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Article

Methane, nitrous oxide and ammonia emissions from livestock farming in the Red River Delta, Vietnam: an inventory and projection for 2000-2030

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Abstract: Livestock farming is a major source of greenhouse gas and ammonia emissions. In this study, we estimate methane, nitrous oxide and ammonia emission from livestock sector in the Red River Delta region from 2000 to 2015 and projection to 2030 using IPCC 2006 methodologies with the integration of local emission factors and provincial statistic livestock database. Methane, nitrous oxide and ammonia emissions in 2030 are estimated at 132 kt, 8.3 kt and 34.2 kt, respectively. Total global warming potential is 9.7 $MtCO_{2eq}$ in 2030, accounts for 33% greenhouse gas emissions from livestock in Vietnam. Pig farming is responsible for half of both greenhouse gases and ammonia emissions in the studied region. Other major livestock for greenhouse gas emission is cattle and for ammonia emission is poultry. Hanoi contributes for the largest emissions in the region in 2015 but will be caught up and surpassed by other provinces in 2030.

Keywords: emission inventory; livestock; greenhouse gases, air pollutant

1. Introduction

Economic growth in Vietnam has shifted food consumption patterns to incorporate more livestock products (meat, dairy products, and eggs) [1]. With the growing demand for livestock products, livestock farming is expanding in Vietnam and is among the fastest growing agricultural production subsectors in Vietnam [1]. In 2015, livestock accounted for 28% of value added from the agriculture sector. The development and intensification of this subsector has led to an increase in the total animal population during the past decade. In 2016, Vietnam had 29 million pigs, 5.5 million cattle, 2.5 million buffalos, and 361 million poultry [2]. The largest population increases compared to 2005 have been in poultry (by 142 million head), followed by pigs (2 million head); numbers of cattle and buffalo have fluctuated slightly.

The development and intensification of livestock farming helps to ensure national food security and boosts economic growth. However, this sector is also a significant contributor to environmental pollution in general and air pollution in particular. Livestock farming contributes significantly to global greenhouse gas (GHG) emissions [3] by releasing methane (CH_4) and nitrous oxide (N_2O), as well as air pollutants, mostly ammonia (NH_3), to the atmosphere. Livestock farming is the largest emissions source of NH_3 [4–6], which plays a major role in eutrophication and acidification [7]. The Food and Agriculture Organization (FAO) has estimated that 18% of global GHG emissions originate from the livestock sector.

Vietnam is listed among the 20 countries with the highest GHG emissions in the UNFCCC and FAOSTAT databases [8]. Emissions from livestock farming account for approximately 20% of greenhouse gas emissions from agricultural activities in Vietnam according to the National GHG

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emissions inventory for 2010 [9]. Emissions from enteric digestion are responsible for half of all livestock emissions, with the other half originating from manure management, one of the fastest-growing sources of GHG emissions in Vietnam during 1994–2010 [5]. An inventory of CH_4 emissions from livestock in Asia in 2000 [10] showed that poultry emitted the largest amounts of CH_4 in Vietnam, followed by cattle, buffalo, and pigs. A CH_4 and N_2O emissions inventory for South, Southeast, and East Asia was recently conducted [11] using emissions inventory methodologies from the International Panel on Climate Change (IPCC) 1997 Guidelines for National Emission Inventory, and ranked Vietnam in 6th place for NH_3 emissions and 7th place for CH_4 and N_2O emissions among the 23 countries studied. An estimate of air pollutants and GHGs over Asia aggregated Vietnam within the Southeast Asia region [12]. To our knowledge, no emissions inventory has been conducted for CH_4 and N_2O in Vietnam using IPCC 2006 methodologies. Previous studies estimating livestock farming emissions in Vietnam have been conducted at the provincial scale or for one type of pollutant (GHG or air pollutant). Examples of such studies include estimates of CH_4 emissions from cattle in Daklak province [13], CH_4 emissions from cattle in Quang Ngai province, with mitigation scenarios [14], and GHG and pollutants from livestock farming within a ward of Hung Yen province [15].

It is important to develop a historical inventory and projections of future livestock GHG and air pollutants to improve our understanding of the evolution of emissions and their associated impact on air quality. In this study, we focused on the Red River Delta (RRD) region, which is among the largest livestock farming centers of Vietnam. This region contained 8,726 livestock farms in 2016, accounting for 42% of all livestock farms in the country [2]. RRD contains the largest number of pigs and poultry, with populations of 7.4 million and 93.7 million head, respectively. This inventory attempts to quantify emissions of CH_4, N_2O, and NH_3, the three main GHGs and air pollutants produced by livestock farming, in RRD from 2000 to 2030 at a 5-years resolution using the IPCC 2006 Guidelines for National Emission Inventory [16] and regional or country-specific emission factors wherever applicable. The results of this study are expected to contribute to better regional air quality modeling and management, and to improve national inventory management.

2. Materials and Methods

2.1. Emission inventory methodology

We conducted an emissions inventory for livestock farming for the sources and pollutant species listed in Table 1. We applied emissions inventory methodologies from the IPCC Guidelines for National Emission Inventory [16]. In general, we applied Tier 1 methods, such that activity data were multiplied by relevant emission factors. Country-specific emission factors were used (Tier 2 method) wherever applicable. The general equation for estimating livestock emission is Equation 1 [17]

Equation 1

$$E_{i,j} = \sum Na_i \times EF_{i,j} \quad (1)$$

where $E_{i,j}$ is the emission from animal type i and pollutant j; Na_i is the number of animal of type i, $EF_{i,j}$ is the emission factor for animal type i for pollutant j.

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Table 1. Activities and pollutant species included in the inventory.

Source/pollutant	CH_4	N_2O	NH_3
Enteric fermentation	✓		
Manure management	✓	✓	✓

Equation 2 from IPCC 2006 Guidelines was used to estimate direct N_2O emissions from manure management.

Equation 2

$$E_{N2O} = \left[\sum_S \left[\sum_T (N_T \times Nex_T \times MS_{T,S})\right] \times EF_S\right] \times \frac{44}{28} \quad (2)$$

where N_T is number of animal type T, Nex_T is the annual average N excretion per head of animal type T. Nex_T is calculated using Equation 3, where $N_{rate\,T}$ is the default N excretion rate; TAM is the typical animal mass for animal type T. Both values are provided in IPCC 2006 Guidelines. Value of Nex_T for animals in Asia are listed in Table 2. $MS_{T,S}$ is the fraction of total annual nitrogen excretion for each animal of type T in manure management system S. $MS_{T,S}$ is provided in Table 4. EF_S is default emission factor for direct N_2O emission from manure management system S (Table 4). 44/28 is the conversion of N_2O-N emissions to N_2O emissions.

Equation 3

$$Nex_T = N_{rate\,T} \times TAM/1000 \times 365 \quad (3)$$

Table 2. Nitrogen (N) excretion per animal type (kgN head^{-1} yr^{-1})

Animal	$N_{rate\,T}$ (kgN/1000kg animal mass/day)	TAM (kg/animal)	Nex_T (kgN/head/yr)
Dairy cattle	0.47	350	60.043
Other cattle	0.34	319	39.588
Pigs	0.42	28	4.292
Poultry	0.82	1.8	0.539
Goats	1.37	30	15.002
Horses	0.46	238	39.960
Buffalo	0.32	380	44.384

N_{rateT}, default N excretion rate; TAM, typical animal mass for animal of type T; Nex_T, annual average N excretion per head of animal of type T.

2.2. Data

The RRD region consists of 10 provinces and two cities, including Hanoi, the capital of Vietnam. In our inventory, historical activity data from 2000 to 2015 was acquired at the provincial level and summed to obtain regional data. Projected activities were obtained from approved provincial, regional, and national agricultural development plans.

Historical data on provincial livestock numbers were obtained from the Statistical Yearbook of each province and from the Vietnam Statistical Yearbook [18,19]. More detailed data (e.g., numbers of dairy cows and laying hens) were obtained from the Department of Livestock Production, Ministry of Agriculture and Rural Development, and are publicly accessible [20]. Livestock is classified into the following groups: dairy cattle, other cattle, pigs, poultry, horses, and goats.

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Table 3. Livestock population data used in this emissions inventory.

Animal (10^3 head)	2000	2005	2010	2015	2020	2025	2030
Dairy Cattle	13.5	20.0	19.3	48.3	45.3	63.7	77.5
Other cattle	489.4	689.9	604.0	445.4	754.1	757.7	871.4
Poultry	54,742	59,597	76,394	90,829	97,686	109,352	124,153
Horses	1.5	1.3	1.8	0.9	1.0	1.0	0.9
Goat	10.5	10.5	75.6	79.1	96.8	112.1	129.6
Buffalo	278.1	209.1	168.7	130.4	130.2	108.4	108.7
Pig	5,688	7,796	7,301	7,061	9,326	9,906	10,476

Projected livestock numbers for 2020 were obtained from the Provincial Agriculture Development Plan [21] for each province. Projections for 2030 were not available for all provinces examined in this study; therefore, we forecasted the livestock populations in these provinces by dividing the proportion of each type of animal within the province by the national total. Historical and projected livestock populations are presented in Table 3.

Distributions of N excretion for each animal type managed under different manure management systems are provided in Table 4. We estimated the proportion of manure by type of management system for the pig and poultry industries using results from previous studies [22–24]. We used default values from the IPCC 2006 Guidelines for cattle, buffalo, and other animals.

Table 4. Fraction of total annual N excretion for each animal type and emission factors by manure management system

Manure management system	**Animal**							**Emission factor kg N2O-N /kg N excreted**
	Dairy cow	Other cattle	Pig	Horse s	Goat	Buffalo	Poultry	
Pasture/range	0.2	0.5		1	1	0.5		-
Daily spread	0.29					0.04	0.55	0
Solid storage			0.15					0.005
Dry lot	0.07	0.48				0.46		0.02
Liquid/slurry (with natural crust cover)	0.38		0.15					0.05
Uncovered anaerobic lagoon	0.04							0
Pit storage								0.002
Anaerobic digester	0.02		0.3					0
Composting static pile			0.4					0.006
Poultry manure with litter							0.45	0.001

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2.3. *Emission factors*

A summary of the CH_4 and NH_3 emission factors used in this study is provided in Table 5. We used regional emission factors for CH_4 emission from enteric fermentation from previous studies for dairy and beef cattle [25,26] and buffalo [15]. We used the IPCC 2006 default values for all other animals. We used the IPCC 2006 Guidelines for N_2O, in which emission factors were specified for manure management systems (Table 4). We used an adjusted European NH_3 emission factor [11] adjusted European emission factor. These values were also used in a previous study [15] for Vietnam.

Table 5. Methane (CH4) and ammonia (NH3) emission factors

	Dairy cow	Other cattle	Pig	Horses	Goat	Buffalo	Poultry
Enteric fermentation							
CH_4(kg/head^{-1}yr^{-1})	94.5[a]	41[a]	1[c]	18[c]	5[c]	82.3[b]	-
Manure Management							
CH_4(kg/head^{-1}yr^{-1})	26[c]	1[c]	6[c]	1.64[c]	0.17[c]	2[c]	0.02[c]
NH_3 (kg/head^{-1}yr^{-1})	5.6[b]	3[b]	1.5[b]	7[b]	1.1[b]	3.4[b]	0.12[b]

[a] [26]; [b] [15]; [c] [16]

3. Results

3.1. *Estimated total emissions*

Estimated emissions from livestock farming in RRD are shown in Figure 1. Total CH_4 emissions in 2010 were 95 kt, or 5,320 kt CO_2 equivalents (CO_{2eq}) as determined using the global warming potential (GWP) for CH_4 in a previous study [27]. Given the current agricultural development plan, the total amount of CH_4 emissions for RRD in 2030 was estimated at 132 kt, or 7,392 kt CO_{2eq}. Decreases in CH_4 emissions in 2010 and 2015 were due to decreases in numbers of other cattle and buffalo in those years. Although the buffalo population continued to decrease in the subsequent years, increases in the numbers of other animals kept CH_4 emissions on an upward trend from 2020 onward. Enteric fermentation and manure management contributed equally to total CH_4 emissions, which were estimated at 63 and 69 kt, respectively, for 2030. N_2O emissions showed an upward trend, reaching 6 kt by 2030, or 1,680 kt CO_{2eq}. Although N_2O emissions were 21-fold lower than those of CH_4, higher GWP limited the global warming impacts of N_2O to 4 times lower than those of CH_4.

The total GHG emissions from livestock from our estimation for RRD region is 6.5 $MtCO_{2eq}$. Emissions projection for 2020 and 2030 are 8.4 and 9.7 $MtCO_{2eq}$, respectively. Our estimations indicates that RRD region accounts for about one-third of Vietnam's GHG emissions from livestock farming according to the national GHG inventory [9]. This result reflects the fact that RRD is the largest livestock farming center in Vietnam. Compare with a previous estimate [28], as summarized in [1], our estimation results in much higher GHG emissions. Total GHG emissions from livestock in RRD is estimated at 2.1 $MtCO_{2eq}$ in 2012 in the study of [28] while our estimation for 2010 is 6.8 $MtCO_{2eq}$.

NH_3 emissions increased over time as the animal population expanded during the past decade, and are projected to further increase until 2030. By 2030, total NH_3 emissions from livestock in RRD are expected to reach 34 kt.

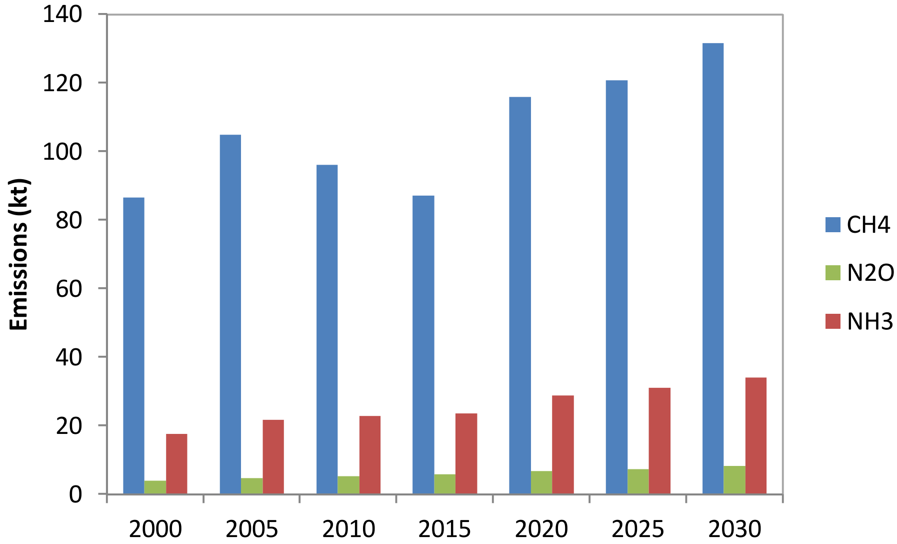
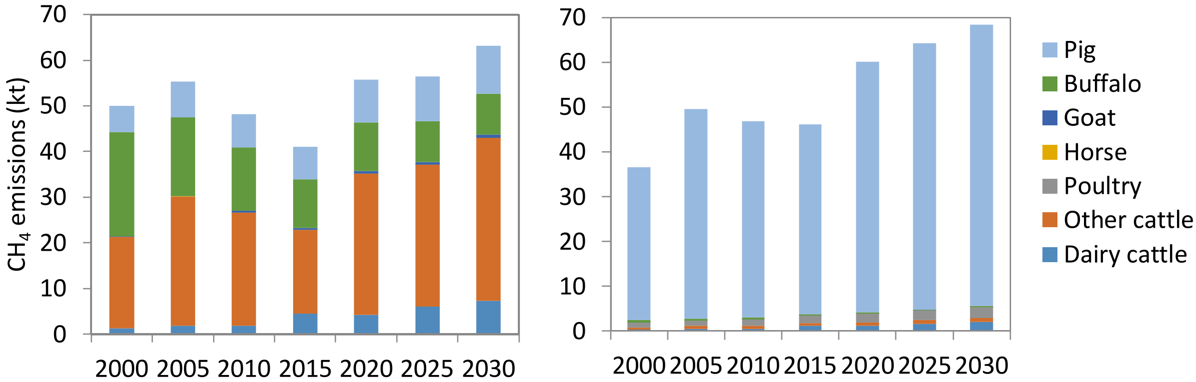


Figure 1. Total emissions from livestock farming in RRD region

3.2 Emissions by by animal type

CH_4 emissions from enteric fermentation and manure management were of the same order of magnitude. However, the contributions differed by animal type in these emissions categories. Cattle contributed the largest proportion of CH_4 emissions from enteric digestion (Figure 2a). Modifying diet is one of the mitigation option for methane emissions from enteric fermentation [29]. Several studies have explored the potential for emissions reduction by changing cattle diet at a local scale [13,25,26]. The National Plan for GHG emissions reduction in the agricultural sector by 2020 [30] has proposed two measures to reduce enteric fermentation emissions: (i) changing feeding proportion in 30% of total amount of animal feed to reduce 0.91 $MtCO_{2eq}$ (3.73% GHG emissions in livestock production projected for 2020) and (ii) supply Molasses Urea Block for 192 000 dairy cows for a reduction of 0.37 $MtCO_{2eq}$ (1.51% GHG emissions in livestock production projected for 2020). However, the practice of implementing those mitigation measures nation-wide is not yet documented.

CH_4 emissions from manure management are produced mainly from pig farming (Figure 2b). Pig husbandry emits 50 kt of methane in 2015, accounts for 57% total methane emission. The dominance of pig farming in CH_4 emission suggests that more effort should be made to effectively mitigate emissions in this sector, as RRD has the highest pig farming density in Vietnam. The most common method of emissions mitigation in Vietnam is the production of biogas from pig manure due to subsidization of anaerobic digester construction by the government [31].



(a) (b)

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Figure 2. CH_4 emissions from enteric fermentation (a) and manure management (b)

Poultry and pig farming are responsible for about 90% of N_2O (Figure 3) and NH_3 emissions (Figure 4). Poultry accounted for largest share of N_2O emissions (60%) followed by pigs (26%). The farming of these animals contributed equally to NH_3 emissions. Although chicken manure is a preferred source of organic fertilizer [1], the remaining uncollected poultry manure apparently has a considerable impact. GHG emissions from poultry husbandry accounted for 17% of total GHG emissions from livestock farming.

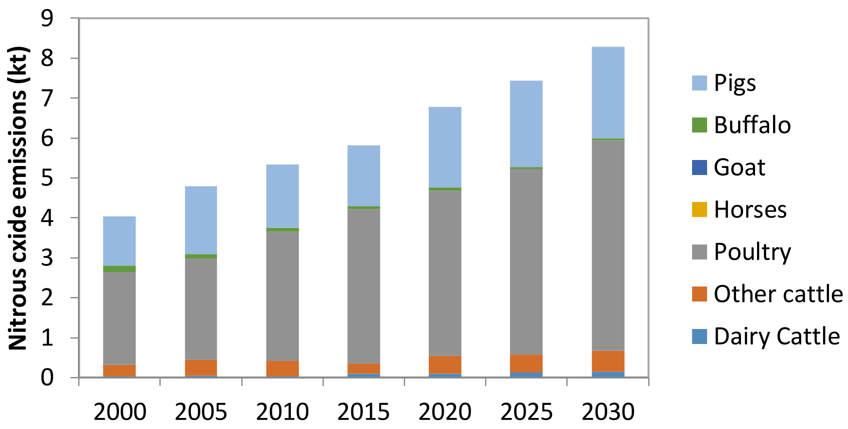

Figure 3. Nitrous oxide (N_2O) emissions by animal type

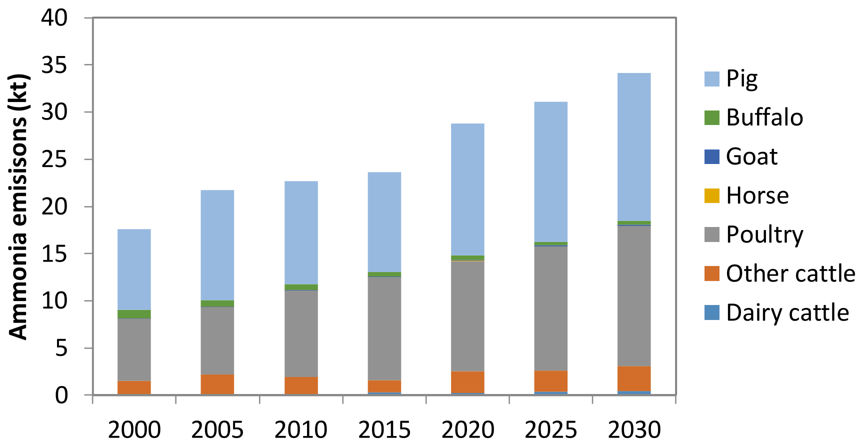

Figure 4. Ammonia (NH_3) emissions by type of animal

3.3 Emissions by provinces

Figure 5 presents methane, nitrous oxide and ammonia emissions by provinces in Red River Delta in 2015 and projection for 2030. In 2015, Hanoi is the dominant city for emissions with 21 kt of methane, 1 kt of nitrous oxide and 5.5 kt of ammonia (Figure 5a). However, Quang Ninh becomes the highest emission province in RRD by 2030, followed closely by Hanoi, Vinh Phuc and Thai Binh (Figure 5b). This projection reflects that livestock farming will be developed more in other provinces rather than in the capital city.

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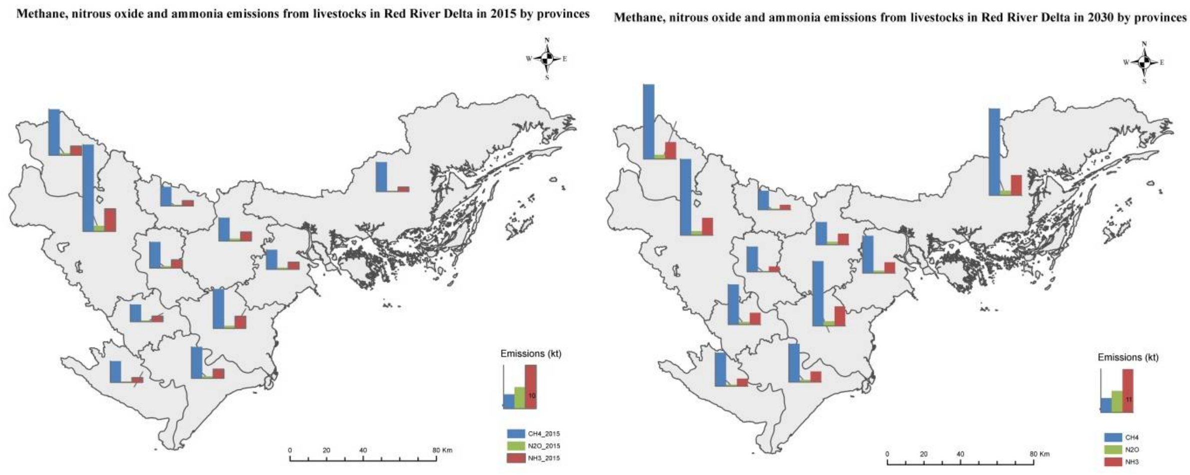

(a) (b)

Figure 5. Emissions from livestock by provinces in 2015 (a) and projection for 2030 (b)

4. Discussion

In emission inventory, emission factor is a very important element to the accuracy of the estimations. Default methane emission factors for enteric fermentation in IPCC 2006 Guidelines for Asia is 68 kg head^{-1} yr^{-1}for dairy cattle and 47 kg head^{-1} yr^{-1}for other cattle. We used emission factor from or from studies of [25,26], which resulted from RUMINANT model (Tier 3 methodology). These emission factors are higher for dairy cow and lower for other cattle compared to the default values in IPCC 2006 (see Table A1, Appendix ATable 5). These emission factor discrepancies were mainly due to higher milk yield from dairy cattle and lower weight in beef cattle in the studied area. Another study [10] used IPCC 1997 default emission factors which are lower than IPCC 2006 values for both dairy and non-dairy cattle.

Previous studies [11,15] have used a manure management CH_4 emission factor of 16 kg head^{-1} year^{-1} for dairy cattle in a temperate climate region with annual average temperature ranging from 15 to 25°C. However, the IPCC 2006 guidelines provide CH_4 emission factors for temperatures classified at a finer scale. We calculated the annual average temperature for the RRD region to be approximately 25°C using historical data from three monitoring stations in the region. According to the IPCC 2006 guidelines, the manure management CH_4 emission factor for dairy cattle is 26 kg head^{-1} year^{-1}, much higher than the value used in previous inventories.

The N_2O emission factors used in this study are presented Table, and expressed in emission per animal head per year to be able to compare with the ones used in previous studies. . Some studies have used IPCC 1997 default N_2O emission factors for each animal type (e.g., [11]), which were calculated based on proportional regional values of manure production. Our calculation resulted in higher emission factors for all animals except horses and goats; these are "pasture animals", which N_2O emission is not accounted for livestock but for soil management. Our emission factors for dairy cattle and poultry were an order of magnitude higher than those used previously [11,15]. We used the IPCC 2006 default values for dairy and non-dairy cattle to calculate emission factors, resulting in higher values than those obtained using the IPCC 1997 guidelines due to the incorporation of different manure management systems and the more detailed classification systems employed in the IPCC 2006 guidelines.

The production of emissions from livestock farming depends on various factors including feeding practices, housing systems, and manure management systems. Detailed historical data on the feed composition for each animal type and the proportions of manure managed by different management systems are needed to obtain more accurate emissions estimates. However, these data are not yet systematically collected or well documented for emissions inventory purposes. Improving the quantity and quality of data and research related to livestock farming will help to improve emissions monitoring in this sector.

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Currently, environmental protection regulations for livestock farming in Vietnam mainly focus on water quality, not air quality. There is a national technical standard for wastewater from livestock farming in Vietnam, but no specific regulations with respect to manure management and air quality. In practice, compliance with and enforcement of related environmental regulations in the livestock sector are currently weak [1]. The significant contributions to GHG and air pollutant emissions from this sector deserve more attention.

5. Conclusions

In this study, we estimated CH_4, N_2O, and NH_3 emissions from livestock farming in RRD, northern Vietnam from 2000 to 2015 and projected future emissions to 2030. This inventory and projection yielded emissions by animal type and by province. The results of our emissions inventory indicate that livestock farming in RRD contributes significantly to GHGs, particularly NH_3. The emissions inventory and projection showed an upward trend in GHG and NH_3 emissions during 2000–2030. Total CH_4, N_2O, and NH_3 emissions from livestock in RRD by 2030 were estimated at 132, 8.3, and 34.2 kt, respectively. The GWP of CH_4 and N_2O emissions was 9.7 $MtCO_{2eq}$ in 2030, representing 33% of GHG emissions from livestock nationwide. Pig farming contributed the largest proportion of GHG and NH_3 emissions, at 50%. Cattle were responsible for the second largest share of GHG emissions, whereas poultry contributed most of the remaining NH_3 emissions. Hanoi is the largest emitter among the provinces in Red River Delta in 2015 and has a big gap with the province in second place. However, Quang Ninh will take Hanoi's place by 2030 and other provinces are closing the gap.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, Table S1. Livestock number by provinces in Red River Delta from 2000 to 2030

Table S1. Livestock number (in million head) by provinces in Red River Delta from 2000 to 2030

Hanoi	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Dairy Cattle	0.00941	0.01390	0.01367	0.02710	0.02000	0.02659	0.02975
Other cattle	0.11769	0.17390	0.17097	0.11477	0.15500	0.13094	0.12295
Poultry	10.68100	14.15700	17.25400	21.79400	15.00000	15.76200	14.63500
Horses	0.00060	0.00060	0.00056	0.00029	0.00025	0.00025	0.00025
Goat	0.01050	0.01050	0.01017	0.00643	0.00643	0.00394	0.00394
Buffalo	0.04980	0.03430	0.02690	0.02306	0.01600	0.01109	0.00564
Pigs	1.20470	1.69230	1.62520	1.49830	1.50000	1.41597	1.35337
Bac Ninh	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Dairy Cattle	0.00056	0.00078	0.00055	0.00103	0.00070	0.00080	0.00100
Other cattle	0.04204	0.05902	0.04170	0.03300	0.03247	0.03062	0.03149
Poultry	3.03800	3.67600	4.22900	4.68000	4.48000	4.47100	4.45700
Horses	0.00094	0.00068	0.00031	0.00013	0.00009	0.00009	0.00009
Goat	0.00000	0.00000	0.00030	0.00096	0.00209	0.00209	0.00209
Buffalo	0.01710	0.00800	0.00290	0.00240	0.00456	0.00673	0.00673
Pigs	0.41970	0.46270	0.38930	0.40510	0.39660	0.38810	0.37960
Hung Yen	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Dairy Cattle	0.00088	0.00130	0.00131	0.00316	0.00178	0.00255	0.00278
Other cattle	0.02832	0.04190	0.04246	0.03481	0.03847	0.03459	0.03259
Poultry	5.54300	6.49600	7.59400	8.29675	3.72201	2.66560	2.66560
Horses	0.00000	0.00000	0.00004	0.00006	0.00006	0.00008	0.00009
Goat	0.00000	0.00000	0.00231	0.00457	0.00484	0.00644	0.00771
Buffalo	0.00600	0.00330	0.00238	0.00223	0.00237	0.00232	0.00231

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Pigs	0.40020	0.59960	0.63010	0.59440	0.63009	0.61819	0.61818
Vinh Phuc	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Dairy Cattle	0.00215	0.00324	0.00300	0.01579	0.02125	0.03160	0.04072
Other cattle	0.09725	0.14636	0.13569	0.08616	0.13875	0.12326	0.12478
Poultry	5.01800	0.54100	7.33100	8.38501	12.50000	14.57434	17.15884
Horses	0.00000	0.00000	0.00017	0.00003	0.00008	0.00008	0.00008
Goat	0.00000	0.00000	0.00270	0.00125	0.00375	0.00362	0.00362
Buffalo	0.03720	0.03160	0.02696	0.02016	0.01900	0.01408	0.01010
Pigs	0.46180	0.54900	0.54870	0.53570	0.82000	0.90610	1.04175
Quang Ninh	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Dairy Cattle	0.00016	0.00027	0.00028	0.00069	0.00133	0.00182	0.00285
Other cattle	0.01444	0.02383	0.02465	0.01743	0.06867	0.08094	0.14715
Poultry	2.16500	2.10500	2.35100	2.72740	8.00000	10.00847	18.00000
Horses	0.00000	0.00000	0.00011	0.00009	0.00008	0.00006	0.00006
Goat	0.00000	0.00000	0.00740	0.01048	0.02000	0.02523	0.03500
Buffalo	0.06440	0.06320	0.06378	0.04394	0.05000	0.03879	0.05000
Pigs	0.28920	0.37490	0.35450	0.35690	1.20000	1.48263	1.48263
Hai Duong	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Dairy Cattle	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Other cattle	0.03750	0.04740	0.02840	0.02132	0.02200	0.02200	0.02200
Poultry	7.00300	8.03400	8.07300	10.18280	13.00000	15.34560	15.00000
Horses	0.00000	0.00000	0.00012	0.00009	0.00009	0.00007	0.00007
Goat	0.00000	0.00000	0.00193	0.00209	0.00209	0.00220	0.00220
Buffalo	0.03560	0.01870	0.00719	0.00456	0.00255	0.00255	0.00255
Pigs	0.61350	0.85550	0.58620	0.59210	0.60000	0.60657	0.60657
Hai Phong	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Dairy Cattle	0.00000	0.00000	0.00000	0.00010	0.00004	0.00008	0.00010
Other cattle	0.01030	0.01380	0.01714	0.01361	0.03057	0.03386	0.04057
Poultry	4.24700	4.59100	6.20400	7.57409	7.26700	8.07803	8.60953
Horses	0.00000	0.00000	0.00020	0.00008	0.00008	0.00008	0.00008
Goat	0.00000	0.00000	0.01236	0.01136	0.00627	0.00390	0.00390
Buffalo	0.01720	0.01050	0.00889	0.00677	0.00609	0.00445	0.00305
Pigs	0.48300	0.61280	0.52600	0.48470	0.80229	0.88062	1.01877
Thai Binh	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Dairy Cattle	0.00000	0.00000	0.00000	0.00005	0.00000	0.00002	0.00002
Other cattle	0.05740	0.05400	0.06444	0.03997	0.13770	0.15396	0.19059
Poultry	6.61500	8.15000	8.86400	10.44110	14.14273	16.42801	19.06738
Horses	0.00000	0.00000	0.00021	0.00009	0.00009	0.00009	0.00009
Goat	0.00000	0.00000	0.00238	0.00310	0.00318	0.00369	0.00409
Buffalo	0.01260	0.00910	0.00550	0.00434	0.00445	0.00372	0.00320
Pigs	0.69080	1.13380	1.13120	1.04130	1.27650	1.29497	1.36761
Ha Nam	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Dairy Cattle	0.00032	0.00050	0.00045	0.00033	0.00015	0.00020	0.00020
Other cattle	0.02718	0.04180	0.03424	0.02437	0.03600	0.05000	0.05088
Poultry	2.57300	3.41200	4.49800	5.52620	7.34900	8.64207	10.06757
Horses	0.00000	0.00000	0.00001	0.00000	0.00002	0.00002	0.00002
Goat	0.00000	0.00000	0.01175	0.00965	0.02000	0.03000	0.03413

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Buffalo	0.01110	0.00670	0.00279	0.00255	0.00358	0.00335	0.00375
Pigs	0.27840	0.36980	0.36780	0.39040	0.72000	0.84493	1.02103
Nam Đinh	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Dairy Cattle	0.00003	0.00004	0.00004	0.00004	0.00005	0.00005	0.00006
Other cattle	0.02837	0.03896	0.03816	0.03057	0.04500	0.04475	0.04817
Poultry	4.84600	5.39900	6.38200	7.26700	7.50000	8.16767	8.72667
Horses	0.00000	0.00000	0.00005	0.00001	0.00014	0.00016	0.00016
Goat	0.00000	0.00000	0.00191	0.00627	0.00457	0.00691	0.00824
Buffalo	0.00520	0.00330	0.00664	0.00609	0.00700	0.00693	0.00711
Pigs	0.56270	0.77500	0.74270	0.80230	0.85000	0.90563	0.95928
Ninh Binh	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Dairy Cattle	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
Other cattle	0.02889	0.04889	0.03454	0.02943	0.04949	0.05277	0.06024
Poultry	3.01300	3.03600	3.61400	3.95467	4.72550	5.20956	5.76531
Horses	0.00000	0.00000	0.00000	0.00002	0.00002	0.00003	0.00003
Goat	0.00000	0.00000	0.02240	0.02296	0.02355	0.02412	0.02469
Buffalo	0.02190	0.02040	0.01479	0.01425	0.01462	0.01438	0.01430
Pigs	0.28370	0.37010	0.39930	0.36000	0.53100	0.56180	0.62765

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Appendix A

Table A1. Comparision of emission factors used in this study and previous studies

	Source	Methodology	Type of animal							
			Dairy cow	Other cattle	Pig	Horses	Sheep	Goat	Buffalo	Poultry
Enteric fermentation										
CH_4(kg/head^{-1}yr^{-1})	[16] for developing country	Tier 1	68	47	1	18	5	5	55	-
	[15]	Tier 2	50.46	64.15					82.3	
	[25]; [26]	Tier 3, RUMINANT model	94.5	41						
	[10]	Tier 1	47	44.9	1	18	5	5	53.2	
Manure Management										
CH_4(kg/head^{-1}yr^{-1})	IPCC 1997 [10,15]	Tier 1	16	1	4	1.6	0.16	0.18	2	0.018
	IPCC 2006 temp 25degC	Tier 1	26	1	6	1.64	0.15	0.17	2	0.02
N_2O (kg/head^{-1}yr^{-1})	[11,15]	Tier 1	0.29	0.34	0.18	0.87	0.21	0.17	0.39	0.0069
	IPCC 1997;	Tier 1	0.29	0.34	0.18	0.77	0.21	0.77	0.34	0.0068
	Used in this study		1.92	0.60	0.22	0.00	0.00	0.00	0.55	0.0425
NH_3 (kg/head^{-1}yr^{-1})	[15]; [11]		5.6	3	1.5	7	1.4	1.1	3.4	

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