Danish experiences using life Cycle Assessment (LCA) as a tool for assessing a livestock product’s energy use and environmental impact through its life cycle

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Global warming

- Global climate is affected by greenhouse gases (nitrous oxide, methane, CO$_2$... etc)
- CO$_2$ is only one out of many other greenhouse gases
- Other important greenhouse gases from the agricultural sector are: Nitrous oxide and methane
- Several stages in the food chain contribute to GHG emissions
- What is the relative importance of energy use for traction and transport?
- A product oriented and chain based assessment tool is in need!
Topics:

- Comparing energy use and GHG emissions in Dairy systems
- The relative importance of transport in GHG emissions from pork
- The farm level emissions of GHG
- Improvement options for reducing GHG in livestock farms
- The role of integrated bioenergy in LCAs for livestock products
- The relative importance of changes in soil carbon content
Energy use in organic and conventional production systems

Modelled on the basis of results from private farms, Refsgaard et al., 1997
Energy use in organic and conventional production systems

Energy use, milk production:

<table>
<thead>
<tr>
<th>MJ per KG</th>
<th>IRRIG. SAND</th>
<th>CLAY SOILS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic</td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Conventional</td>
<td>3.5</td>
<td>3.2</td>
</tr>
<tr>
<td>Conv., more grass</td>
<td>2.7</td>
<td>2.8</td>
</tr>
<tr>
<td>Org., pellets</td>
<td>2.0</td>
<td>2.5</td>
</tr>
</tbody>
</table>

IRRIG. SAND CLAY SOILS
Energy use in organic and conventional production systems

Land used for 500 t milk production:

<table>
<thead>
<tr>
<th></th>
<th>ORGAN.</th>
<th>CONV.</th>
</tr>
</thead>
<tbody>
<tr>
<td>AREA, HA</td>
<td>71</td>
<td>44</td>
</tr>
<tr>
<td>% FEED IMPORT</td>
<td>20</td>
<td>35</td>
</tr>
</tbody>
</table>

Area needed conventional farm

Extra area organic farm
LCA of organic and conventional milk, environmental impacts per kg fresh milk ab farm, relative values, conventional= 100

![Graph showing environmental impacts of organic and conventional milk production.](image-url)
Sources of greenhouse gases: related to cheese production, g CO₂-equiv. per kg cheese

Analyserer 1 kg materiale 'Cheese.'; Metode: EDIP, (LCAfood), uden tox / EDIP World/Dk / karakterisering

www.LCAfood.dk
Framework for Life Cycle Assessment (LCA) of Danish pork

- Soybean production (Argentina)
- Fertiliser production
- Grain production
- Farm in Denmark
- Slaughterhouse

Gases and pollutants:
- CO₂
- Nitrous oxide
- Nitrate
- Methane
- Sulfur dioxide

How it works:
1. Soybean production in Argentina
2. Fertiliser production
3. Grain production
4. Farm in Denmark
5. Slaughterhouse
What types of greenhouse gases are emitted during the production of Danish pork?

- Nitrous oxide (44%)
- Methane (19%)
- Fossil CO₂ (36%)
- Others (1%)
Where do the greenhouse gases come from? (production of 1 kg pork meat at retail)
LCA for pork meat and milk, Farm process
Contribution to Global Warming Potential

www.lcafood.dk
Farm level contributions to important greenhouse gases: N2O per kg pig and CH4 per kg milk
Transport and its contribution to global warming

Slaugterring in Denmark

Global warming + 8%
Distance: 300 km

Hamburg in Germany

Global warming + 3%
Distance: 670 km
1 day, + 5°C

Global warming + 0.2%
Harwich in UK
Distance: 21,000 km
40 days, - 20°C

Global warming + 7%

Global warming
2.4 kg CO₂-eq. per kg pork from farm gate

Study for the Danish Meat Association, Dalgaard et al., 2007
Is transport of Danish pork an environmental hot spot?

- No! The transport of pork only contributes with a small part (1.5%) of the total greenhouse gases emitted from the product chain of pork.

"Local food systems can reduce "food miles" and transportation costs, offering significant energy savings. The vast majority of energy used in the U.S. food system (around 80 percent) goes to processing, packaging, transporting, storing, and preparing food." http://attra.ncat.org/farm_energy/food_miles.html

The ‘food miles’ is too simple as an environmental indicator, especially for livestock products!!
**LCA of Danish pork (2005): More than greenhouse gas emissions!**

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Unit</th>
<th>1 kg Danish pork</th>
<th>9 km car driving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global warming</td>
<td>kg CO₂ eq.</td>
<td>3.6</td>
<td>3.6</td>
</tr>
<tr>
<td>Nutrient enrichment</td>
<td>g NO₃ eq.</td>
<td>319</td>
<td></td>
</tr>
<tr>
<td>Acidification</td>
<td>g SO₂ eq.</td>
<td>59</td>
<td></td>
</tr>
</tbody>
</table>

Three main environmental categories relevant for assessment of livestock products:
Green house gas emission is not the only important dimension!
Pesticides use (Human and Eco tox) and smog not included here!

Functional Unit. 1 kg Danish pork (carcass weight) delivered to Harwich
Improvements in the environmental profile of Danish pork (1992-2005):

- Global warming: -17%
- Nutrient enrichment: -39%
- Acidification: -29%
The environmental profile of Danish pork has improved during the last 13 years. Why?

- Improved feed conversion: Less feed is used per kg pig produced
- Amino acid optimisation: Decreased protein content in feed => less Nitrogen in manure/slurry
- Reduced ammonia emission from manure/slurry and higher manure N use efficiency in the field crops
How can the environmental profile of Danish pork be further improved?

Two examples:

**Increased productivity (DK 2015)**
- Pigs weaned per sow per year (+10%)
- Feed consumed per kg pig (-10%)

**Anaerobic digestion of manure/slurry**
- All manure/slurry from pig is anaerobic digested and the gas is used for heat and power production
Biogas production from manure on pig farms

- Relative importance for GHG emissions per kg pork?
- Energy yield from manure:
- 22 m³ methane per tonnes = 1.7 + 3.3 kWh => Substitution of gas power plant (!) => Avoided emission of 49 t CO2 Eq.
Two examples of improvements

- Global warming
- Nutrient enrichment
- Acidification

DK2005 = 100

DK 2005
DK 2015
Anaerobic digestion
How to account for emissions from manure?

Global warming potential per pig: 12% of the emissions are from manure. Nitrous oxide (N2O) dominates.

Emissions from stable and storage:
Ammonia
Nitrous oxide

Emissions from fields:
Ammonia
Nitrous oxide
Nitrate
Phosphate

What if manure is transferred from a pig farm to a cash crop farm?

Who bears the burden?
LCA methodology:

Increased demand for pork => more manure!

Pig farm

Emissions (only the most important)
- Ammonia
- Nitrous oxide
- Fossil CO₂
- Nitrate

Cash crop farm

Use of artificial fertilizer

- Ammonia
- Nitrous oxide
- Nitrate
- Fossil CO₂
- Nitrous oxide

Manure transfer

‘System expansion’ is used as an alternative to allocation between co-products:
Manure use leads to avoided fertilizer use and production
Inventory for ‘1 kg manure-N exported from pig farm’:

- 600 g N artificial fertilizer
+ 5.3 liters diesel for transport (3 km)
+ 69 g ammonia-N
+ 21 g nitrous oxide-N
+ 310 kg nitrate-N

Total N = 1000 g

Characterized results:

Acidification potential: 133 g SO₂ eq.
Eutrophication potential: 1.75 kg NO₃ eq.
Global warming potential: 578 g CO₂ eq.

Impact assessment: EDIP (version 2.03)
Global warming potential per kg manure-N exported from pig farm

Impact assessment method: EDIP (version 2.03)

Transport (3 km)  Cash crop farm  Avoided production of artificial fertilizer  Total (578 g CO₂ eq.)

kg CO₂ eq.
Global warming potential per kg manure-N exported from pig farm

Impact assessment method: EDIP (version 2.03)

Impact assessment method: EDIP (version 2.03)
LCA of pork from Danish organic and conventional farms

Trade offs:
- Animal welfare and agro-ecology vs environment and GHG
- Energy use in stables (cost of construction and running costs) vs emissions of GHG from fields
- The relative importance of buildings and soil C changes for GHG emissions from pork production
LCA of pork from Danish farm

<table>
<thead>
<tr>
<th>Impact category²</th>
<th>Organic pig system¹ / Unit</th>
<th>Free range sows</th>
<th>All pigs free range</th>
<th>Tent system</th>
<th>Conventional system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global warming (GWP 100)</td>
<td>g CO₂-eq</td>
<td>g CO₂-eq</td>
<td>g CO₂-eq</td>
<td>g CO₂-eq</td>
<td>g CO₂-eq</td>
</tr>
<tr>
<td>Soil C sequestration³</td>
<td>g CO₂-eq</td>
<td>g CO₂-eq</td>
<td>g CO₂-eq</td>
<td>g CO₂-eq</td>
<td>g CO₂-eq</td>
</tr>
<tr>
<td>Acidification</td>
<td>g SO₂-eq</td>
<td>g SO₂-eq</td>
<td>g SO₂-eq</td>
<td>g SO₂-eq</td>
<td>g SO₂-eq</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>g NO₃-eq</td>
<td>g NO₃-eq</td>
<td>g NO₃-eq</td>
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**FU: 1 kg liveweight pig ab farm**

1): Organic systems from Halberg et al., 2007; conventional from Dalgaard et al., 2007.
2): Calculated according to EDIP method (Wenzel et al., 1997; updated 2003)
LCA of pork from Danish farm

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</thead>
<tbody>
<tr>
<td>Global warming (GWP 100)</td>
<td>g CO₂-eq</td>
<td>2920 b⁴</td>
<td>3320 a</td>
<td>2830 b</td>
<td>2700</td>
</tr>
<tr>
<td>Soil C sequestration</td>
<td>g CO₂-eq</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acidification</td>
<td>g SO₂-eq</td>
<td>57.3 a</td>
<td>61.4 a</td>
<td>50.9 b</td>
<td>43</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>g NO₃-eq</td>
<td>269 b</td>
<td>381 a</td>
<td>270 b</td>
<td>230</td>
</tr>
</tbody>
</table>

*FU: 1 kg liveweight pig ab farm*

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## LCA of pork from Danish farm

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</tr>
</thead>
<tbody>
<tr>
<td>Global warming (GWP 100)</td>
<td>g CO₂-eq</td>
<td>2920 b&lt;sup&gt;4&lt;/sup&gt;</td>
<td>3320 a</td>
<td>2830 b</td>
<td>2700</td>
</tr>
<tr>
<td>Soil C sequestration</td>
<td>g CO₂-eq</td>
<td>-300</td>
<td>-400</td>
<td>-500</td>
<td>0</td>
</tr>
<tr>
<td>Acidification</td>
<td>g SO₂-eq</td>
<td>57.3 a</td>
<td>61.4 a</td>
<td>50.9 b</td>
<td>43</td>
</tr>
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<td>Eutrophication</td>
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**FU: 1 kg liveweight pig ab farm**

1): Organic systems from Halberg et al., 2007; conventional from Dalgaard et al., 2007.
2): Calculated according to EDIP method (Wenzel et al., 1997; updated 2003)
Green house gas emissions from Barley under different soil tillage systems

<table>
<thead>
<tr>
<th>Soil tillage system</th>
<th>Conventional</th>
<th>Reduced</th>
<th>No-till</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield, diesel use and emissions per ha barley</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield (kg)</td>
<td>4904</td>
<td>4904</td>
<td>4414</td>
</tr>
<tr>
<td>Diesel for traction (litre)</td>
<td>74.8</td>
<td>54.7</td>
<td>42.7</td>
</tr>
<tr>
<td>Nitrous oxide (kg N2O)</td>
<td>4.8</td>
<td>4.8</td>
<td>4.8</td>
</tr>
<tr>
<td>CO2 from SOM, (kg)</td>
<td>990</td>
<td>623</td>
<td>440</td>
</tr>
<tr>
<td>GHG emissions per kg barley, CO2 Equivalents</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total of all processes (g CO2)</td>
<td>817</td>
<td>676</td>
<td>725</td>
</tr>
<tr>
<td>Soil organic matter (g CO2)</td>
<td>492</td>
<td>380</td>
<td>417</td>
</tr>
<tr>
<td>Fertiliser (N) (g CO2)</td>
<td>213</td>
<td>213</td>
<td>213</td>
</tr>
<tr>
<td>Traction (g CO2)</td>
<td>48.8</td>
<td>27.8</td>
<td>35.6</td>
</tr>
</tbody>
</table>
LCA of reduced tillage

- Dinitrogen monoxide contributed 53% and carbon dioxide 45% and methane less than 2% of the total emission of GHG per kg spring barley under conventional tillage.
- The larger part of carbon dioxide release (55%) came from the soil carbon mineralization, while fertiliser production accounted for 21% and traction for 15%.
- The CO2 “cost” of using machines in terms of the depreciation of their production costs (in CO2 units) accounted for less than 1% of total GHG emissions from barley production.
- Comparing with reduced and no tillage systems the main change in GHG emissions arise from the reduced CO2 release from mineralization while the difference in traction and machine use was less important.
How to establish Inventory for LCA?

Farm level:
- Representative data from accounts
- On-farm studies and surveys of input use, production level
- Calculation of nutrient flows and balances
- Modelling of emissions
Conclusions:

- Differences in energy use between livestock farming systems are significant but may be overshadowed by other emissions.
- The transport of Danish pork to UK contributes with 1.5% of the total amount of greenhouse gases emitted from the product chain of pork.
- The environmental profile of Danish pork has improved during the last 13 years due to improved feeding and manure use efficiency.
- Further improvements can be obtained by, for example, better feed efficiencies and anaerobic digestion of manure/slurry.
- Changes in Soil Organic matter are important when comparing farming systems with different crop rotations or tillage methods.
- Emissions from manure exported from the pig farm should be included in the LCA using systems expansion.
- Bioenergy production as integrated part of farming systems should be included in the LCA of livestock products: Need to know the marginal fossil energy source.
- Statistical methods for comparing products and food chains in need!
Interested in more details? Maybe you’ll find them at ‘The Danish LCA food database’

Milk, beef, pork, milk, cheese, butter, oat, wheat, mackerel, lobster, potatoes, bread, rape seed, egg, chicken, rye, etc....

Organic vs conventional, ...

Visit: www.LCAfood.dk
Thank you ouuuu...!
Critical issues re. Data quality

- Farm level production and emissions often contribute the most important part of LCA on food items
- Models vs farm data for input and production?
- Representativity
- Coherence
- Models vs experimental data for emissions?
Critical issues when comparing products, food chains and production methods

- Consistency in LCA methodology across products (consequencial vs attributional, allocation vs systems expansion, systems delimitation)
- Comparable data handling and modelling approach (representativity,
- Interpreting differences between foods and farm types: When is the energy use or GHG emission from one product larger than another?
- Statistical testing at specific items in the chain (farm level, transport distances, ...)
- Monte Carlo simulation of LCA results (available in std. Software packages)
- Prepare for testing when modelling or recording data: CV’s are needed!
LCA methodology: critical decisions

- What are the questions we want the answers to? (Jeopardy type modelling?)
- The questions should guide the LCA approach
- If the focus is on changed consumer behavior then model the consequences of changed demand for different food products
- Systems delimitation: Farm inputs generally come from a world market
- Sourcing local inputs or food products must assume changed/increased production to be a relevant alternative (?)
- Systems expansion for modelling impact of co-products: What are the marginal products to replace and what are the world market situation for these products?
Interpretation of LCA results:

- Normalisation and comparing with other foods?
- Taking into account site-specific environmental conditions?
LCA of 1 kg cheese: Information for product declarations…??

A: Normalised by one kg of average food consumption

B: Normalised by an average product consumed with the same cost
LCA of 1 kg cheese: Information for product declarations…??

C: Normalised by average food consumption at identical cost

A. B.
Development in pig production

(ton)

10,000,000

9,000,000

8,000,000

7,000,000

6,000,000

5,000,000

4,000,000

3,000,000

2,000,000

1,000,000

0


United States of America
Spain
Brazil
Denmark
Netherlands
Comparative LCA of pork: Site generic (in-dependant) impact assessment

Anne Merete Nielsen, 2.-0 LCA consultants
Llorenç Milà i Canals, CES (University of Surrey)
Imke de Boer, Bo Weidema, Pere Fullana,
Niels Halberg
Comparative LCA of pork: Site dependant impact assessment

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Soybean meal production

- Soybean meal 1000 g
- Soybean oil 191 g
- Soybean mill
- Soybeans 1210 g
- Soybean cultivation 4.5 m²

Avoided production of oil palms

- Palm oil -191 g
- Palm kernel oil -20 g
- Palm kernel meal -23 g
- Palm kernel mill
- Palm oil from mesocarp -171 g
- Palm kernels -20 g
- Palm oil mill
- Fresh fruit bunches -852 g
- Oil palm cultivation -0.5 m²
- Organic residues -630 g

Marginal meal production

- Marginal meal 17 g
- Soybean meal 5 g
- Spring barley 12 g
- Spring barley cultivation 0.02 m²
- Avoided production of oil palms
Soybean meal production

- Soybean meal 1000 g
- Soybean oil 191 g
- Soybeans 1210 g
- Soybean cultivation 4.5 m²

Avoided production of rapeseeds

- Rapeseed oil -191 g
- Rapeseeds -525 g
- Rapeseed cultivation -1.2 m²

Marginal meal production

- Marginal meal 305 g
- Spring barley 92 g
- Spring barley cultivation 0.2 m²
Variation in greenhouse gas emissions per kg pork on ten farms delivering to the same slaughterhouse (avr. over a year)
# Organic and Conventional Carrot production

<table>
<thead>
<tr>
<th>Per Ha</th>
<th>Conventional</th>
<th>Organic intensive</th>
<th>Organic Extensive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertiliser kg N</td>
<td>83</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fertiliser kg P</td>
<td>48</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Manure, kg N</td>
<td>-</td>
<td>270</td>
<td>135</td>
</tr>
<tr>
<td>Electricity, kWh</td>
<td>518</td>
<td>518</td>
<td>518</td>
</tr>
<tr>
<td>Diesel, MJ</td>
<td>14981</td>
<td>18758</td>
<td>15768</td>
</tr>
<tr>
<td><strong>Yields</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carrots, ton</td>
<td>61,6</td>
<td>52,8</td>
<td>40,0</td>
</tr>
<tr>
<td><strong>Emissions, selected</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate-N, kg</td>
<td>17</td>
<td>150</td>
<td>39</td>
</tr>
<tr>
<td>Ammonia-N, kg</td>
<td>8</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>Nitrous Oxide-N, kg</td>
<td>2</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

Selected inputs and yield of saleable product per hectare per year
LCA af Danske økologiske og konventionelle gulerødder, Funktional enhed: 1kg ab lager, relative Konv=100

Not Included: Pesticides!!
# Mælkebedrifter

<table>
<thead>
<tr>
<th></th>
<th>Konv. mælk</th>
<th>Øko. mælk</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input pr. ha</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foder, kg N</td>
<td>103</td>
<td>39</td>
</tr>
<tr>
<td>Kunstgødning, kg N</td>
<td>55</td>
<td>0</td>
</tr>
<tr>
<td><strong>Produkter pr. ha</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mælk, tons EKM</td>
<td>7,7</td>
<td>5,7</td>
</tr>
<tr>
<td>Kød &amp; afgrøder, tons</td>
<td>0,5</td>
<td>0,3</td>
</tr>
<tr>
<td><strong>Tab pr. ha</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrat-N</td>
<td>108</td>
<td>32</td>
</tr>
<tr>
<td>Ammoniak-N</td>
<td>43</td>
<td>27</td>
</tr>
<tr>
<td>Lattergas-N</td>
<td>9</td>
<td>6</td>
</tr>
</tbody>
</table>