SUPPORTING INFORMATION

Mitigating Greenhouse Gas and Ammonia Emissions from Swine Manure Management: a system analysis

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Including 78 pages, 12tables and 2 figures

SI text

Overview

The main purpose of this supporting information (SI) is to present brief description of some manure management terms; also the detailed methods, equations, parameters, and assumptions for calculating the emissions for baseline and mitigation scenarios of each phase and whole systems. The calculation steps are fully documented in the SI information and can be followed in Dataset S1, specific tabs and cells of which we reference in the text below.

1 Description of manure management terms

1.1 The terms of land application method

Slurry injection: slurry being directly injected into the soil by using high-pressure injector.

Slurry/solid incorporation: the slurry or solid manure being applied onto the surface of the soil first, followed with being covered by soil through ploughing or rotary harrow, etc. Here “rapid” means limit the time gap between manure being surface applied and incorporated into soil less than 6 hours.

Slurry band spreading: Slurry is pumped to a manifold distributor, and then the connected trailing pipes can part the crop and make sure that slurry being applied directly onto the surface of the soil.

1.2 Mitigation measures

1.2.1 Mitigation measures for in-house management

LCP diet: lower crude protein content (usually 2%-4%) of the feed than the control diet.

Feed additive: feed supplements such as vitamins, amino acids, fatty acids, and minerals.

Biofilter: using a bioreactor containing living material to capture and biologically degrade pollutants.

1.2.2 Mitigation measures for outdoor slurry or solid manure management

Slurry covering: using cover material to keep rain out and odours and ammonia in, while the cover material are various in type including straw, oil, plastic, granule, etc.

Cooling: decrease the manure temperature such as using cold water.

Slurry acidification: decrease the slurry pH by adding sulphuric acid (H_2SO_4) or hydrochloric acid (HCl), etc.

Compost additive: adding alum, zeotile, the acidifying agent or ammonia absorbent to compost.

Compost cover: similar meaning as slurry cover.

1.2.3 Mitigation measures for manure land application

The liquid or solid manure surface spreading was seen as a reference, thus changing surface spreading to injection or incorporation was set as mitigation measures.

Digested manure vs. raw manure: using digested manure to substitute raw manure as fertilizer in land application.

Nitrification inhibitor (NI): chemical supplements which can inhibite the transformation of N via the nitrification pathway, thus being deeded as having the potential to reduce N loss from soils and increase N use efficiency when fertilized with manure.

2 Calculation of gas emissions from baseline scenario of four manure management systems

2.1 Calculation of CH_4 emissions

CH_4 emissions from each manure management system were the sum of emissions from each phase; however, those from manure land application were omitted, as little CH_4 would be emitted from crop production with the exception of rice paddy production. For the separation-based system, when the separated solid and liquid manure was transferred to outdoor, the total emission should be calculated as the sum of the emissions from the liquid and solid components of the manure. According to calculations based on the study by De Vries et al.,[1] for in-house separation, 4% and 96% of volatile solid (VS) were preserved in the liquid and solid fractions, respectively. Therefore, we assumed that CH_4 emission factors from the subsequent storage of liquid manure would be 4% of the total CH_4 emission factor when all slurry was poured into the lagoon, and CH_4 emissions from the separated solid manure compost would be 96% of the total CH_4 emission factor when all manure was composted. CH_4 emissions from each manure management system were calculated based on the equations below.

For CH_4 emissions from deep-pit-based system ($A\_E_{CH4}DPS$) (DeepPitBasedSystem tab, cell O5 in Dataset S1):

$$A\_E_{CH4}DPS = P\_E_{CH4}IN_{dp} + P\_E_{CH4}OU_{lg} \quad [S1]$$

where:

$P\_E_{CH4}\mathrm{IN_{dp}}$ is the CH_4 emission factor for in-house deep-pit storage (see Table S3, also D5 in EmissionFactors tab in Dataset S1);

$\mathrm{P\_E_{CH4}OU_{lg}}$ is the CH_4 emission factor from outdoor lagoon storage (see Table S4, also D22 in EmissionFactors tab in Dataset S1).

For CH_4 emissions from the pull-plug-based system ($\boldsymbol{A_E_{CH4}}$PPS) (PullPlugBasedSystem tab, cell O5 in Dataset S1):

$$\mathrm{A\_E_{CH4}PPS = P\_E_{CH4}IN_{PP} + P\_E_{CH4}OU_{lg}} \quad [S2]$$

where:

$P\_E_{CH4}\mathrm{IN_{PP}}$ is the CH_4 emission factor for the in-house pull-plug manure collection practice (see Table S3, also D6 in EmissionFactors tab in Dataset S1).

For CH_4 emissions from the bedding-based system ($\boldsymbol{A_E_{CH4}}$BDS) (BeddingBasedSystem tab, cell M5 in Dataset S1):

$$\mathrm{A\_E_{CH4}BDS = P\_E_{CH4}IN_{bd} + P\_E_{CH4}OU_{cm}} \quad [S3]$$

where:

$\mathrm{P\_E_{CH4}IN_{bd}}$ is the CH_4 emission factor for in-house bedding (see Table S3, also D7 in EmissionFactors tab in Dataset S1);

$\mathrm{P\_E_{CH4}OU_{cm}}$ is the CH_4 emission factor for outdoor manure composting (see Table S4, also D23 in EmissionFactors tab in Dataset S1).

For CH_4 emissions from the separation-based system ($\boldsymbol{A_E_{CH4}}$SPS) (SeparationBasedSystem tab, cell N5 in Dataset S1):

$$A\_E_{CH4}\mathrm{SPS} = P\_E_{CH4}\mathrm{IN_{sp}} + A\_E_{CH4}\mathrm{OU_{lg\_SPS}} + A\_E_{CH4}\mathrm{OU_{cm\_SPS}} \quad [S4]$$

$$A\_E_{CH4}\mathrm{OU}_{\mathrm{lg\_SPS}} = 0.04 \times P\_E_{CH4}\mathrm{OU}_{\mathrm{lg}} \tag{S5}$$

$$A\_E_{CH4}\mathrm{OU}_{\mathrm{cm\_SPS}} = 0.96 \times P\_E_{CH4}\mathrm{OU}_{\mathrm{cm}} \tag{S6}$$

where:

$P\_E_{CH4}\mathrm{IN}_{\mathrm{sp}}$ is the CH_4 emission factor for in-house separation (see Table S3, also D8 in EmissionFactors tab in Dataset S1).

2.2 Calculation of the direct N_2O emissions

The integrated baseline N_2O emissions from four MMSs were calculated based on the N mass flow method. The direct N_2O emissions from outdoor phase and land application phase should be calculated by using the emission factor (kg N_2O-N (kg TN)$^{-1}$) multiplying by N input at each phase, whereas the N input for outdoor phase was calculated as annual N excreta (P_N_{ex} = 94.9 kg N AU^{-1} yr^{-1}, see Table S10) minus N loss in-house, and N input for land application phase was calculated based on the N input for outdoor phase minus the N loss during the outdoor phase. Finally, the system level N_2O emission would be the sum of the three phases.

Deep-pit-based system

The direct N_2O emissions from the deep-pit-based MMS (A_E_{N2O}DPS) were the sum of the emissions from each phase, according to the formula below (DeepPitBasedSystem tab, cell P5 in Dataset S1):

$$\mathrm{A\_E_{N2O}DPS} = \mathrm{P\_E_{N2O}IN_{dp}} + \mathrm{A\_E_{N2O}OU_{lg}} + \mathrm{A\_E_{N2O}lA_{ls\_DPS}} \tag{S7}$$

where:

$\mathrm{P\_E_{N2O}IN_{dp}}$ is the N_2O emission factor for in-house deep-pit storage (see Table S3, also D13 in EmissionFactors tab in Dataset S1);

$\mathrm{A\_E_{N2O}OU_{lg}}$ is N_2O emission from the lagoon;

$\mathrm{A\_E_{N2O}lA_{ls\_DPS}}$ is N_2O emission from surface broadcasting of the liquid slurry in the deep-pit-based system.

$\mathrm{A\_E_{N2O}OU_{lg}}$ and $\mathrm{A\_E_{N2O}lA_{ls\_DPS}}$ are calculated according to Eq.S8 and Eq. S9:

$$\mathrm{A\_E_{N2O}OU_{lg}} = \mathrm{P\_EF_{N2O}OU_{lg}} \times (\mathrm{P\_N_{ex}} - \mathrm{A\_N_{loss}IN_{dp}}) \times \frac{44}{28} \qquad [S8]$$

$$A\_E_{N2O}LA_{\mathrm{ls\_DPS}} = P\_EF_{N2O}LA_{\mathrm{ls}} \times (P\_N_{ex} - A\_N_{loss}IN_{dp} - A\_N_{loss}OU_{\mathrm{lg}}) \times \frac{44}{28} \qquad [S9]$$

where:

$P\_EF_{N2O}OU_{lg}$ is the N_2O-N emission factor from the lagoon (see Table S4, also D25 in EmissionFactors tab in Dataset S1);

$P\_EF_{N2O}LA_{\mathrm{ls}}$ is the N_2O-N emission factor from the surface broadcasting of liquid manure (see Table S5, also D43 in EmissionFactors tab in Dataset S1);

$A\_N_{loss}IN_{dp}$ and $A\_N_{loss}OU_{\mathrm{lg}}$ represent N loss from in-house deep-pit storage and outdoor lagoon storage, respectively. These two variables were calculated according to Eq.S10 and Eq. S11:

$$A\_N_{loss}IN_{dp} = P\_E_{NH3}IN_{dp} \times \frac{14}{17} + P\_E_{N2O}IN_{dp} \times \frac{28}{44} \qquad [S10]$$

$$A\_N_{loss}OU_{\mathrm{lg}} = A\_E_{NH3}OU_{\mathrm{lg}} \times \frac{14}{17} \div \mathrm{P\_Frac\_lg}\frac{NH3\_Nloss}{TNloss} \qquad [S11]$$

where:

$P\_E_{NH3}IN_{dp}$ and $P\_E_{N2O}IN_{dp}$ represent NH_3 and N_2O emission factors, respectively, during in-house deep-pit storage (Table S3, also D9 and D13 in EmissionFactors tab in Dataset S1, respectively).

The formula for calculating $A\_N_{loss}IN_{dp}$ was based on the 2006 IPCC Guideline,[2] as the values of N loss due to volatilization of N-NH_3 and N-NOx (in terms of the percentage of TN content, %) from deep pit (25%) or liquid/slurry storage (48%) are the same as total N loss from the corresponding phases of manure management. Thus, in this study, N loss from NH_3-N and N_2O-N during in-house slurry management was used to substitute TN loss as data about in-house TN loss were not available.

$A\_E_{NH3}OU_{\mathrm{lg}}$ represents NH_3 emissions from outdoor lagoon storage, and $\mathrm{P\_Frac\_lg}\frac{NH3\_Nloss}{TNloss}$ represents the ratio of NH_3-N loss to TN loss for slurry stored in the lagoon (see Table S11, also D10 in NLossRatio tab in Dataset S1). The calculation of $A\_N_{loss}OU_{\mathrm{lg}}$ was designed based on the 2006 IPCC Guideline, as TN loss from lagoon storage (78%) was much higher than the sum of N-NH_3 and N-NOx loss (40%), and as such, was calculated based on $\mathrm{P\_Frac\_lg}\frac{NH3\_Nloss}{TNloss}$ driven by meta-analysis.

Pull-plug-based system

For the direct N_2O emissions from the pull-plug-based system, the calculations were similar to those used for deep-pit-based system. The specific parameters that changed in accordance with this type of management are not detailed here.

Bedding-based system

The direct N_2O emissions from the bedding-based manure management system ($A\_E_{N2O}\mathrm{BDS}$) were the sum of the emissions from each phase, according to the formula below (BeddingBasedSystem tab, cell N5 in Dataset S1):

$$A\_E_{N2O}\mathrm{BDS} = P\_E_{N2O}IN_{bd} + A\_E_{N2O}OU_{cm\_BDS} + A\_E_{N2O}lA_{ss\_BDS} \quad [S12]$$

where:

$P\_E_{N2O}IN_{bd}$ is the N_2O emission factor for in-house bedding (see Table S3, also D15 in EmissionFactors tab in Dataset S1);

$A\_E_{N2O}OU_{cm\_BDS}$ is N_2O emission from outdoor manure composting;

$A\_E_{N2O}lA_{ss\_BDS}$ is N_2O emission from the surface broadcasting of solid manure. The variables were calculated according to Eq.S13 and Eq. S14:

$$A\_E_{N2O}OU_{cm\_BDS} = P\_EF_{N2O}OU_{cm} \times (P\_N_{ex} - A\_N_{loss}IN_{\mathrm{bd}}) \times \frac{44}{28} \qquad [S13]$$

$$A\_E_{N2O}lA_{ss\_BDS} = P\_EF_{N2O}LA_{\mathrm{ss}} \times (P\_N_{ex} - A\_N_{loss}IN_{\mathrm{bd}} - A\_N_{loss}OU_{\mathrm{cm\_BDS}}) \times \frac{44}{28} \qquad [S14]$$

where:

$P\_EF_{N2O}OU_{cm}$ is the N_2O-N emission factor from outdoor composting (see Table S4, also D26 in EmissionFactors tab in Dataset S1),

$P\_EF_{N2O}LA_{\mathrm{ss}}$ is the N_2O-N emission factor from the surface broadcasting of solid manure (see Table S5, also D47 in EmissionFactors tab in Dataset S1);

$A\_N_{loss}IN_{\mathrm{bd}}$ and $A\_N_{loss}OU_{\mathrm{cm\_BDS}}$ represent N loss from in-house bedding and outdoor composting of bedding-based system, respectively, which were calculated according to Eq.S15 and Eq. S16:

$$A\_N_{loss}IN_{\mathrm{bd}} = P\_E_{NH3}IN_{\mathrm{bd}} \times \frac{14}{17} \div \mathrm{P\_Frac\_sp}\frac{NH3\_Nloss}{TNloss} \qquad [S15]$$

$$A\_N_{loss}OU_{\mathrm{cm\_BDS}} = A\_E_{NH3}OU_{\mathrm{cm\_BDS}} \times \frac{14}{17} \div \mathrm{P\_Frac\_cm}\frac{NH3\_Nloss}{TNloss} \qquad [S16]$$

where:

$P\_E_{NH3}IN_{bd}$ represents the NH_3 emission factor for in-house bedding (see Table S3, D11 in EmissionFactors tab in Dataset S1);

$\mathrm{P\_Frac\_sp}\frac{NH3\_Nloss}{TNloss}$ represents the ratio of NH_3-N loss to TN loss for stockpile outdoor (see Table S11, D8 in NLossRatio tab in Dataset S1).

While considering the similarities between solid manure storage in-house and outdoor, $\mathrm{P\_Frac\_sp}\frac{NH3\_Nloss}{TNloss}$ was used to substitute the ratio of NH_3-N loss to TN loss of in-house bedding, due to the lack of available data on the ratio of N loss during this process. The formula was set based on the 2006 IPCC Guideline, as the values of N loss due to volatilization of N-NH_3 and N-NOx (in terms of the percentage of TN content, %) from in-house bedding is 40%, and the default value of TN loss from in-house bedding is 50%. Thus, TN loss from in-house bedding in this study was calculated based on $\mathrm{P\_Frac\_sp}\frac{NH3\_Nloss}{TNloss}$ driven by meta-analysis. $A\_E_{NH3}OU_{\mathrm{cm\_BDS}}$ represents NH_3 emissions from outdoor composting in the bedding-based system, and $\mathrm{P\_Frac\_cm}\frac{NH3\_Nloss}{TNloss}$ represents the ratio of NH_3-N loss to TN loss during composting (see Table S11, also D9 in NLossRatio tab in Dataset S1). The calculation was designed as NH_3-N loss was only part of the TN loss during manure composting; thus, TN loss from outdoor composting was calculated based on $\mathrm{P\_Frac\_cm}\frac{NH3\_Nloss}{TNloss}$ driven by meta-analysis.

Separation-based system

The direct N_2O emissions from the separation-based manure management system ($A\_E_{N2O}\mathrm{SPS}$) were the sum of the emissions from each phase, as manure was separated into liquid and solid parts in-house. Thus, GHG from outdoor phase and land application phase should include both the liquid and solid components of the manure. $A\_E_{N2O}\mathrm{SPS}$ was calculated based on Eq. S17 (SeparationBasedSystem tab, cell O5 in Dataset S1):

$$A\_E_{N2O}\mathrm{SPS} = P\_E_{N2O}IN_{sp} + A\_E_{N2O}OU_{\mathrm{lg}\_SPS} + A\_E_{N2O}OU_{\mathrm{cm}\_SPS} + A\_E_{N2O}lA_{ls\_SPS} + A\_E_{N2O}lA_{\mathrm{ss}\_SPS} \quad [S17]$$

where:

$P\_E_{N2O}IN_{sp}$ is the N_2O emission factor for in-house separation (see Table S3, also D16 in EmissionFactors tab in Dataset S1);

$A\_E_{N2O}OU_{\mathrm{lg}\_SPS}$ and $A\_E_{N2O}OU_{\mathrm{cm}\_SPS}$ represent N_2O emissions from lagoon storage of the separated liquid fraction and composting of the separated solid fraction, respectively (Eq. S18 and Eq. S19).

$A\_E_{N2O}lA_{ls\_SPS}$ and $A\_E_{N2O}lA_{\mathrm{ss}\_SPS}$ represent N_2O emissions from surface broadcasting of the separated liquid and solid fractions, respectively (Eq. S20 and Eq. S21).

According to calculations based on data from De Vries et al.,[1] for in-house separation, 40% of TN is preserved in the liquid fraction and 60% is preserved in the solid fraction. Therefore, the N flow should be partitioned into liquid and solid components, and considered in the corresponding calculations.

$$A\_E_{N2O}OU_{\mathrm{lg}\_\mathrm{SPS}} = P\_EF_{N2O}OU_{\mathrm{lg}} \times (P\_N_{ex} - A\_N_{loss}IN_{sp}) \times 0.4 \times \frac{44}{28} \quad [S18]$$

$$A\_E_{N2O}OU_{\mathrm{cm}\_SPS} = P\_EF_{N2O}OU_{cm} \times (P\_N_{ex} - A\_N_{loss}IN_{\mathrm{sp}}) \times 0.6 \times \frac{44}{28} \quad [S19]$$

$$A\_E_{N2O}lA_{ls\_SPS} = P\_EF_{N2O}LA_{\mathrm{ls}} \times ((P\_N_{ex} - A\_N_{loss}IN_{sp}) \times 0.4 - A\_N_{loss}OU_{\mathrm{lg}\_\mathrm{SPS}}) \times \frac{44}{28} \quad [S20]$$

$$A\_E_{N2O}lA_{\mathrm{ss}\_SPS} = P\_EF_{N2O}LA_{\mathrm{ss}} \times ((P\_N_{ex} - A\_N_{loss}IN_{\mathrm{sp}}) \times 0.6 - A\_N_{loss}OU_{\mathrm{cm\_SPS}}) \times \frac{44}{28}$$

[S21]

where:

$A\_N_{loss}IN_{\mathrm{sp}}$ is N loss from in-house separation, and should be calculated according to Eq.S22:

$$A\_N_{loss}IN_{\mathrm{sp}} = P\_E_{NH3}IN_{\mathrm{sp}} \times \frac{14}{17} + P\_E_{N2O}IN_{\mathrm{sp}} \times \frac{28}{44} \qquad [S22]$$

where:

$P\_E_{NH3}IN_{\mathrm{sp}}$ is the NH_3 emission factor for in-house separation (Table S3, also D12 in EmissionFactors tab in Dataset S1).

$A\_N_{loss}OU_{\mathrm{lg\_SPS}}$ and $A\_N_{loss}OU_{\mathrm{cm\_SPS}}$ are N loss from outdoor lagoon storage of the separated liquid fraction and N loss from composting of the separated solid fraction, respectively, and should be calculated as:

$$A\_N_{loss}OU_{\mathrm{lg\_SPS}} = A\_E_{NH3}OU_{\mathrm{lg\_SPS}} \times \frac{14}{17} \div \mathrm{P\_Frac\_lg}\frac{NH3\_Nloss}{TNloss} \qquad [S23]$$

$$A\_N_{loss}OU_{\mathrm{cm\_SPS}} = A\_E_{NH3}OU_{\mathrm{cm\_SPS}} \times \frac{14}{17} \div \mathrm{P\_Frac\_cm}\frac{NH3\_Nloss}{TNloss} \qquad [S24]$$

where:

$A\_E_{NH3}OU_{\mathrm{lg\_SPS}}$ and $A\_E_{NH3}OU_{\mathrm{cm\_SPS}}$ are NH_3 emissions from outdoor lagoon storage of the separated liquid and compost of the separated solid fractions, respectively. The calculation method is introduced in the NH_3-related section of the text below (section 3.3).

2.3 Calculation of NH_3 emissions

The integrated baseline emissions of NH_3 for the four manure management systems were calculated based on the N mass flow method. The NH_3 emissions from outdoor phase and land application phase should be calculated by using the emission factor (kg NH_3-N (kg TN)$^{-1}$) multiplying by N input at each phase. The N input for outdoor phase was calculated as annual N excreta minus N loss in-house, and N input for land application phase was calculated based on the N input for outdoor phase minus the N loss during the outdoor phase, as indicated in the former section of N_2O emission calculation. Finally, the system level NH_3 emission would be the sum of the three phases.

Deep-pit-based system

NH_3 emissions from the deep-pit-based manure management system ($A\_E_{NH3}\mathrm{DPS}$) were the sum of the emissions from each phase (DeepPitBasedSystem tab, cell Q5 in Dataset S1), according to the formula below:

$$A\_E_{NH3}DPS = P\_E_{NH3}IN_{dp} + A\_E_{NH3}OU_{lg} + A\_E_{NH3}lA_{ls\_DPS} \qquad [S25]$$

where:

$P\_E_{NH3}IN_{dp}$ is the NH_3 emission factor for in-house deep-pit storage (see Table S3, also D9 in EmissionFactors tab in Dataset S1);

$A\_E_{NH3}OU_{lg}$ is the NH_3 emission from lagoon storage (Eq. S26);

$A\_E_{NH3}lA_{ls\_DPS}$ is NH_3 emissions from surface broadcasting of liquid slurry in the deep-pit-based system (Eq. S27).

$$A\_E_{NH3}OU_{lg} = P\_EF_{NH3}OU_{\mathrm{lg}} \times (P\_N_{ex} - A\_N_{loss}IN_{dp}) \times \frac{17}{14} \qquad [S26]$$

$$A\_E_{NH3}lA_{\mathrm{ls\_DPS}} = P\_EF_{NH3}LA_{\mathrm{ls}} \times (P\_N_{ex} - A\_N_{loss}IN_{dp} - A\_N_{loss}OU_{\mathrm{lg}}) \times \frac{17}{14} \quad [S27]$$

where:

$P\_EF_{NH3}\mathrm{OU}_{\mathrm{lg}}$ is the NH_3-N emission factor for slurry lagoon storage (see Table S4, also M28 in EmissionFactors tab in Dataset S1);

$P\_EF_{NH3}LA_{\mathrm{ls}}$ is the NH_3-N emission factor for surface broadcasting of liquid slurry (see Table S5, also D37 in EmissionFactors tab in Dataset S1).

Pull-plug-based system

For NH_3 emissions from the pull-plug-based system, the calculation procedures were similar to that used for the deep-pit-based system. The parameters that changed in accordance with the pull-plug-based system are not detailed here.

Bedding-based system

NH_3 emissions from the bedding-based system ($A\_E_{NH3}\mathrm{BDS}$) were the sum of the emissions from each phase (BeddingBasedSystem tab, cell O5 in Dataset S1), according to the formula below (Eq. S28):

$$A\_E_{NH3}\mathrm{BDS} = P\_E_{NH3}IN_{bd} + A\_E_{NH3}OU_{cm\_BDS} + A\_E_{NH3}lA_{ss\_BDS} \qquad \text{[S28]}$$

where:

$P\_E_{NH3}IN_{bd}$ is the NH_3 emission factor for in-house bedding (see Table S3, D11 in EmissionFactors tab in Dataset S1),

$A\_E_{NH3}OU_{cm\_BDS}$ is NH_3 emission from outdoor manure composting (Eq. S29),

$A\_E_{NH3}lA_{ss\_BDS}$ is NH_3 emission from the surface spreading of solid manure in bedding-based system (Eq. S30)

$$A\_E_{NH3}OU_{cm\_BDS} = P\_EF_{NH3}OU_{cm} \times (P\_N_{ex} - A\_N_{loss}IN_{\mathrm{bd}}) \times \frac{17}{14} \qquad \text{[S29]}$$

$$A\_E_{NH3}lA_{ss\_BDS} = P\_EF_{NH3}LA_{\mathrm{ss}} \times (P\_N_{ex} - A\_N_{loss}IN_{\mathrm{bd}} - A\_N_{loss}OU_{\mathrm{cm\_BDS}}) \times \frac{17}{14} \qquad \text{[S30]}$$

where:

$P\_EF_{NH3}OU_{cm}$ is the NH_3 emission factor from outdoor manure composting (see Table S4, also D29 in EmissionFactors tab in Dataset S1);

$P\_EF_{NH3}LA_{ss}$ is the NH_3 emission factor from the surface spreading of solid manure (see Table S5, also D41 in EmissionFactors tab in Dataset S1).

Separation-based system

NH_3 emissions from the separation-based system ($A\_E_{NH3}\mathrm{SPS}$) were the sum of the emissions from each phase. As manure was separated into liquid and solid components in-house, the GHG emissions from outdoor manure storage and land application should include both the liquid and solid components of the manure (SeparationBasedSystem tab, cell P5 in Dataset S1), according to the following calculation (Eq. S31):

$$A\_E_{NH3}\mathrm{SPS} = P\_E_{NH3}IN_{sp} + A\_E_{NH3}OU_{\mathrm{lg}\_SPS} + A\_E_{NH3}OU_{\mathrm{cm}\_SPS} + A\_E_{NH3}lA_{\mathrm{ls}\_SPS} + A\_E_{NH3}lA_{\mathrm{ss}\_SPS} \quad [S31]$$

where:

$P\_E_{NH3}IN_{sp}$ is the NH_3 emission factor for in-house separation (see Table S3, also D12 in EmissionFactors tab in Dataset S1);

$A\_E_{NH3}OU_{\mathrm{lg}\_SPS}$ and $A\_E_{NH3}OU_{\mathrm{cm}\_SPS}$ represent NH_3 emissions from outdoor lagoon storage of the separated liquid fraction and compost of the separated solid fraction, respectively (Eq. S32 and Eq. S33).

$A\_E_{NH3}lA_{ls\_SPS}$ and $A\_E_{NH3}lA_{\mathrm{ss}\_SPS}$ represent NH_3 emissions from surface broadcasting of the separated liquid and solid fractions in separation-based system, respectively (Eq. S34 and Eq. S35).

As stated in the SI text (section 3.2), for in-house separation, 40% of the TN is preserved in the liquid fraction and 60% is preserved in the solid fraction. Therefore, the N flow should be partitioned into liquid and solid parts, and considered in the corresponding calculation.

$$A\_E_{NH3}OU_{\mathrm{lg}\_SPS} = P\_EF_{NH3}OU_{\mathrm{lg}} \times (P\_N_{ex} - A\_N_{loss}IN_{sp}) \times 0.4 \times \frac{17}{14} \qquad [S32]$$

$$A\_E_{NH3}OU_{\mathrm{cm}\_SPS} = P\_EF_{NH3}OU_{cm} \times (P\_N_{ex} - A\_N_{loss}IN_{\mathrm{sp}}) \times 0.6 \times \frac{17}{14} \qquad [S33]$$

$$A\_E_{NH3}lA_{ls\_SPS} = P\_EF_{NH3}LA_{\mathrm{ls}} \times ((P\_N_{ex} - A\_N_{loss}IN_{sp}) \times 0.4 - A\_N_{loss}OU_{\mathrm{lg\_SPS}}) \times \frac{17}{14}$$

[S34]

$$A\_E_{NH3}lA_{\mathrm{ss}\_SPS} = P\_EF_{NH3}LA_{\mathrm{ss}} \times ((P\_N_{ex} - A_{N_{loss}}IN_{\mathrm{sp}}) \times 0.6 - A\_N_{loss}OU_{\mathrm{cm\_SPS}}) \times \frac{17}{14}$$

[S35]

2.4 Calculation of indirect N_2O emissions

The indirect N_2O emission comprises the N_2O emission from atmospheric deposition of N volatilized from every phase of manure management, and leaching/runoff of manure N applied to land. Thus the indirect N_2O emission from the whole manure management chain should be calculated as following (Eq. S36):

$$\mathrm{A\_E_{N2O-ind} = A\_E_{N2O-vol}IN + A\_E_{N2O-vol}OU + A\_E_{N2O-vol}LA + A\_E_{N2O-leach}LA}$$

[S36]

where:

$\mathrm{A\_E_{N2O-ind}}$ indicates the indirect N_2O emission from the whole manure management chain;

$\mathrm{A\_E_{N2O-vol}IN}$, $\mathrm{A\_E_{N2O-vol}OU}$ and $\mathrm{A\_E_{N2O-vol}LA}$ indicate the indirect N_2O emission from deposition of N volatilized from in-house phase, outdoor phase and land-application phase, respectively;

$\mathrm{A\_E_{N2O-leach}LA}$ indicates the indirect N_2O emission due to N leaching/runoff from land application phase;

First, the $\mathrm{A\_E_{N2O-vol}}$ (including $\mathrm{A\_E_{N2O-vol}IN}$, $\mathrm{A\_E_{N2O-vol}OU}$ and $\mathrm{A\_E_{N2O-vol}LA}$) should be calculated as following (Eq. S37):

$$\mathrm{A\_E_{N2O-vol}} = A\_E_{NH3} \times \frac{14}{17} \times EF4 \times \frac{44}{28} \qquad [S37]$$

where:

$\mathrm{A\_E_{N2O-vol}}$ indicates the indirect N_2O emissions from deposition of N volatilized from manure management

A_E_{NH3} indicates the NH_3 that volatilized from each phase of manure management,

EF4 indicates emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N_2O-N (kg NH_3-N + NOx-N volatilised)$^{-1}$; default value is 0.01 kg N_2O-N (kg NH_3-N +NOx-N volatilised)$^{-1}$ based on IPCC 2006; while the NOx-N volatilized is not considered here.

Then, $\mathrm{A\_E_{N2O-leach}LA}$ should be calculated as following (Eq. S38):

$$\mathrm{A\_E_{N2O-leach}LA} = N_{leaching} \times EF5 \times \frac{44}{28} \qquad [S38]$$

$$N_{leaching} = N_{land-application} \times Frac_{leachMS} \qquad [S39]$$

where:

EF5 indicates the emission factor for N_2O emissions from nitrogen leaching and runoff, kg N_2O-N/kg N leaching and runoff (default value 0.0075 kg N_2O-N (kg N leaching/runoff)$^{-1}$, IPCC 2006).

$N_{leaching}$ indicates the amount of N being lost due to leaching and runoff during manure land application phase;

$N_{land-application}$ indicates the N being transferred to the land-application phase after some part of excreted N being lost during in-house phase and outdoor phase;

$Frac_{leachMS}$ indicates the fraction of managed manure N losses due to leaching/runoff during manure land application phase (default value 0.3 kg N/kg of manure N, IPCC 2006),

3 Calculation of gas emissions under mitigation scenarios for four manure management systems

3.1 For mitigation measures with known gas emission factors under the mitigation mode, the emission factor in the mitigation mode was used to substitute the emission factor in the baseline mode to calculate the gas emissions from the mitigation scenario. For example NH_3 emission from injection of liquid slurry during land application phase in the deep-pit based system ($A\_E_{NH3}lA_{linj\_DPS}$) (K11 in DeepPitBasedSystem tab in Dataset S1) was calculated as:

$$A\_E_{NH3}lA_{\mathrm{linj\_DPS}} = P\_EF_{NH3}LA_{\mathrm{linj}} \times (P\_N_{ex} - A\_N_{loss}IN_{dp} - A\_N_{loss}OU_{\mathrm{lg}}) \times \frac{17}{14} \quad [S40]$$

where:

$P\_EF_{NH3}LA_{\mathrm{linj}}$ is the NH_3-N emission factor of liquid manure injection (see Table S5, also D38 in EmissionFactors tab in Dataset S1);

P_N_{ex} is N excreta of swine per AU per year; $A\_N_{loss}IN_{dp}$ is N loss from in-house deep-pit storage phase;

$A\_N_{loss}OU_{\mathrm{lg}}$ is N loss from outdoor lagoon storage.

3.2 For mitigation measures without available gas emission factors in the mitigation mode, but with known gas ME for the corresponding phase, the total mitigated emission was calculated based on the baseline emission factor multiplied by the ME. For example, NH_3 emission from acidified slurry for the deep-pit-based system ($A\_E_{NH3}OU_{\mathrm{lg}\_AC}$) (H9 in DeepPitBasedSystem tab in Dataset S1) was calculated as Eq. S41:

$$A\_E_{NH3}OU_{\mathrm{lg}\_AC} = A\_E_{NH3}OU_{\mathrm{lg}} \times \left(1 + P\_ME_{NH3}OU_{\mathrm{lg\_AC}}\right) \qquad [S41]$$

where:

$A\_E_{NH3}OU_{lg}$ is the NH_3 emission from lagoon storage;

$P\_ME_{NH3}OU_{\mathrm{lg\_AC}}$ is the median value of ME for NH_3 emission from lagoon storage with acid additive compared to control slurry storage without acidification (Table S8).

3.3 Because N-gas emissions were calculated on the basis of N flow, N flow influenced by each mitigation option should also be taken into account, such as N excreta (N_{ex}) affected by a low CP diet (N_{ex_lowCP}, Eq. S42), or the use of biofilter in animal house.

a) Calculation of N_2O emissions for mitigation scenario of low CP diet

For low CP diet, as N transferred to the next phase would also be eliminated simultaneously, NH_3 emissions in the outdoor phase and land application phase were also influenced in the whole system.

$$N_{ex\_lowCP} = 94.9 \times \left(1 + P\_Ratio_{Nex\_lowCP}\right) \qquad [S42]$$

where:

$P\_Ratio_{Nex\_lowCP}$ is the median value of ME of Nex with low CP treatment (Table S9).

b) Calculation of N related gas emissions for mitigation scenario of biofilter

Biofilters are an effective technology for gas mitigation in livestock buildings. During the filtration process, the polluted air stream is slowly pumped through the biofilter and the NH_3 emissions are reduced by being absorbed into the biofilter media material. Some NH_3 can be converted into N_2O during this phase, as reported by Melse et al.,[3] who demonstrated that for a full-scale packed-bed biotrickling filter, 5% of the removed NH_3-N was converted into N_2O-N in the biofilter and emitted as N_2O ($P\_Frac\_bf\,\frac{N2O\_N\text{produced}}{NH3\_Nremoved} = 5\%$). For simplicity, we present a detailed, step-by-step numerical example of N_2O emission calculation from the mitigation scenario of biofilter in deep-pit-based system (Scenario 2 in the DeepPitBasedSystem tab of Dataset S1), while the determination of ME for in-house CH_4 and NH_3 is the same as other mitigation measures.

N_2O emissions from the in-house phase with biofilter treatment ($A\_E_{N2O}IN_{biofilter}$) should be calculated based on the following formula:

$$A\_E_{N2O}IN_{biofilter} = A\_E_{N2O}IN_{conditioned\ reference} + A\_E_{N2O\_\text{change}} \quad [S43]$$

where:

$A\_E_{N2O}IN_{conditioned\ reference}$ is N_2O emissions under the conditioned reference scenario without the use of a biofilter (Eq. S44)

$A\_E_{N2O\_\text{change}}$ represents N_2O emissions from the conversion of removed NH_3 in the biofilter (Eq. S45).

For calculation of $A\_E_{N2O}IN_{conditioned\ reference}$, if there is other treatment in-house but not a biofilter (such as Scenario 7, the combined function of low CP and biofilter), then the $A\_E_{N2O}IN_{conditioned\ reference}$ represents the N_2O emission with low CP function (D6 in DeepPitBasedSystem tab in Dataset S1), and should be calculated based on Eq. S41:

$$A\_E_{N2O}IN_{conditioned\ reference} = P\_E_{N2O}IN \times \left(1 + P_{ME_{N2O}}IN_{\text{mitigation option}}\right) \quad [S44]$$

where:

$P_{ME_{N2O}}IN_{\text{mitigation option}}$ indicates the N_2O ME of the other mitigation option used;

$P\_E_{N2O}IN$ includes $P\_E_{N2O}IN_{dp}$, $P\_E_{N2O}IN_{pp}$, $P\_E_{N2O}IN_{bd}$, and $P\_E_{N2O}IN_{sp}$.

For calculation of $A\_E_{N2O\_\text{change}}$

$$A\_E_{N2O\_\text{change}} = \text{A\_E\_removed}_{NH3} \times \frac{14}{17} \times P\_Frac\_bf\,\frac{N2O\_N\text{produced}}{NH3\_Nremoved} \times \frac{44}{28} \quad [S45]$$

where:

A_E_removed$_{NH3}$ indicates the mitigated NH_3 due to the biofilter, and should be calculated based on Eq. S46:

$$\text{A\_E\_removed}_{NH3} = A\_E_{NH3}IN_{conditioned\ reference} \times P\_ME_{NH3}IN_{\text{BF}} \qquad [S46]$$

where:

$P\_ME_{NH3}IN_{\text{BF}}$ represents the NH_3 ME due to the biofilter (Table S8, also E56 in MitigationEffect tab in dataset S1);

$A\_E_{NH3}IN_{conditioned\ reference}$ indicates NH_3 emissions under the conditioned reference scenario with or without the use of a biofilter. If there is no other treatment in-house, it refers to $P\_E_{NH3}IN$, including $P\_E_{NH3}IN_{dp}$, $P\_E_{NH3}IN_{pp}$, $P\_E_{NH3}IN_{bd}$, and $P\_E_{NH3}IN_{sg}$ (here, it means E5 in Deep-pit-based system in Dataset S1). If there is other treatment in-house but not a biofilter, it should be calculated based on the following equation:

$$A\_E_{NH3}IN_{conditioned\ reference} = P\_E_{NH3}IN \times (1 + P\_ME_{NH3}IN_{\text{mitigation option}}) \quad [47]$$

where $P\_ME_{NH3}IN_{\text{mitigation option}}$ refers to the NH_3 ME of the other mitigation option used.

N flow to the next phase with biofilter treatment

For N flow influenced by biofilters, as removed N is absorbed by the biofilter media material, which is facilitated in outdoor storage, biofilter-removed N cannot be preserved in the manure in-house, and thus cannot be transferred to the next phase. Therefore, N transferred to the next phase ($N_{trans}IN_{biofilter}$) with biofilter used is calculated as the N that is preserved in-house when biofilter function is not taken into consideration.

Finally, $N_{trans}IN_{biofilter}$ should be calculated by subtracting $N_{loss}IN_{biofilter}$ from the P_N_{ex}, meaning

$$N_{trans}IN_{biofilter} = P\_N_{ex} - N_{loss}IN_{biofilter} \qquad [S48]$$

where:

$N_{loss}IN_{biofilter}$ is N loss in-house when using a biofilter, and can be calculated in two modes because of the different scenarios of in-house manure management:

For in-house lagoon, pull-plug, and segregation practices:

$$N_{loss}IN_{biofilter} = A\_E_{NH3}IN_{conditioned\ reference} \times \frac{14}{17} + A\_E_{N2O}IN_{conditioned\ reference} \times \frac{28}{44}. \qquad [S49]$$

For the in-house bedding practice:

$$N_{loss}IN_{biofilter} = A\_E_{NH3}IN_{conditioned\ reference} \times \frac{14}{17} \div \text{P\_Frac\_sp}\frac{NH3\_Nloss}{TNloss} \qquad [S50]$$

3.4 For manure with biogas fermentation treatment, there were no available data on the ME of GHG and NH_3 emissions; thus, the total mitigated gas emissions were calculated based on biogas production, biogas leakage and the emission from biogas digestate storage and land application. Calculation methods were shown as below.

Assuming that biogas digester treatment just occurs in the deep-pit and pull-plug based systems (Scenario 3 in the DeepPitBasedSystem tab and PullPlugBasedSystem tab in Dataset S1), the slurry from those two systems would be fed into biogas digesters after being removed out from house. The gas emissions from in-house storage, biogas digester treatment, digestate storage, and land application should be summed to obtain the emissions of the whole system; among which, the emissions from the in-house phase are not influenced by biogas digester treatment. In the biogas treatment scenario, we assume that, with the exception of VS and TN that being decomposed during the in-house phase, the remaining amounts of VS and TN are fully transferred into biogas digesters. The degradation fraction of VS in biogas digester ($P\_Frac_{deg}BG_{VS}$) is set as 80% (Table S10), while the N degradation factor in biogas digester ($P\_Frac_{\mathrm{loss}}BG_{N}$) is 0% (Table S10). A total of 10% CH_4 produced in biogas digester may leak (P_MCF_{bgleak} = 10%, Table S10), and should be taken into account in the GHG emissions. All of the biogas digester effluent would be stored in the lagoon and finally applied to land, and gas emissions would occur from both the digestate storage and land application phases. For simplicity, we present a detailed, step-by-step numerical example of CH_4, N_2O, and NH_3 emission calculations from the mitigation scenario of biogas (Scenario 3) in deep-pit-based system.

a) Calculation of CH_4 emissions for mitigation scenario of biogas

CH_4 emissions from the whole system of biogas treatment ($\mathrm{A\_E}_{CH4}BDS_{bg}$) should be the sum of CH_4 emissions from in-house storage ($P\_E_{CH4}\mathrm{IN}_{\mathrm{dp}}$), biogas leakage ($\mathrm{A\_E}_{CH4\_\mathrm{leak}}$), and outdoor lagoon storage of biogas digestate ($A\_E_{CH4}OU_{lg\_digestate}$), and should be calculated as Eq. S51:

$$\mathrm{A\_E}_{CH4}BDS_{bg} = P\_E_{CH4}\mathrm{IN}_{\mathrm{dp}} + \mathrm{A\_E}_{CH4\_\mathrm{leak}} + A\_E_{CH4}OU_{lg\_digestate} \quad [S51]$$

where:

$\mathrm{A\_E}_{CH4\_\mathrm{leak}}$ (L8 in DeepPitBasedSystem tab in dataset S1) and $A\_E_{CH4}OU_{lg\_digestate}$ (F8 in DeepPitBasedSystem tab in dataset S1) should be calculated as Eq. S52 and Eq. S53:

$$\mathrm{A\_E}_{CH4\_\mathrm{leak}} = (P\_VS_{ex} - A\_VS_{loss\_inhouse}) \times P\_\mathrm{B}_O \times P\_MCF_{bgleak} \times 0.67 \quad [\mathrm{S52}]$$

$$A\_E_{CH4}OU_{lg\_digestate} = A\_VS_{digestate} \times P\_EF_{CH4}OU_{\mathrm{lg}\_digestate} \quad [\mathrm{S53}]$$

For calculation of $\mathrm{A\_E}_{CH4\_\mathrm{leak}}$ (Eq. S47), P_VS_{ex} is VS excreta of swine per AU per year (Table S10), P_B_O is the maximum CH_4 producing capacity for swine manure (Table S10), P_MCF_{bgleak} is the CH_4 ratios of biogas leakage from the biogas system (Table S10), 0.67 is the conversion factor of m^3 CH_4 to kilograms CH_4 (Table S10), and $A\_VS_{loss\_inhouse}$ is the amount of VS loss in-house, and is calculated based on the following Eq. S54:

$$A\_VS_{\mathrm{loss}\_inhouse} = P\_E_{CH4}\mathrm{IN}_{\mathrm{dp}} \div P\_\mathrm{B}_O \div P\_MCF_{pit} \div 0.67 \quad [\mathrm{S54}]$$

where: P_MCF_{pit} is the CH_4 conversion factor for deep pit storage (Table S10).

For calculation of $A\_E_{CH4}OU_{lg\_digestate}$ (Eq. S53), it means that VS remaining in the digestate ($A\_VS_{digestate}$) should multiply by the meta-analysis results of the CH_4 emission factor for biogas digestate ($P\_EF_{CH4}OU_{\mathrm{lg}\_digestate}$, Table S12, also C12 in EmissionofDigestate tab in Dataset S1).

For $A\_VS_{digestate}$, the VS discharged from in-house would be decomposed in the biogas plant, and thus the VS remained in digestate would be stored in the digestate lagoon, and should be calculated as Eq. S55:

$$A\_VS_{digestate} = (P\_VS_{ex} - A\_VS_{\mathrm{loss}\_inhouse}) \times (1 - P\_Frac_{deg}BG_{VS}) \quad [\mathrm{S55}]$$

where: $P\_Frac_{deg}BG_{VS}$ is the VS degradation ratio in the biogas digester (Table S10).

b) Calculation of NH_3 emissions for mitigation scenario of biogas

NH_3 emissions from the whole system of biogas treatment ($\mathrm{A\_E}_{NH3}BDS_{bg}$) should be the sum of NH_3 emissions from the in-house phase ($P\_E_{NH3}\mathrm{IN}_{\mathrm{dp}}$), those from outdoor storage of biogas digestate ($A\_E_{NH3}OU_{lg\_digestate}$), and biogas digestate land application ($A\_E_{NH3}LA_{ls\_digestate}$), and should be calculated as Eq. S56, here we assumed there were no NH_3 emissions in the biogas digester plant.

$$\mathrm{A\_E}_{NH3}BDS_{bg} = P\_E_{NH3}\mathrm{IN}_{\mathrm{dp}} + A\_E_{NH3}OU_{lg\_digestate} + A\_E_{NH3}LA_{ls\_digestate} \quad [S56]$$

where:

$A\_E_{NH3}OU_{lg\_digestate}$ (H8 in DeepPitBasedSystem tab in Dataset S1) and $A\_E_{NH3}LA_{ls\_digestate}$ (K8 in DeepPitBasedSystem tab in Dataset S1) should be calculated as Eq. S57 and Eq. S58, respectively:

$$A\_E_{NH3}OU_{lg\_digestate} = \mathrm{A\_}TN_{digestate} \times P\_EF_{NH3}OU_{\mathrm{lg}\_digestate} \times \frac{17}{14} \quad [S57]$$

$$A\_E_{NH3}LA_{ls\_digestate} = A\_EF_{NH3}LA_{ls\_digestate} \times (P\_N_{ex} - A\_N_{loss}IN_{dp} - A\_N_{loss}OU_{lg\_\mathrm{digestate}}) \times \frac{17}{14} \quad [S58]$$

For calculation of $A\_E_{NH3}OU_{lg\_digestate}$ (Eq. S57), $A\_TN_{digestate}$ is N contained in the digestate, which can be calculated as Eq. S59:

$$A\_TN_{digestate} = (P\_N_{ex} - A\_N_{loss}IN_{dp}) \times (1 - P\_Frac_{loss}BG_N) \quad [S59]$$

where:

$A\_N_{loss}IN_{dp}$ refers to N loss for in-house deep pit storage (Eq. S10), $P\_Frac_{loss}BG_N$ is the N loss ratio in biogas digester (Table S10).

$P\_EF_{NH3}OU_{\mathrm{lg}\_digestate}$ is the NH_3-N emission factor for biogas digester effluent stored in lagoon (see Table S12, also C11 in EmissionofDigestate tab in Dataset S1)

For calculation of $A\_E_{NH3}LA_{ls\_digestate}$ (Eq. S58), $A\_EF_{NH3}LA_{ls\_digestate}$ is the ratio of NH_3-N to TN for the surface broadcasting of digestate, and is calculated based on the meta-analysis results of the ME of NH_3 emissions from land application of digestate compared to land application of raw manure ($P\_ME_{NH3}LA_{digestate}$, table S8, also E80 in Mitigation eEffect tab in Dataset S1), and the formula is as follows:

$$A\_EF_{NH3}LA_{ls\_digestate} = P\_EF_{NH3}LA_{ls} \times (1 + P\_ME_{NH3}LA_{digestate}) \qquad [S60]$$

Then, N loss during outdoor lagoon storage of digestate ($A\_N_{loss}OU_{lg\_\mathrm{digestate}}$) is calculated as:

$$A\_N_{loss}OU_{lg\_\mathrm{digestate}} = A\_E_{NH3}OU_{lg\_digestate} \div \mathrm{P\_Frac\_lg}\frac{NH3\_Nloss}{TNloss} \times \frac{14}{17} \qquad [S61]$$

c) Calculation of N_2O emissions for mitigation scenario of biogas

N_2O emissions from the whole system of biogas treatment should be the sum of N_2O emissions from the in-house phase ($P\_E_{N2O}\mathrm{IN}_{\mathrm{dp}}$), those from outdoor lagoon storage of biogas digestate ($A\_E_{\mathrm{N2O}}OU_{lg\_digestate}$), and those from the surface broadcasting of biogas digestate ($A\_E_{\mathrm{N2O}}LA_{ls\_digestate}$).

$$\mathrm{A\_E}_{N2O}BDS_{bg} = P\_E_{N2O}\mathrm{IN}_{\mathrm{dp}} + A\_E_{N2O}OU_{lg\_digestate} + A\_E_{N2O}LA_{ls\_digestate} \qquad [S62]$$

For $A\_E_{\mathrm{N2O}}OU_{lg\_digestate}$, it is regarded that no N_2O emission occurred from digestate stored in the lagoon (G8 in DeepPitBasedSystem tab in Dataset S1).

$A\_E_{N2O}LA_{ls\_digestate}$ (J8 in DeepPitBasedSystem tab in Dataset S1) is calculated as Eq. S63:

$$A\_E_{N2O}LA_{ls\_digestate} = A\_EF_{N2O}LA_{ls\_digestate} \times (P\_N_{ex} - P\_E_{N2O}\mathrm{IN}_{\mathrm{dp}} - \mathrm{A}\_N_{loss}OU_{lg\_\mathrm{digestate}}) \times \frac{44}{28} \qquad [S63]$$

where:

$A\_EF_{N2O}LA_{ls\_digestate}$ refers to the ratio of N_2O-N to TN for the surface broadcasting of digestate, and is calculated based on the meta-analysis results of the ME of N_2O emissions from land application of digestate compared to land application of raw manure ($P\_ME_{N2O}LA_{digestate}$, Table S7, also E51 in MitigationEffect tab in Dataset S1), and the formula is as follows:

$$A\_EF_{N2O}LA_{ls\_digestate} = P\_EF_{N2O}LA_{ls} \times (1 + P\_ME_{N2O}LA_{digestate}) \qquad [S64]$$

SI tables

Table S1. Unit conversion of emission data in the literature.

Table S1A. In-house emissions (CH_4, N_2O, NH_3)

Original units	Calculation of unit conversion to kg/AU/yr
g/AU/d	$\times 365\left(\frac{\mathrm{d}}{\mathrm{yr}}\right)\times 0.001(\frac{\mathrm{kg}}{\mathrm{g}})$
g/herd/d	$\times\ 365\left(\frac{\mathrm{d}}{\mathrm{yr}}\right)\times 0.001\left(\frac{\mathrm{kg}}{\mathrm{g}}\right)\times\ 500\left(\frac{\mathrm{kg}}{\mathrm{AU}}\right)\div \text{pig weight}(\frac{\mathrm{kg}}{\mathrm{herd}})$
g/pig/period	$\div \text{period}(\mathrm{d})\times 365\left(\frac{\mathrm{d}}{\mathrm{yr}}\right)\times 0.001(\frac{\mathrm{kg}}{\mathrm{g}})\times 500\left(\frac{\mathrm{kg}}{\mathrm{AU}}\right)\div \text{pig weight}(\frac{\mathrm{kg}}{\mathrm{herd}})$
g/d/site	$\times 365\left(\frac{\mathrm{d}}{\mathrm{yr}}\right)\div \text{pig number in this site}(\frac{\mathrm{herd}}{\mathrm{site}})\times 0.001\left(\frac{\mathrm{kg}}{\mathrm{g}}\right)\times 500\left(\frac{\mathrm{kg}}{\mathrm{AU}}\right)\div \text{pig weight}(\frac{\mathrm{kg}}{\mathrm{herd}})$
g/m^2/d	$\times \text{site area}\left(\frac{\mathrm{m2}}{\mathrm{site}}\right)\times 365\left(\frac{\mathrm{d}}{\mathrm{yr}}\right)\times 0.001\left(\frac{\mathrm{kg}}{\mathrm{g}}\right)\div \text{pig number in this site}(\frac{\mathrm{herd}}{\mathrm{site}})\times 500\left(\frac{\mathrm{kg}}{\mathrm{AU}}\right)\div \text{pig weight}(\frac{\mathrm{kg}}{\mathrm{herd}})$

Table S1B. Emissions from outdoor slurry storage (CH_4, NH_3)

Original units	Calculation of unit conversion to kg/AU/yr
g/AU/d	$\times 365\left(\frac{\mathrm{d}}{\mathrm{yr}}\right) \times 0.001(\frac{\mathrm{kg}}{\mathrm{g}})$
g/herd/d	$\times\ 365\left(\frac{\mathrm{d}}{\mathrm{yr}}\right) \times 0.001\left(\frac{\mathrm{kg}}{\mathrm{g}}\right) \times\ 500\left(\frac{\mathrm{kg}}{\mathrm{AU}}\right) \div \text{pig weight}(\frac{\mathrm{kg}}{\mathrm{herd}})$
g/d/site	$\times 365\left(\frac{\mathrm{d}}{\mathrm{yr}}\right) \div \text{pig number in this site}(\frac{\mathrm{herd}}{\mathrm{site}}) \times 0.001\left(\frac{\mathrm{kg}}{\mathrm{g}}\right) \times 500\left(\frac{\mathrm{kg}}{\mathrm{AU}}\right) \div \text{pig weight}(\frac{\mathrm{kg}}{\mathrm{herd}})$
g/m^2 lagoon/d	$\times\ \text{lagoon surface area}\ (\frac{m^2}{\mathrm{site}}) \times\ 365\left(\frac{\mathrm{d}}{\mathrm{yr}}\right) \times 0.001\left(\frac{\mathrm{kg}}{\mathrm{g}}\right) \div \text{pig number in this site}(\frac{\mathrm{herd}}{\mathrm{site}})\ \times 500\left(\frac{\mathrm{kg}}{\mathrm{AU}}\right) \div \text{pig weight}(\frac{\mathrm{kg}}{\mathrm{herd}})$

To calculate the N-related gas using the N flow method, the NH_3 emission factor from outdoor lagoon storage in units of kg AU^{-1} yr^{-1} ($P\_E_{NH3}OU_{lg}$) should be converted into kg NH_3-N (kg TN)$^{-1}$ ($P\_EF_{NH3}OU_{\mathrm{lg}}$) with Eq. S65:

$$P\_EF_{NH3}OU_{\mathrm{lg}} = P\_E_{NH3}OU_{lg} \times \frac{14}{17} \div (P\_N_{ex} - A\_N_{loss}IN) \qquad [S65]$$

where: P_N_{ex} is N excreta of swine per AU per year;

$A\_N_{loss}IN$ is N loss from the in-house phase. As the slurry in outdoor lagoon storage usually comes from the effluent from in-house deep pit or pull-plug storage, the N loss in-house ($A\_N_{loss}IN$) was assumed to be the mean of N loss from in-house deep-pit ($A\_N_{loss}IN_{dp}$) or pull-plug ($A\_N_{loss}IN_{pp}$) storage, meaning $A\_N_{loss}IN$ should be calculated with Eq. S66:

$$A\_N_{loss}IN = \frac{1}{2} \times (A\_N_{loss}IN_{dp} + A\_N_{loss}IN_{pp}) \qquad [S66]$$

Table S1C. CH_4 emissions from compost or solid stocking pile

Original units	Calculation of unit conversion to kg/AU/yr
g/kg manure	$\times 15650(\text{kg manure/AU/year}) \times 0.001\left(\frac{\text{kg}}{\text{g}}\right)$ *
g (cumulative emission)/pile	$\div$ manure quality of the pile $\left(\frac{\text{kg manure}}{\text{pile}}\right) \times 15650(\text{kg manure/AU/year}) \times 0.001\left(\frac{\text{kg}}{\text{g}}\right)$
CH_4-C/TC	$\times \text{TC}\left(\frac{\text{g}}{\text{kg DM}}\right) \times \frac{16}{12} \times (1 - \text{moisture content})\left(\frac{\text{kg DM}}{\text{kg manure}}\right) \times 0.001\left(\frac{\text{kg}}{\text{g}}\right)$

* Manure production rate=84 kg/1000 kg LW/d =15650 kg manure/AU/year (table S10)

Table S1D. NH_3 emission factor of manure composting or solid stocking pile

Original units	Calculation of unit conversion to NH_3-N/TN
g NH_3-N/kg manure	$\div$ TN content of the manure$\left(\frac{\text{g}}{\text{kg manure}}\right)$

Table S1E. N_2O emission factor of manure composting or solid stocking pile

Original units	Calculation of unit conversion to N_2O-N/TN
g N_2O-N/kg manure	$\div$ TN content of the manure$\left(\frac{\text{g}}{\text{kg manure}}\right)$

Table S1F. CH_4 emission factor of field manure application

Original units	Calculation of unit conversion to kg CH_4/AU/yr
kg CH_4/ha	$\div$ manure application rate$\left(\frac{\text{kg manure}}{\text{ha}}\right) \times 15650(\text{kg manure/AU/year})$

Table S1G. NH_3 emission factor of field manure application

Original units	Calculation of unit conversion to NH_3-N/TN
g NH_3-N/kg manure	$\div$ TN content of the manure$\left(\frac{\text{g}}{\text{kg manure}}\right)$
kg NH_3-N/ha	$\div$ TN application rate$\left(\frac{\text{kg N}}{\text{ha}}\right)$
NH_3-N/TAN	$\times \frac{\text{TAN}}{\text{TN}}$ *

* If the ratio of TAN/TN is not available in the target study, then choose the default value of 56% (Data source: table S10)

Table S1H. N_2O emission factor of field manure application

Original units	Calculation of unit conversion to N_2O-N/TN
g N_2O-N/kg manure	$\div$ TN content of the manure$\left(\frac{\text{g}}{\text{kg manure}}\right)$
kg N_2O-N/ha	$\div$ TN application rate$\left(\frac{\text{kg N}}{\text{ha}}\right)$

Table S2. Description of the reference scenarios and emission mitigation measures used for the analysis of each manure management system: (a) deep-pit system; (b) pull-plug system; (c) bedding system; (d) separation system.

Table S2A. Deep-pit system

		In-house		Outdoor				Land application	
	Scenario ID	**Dietary CP content**	**Biofilter**	**Solid-liquid separation**	**Biogas**	**Slurry/liquid fractions**	**Solid manure/ solid fractions**	**Slurry/liquid fractions**	**Solid manure/solid fractions**
DPS-Ref	Deep-pit system reference	Conventional	No biofilter			Lagoon		Surface broadcasting	
DPS-S1	Low CP	Low CP	No biofilter			Lagoon		Surface broadcasting	
DPS-S2	Biofilter	Conventional	Biofilter			Lagoon		Surface broadcasting	
DPS-S3	Biogas	Conventional	No biofilter		Biogas	Lagoon		Surface broadcasting	
DPS-S4	Slurry acidification	Conventional	No biofilter			Acidification		Surface broadcasting	
DPS-S5	Slurry plastic cover	Conventional	No biofilter			Plastic cover		Surface broadcasting	
DPS-S6	Slurry injection	Conventional	No biofilter			Lagoon		Injection	
DPS-S7	Low CP + biofilter	Low CP	Biofilter			Lagoon		Surface broadcasting	
DPS-S8	Low CP + slurry acidification	Low CP	No biofilter			Acidification		Surface broadcasting	
DPS-S9	Low CP + slurry acidification + slurry injection	Low CP	No biofilter			Acidification		Injection	
DPS-S10	Low CP + slurry plastic cover	Low CP	No biofilter			Plastic cover		Surface broadcasting	

		In-house				Outdoor		Land application	
	Scenario ID	**Dietary CP content**	**Biofilter**	**Solid-liquid separation**	**Biogas**	**Slurry/liquid fractions**	**Solid manure/ solid fractions**	**Slurry/liquid fractions**	**Solid manure/solid fractions**
DPS-S11	Low CP + slurry plastic cover + slurry injection	Low CP	No biofilter			Plastic cover		Injection	
DPS-S12	Biofilter + slurry acidification + slurry injection	Conventional	Biofilter			Acidification		Injection	
DPS-S13	Biofilter + slurry plastic cover + slurry injection	Conventional	Biofilter			Plastic cover		Injection	
DPS-S14	Biogas + slurry injection	Conventional	No biofilter		Biogas	Lagoon		Injection	
DPS-S15	Biofilter + biogas + slurry injection	Conventional	Biofilter		Biogas	Lagoon		Injection	
DPS-S16	Low CP + biogas+ slurry injection	Low CP	No biofilter		Biogas	Lagoon		Injection	
DPS-S17	Low CP + biofilter + biogas + slurry injection	Low CP	Biofilter		Biogas	Lagoon		Injection	
DPS-S18	Low CP + biofilter + slurry acidification	Low CP	Biofilter			Acidification		Surface broadcasting	
DPS-S19	Low CP + biofilter + slurry acidification + slurry injection	Low CP	Biofilter			Acidification		Injection	
DPS-S20	Low CP + biofilter + slurry plastic cover	Low CP	Biofilter			Plastic cover		Surface broadcasting	
DPS-S21	Low CP + biofilter + slurry plastic cover + slurry injection	Low CP	Biofilter			Plastic cover		Injection	
DPS-S22	Separation	Conventional	No biofilter	Centrifuge		Lagoon	Compost	Surface broadcasting	Surface spreading
DPS-S23	Separation (Liquid biogas)	Conventional	No	Centrifuge	Separated	Lagoon	Compost	Surface	Surface spreading

		In-house			**Outdoor**			**Land application**	
	Scenario ID	**Dietary CP content**	**Biofilter**	**Solid-liquid separation**	**Biogas**	**Slurry/liquid fractions**	**Solid manure/ solid fractions**	**Slurry/liquid fractions**	**Solid manure/solid fractions**
			biofilter		liquid for biogas			broadcasting	
DPS-S24	Low CP + biofilter + separation	Low CP	Biofilter	Centrifuge		Lagoon	Compost	Surface broadcasting	Surface spreading
DPS-S25	Low CP + biofilter + separation (solid compost additive + liquid slurry acidification)	Low CP	Biofilter	Centrifuge		Acidification	Compost additive	Surface broadcasting	Surface spreading
DPS-S26	Low CP + biofilter + separation (solid compost additive + Liquid slurry plastic cover)	Low CP	Low CP	Centrifuge		Plastic cover	Compost additive	Surface broadcasting	Surface spreading
DPS-S27	Low CP + biofilter + separation (solid compost incorporation + Liquid slurry injection)	Low CP	Low CP	Centrifuge		Lagoon	Compost	Injection	Incorporation
DPS-S28	Low CP + biofilter + separation (solid compost additive + liquid slurry plastic cover + Solid compost incorporation + Liquid slurry injection)	Low CP	Biofilter	Centrifuge		Plastic cover	Compost additive	Injection	Incorporation
DPS-S29	Low CP + biofilter + separation (solid compost additive + liquid slurry acidification + Solid compost incorporation + Liquid slurry injection)	Low CP	Biofilter	Centrifuge		Acidification	Compost additive	Injection	Incorporation

Table S2B. Pull-plug system

		In-house		Outdoor				Land application	
	Scenario ID	**Dietary CP content**	**Biofilter**	**Solid-liquid separation**	**Biogas**	**Slurry/liquid fractions**	**Solid manure/solid fractions**	**Slurry/liquid fractions**	**Solid manure/solid fractions**
PPS-Ref	Pull-plug system reference	Conventional	No biofilter			Lagoon		Surface broadcasting	
PPS-S1	Low CP	Low CP	No biofilter			Lagoon		Surface broadcasting	
PPS-S2	Biofilter	Conventional	Biofilter			Lagoon		Surface broadcasting	
PPS-S3	Biogas	Conventional	No biofilter		Biogas	Lagoon		Surface broadcasting	
PPS-S4	Slurry acidification	Conventional	No biofilter			Acidification		Surface broadcasting	
PPS-S5	Slurry plastic cover	Conventional	No biofilter			Plastic cover		Surface broadcasting	
PPS-S6	Slurry injection	Conventional	No biofilter			Lagoon		Injection	
PPS-S7	Low CP + biofilter	Low CP	Biofilter			Lagoon		Surface broadcasting	
PPS-S8	Low CP + slurry acidification	Low CP	No biofilter			Acidification		Surface broadcasting	
PPS-S9	Low CP + slurry acidification + slurry injection	Low CP	No biofilter			Acidification		Injection	
PPS-S10	Low CP + slurry plastic cover	Low CP	No biofilter			Plastic cover		Surface broadcasting	
PPS-S11	Low CP + slurry plastic cover + slurry injection	Low CP	No biofilter			Plastic cover		Injection	
PPS-S12	Biofilter + slurry acidification + slurry injection	Conventional	Biofilter			Acidification		Injection	
PPS-S13	Biofilter + slurry plastic cover + slurry injection	Conventional	Biofilter			Plastic cover		Injection	
PPS-S14	Biogas + slurry injection	Conventional	No biofilter		Biogas	Lagoon		Injection	

		In-house		Outdoor				Land application	
	Scenario ID	**Dietary CP content**	**Biofilter**	**Solid-liquid separation**	**Biogas**	**Slurry/liquid fractions**	**Solid manure/solid fractions**	**Slurry/liquid fractions**	**Solid manure/solid fractions**
PPS-S15	Biofilter + biogas + slurry injection	Conventional	Biofilter		Biogas	Lagoon		Injection	
PPS-S16	Low CP + biogas + slurry injection	Low CP	No biofilter		Biogas	Lagoon		Injection	
PPS-S17	Low CP + biofilter + biogas + slurry injection	Low CP	Biofilter		Biogas	Lagoon		Injection	
PPS-S18	Low CP + biofilter + slurry acidification	Low CP	Biofilter			Acidification		Surface broadcasting	
PPS-S19	Low CP + biofilter + slurry acidification + slurry injection	Low CP	Biofilter			Acidification		Injection	
PPS-S20	Low CP + biofilter + slurry plastic cover	Low CP	Biofilter			Plastic cover		Surface broadcasting	
PPS-S21	Low CP + biofilter + slurry plastic cover + slurry injection	Low CP	Biofilter			Plastic cover		Injection	
PPS-S22	Separation	Conventional	No biofilter	Centrifuge		Lagoon	Compost	Surface broadcasting	Surface spreading
PPS-S23	Separation (Liquid biogas)	Conventional	No biofilter	Centrifuge	Separated liquid for biogas	Lagoon	Compost	Surface broadcasting	Surface spreading
PPS-S24	Low CP + biofilter + separation	Low CP	Biofilter	Centrifuge		Lagoon	Compost	Surface broadcasting	Surface spreading
PPS-S25	Low CP + biofilter +	Low CP	Biofilter	Centrifuge		Acidification	Compost	Surface broadcasting	Surface spreading

		In-house		Outdoor				Land application	
	Scenario ID	**Dietary CP content**	**Biofilter**	**Solid-liquid separation**	**Biogas**	**Slurry/liquid fractions**	**Solid manure/solid fractions**	**Slurry/liquid fractions**	**Solid manure/solid fractions**
	separation (Solid compost additive + Liquid slurry acidification)						additive		
PPS-S26	Low CP + biofilter + separation (Solid compost additive + Liquid slurry plastic cover)	Low CP	Biofilter	Centrifuge		Plastic cover	Compost additive	Surface broadcasting	Surface spreading
PPS-S27	Low CP + biofilter + separation (solid compost incorporation + liquid slurry injection)	Low CP	Biofilter	Centrifuge		Lagoon	Compost	Injection	Incorporation
PPS-S28	Low CP + biofilter + separation (solid compost additive + liquid slurry plastic cover + solid compost incorporation + liquid slurry injection)	Low CP	Biofilter	Centrifuge		Plastic cover	Compost additive	Injection	Incorporation
PPS-S29	Low CP + biofilter + separation (solid compost additive + liquid slurry acidification + solid compost incorporation + liquid slurry injection)	Low CP	Biofilter	Centrifuge		Acidification	Compost additive	Injection	Incorporation

Table S2C. Bedding system

		In-house		Outdoor	Land application
Scenario ID		Dietary CP content	Biofilter	Solid manure	Solid manure
BDS-Ref	Bedding system reference	Conventional	No biofilter	Compost	Surface spreading
BDS-S1	Low CP	Low CP	No biofilter	Compost	Surface spreading
BDS-S2	Biofilter	Conventional	Biofilter	Compost	Surface spreading
BDS-S3	Compost cover	Conventional	No biofilter	Compost cover	Surface spreading
BDS-S4	Compost additive	Conventional	No biofilter	Compost additive	Surface spreading
BDS-S5	Compost incorporation	Conventional	No biofilter	Compost	Incorporation
BDS-S6	Low CP + biofilter	Low CP	Biofilter	Compost	Surface spreading
BDS-S7	Low CP + compost cover + compost incorporation	Low CP	No biofilter	Compost cover	Incorporation
BDS-S8	Biofilter + compost cover + compost incorporation	Conventional	Biofilter	Compost cover	Incorporation
BDS-S9	Biofilter + compost additive + compost incorporation	Conventional	Biofilter	Compost additive	Incorporation
BDS-S10	Low CP + compost additive	Low CP	No biofilter	Compost additive	Surface spreading
BDS-S11	Low CP + compost additive + compost incorporation	Low CP	No biofilter	Compost additive	Incorporation
BDS-S12	Low CP + biofilter + compost cover	Low CP	Biofilter	Compost cover	Surface spreading
BDS-S13	Low CP + biofilter + compost cover + compost incorporation	Low CP	Biofilter	Compost cover	Incorporation
BDS-S14	Low CP + biofilter + compost additive	Low CP	Biofilter	Compost additive	Surface spreading
BDS-S15	Low CP + biofilter + compost additive + compost incorporation	Low CP	Biofilter	Compost additive	Incorporation

Table S2D. Separation system

		In-house		Outdoor		Land application	
	Scenario ID	Dietary CP content	Biofilter	Slurry/liquid fractions	Solid manure/solid fractions	Slurry/liquid fractions	Solid manure/solid fractions
SPS-Ref	Separation system reference	Conventional	No biofilter	Lagoon	Compost	Surface broadcasting	Surface spreading
SPS-S1	Low CP	Low CP	No biofilter	Lagoon	Compost	Surface broadcasting	Surface spreading
SPS-S2	Biofilter	Conventional	Biofilter	Lagoon	Compost	Surface broadcasting	Surface spreading
SPS-S3	Compost additive (slurry acidification)	Conventional	No biofilter	Acidification	Compost additive	Surface broadcasting	Surface spreading
SPS-S4	Compost cover (slurry acidification)	Conventional	No biofilter	Acidification	Compost cover	Surface broadcasting	Surface spreading
SPS-S5	Compost additive (slurry plastic cover)	Conventional	No biofilter	Plastic cover	Compost additive	Surface broadcasting	Surface spreading
SPS-S6	Compost cover (slurry plastic cover)	Conventional	No biofilter	Plastic cover	Compost cover	Surface broadcasting	Surface spreading
SPS-S7	Compost incorporation (slurry injection)	Conventional	No biofilter	Lagoon	Compost	Injection	Incorporation
SPS-S8	Low CP + biofilter	Low CP	Biofilter	Lagoon	Compost	Surface broadcasting	Surface spreading
SPS-S9	Low CP + compost additive (slurry acidification)	Low CP	No biofilter	Acidification	Compost additive	Surface broadcasting	Surface spreading
SPS-S10	Low CP + compost additive (slurry acidification) + compost incorporation (slurry injection)	Low CP	No biofilter	Acidification	Compost additive	Injection	Incorporation
SPS-S11	Low CP + compost additive (slurry plastic cover)	Low CP	No biofilter	Plastic cover	Compost additive	Surface broadcasting	Surface spreading
SPS-S12	Low CP + compost additive (slurry plastic cover) + compost incorporation (slurry injection)	Low CP	No biofilter	Plastic cover	Compost additive	Injection	Incorporation
SPS-S13	Low CP + compost cover (slurry acidification)	Low CP	No biofilter	Acidification	Compost cover	Surface broadcasting	Surface spreading
SPS-S14	Low CP + compost cover(slurry acidification) + compost incorporation	Low CP	No biofilter	Acidification	Compost cover	Injection	Incorporation

		In-house		Outdoor		Land application	
	Scenario ID	**Dietary CP content**	**Biofilter**	**Slurry/liquid fractions**	**Solid manure/solid fractions**	**Slurry/liquid fractions**	**Solid manure/solid fractions**
	(slurry injection)						
SPS-S15	Low CP + compost cover (slurry plastic cover)	Low CP	No biofilter	Plastic cover	Compost cover	Surface broadcasting	Surface spreading
SPS-S16	Low CP + compost cover (slurry plastic cover) + compost incorporation (slurry injection)	Low CP	No biofilter	Plastic cover	Compost cover	Injection	Incorporation
SPS-S17	Biofilter + compost additive (slurry acidification) + compost incorporation (slurry injection)	Conventional	Biofilter	Acidification	Compost additive	Injection	Incorporation
SPS-S18	Biofilter + compost additive (slurry plastic cover) + compost incorporation (slurry injection)	Conventional	Biofilter	Plastic cover	Compost additive	Injection	Incorporation
SPS-S19	Biofilter + compost cover (slurry acidification) + compost incorporation (slurry injection)	Conventional	Biofilter	Acidification	Compost cover	Injection	Incorporation
SPS-S20	Biofilter + compost cover (slurry plastic cover) + compost incorporation (slurry injection)	Conventional	Biofilter	Plastic cover	Compost cover	Injection	Incorporation
SPS-S21	LCP + biofilter + compost additive (slurry acidification)	Low CP	Biofilter	Acidification	Compost additive	Surface broadcasting	Surface spreading
SPS-S22	LCP + biofilter + compost additive (slurry acidification) + compost incorporation (slurry injection)	Low CP	Biofilter	Acidification	Compost additive	Injection	Incorporation

		In-house		Outdoor		Land application	
	Scenario ID	Dietary CP content	Biofilter	Slurry/liquid fractions	Solid manure/solid fractions	Slurry/liquid fractions	Solid manure/solid fractions
SPS-S23	LCP + biofilter + compost cover (slurry acidification)	Low CP	Biofilter	Acidification	Compost cover	Surface broadcasting	Surface spreading
SPS-S24	LCP + biofilter + compost cover (slurry acidification) + compost incorporation (slurry injection)	Low CP	Biofilter	Acidification	Compost cover	Injection	Incorporation
SPS-S25	LCP + biofilter + compost additive (slurry plastic cover)	Low CP	Biofilter	Plastic cover	Compost additive	Surface broadcasting	Surface spreading
SPS-S26	LCP + biofilter + compost additive (slurry plastic cover) + compost incorporation (slurry injection)	Low CP	Biofilter	Plastic cover	Compost additive	Injection	Incorporation
SPS-S27	LCP + biofilter + compost cover (slurry plastic cover)	Low CP	Biofilter	Plastic cover	Compost cover	Surface broadcasting	Surface spreading
SPS-S28	LCP + biofilter + compost cover (slurry plastic cover) + compost incorporation (slurry injection)	Low CP	Biofilter	Plastic cover	Compost cover	Injection	Incorporation

Table S3. Meta-analysis results of CH_4, NH_3, and N_2O emission factors for in-house manure management (these data also appear in the EmissionFactors tab in Dataset S1; see dynamic links to other tabs that present the raw data in Dataset S1).

		Parameter	Range	Mean(se)	Median	IQR[a]	N	Reference
CH_4 (kg AU^{-1} y^{-1})	Deep-pit	$P\_E_{CH4}\mathrm{IN}_{\mathrm{dp}}$	3.10~235.29	69.32(13.69)	64.37	64.37	8(25)	4-11
	Pull-plug	$P\_E_{CH4}\mathrm{IN}_{\mathrm{PP}}$	16.79~265.70	81.80(26.29)	47.09	47.09	2(9)	12,13
	Bedding	$P\_E_{CH4}\mathrm{IN}_{\mathrm{bd}}$	4.80~44.20	14.56(2.50)	10.63	10.63	7(21)	4,5, 14-18
	Separation	$P\_E_{CH4}\mathrm{IN}_{\mathrm{sg}}$	3.50~15.98	10.28(1.73)	10.93	10.93	2(8)	19,20
NH_3 (kg AU^{-1} y^{-1})	Deep-pit	$P\_E_{NH3}IN_{dp}$	3.64~53.55	14.96(1.72)	11.99	11.99	11(37)	4-8, 8-11,,21-24
	Pull-plug	$P\_E_{NH3}IN_{pp}$	1.20~21.79	11.94(2.24)	14.98	14.98	4(7)	6,7, 22, 23
	Bedding	$P\_E_{NH3}IN_{bd}$	1.94~54.02	13.54(2.69)	8.05	8.05	9(24)	4,5, 14-18, 24,25
	Separation	$P\_E_{NH3}IN_{sg}$	9.76~17.42	13.61(0.95)	13.79	13.79	2(7)	20, 24
N_2O (kg AU^{-1} y^{-1})	Deep-pit	$P\_E_{N2O}IN_{dp}$	0.00~2.59	0.78(0.17)	0.7	0.7	7(22)	4-9, 11
	Pull-plug	$P\_E_{N2O}IN_{pp}$	0.00~0.55	0.14(0.09)	0	0	3(6)	6,7, 13
	Bedding	$P\_E_{N2O}IN_{bd}$	0.00~29.29	9.10(2.13)	4.7	4.7	7(20)	4, 5, 15-18, 25
	Separation	$P\_E_{N2O}IN_{sg}$	0.20~0.31	0.26(0.03)	0.27	NA[b]	1(3)	19

[a] IQR = Interquartile range; [b] NA = not applicable

Table S4. Meta-analysis results of CH_4, NH_3, and N_2O emission factors for outdoor manure management (these data also appear in the EmissionFactors tab in Dataset S1; see dynamic links to other tabs that present the raw data in Dataset S1).

		Parameter	Range	Mean(se)	Median	IQR[a]	N	Reference
CH_4 (kg AU^{-1} y^{-1})	lagoon	$P\_E_{CH4}\mathrm{OU}_{\mathrm{lg}}$	5.60~191.99	53.36(16.09)	50.37	63.5	6(11)	7, 13, 26-29
	compost	$P\_E_{CH4}\mathrm{OU}_{\mathrm{cm}}$	0.00~202.81	42.99(11.47)	11.14	78.6	8(30)	30-37
	stockpile	$P\_E_{CH4}\mathrm{OU}_{\mathrm{sp}}$	4.49~33.39	14.41(3.40)	9.44	17.05	5(9)	38-42
N_2O-N/TN (kg N_2O-N kg TN^{-1})	lagoon	$P\_EF_{N2O}OU_{lg}$	0.0000~0.01	0.0012(0.0011)	0	0	6(11)	29, 43-47
	compost	$P\_EF_{N2O}OU_{cm}$	0.0001~0.1122	0.028(0.004)	0.017	0.037	12(39)	30- 37,48-51
	stockpile	$P\_EF_{N2O}OU_{sp}$	0.000~0.046	0.012(0.004)	0.0017	0.03	8(13)	39-42, 52-55
NH_3-N/TN (kg NH_3-N kg TN^{-1})	lagoon	$P\_EF_{NH3}OU_{lg}$	0.025~0.920	0.310(0.066)	0.17	0.48	6(19)	7, 56-60
	compost	$P\_EF_{NH3}OU_{cm}$	0.035~0.489	0.235(0.020)	0.249	0.18	10(36)	30, 32-37, 48, 50, 51
	stockpile	$P\_EF_{NH3}OU_{sp}$	0.0015~0.308	0.086(0.028)	0.047	0.13	7(13)	40, 41, 52, 54, 55, 61, 62

[a] IQR = Interquartile range

Table S5. Meta-analysis results of CH_4, NH_3 and N_2O emission factors for land application of manure in paddy field and upland, respectively: (a) for paddy field, (b) for upland (these data also appear in the EmissionFactors tab in Dataset S1; see dynamic links to other tabs that present the raw data in Dataset S1).

Table S5A. Paddy field

	Manure style	Management option	Parameter	range	mean(se)	median	IQR[a]	N	Reference
CH_4 (kg AU^{-1} y^{-1})	Pig manure	Incorporation	$P\_EF_{CH4}LA_{paddy}$	19.10~375.60	163.5(67.1)	113.4	282.3	3(5)	63-65
N_2O-N/TN (kg N_2O-N kg TN^{-1})	Pig manure	Incorporation	$P\_EF_{N2O}LA_{paddy}$	0.0000~0.0023	0.0012(0.0005)	0.0013	0.00	3(4)	64, 66, 67
NH_3-N/TN (kg NH_3-N kg TN^{-1})	Pig manure	Incorporation						0(0)	

[a] IQR = Interquartile range

Table S5B. Upland

	Manure style	Management option	Parameter	range	mean(se)	median	IQR[a]	N	Reference
CH_4 (kg AU^{-1} y^{-1})	Liquid manure	Surface broadcasting						0(0)	
		Injection						0(0)	
		Rapid incorporation						0(0)	
		Band spreading						0(0)	
	Solid manure	Surface spreading						0(0)	
		Incorporation	$P\_EF_{CH4}LA_{\mathrm{sinc}}$			8.29		1(1)	68
NH_3-N/TN (kg NH_3-N kg TN^{-1})	Liquid manure	Surface broadcasting	$P\_EF_{NH3}LA_{\mathrm{ls}}$	0.0870~0.5034	0.3028(0.0226)	0.3177	0.18	5(26)	69-73
		Injection	$P\_EF_{NH3}LA_{\mathrm{linj}}$	0.0000~0.0638	0.0103(0.0038)	0.0049	0.01	4(17)	69, 71, 72, 74
		Rapid incorporation	$P\_EF_{NH3}LA_{\mathrm{linc}}$	0.0120~0.2490	0.0986(0.0117)	0.0995	0.06	3(22)	69, 73, 74
		Band spreading	$P\_EF_{NH3}LA_{\mathrm{bds}}$	0.0405~0.1792	0.0861(0.0122)	0.073	0.08	4(15)	71, 72, 74, 75
	Solid manure	Surface spreading	$P\_EF_{NH3}LA_{\mathrm{ss}}$	0.1180~0.3450	0.184(0.0219)	0.18	0.09	3(10)	70, 76, 77
		Incorporation	$P\_EF_{NH3}LA_{\mathrm{sinc}}$	0.0070~0.0670	0.0294(0.0077)	0.024	0.04	2(9)	68, 76
N_2O-N/TN (kg N_2O-N kg TN^{-1})	Liquid manure	Surface broadcasting	$P\_EF_{N2O}LA_{\mathrm{ls}}$	0.0009~0.049	0.0093(0.0017)	0.0058	0.01	8(37)	78-85
		Injection	$P\_EF_{N2O}LA_{\mathrm{linj}}$	0.0005~0.123	0.0256(0.0057)	0.015	0.03	9(25)	74, 78-80, 83,86-89
		Rapid incorporation	$P\_EF_{N2O}LA_{\mathrm{linc}}$	0.0000~0.1850	0.0365(0.0074)	0.017	0.04	10(44)	74, 85, 89-96
		Band spreading	$P\_EF_{N2O}LA_{\mathrm{lbds}}$	0.0022~0.0135	0.0074(0.0017)	0.0078	0.01	3(6)	74, 86,90
	Solid manure	Surface spreading	$P\_EF_{N2O}LA_{\mathrm{ss}}$	0.00000~0.00020	0.00008(0.00004)	0.0001	0.0001	2(5)	53, 76
		Rapid incorporation	$P\_EF_{N2O}LA_{\mathrm{sinc}}$	0.0001~0.0190	0.0047(0.0021)	0.0009	0.01	5(11)	53, 68, 76, 91, 92

[a] IQR = Interquartile range

Table S6. Meta-analysis results of changes of CH_4 emissions under different mitigation measures at their corresponding phase of manure management (these data also appear in the MitigationEffect tab in Dataset S1; see dynamic links to other tabs that present the raw data in Dataset S1).

		Mitigation option	Parameter	Min-Max	Mean	SE	Median	IQR[a]	P value	N	Reference
In-house		low crude protein diet	$P\_ME_{CH4}IN_{\mathrm{LCP}}$	(-0.32)~0.15	-0.1517	0.0712	-0.17	0.2825	0.116	5(6)	10, 96-99
		feed additive	$P\_ME_{CH4}IN_{\mathrm{FA}}$	0.12~0.25	0.2	0.04041	0.23	0.130	0.109	1(3)	97
		biofiltration	$P\_ME_{CH4}IN_{\mathrm{BF}}$	(-0.83)~0.10	-0.2629	0.05654	-0.24	0.195	0.002	4(14)	100-103
Outdoor	Liquid	straw cover	$P\_ME_{CH4}OU_{\mathrm{lg\_SC}}$	(-0.50)~2.47	0.0264	0.1037	-0.14	0.465	0.49	4(14)	43, 104-106
		oil cover	$P\_ME_{CH4}OU_{\mathrm{lg\_OC}}$	(-0.13)~(-0.10)	-0.115	0.015	-0.12	0.030	0.18	1(2)	105
		plastic cover*	$P\_ME_{CH4}OU_{\mathrm{lg\_PC}}$				0.00				
		granule cover	$P\_ME_{CH4}OU_{\mathrm{lg\_GC}}$	(-0.17)~(0.14)	-0.052	0.05598	-0.09	0.225	0.357	3(5)	44, 104,105
		cooling	$P\_ME_{CH4}OU_{\mathrm{lg\_CL}}$	(-0.61)~(-0.23)	-0.3933	0.05542	-0.38	0.215	0.028	2(6)	107, 108
		acid additive	$P\_ME_{CH4}OU_{\mathrm{lg\_AC}}$	(-0.99)~(-0.31)	-0.7625	0.15553	-0.88	0.543	0.068	2(4)	109, 110
	Solid	**Stockpile**									
		Cover	$P\_ME_{CH4}OU_{\mathrm{sp\_C}}$				-0.88			1(1)	38
		Compost									
		Additive	$P\_ME_{CH4}OU_{\mathrm{cm\_AD}}$	(-0.63)~0.15	-0.165	0.17333	-0.09	0.650	0.465	1(4)	111
		Cover	$P\_ME_{CH4}OU_{\mathrm{cm\_CV}}$	0.32~0.72	0.4533	0.03556	0.48	0.145	0.028	2(6)	32, 33
Land application		**For rice paddy**									
		Without manure vs. manure	$P\_ME_{CH4}LA_{\mathrm{no\ manure}}$	(-0.97)~0.05	-0.5276	0.0655	-0.57	0.473	0	15(21)	63-67, 112-121
		For upland									
		Slurry injection	$P\_ME_{CH4}LA_{\mathrm{l\_INJ}}$							0(0)	
		Slurry incorporation	$P\_ME_{CH4}LA_{\mathrm{l\_INC}}$							0(0)	
		Solid incorporation	$P\_ME_{CH4}LA_{\mathrm{s\_INC}}$							0(0)	
		Digested slurry	$P\_ME_{CH4}LA_{digestate}$							0(0)	
		NI addition	$P\_ME_{CH4}LA_{\mathrm{NI}}$							0(0)	

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[a] IQR = Interquartile range

Table S7. Meta-analysis results of changes of N_2O emissions under different mitigation measures at their corresponding phase of manure management (these data also appear in the MitigationEffect tab in Dataset S1; see dynamic links to other tabs that present the raw data in Dataset S1).

		Mitigation option	Parameter	Min-Max	Mean	SE	Median	IQR[a]	P value	N	Reference
In-house		low crude protein diet	$P\_ME_{N2O}IN_{\mathrm{LCP}}$	0.05~0.96	0.3633	0.29846	0.08	0.910	0.109	3(3)	97-99
		feed additive	$P\_ME_{N2O}IN_{\mathrm{FA}}$	(-0.01)~0.25	0.1167	0.07513	0.11	0.260	0.285	1(3)	97
		biofiltration	$P\_ME_{N2O}IN_{\mathrm{BF}}$	(-0.22)~0.81	0.1331	0.07252	0.12	0.260	0.195	3(13)	101-103
Outdoor	Liquid	straw cover	$P\_ME_{N2O}OU_{\mathrm{lg\_SC}}$	4.68~396.00	110.188	73.691	28.96	24.193	0.043	3(5)	43, 104, 106
		oil cover	$P\_ME_{N2O}OU_{\mathrm{lg\_OC}}$							0(0)	
		plastic cover	$P\_ME_{N2O}OU_{\mathrm{lg\_PC}}$				0.00			0(0)	
		granule cover	$P\_ME_{N2O}OU_{\mathrm{lg\_GC}}$	2.62~2.80	2.71	0.09	2.71	NA[b]	0.18	1(2)	104
		cooling	$P\_ME_{N2O}OU_{\mathrm{lg\_CL}}$							0(0)	
		acid additive	$P\_ME_{N2O}OU_{\mathrm{lg\_AC}}$							0(0)	
	Solid	**Stockpile**									
		Cover	$P\_ME_{N2O}OU_{\mathrm{sp\_AD}}$				-0.99	NA		1(1)	38
		Compost									
		Additive	$P\_ME_{N2O}OU_{\mathrm{cm\_AD}}$	(-0.94)~(-0.09)	-0.45	0.09776	-0.32	0.660	0.003	4(11)	48-50, 111
		Cover	$P\_ME_{N2O}OU_{\mathrm{cm\_CV}}$	(-0.39)~(0.19)	-0.1233	0.08445	-0.16	0.348	0.173	2(6)	32, 33
Land application		**For rice paddy**									
		Without manure vs. manure	$P\_ME_{N2O}LA_{\mathrm{no\ manure}}$	(-0.77)~5.12	0.598	0.5993	-0.23	1.169	0.575	8(10)	64, 65, 115-120
		For upland									
		Slurry injection	$P\_ME_{N2O}LA_{\mathrm{l\_INJ}}$	(-0.34)~10.00	2.05	0.72346	0.84	2.820	0.003	6(15)	78-80, 83, 88, 122
		Slurry incorporation	$P\_ME_{N2O}LA_{\mathrm{l\_INC}}$	(-0.11)~0.49	0.18	0.12689	0.17	0.490	0.273	3(4)	79, 85, 122
		Solid incorporation	$P\_ME_{N2O}LA_{\mathrm{s\_INC}}$	(-0.83)~45.71	4.196	4.164	-0.31	2.330	0.79	2(11)	53, 76
		Digested slurry	$P\_ME_{N2O}LA_{digestate}$	(-0.71)~2.33	-0.0484	0.11252	-0.25	0.608	0.158	8(32)	84, 86, 89, 93. 123-126
		NI addition	$P\_ME_{N2O}LA_{\mathrm{NI}}$	(-0.83)~0.34	-0.3333	0.10267	-0.28	0.590	0.016	5(12)	83, 123, 125, 127, 128

[a] IQR = Interquartile range; [b] NA = not applicable

Table S8. Meta-analysis results of changes of NH_3 emissions under different mitigation measures at their corresponding phase of manure management (these data also appear in the MitigationEffect tab in Dataset S1; see dynamic links to other tabs that present the raw data in Dataset S1).

		Mitigation option	Parameter	Min-Max	Mean	SE	Median	IQR[a]	P value	N	Reference
In-house		low crude protein diet	$P\_ME_{NH3}IN_{\mathrm{LCP}}$	(-0.62)~(-0.23)	-0.3878	0.04867	-0.30	0.255	0.008	6(9)	10, 96-99, 129
		feed additive	$P\_ME_{NH3}IN_{\mathrm{FA}}$	(-0.510~(-0.10)	-0.3467	0.12548	-0.43	NA[b]	0.109	1(3)	97
		biofiltration	$P\_ME_{NH3}IN_{\mathrm{BF}}$	(-0.86)~0.01	-0.6343	0.07497	-0.72	0.240	0.001	4(14)	101-103, 130
Outdoor	Liquid	straw cover	$P\_ME_{NH3}OU_{\mathrm{lg\_SC}}$	(-0.89)~0.00	-0.5923	0.08433	-0.75	0.520	0.002	4(13)	43, 104, 105, 131
		oil cover	$P\_ME_{NH3}OU_{\mathrm{lg\_OC}}$	(-1.00)~(-0.50)	-0.816	0.08606	-0.85	0.315	0.043	3(5)	105, 131, 132
		plastic cover	$P\_ME_{NH3}OU_{\mathrm{lg\_PC}}$	(-1.00)~(-0.74)	-0.946	0.05154	-1.00	0.135	0.039	3(5)	131-133
		granule cover	$P\_ME_{NH3}OU_{\mathrm{lg\_GC}}$	(-1.00)~(-0.17)	-0.8029	0.05298	-0.87	0.265	0.000	5(17)	104, 105, 131, 132, 134
		cooling	$P\_ME_{NH3}OU_{\mathrm{lg\_CL}}$				-0.60	NA		1(1)	108
		acid additive	$P\_ME_{NH3}OU_{\mathrm{lg\_AC}}$	(-0.84)~0.00	-0.54	0.09356	-0.56	0.330	0.018	4(8)	109, 110, 135, 136
	Solid	**Stockpile**									
		Cover					-0.12	NA		1(1)	38
		Compost									
		Additive	$P\_ME_{NH3}OU_{\mathrm{cm\_AD}}$	(-0.92)~0.86	-0.3675	0.14131	-0.42	0.390	0.028	4(11)	48, 50, 111, 137
		Cover	$P\_ME_{NH3}OU_{\mathrm{cm\_CV}}$	(-0.35)~(-0.03)	-0.16	0.04442	-0.14	0.155	0.028	2(6)	32, 33
Land application		**For rice paddy**									
		Without manure vs. manure	$P\_ME_{NH3}LA_{no\ manure}$							0(0)	
		For upland									
		Slurry injection	$P\_ME_{NH3}LA_{\mathrm{l\_INJ}}$	(-0.99)~(-0.70)	-0.936	0.02077	-0.99	0.069	0.001	5(15)	69, 72, 83, 138, 139
		Slurry incorporation	$P\_ME_{NH3}LA_{\mathrm{l\_INC}}$	(-0.90)~(-0.33)	-0.613	0.03656	-0.67	0.263	0.000	2(20)	69, 73

	Solid incorporation	$P\_ME_{NH3}LA_{\mathrm{s\_INC}}$	(-0.94)~(-0.44)	-0.788	0.0618	-0.85	0.258	0.012	1(8)	76
	Digested slurry	$P\_ME_{NH3}LA_{\mathrm{digestate}}$	(-0.44)~(0.67)	0.119	0.23103	-0.06	1.002	0.686	2(5)	84, 140
	NI addition	$P\_ME_{NH3}LA_{\mathrm{NI}}$	(-0.17)~(0.00)	-0.045	0.04173	-0.01	0.130	0.18	4(4)	83, 127, 128, 141

[a] IQR = Interquartile range; [b] NA = not applicable

Table S9. Meta-analysis result of the response ratio of N excreta because of dietary CP reduction (these data also appear in the NExcretaResult tab in Dataset S1; see dynamic links to other tabs that present the raw data in Dataset S1).

.	Parameter	range	mean(se)	median	IQR[a]	P value	N	Reference
N excreta change ratio	$P\_Ratio_{Nex\_lowCP}$	-0.27~0.03	-0.153(0.023)	-0.170	0.165	0.001	6 (16)	99, 129, 142-145

[a] IQR = Interquartile range

Table S10. Parameters used in calculation

Item	Meaning	Value	Reference
P_N_{ex}	N excreta of swine per AU per year	94.9	146
P_VS_{ex}	VS excreta of swine per AU per year	1551.25	146
P_Manure_{ex}	Total manure excreta of swine per AU per year	15650	146
P_B_0	maximum methane producing capacity for swine manure	0.45 m^3 CH_4 kg^{-1} VS	2
P_MCF_{bg}	methane conversion factors for biogas leakage	10%	2
0.67	conversion factor of m^3 CH_4 to kilograms CH_4		2
P_MCF_{pit}	methane conversion factors for pit	42%	2
$P\_Frac_{deg}BG_{VS}$	VS degradation ratio in biogas digester	80%	147
$P\_Frac_{\mathrm{loss}}BG_N$	N loss ratio in biogas digester	0%	148

Table S11. Meta-analysis result of the ratio of NH_3-N loss to TN loss for different manure management (these data also appear in the NLossRatio tab in Dataset S1; see dynamic links to other tabs that present the raw data in Dataset S1).

Management option	Parameter	range	mean(se)	median	IQR[a]	N	Reference
Stockpile	$P\_Frac\_sp\frac{NH3\_Nloss}{TNloss}$	0.42~0.48	0.4500(0.02900)	0.45	NA[b]	1(2)	61
Compost	$P\_Frac\_cm\frac{NH3\_Nloss}{TNloss}$	0.24~0.93	0.7250(0.03358)	0.71	0.19	4(22)	32, 33, 35, 48
Lagoon	$P\_Frac\_lg\frac{NH3\_Nloss}{TNloss}$	0.41~0.84	0.6238(0.06529)	0.6408	0.2906	1(6)	149

[a] IQR = Interquartile range; [b] NA = not applicable

Table S12. Meta-analysis result of CH_4 and NH_3 emission factors for biogas digestate stored in lagoon (these data also appear in the EmissionOfDigestate tab in Dataset S1; see dynamic links to other tabs that present the raw data in Dataset S1).

Emission factors	Parameter	Range	Mean (se)	Median	IQR[a]	N	Reference
NH_3-N/TN (kg NH_3-N kg TN^{-1})	$P\_EF_{NH3}OU_{\mathrm{lg}\_digestat}$	4.30~33.00	16.90(4.95)	0.16	0.212	1(6)	149
CH_4 emission factor (kg CH_4 kg VS^{-1})	$P\_EF_{CH4}OU_{\mathrm{lg}\_digestat}$	0.00~0.01	0.0056(0.0022)	0.0045	0.01	1(6)	

[a]IQR = Interquartile range

SI figures

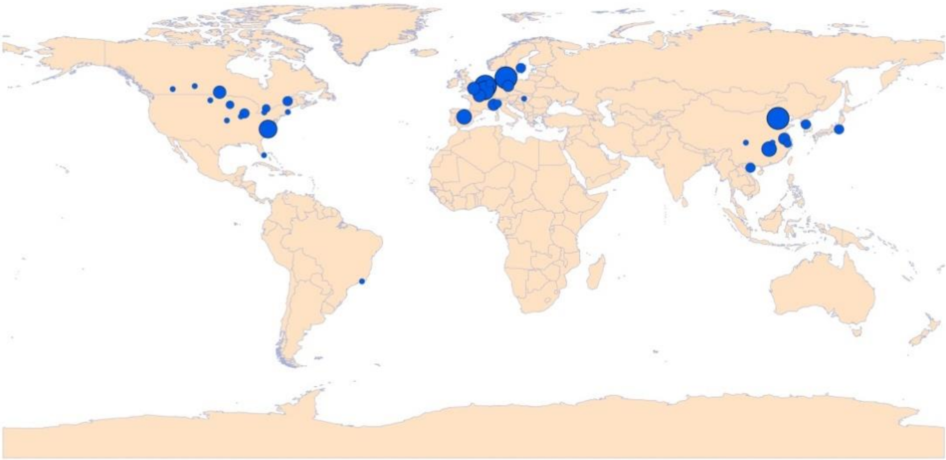
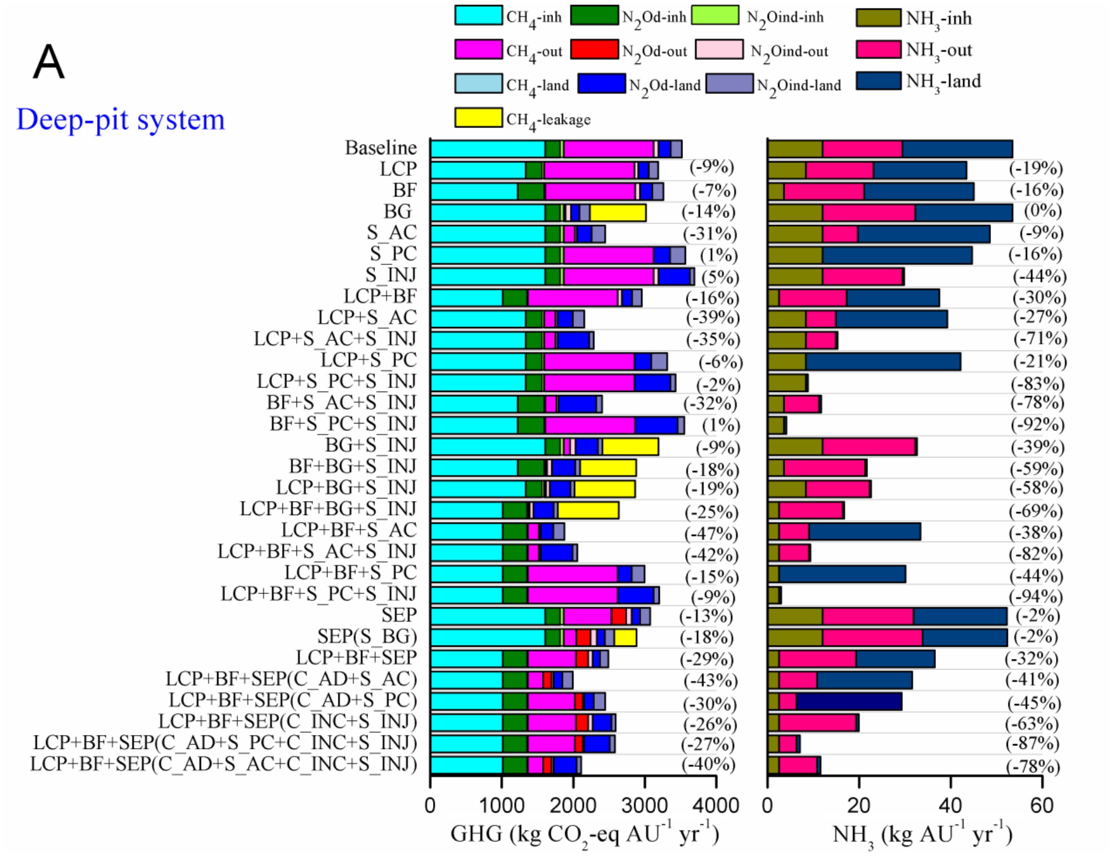
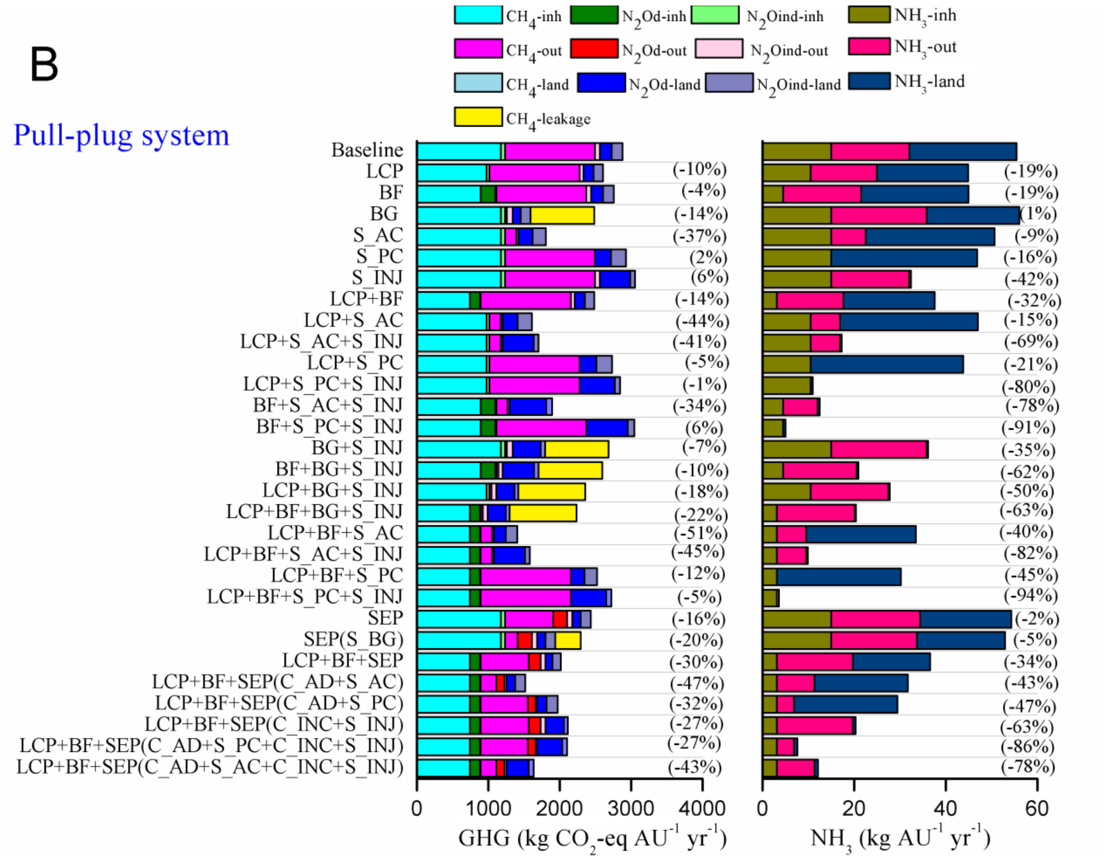
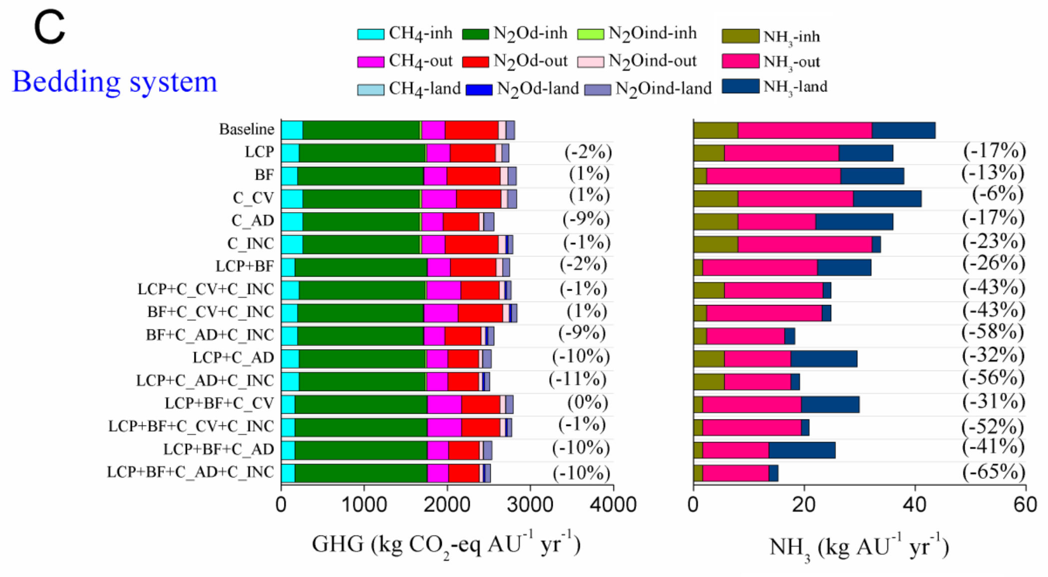


Figure S1. The location and distribution of the literature sources used in this study (Larger circles means more literatures available in the specific region).




B
Pull-plug system
CH_4-inh
N_2Od-inh
N_2Oind-inh
NH_3-inh
CH_4-out
N_2Od-out
N_2Oind-out
NH_3-out
CH_4-land
N_2Od-land
N_2Oind-land
NH_3-land
CH_4-leakage
Baseline
LCP (-10%) (-19%)
BF (-4%) (-19%)
BG (-14%) (1%)
S_AC (-37%) (-9%)
S_PC (2%) (-16%)
S_INJ (6%) (-42%)
LCP+BF (-14%) (-32%)
LCP+S_AC (-44%) (-15%)
LCP+S_AC+S_INJ (-41%) (-69%)
LCP+S_PC (-5%) (-21%)
LCP+S_PC+S_INJ (-1%) (-80%)
BF+S_AC+S_INJ (-34%) (-78%)
BF+S_PC+S_INJ (6%) (-91%)
BG+S_INJ (-7%) (-35%)
BF+BG+S_INJ (-10%) (-62%)
LCP+BG+S_INJ (-18%) (-50%)
LCP+BF+BG+S_INJ (-22%) (-63%)
LCP+BF+S_AC (-51%) (-40%)
LCP+BF+S_AC+S_INJ (-45%) (-82%)
LCP+BF+S_PC (-12%) (-45%)
LCP+BF+S_PC+S_INJ (-5%) (-94%)
SEP (-16%) (-2%)
SEP(S_BG) (-20%) (-5%)
LCP+BF+SEP (-30%) (-34%)
LCP+BF+SEP(C_AD+S_AC) (-47%) (-43%)
LCP+BF+SEP(C_AD+S_PC) (-32%) (-47%)
LCP+BF+SEP(C_INC+S_INJ) (-27%) (-63%)
LCP+BF+SEP(C_AD+S_PC+C_INC+S_INJ) (-27%) (-86%)
LCP+BF+SEP(C_AD+S_AC+C_INC+S_INJ) (-43%) (-78%)
0 1000 2000 3000 4000
GHG (kg CO_2-eq AU^{-1} yr^{-1})
0 20 40 60
NH_3 (kg AU^{-1} yr^{-1})


C
Bedding system
CH_4-inh
N_2Od-inh
N_2Oind-inh
NH_3-inh
CH_4-out
N_2Od-out
N_2Oind-out
NH_3-out
CH_4-land
N_2Od-land
N_2Oind-land
NH_3-land
Baseline
LCP (-2%) (-17%)
BF (1%) (-13%)
C_CV (1%) (-6%)
C_AD (-9%) (-17%)
C_INC (-1%) (-23%)
LCP+BF (-2%) (-26%)
LCP+C_CV+C_INC (-1%) (-43%)
BF+C_CV+C_INC (1%) (-43%)
BF+C_AD+C_INC (-9%) (-58%)
LCP+C_AD (-10%) (-32%)
LCP+C_AD+C_INC (-11%) (-56%)
LCP+BF+C_CV (0%) (-31%)
LCP+BF+C_CV+C_INC (-1%) (-52%)
LCP+BF+C_AD (-10%) (-41%)
LCP+BF+C_AD+C_INC (-10%) (-65%)
0 1000 2000 3000 4000
GHG (kg CO_2-eq AU^{-1} yr^{-1})
0 20 40 60
NH_3 (kg AU^{-1} yr^{-1})

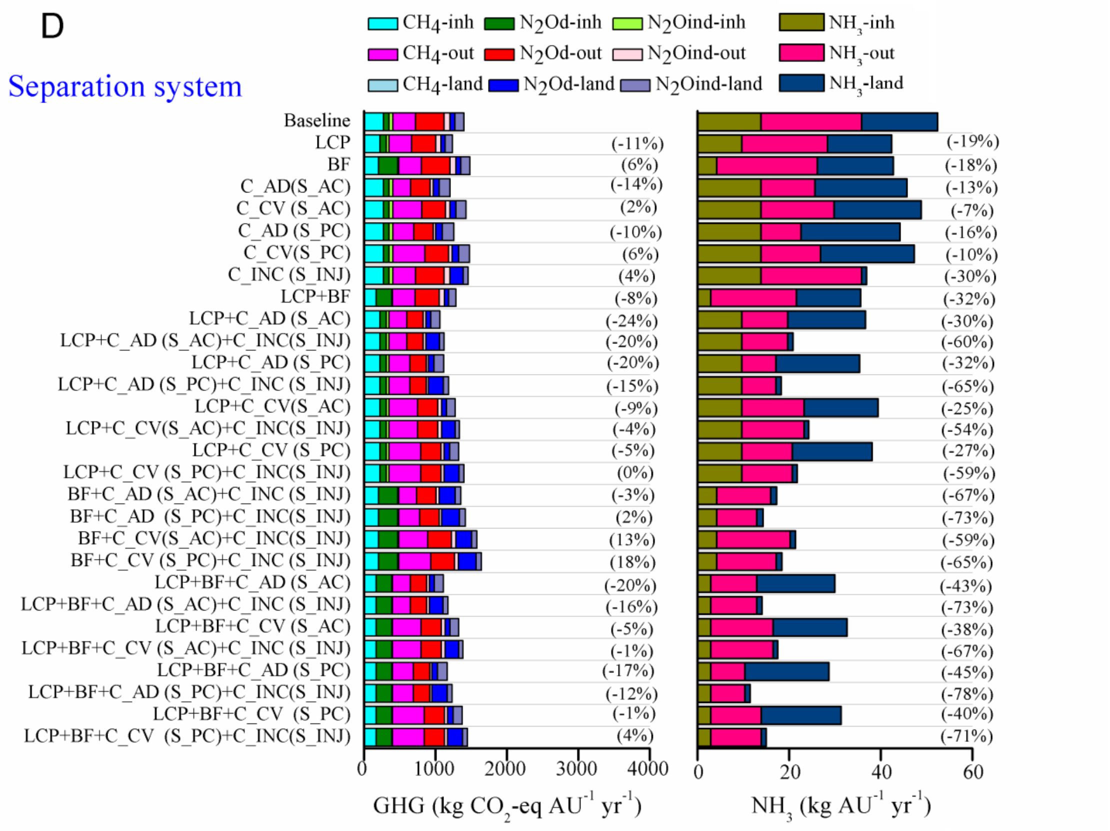


Figure S2. GHG and NH_3 emissions in baseline and mitigation scenarios for each system; the numbers in parentheses indicate the mitigation efficiency: Deep-pit system (A), Pull-plug system (B), Bedding system (C), Separation system (D). N_2Od=direct N_2O emission; N_2Oind=indirect N_2O emission; in=in-house; out=outdoor; land=land application; LCP=low crude protein; BF=biofilter; BG = biogas; S_AC=slurry acidification; SEP=outdoor separation; S_BG = separated slurry for biogas fermentation; C_AD=compost additive; C_INC=compost incorporation; S_PC=slurry plastic cover; S_INJ=slurry injection; C_CV=compost cover; C_AD=compost additive; C_INC=compost incorporation; AU=animal unit (1AU= 500kg).

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