Methane production by ruminants

Dana Olijhoek and Peter Lund
Department of Animal Science
AU-Foulum

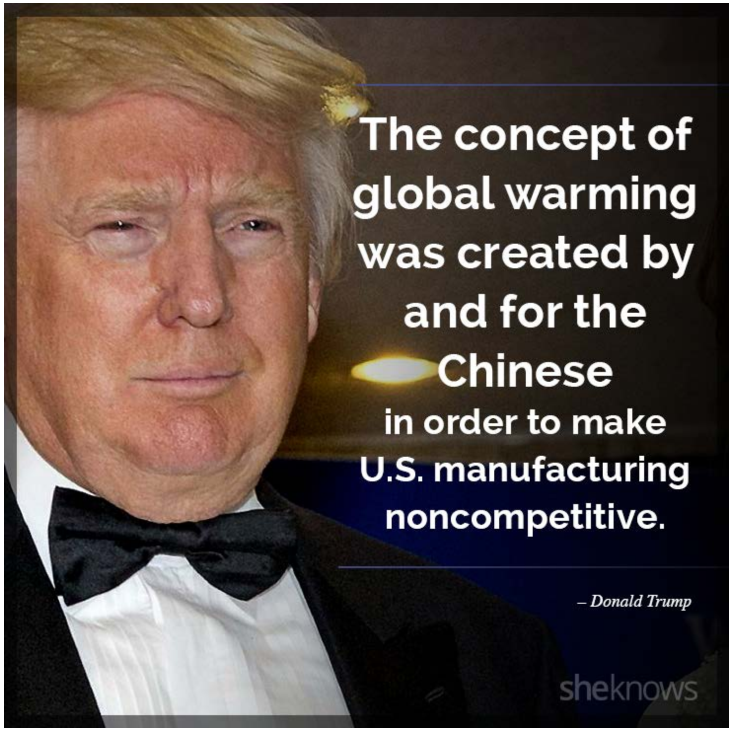
AARHUS
UNIVERSITY

Outline

- Methane emission numbers
- Methanogenesis: why? By who?
- Measurement techniques
- Mitigation strategies

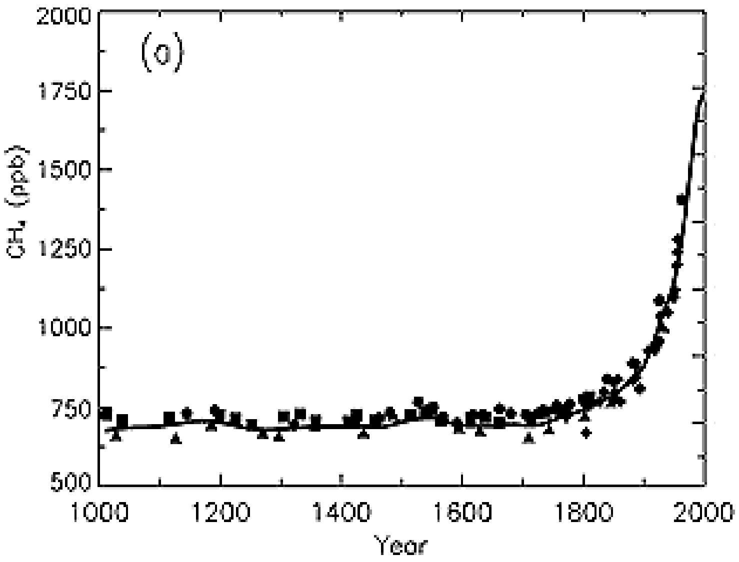
AARHUS
UNIVERSITY

CLIMATE CHANGE ??

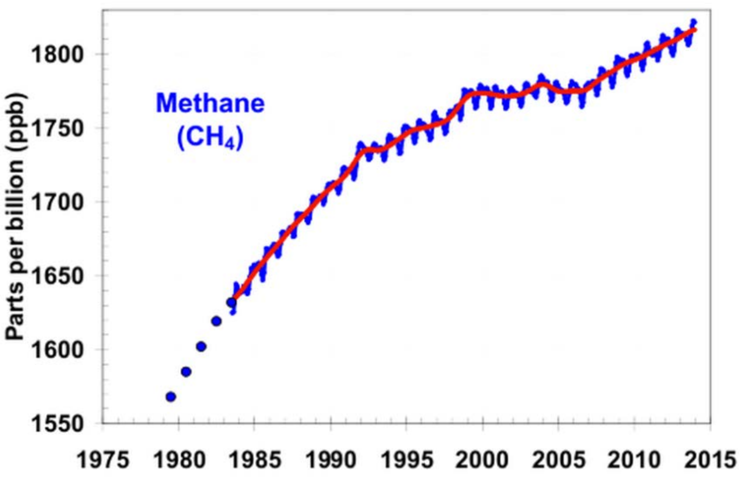


AARHUS
UNIVERSITY

Global methane (CH_4) trends



Increase in world population!



14% of the increase was in only 23 years!!

NO GREENHOUSE GASSES !!

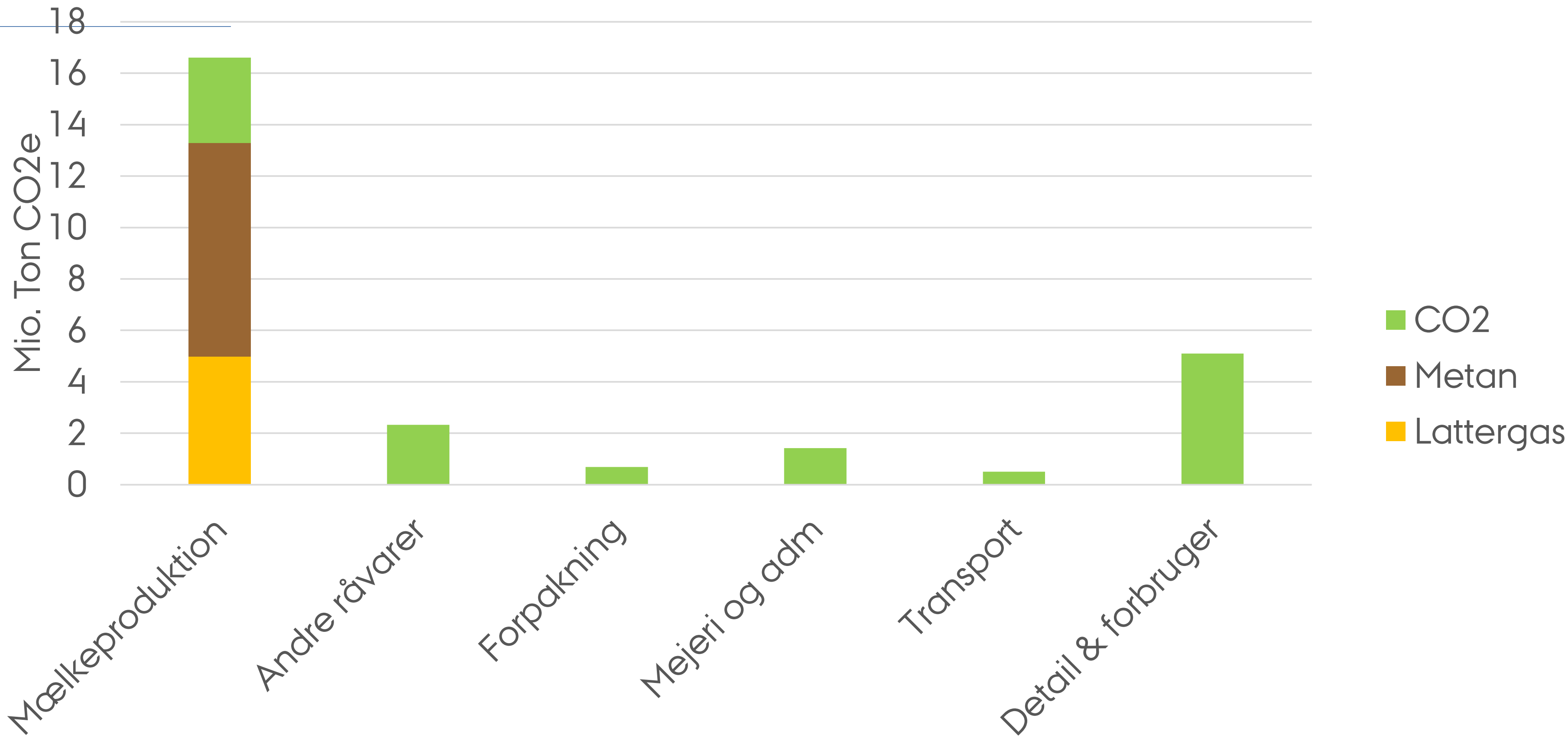
-18 °C

CO_2-EQ

- **1 kg Carbondioxide (CO_2) = 1 kg CO_2-eq.**
  - Fossile fuels
- **1 kg Methane (CH_4) = 25 kg CO_2-eq.**
  - Digestion
  - Manure
- **1 kg Nitrous oxide (N_2O) = 298 kg CO_2-eq.**
  - N metabolism in manure and soil

(100-years timespan, IPCC)

THE COST OF PRODUCING MILK



Bligaard (2017)

COWS AND METHANE IS HOT

Jyllands-Posten

INDBLIK

SØNDAG

SAMFUNDETS FJENDE

viden/miljoe/tang-spisende-kvaeg-boevser-op-til-99-procent-mindre-metan

DR dk | NYHEDER | TV | RADIO | MERE

Nyhedsoverblik | Politik | Sport | Viden | Kultur | Debat | Lev Nu

VIDEN

VIDEN FORSIDE | TECH | KLIMA & MILJØ | NATURVIDENSKAB

20. OKT. 2016 KL. 19.39

Tang-spisende kvæg bøvser op til 99 procent mindre metan

Ny forskning viser, at udledningen af drivhusgasser fra produktion af kvæg kan reduceres drastisk blot ved at tilføje lidt tang til dyrenes menu.

jp.dk | epn.dk | fpn.dk | TV | Mobil | Tjenester |

TIP EN VEN | PRINT VERSION

Annonce:

Danske køer skal prutte og bøvse mindre

Offentliggjort 02.04.08 kl. 07:42

ws Internet Explorer

mark/80402005/

Superfoder skal bekæmpe prutter fr køer

08:49

IKEN.DK

Ingeniøren

Privatlivspolitik

Nyheder | Blogs | Debat | Jobfinder | Avisarkiv | Kursusguide | Events | Insights

TENDENS FREMTIDENS FØDEVARER | KVANTETEKNOLOGI | DINE GODE BAKTERIER | FOKUS FEMERN-FORBINDELSEN | 3D-P

Køer og svin forurener mere end biler

Kødbranchen producerer 18 procent flere skadelige drivhusgasser end transportsektoren, viser ny rapport fra FN. Rapporten konkluderer, at der er et akut behov for mere effektive produktionsmetoder.

Af Anne Rahn 30. nov 2006 kl. 00:00

Opdræt af svin og kvæg er mere skadeligt for miljøet end transportsektoren. Det fremgår af en ny rapport fra FN's fødevare- og landbrugsorganisation, FAO.

»Husdyrproduktion er en de største bidragsydere til tidens mest alvorlige miljøproblemer,« siger chefkonsulent i FAO, Henning Steinfeld.

dland/2009/02/kritik-forslag-boevse-prutteafgift-paa-koeer

Information

Fotografiske Fortællinger

Kritik af forslag om bøvse- og prutteafgift på køer

Skattekommissionens forslag om en klimaafgift på methan-udslip fra køer og grise giver

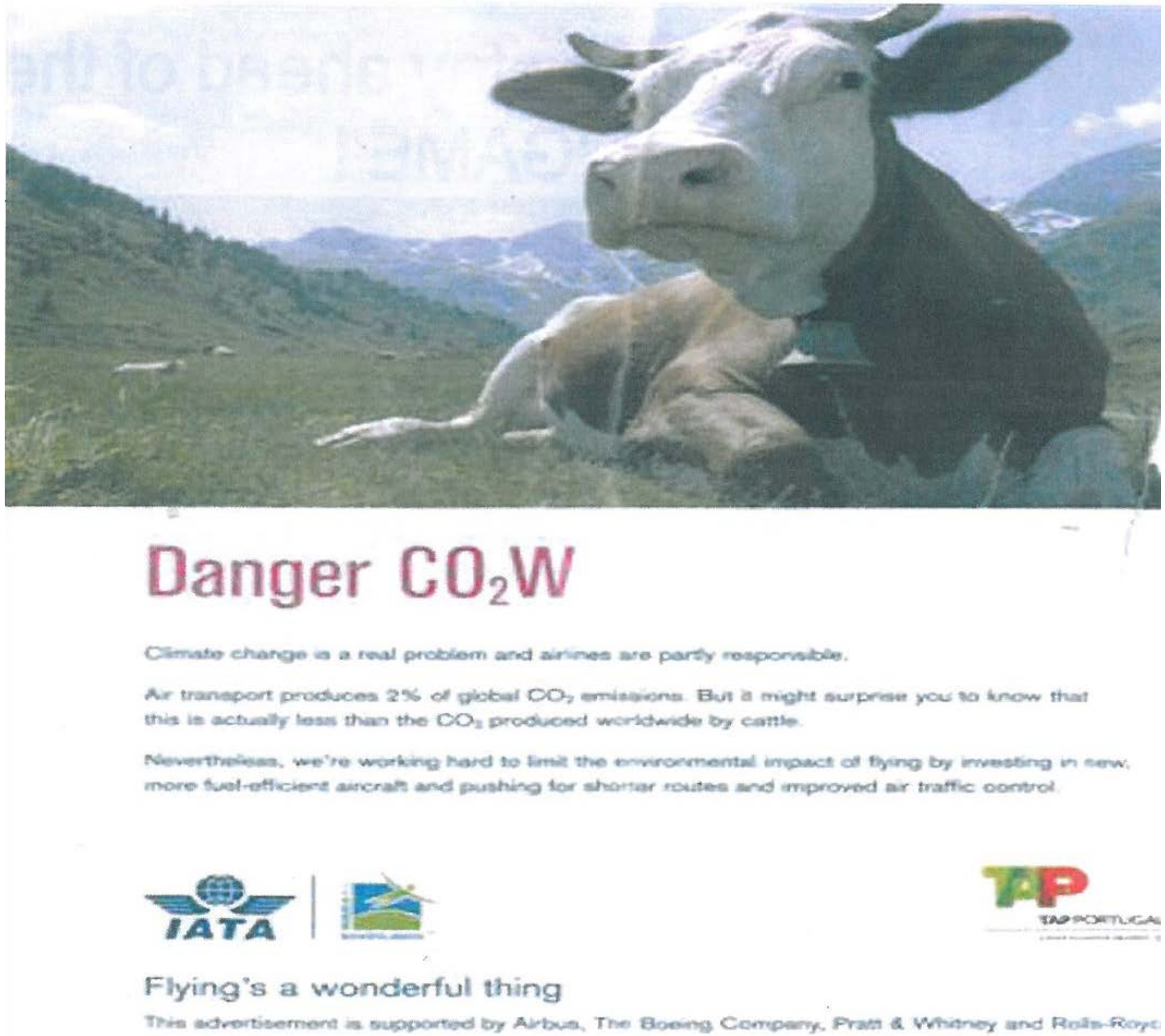
2. feb 2008 kl. 13:26

erd kan skade miljøet

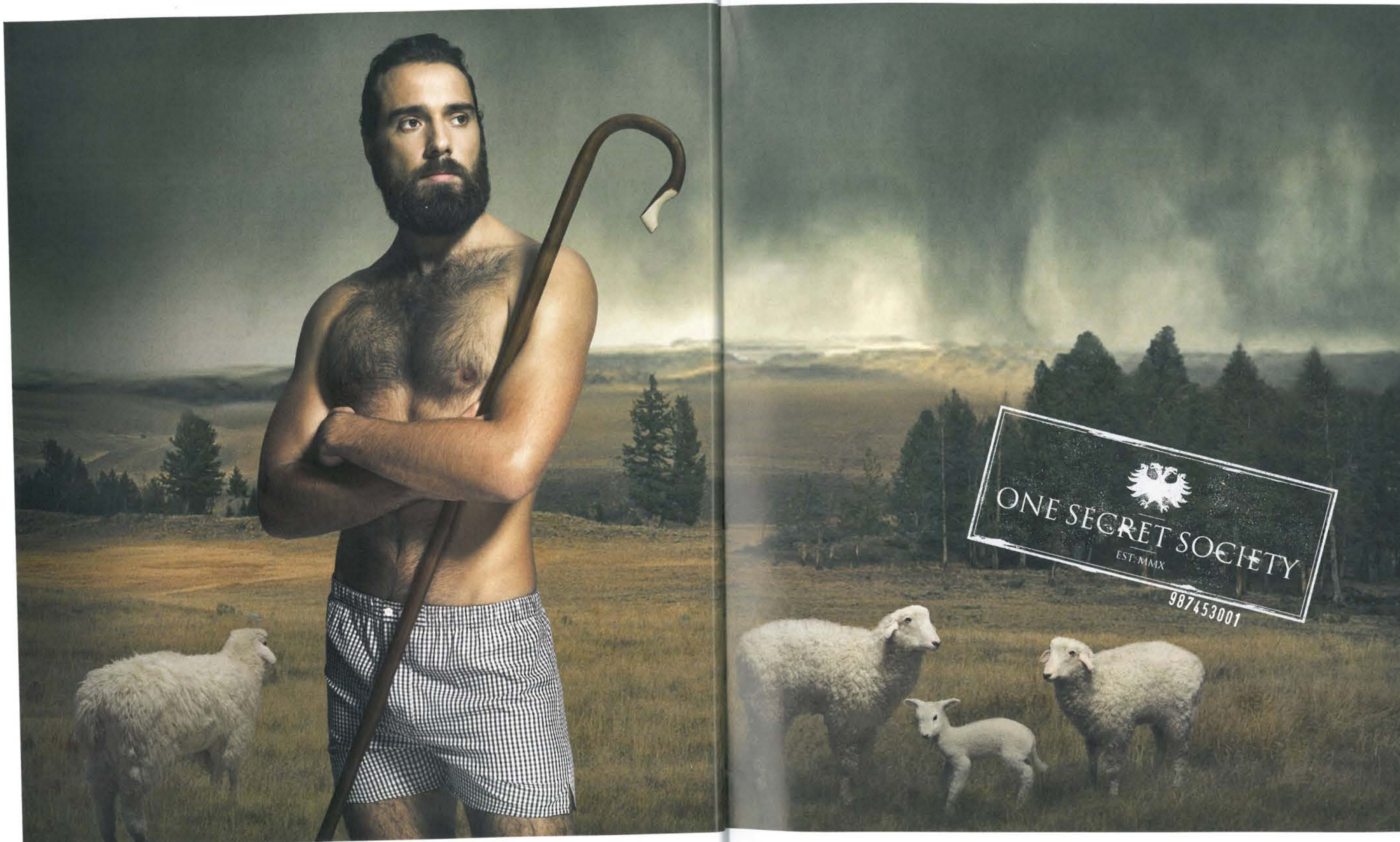
og grise på spaltegulv er godt for dyrene. Men mere kvælstof til naturen og flere drivhusgasser

enborg | Print artikel | Send arti

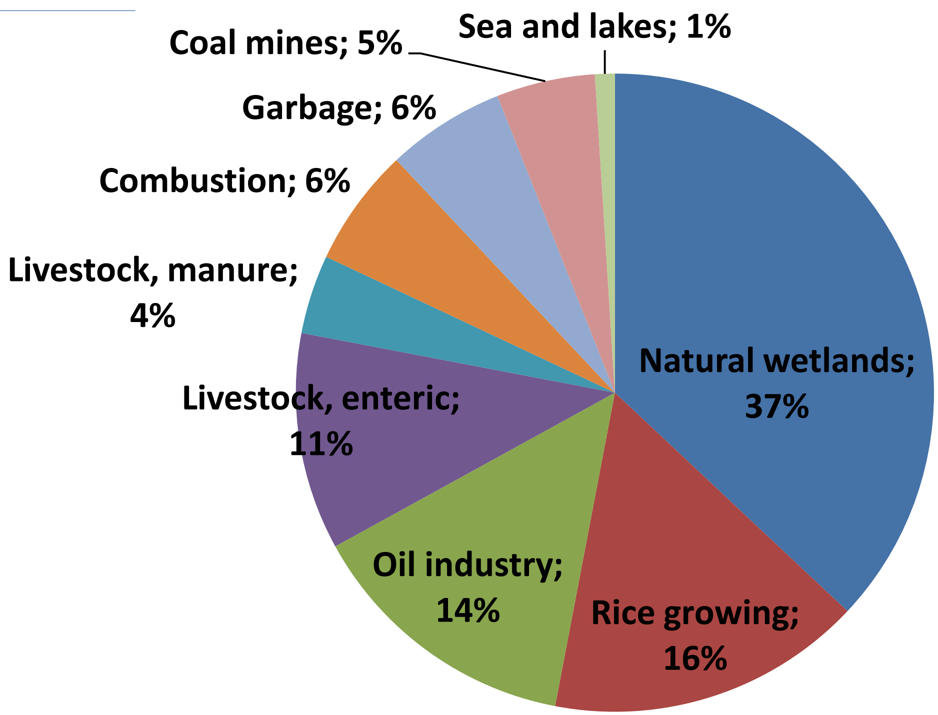
SPIN!!



Danger CO_2W
Climate change is a real problem and airlines are partly responsible.
Air transport produces 2% of global CO_2 emissions. But it might surprise you to know that this is actually less than the CO_2 produced worldwide by cattle.
Nevertheless, we're working hard to limit the environmental impact of flying by investing in new, more fuel-efficient aircraft and pushing for shorter routes and improved air traffic control.
IATA
TAP
Flying's a wonderful thing
This advertisement is supported by Airbus, The Boeing Company, Pratt & Whitney and Rolls-Royc


ONE SECRET SOCIETY
EST. MMX
987453001

Global greenhouse gas sources



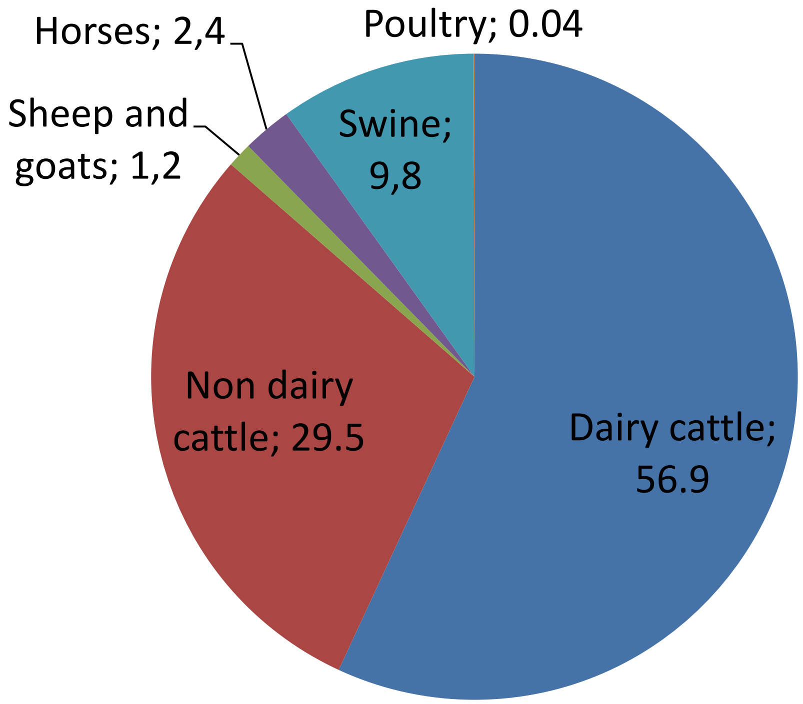
~70% anthropogenic source
~30% natural source

- Sinks:
  - Atmosphere: CH_4 + OH → CH_3 + H_2O → … (83%)
  - Microbial uptake in soil (~5%)
- Excess: 12%

Moss *et al.*, 2000

AARHUS
UNIVERSITY

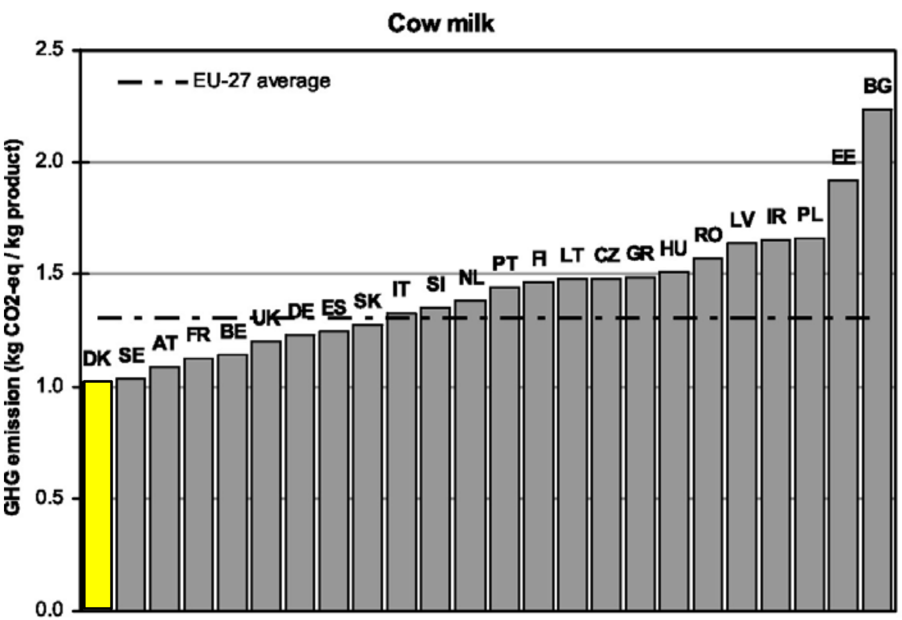
Enteric methane production Denmark

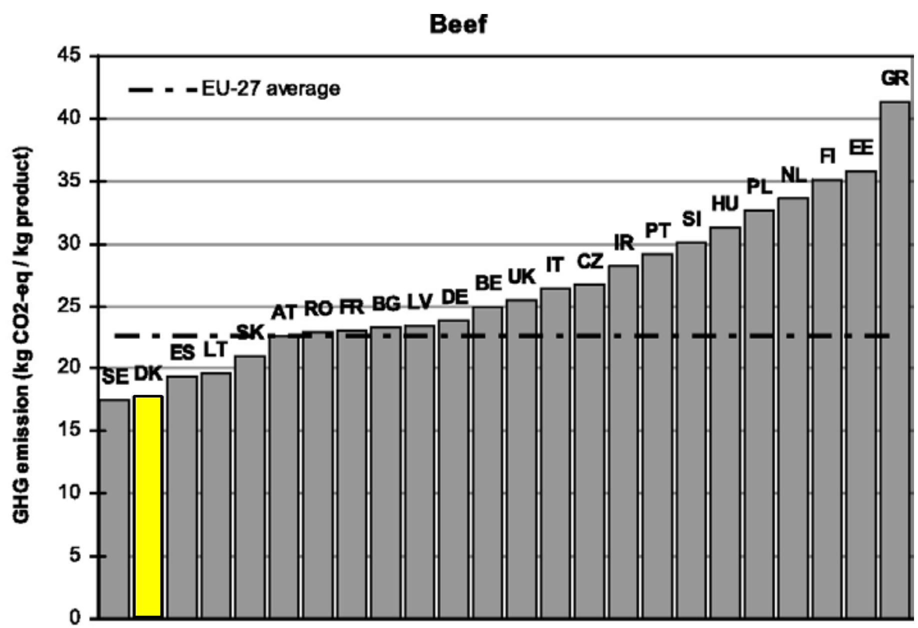


Nielsen *et al.* 2014

AARHUS
UNIVERSITY

Comparison of countries

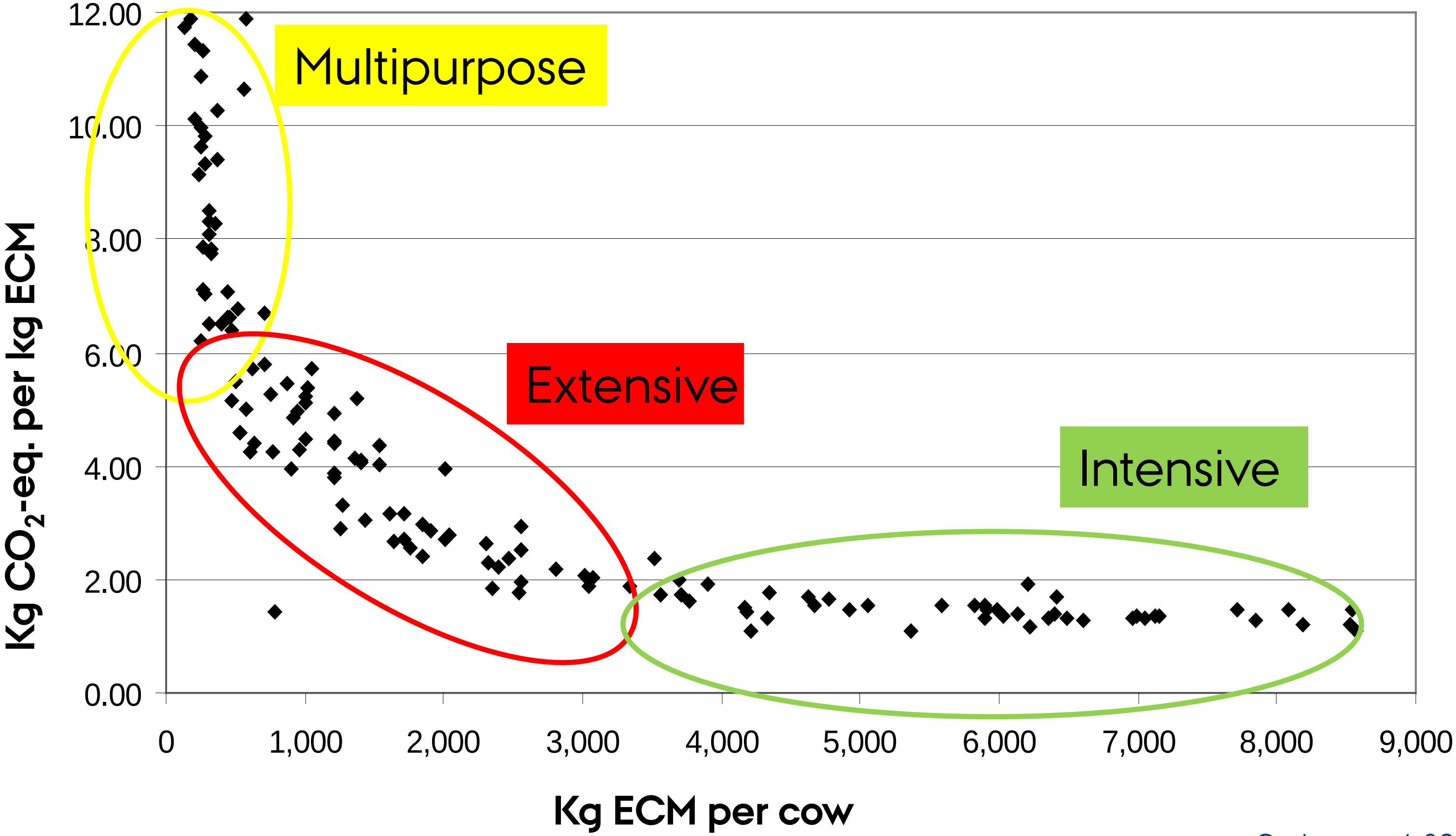




AARHUS
UNIVERSITY

Yield level is important

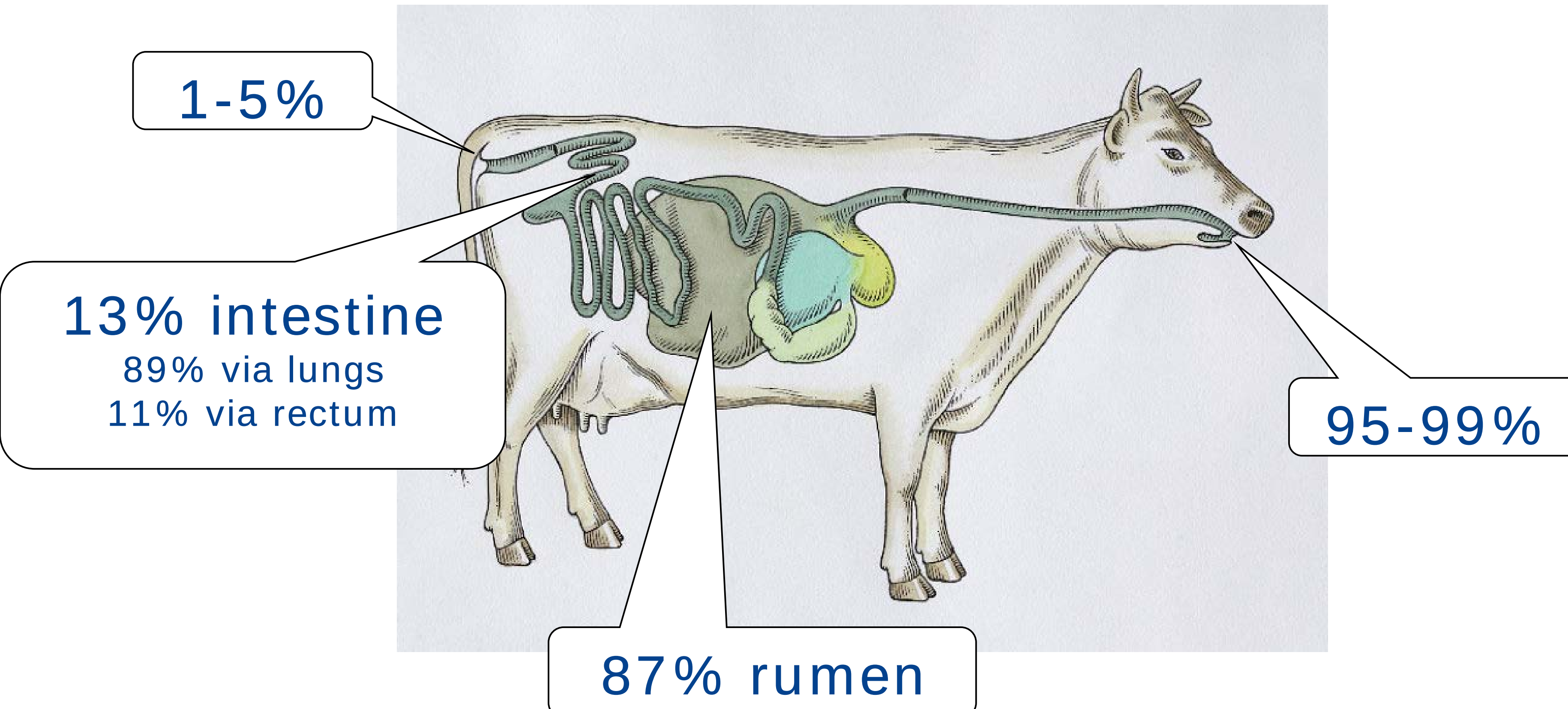
1 symbol = 1 country



Gerber *et al.*, 2011

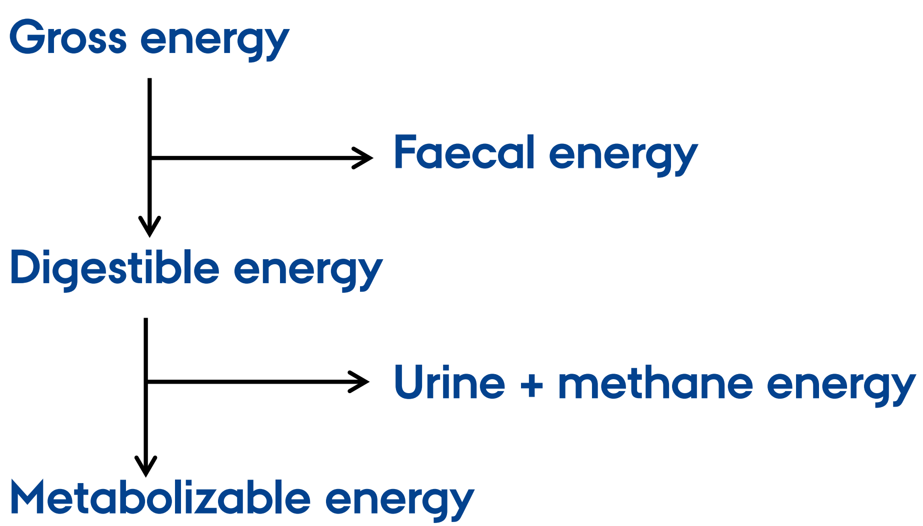
AARHUS
UNIVERSITY

Emission of methane



Why is it a problem?

- Global warming potential: **28** (IPCC, 2014)
- 2-12% loss of gross energy (feed)
  - CH_4 GE value: 55 MJ/kg (e.g. glucose 15.6, fat 39.3)



Why do cows produce CH_4...?

AARHUS
UNIVERSITY

Hydrogen!

H_2

$$CO_2 + \mathbf{4H_2} \rightarrow CH_4 + 2H_2O$$

AARHUS
UNIVERSITY

Why do cow's produce CH_4...?

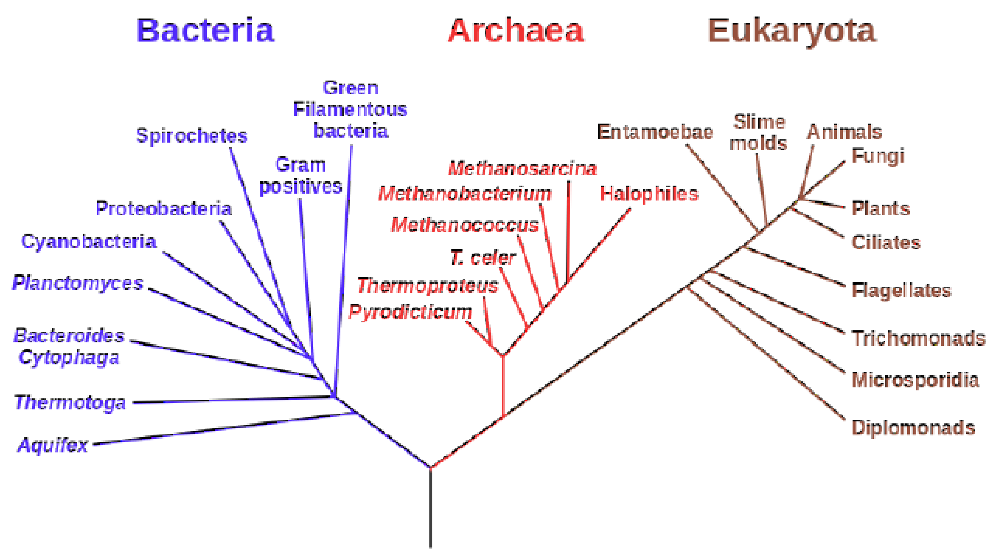
- Surplus H_2 needs to be removed (excreted or oxidized)
- Inhibits fermentation processes

CHO fermentation:

- $C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 2CO_2 + \mathbf{4H_2}$ **acetic acid**
- $C_6H_{12}O_6 + \mathbf{2H_2} \rightarrow 2CH_3CH_2COOH + 2H_2O$ **propionic acid**
- $C_6H_{12}O_6 \rightarrow CH_3CH_2CH_2COOH + 2CO_2 + \mathbf{2H_2}$ **butyric acid**

Diversity in the rumen

- Microbes (10^{12} microbes mL^{-1} in the rumen fluid)
  - Bacteria
  - Protozoa
  - Fungi
  - Archaea
  - Viruses



AARHUS
UNIVERSITY

Diversity in the rumen

- Microbes
  - Bacteria
  - Protozoa
  - Fungi
  - Archaea
  - Viruses

Bacteria, Protozoa: Digest feed CHO (fibre, starch and sugar) and protein

Fungi: Mainly fibre rich diets

(Bacteria, Protozoa, Fungi): Produce hydrogen

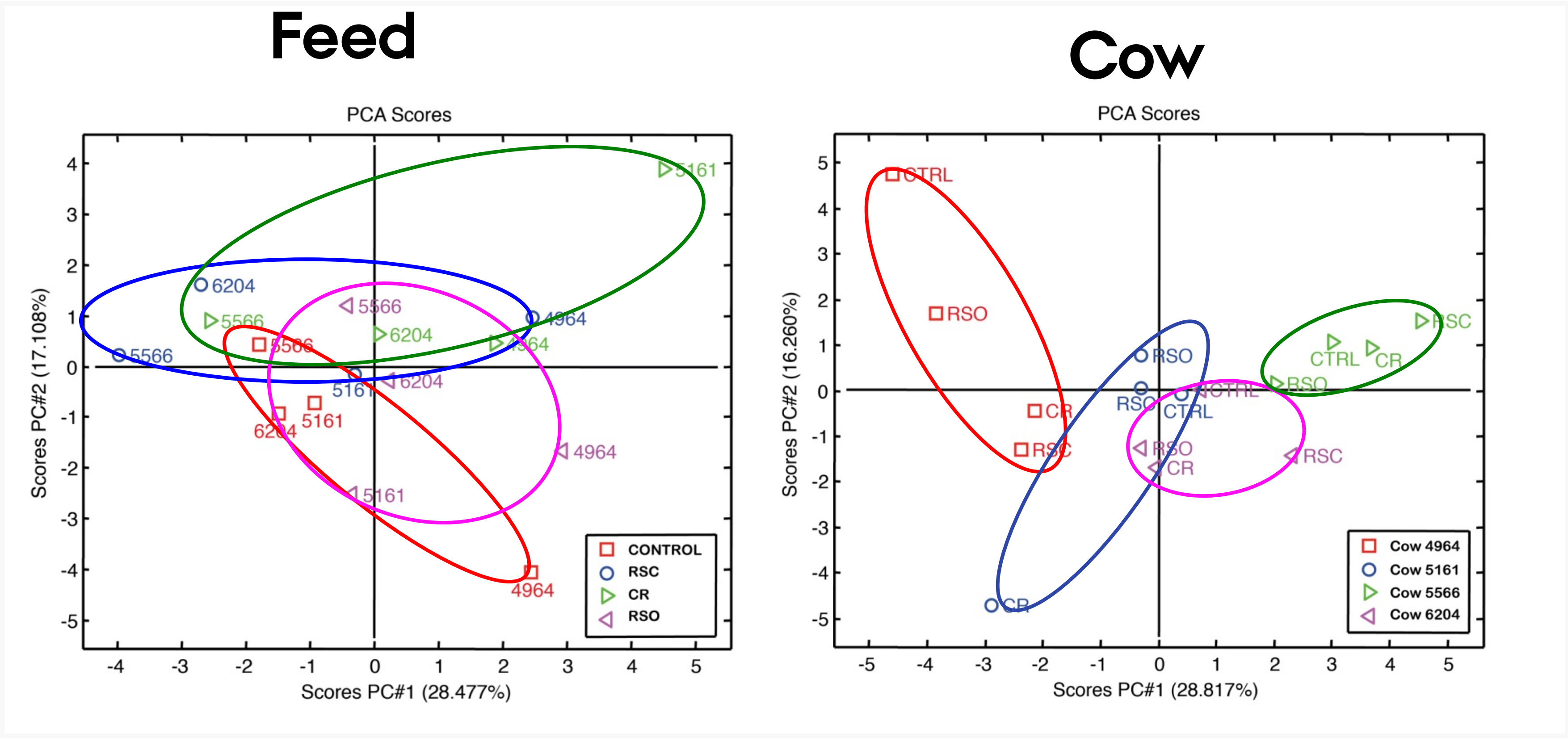
Archaea: Mainly methanogens

Viruses: Do not contribute to any fermentation

Protozoa foraging on organic material including fungi

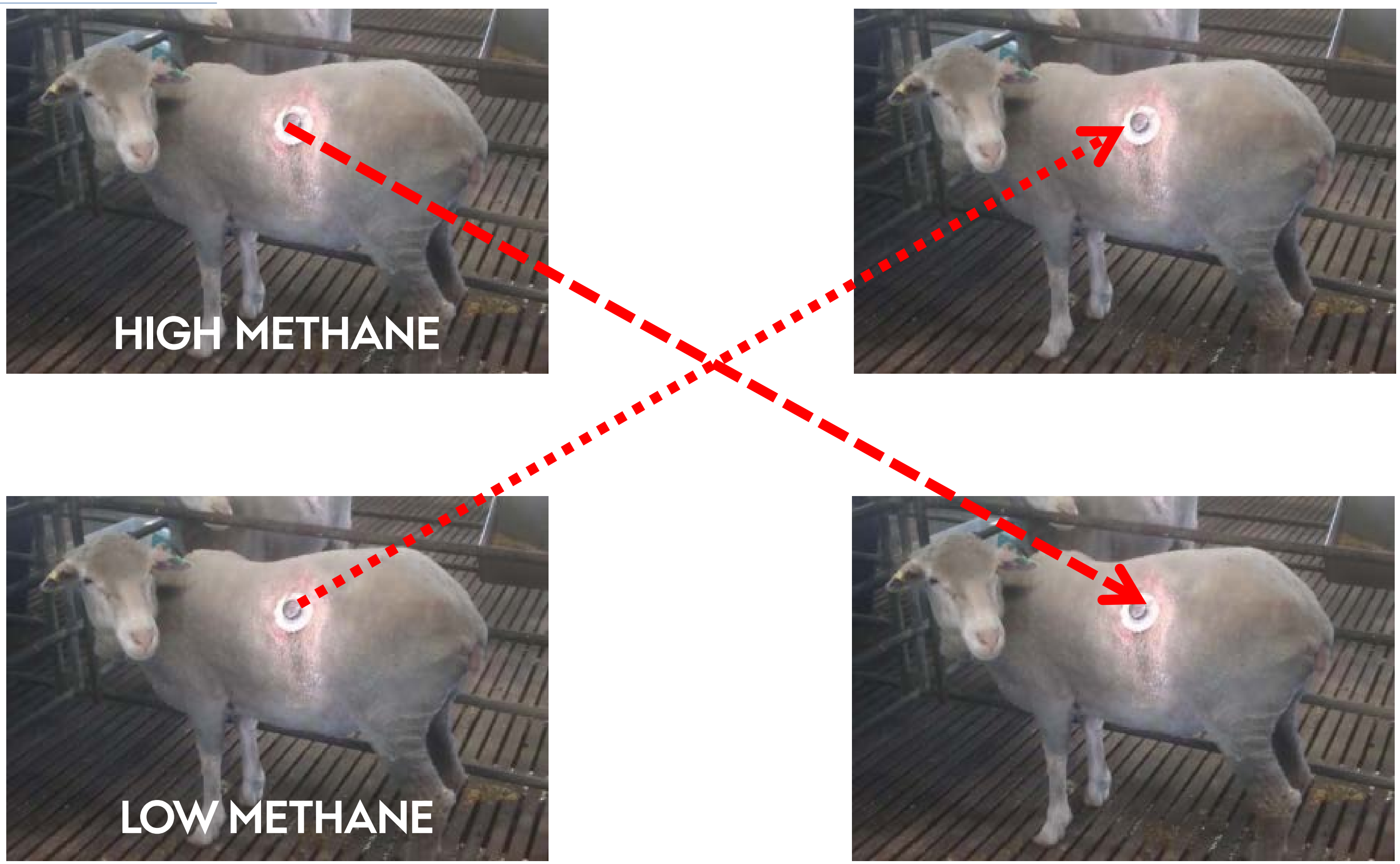
AARHUS
UNIVERSITY

Microbial community



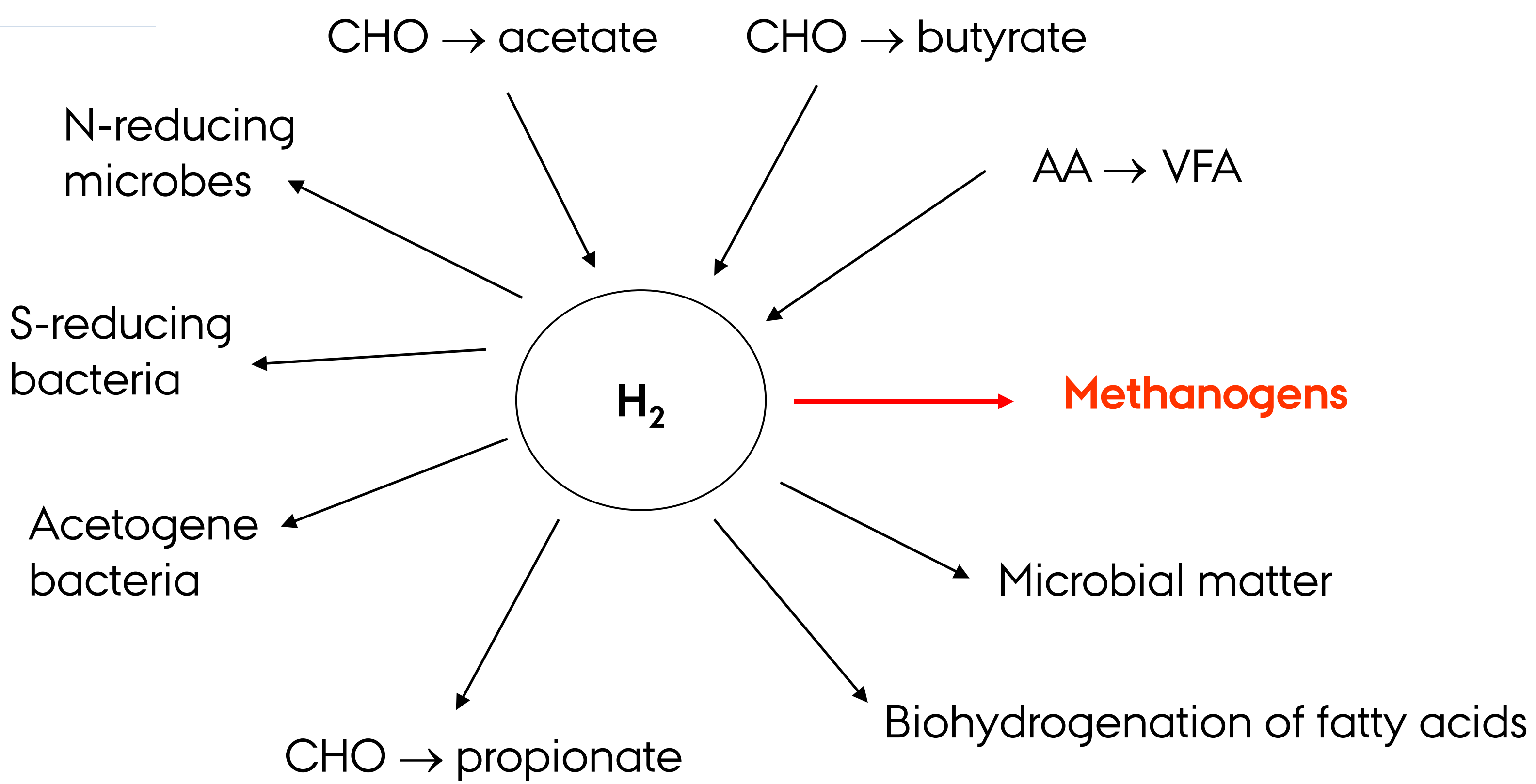
Microbial diversity is more related to the cow than to the feed

Animal variation



AARHUS
UNIVERSITY

Where does H_2 goes to?



Energy efficiency

- The fermentation pathways differ in their energetic efficiency
- ΔG is the difference in free energy with a chemical reaction, i.e. a reaction is favourable when ΔG is low
- ΔG = Gibbs free energy change

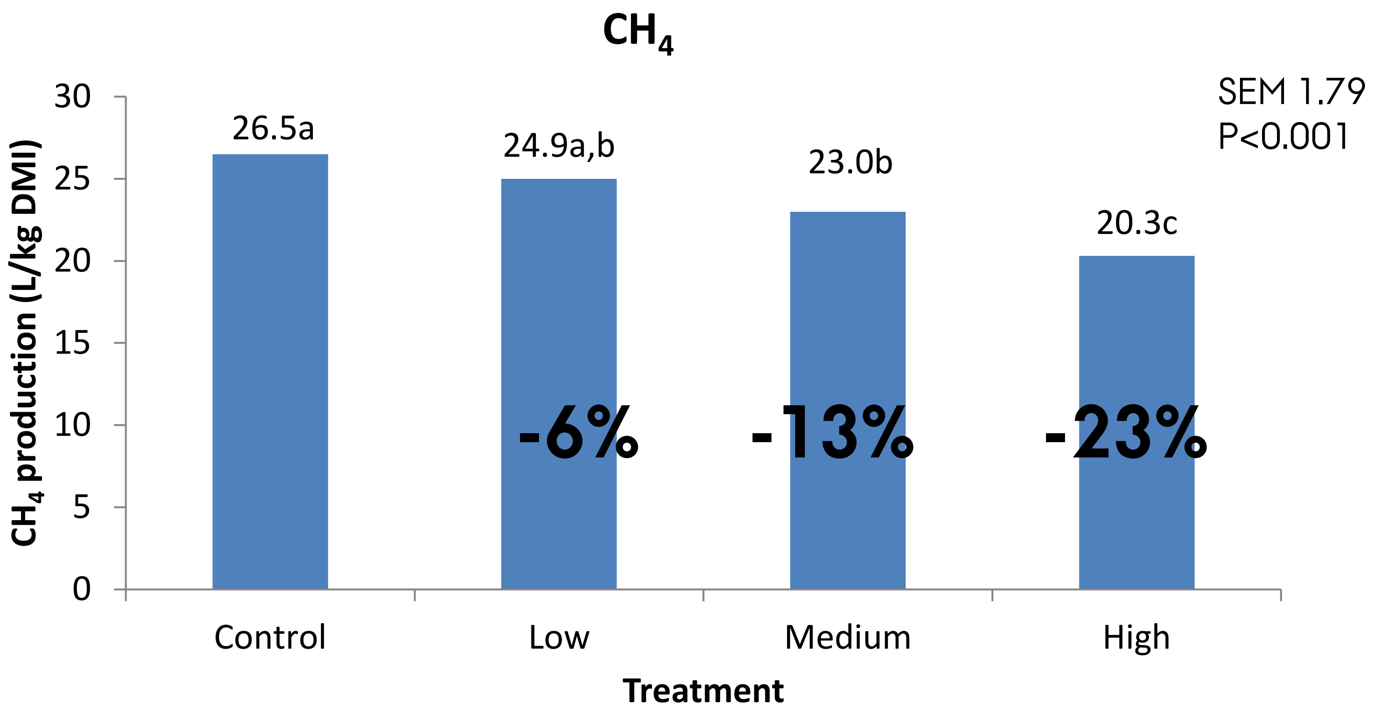
Reaction	**ΔG**	**Substrate availability**
$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$	-67.4	High
$CO_2 + 4H_2 \rightarrow CH_3COO^- + H^+ + 2H_2O$	-8.8	High
$SO_4^{2-} + 4H_2 + H^+ \rightarrow HS^- + 4H_2O$	-84.4	Low
$NO_3^- + H_2 + 2H^+ \rightarrow NO_2^- + 2H_2O$	-130	Low
$NO_2^- + 3H_2 + 2H^+ \rightarrow NH_4^+ + 2H_2O$	-371	Low

(Ungerfeld & Kohn, 2006)

Nitrate (NO_3^-) as mitigation strategy

- 4 cows, Latin Square design
- Calcium nitrate (Bolifor CNF)
- Treatments with nitrate dose (g NO_3^-/kg DM):
  - Control: 0
  - Low: 5
  - Medium: 14
  - High: 21

Nitrate study: results



Olijhoek *et al.*, 2016

AARHUS
UNIVERSITY

Nitrate study: results

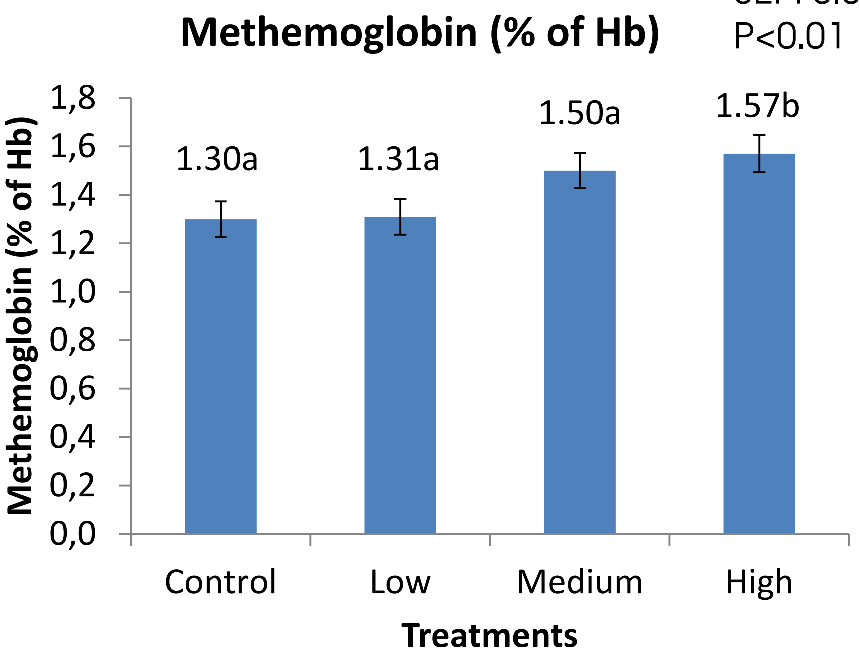
Hemoglobin (Fe^{2+})

NO_2^- (absorbed from rumen)

Methemoglobin (Fe^{3+})

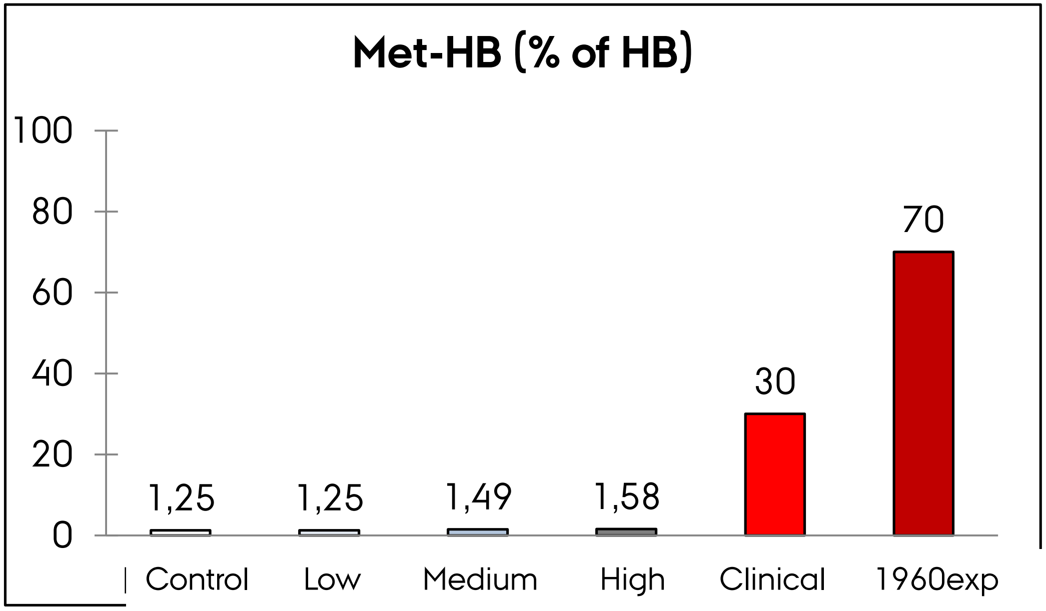
Clinical signs of methemoglobinemia: methemoglobin at 30-40% of Hb

SEM 0.08
P<0.01

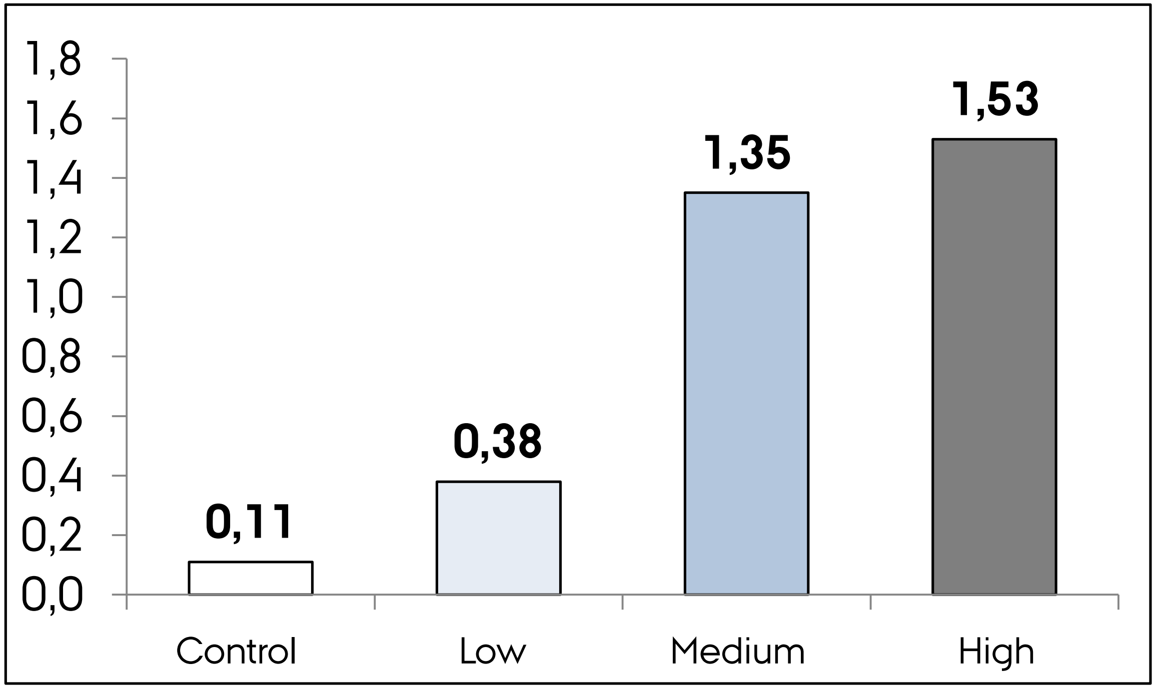


Olijhoek *et al.*, 2016

Met-haemoglobin

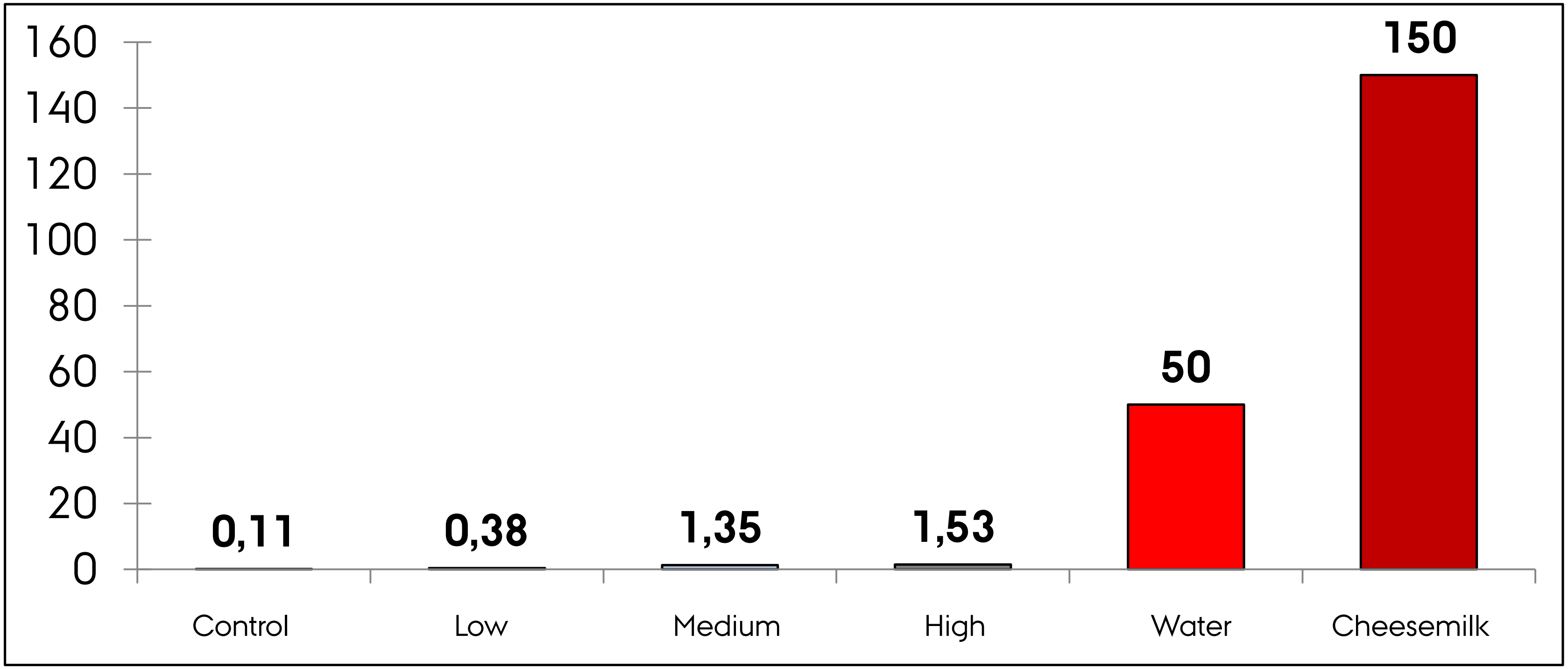


Nitrate i milk (mg/kg)

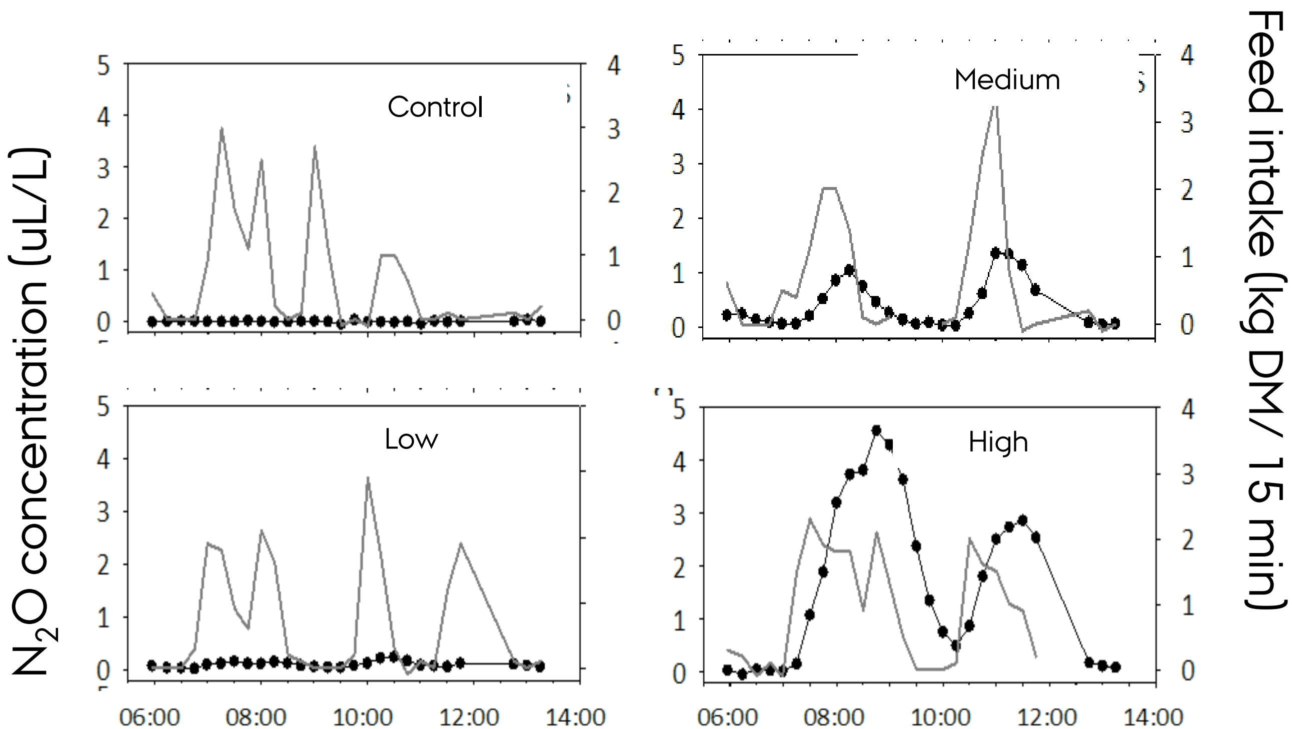


P < 0,001

NITRATE IN MILK (MG/KG)



N_2O (256 X CO_2)



Control
Medium
Low
High
N_2O concentration (uL/L)
Feed intake (kg DM/ 15 min)
06:00
08:00
10:00
12:00
14:00

Measurement techniques

AARHUS
UNIVERSITY

Measurement techniques

Open circuit chambers

GreenFeed

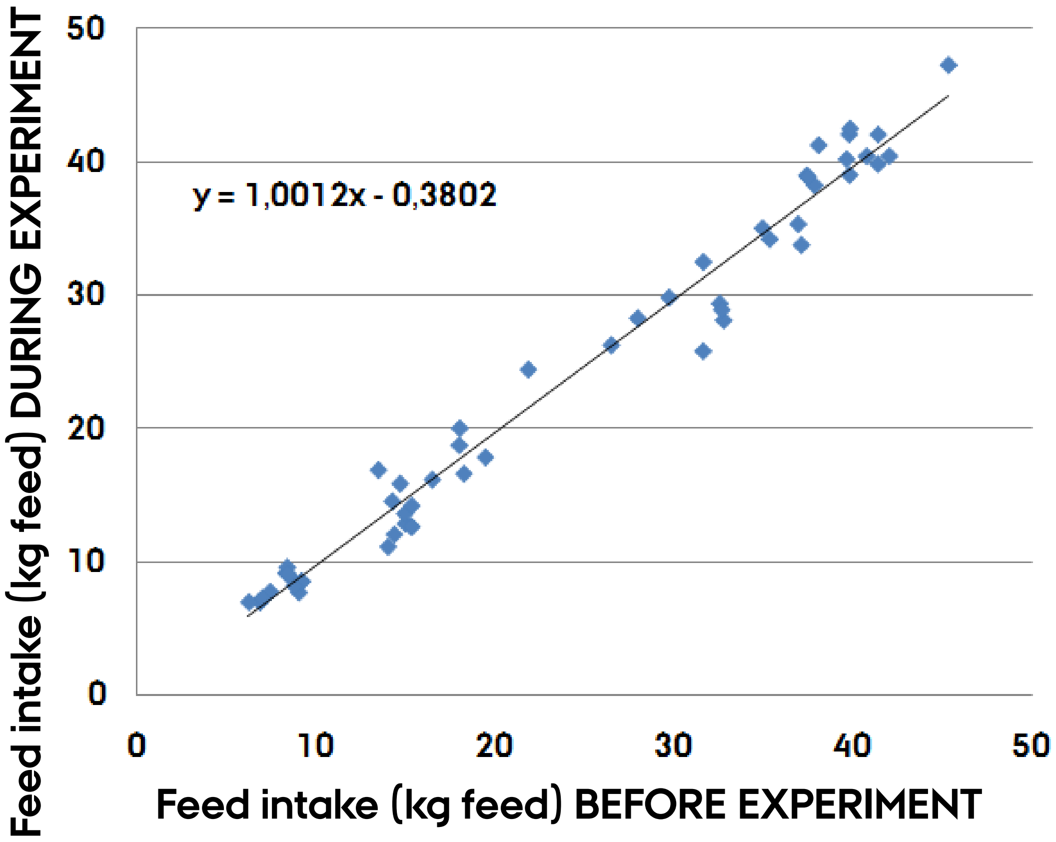
SF_6 tracer

AARHUS
UNIVERSITY

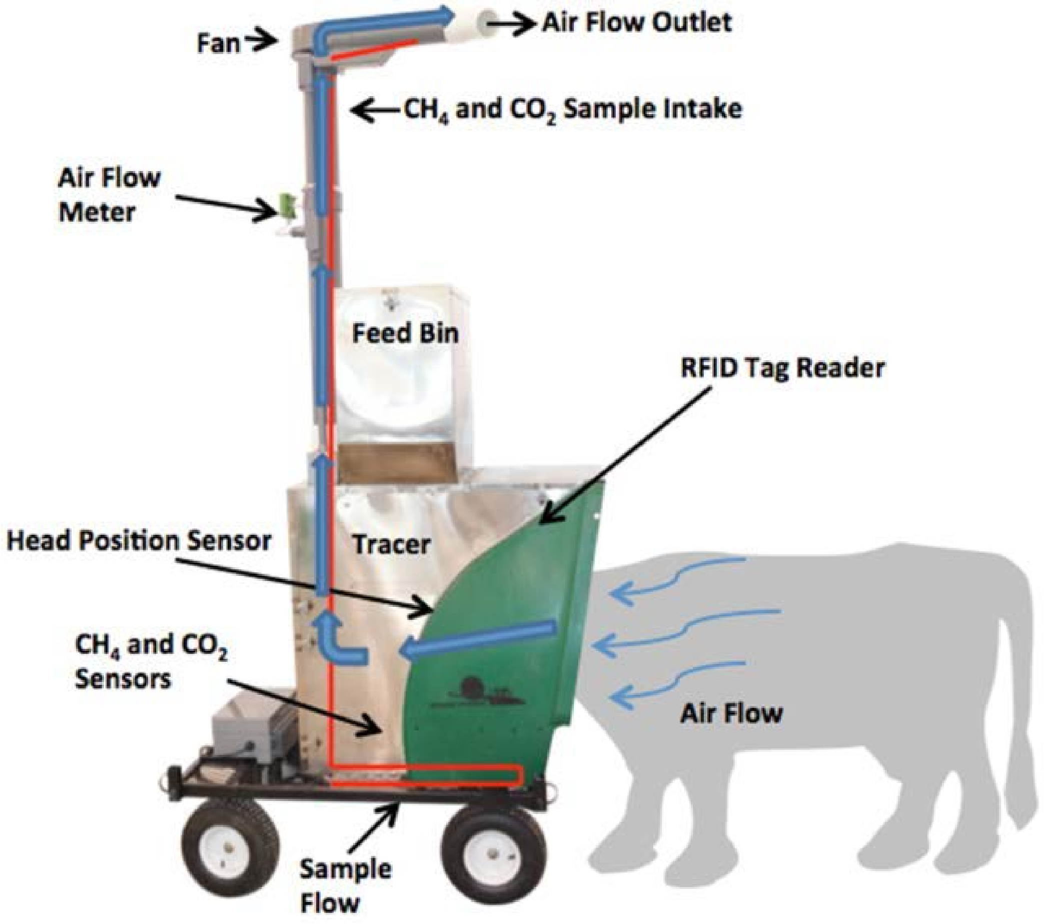
Respiration chambers

- Considered as a reference method
- Animals are kept in closed chambers (slight under-pressure)
- Continuous air flow
- Gas flow rate (L/min) measured
- Gases measured: CO_2, O_2, CH_4, H_2, H_2S
  - Concentration in inflow and outflow air

Welfare is important



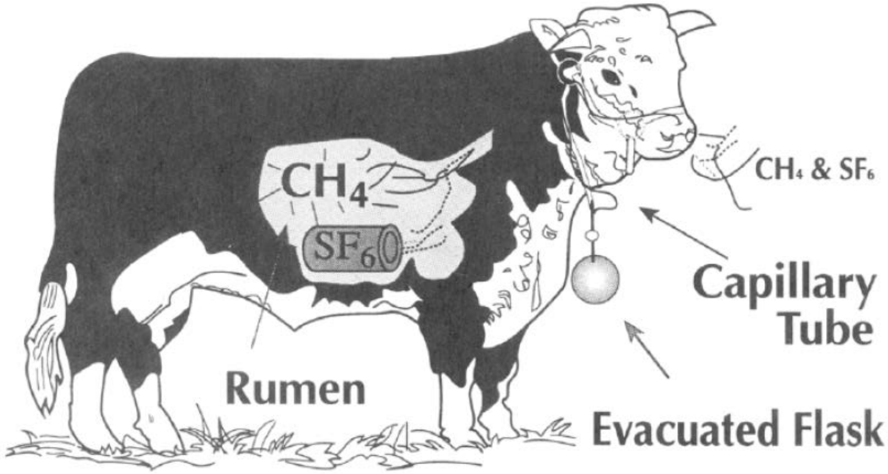
GreenFeed



C-Lock

AARHUS
UNIVERSITY

SF_6 (sulphur hexafluoride) technique



Storm *et al.* 2012

Reducing (mitigating) methane emission

Mitigation strategies:

1. Inhibit the methanogens specifically
2. Reduce the substrate (H_2) source
3. Promote other H_2 consuming processes/organisms
4. Increase productivity
5. Combination of 1-3

Reducing (mitigating) methane emission

1. Inhibit the methanogens specifically:
   - 2-bromoethanesulphonate (BES)
   - Plant secondary metabolites: condensed tannins, essential oils
   - Vaccination
   - Long chained (unsaturated) fatty acids (see further later on)

- Inhibitor sensitivity differs among methanogens…!

Reducing methane emission

- 2. Reduce the H_2 source
  - Inhibit H_2 producing protozoa (defaunation)
  - Antibiotic treatment:
    - E.g. monensin (ionophore): targets H_2 producing Gram$^+$ bacteria and protozoa
    - Works… but controversial approach…!

Reducing methane emission (1)

3. Promote other H_2 consuming processes

- More dietary starch (concentrate) and less cellulose-rich roughage
  - Less H_2 production
  - Risk of increased lactate production (rumen acidosis)

Reducing methane emission (2)

<u>3. Promote other H_2 consuming processes</u>

- Promote reductive acetogenesis: $CO_2 + 4H_2 \rightarrow CH_3COO^- + H^+ + 2H_2O$
  - The process is thermodynamically less favorable than methanogenesis
  - Acetogens have lower H_2 affinity than methanogens
  - An enigma why the process can dominate in e.g. Kangaroos
- Dietary nitrate/sulphate (electron acceptors) addition
  - Works… but problematic…?!?
  - Production/emission of N_2O (greenhouse gas)
  - Production of hydrogensulphide (H_2S; toxic and odorous compound) and nitrite (NO_2^-; toxic)

AARHUS
UNIVERSITY

Reducing methane emission

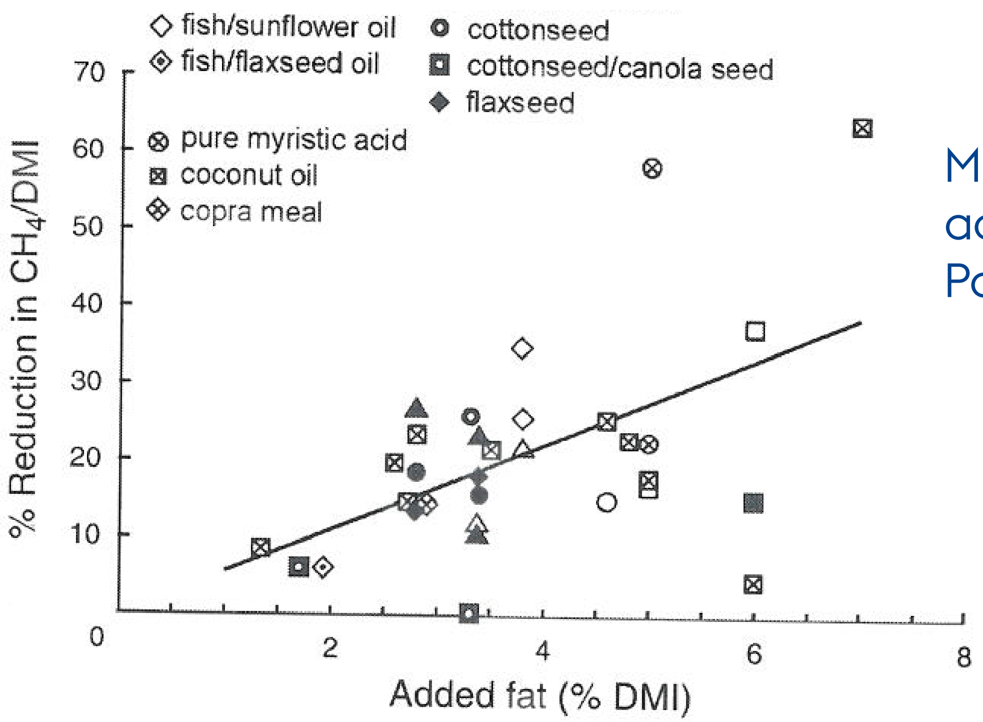
4. Increase productivity of the animal

- By higher feed quality, management, genetics
- Less CH_4/kg product (meat or milk)
- "Dilution of maintenance"

5. Dietary fat (combining strategies)

AARHUS
UNIVERSITY

Methane reduction through fat



Methane reduced 5-6% per 1% fat added

Potential: 10-25% reduction

Beauchemin (2007)

AARHUS
UNIVERSITY

Effects of dietary fat on CH_4 production

- Long-chained fatty acids are not fermented in the rumen; no substrate input for the methanogens
- Bio-hydrogenation (saturation) of unsaturated fatty acids is an alternative H_2 sink
- Can inhibit methanogens directly, especially medium-chained fatty acids
- Reduces the number of protozoa (H_2 producers)

Rapeseed plant

Whole seeds

Extruding process

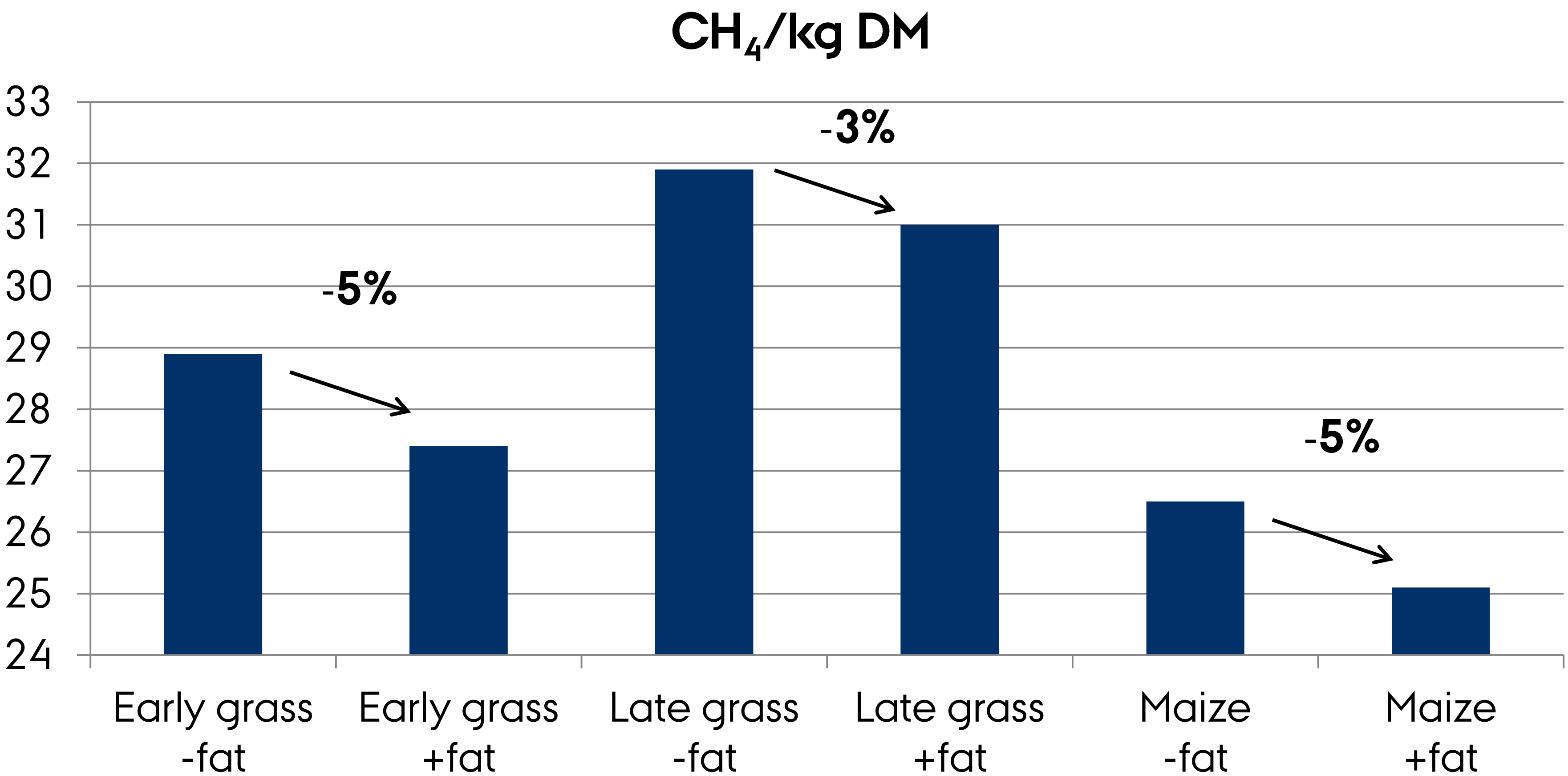
Rapeseed oil

Effects of dietary fat on CH_4 production

But:

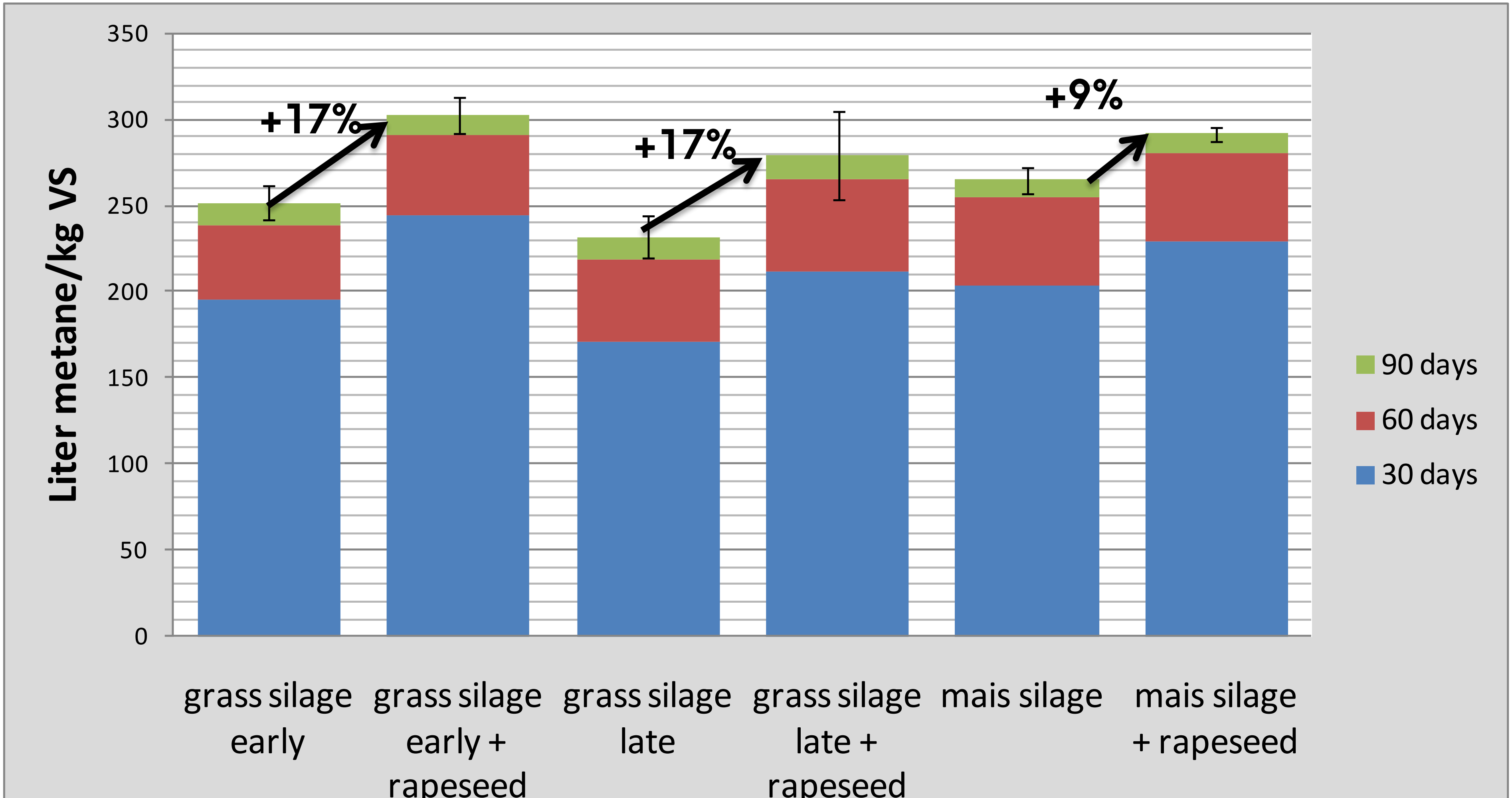
- Unsaturated fatty acids are also toxic for cellulolytic bacteria – reduced fibre digestion…!?!
- Reduction in DMI?
- What about milk composition and quality…?!?

FAT X FORAGE – COW



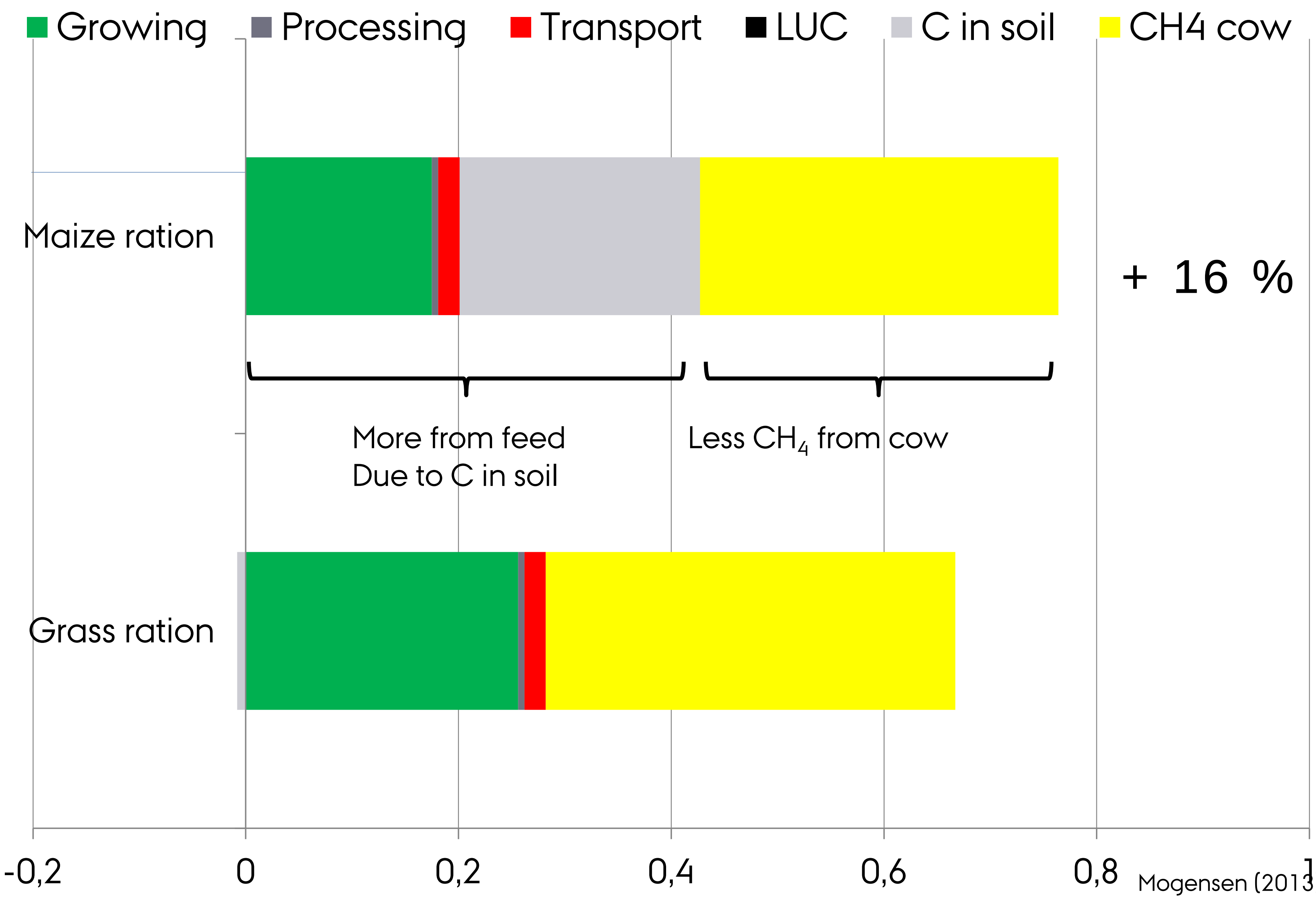
Brask (2013)

FAT X FORAGE – BIOGAS POTENTIAL



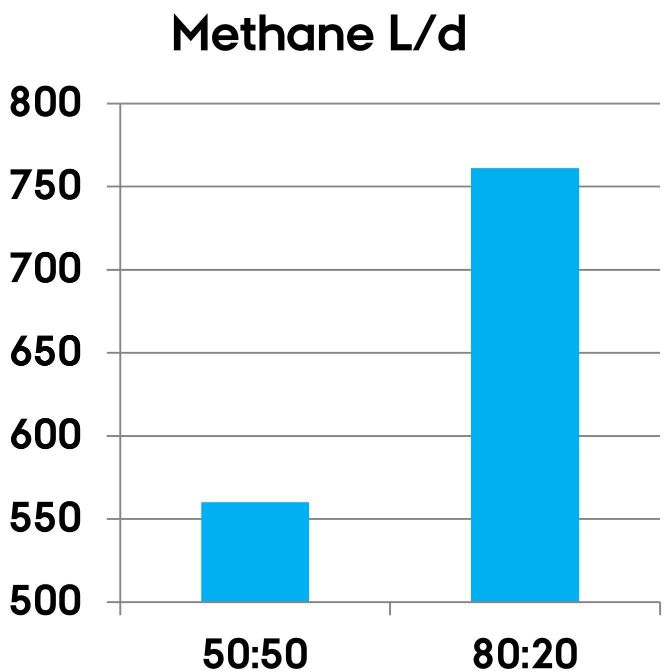
Møller (2013)

GHG from feed + CH_4 from cow, kg CO_2/kg ECM

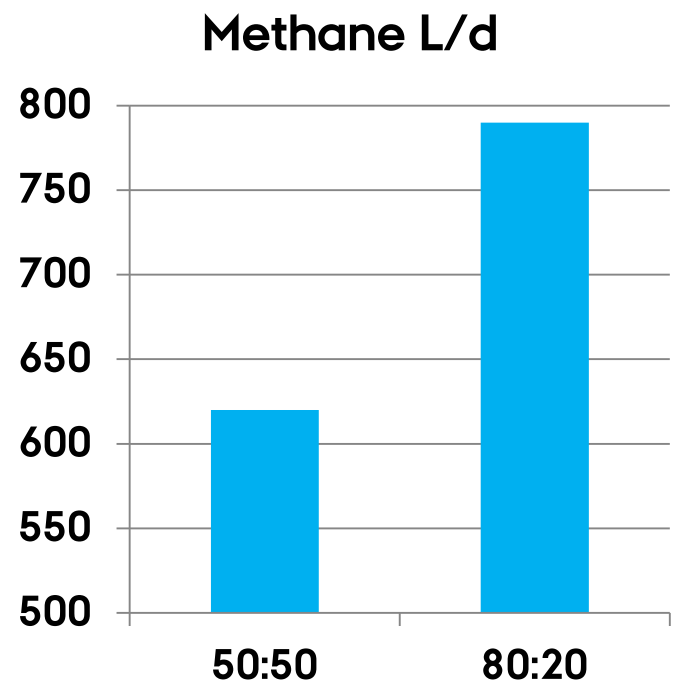


Mogensen (2013)

FORAGE: CONCENTRATE RATIO



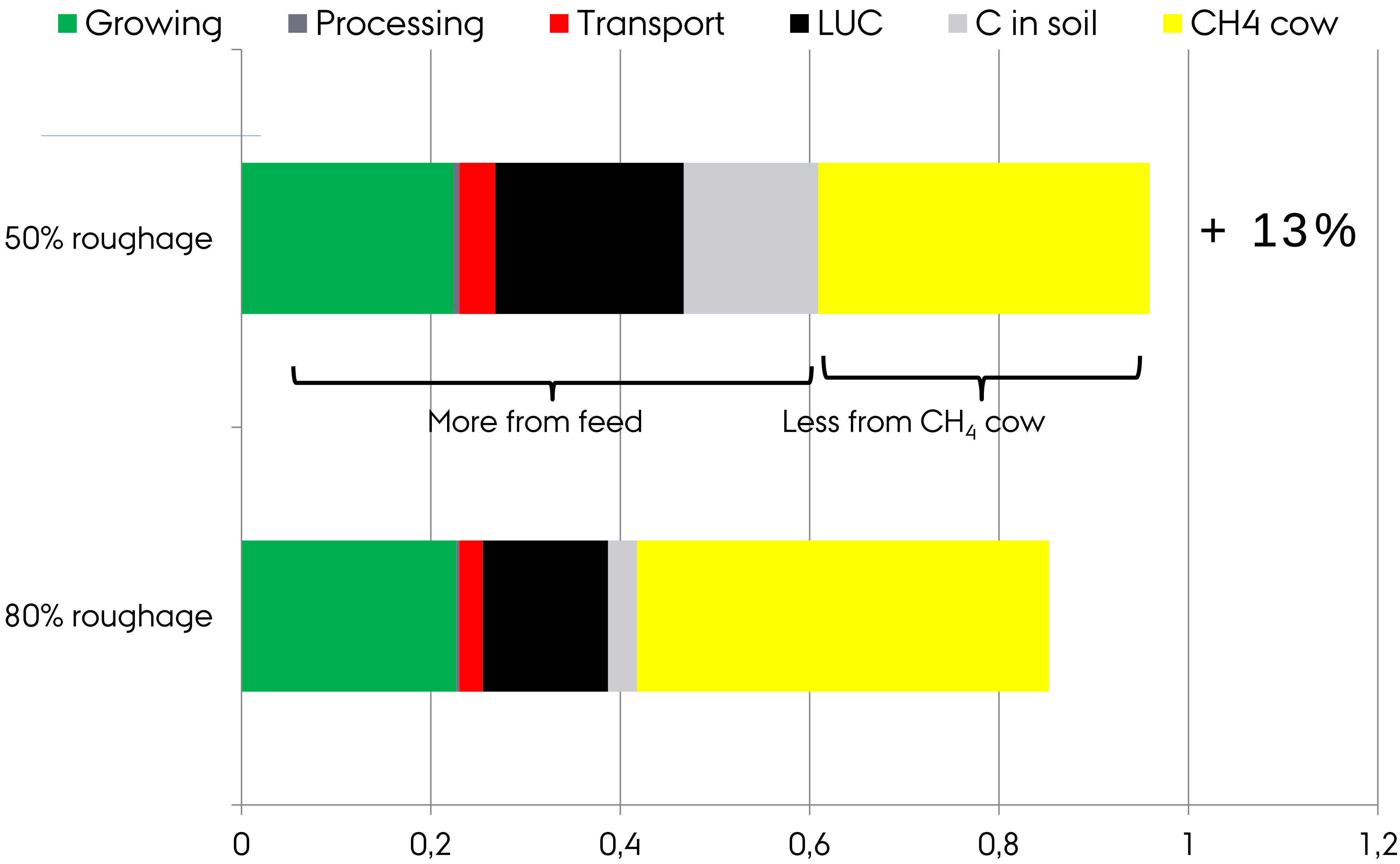
High quality GS



Low quality GS

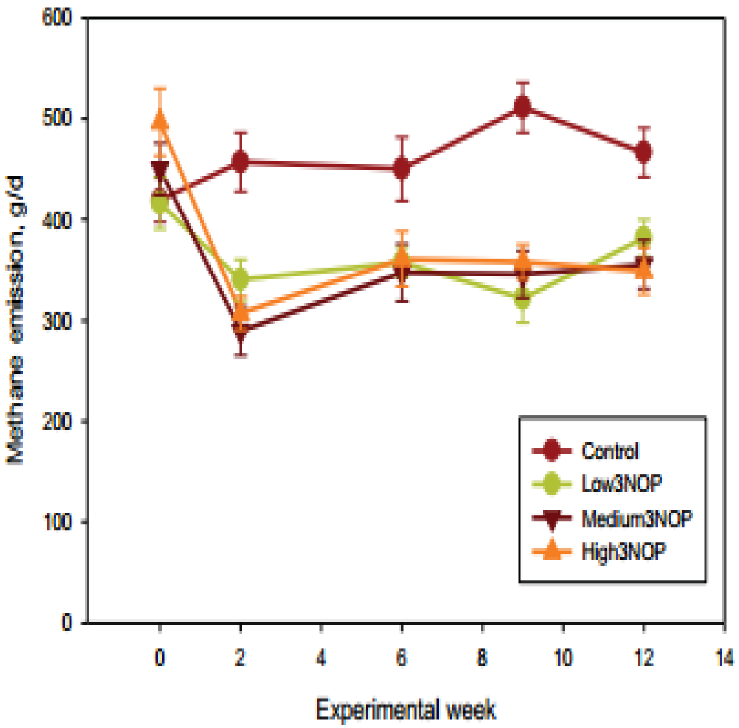
Hellwing (2012)

GHG from feed + CH_4 from cow, kg CO_2/kg ECM



WUNDERDRUGS

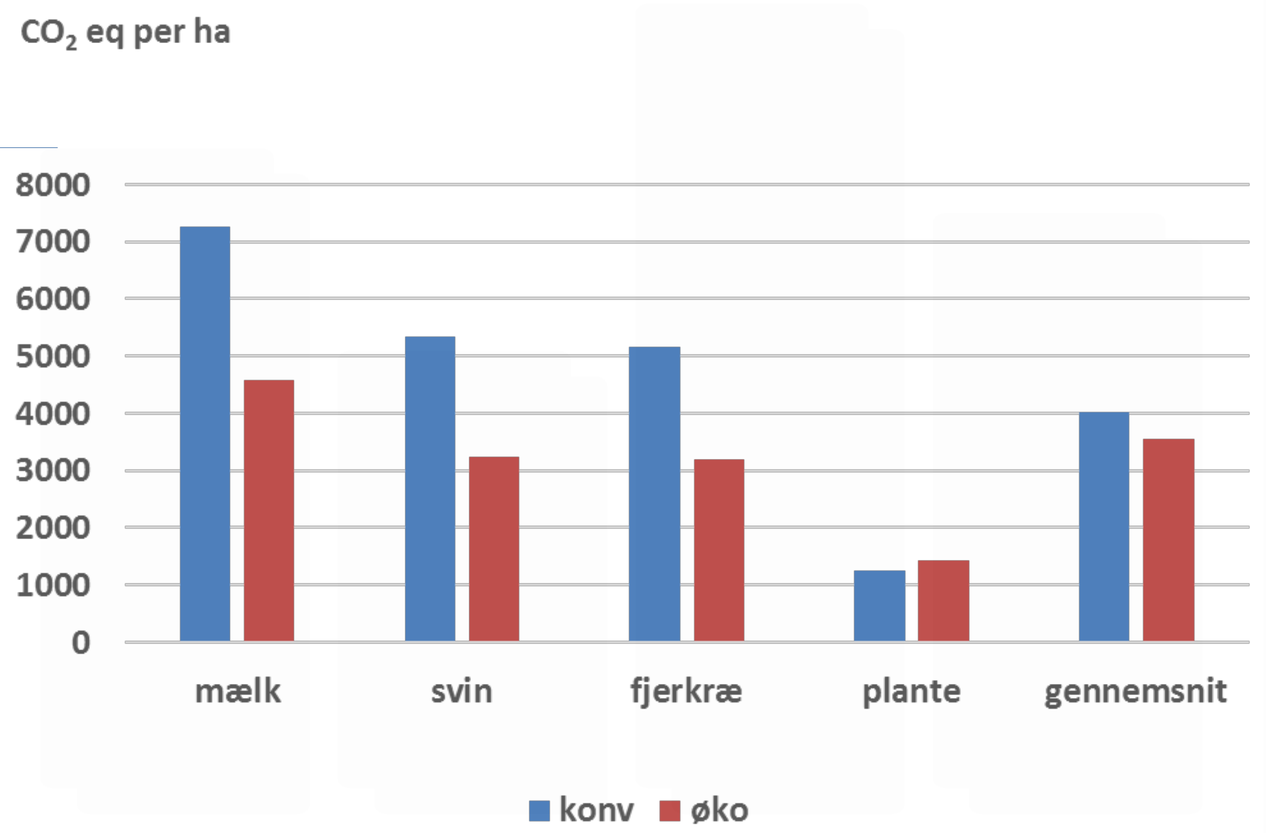
- Nitrate
- Oregano
- Garlic
- Essential oils
- 3 NitroOxyPropanol
- Saponins
- Tanins
- Sea weed
- ....



25-32 % reduction

AARHUS
UNIVERSITY

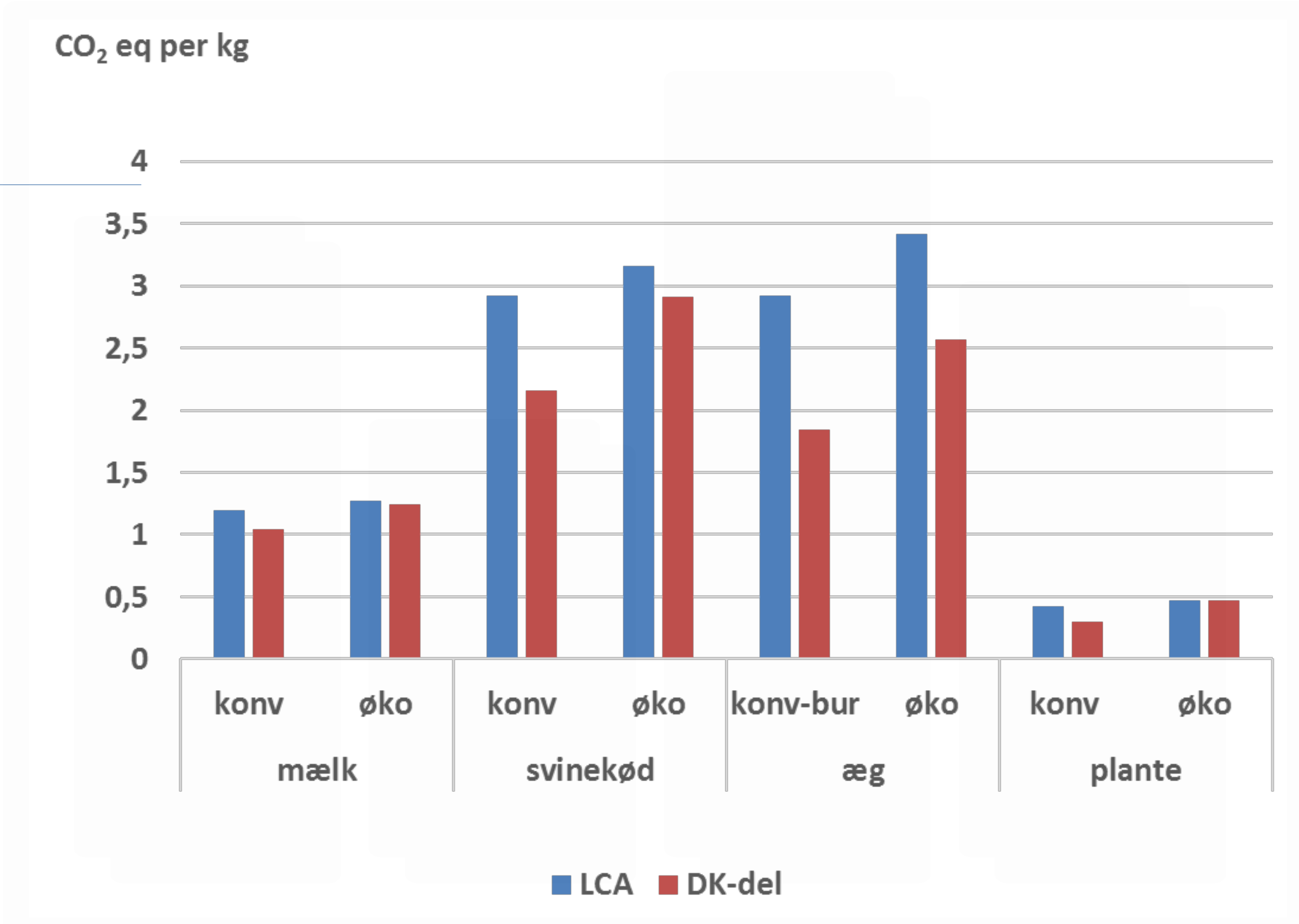
ORGANIC VS CONVENTIONAL



Kristensen (2017)

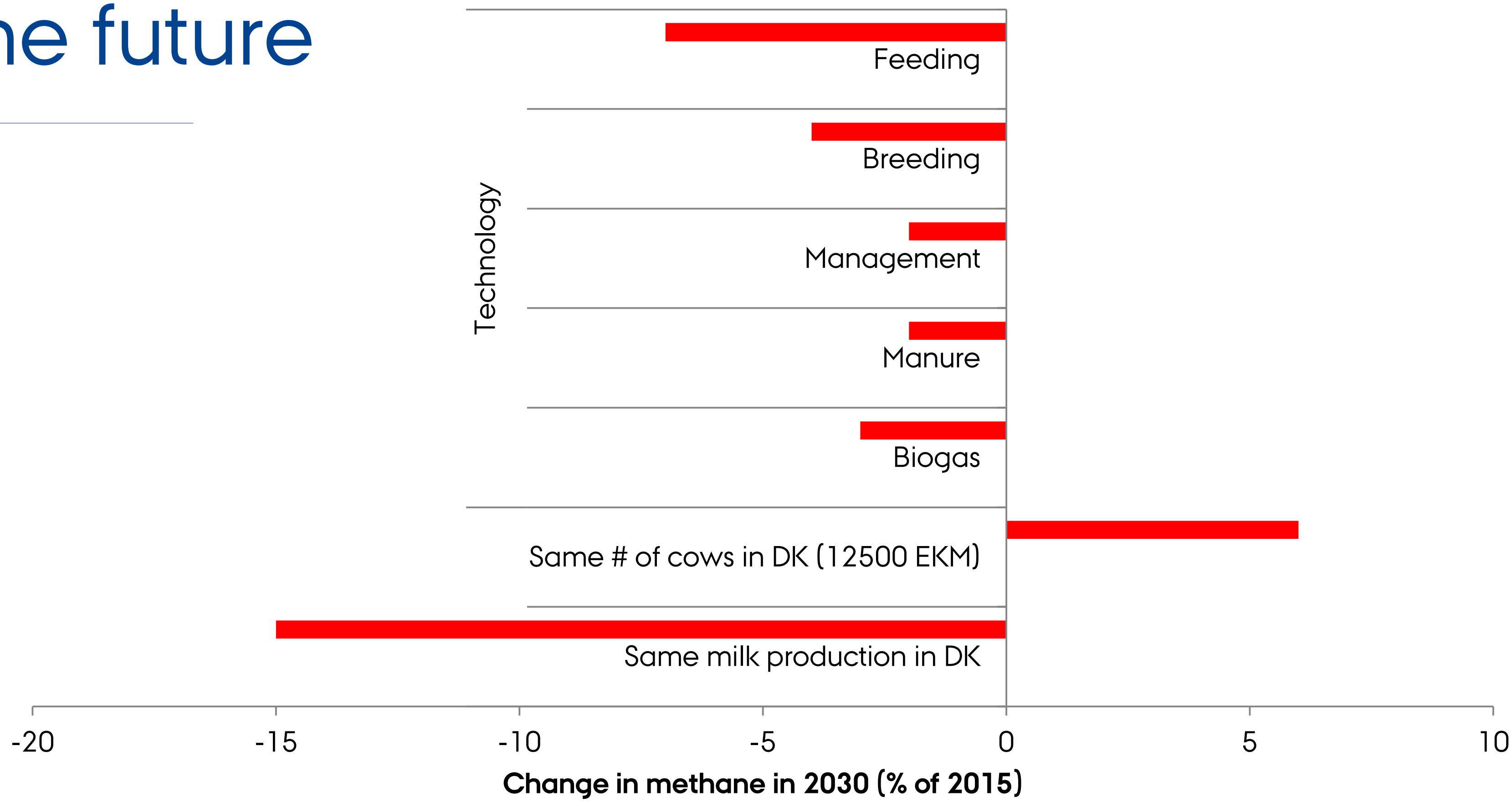
AARHUS
UNIVERSITY

ORGANIC VS CONVENTIONAL



Kristensen (2017)

The future



Lund & Kristensen (2017)

AARHUS
UNIVERSITY

Thank you for your attention!