LCA of animal production: from temperate to tropical systems

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Case Studies

- Life Cycle Assessment of dairy farms (EDEN)
- Chicken production systems (AviTer)
- Fish aquaculture systems (EVAD)
LCA tool: EDEN

Evaluation de la Durabilité des Exploitations
Objectives

• Estimate the potential environmental impacts of milk production
• Identify the key processes or stages that contribute to potential impacts (“hotspots”)
• Divide total impacts into direct (on-farm) and indirect (pre-farm) components
Input Data

- farm structure
- livestock
- herd management
- buildings and wastes
- crops and fertiliser management
- mineral fertilisers
- concentrated feed
- forages and other plants
- pesticides
- energy consumed
- plastics consumed
- machinery
Structure of EDEN

Practices
Inputs
Calculations
Resources Used and Emissions
Characterization factors
Potential Impacts

Characterization method: CML 2001 baseline
Functional Units

- 1000 kg fat-and-protein-corrected milk (FPCM)
- global hectares: on-farm and estimated off-farm surface area occupied
Dairy farms of the ETRE and BIO networks

- Organic farm
- Conventional farm
### Impacts per 1000 kg of milk and per ha of land occupied

<table>
<thead>
<tr>
<th>Impact</th>
<th>Per 1000 kg of milk sold</th>
<th>Per ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eutrophication</td>
<td>kg PO4 eq.</td>
<td>5.0</td>
</tr>
<tr>
<td>Acidification</td>
<td>kg SO2 eq.</td>
<td>6.8</td>
</tr>
<tr>
<td>Climate change</td>
<td>kg CO2 eq.</td>
<td>1082</td>
</tr>
<tr>
<td>Terrestrial toxicity</td>
<td>kg 1.4-DCB eq.</td>
<td>0.75</td>
</tr>
<tr>
<td>Energy use</td>
<td>GJ</td>
<td>2.6</td>
</tr>
<tr>
<td>Land occupation</td>
<td>m².year</td>
<td>2085</td>
</tr>
</tbody>
</table>

Yellow = significant \((P<0.05)\) difference
Energy use and GHG emissions/1000 kg of milk versus kg milk sold per ha

- Energy Use - conventional
- Energy Use - organic
- Climate change - conventional
- Climate change - organic

kg FPCM sold per ha of on- and off-farm land occupied

Pot. impacts per 1000 kg FPCM sold (MJ or Kg CO2-eq.)
Eutrophication per 1000 kg of milk versus kg milk sold per ha

Pot. impact per 1000 kg FPCM sold (kg PO₄-eq.)

kg FPCM sold per ha of on- and off-farm land occupied

- Eutrophication - conventional
- Eutrophication - organic

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Conclusion

• Strong variability in potential environmental impacts exists among farms, even within the same production mode (conventional vs. organic)
• The effect of production mode on impacts is strong for a functional unit of 1 ha, but weak for the functional unit of 1000 kg of milk sold
• With modification, this tool could be applied to tropical dairy production systems
AviTer

- AviTer = Filières Avicoles en France et au Brésil : Impacts sur le Développement Durable des Bassins de Production et des Territoires
- Economic, social, and environmental analysis of production regions in France and Brazil
- Brazilian partners:
Introduction

**Objective:** show the influence of different scenarios of Brazilian grain production on meat chicken production

- Most environmental impacts come from feed production (maize and soybeans)
- Much variability exists in maize and soybean production in Brazil
- Thus, one single type of “Brazilian” maize and soybean does not exist
Methods

The most representative regions for maize, soybean, and chicken production:

- Center-West (CW)
- South (SO)
System Limits

Main flows of the chicken production system

- Grain production (maize and soybean)
- Mineral and medical supplements
- Feed production
- Water
- Energy
- Farmer, Technicians, Industry
- Manure storage
- Soil and water emissions
- Organic waste
- Animal feed
- Packaging industry
- Poultry equipment industry
- Chicken processing
- Product (whole, cuts, processed meat)
- Domestic consumption
- Export market
- Transportation
- Limit at the port
- Limit at the slaughterhouse gate

* Adapted from Spies (2003)
Methods

• Grain production: We examined different levels of use of inorganic and organic (slurry) fertilizers, pesticides, machines, input transport distances, crop yields, and deforestation.

• Other variables: transport distances (grains, feed, chicken, litter), electricity consumption, emissions in buildings and from manure storage, feed conversion ratio, chicken density, and final liveweight.
Methods

Distances involved in each scenario

**Santa Catarina, southern Brazil - SC**
- Farm to Feed Prod.: 42 km, 13 t/truck
- Farm to Hatchery: 100 km
- Farm to Slaughterhouse: 95 km, 3130 birds/truck
- Slaughterhouse to Port: 544 km
- Hatchery to Port: 1650 km

**Goiás, Center-West of Brazil - CW**
- Farm to Feed Prod.: < 42 km, 26 t/truck
- Farm to Hatchery: 100 km
- Farm to Slaughterhouse: < 100 km, 7170 birds/truck
- Slaughterhouse to Port: 60 km
- Hatchery to Port: 1650 km
Methods

Feed production scenarios (maize and soybean) for each region:

**Tillage**
- no-till (80%)
- plowing (20%)

**Fertilizer**
- organic (pig slurry) + added N (0.4 - 4.8%)
- inorganic (95.2 – 99.6%)

<table>
<thead>
<tr>
<th>Region</th>
<th>Fertilizer</th>
<th>Maize</th>
<th>Soybean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No-till</td>
<td>Plowing</td>
</tr>
<tr>
<td>Center West</td>
<td>Pig slurry</td>
<td>0.4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Inorganic</td>
<td>79.6</td>
<td>20</td>
</tr>
<tr>
<td>South</td>
<td>Pig slurry</td>
<td>4.8</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>Inorganic</td>
<td>75.2</td>
<td>18.8</td>
</tr>
</tbody>
</table>
Methods

Functional Unit:

- **maize and soybean:** 1 tonne of grain delivered to regional storage facility
- **feed:** 1 tonne produced at the factory
- **chicken:** 1 tonne of live chickens delivered to the slaughterhouse

Characterization method: CML 2001 baseline

Impact categories:
- climate change
- cumulative energy demand
- eutrophication
- terrestrial ecotoxicity
Results and discussion

Impact variability of soybean in Brazil:

Deforestation (CW)
Fertilization level (↑ CW)
Crop yields (↑ CW)
Transportation (↑ CW)
Emissions: phosphate (soil loss) (↑ CW)
    nitrate loss (↑ SO)
    heavy metals: inorganic fertilizer (↑ CW)
    and slurry (↑ SO)
Results and discussion

Impact of producing 1 tonne of soybeans

Climate change

Cumulative energy demand
Results and discussion

Impact variability of maize production in Brazil:

Deforestation (maize after soybean in CW)
Crop yields (↑ SO)
Transportation (↑ CW)
Emissions: phosphate (soil loss) (↑ CW)
heavy metals: slurry (↑ SO)
Results and discussion

Impacts of producing 1 tonne of maize

Climate change

Cumulative energy demand

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Results and discussion
Impacts of producing 1 tonne of feed

Climate change
Cumulative energy demand

<table>
<thead>
<tr>
<th></th>
<th>SO moyenne</th>
<th>CW moyenne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other ingredients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean oil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean meal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Results and discussion

Impacts of producing 1 tonne of feed

**Eutrophication**

**Terrestrial ecotoxicity**

- **SO moyenne**
- **CW moyenne**

**Transportation**
- **Electricity**
- **Other ingredients**
- **Soybean oil**
- **Maize**
- **Soybean meal**
Results and discussion
Impacts of producing 1 tonne of chickens

Climate change
Cumulative energy demand

-200
0
200
400
600
800
1000
1200
1400
kg CO₂ eq.

Avoided fertilizer
Transportation
Electricity
Litter
Natural gas
Feed
Farm emissions

-5000
0
5000
10000
15000
20000
MJ

Centre Ouest
Sud
Conclusion

The largest contribution to environmental impacts of chicken production in Brazil is the production and transport of maize and soybeans.

Deforestation, transportation (diesel consumption), and fertilizer and machine use are key factors that influence the environmental impacts of feed production.
Conclusion

Improvement paths for chicken in Brazil:

- End deforestation for grain production
- Improve transportation logistics for grain, feeds, and chicken
- Optimize fertilization and machine use to decrease emissions of greenhouse gases
- Follow soil conservation practices to decrease erosion
- Improve production techniques to increase grain yields
- Adopt integrated pest management to minimize the use of pesticides
Life Cycle Assessment
Fish Production Systems in Temperate and Tropical Areas

Rainbow trout in pond

Sea bass and sea bream in cage

Tilapia, Catfish in pond with pig

Shrimp, crab and fish polyculture

Catfish in pond

Carp and Tilapia in double-layer net cage
System definition

- Raw material extraction
- Infrastructure building
- Equipment manufacturing
- Fish production
- Feeds processing
- Waste management
## Potential Impact Categories

<table>
<thead>
<tr>
<th>Impact Categories</th>
<th>Unit</th>
<th>Resources and Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy use</td>
<td>MJ</td>
<td>Coal, oil, gas, uranium, lignite</td>
</tr>
<tr>
<td>N. Prim. Production use</td>
<td>kg C</td>
<td>Biotic resources</td>
</tr>
<tr>
<td>Climate Change</td>
<td>kg CO₂-eq</td>
<td>CO₂, N₂O, CH₄</td>
</tr>
<tr>
<td>Acidification</td>
<td>kg SO₂-eq</td>
<td>NH₃, NO₂, NOₓ, SO₂</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>kg PO₄-eq</td>
<td>NH₃, NO₃, NO₂, NOₓ, PO₄, COD, ThOD</td>
</tr>
<tr>
<td>Water dependence</td>
<td>m³</td>
<td>River, sea, spring, ground water</td>
</tr>
<tr>
<td>Surface use</td>
<td>m²</td>
<td>Land</td>
</tr>
</tbody>
</table>

Characterization method: CML 2001 baseline
Rainbow trout flow-through system in Brittany

- Carnivorous fish
- Artificial feeds 40% protein
- FCR: around 1.0
- Growth: 8-24 months (depending on final fish size)
- Yield: 50-400 tonnes per fish farm/year
- No water recirculation
- Often use of liquid oxygen
- Water outlet filtering
Sea bass and sea bream cages in the Mediterranean Sea

- Carnivorous fish
- Sea cages
- 45-50% of protein in feeds with high level of marine sources
- FCR: around 2.0
- Growth: 18-30 months
- Yield: 200-600 tonnes per farm
- Direct release of wastes into the sea
Polyculture of shrimp, crabs, tilapia and milkfish in brackish ponds in the Philippines

Polyculture system of five species
• Black tiger prawn (*Panaeus monodon*)
• King mud crab (*Scylla serrata*)
• Orange mud crab (*Scylla olivacea*)
• Milkfish (*Chanos chanos*)
• Tilapia (*Oreochromis niloticus*)
**System characteristics**

<table>
<thead>
<tr>
<th>Species</th>
<th>Stocking density (per m²)</th>
<th>Mortality rate (%)</th>
<th>Production (kg/ha/yr)</th>
<th>Price (peso)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black tiger prawn</td>
<td>5.61</td>
<td>95</td>
<td>218</td>
<td>375 to 700 per kg</td>
</tr>
<tr>
<td>Mud crab</td>
<td>0.51</td>
<td>50</td>
<td>191</td>
<td>70 to 300 per pcs</td>
</tr>
<tr>
<td>Milkfish</td>
<td>0.70</td>
<td>32</td>
<td>269</td>
<td>40 to 60 per kg</td>
</tr>
<tr>
<td>Tilapia</td>
<td>0.64</td>
<td>39</td>
<td>563</td>
<td>30 to 40 per kg</td>
</tr>
</tbody>
</table>

Note: The pond size varies from less than 1 to more than 10 hectares
Polyculture of tilapia and clarias in ponds in Cameroon

- Association of tilapia (*O. niloticus*) and Clarias (*C. gariepinus*)
- Pond size around 200 m²
- Ponds fed with pig or chicken manure and vegetable wastes
- Ponds integrated in family agriculture system
- Yield: around 5 tonnes/ha/year
Production of Pangasius in ponds on Sumatra, Indonesia

- Pond size 600 m²
- Density of 15-20 fingerlings/m²
- Locally-made feed (dried fish 45% and rice bran 40%)
- FCR: varies from 1.4-2.0
- Harvesting partially depends on market demand (harvested size is 4-5 fish/kg)
- Yield: around 1-1.5 tons/pond
Production of carp and tilapia in net cages in Cirata lake, Java, Indonesia

- Double-net cages
- Density is 35 fingerling carp/m³
- Feeds (around 25% protein) composed of 20% fish meal
- FCR: around 1.7
- Yield: 9-18 kg/m³/yr
Eutrophication
For 1 tonne of fish

Eutrophication (kg eq. PO₄)

0
50
100
150
200
250
300
350
400

Truite Bret.
Cages Méd.
Polyc. Cameroun
Cages Côtea
Panga.Tangkit
Polyc. Philippines

Marketing
On farm Energy
Infrastructures / equipment
Chemicals
Animal manure
Feed production
Eggs / Fingerlings
Rearing stage
Climate Change
For 1 tonne of fish

Climate change (kg eq. CO₂)

- Marketing
- On farm Energy
- Infrastructures / equipment
- Chemicals
- Animal manure
- Feed production
- Eggs / Fingerlings
- Rearing stage

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Acidification
For 1 tonne of fish

Acidification (kg eq. SO₂)

- Marketing
- On farm Energy
- Infrastructures / equipment
- Chemicals
- Animal manure
- Feed production
- Eggs / Fingerlings
- Rearing stage

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Energy Use
For 1 tonne of fish

Energy use (MJ)

- Marketing
- On farm Energy
- Infrastructures / equipment
- Chemicals
- Animal manure
- Feed production
- Eggs / Fingerlings
- Rearing stage

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Net Primary Production Use
For 1 tonne of fish

NPP use (kg C)

- Marketing
- On farm Energy
- Infrastructures / equipment
- Chemicals
- Animal manure
- Feed production
- Eggs / Fingerlings
- Rearing stage
Land Occupation
For 1 tonne of fish

Land occupation (m²)

- Marketing
- On farm Energy
- Infrastructures / equipment
- Chemicals
- Animal manure
- Feed production
- Eggs / Fingerlings
- Rearing stage

For 1 tonne of fish

- Truite Bret.
- Cages Méd.
- Polyc. Cameroun
- Cages Cirala
- Panga.Tangkit
- Polyc. Philippines

Marketing

- Infrastructures / equipment
- Chemicals
- Animal manure
- Feed production
- Eggs / Fingerlings
- Rearing stage
Comparative LCA Profiles

Each impact expressed relatively to the higher level.
Conclusion

• What are the hot spots in aquaculture systems from a LCA point of view?
  – Intensification level and efficiency of input use
  – Feed components and feeding management
  – Energy consumption and energy carriers
  – Freshwater dependence

• Improvement paths
  – Trophic chain optimization
  – Marine input substitution
  – Recycling
  – Integrated systems (e.g., co-production)
  – Health management
  – Energy management
General Comments

• Animal and crop production systems more varied in tropical than in temperate regions

• Because fewer data exist for tropical production systems, data collection will require surveys

• Because most impacts of animal production are due to feed production, more data about tropical crop production are necessary

• Emission, fate, and characterization factors from temperate climates should be used with caution in tropical climates

• Additional site-specific experiments and models would improve prediction of these factors
LCA Approach

System definition

Inventory analysis

Impact evaluation

Expressed per Functional Unit (e.g., kg of meat)