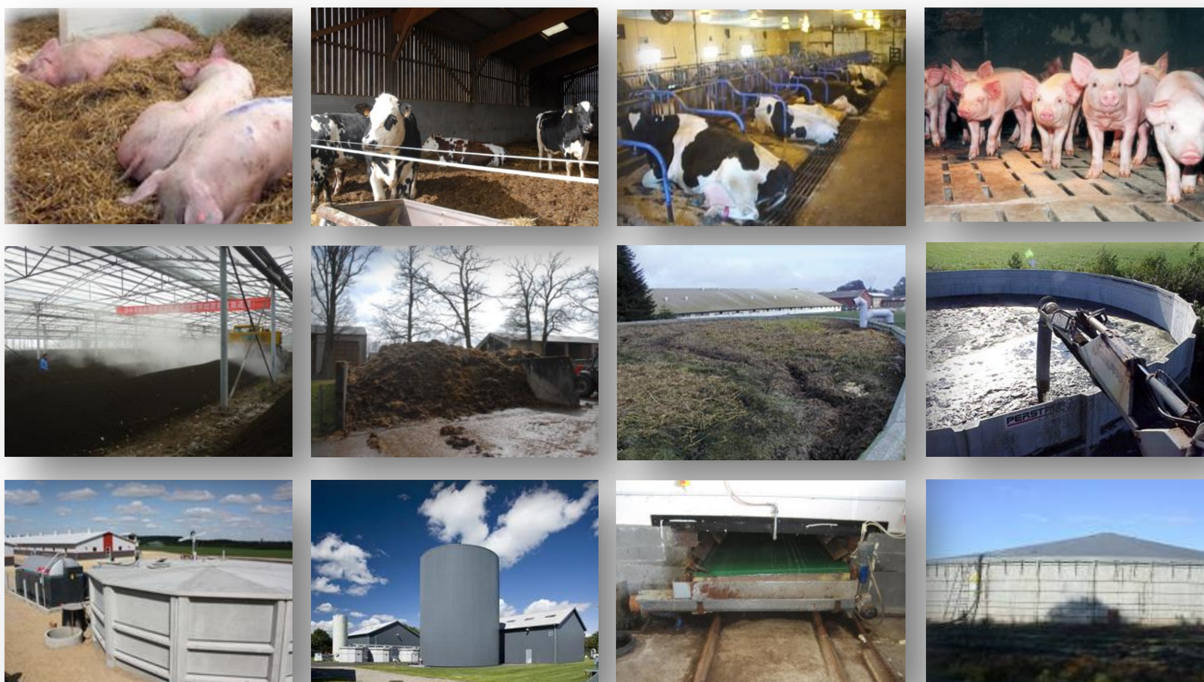
Predicting methane emissions from manure management

Søren O. Petersen, Aarhus University, DK



AARHUS UNIVERSITY

On-farm GHG emissions

CH_4 from manure management

	Enteric fermentation	Manure management	% from MM
Total	85.63	17.52	17
Selected regions:			
Central and South America	21.17	1.41	6
India	11.82	0.95	7
China	8.85	3.84	30
Eastern Europe, CIS	5.66	1.38	20
North America	5.05	3.39	40
Western Europe	5.7	4.08	42

(Steinfeld et al., 2006)

Brazil: confined livestock production

Table 4. Number of heads of swine and confined cattle. Brazil and Southern Region: 2006

Region and States	Swine		Confined Cattle	
	Number of establishments	Number of heads	Number of establishments	Confined animals
Brazil	1,496,107	31,189,339	20,864	4,049,210
Southern Region	451,870	16,750,420	5,750	603,153
Paraná	135,477	4,569,275	2,633	366,577
Santa Catarina	82,324	6,569,714	1,299	77,104
Rio Grande do Sul	234,069	5,611,431	1,818	159,472

Source. IBGE (2007)

31 million swine
4 million cattle

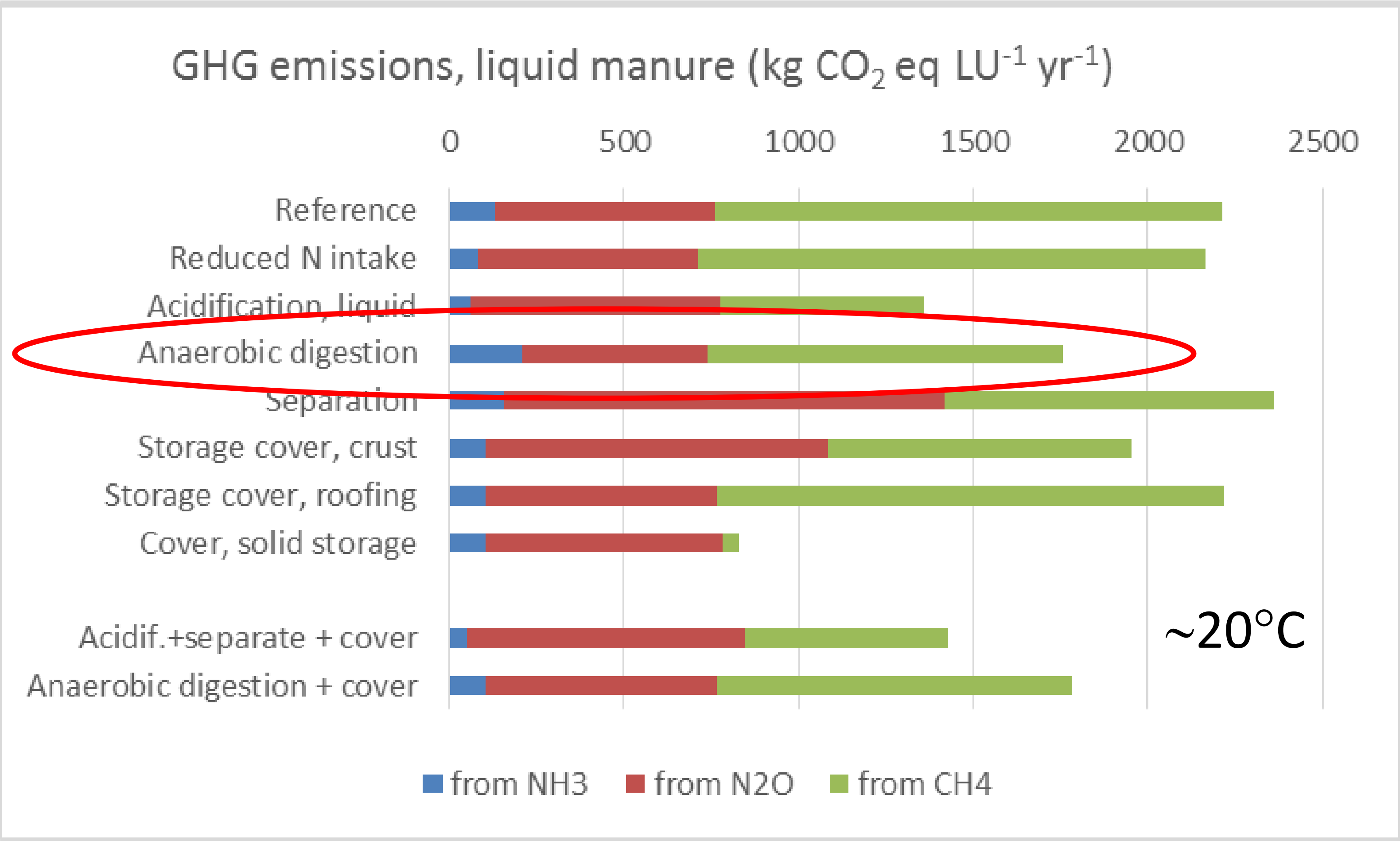
Brazil: manure management practices

Table 3. Treatment of manure per establishment. Brazil and Southern Region, 2006.

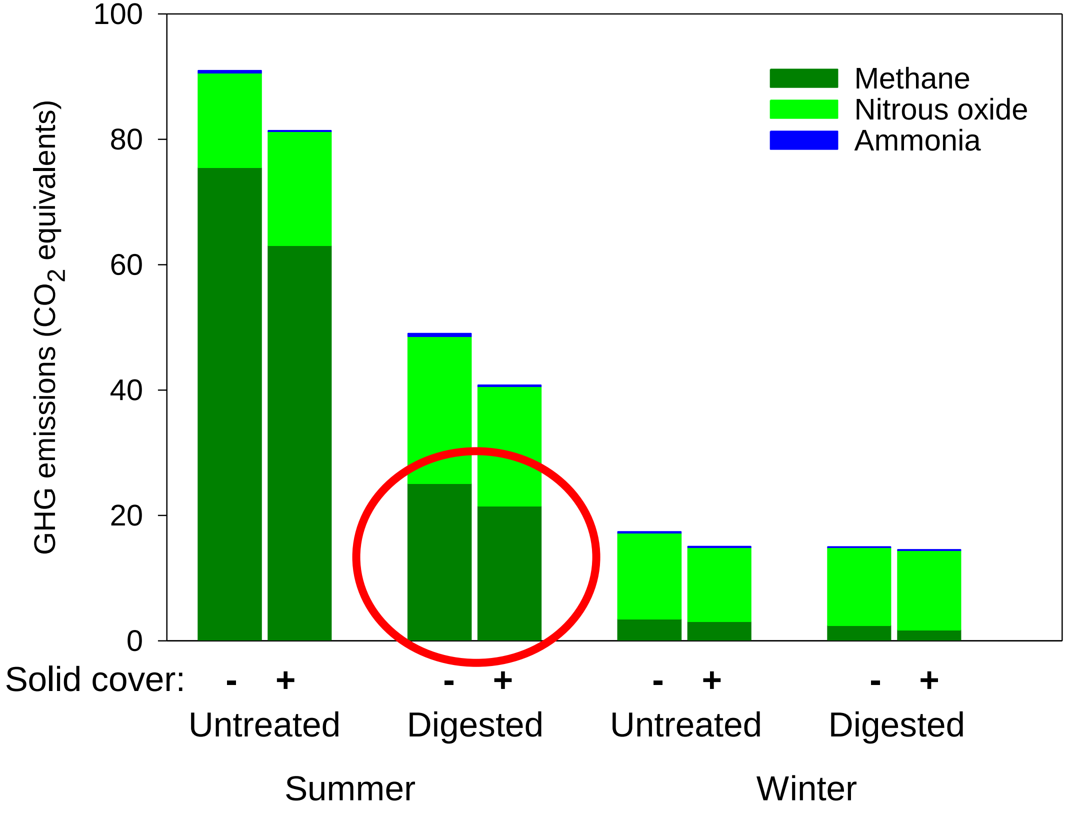
Brazil and Southern Region	Total properties	Treatment in anaerobic lagoon	Treatment in open tanks	Treatment in bio-digester	Treatment with composting	Treatment elsewhere
Brazil	*5,175,489*	*3,269*	*131,232*	*2,387*	*31,849*	*27,197*
Southern Region	*1,006,181*	*1,618*	*82,609*	*1,223*	*21,379*	*7,877*
Paraná	371,051	490	13,036	393	6,271	3,043
Santa Catarina	193,663	529	28,016	490	7,823	1,478
Rio Grande do Sul	441,467	599	41,557	340	7,285	3,356

Source. IBGE, Agricultural and Livestock Census 2006.

Importance of CH_4 for GHG mitigation

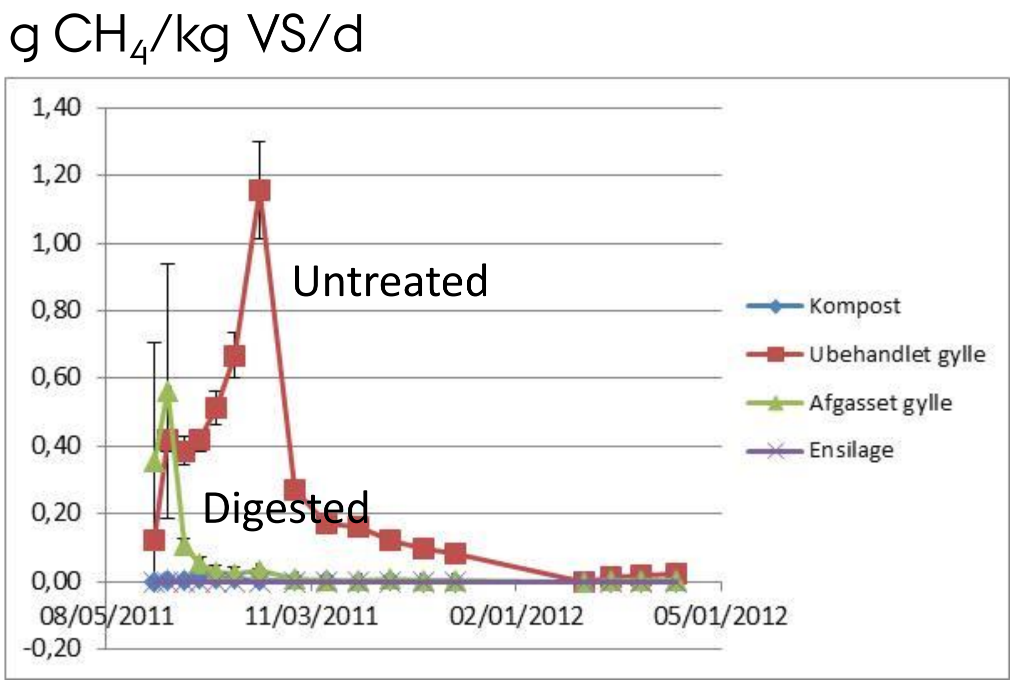


AD reduces CH_4 emission during storage

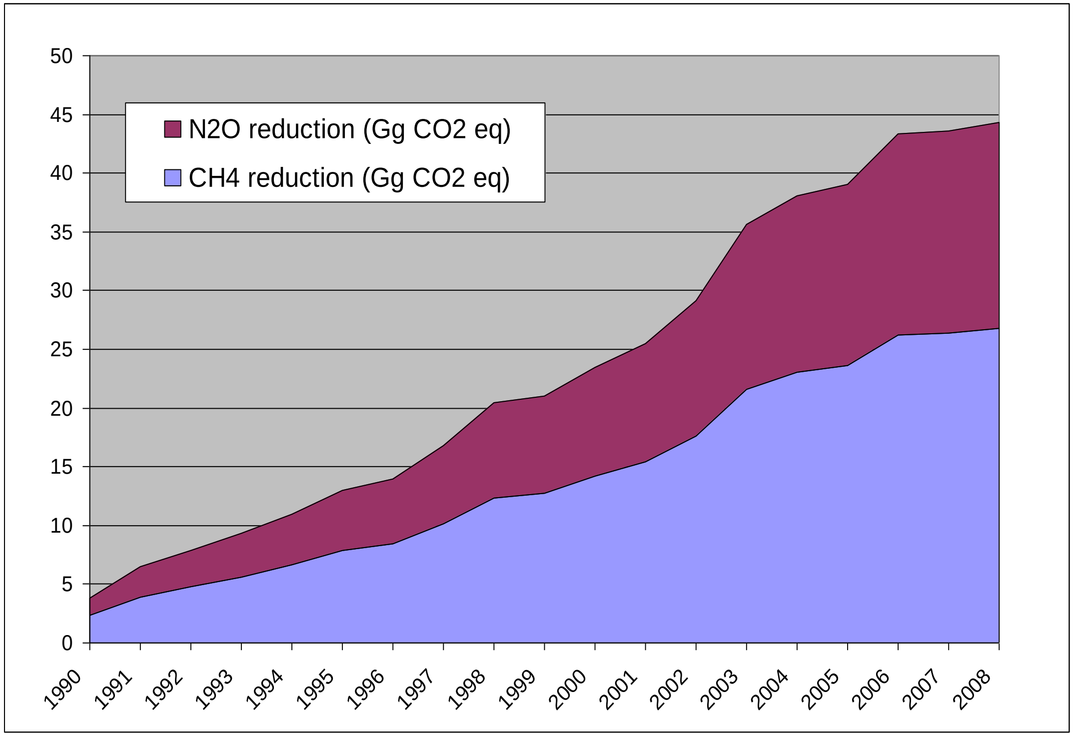


(Clemens et al., 2006)

AD reduces CH_4 emission during storage



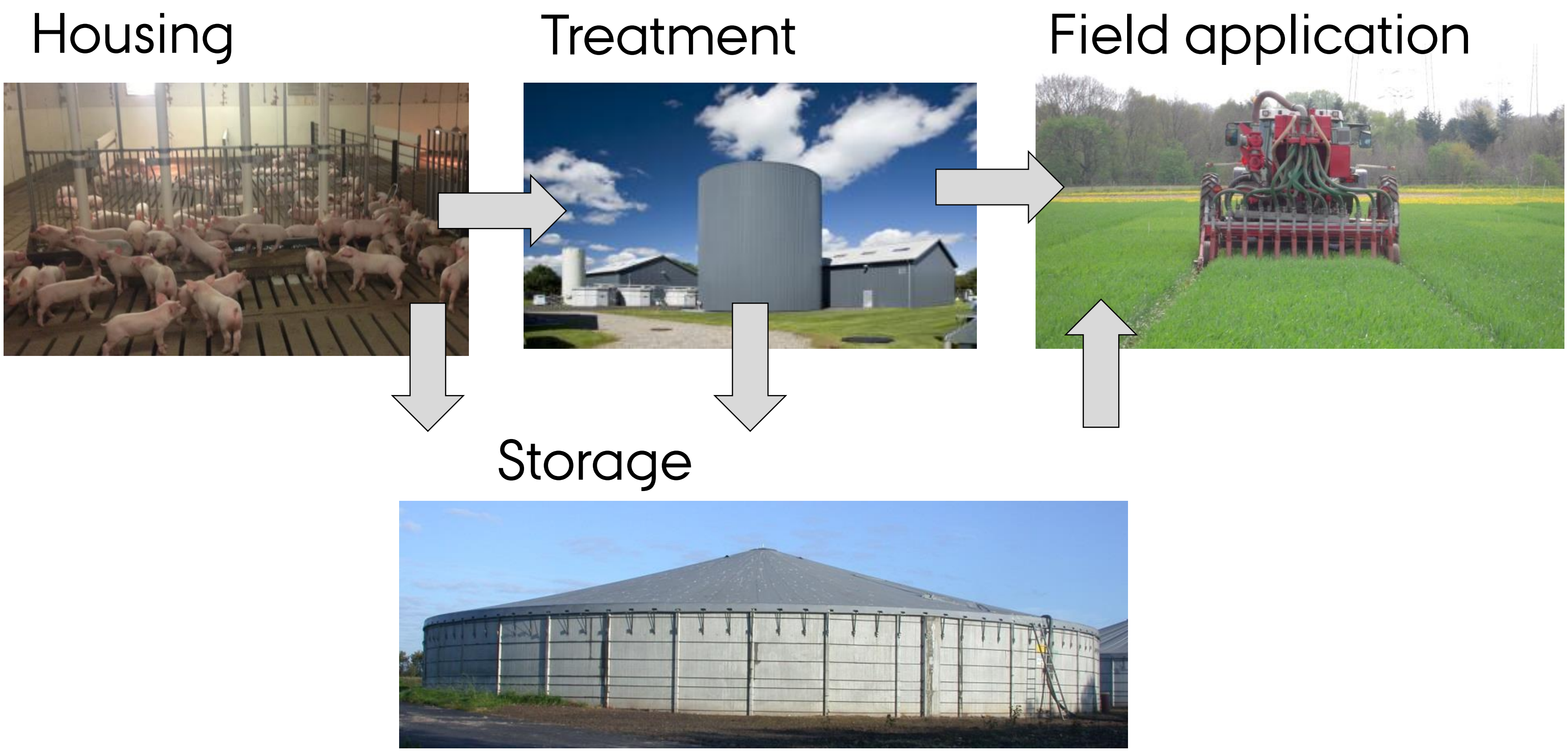
GHG reduction by AD 1990-2008



- Calculations based on results with empirical model
- Lack of validation
- Lack of information about upstream emissions

AD reduces CH_4 emission during storage

Emissions of CH_4 from housing (slurry pits)?



Predicting CH_4 emission during slurry storage

Requirements for simulation model

A simulation model should:

- simulate important processes that affect CH_4 emissions with changes in farm management;
- provide process-level representation of major emission components;
- satisfactorily predict observed data for all realistic storage conditions;
- Model inputs and parameters limited to readily available data.

Nutrient Cycling in Agroecosystems **69:** 143–154, 2004.

Algorithms for calculating methane and nitrous oxide emissions from manure management

S.G. Sommer[1,*], S.O. Petersen[2] and H.B. Møller[1]

Algorithms for calculating methane and nitrous oxide emissions from manure management

Approach: quantify CH_4 emissions on daily basis based on the composition of excreted VS as modified by temperature

$$F(t) = (VS_d + 0.01 \times VS_{nd}) \times \exp(\ln A - E_a/RT)$$

Two VS pools of volatile solids (VS)

- degradable VS (VS_d)
- ”non-degradable” VS (VS_{nd})

Temperature response of CH_4 production expressed *via* Arrhenius relationship

Predicting CH_4 emission during slurry storage

Estimation of VS_d and VS_{nd}

$$\frac{VS_d}{VS} = \frac{B_0}{CH_{4,potential}}$$

$$VS_{d,i} = \Delta CO_2\text{-}C_i \,/\, TOC_i$$

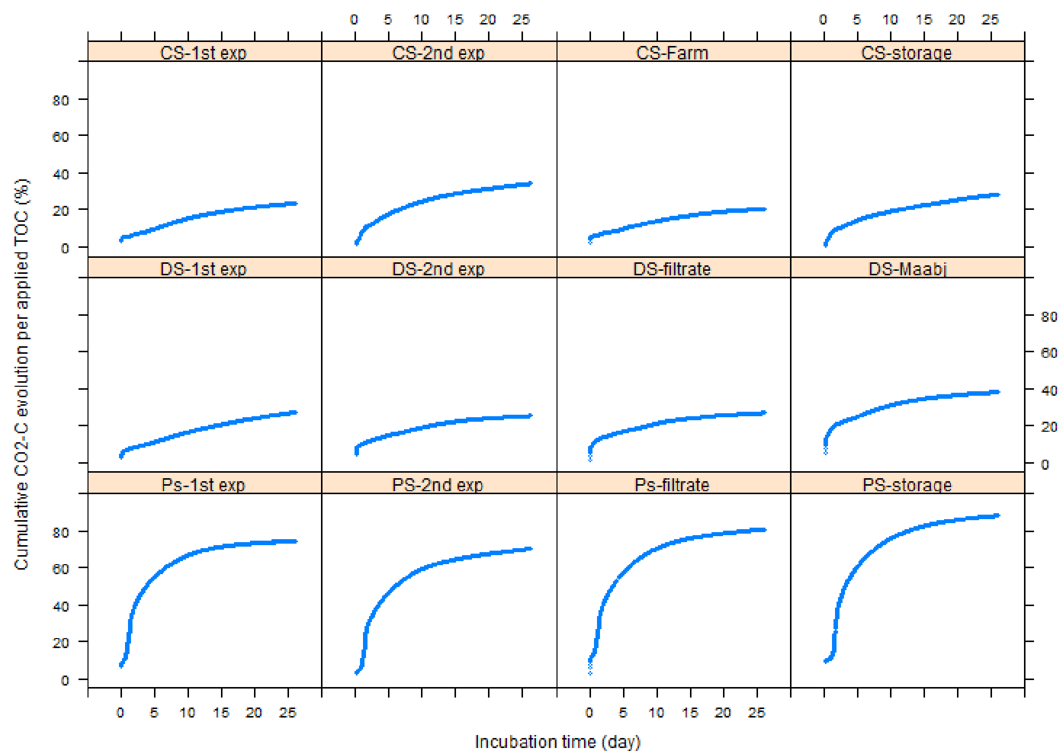
Sommer et al., 2004;
based on excreta characteristics

Alternative approach;
based on manure sample

Cattle slurries

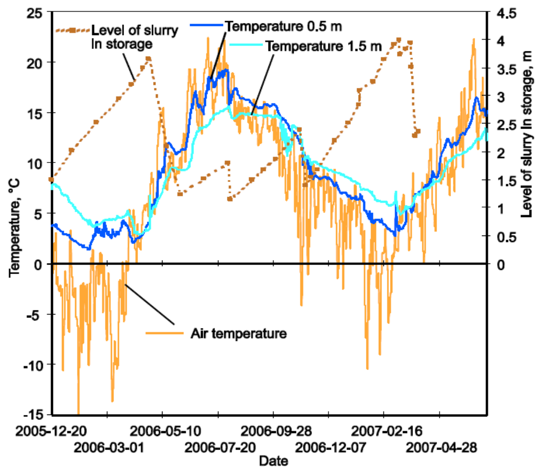
Digestates

Pig slurries



Predicting CH_4 emission during slurry storage

Empirical model of daily emissions



(Rodhe et al., 2009)

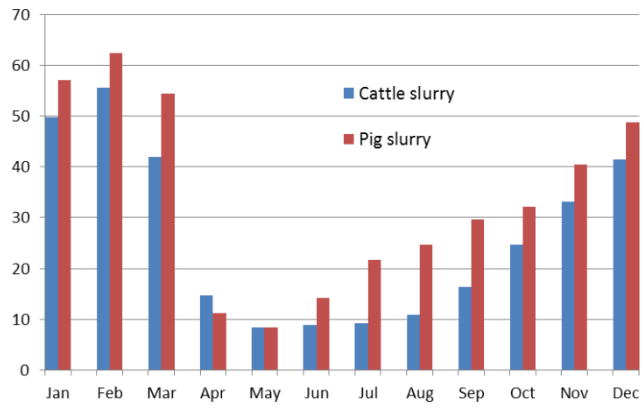


Table 3. Parameters for calculating CH_4 emissions from cattle and pig slurry by use of Equation 4.

Parameters		Cattle	Pig
Arrhenius parameter, store in-house	ln(A)	44.29	44.22
Arrhenius parameter, store outside	ln(A)	43.33	43.21
Activation energy	E	112.7×10^3	112.7×10^3
Gas constant	R	8.314	8.314
Rate correction factor for VS_d	b1	1	1
Rate correction factor for VS_{nd}	b2	0.01	0.01

(Parameters based on literature data or best estimates)

Predicting CH_4 emission during slurry storage

Validation of temperature response

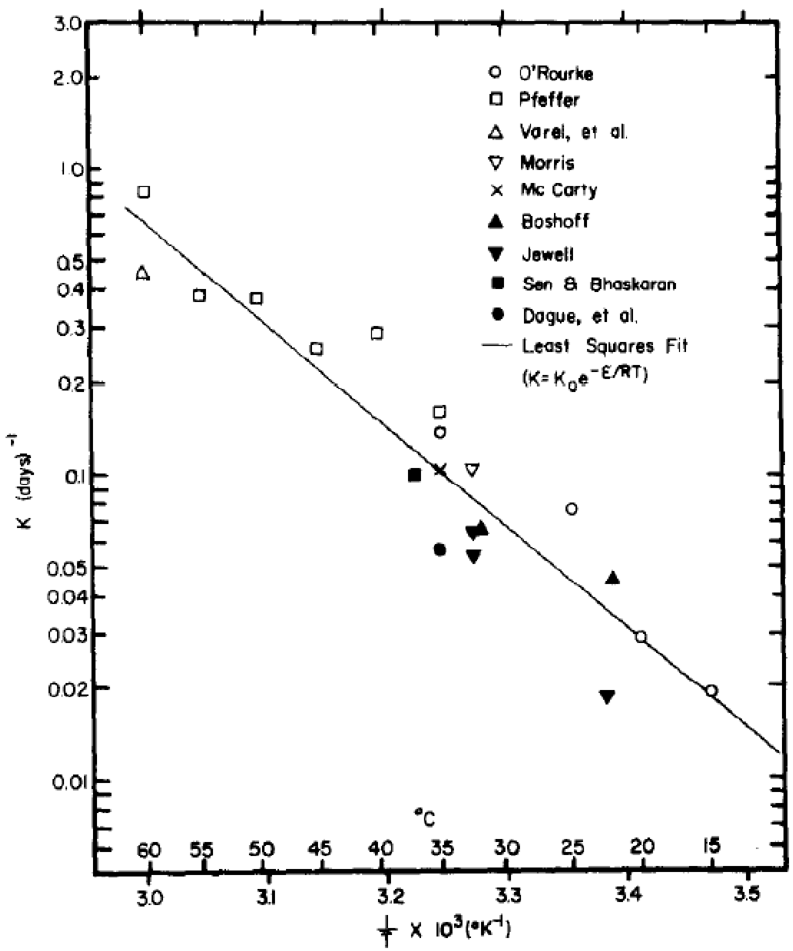


Fig. 4. Rate constant as a function of temperature.

Temperature response function for biowastes based on 9 different studies

(Ashare et al., 1979)

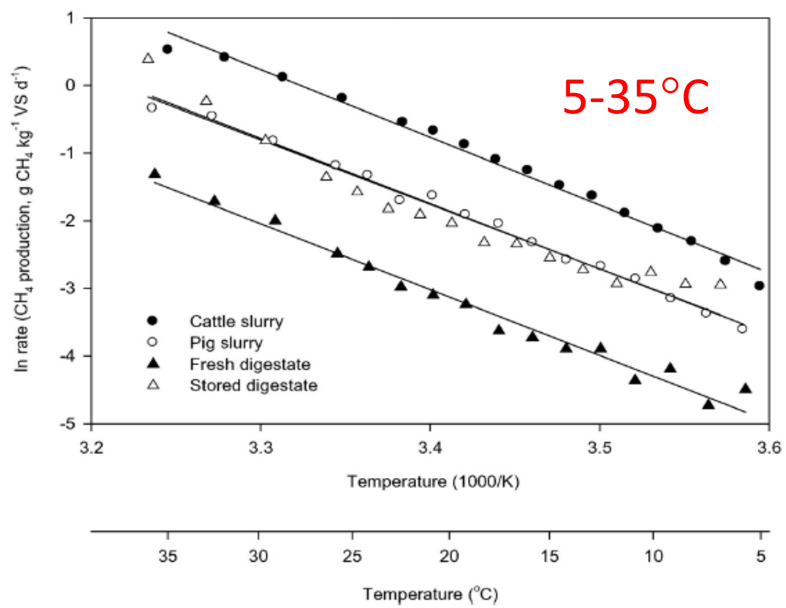
Predicting CH_4 emission during slurry storage

Validation of temperature response

$$F(t) = (VS_d + 0.01 \times VS_{nd}) \times \exp(\ln A - E_a/RT)$$

Temperature gradient block, 20 indiv temperatures between 5 and 52°C

- Cattle slurry, CS
- Pig slurry, PS
- Fresh digestate, FD
- Stored digestate, SD



(Elsgaard et al., 2015)

Predicting CH_4 emission during slurry storage

Validation of temperature response

$$F(t) = (VS_d + 0.01 \times VS_{nd}) \times \exp(\ln A - E_a/RT)$$

Table 3
Arrhenius parameters (activation energy, E_a, and log-transformed frequency factor, ln A) and temperature sensitivity (Q_{10}) of methane production for the four slurry types. The 95% confidence intervals are shown in parentheses. Data were analyzed for similar incubation periods (17 h).

Type	E_a (kJ mol^{-1})	ln A	Q_{10} (5–15 °C)
Cattle slurry	83.3 (78.2–88.4)	33.3 (31.2–35.4)	3.5 (3.2–3.8)
Pig slurry	80.2 (76.5–83.9)	31.1 (29.5–32.6)	3.3 (3.2–3.5)
Fresh digestate	80.9 (74.1–87.7)	30.1 (27.3–32.9)	3.4 (3.0–3.7)
Stored digestate	79.2 (66.7–91.7)	30.6 (25.5–35.8)	3.3 (2.7–3.9)

n.s. *P<0.001*

E_a avg: 80.9 kJ mol^{-1}

(Elsgaard et al., 2015)

Predicting CH_4 emission during slurry storage

Validation of emissions (slurry pits)

$$F(t) = (VS_d + 0.01 \times VS_{nd}) \times \exp(\ln A - E_a/RT)$$

Table 5.1. Overview of farms visited; all farms supplied slurry to Thorsø Biogas Plant.

Animal category	Housing system	Slurry system	Collection for biogas plant (times per week)	No. visits	Slurry samples per visit
Dairy cattle	Cubicles	Ring canal	3	2	1
Dairy cattle	Cubicles	Ring canal	1	2	1
Dairy cattle	Cubicles	Scrapers + backflush	3	2	2
Dairy cattle	Cubicles	Scrapers + backflush	2	2	2
Finishing pigs	Partly slatted	pull-plug	1	1	1
Finishing pigs	Partly slatted	pull-plug	2	2	6
Farrowing sows	Indiv confinement	pull-plug	2	2	6
Farrowing sows	Loose, indiv confinement	pull-plug	2-3	1	5
Piglets	Partly slatted	pull-plug	1	1	1

Management types represent 67% of slurry produced in DK

Subsamples (n = 6) incubated at *in-situ* temperatures within 24 h

Predicting CH_4 emission during slurry storage

Validation of emissions (slurry pits)

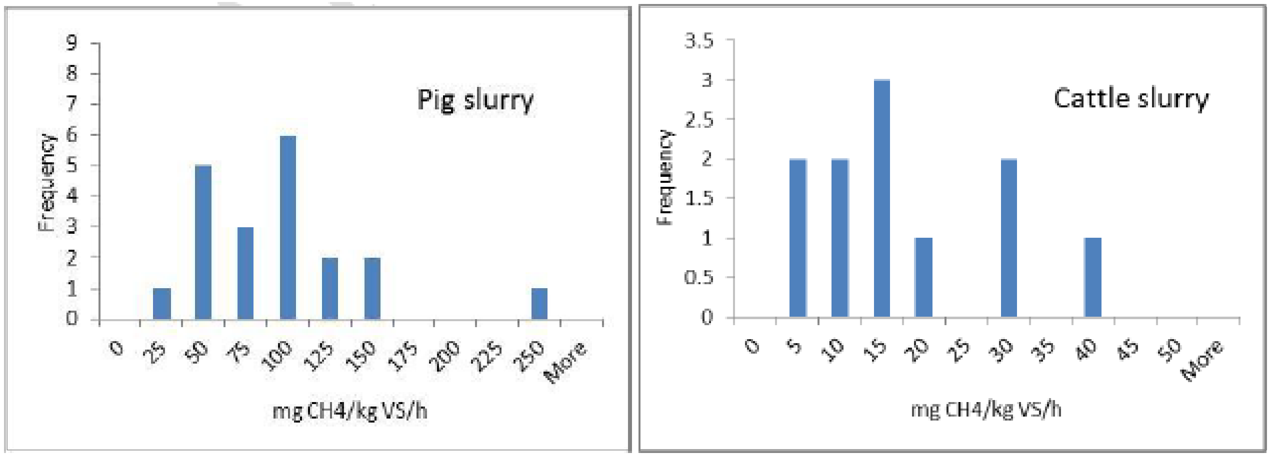
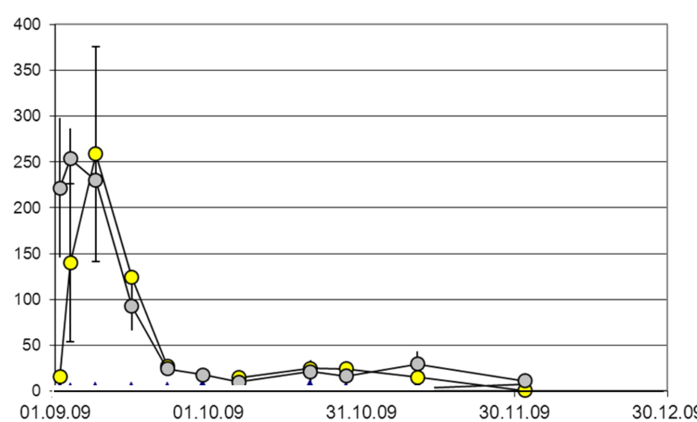


Fig. 5.2. Frequency distribution for observed methane production rates in pig and cattle slurries.

(Example data)

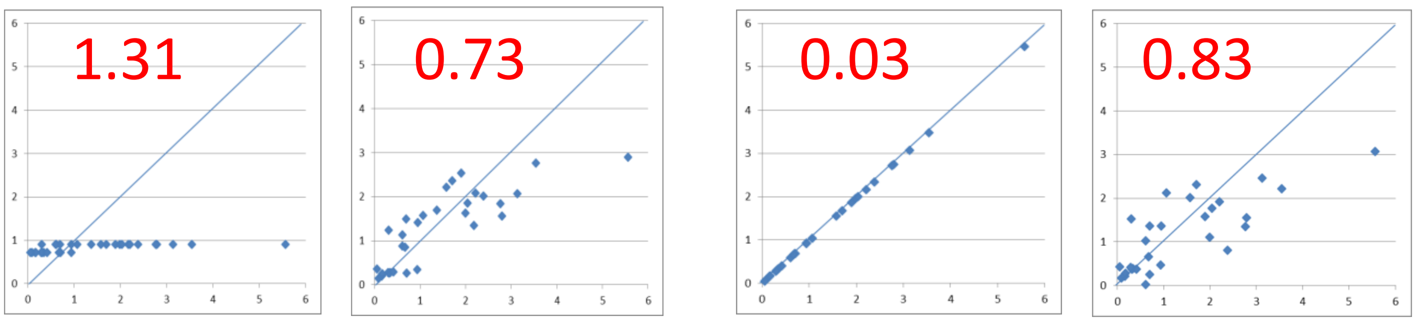
Temporal dynamics of CH_4 emissions from pig slurry



Predicting CH_4 emission during slurry storage

Model vs. observations

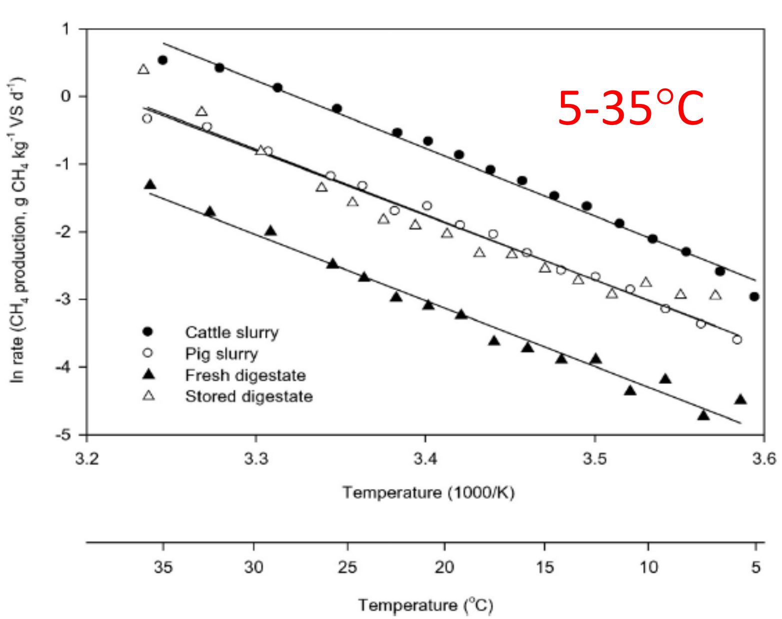
RMSE:



	Sommer et al. (2004)		New study	
VS_d, VS_{nd}	Literature data	Literature data	Observed (indiv)	Obs (avg pig, cattle)
E_a	Literature data	Literature data	Observed (external)	Obs (external)
lnA	Literature data	Literature data	Observed (indiv)	Obs (avg pig, cattle)
Slurry temp.	Literature data	Observed	Observed	Obs

$$Sensitivity\ index = \left(\frac{y_{+5\%} - y_{-5\%}}{x_{+5\%} - x_{-5\%}}\right) \times \left(\frac{x_{ref}}{y_{ref}}\right)$$

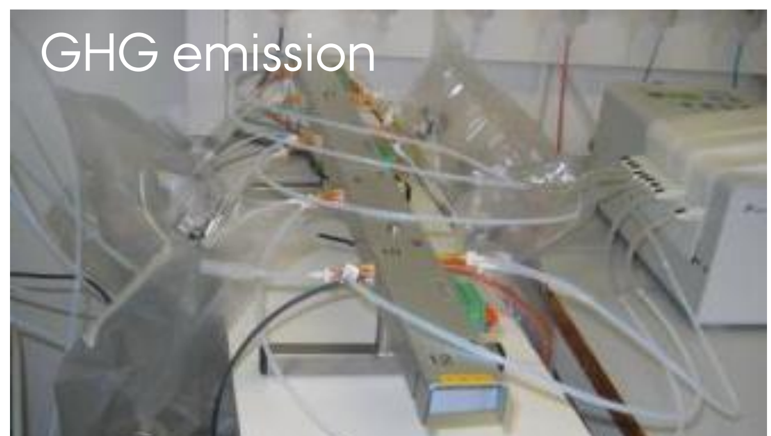
***SI*, ± 5%**	**ln*A***	**VS_d**	**Temperature**
	g CH_4 kg^{-1} VS h^{-1}	kg kg^{-1}	°C
Pig slurry	45.75	0.98	2.25
Cattle slurry	88.89	1.22	2.41



What does ln*A* represent?

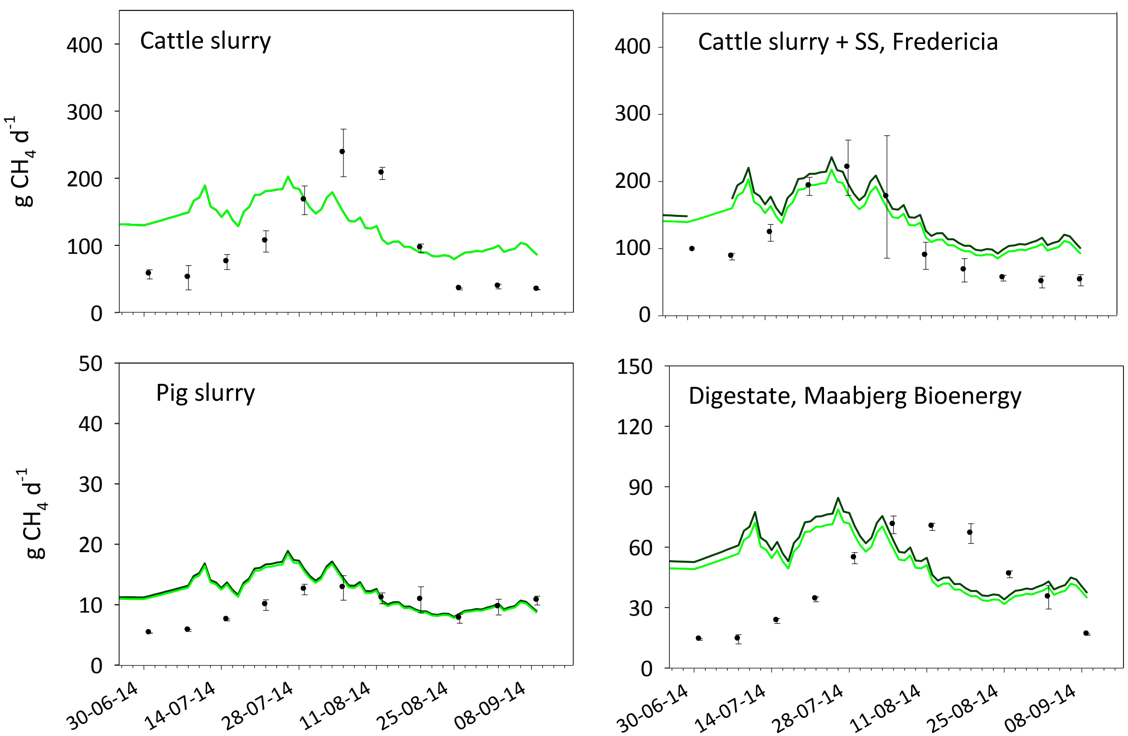
How to quantify ln*A*?

Pilot-scale facility
Ventilated to simulate open-storage conditions



Storage experiment

- Cattle slurry
- Cattle slurry + digested, dewatered sludge
- Pig slurry
- Digestate, centralized biogas facility



Conclusions

- Methane emissions from manure management can be significant, especially in warm climates
- Anaerobic digestion achieves substantial reductions in CH_4 emissions during storage
- Pre-digestion emissions are not accounted for; need for validation of prediction model
- Similar temperature response of methanogenesis independent of slurry type
- Model prediction was not satisfactory, work ongoing