Carbon accounting of pig manure management with a focus in China – discrepancies and recommendations

Lei Zhang[a,1], Xiaoshan Hu[b,1], Xietian Zheng[a,d], Chenyuan Zhang[a], Qiang Liu[c], Zhonghao Chen[a], Hongwei Liu[b], Chuan Wang[b], Lei Wang[a,c,d*]

a. Center for Biobased Materials, Muyuan Laboratory, 110 Shangding Road, Zhengzhou 450016, Henan Province, China

b. School of Engineering, Westlake University, 18 Shilongshan Road, Hangzhou, 310024, Zhejiang Province, China

c. Muyuan Foodstuff Co., Ltd, Longsheng Industrial Park Wolong District, Nanyang, 473000, Henan Province, China

d. Institute of Advanced Technology, Westlake Institute for Advanced Study, Hangzhou, Zhejiang 310024, China

* Corresponding author.

E-mail address: wang_lei@westlake.edu.cn (L.W.)

Content

Appendix A. Literature review

Appendix B. Emission calculation

Appendix C. Scenario analysis

Appendix A. Literature review

a. Keywords

The selected research keywords were ("Carbon footprint" OR "Environmental impact" OR "Environmental assessment" OR "Life cycle assessment" OR "Life cycle analysis" OR "LCA") AND (pig OR swine OR pork). The searched areas were article title, abstract, and author keywords, with search terms adapted for each database. The search was also limited to year intervals from 2010 to mid-February 2022.
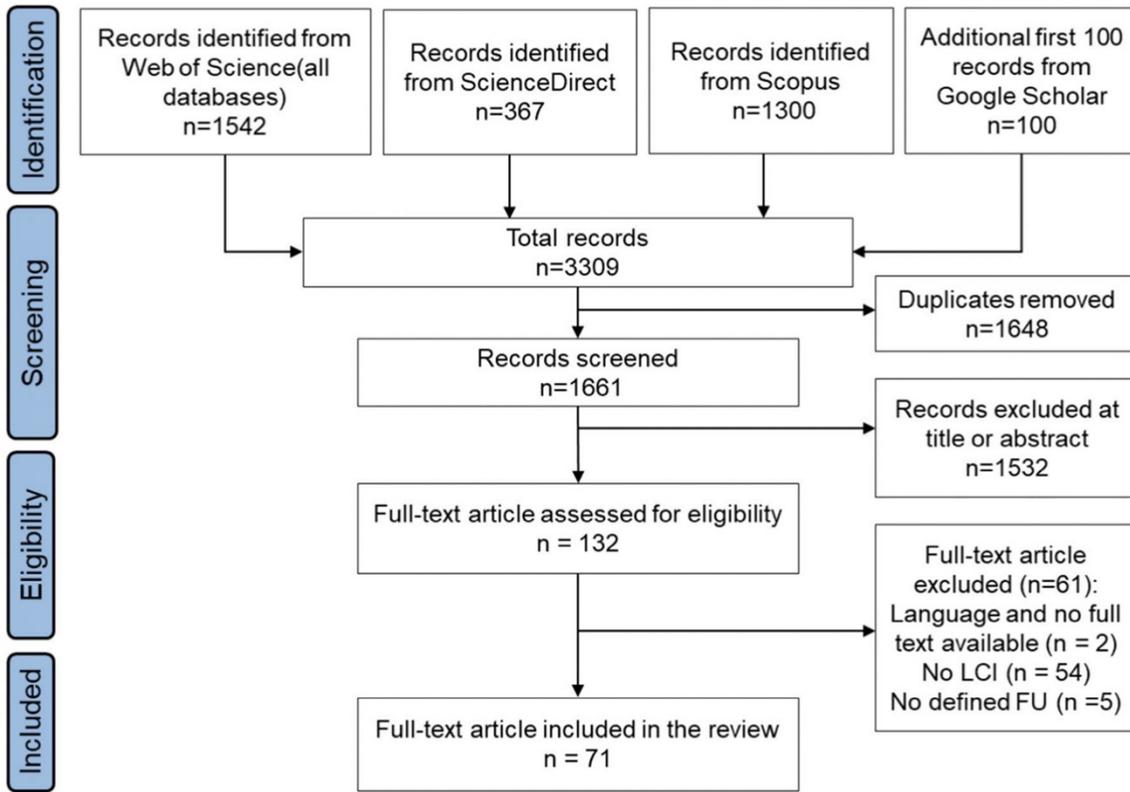
b. Review process flow chart

Fig. S1. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow chart. Indicating the selection steps (left panels), outcomes after meeting criteria (centre) and selection criteria (right) [1].

c. Chinese emission factor database review process

Keywords   The research keywords were determined as ("emissions") and ("manure" OR "slurry" OR "urine" OR "feces") AND (pork OR swine OR pig). The searched areas are article title, abstract, and author keywords. The search was limited to year intervals from 2000 to mid-February 2022 and country "China" in four databases: Web of Science, Google Scholar, ScienceDirect, and Scopus.

Table S1. Eligibility criteria for inclusion of articles for Chinese emission factor (EF) database.

|	Inclusion	Exclusion
Type of evidence	Peer-reviewed research articles	Conference proceedings, reviews, unpublished manuscripts, books and theses
Year of dissemination	Published before February 2022	Published before 2000
Language and availability	Full text available	No full text available
Field of interest	Focusing on manure management and environmental impact of Chinese pig farming.	No mention of greenhouse gas emission in the abstract; focusing on microbial community and antibiotic residue of manure
Transparency restriction	Greenhouse gaseous emission factors need to be provided in the article	No specific emission factors of greenhouse gas emissions
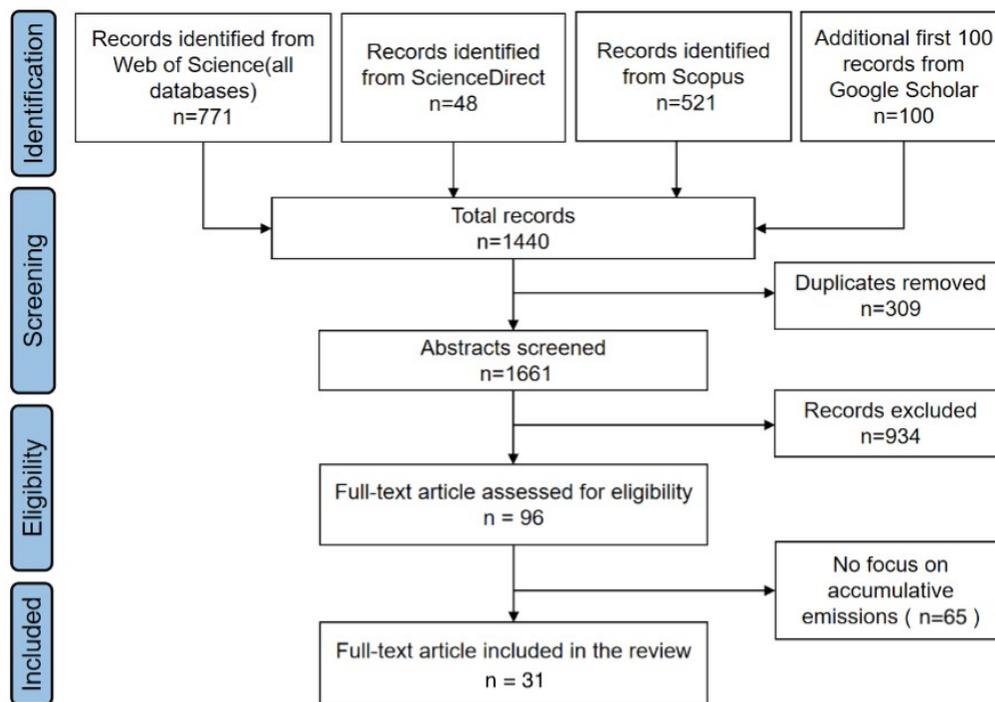
Fig. S2 Preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow chart of eligible manure management emissions studies.

Appendix B. Emission calculation

a. Tier 2 Methodology

For the estimation of greenhouse gas (GHG) emissions at Tier 2 level, the equations, calculation framework and emission factors are derived from The IPCC Tier 2 method [2-4] .

Methane emissions

The IPCC Tier 2 equations mainly depend on the amount of volatile solids excreted by the animals (VS) along with the maximum methane producing capacity for the manure (B_0).

$$CH_{4manure} = EF_{(T)} \cdot AAP_{(T)}$$
Eq. A1

$$EF_{(T)} = (VS_{(T)} . 365) \cdot \left[B_{0(T)} \cdot 0.67 \cdot \sum_{s,k} MCF_{(sk)} \cdot AWMS_{(T,s,k)} \right]$$
Eq. A2

$$VS_{(T)} = \frac{\left[GE_{(T)} \cdot (1-DE_{(T)}) + (UE \cdot GE_{(T)}) \right] \cdot [(1-ASH)]}{18.45}$$
Eq.A3

$$GE_{(T)} = Feed\ intake\ per\ day \cdot 87\% \cdot 18.45$$
Eq.A4

Where $CH_{4manure}$ is the annual CH_4 emission from manure management system, kg CH_4 yr^{-1}; $EF_{(T)}$ is the annual CH_4 emission factor for the livestock category T, kg CH_4 animal^{-1}yr^{-1}; $AAP_{(T)}$ is the annual average population for the livestock category T, animal. $VS_{(T)}$ is the daily volatile solid excreted for the livestock category T, kg DM day^{-1}; B_o is maximum methane producing capacity for manure, 0.45 N m^3 CH_4 kg^{-1} VS for intensive pig farming [3, 4]; 0.67 is the conversion factor of m^3 CH_4 to kilograms CH_4; $MCF_{(sk)}$ is the methane conversion factors for each manure management system S by climate region k, % (Table 1 from Manuscript); $AWMS_{(T,s,k)}$ is the fraction of livestock category T's manure handled using animal waste management system S in climate region k. $GE_{(T)}$ is gross energy for the livestock category T, MJ kg^{-1} feed; $DE_{(T)}$ is digestibility of the feed for the livestock category T (Mature Swine: 70%-80%, Growing Swine: 80%-90%); UE is the urinary energy expressed as % of gross energy intake, 2% for pigs; ASH is the ash content of feed, assumed as 4%.

Direct nitrous oxide emissions

The calculation of direct N_2O emissions from manure management is based on IPCC guidelines [2, 3] and Tier II MRV of livestock emissions in China [4]

$$N_2O_{direct} = \left[\sum_s \left[\sum_T (N_{(T)} . Nex_{(T)} . AWMS_{(T,S)}) \right] . EF_{3(s)} \right] \cdot \frac{44}{28}$$
Eq. A5

$$Nex_{(T)} = N_{intake(T)} . (1 - N_{retention(T)})$$
Eq. A6

$$N_{intake(T)} = \frac{GE_{(T)}}{18.45} . \left(\frac{\frac{CP}{100}}{6.25} \right) . 365$$
Eq. A7

$$N_2O_{direct\ app} = F_{ON} . EF_1 . \frac{44}{28}$$
Eq. A8

Where N_2O_{direct} is the direct N₂O emissions from the manure management, kg N₂O yr⁻¹; $N_{(T)}$ is the number of head of livestock species per category T; $Nex_{(T)}$ is annual average N excretion per head of species/category T, kg N animal⁻¹yr⁻¹; $AWMS_{(T,S)}$ is the fraction of the total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S; $EF_{3(s)}$ is the emission factor for direct N₂O emissions from the manure management system S, kg N₂O-N/kg N in manure management system S, details were showed on Table 1; and $\frac{44}{28}$ is the factor to convert 1 kg N₂O-N into 1 kg N₂O gas. $N_{intake(T)}$ is the daily N intake per head of animal of species/category T, kg N animal⁻¹ day⁻¹; $N_{retention(T)}$ is amount of daily N intake by head of animal of species / category T,0.3 kg N/ kg N intake for pig [4]; CP is percent crude protein of feed in dry matter for growth stage, % CP per kg feed. F$_{ON}$ is the annual amount of animal manure applied to soils, kg N yr⁻¹, EF₁   is emission factor for N₂O emissions from N inputs, 0.01kg N₂O–N (kg N input)⁻¹ [2].

Indirect nitrous oxide emissions

Other forms of nitrogen loss (e.g., ammonia and nitrous oxide) may also occur during manure management. Nitrogen volatilizes in the form of ammonia can be deposited at sites downwind from the manure handling areas, indirectly emitting N₂O. According to 2006 IPCC guidelines, indirect N₂O emissions due to nitrogen loss due to volatilization during manure management can be quantified.

$$N_2O_{indirect} = N_2O_{volatilization} + N_2O_{leaching} \qquad \text{Eq. A9}$$

$$N_2O_{volatilization} = \sum_s \left[\sum_T \left[(N_{(T)}.Nex_{(T)}.AWMS_{(T,S)}).Frac_{GasMS\,(T,S)} \right].EF_4 \right].\frac{44}{28} \qquad \text{Eq. A10}$$

$$N_2O_{Leach} = \sum_s \left[\sum_T \left[(N_{(T)}.Nex_{(T)}.AWMS_{(T,S)}).Frac_{LeachMS\,(T,S)} \right].EF_5 \right].\frac{44}{28} \qquad \text{Eq. A11}$$

$$N_2O_{indirect\,app} = F_{ON}.Frac_{GASM}.EF_4.\frac{44}{28} + F_{ON}.Frac_{Leach\,app}.EF_5.\frac{44}{28}$$
Eq. A12

Where $N_2O_{indirect}$ is the indirect N₂O emissions from the manure management, kg N₂O yr⁻¹; $N_2O_{volatilization}$ is indirect N₂O emissions due to the volatilisation of NH₃ and NO$_x$, kg N₂O yr⁻¹; $N_2O_{leaching}$ is indirect N₂O emissions due to leaching and runoff from Manure Management, kg N₂O yr⁻¹. $Frac_{GasMS}$ is the percent of the manure nitrogen for the livestock category T that volatilises as NH₃ and NO$_x$ in the manure management system S, Table S1.In this study, we chose $Frac_{GasMS}$ from IPCC guideline,2006. EF_4 is the emission factor for the N₂O emissions from atmospheric deposition of nitrogen on soils and water surfaces, default value is 0.01 kg N₂O-N (kg NH₃-N + NO$_x$-N volatilised) ⁻¹ from IPCC guideline, 2006. $Frac_{LeachMS\,(T,S)}$ is fraction of managed manure nitrogen for livestock category T that is leached from the manure management system S, in this case, anti-seepage measures are taken at all stages of manure management, and sprinkler irrigation is used for field application (Table 1); EF_5 is the emission factor for the N₂O emissions from nitrogen leaching and runoff, default value is 0.0075 kg N₂O-N (kg N leached and runoff) ⁻¹. $N_2O_{indirect\,app}$ is the indirect N₂O emissions from the manure application, kg N₂O yr⁻¹; $Frac_{GASM}$ is fraction of applied organic N fertiliser materials (F$_{ON}$) that volatilises as NH₃ and NO$_x$,0.10 kg N volatilised (kg of N applied)⁻¹ from Eggleston [2].

Table S2. Default values for nitrogen loss fractions ($Frac_{GasMS}$) due to volatilisation of NH₃ and NO$_x$ of nitrogen from manure management

Default values for nitrogen loss fractions ($Frac_{GasMS}$) due to volatilisation of NH_3 and NO_x of nitrogen from manure management			
	IPCC,2006	IPCC,2019 Refinement	Tier II MRV in China,2020
Pit storage below animal confinements	25%	0.25	25%
Anaerobic digester	20%[a]	0.05-0.5	20%[a]
Anaerobic lagoon	40%	0.4	40%
Field application	0.2	0.21	0.2

*a. [5]

b. Tier 2 Mass Flow Methodology

For the estimation of greenhouse gas (GHG) emissions at Tier 2 Mass Flow framework, the equations were adopted from Long, Wang [6]. The emission factors still remain the same ones as Tier 2 from IPCC 2006 [2] for comparison of Tiered approaches. Tier 2 Mass Flow method is based on the mass balance of carbon and nitrogen in the manure life cycle. Tier 2 Mass Flow method could refine the nutrient excretion and emissions by every individual process on the manure management chain, which can effectively lead to more specific estimation. In addition, this method can also compare alternative advanced techniques in different management phases.

Methane emissions

$$CH_{4manure} = (EF_{(pit\ storage,\ T)} + EF_{(AD,\ T)} + EF_{(lagoon,,\ T)}) \cdot AAP_{(T)}$$
Eq. A13

$$EF_{(pit\ storage,T)} = VS_{(extract,T)} \cdot 365 \cdot B_{0(T)} \cdot 0.67 \cdot MCF_{pit\ storage}$$
Eq. A14

$$VS_{(extract,T)} = \frac{[GE_{(T)} \cdot (1 - DE_{(T)}) + (UE \cdot GE_{(T)})] \cdot [(1 - ASH)]}{18.45}$$
Eq. A15

$$VS_{(post\ pit\ storage,T)} = VS_{(extract,T)} \cdot (1 - Deg_{pit\ storage - VS})$$
Eq. A16

$$VS_{(post\ AD,T)} = VS_{(post\ pit\ storage,T)} \cdot (1 - Deg_{AD - VS})$$
Eq. A17

$$VS_{(post\ lagoon,T)} = VS_{(post\ AD,T)} \cdot (1 - Deg_{lagoon - VS})$$
Eq. A18

$$EF_{(AD,\ T)} = VS_{(post\ pit\ storage,T)} \cdot 365 \cdot B_{0(T)} \cdot 0.67 \cdot MCF_{AD}$$
Eq. A19

$$EF_{(lagoon,\ T)} = VS_{(post\ AD,T)} \cdot 365 \cdot B_{0(T)} \cdot 0.67 \cdot MCF_{lagoon}$$
Eq. A20

Where $EF_{(pit\ storage,T)}$ is the annual CH_4 emission factor during pit storage for the livestock category T, kg CH_4 animal^{-1}yr^{-1}; $EF_{(AD,T)}$ is the annual CH_4 emission factor during anaerobic digester treatment for the livestock category T, kg CH_4 animal^{-1}yr^{-1}; $EF_{(lagoon,T)}$ is the annual CH_4 emission factor during anaerobic lagoon storage for the livestock category T, kg CH_4 animal^{-1}yr^{-1}. $VS_{(extract,\ T)}$ is the daily volatile solid excreted for the livestock category T, kg DM day^{-1}; $VS_{(post\ pit\ storage,\ T)}$ is the VS in the pig's excreta after indoor manure storage, kg DM day^{-1}; $VS_{(post\ AD,\ T)}$ is the VS in the pig's excreta after outdoor manure storage, kg DM day^{-1}; $VS_{(post\ lagoon,\ T)}$ is the VS in the pig's excreta after anaerobic lagoon, kg DM day^{-1}; $Deg_{pit\ sorage - VS}$ is the degradation rate of the fraction (in 3% of the VS) for the first digestion step, $Deg_{AD - VS}$ is the degradation rate of the fraction (in 56%

of the VS) for the first digestion step, $Deg_{lagoon-VS}$ is the degradation rate of the fraction (in 74% of the VS) for the first digestion step. $MCF_{pit\,storage}$, MCF_{AD}, MCF_{lagoon} are the methane conversion factors (Table 1) during pit storage, anaerobic digestion, anaerobic lagoon.

Direct nitrous oxide emissions

$$N_2O_{direct-N2O} = (NO_{(indoor-N2O,\ T)} + NO_{(AD-N2O,\ T)} + NO_{(lagoon-N2O,\ T)} + NO_{(application-N2O,\ T)}) \cdot \frac{44}{28}$$

Eq. A21

$$NF_{(indoor,T)} = NO_{(indoor-NH3,T)} + NO_{(indoor-N2O,T)} + NO_{(indoor-NOx,T)}$$
Eq. A22

$$N_{(post\,house,T)} = Nex_{(T)} - (NF_{(indoor,T)} + NO_{(indoor-N2,T)})$$
Eq. A23

$$NO_{(indoor-N2O/NH3/N2/NOx,\ T)} = Nex_{(T)} \cdot EF_{(pit\,storage-N2O/NH3/N2/NOx)}$$
Eq. A24

Where N_2O_{direct} is the direct N_2O emissions from the manure management, kg N_2O yr^{-1}; $NO_{(indoor-NH3,\ T)}$, $NO_{(indoor-N2O,\ T)}$, $NO_{(indoor-N2,\ T)}$, $NO_{(indoor-NOx,\ T)}$ are the NH_3-N volatilization (kg NH_3-N), N_2O-N losses (kg N_2O-N), N_2-N losses (kg N_2-N), and NOx-N losses (kg NOx -N) during indoor pit storage; $NO_{(AD-NH3,\ T)}$, $NO_{(AD-N2O,\ T)}$, $NO_{(AD-N2,\ T)}$, $NO_{(AD-NOx,\ T)}$ are the NH_3-N volatilization (kg NH_3-N), N_2O-N losses (kg N_2O-N), N_2-N losses (kg N_2-N), and NOx-N losses (kg NOx -N) during anaerobic digester treatment; $NO_{(lagoon-NH3,\ T)}$, $NO_{(lagoon-N2O,\ T)}$, $NO_{(lagoon-N2,\ T)}$, $NO_{(lagoon-NOx,\ T)}$ are the NH_3-N volatilization (kg NH_3-N), N_2O-N losses (kg N_2O-N), N_2-N losses (kg N_2-N), and NOx-N losses (kg NOx -N) during anaerobic lagoon storage; $NO_{(application-NH3,\ T)}$, $NO_{(application-N2O,\ T)}$, $NO_{(application-N2,\ T)}$, $NO_{(application-NOx,\ T)}$ are the NH_3-N volatilization (kg NH_3-N), N_2O-N losses (kg N_2O-N), N_2-N losses (kg N2-N), and NOx-N losses (kg NOx-N) during field organic fertilizer application. $NF_{(indoor,T)}$ is the Nr emissions during indoor storage, kg Nr. $N_{(post\,house,T)}$ is the N content in pig's excreta after indoor storage, kg N; $NF_{(indoor,T)}$ is the Nr emissions during indoor pit storage, kg Nr. $EF_{(pit\,storage-NH3/N2O/N2/NOx)}$ is the NH_3-N (% NH_3-N kg^{-1} N), N_2O-N (% N_2O-N kg^{-1} N), N_2-N (% N_2-N kg^{-1} N), NO_x-N (% NOx-N kg^{-1} N) emission factors for pit storage (Table 1).

$$N_{(post\,AD,T)} = N_{(post\,house,T)} - (NF_{(AD,T)} + NO_{(AD-N2,T)})$$
Eq. A25

$$NF_{(AD,T)} = NO_{(AD-N2O,T)} + NO_{(AD-NH3,T)} + NO_{(AD-NOx,T)}$$
Eq. A26

$$NO_{(AD-N2O/NH3/N2/NOx,\ T)} = N_{(post\,house,T)} \cdot EF_{(AD-N2O/NH3/N2/NOx)}$$
Eq. A27

$$N_{(post\,lagoon,T)} = N_{(post\,AD,T)} - (NF_{(lagoon,T)} + NO_{(lagoon-N2,T)})$$
Eq. A28

$$NF_{(lagoon,T)} = NO_{(lagoon-N2O,T)} + NO_{(lagoon-NH3,T)} + NO_{(lagoon-NOx,T)}$$
Eq. A29

$$NO_{(lagoon-N2O/NH3/N2/NOx,\ T)} = N_{(post\,AD,T)} \cdot EF_{lagoon-N2O/NH3/N2/NOx}$$
Eq. A30

$N_{(post\ AD,T)}$ is the N content in pig's excreta after anaerobic digester, kg N. $EF_{(AD-NH3/N2O/N2/NOx)}$ is the NH$_3$-N (% NH$_3$-N kg^{-1} N), N$_2$O-N (% N$_2$O-N kg^{-1} N), N$_2$-N (% N$_2$-N kg^{-1} N), NOx -N (% NOx-N kg^{-1} N) emission factors for AD (Table 1); $EF_{(lagoon-NH3/N2O/N2/NOx)}$ is the NH$_3$-N (% NH$_3$-N kg^{-1} N), N$_2$O-N (% N$_2$O-N kg^{-1} N), N$_2$-N (% N$_2$-N kg^{-1} N), NOx-N (% NOx-N kg^{-1} N) emission factors for anaerobic lagoon (Table 1).

$$NF_{(application,T)} = NO_{(app-NH3,T)} + NO_{(app-N2O,T)} + NO_{(app-NOx,T)} + NO_{(app-runoff,T)} + NO_{(app-erosion,T)} + NO_{(app...}$$

Eq. A31

$$NO_{(app-N2O/NH3/NOx,\ T)} = N_{(post\ lagoon,T)} \cdot EF_{App-N2O/NH3/NOx}$$ Eq. A32

Where $NF_{(application,T)}$ is the Nr emissions during manure application to cropland, kg Nr; $NF_{(app,T)}$ is the Nr emissions during manure application to cropland, kg Nr. $NO_{(app-NH3,T)}$, $NO_{(app-N2O,T)}$ and $NO_{(app-NOx,T)}$ are the NH$_3$-N volatilization (kg NH$_3$-N), N$_2$O-N losses (kg N$_2$O -N), and NOx-N losses (kg NOx-N) during manure application; $NO_{(app-runoff,T)}$, $NO_{(app-erosion,T)}$, and $NO_{(app-leaching,T)}$ are the runoff N loss (kg NO$_3$-N), erosion N loss (kg NO$_3$-N), and leaching N loss (kg NO$_3$-N) during manure application. $N_{(post\ lagoon,T)}$ is the N content in pig's excreta after outdoor storage and treatment, kg N.

Indirect nitrous oxide emissions

$$N_2O_{indirect} = (NO_{(ID-indoor-N2O,\ T)} + NO_{(ID-AD-N2O,\ T)} + NO_{(ID-lagoon-N2O,\ T)} + NO_{(ID-application-N2O,\ T)}...\frac{44}{28}$$

Eq. A33

$$NO_{(ID-indoor-N2O,\ T)} = (NO_{(indoor-NH3,T)} + NO_{(indoor-NOx,T)}) \cdot EF_4$$ Eq. A34

$$NO_{(ID-AD-N2O,\ T)} = (NO_{(AD-NH3,T)} + NO_{(AD-NOx,T)}) \cdot EF_4$$ Eq. A35

$$NO_{(ID-lagoon-N2O,\ T)} = (NO_{(lagoon-NH3,T)} + NO_{(lagoon-NOx,T)}) \cdot EF_4$$ Eq. A36

$$NO_{(ID-application-N2O,\ T)} = (NO_{(application-NH3,T)} + NO_{(application-NOx,T)}) \cdot EF_4 + (NO_{(application-runoff,T)} + NO_{(application-leaching,T)}) \cdot EF_5$$

Eq. A37

Where $NO_{(ID-indoor/AD/lagoon/application-N2O,\ T)}$ are the indirect N$_2$O emissions during indoor manure storage, anaerobic digester , anaerobic lagoon and field application, kg N$_2$O; EF_4 is the emission factor for indirect N$_2$O emissions from volatilized and re-deposited N, default EF_4 is 0.01 kg N$_2$O -N kg^{-1} NH3-N + NOx-N volatilized; EF_5 is the emission factor for N$_2$O emissions from N leaching and runoff, default EF_5 here is 0.0075 kg N$_2$O -N kg^{-1} leaching N + runoff N). To prevent groundwater pollution in pig farming, concrete anti-seepage measures have been implemented in the pig houses, storage tanks and pipe networks. Additionally, the anaerobic digester and anaerobic lagoon have been lined with vertical high-density polyethylene (HDPE) membrane and concrete anti-seepage measures after clearing and compacting. Therefore, for pit storage, AD and lagoon storage, run-off and leaching losses of N were zero.

Table S3. Primary data of the case farm

Items	AAP	FI	TAM	CP
	Annual average population	Feed intake per day	Typical animal mass for livestock category	Crude protein content in feeds
Unit	animal	kg/day	kg/animal	% CP/feed
Nursery pig	17608	0.64	18.5	0.175
Growing-finishing pig	30754	2.04	75	0.123
Gestating sow	3237	2.1	165	0.112
Lactating sow	792	6.35	210	0.168
Replacement gilt	1681	2.44	90	0.108
Empty sow	287	2.44	120	0.108

c. Tier 3 Methodology

Table S4. Input parameters for Manure-DNDC model.

| Information		Unit
Population	100000	head
Feed rate	1.65	Kg/head/d
Crude protein	13	%
P concentration	0.55	%
Feedlot		
Flushing water	0	m^3
Manure removal frequency	1	d/time
Fraction removed		
Compost-Solid(0-1)	0	
Digester-Solid(0-1)	1	
Compost-Liquid(0-1)	0	
Digester-Liquid(0-1)	1	
Anaerobic digestion		
Processing temperature	<20	°C
Retention time(days)	30	d
Fraction applied to lagoon (0-1)	1	
Lagoon		
Lagoon coverage	Without cover	
Capacity	50821	m^3
Surface area	5082	m^2
Fraction applied to this farm field (0-1)	1	
Field application		
Application method	Surface spread	
Land use type	Upland crop field	
Crop type	Corn	
Field area	400	ha
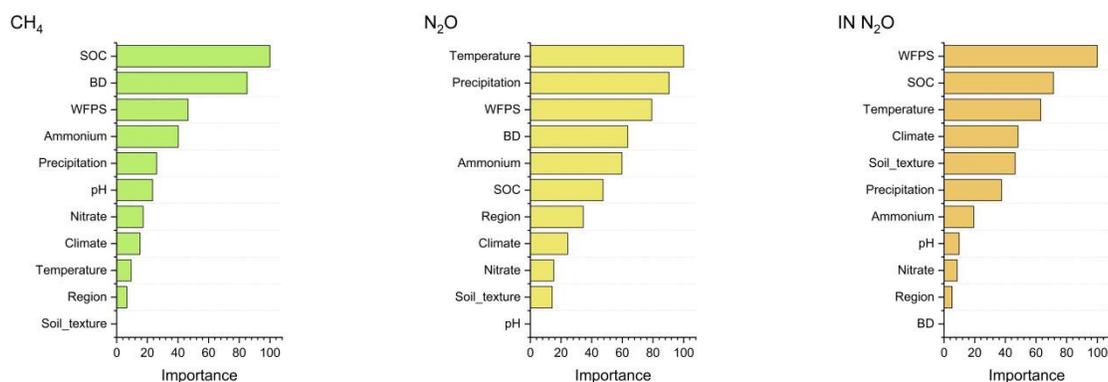
Fig. S3 Factors Influencing CH_4, N_2O, indirect N_2O Emissions.

Appendix C. Scenario analysis

Table S5. Gross energy intake (GE) for the different livestock categories

Gross energy intake (GE) for the different livestock categories		
	Farm average[a]	On-Site[b]
Unit	MJ/day	MJ/day
Nursery pig	10.27296	10.96569038
Growing-finishing pig	32.74506	34.91046025
Gestating sow	33.70815	32.77405858
Lactating sow	101.927025	105.5322176
Replacement sow	39.16566	39.13188285
Empty sow	39.16566	39.13188285

a. GE = Feed intake per day*87%(dry matter%)*18.45

b. The gross energy (GE) of feeds and faeces were calculated from the proximate components according to the equation of Ewan (1989):GE = 4143 + (56 x % EE) + (15 x % CP) - (44 x % Ash); Where: GE = Gross energy (kcal/ g), EE = Ether extract, CP = Crude protein (N x 6.25) and Ash = Crude ash.

Table S6. Digestibility (DE) of the feed in percent for the different livestock categories

Digestibility (DE) of the feed in percent for the different livestock categories			
	IPCC guidelines[a]	Intensive average DE[b]	On-site DE
Mature Swine – confinement	70%-80%	-	-
Growing Swine - confinement	80%-90%	-	-
Pig at industrial systems	-	84.97%	-
Nursery pig	-	-	79.4%
Growing-finishing pig	-	-	82.5%
Sow	-	-	83.5%

a. [2, 3]
b. [6]

Table S7. Annual average N excretion per head of species (Nex) for the different livestock categories

Annual average N excretion per head of species (Nex) for the different livestock categories		
	IPCC guideline[a]	Tier II MRV in China,2020
Unit	kg N/animal/yr	kg N/animal/yr
Nursery pig	4.3	4.5
Growing-finishing pig	9.5	7.5
Gestating sow	8.1	11.5
Lactating sow	39.3	11.5
Replacement gilt	9.4	11.5
Empty sow	9.4	11.5

a.Annual N excretion rates(Tier 2): Nex(T) = Nintake(T)*(1-Nretention_frac(T))*365 [2]

References

[1] Zhang L, Mao Y, Chen Z, Hu X, Wang C, Lu C, et al. A systematic review of life-cycle GHG emissions from intensive pig farming: Accounting and mitigation. Science of The Total Environment. 2024;907:168112. https://doi.org/https://doi.org/10.1016/j.scitotenv.2023.168112

[2] Eggleston H, Buendia, Leandro, Miwa, Kyoko, Ngara, Todd, Tanabe, Kiyoto. 2006 IPCC guidelines for national greenhouse gas inventories. 2006.

[3] Calvo Buendia E, Tanabe, K., Kranjc, A., Baasansuren, J., Fukuda, M., Ngarize, S., Osako, A., Pyrozhenko, Y., Shermanau, P. and Federici, S. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. 2019, https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html.

[4] Dong H, Zhu Z, Li Ye, Wei S, Zhang Y, Wollenberg L, et al. Tier II MRV of livestock emissions in China - Final report & Annexes. Wageningen, The Netherlands: CGIAR Research Program on Climate Change Agriculture and Food Security (CCAFS)2020.

[5] Dong YZH. 中国规模化生猪养殖碳足迹评估方法与案例研究. 中国农业科学院 2018.

[6] Long W, Wang H, Hou Y, Chadwick D, Ma Y, Cui Z, et al. Mitigation of Multiple Environmental Footprints for China's Pig Production Using Different Land Use Strategies. Environmental Science & Technology. 2021;55:4440-51. https://doi.org/10.1021/acs.est.0c08359