



# The trends and projections of greenhouse gas emission by the livestock sector in Malaysia

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## Abstract

The greenhouse gas (GHG) emission from the livestock sector is a major concern as GHG can contribute to climate change event such as global warming. The country demand for livestock is rapidly increasing, due to population and economic growth. However, in Malaysia, there is still limited studies on GHG assessment from the livestock sector and its projection based on the self-sufficient level under population growth. In this study, the GHG emissions of different livestock were estimated using the livestock population data published in the year 2010–2019, based on Intergovernmental Panel on Climate Change. Malaysia's livestock sector is dominated by poultry, swine, non-dairy cattle and goat. The emission is dependent on the livestock species and population. For enteric fermentation, non-dairy cattle accounted for 73.91% of the CH<sub>4</sub> emission. For manure management, the main contributors were swine and poultry, accounting for 61.49% and 26.24% of the CH<sub>4</sub> emission. Poultry and non-dairy cattle contributed to 63.25% and 20.79% of the direct N<sub>2</sub>O emission from manure management. Comparatively, enteric fermentation was observed to contribute for more than 50% share of the total CO<sub>2</sub>-eq emission. The GHG projection was carried out in two scenarios based on the population projection, self-sufficient level and product consumption per capita for the year 2019, 2030 and 2040. The scenario analysis showed that increasing the animal mass by 1% without increasing the livestock population could help in elevating the sufficiency level of food product even with increasing product demand.

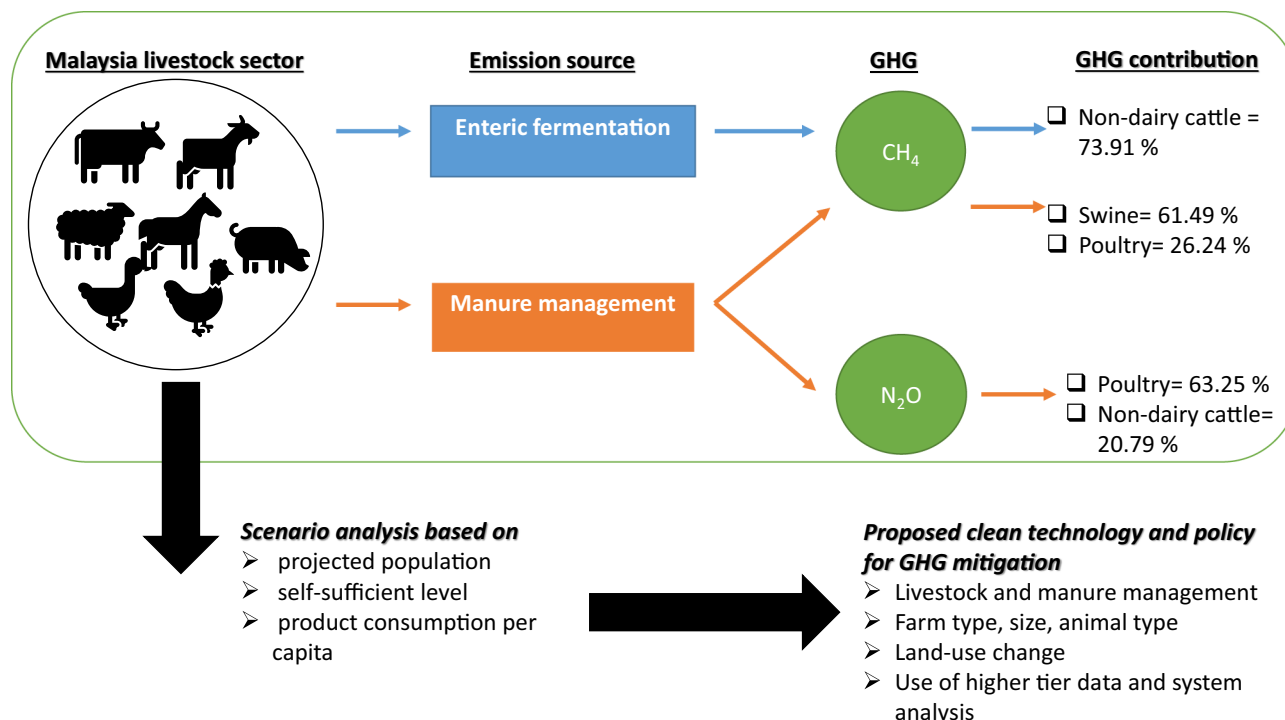
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## Graphic abstract



**Keywords** Greenhouse gas · Climate change · Livestock management · Greenhouse gas mitigation

## Introduction

The global demand for livestock products is expected to be doubled by 2050 due to population growth and higher life quality (Rojas-Downing et al. 2017). The increasing production of the livestock sector rises concern over its impact on climate change due to the emission of greenhouse gas (GHG). Livestock production accounts for 14.5% of the global GHG (Gerbel et al. 2013). The global GHG emissions from livestock have increased by 51% from the year 1961–2010 in developing countries (Caro et al. 2014). Malaysia, a continuously developing country, is also expecting a higher GHG emission from the livestock sector. In the Third National Communication and Second Biennial Update Report Malaysia (NC3BUR2, 2016), the country's livestock industry grows at a 5.4% rate annually. Malaysia has pledged for a GHG emissions reduction target of 45% in terms of intensity of a gross domestic product (GDP) by the year 2030 relative to the year 2005. Thus, an updated GHG projection from the livestock sector is crucial for the country to have quantifiable means to measure the current progress and formulate mitigation approaches from both local and global perspectives.

Several approaches were performed for the modelling of GHG across different studies, with the main objectives to quantify the GHG emission and the effect of mitigation measures. Ghahramani and Bowran (2018) modelled a complex crop-livestock farm system to analyse the impact of localised climate change on the agriculture system and the effectiveness of different adaptation options. The results suggested a need for emission intensity control policy due to increasing GHG emission despite implementing the adaptation options. Tang et al. (2018) presented a whole-farm bio-economic analysis in modelling the GHG emission under different land-use patterns, farm practices and carbon tax. The analysis observed a shift from livestock to crop production and a shift of crops under a carbon tax, where changing land-use patterns and farm management practices offered low-cost GHG abatement potential. Wei et al. (2018) calculated the inventories of GHGs and NH<sub>3</sub> for peri-urban livestock production in Beijing. The spatial distribution of the GHG emission showed that the total industrial livestock production increased by 17% from 2010 to 2014, whereas the scenario analysis suggested that GHG mitigation policies should be focusing on optimising livestock diet, on-farm manure management, industrial production systems and pig and poultry sectors. Key and Tallard (2012) performed an economic model of global agricultural activities to analyse

the effect of incentive policies on GHG mitigation. The study showed that the effectiveness of the policies is affected by the country developing status and location of livestock production.

Studies that modelled on the GHG emission from the livestock sector also showed that the GHG emission intensity is livestock dependent, including type of livestock and the management practices. From the global perspective, beef and dairy cattle accounted for 74% of global livestock emissions (Caro et al. 2014). For India's livestock sector, cattle and buffalo contributed 55% and 37% of the total GHG emission (Patra 2017). In a case study for Beijing, China, enteric beef cattle production (58%) and dairy production (47%) are the most significant sources for enteric fermentation, whereas sheep (36%) and pig production (34%) are the main contributors for manure management (Wei et al. 2018). Zervas and Tsiplakou (2012) also reviewed the effect of the production system on large and small ruminants. The study showed a similar observation that ruminants had the highest GHG share. In contrast, small ruminants have the highest emission per kg body weight due to their higher forage, concentrate ratio in their diet and production system (grazing and mixed). The CF per unit of beef feeding on grass-finished is 74% higher than feedlot (Capper 2010). The CF is the amount of CO<sub>2</sub> and other GHG, usually measured based on their respective global warming potential at a specific time horizon, to CO<sub>2</sub> eq (IPCC 2009). The CH<sub>4</sub> and NH<sub>3</sub> emission were negatively related to farm size due to the capacity of larger farm to implement more effective manure treatment, while N<sub>2</sub>O and CO<sub>2</sub> emission increased

accordingly with farm size due to higher energy consumption (Wei et al. 2018).

In addition to livestock management and manure management, the GHG emission from the livestock sector can also be related to land-use and N fertiliser for crop cultivation. Around 1/3 of global cereal harvest has been channelled to livestock production for animal feed (Rojas-Downing et al. 2017). Studies showed that such emission source can be better managed through the use of organic amendments by reducing synthesis N fertiliser usage (Chen et al. 2014) and reuse of agricultural residue to soil (Li et al. 2017). Li et al. (2017) compared the GHG emissions between the separated system of livestock and crop, with a crop-swine integrated system in China. Comparatively, the integrated system released about 10.15% less GHG emission than the separated system, with increased soil carbon storage and the recycling of the animal manure to field. A similar observation was made by Guo et al. (2020) where substitution of pig and chicken manure with chemical fertilisers increased the soil organic carbon, total N, maize yield and N use efficiency (Zervas and Tsiplakou 2012). When land-use approach is integrated as mitigation options, the livestock emission of the same area could be reduced significantly (Chiriaco and Valentini 2021). Table 1 shows the mitigation measures adopted in the different literature to reduce GHG emission. They are categorised into measures dealing with enteric fermentation (yellow), manure management (orange) and land-use change (green).

There is still limited study available on the GHG emission for the livestock sector in Malaysia, especially in terms

**Table 1** An overview of GHG modelling and mitigation measures for livestock sector

Reference	Country	Objective	Countermeasures Considered								
			Diet feed	Animal species	Manure storage	Anaerobic digestion	Compost -ing	Manure spreading	N fertiliser	Managed land/ soil	Agricultural residues
Chiriaco and Valentini (2021)	Italy	To assess land-use mitigation options	✓			✓			✓	✓	✓
Patra (2017)	India	To quantify GHG emission from livestock and CF of products		✓							
Li et al. (2017)	China	To compare the GHG emission between separated and integrated crop-swine system						✓	✓	✓	✓
Wei et al. (2018)	China	To quantify GHG emission and changes from livestock farms in peri-urban areas	✓		✓	✓	✓				
Guo et al. (2020)	China	To determine the GHG loss after long-term manure application on a maize system						✓			
Ersoy and Ugurlu, 2020	Turkey	To determine the effect of biogas production on GHG emission by total and varied manure recovery rate				✓					
González - Recio et al., 2020	Spain	To determine the mitigation of GHG in dairy cattle via genetic selection	✓	✓							

of the projection based on the self-sufficiency level (SSL) of the livestock production. GHG quantification and projection for the livestock industry still lack accuracy due to the limitation of country-specific data. The projection might vary with time due to the intervention of new policies and implementation of various mitigation approaches. This paper has two aims. Firstly, it aims to quantify the GHG emission from the livestock sector from the year 2010–2019 based on the respective animal category. Secondly, it aims to project the GHG emission under scenarios with intervention from selected policies and assumptions, including population growth, self-sufficiency level, and product consumption per capita. The projection trends obtained in this study were estimated based on the livestock sector's historical data provided by existing Malaysia's reports and inputs from related agencies on their policies and future target. This paper is divided into four sections. Section 1 introduces the background, the literature review and objective of the study. Section 2 describes the methodology approach on data sourcing, equations used, and scenarios considered. Two scenarios, in which scenario 1 assumed an increasing animal population and scenario 2 with increasing animal body mass, are projected while meeting the demand of increasing SSL. Section 3 presents and discusses the GHG emission and policy suggestion derived from the scenario analysis. Lastly, Sect. 4 concludes with the principal findings and recommendation for future work.

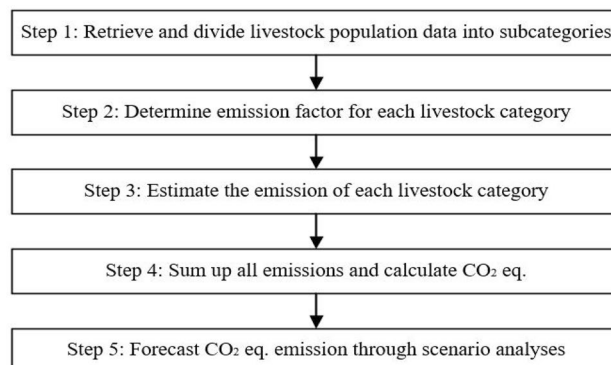
Malaysia is one of the 12 mega-diverse countries, with 15,000 flora and more than 152,320 fauna species, including mammals, reptiles, amphibians, freshwater fish and invertebrates (MyBIS 2021). As a biologically diverse country with substantial biological resources, Malaysia needs a clear policy to strike a balance between development and environmental sustainability. The review and scenario analysis will provide more precise insight into Malaysia's livestock sector's GHG emission pattern and identify policies that lead to a low carbon-emitting livestock sector. Policies that lead to an increase in livestock populations are expected to lead to higher GHG emissions since the number of livestock populations can be considered the main parameter that contributes to GHG emissions from the livestock sector.

## Methodology

Generally, methods for estimating GHG emissions from livestock can be divided into three tiers. Tier 1 is the most basic and usually sufficient for most species of animal in most countries. This approach utilises animal populations and typical emission factors that can be determined based on the region's livestock characteristics and origin. Different regions and livestock characteristics lead to different emission factors (IPCC 2006). Tier 2 and Tier 3, also known as

*higher tiers*, require more detailed and complex livestock characteristic information such as livestock's productivity, growth rate, pregnancy, diet quality, diet quantity and management circumstances. It is encouraged to use these tiers if adequate data are available since they are generally considered more accurate (Romijn et al. 2018; Yona et al. 2020). For this study, the Tier 1 method was employed due to its simplicity in GHG estimation and limited data for Tier 2 or Tier 3. However, the Tier 1 method was enhanced to improve the livestock's GHG emission estimation by combining typical and Malaysia-specific emission factors. The Tier 1 steps employed in this study are shown in Fig. 1.

In step 1, livestock population data were retrieved from Malaysia's Third Biennial Update Report (BUR 3) and divided into subcategories such as cattle for dairy, cattle for non-dairy, buffalo, sheep, goat, horse, swine and poultry. The duck and chicken populations are combined under the poultry subgroup. Then, typical and country-specific emission factors for each category were determined in Step 2. In Step 3, each livestock category's emission was determined using the Tier 1 approach on collected data. In Step 4, the emissions from all categories were summed up to determine the emission of Malaysia's livestock sector. The global warming potential (GWP) values, which were retrieved from the IPCC Fifth Assessment Report (IPCC 2013), were used to estimate the carbon dioxide equivalent (CO<sub>2</sub> eq.) for an accurate comparison between GHG emissions. The GWP for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O are taken as 1, 28 and 265 CO<sub>2</sub>eq, respectively. Lastly, two scenarios were carried out to forecast the potential livestock emission of Malaysia. The forecasted scenarios would determine the emission and Malaysia's self-sufficient level (SSL) of livestock through Eq. (1) based on population projection and product consumption per capita (PCC) of 2019, 2030 and 2040.



**Fig. 1** Step-by-step procedure employed for estimating livestock's GHG emissions

$$\begin{aligned}
 \text{SSL}(\%) &= \frac{\text{Production}}{\text{Production} + \text{Imports} - \text{Exports}} \times 100 \\
 &= \frac{\text{Production}}{\text{PCC} \times \text{Human's population}} \times 100
 \end{aligned}
 \tag{1}$$

In this study, two livestock emissions sources were considered: enteric fermentation and manure management, as shown in Fig. 2. Enteric fermentation is one of the primary sources of livestock's CH<sub>4</sub> emissions. It is a process of digesting carbohydrates into simple molecules essential for livestock. The emission from the process is affected by various factors such as livestock's age, weight and intake.

For the Tier 1 estimation, only the livestock categories' population (N<sub>i</sub>) and emission factor (EF<sub>i</sub>) were used, as shown in Eq. (2) (IPCC, 2006). The EF<sub>i</sub> for CH<sub>4</sub> emissions due to each livestock category's enteric fermentation can be found in the "Appendix 1" section.

$$\text{CH}_4\text{Emission}(\text{GgCH}_4/\text{yr}) = \sum_i \frac{(\text{EF}_i \times \text{N}_i)}{10^6}
 \tag{2}$$

For manure management, the GHG emissions are based on the CH<sub>4</sub> and N<sub>2</sub>O of the livestock's dung and urine. The emissions are dependent on the management of the manure

since different manure management systems lead to different emission factors. Combinations of different types of manure management are commonly used for each livestock, depending on the livestock and the best practices employed in the country. It is not easy to accurately categorise the portions for each type of manure management for every livestock species; hence, Malaysia employs expert judgement from Agriculture GHG Inventory Sub-Working Group to determine manure management systems (BUR 3)'s fractions. The livestock population of each category, typical emission factors and country-specific emission factors were also used for the Tier 1 estimation for manure management. For estimating the CH<sub>4</sub> emission from manure management, Eq. (2) and EF<sub>i</sub> for manure management were used. Meanwhile, for the N<sub>2</sub>O emission, Eq. (3) from IPCC Guidelines for GHG emission estimation (IPCC 2006) was used. This included additional parameters such as animal mass (AM<sub>i</sub>), excretion rate (N<sub>rate,i</sub>) and each livestock category's fraction of manure management systems obtained from expert judgement (MS<sub>i,j</sub>) and emission factor (EF<sub>s</sub>). The emission factors (EF<sub>i</sub> and EF<sub>s</sub>), AM<sub>i</sub>, and N<sub>rate,i</sub> due to manure management for each livestock category can also be found in the "Appendix 1".

$$\text{N}_2\text{OEmission}(\text{GgN}_2\text{O}/\text{yr}) = \left[ \sum_j \left[ \sum_i \left( \frac{(\text{AM}_i \times \text{N}_{\text{rate},i} \times 365)}{1000} \times \frac{\text{N}_i \times \text{MS}_{i,j}}{10^6} \right) \right] \times \text{EF}_s \right] \times \frac{44}{28}
 \tag{3}$$

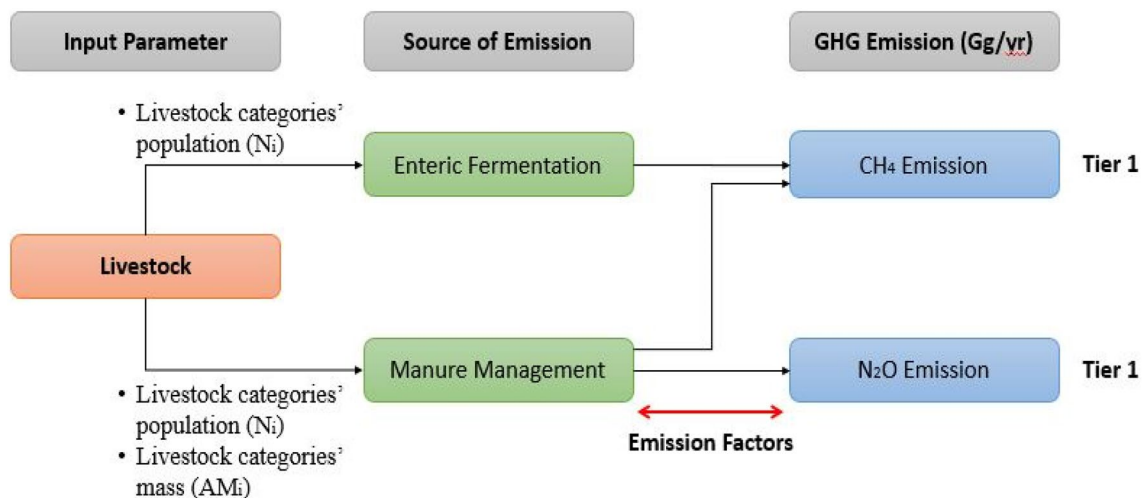


Fig. 2 Superstructure of livestock's GHG emission

**Table 2** Livestock population in Malaysia (BUR3 Malaysia, 2020)

Year	Livestock population ('000)							
	Cattle -Dairy Cattle	Cattle -Non-Dairy	Buffalo	Sheep	Goat	Horse	Swine	Poultry
2010	46	744	130	123	498	4	1931	225,718
2011	45	723	128	126	479	4	1817	238,362
2012	43	701	125	132	463	4	1852	260,508
2013	44	708	124	142	434	4	1843	282,143
2014	45	702	121	142	429	4	1844	297,806
2015	46	697	119	147	432	4	1887	296,518
2016	46	693	119	138	417	4	1654	299,299
2017	43	661	114	131	385	4	1849	302,585
2018	40	636	107	128	359	4	1968	270,607
2019	45	613	102	122	313	3	1888	294,440

The following section discusses the potential livestock emission of Malaysia forecasted through two different scenarios. The forecast's objective is to provide an overview so that decision-makers can plan potential action or policies that could bring positive impact on Malaysia's livestock-based GHG emissions.

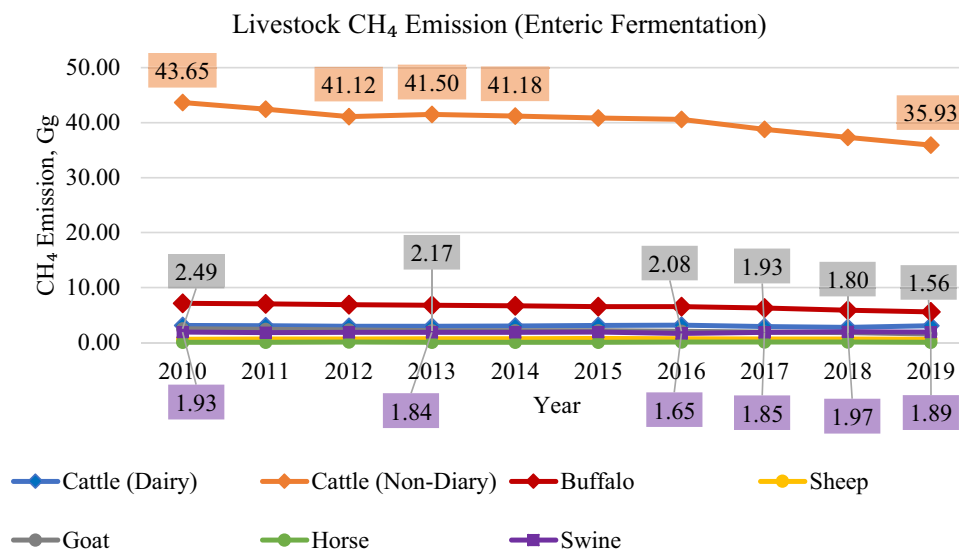
## Results and discussion

### GHG emission from livestock sector

Table 2 shows the livestock population in Malaysia from 2010 to 2019 obtained from Malaysia's third Biennial Update Report (BUR3) (2020). BUR3 uses standard guideline proposed by IPCC (2006) to account for GHG emissions. In general, it can be seen that the poultry population is the majority with more than 200 million populations throughout the year range, with its population reaching 300

million populations in 2017. Swine followed by having a population close to 2 million populations each year, then non-dairy cattle with more than 600,000 populations, goat with more than 300,000 populations, sheep and buffalo interchangeably each year with more than 100,000 populations, dairy cattle with more than 40,000 populations and lastly, horse with more than 4,000 populations each year. Livestock population contributes to the emissions from animals' enteric fermentation process and discharge process. Next section discusses GHG composition by each livestock and processes throughout the reported timeline (2010–2019).

Enteric fermentation is a digestive process which emitted  $\text{CH}_4$ . Based on BUR3 (2020), in average, most of the gas is contributed by non-dairy cattle (73.91%) followed by buffalo (11.98%), dairy cattle (5.52%), goat (3.86%), swine (3.40%), sheep (1.22%), and finally horse (0.13%). Due to insufficient data to develop the default emission factor for poultry as stated in IPCC Guideline, the  $\text{CH}_4$  emission from poultry enteric fermentation throughout the timeline is not

**Fig. 3**  $\text{CH}_4$  emissions from livestock enteric fermentation (BUR3, 2020)



**Table 3** Self-sufficient level (SSL) and annual product consumption per capita (PCC) for year 2019 (Malaysian Ministry of Agriculture and Food Industries, 2019)

Livestock (Product)	SSL (%)	Annual consumption (kg/yr) per capita
Cattle -Dairy Cattle (Milk)	63	2.0
Cattle -Non-Dairy/Bufalo (Beef)	22.3	6.1
Sheep/Goat (Mutton)	11.8	1.1
Swine (Pork)	92.1	18.6
Poultry (Poultry meat)	104.1	48.9

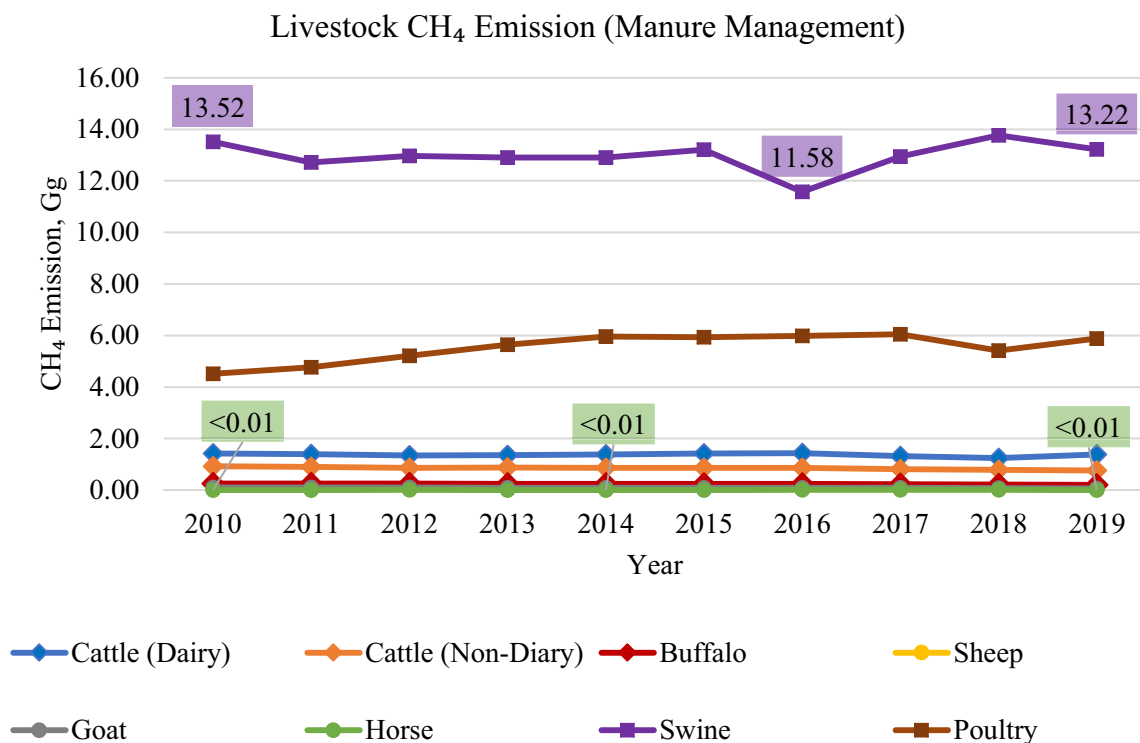
reported. Similar observation was reported by Patra (2017) where cattle and buffaloes contributed for 54% and 38% of the enteric CH<sub>4</sub> emission in India.

Figure 3 shows the CH<sub>4</sub> emissions from livestock enteric fermentation. For all livestock, the CH<sub>4</sub> emission for enteric fermentation process generally fluctuate throughout the timeline and among each livestock. The general trend line emission from non-dairy cattle can be seen to decrease from 43.65 Gg in 2010 to 35.93 Gg in 2019 due to a decrease in the population in non-dairy cattle, around 17.6% (Table 3), from 2010 to 2019. However, the emission increased from 41.12 Gg in the year 2012 to 41.50 Gg in the year 2013. This is due to the increase in non-dairy cattle population from 701,000 populations to

708,000 populations in 2012 to 2013. Goat, in general, emits more CH<sub>4</sub> from enteric fermentation compared to swine as shown in the figure. However, in 2018 and 2019, emission from swine livestock is shown to be greater than goat due to the population size difference between both livestock. In 2019, about 13% of decrease in population size from goat was observed as compared to a 4% population decline in swine.

Manure produced from livestock also contributes to CH<sub>4</sub> emissions. This emission is reported under manure management as a subsector under livestock as proposed by IPCC. In average, most of the emission share comes from swine (61.49%), followed by poultry (26.24%), then dairy cattle (6.5%), non-dairy cattle (4.04%), buffalo (1.13%), goat (0.44%), sheep (0.13%), and lastly, horse (0.04%).

Figure 4 shows the CH<sub>4</sub> emission from livestock manure produced throughout the timeline. Similar to CH<sub>4</sub> emission from enteric fermentation, the fluctuation of emission from livestock discharge is related to the fluctuation in each livestock population. For example, swine produced the most CH<sub>4</sub> from manure discharge in the year 2010 (13.52 Gg), which is the year with the highest swine population. The emission decreased in the year 2019 with 13.22 Gg, which is reflected by a lower swine population. As such, the lowest CH<sub>4</sub> emission from swine manure discharge was seen in the year 2016 where the lowest swine population size was observed. Similarly, the lowest share of CH<sub>4</sub> emission from



**Fig. 4** CH<sub>4</sub> emission from livestock manure produced (BUR3, 2020)

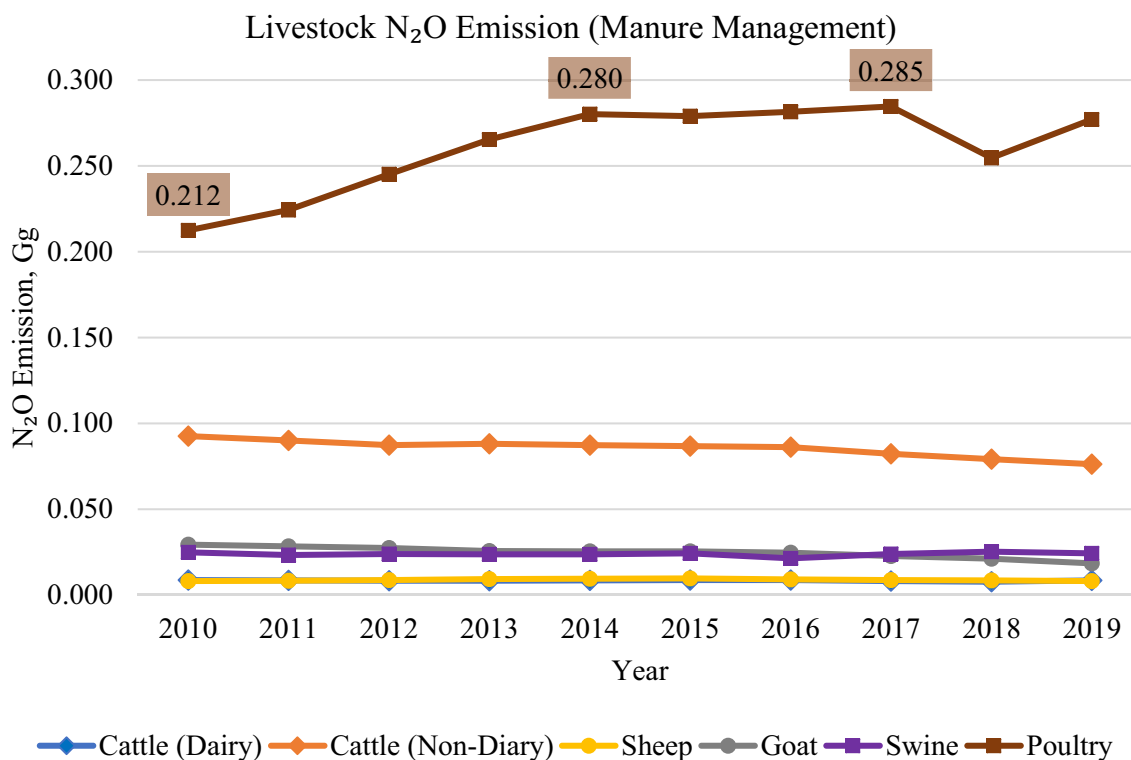


Fig. 5 N<sub>2</sub>O emission from livestock manure produced (BUR3, 2020)

manure discharge comes from the horse livestock, with less than 0.01 Gg emission, throughout the studied timeline due to its relatively small population in Malaysia.

Other than CH<sub>4</sub> emission, manure production also contributes to N<sub>2</sub>O emission. Majority of the N<sub>2</sub>O emission, in average, is contributed by poultry (63.25%), then non-dairy cattle (20.79%), followed by goat (6.03%), swine (5.78%),

sheep (2.13%), and finally from dairy cattle (2.03%). Based on BUR3, horse’s contribution to N<sub>2</sub>O emission is not applicable, neither in emissions nor removal. Thus, it is not included in the GHG reporting. Manure N<sub>2</sub>O emission from buffalo is also not reported since it is assumed that all buffalo discharged is managed through anaerobic lagoons.

Fig. 6 Total emission (CO<sub>2</sub> eq) from enteric fermentation and manure management

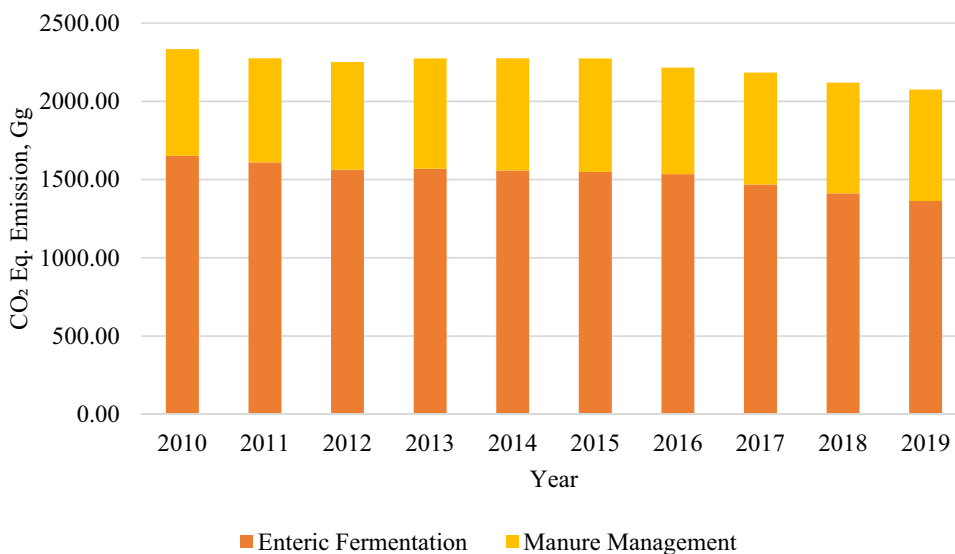




Figure 5 shows the N<sub>2</sub>O emission from livestock manure produced throughout the reported timeline. For poultry, the least emission is in the year 2010 with 0.212 Gg. The emission then increases with the increased livestock population size until 2014 where the emission at the following year decreases with decreasing population. The highest N<sub>2</sub>O emission is seen in 2017 with 0.285 Gg emission which can be reflected from the highest poultry population. It ought to be noted that while N<sub>2</sub>O emissions increase with increasing livestock population, other factors such as mass of animal and excretion rate are also important. Since both factors remain constant for each livestock throughout the reported timeline, livestock population contributes to the fluctuation in each livestock N<sub>2</sub>O emission. As shown in Table 9, among the livestock species, goat comes with the highest excretion rate of 1.37, poultry 0.82, with the rest lower than 0.5 kg N/1000 kg animal mass/d. The effect of livestock mass will be discussed in scenario studies.

Figure 6 shows the CO<sub>2</sub> equivalent emission from enteric fermentation process and manure management. From the figure, it can be seen that most of the emission is contributed by enteric fermentation of livestock while manure management contributed to about more or less half of the contribution of enteric fermentation. In India, the enteric CH<sub>4</sub> accounted for 89.7% of the total GHG emission (Patra 2017). This is evident by looking at the decreasing total CO<sub>2</sub> equivalent, which follows the decreasing enteric fermentation compared to the increasing emissions from manure management. By looking at this, more emphasis on improving livestock digestive efficiency should be taken to reduce the emissions.

## Scenario analysis

For the scenario analysis, the projection of the Malaysian population obtained from the Department of Statistics is used. The population projected are 32,523,000 for year 2019, 36,000,000 for year 2030, and 38,600,000 for year 2040. Table 3 shows the self-sufficient level (SSL) and product consumption per capita (PCC) for year 2010 and

2019 obtained from Agro-food Statistics 2019 published by Malaysian Ministry of Agriculture and Food Industries.

Scenario I—Maintaining self-sufficient level (SSL) with increasing Malaysian population.

### Assumptions

- (1) Per capita consumption (PCC) for projection years (2030, 2040) remains the same as the year 2019.
- (2) Horse population for projection years (2030, 2040) remain the same as the year 2019.
- (3) No changes in mass for each livestock.

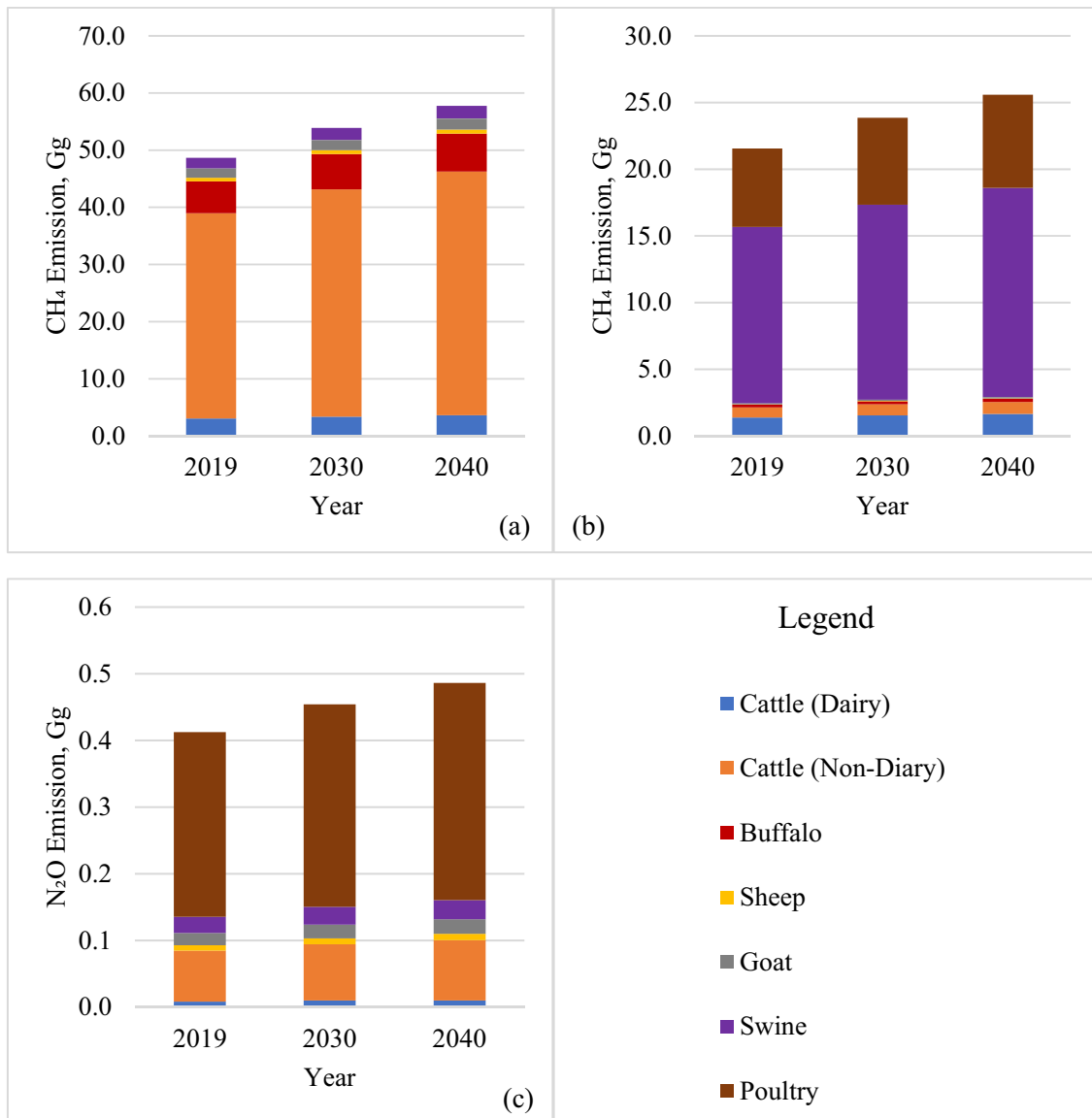
Table 4 summarises the livestock population resulted from increasing population in Malaysia. Increasing population in Malaysia increases the demand for food product, thus, to maintain SSL from the year 2019, livestock population is increased to meet the demand. Since this scenario is to study the effect of food demand to livestock population, horse population in the projected years remains the same as in 2019 and so will the emission projection.

Figure 7a–c shows the emissions projection in Scenario I. As stated before, CH<sub>4</sub> emission from enteric fermentation process is directly related to the population size which can be seen clearly in Fig. 7a where all emissions (except for horse) are projected to increase until 2040. Similar results are obtained from manure management as can be seen in Fig. 7b and c where CH<sub>4</sub> and direct N<sub>2</sub>O emissions from discharged manure are projected to increase until 2040 while emission from horse manure remains constant starting from 2019. The distribution share of emissions from each livestock to each process remains the same as those obtained in 2019 since 2019 is used as base of the projection years. Figure 8 summarises the CO<sub>2</sub> equivalent emitted from enteric fermentation and manure management. From the figure, enteric fermentation continues to emit the majority of CO<sub>2</sub> equivalent compared to manure management. With increasing population, the CO<sub>2</sub> emitted per population decreases due to the distribution of one animal to more than one customer. For example, a 30 kg sheep or goat could provide a kilogram of mutton to 30 people which is the annual PCC value for mutton. Meaning, the emission from one livestock is distributed amongst numbers of citizens, lowering the CO<sub>2</sub> equivalent per capita.

Scenario II—Increasing animal mass while maintaining livestock population amidst increasing population in Malaysia.

**Table 4** Projected livestock population for Scenario I

Livestock	Population ('000)		
	2019	2030	2040
Cattle -Dairy Cattle	45	50	53
Cattle -Non-Dairy	613	678	727
Buffalo	102	113	121
Sheep	122	135	144
Goat	313	346	371
Horse	3	3	3
Swine	1,888	2,090	2,241
Poultry	294,440	325,918	349,457



**Fig. 7** a Projected CH<sub>4</sub> emission from enteric fermentation for Scenario I; b Projected CH<sub>4</sub> emission from manure produced for Scenario I; c Projected direct N<sub>2</sub>O emission from manure produced for Scenario I

### Assumptions

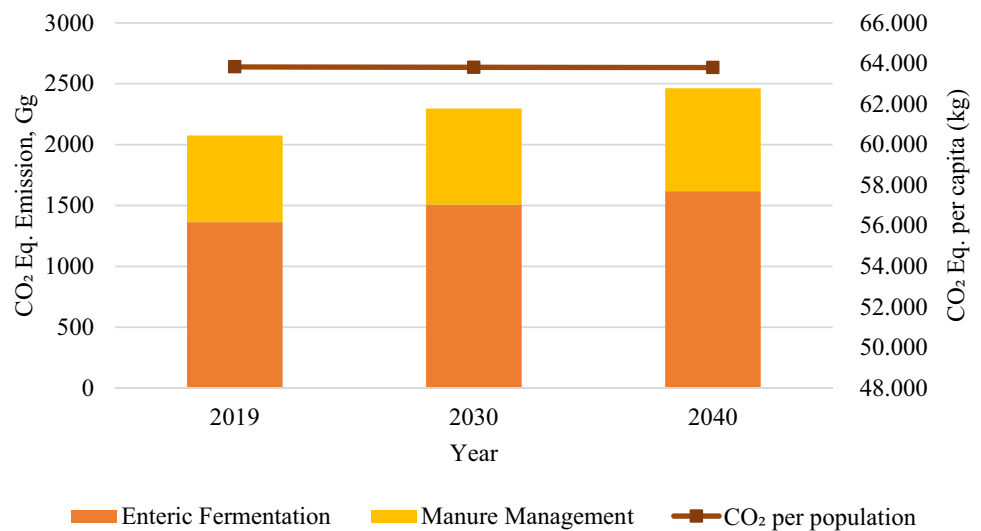
- I. Livestock population for projection years (2030, 2040) remain the same as the year 2019.
- II. Increase livestock mass by 1% per year with respect to animal mass in the year 2019 for each livestock.
- III. PCC for projection years (2030, 2040) remain the same as the year 2019.

Table 5 shows the SSL resulted from increasing animal mass and demand. Since this scenario concerns with the sufficiency of food product, SSL projection for horse is not applicable in this scenario. In Table 5, it can be seen that,

by 2040, increasing the animal mass without increasing the livestock population helped in elevating the sufficiency level of food product even with increasing product demand.

It can be seen in Fig. 9a below that changing animal mass does not change the CH<sub>4</sub> emission from enteric fermentation calculated. This is because, in Tier 1 reporting, while livestock population plays important part in the emissions, only N<sub>2</sub>O emission from manure management considers mass of livestock as other factor contributing to GHG emissions. However, once Tier 2 reporting is used, the effect from changing the animal mass will be reflected in the reported CH<sub>4</sub> emissions since Tier 2 will include a more detail emission related to diet (consumption) of the livestock. Figure 9b also shows no changes of projected CH<sub>4</sub> emission from discharged manure since animal

**Fig. 8** CO<sub>2</sub> equivalent projection for Scenario I



mass is not one of the factors affecting the emission. Since Scenario II concerns with the effect of increasing animal mass, changes in emissions can only be seen in Fig. 9c. From Fig. 9c, increasing animal mass subsequently causes all N<sub>2</sub>O emissions to increase in the projected years. Figure 10 summarises the findings for Scenario II where we can see that CO<sub>2</sub> equivalent projection from enteric fermentation remains constant after 2019 while manure management can be seen to be increasing after 2019 contributed by direct N<sub>2</sub>O emission and since smaller contribution is experienced from direct N<sub>2</sub>O emission, upward projection for Scenario II total CO<sub>2</sub> equivalent is less steep than Scenario I. In this scenario, too, CO<sub>2</sub> equivalent per capita decreases with increasing Malaysian population due to more efficient resource distribution among more consumers.

**Recommendation and policy implication**

Kipling et al. (2019) investigated on the challenges to implement GHG mitigation measures in livestock agriculture. The study categorised the factors into 4, which are practical limitation in terms of resources, knowledge limitation, cognitive limitations on recognising limitations and finding effective solution, and interest such as supply chain and customers. The study further emphasized that cognitive limitations as a

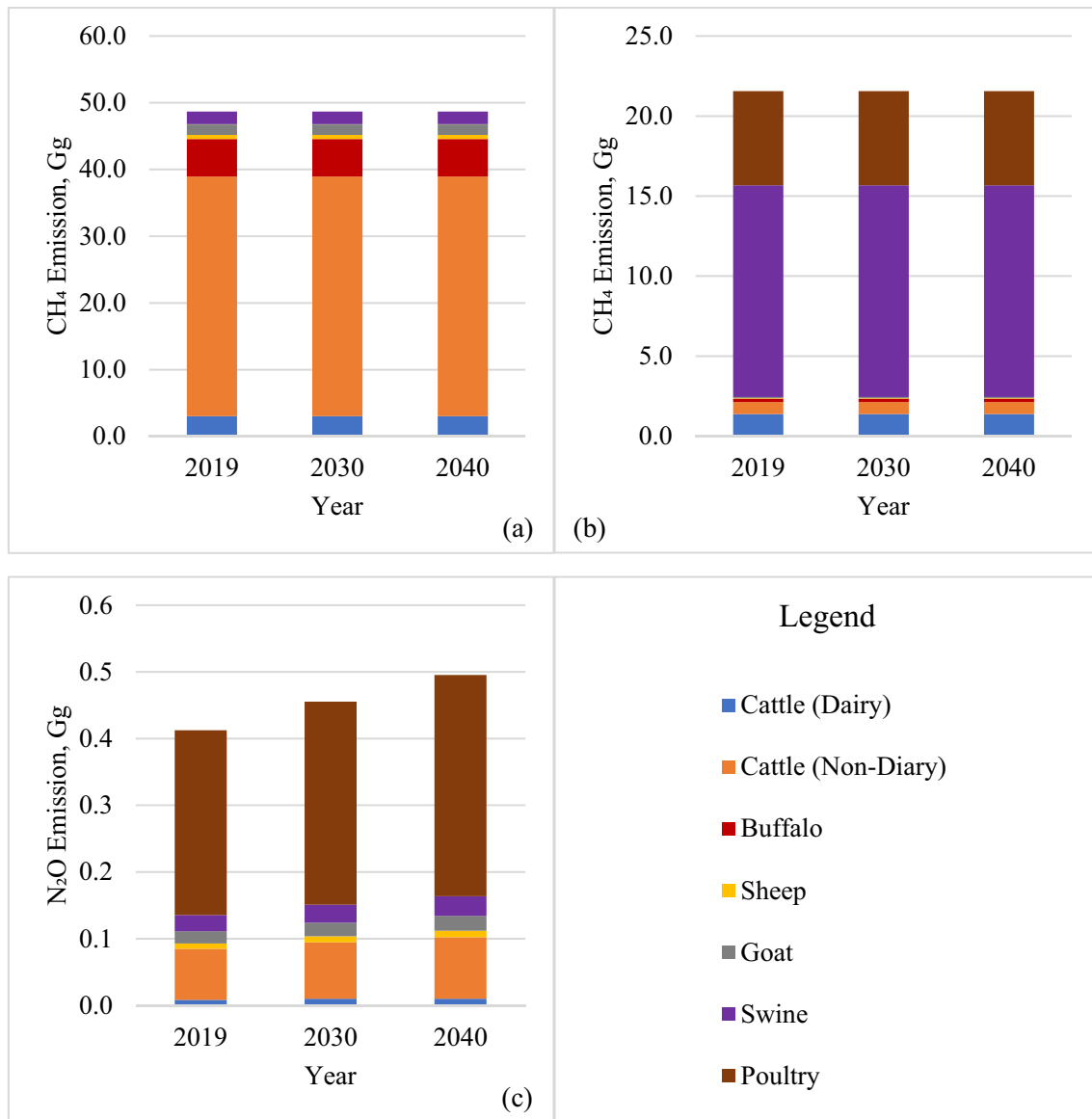
challenge needs to critically examined of how and by whom change is to be determined, implemented and governed. In the EU, the common agricultural policy (CAP) offers a number of instruments to address climate change challenges towards a sustainable EU agriculture (EC 2021), such as cross-compliance mechanisms, Green Direct Payment and promoting resource efficiency and shifting towards low carbon. Incentive policies based on producer-level emissions is not recommended due to high administrative costs and producer transaction costs, but incentivisation based on sectoral emissions, e.g. carbon tax and emission trading scheme based on average national CH<sub>4</sub> emission per unit commodity is shown to be effective in developing countries (Key and Tallard 2012).

The livestock industry in Malaysia is generally divided into ruminants and non-ruminants. The National Agro-Food Policy (2011–2020) estimated a 2.7% growth per annum for meat production and a 2.4% growth per annum on meat consumption. The Malaysian Livestock Breeding Policy (2013) aims to conserve and improve the breeding of quality livestock through genetic principles, which leads to an economical and sustainable livestock industry. A total of 101 breeds and breed crosses are available by the Farm Animal Genetic Resources in Malaysia. There are planned programmes in reducing the environmental impact and promoting the sustainable utilisation, including the special feed additives to reduce CH<sub>4</sub> production, capturing CH<sub>4</sub> as biogas and the breeding of special breeds with lower CF. The mitigation measures ought to be in line with the reduction targets set in accordance with policy requirements (Wei et al. 2018) and to avoid negative environment impact.

From the projection, it showed that the GHG emission is dependent on livestock type. Cattle and swine accounted the most for CH<sub>4</sub> emission from enteric fermentation and manure management, respectively, whereas poultry accounted the most for N<sub>2</sub>O emission. Among the GHG

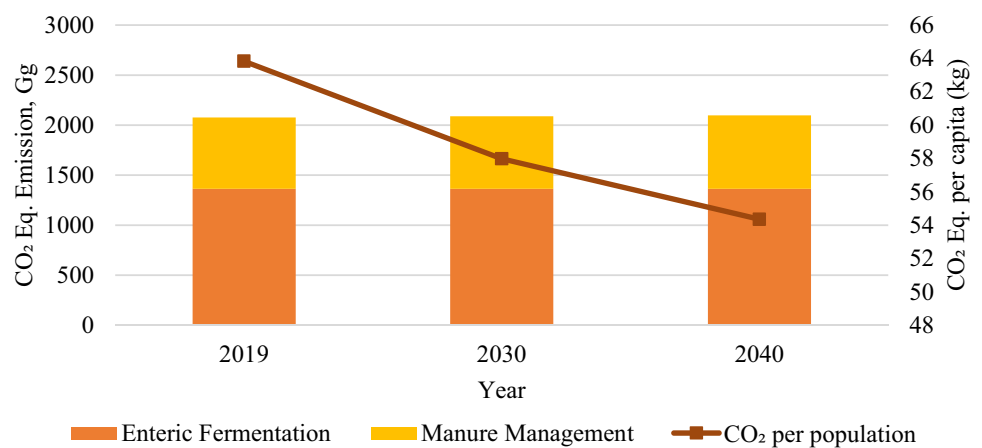
**Table 5** Projected SSL (%) for Scenario II

Livestock (Product)	SSL (%)		
	2019	2030	2040
Cattle -Dairy Cattle (Milk)	63.00	63.21	64.26
Cattle -Non-Dairy/Buffalo (Beef)	22.28	22.25	22.62
Sheep/Goat (Mutton)	11.83	11.77	11.97
Swine (Pork)	92.06	92.33	93.87
Poultry (Poultry meat)	104.11	104.37	106.11



**Fig. 9** a Projected CH<sub>4</sub> emission from enteric fermentation for Scenario II; b Projected CH<sub>4</sub> emission from manure produced for Scenario II; c Projected direct N<sub>2</sub>O emission from manure produced for Scenario II

**Fig. 10** CO<sub>2</sub> equivalent projection for Scenario II



sources, enteric fermentation makes up 60% of the total GHG emission, in terms of CO<sub>2</sub> eq. In addition, based on the scenario analysis, increasing livestock biomass serves as a better approach in satisfying the increasing SSL than increasing livestock population. This suggests that the expansion of the livestock sector could consider prioritising the expansion of certain livestock species or formulate appropriate ratio among livestock with different emission intensity to minimise the environmental impact. Breeding breeds with lower CF and higher economic viability with greater product yield and encourage non-ruminants over ruminants are also recommended to reduce GHG emission (Patra 2017). However, there are questions that remain on the maximum body mass per animal achievable and ought to be taken as a constraint into future modelling.

Another approach is to achieve GHG mitigation through feed formulation. Wei et al. (2018) showed that optimising livestock diet can be effective than increased intensification rate and improved manure management in reducing GHG emission, while improving manure management is more effective in reducing NH<sub>3</sub> emission. The CH<sub>4</sub> emission from the enteric fermentation is affected by the feed intake and the associated methanogenesis where strategies such as high grain level, lipid supplementation and higher concentrate to forage ratio can improve the product efficiency where low feed efficiency with low product yield are major factors contributing to a high CF (Zervas and Tsipakou 2012). Supplying up to 3% of lipid to the animal feed was observed to achieve a mitigation potential of 0.28–0.86 Mg CO<sub>2</sub>/ head/ yr (Chiriaco and Valentini 2021), where 1% increase in dietary fat can decrease enteric CH<sub>4</sub> fermentation up to 4–5% (Martin et al. 2010).

The National Agro-Food Policy (2011–2020) of Malaysia also listed out several initiatives and future direction, including increase production the modernisation of agriculture and increase livestock production, facilitate private investment, to encourage a sustainable and profitable livestock agriculture (Dardak 2019). Land application of manure also needs to be regulated with tight policy and guidance where studies showed more than 20% manure-based N had directly entered watercourses (Chadwick et al. 2015). Livestock production plays fairly important role in the agricultural GHG emission as they consume feed. Nevertheless, some challenges in implementing such mitigation policies could be on the economic and technical feasibility. For future work, the modelling is recommended to account for mitigation measures with such considerations to enable a multicriteria policy recommendations.

## Conclusion

In terms of GHG emission, the two main activities accounted are enteric fermentation and manure management. For enteric fermentation, most of the gas is contributed by

non-dairy cattle (73.91%) followed by buffalo (11.98%), dairy cattle (5.52%), goat (3.86%), swine (3.40%), sheep (1.22%), and lastly, horse (0.13%). For manure management, the main CH<sub>4</sub> contributor is by the swine livestock (61.49%), followed by poultry (26.24%), then dairy cattle (6.5%), non-dairy cattle (4.04%), buffalo (1.13%), goat (0.44%), sheep (0.13%), and finally horse (0.04%). For the N<sub>2</sub>O emission from manure, it is the highest by poultry (63.25%), then followed by the non-dairy cattle (20.79%), goat (6.03%), swine (5.78%), sheep (2.13%), and finally from dairy cattle (2.03%). The GHG emission in CO<sub>2</sub>-eq of the enteric fermentation is more than double of the manure management. The scenario analysis also showed that it is possible to meet the growing self-sufficiency level and demand by increasing the animal body mass instead of increasing the animal population. Comparing the two scenarios, increasing animal mass did not show great increment in GHG emission intensity despite growing livestock demand. Furthermore, this approach also CO<sub>2</sub> equivalent per capita decreases with increasing population due to more efficient resource distribution among more consumers. This can offer a new direction in the national and global effort in accelerating GHG mitigation. Thus, policies and mitigation measures focusing on maximising the livestock productivity, for example, the breeding of desirable traits and improving feed formulation that can reduce enteric fermentation and maximising mass per animal, could be of high priority.

GHG quantification and projection for the livestock industry still lack in accuracy due to the limitation of country-specific data. The emissions projected in this study is based on Tier 1 data. It is expected that once Tier 2 reporting is used, there would be a change in the projected CH<sub>4</sub> emissions due to inclusion of more precise activity data. In addition, along with higher tier data, statistical analysis and uncertainty analysis to capture the projection trend with higher accuracy could be used to fine tune the projection. Due to the limited data availability, this study only considers two scenarios, which are increasing animal population and increasing body mass for satisfying increasing SSL. Furthermore, there are increasing consideration on the GHG emission on the land-use change associated with livestock production, including the land use and fertiliser consumption for producing animal feeds. Accordingly, studies have also shown the positive synergies in an integrated crop-livestock system to mitigate GHG emission. In the integrated system, the generated waste with negative environment impact can be diverted back to the field as resources with positive environmental impact, such as land application of manure and biomass combustion for energy. Future work shall take into the consideration of different mitigation measures based on the GHG emission from the respective livestock species as identified in this study.

## Appendix 1

See Tables 6, 7, 8 and 9.

**Table 6** CH<sub>4</sub> emission factors for enteric fermentation

Livestock category	Emission factor (EF <sub>i</sub> )
Cattle -Dairy Cattle	68
Cattle -Non-Dairy Cattle	58.65
Buffalo	55
Sheep	5
Goat	5
Horse	18
Swine	1
Poultry	N/A

**Table 7** CH<sub>4</sub> emission factors for manure management

Livestock category	Emission factor (EF <sub>i</sub> )
Cattle -Dairy Cattle	31
Cattle -Non-Dairy Cattle	1.24
Buffalo	2
Sheep	0.2
Goat	0.22
Horse	2.19
Swine	7
Poultry	0.02

**Table 8** Values of animal mass and excretion rate for manure management

Livestock category	Animal mass (kg)	Excretion rate, kg N/1000 kg animal mass/day (N <sub>rate<i>i</i></sub> )
Cattle -Dairy Cattle	350.00	0.47
Cattle -Non-Dairy Cattle	319.00	0.34
Buffalo	380.00	0.32
Sheep	28.00	1.17
Goat	30.00	1.37
Horse	238.00	0.46
Swine	28.00	0.40
Poultry	1.20	0.82

**Table 9** Emission factors of different manure management systems

Manure management system	Emission factor (EF <sub>s</sub> )
Anaerobic lagoons	0.000
Solid storage	0.005

This section displays the parameters used to estimate Malaysia's livestock's GHG emission. These parameters consist of typical and country-specific values retrieved from IPCC Guidelines (2006) and Malaysia's Third Biennial Update Report (2020).

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**Data Availability** The data used in this manuscript are provided with the data sources and can be accessed through the information found in the reference list.

## Declarations

**Conflict of interest** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The submitted manuscript is our original work and has neither been published elsewhere nor be submitted to more than one journal for simultaneous consideration.

**Ethical approval** The submitted manuscript is our original work and has neither been published elsewhere nor be submitted to more than one journal for simultaneous consideration.

**Consent for publication** All authors read and approved the final manuscript.

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