calculate the Average Annual Population for all livestock that have a lifespan of less than one annual cycle.		

8	Calculate the total methane emissions from manure management using Equation 10.22 and the IPCC Workbook.		
9	Review the livestock data collection method, especially to see whether the livestock sub-species data were collected and aggregated (or disaggregated) correctly.		
10	Compare the data with those from previous years to ensure that the data is reasonable and consistent with the expected trend.		
11	Document the data collection method(s), identify potential areas of bias and comment on the representativeness of the data. If population modelling is used (extrapolation, interpolation, etc.), document this process as well for each livestock category. In cases where activity data was not available directly from databases, document the information and assumptions that were used to determine the activity data.		
12	List the source used to collect all activity data.		

Nitrous Oxide Emissions from Manure Management.

	The following steps must be followed to collect data and calculate emissions from manure management:	**Status**	**Task completed by:**
1	Identify the approach as per the 2006 IPCC guidelines for National Greenhouse Gas Inventory to calculate N_2O emissions from manure management. Also refer to the Decision tree for guidance. ☐Tier 1 ☐Tier 2 ☐Tier3		
2	Identify the key livestock categories and the manure management systems (refer to Table 10.18) for which the emissions need to be calculated for based on national data.		
3	Liaise with relevant stakeholders and list the total population headcount for all key livestock categories for the last 20 years (you can go back even further if the data is available). ☐Dairy Cattle ☐Other Cattle ☐Swine (further disaggregate into breeding and market swine) ☐Sheep ☐Goats ☐Horses ☐Poultry (further disaggregated into layers and broilers) *Key stakeholder is the Ministry of Agriculture, Fiji.		

4	Calculate the Average Annual Population for all livestock that have a lifespan of less than one annual cycle.		
5	For each livestock category, document: ☐lifespan, years ☐average annual live-weight, kg		
6	Determine the default nitrogen excretion rate ($N_{rate(T)}$) form Table 10.19 and use Equation 10.30 to calculate the annual nitrogen excretion ($Nex_{(T)}$) for each livestock category.		
7	Determine the fraction of total annual nitrogen excretion for each livestock category that is managed in specific manure management systems.		
8	Determine the default emission factors for each manure management system identified from Table 10.21.		
9	Calculate the total nitrous oxide emissions from manure management using Equation 10.25 and the IPCC Workbook.		
10	Review the livestock data collection method, especially to see whether the livestock sub-species data were collected and aggregated (or disaggregated) correctly.		
	Document the process of manure management system allocation as per stakeholders.		
11	Compare the data with those from previous years to ensure that the data is reasonable and consistent with the expected trend.		
12	Document the data collection method(s), identify potential areas of bias and comment on the representativeness of the data. If population modelling is used (extrapolation, interpolation, etc.), document this process as well for each livestock category. In cases where activity data was not available directly from databases, document the information and assumptions that were used to determine the activity data.		
13	List the source used to collect all activity data.		