Life Cycle Assessment (LCA) of organic food and farming systems

Focusing on greenhouse gas emissions, carbon sequestration potential and methodological challenges and status

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Background

• Food production and consumption: approx. 25% of GHG
  (33% if deforestation for agriculture included)

• Organic agriculture:
  • Offers alternative food production systems (and food supply and consumption?)

• Does organic make a difference with regard to climate change?
  • Not specifically considered in regulation
  • Need to know to preserve credibility and comply with organic principles

• Life Cycle Assessment (LCA) – best tool for greenhouse gas emissions

• Challenges of LCA for organic products
  • Interactions in farming systems
  • Carbon sequestration
Aim of the report

- Overview and contribution to Life Cycle Assessment (LCA) methods, models and databases to be used for greenhouse gas estimates of organic food and farming systems

Three main sections:

1. Overview of greenhouse gas emissions of organic vs. conventional products

2. Main methodological challenges within LCA of organic products
   a. How to allocate and account for interactions in farming systems?
   b. How to account for carbon sequestration?

3. Inventory and emissions for LCA of organic products
   a. Representativity and consistency of data
   b. Estimation of emissions
# Outline of the report

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1.3 LCA methodology

- Global warming
- Acidification
- Ozone depletion
- Nutrient enrichment
- Pesticide pollution
- Land use
- Soil fertility and erosion
- Biodiversity

ICROFS
1.3 LCA methodology: Example of LCA of conventional milk
1.3 LCA methodology

Example: LCA of organic orange juice
1.3 LCA methodology: Example of LCA of orange juice

**Objective**

- To compare the environment impacts in the production of organic oranges at small-scale farms with organic large-scale farms and or small-scale conventional farms in Brazil.

- To identify the environmental hotspots in the product chain of organic orange juice from small-scale Brazilian farms imported to Denmark.
1.3 LCA methodology: Example of LCA of orange juice

Functional unit

1. One tonne of oranges produced in the State of São Paulo, Brazil leaving farm gate

2. One litre of organic orange juice grown and processed to concentrate in Brazil, reconstituted and imported to retail distribution centre in Denmark
1.3 LCA methodology: Example of LCA of orange juice

**Impact categories**

- Global warming
- Eutrophication
- Non-renewable energy use
- Acidification
- Biodiversity
- Land use

**Life cycle assessment framework**

- Goal and scope definition
- Inventory analysis
- Impact assessment
- Interpretation
1.3 LCA methodology: Example of LCA of orange juice

System boundaries and allocation
INVENTORY

INPUT
Materials
- Fertilizer
- Seeds or seedlings

Energy
- Fuel
- Natural gas
- Electricity

Chemicals
- Pesticides
- Cleaning substances

Other
- Land use
- Water use

OUTPUT
Crop yield
Residues or co-product

Emissions to air ($N_2O$, $NH_3$, $CO_2$ etc.)

Emissions to soil and water ($NO_3^-$, pesticides etc.)

Production of inputs → Agricultural production → Processing → Packaging → Supermarket

Orange
1.3 LCA methodology: INVENTORY - Estimate emissions

**N INPUT**
- Organic fertilizer
- Mineral fertilizer
- \(N_2\) fixation
- Precipitation, deposition
- Seeds or seedlings

**N OUTPUT**
- Crop yield
- Residues or co-product

**Emissions to air (N\(_2\)O, NH\(_3\) etc.)**

**N balance**

**Emissions to soil and water (NO\(_3^-\) etc.)**

\[ N_{\text{input}} - N_{\text{output}} = N_{\text{surplus}} \]

- Denitrification (incl. N\(_2\)O)
- Ammonia loss (NH\(_3\))
- Nitrate loss (NO\(_3^-\))
- Soil N pool

IPCC guidelines 2006
1.3 LCA methodology: **Impact assessment**

Life cycle assessment framework

- Goal and scope definition
- Inventory analysis
- Impact assessment
- Interpretation

- Emissions are converted and aggregated into the chosen impact categories
### From emissions to impact category...

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Unit</th>
<th>Contributing elements</th>
<th>Characterization factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use</td>
<td>m²</td>
<td>Land occupation</td>
<td>1 for all types of land use</td>
</tr>
<tr>
<td>Non-renewable energy</td>
<td>MJ</td>
<td>Non-renewable energy consumption</td>
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<td>Global warming</td>
<td>CO₂ equivalents</td>
<td>CO₂</td>
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<td></td>
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<td>CH₄</td>
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<td>N₂O</td>
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<tr>
<td>Acidification</td>
<td>SO₂ equivalents</td>
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<td>NH₃</td>
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<td>NOₓ</td>
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<td>NO₃⁻ equivalents</td>
<td>NO₃⁻</td>
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<td></td>
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<td>NH₄⁺</td>
<td>3.64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NOₓ</td>
<td>1.35</td>
</tr>
</tbody>
</table>
Environmental impacts at farm gate

**Eutrophication**
(kg NO₃-eq / t oranges)

- Organic, small-scale: 0.055
- Organic, large-scale: 0.050
- Conventional, small-scale: 0.044

**Non-renewable energy use**
(MJ/ t oranges)

- Land use: 0.050
- Acidification: 0.044
- Global warming: 9.9
- 84
- 8
- 764
- 752
- 952
- 9.9

**Acidification**
(kg SO₂ eq / t oranges)

- Organic, small-scale: 1.1
- Organic, large-scale: 0.7
- Conventional, small-scale: 0.5

**Global warming**
(kg CO₂ eq/ t oranges)

- Organic, small-scale: 11.3
- Organic, large-scale: 9.9
- Conventional, small-scale: 8.1
1.3 LCA methodology.

Example: LCA of organic orange juice

<table>
<thead>
<tr>
<th>INPUT</th>
<th>FARM</th>
<th>PROCESSING</th>
<th>TRANSPORT</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>96</td>
<td>71</td>
<td>244</td>
</tr>
<tr>
<td>12</td>
<td>42</td>
<td>54</td>
<td>71</td>
</tr>
<tr>
<td>12</td>
<td>13</td>
<td>63</td>
<td>39</td>
</tr>
<tr>
<td>Crop (N2O)</td>
<td>Traction</td>
<td>Processing</td>
<td>Truck transport, FCOJ</td>
</tr>
<tr>
<td>10%</td>
<td>20%</td>
<td>30%</td>
<td>40%</td>
</tr>
</tbody>
</table>

Global warming potential (g CO2 eq /kg orange juice)
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5 CONCLUSIONS AND OUTLOOK

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2 Greenhouse gas emissions: Organic vs. conventional

20 studies: Organic lower GHG emissions per kg than conventional

8 studies: Conventional lower GHG emissions per kg than organic

Idea after Niggli et al. (2008)
2 Greenhouse gas emissions: Organic vs. conventional

14 studies: Organic lower GHG emissions per kg than conventional

3 studies: Conventional lower GHG emissions per kg than organic

Idea after Niggli et al. (2008)
2.4 Important hotspots and mitigation options in organic food chains: Organic orange juice imported from Brazil to Denmark

<table>
<thead>
<tr>
<th>Input production</th>
<th>Farm</th>
<th>Processing</th>
<th>Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop (N2O)</td>
<td>12</td>
<td>96</td>
<td>71</td>
</tr>
<tr>
<td>Traction</td>
<td>42</td>
<td>54</td>
<td>71</td>
</tr>
<tr>
<td>Input production</td>
<td>13</td>
<td>63</td>
<td>39</td>
</tr>
<tr>
<td>Truck transport, inputs</td>
<td>15</td>
<td>115</td>
<td></td>
</tr>
<tr>
<td>Truck transport, FCOJ</td>
<td>244</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Truck transport, juice</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Global warming potential (g CO2 eq /kg orange juice)**
2.4 Important hotspots and mitigation options in organic food chains: Organic soybeans imported from China to Denmark

<table>
<thead>
<tr>
<th>INPUT</th>
<th>FARM</th>
<th>PROCESSING</th>
<th>TRANSPORT</th>
</tr>
</thead>
<tbody>
<tr>
<td>3%</td>
<td>35%</td>
<td>11%</td>
<td>51%</td>
</tr>
</tbody>
</table>

Global warming potential (kg CO₂ eq./ton soybeans per year)

- Inputs
- Crop production (N₂O)
- Traction
- Processing
- Ship
- Truck
- Rail

- 13
- 108
- 43
- 48
- 187
- 16
- 15
2.4 Important hotspots and mitigation options in organic food chains:

Mitigation options: Farm level

- ENERGY
  - CO₂
- NITROGEN
  - N₂O
- CARBON
  - CH₄
  - CH₄ & N₂O
2.4 Important hotspots and mitigation options in organic food chains:

Mitigation options: Farm level

- Fuel
- Irrigation
- Crop drying
- Choice of crops
- Plant and livestock efficiency

Nitrogen utilisation
- Minimise N loss from field, stable and storage

Methane emissions
- Avoid peat soils
- Increase carbon sequestration
2.4 Important hotspots and mitigation options in organic food chains

Mitigation options: Food system issues

- Reduce meat consumption
- Minimise transport of inputs and products
- Minimise food waste
- Reduce packaging
- Reduce consumption of highly processed food
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3 LCA of complex agricultural systems: methodological challenges

3.1 How to allocate and account for interactions in farming systems?

3.2 How to account for carbon sequestration in LCA?
CONVENTIONAL

INPUT
Materials
- Mineral fertilizer
- Deposition
- Seeds or seedlings
Energy
- Fuel
- Natural gas
- Electricity
Chemicals
- Pesticides
- Cleaning substances
Other
- Land use
- Water use

OUTPUT
- Crop yield
- Meat and milk yield
- Residues or co-product

Emissions to air (N₂O, NH₃, CO₂ etc.)
Emissions to soil and water (NO₃⁻, pesticides etc.)

CROP e.g. wheat

Fertilizer production etc.
Agricultural production
Processing
Packaging
Supermarket
ORGANIC

Livestock systems

Manure

CROP ROTATION

Emissions to air ($N_2O$, $NH_3$, $CO_2$ etc.)

INPUT

Green manure crop

Wheat

Catch crop

Potatoes

Pea-barley intercrop

OUTPUT

Emissions to soil and water ($NO_3^-$, pesticides etc.)

Transport

Production of inputs

Agricultural production

Processing

Packaging

Supermarket
Problem: How to find the environmental impact of the individual food crop when this is produced in a complex system and one cannot just grow more of that particular crop without impacting on/relying on the other parts of the system

In LCA this is translated to, how to allocate impacts (or benefits) of resource flows within the system. A simple example is how to allocate the environmental impact of meat and milk from a dairy production:

The typical LCA reasoning

1. If the system can be considered as producing a main product and one or more by-products then allocate the entire impact to the main product and correct for any resource savings that the supply of by-products results in. If this is not the case then:

2. If the individual product’s drawing on resources can be meaningfully modelled by bio-physical relations then split the environmental impact according to this

3. Otherwise allocate according to mass or economic value

Can these principles be applied to integrated organic systems and how
3.1 How allocate and account for interactions in farming systems?

Options and our recommendation

System delimitation at:

- **Crop level:**
  - Allocate environmental impacts (or benefits) from green manure, crop residues etc.) according to
    - Area (equally on the crops)
    - N residual/utilization effects of following crops

- **Crop rotation level:**
  - Use one functional unit (e.g. food basket in MJ)
  - Allocate environmental impacts according to
    - economic value of the crops, area (per ha) or mass (per kg DM)
3.1 How to allocate environmental impacts from imported manure?
3.1 How to allocate environmental impacts from imported manure?
3.1 How to allocate and account for manure?

GWP of organic wheat as dependent on how the imported resource ‘manure’ has been accounted for, g CO2e/ kg

![Graph showing GWP of organic wheat](image.png)
3.1 How allocate environmental impacts from imported manure?

Options and our recommendation

- Regard manure as waste from livestock system
  - Plant production will pay for environmental emissions related to transport and application in the field

- Regard manure as a valuable source of N, that otherwise needs to be produced (what is the consequence of using it?) => thus find shadow price of alternative source
  - As mineral fertilizer => environmental costs of production and use of mineral fertilizer = shadow price
  - As green manure => environmental costs of production of green manure = shadow price
  - Other? (recycled waste)
3 LCA of complex agricultural systems: methodological challenges

3.1 How to allocate and account for interactions in farming systems?

3.2 How to account for carbon sequestration in LCA?
3.2 How to account for carbon sequestration in LCA?

- Changes in organic C stocks
  - Soil carbon change
  - Land use change (LUC)
    - Direct (new agricultural land for crop production)
    - Indirect (demand for previous land use move to other places)
### 3.2.1 Soil carbon sequestration

#### LCA of pig production in Denmark

<table>
<thead>
<tr>
<th></th>
<th>Organic pig production</th>
<th>Conventional pig production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Free range sows</td>
<td>All pigs free range</td>
</tr>
<tr>
<td><strong>Global warming potential</strong>&lt;sub&gt;100&lt;/sub&gt;</td>
<td>2920</td>
<td>3320</td>
</tr>
<tr>
<td>(g CO₂ eq/ kg product)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Effect of soil C change</strong>&lt;sub&gt;20&lt;/sub&gt;</td>
<td>-300</td>
<td>-400</td>
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<tr>
<td>(g CO₂ eq/ kg product)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GWP, corrected</strong></td>
<td>2620</td>
<td>2920</td>
</tr>
</tbody>
</table>
### 3.2 Soil carbon sequestration

#### LCA of orange production in Brazil

<table>
<thead>
<tr>
<th></th>
<th>Organic</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Global warming potential</strong>&lt;sub&gt;100 years&lt;/sub&gt; (g CO₂ eq/ kg product)</td>
<td>84</td>
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<td><strong>Effect of soil C change</strong>&lt;sub&gt;IPCC 20 years&lt;/sub&gt; (g CO₂ eq/ kg product)</td>
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<tr>
<td><strong>GWP, corrected</strong> (g CO₂ eq/ kg product)</td>
<td>51</td>
<td>112</td>
</tr>
</tbody>
</table>
3.2.1 Soil carbon sequestration

![Graph showing soil carbon sequestration over time.](image)

- Change in management
- Initial C sequestration
- Final C sequestration

(C in soil vs. Time)
### 3.2 Soil carbon sequestration

Consequential LCA of soybean production methods in China

<table>
<thead>
<tr>
<th></th>
<th>Organic</th>
<th>Conventional</th>
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<td>263</td>
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<td>( \text{IPCC 20 years} )</td>
<td>(g CO(_2) eq/ kg product)</td>
<td>(g CO(_2) eq/ kg product)</td>
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<tr>
<td>( \text{IPCC 20 years} )</td>
<td>(g CO(_2) eq/ kg product)</td>
<td>(g CO(_2) eq/ kg product)</td>
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<td><strong>Effect of soil C change</strong></td>
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<td>+132</td>
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<tr>
<td>( \text{New method 20 years} )</td>
<td>(g CO(_2) eq/ kg product)</td>
<td>(g CO(_2) eq/ kg product)</td>
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<td><strong>Effect of soil C change</strong></td>
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<tr>
<td>( \text{New method 100 year} )</td>
<td>(g CO(_2) eq/ kg product)</td>
<td>(g CO(_2) eq/ kg product)</td>
</tr>
</tbody>
</table>
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5 CONCLUSIONS AND OUTLOOK

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5 Conclusions and outlook

- LCA best tool for greenhouse gas emissions related to agricultural products
- Suboptimisation when focusing on climate change as single environmental impact category
- Farm production and transport are important hotspots
- Earlier studies: no remarkable difference in GHG emissions between organic and conventional products
  - However: soil carbon changes have traditionally not been included!
- Challenges of LCA for organic products
  - Interactions incl. manure should be addressed
  - Carbon sequestration should be included
- Quality data and emission estimates for inventory