What drives environmental impacts of fertilizers produced from fish wastes?

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Background

The increase of waste from fish processing and aquaculture

- Increase in fish production and consumption.
- 5.7 million tonnes in the EU (European Commission, 2020)
- High amounts of waste (Villamil et al., 2017)
  - 50 – 70% waste (viscera etc.)
  - 50% of waste directly discarded
- High nutrient content of waste (Zang et al., 2023)
- → High potential to be valorised to biobased fertilizers.

FAO (2022)

1961: 9 kg of fish / capita
2019: 20.5 kg of fish / capita
The project

Sea2Land

• Pilot production of biobased fertilisers (BBF) from fish waste.
  – 3 pilot studies on aquaculture waste
  – 3 pilot studies on processing waste of wild catch
• Aims:
  – Develop BBFs, determine agronomic & economic potential and environmental impacts.
• Here: Life cycle assessment of selected BBFs conducted inputs

emissions

waste  processing  fertiliser
LCA approach

- **Aims:** Identify hotspots in pilot BBF production to optimize environmental performance
- **Scope:** Cradle-to-factory gate with “burden-free” assumption for organic waste streams
- **Function unit:** Environmental impact of 1 kg fertilizer produced
- **Allocation for co-products:** Economic allocation
- **Impact assessment:** Midpoint impacts from ImpactWorld+ (5 relevant indicators selected)
  - Climate change (short term, GWP 100)
  - Terrestrial Acidification
  - Marine Eutrophication (N)
  - Freshwater Eutrophication (P)
  - Mineral resource use
## From fish waste to BBF: Processes of case studies

<table>
<thead>
<tr>
<th>Input (waste)</th>
<th>Estonia</th>
<th>Spain</th>
<th>Italy</th>
<th>Norway</th>
<th>France</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Salmon scraps &amp; food waste</td>
<td>Viscera (and tuna cooking brine)</td>
<td>Mollusk and fish waste</td>
<td>Fish sludge</td>
<td>Fish processing waste (heads, frames)</td>
</tr>
<tr>
<td><strong>External processes</strong></td>
<td><strong>Transport to BBF factory</strong></td>
<td><strong>Transport to BBF factory</strong></td>
<td><strong>Transport to BBF factory</strong></td>
<td><strong>Mech. dewatering &amp; drying; Transport</strong></td>
<td><strong>Transport to BBF factory</strong></td>
</tr>
<tr>
<td>Mechanical treatment</td>
<td>Crushing</td>
<td>Grinding</td>
<td>Crushing / mincing</td>
<td>Mixing</td>
<td>Freezing &amp; Grinding</td>
</tr>
<tr>
<td>Main treatment</td>
<td><strong>Bokashi fermentation</strong></td>
<td>Acid autolysis</td>
<td>Enzymatic hydrolysis</td>
<td>-</td>
<td>Extrusion</td>
</tr>
<tr>
<td>Liquid-solid separation</td>
<td>Gravitational</td>
<td>Gravitational, centrifugation, membrane filtration</td>
<td>Centrifugation</td>
<td>-</td>
<td>Centrifugation</td>
</tr>
<tr>
<td>Shaping</td>
<td>Granulation</td>
<td></td>
<td></td>
<td>Pelleting</td>
<td>-</td>
</tr>
<tr>
<td>Drying</td>
<td>Sun-powered drum drying</td>
<td>Vacuum concentration</td>
<td>Vacuum concentration (spray drying)</td>
<td>High temperature drying</td>
<td></td>
</tr>
<tr>
<td>BBF (packaged)</td>
<td>Granules</td>
<td>NPK solution</td>
<td>Hydrolysates</td>
<td>Pellets</td>
<td>Solid BBF</td>
</tr>
</tbody>
</table>
Common environmental hotspots

Transport (fish waste to BBF factory)

• Relative contribution of transport to environmental impacts

- Processing of sides streams needs to be close to the source as possible. Co-benefits with odor emissions etc.
Common environmental hotspots

Drying

• Relative contribution of thermal drying to environmental impacts.

Reduction with more efficient technology in industrial scenario (GWP100: -60%).

• High water content (Zang et al., 2023) → Water removal / nutrient concentration key.
• → Drying needs to be combined with energy efficient de-watering and needs to be based on heat recovery.
• → Other options: low temperature drying, biodrying (↔ GHG emissions, Guerra-Gorostegi et al., 2021).
Other hotspots

- **Packaging**: Contribution to impacts ranges from 1% (France) to 25% (Estonia) for GWP100
  - → Packaging should be reduced, re-used and recycled as much as possible.

- **Capital goods: Buildings** have a high contribution to Mineral Resources Use (6% and 40%).
  - → Efficient use of buildings. Less important:
    - Materials for machinery (and mechanical treatment)

- **Enzymes (Italian pilot study)**:
  - High impact due to enzyme substrate (maize, corn, wheat starch) on Freshwater Eutrophication.
  - Hydrolysis needed (biostimulant effect measurable in field trials)? Alternatives: Acid autolysis (Domínguez et al., 2024). Use of ultrasound (Qian et al., 2023).
Discussion and conclusions

- **Environmental hotspots** for pilot production identified → Hotspots remained similar for assumed future industrial production.

- **Optimization:**
  - produce BBF close to fisheries
  - energy-efficient drying technology
  - reduce amount of packaging
  - test if optional high-impact processing steps (e.g. enzymatic hydrolysis) are agronomically justified

- **Burden-free assumption:**
  - Fisheries and aquaculture production excluded → if future demand increases, environmental impacts of potential system changes should be considered (e.g. Pradel et al., 2016)

**Outlook**

- Assess environmental impact of BBF use → including agronomic performance data (cradle-to-farm gate LCA of crop production with BBF).
- Comparison of crops fertilised with BBF vs. mineral fertilisation
References

### Reduction in impacts due to assumed upscaled production

<table>
<thead>
<tr>
<th></th>
<th>Global warming (GWP100)</th>
<th>Terrestrial acidification</th>
<th>Marine eutrophication</th>
<th>Freshwater eutrophication</th>
<th>Mineral resources use</th>
<th>Average per case study</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T3.1: Bokashi granules</strong></td>
<td>-10%</td>
<td>-13%</td>
<td>-15%</td>
<td>-1%</td>
<td>-36%</td>
<td>-15%</td>
</tr>
<tr>
<td><strong>T3.2: NPK solution with amino acids</strong></td>
<td>-37%</td>
<td>-59%</td>
<td>-51%</td>
<td>-22%</td>
<td>-86%</td>
<td>-51%</td>
</tr>
<tr>
<td><strong>T3.3: Hydrolysates</strong></td>
<td>-38%</td>
<td>-37%</td>
<td>-31%</td>
<td>-5%</td>
<td>-53%</td>
<td>-33%</td>
</tr>
<tr>
<td><strong>T4.1: Pelleted fish sludge</strong></td>
<td>Not upscaled (already at industrial scale)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>T4.2: Solid BBF</strong></td>
<td>-64%</td>
<td>-55%</td>
<td>-69%</td>
<td>-85%</td>
<td>-90%</td>
<td>-73%</td>
</tr>
<tr>
<td><strong>Average per impact category</strong></td>
<td>-37%</td>
<td>-41%</td>
<td>-42%</td>
<td>-28%</td>
<td>-66%</td>
<td>-</td>
</tr>
</tbody>
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LCA approach: More details (1)

- Basic assumptions: Burden free (use of ecoinvent cut-off, v.3)
- Upscaling of LCA:
  - Framework of van der Hulst et al., 2020:
    - **Process changes** (source of energy, source / ratio of sidestreams etc.)
    - **Size scaling** (larger machinery, buildings etc.) → efficiency gains?
    - **Minimizing waste / processing inputs**: Can inputs, waste-stream etc. be recycled? Synergies with other processes.
    - **External factors**: Change in future regulations or other (market) conditions?
    - **(Industrial learning)**: process beyond TRL 9, difficult to quantify
  - To reduce complexity: Only model expected changes in efficiency (different yield, processing time, inputs needed etc.).
LCA approach: More details (2)

- Impact assessment method: Impact world+ (Bulle et al., 2019). Selected midpoint indicators:
  - Climate change, short term (GWP100)
  - Terrestrial and freshwater acidification (Roy et al. 2014, 2012)
  - Marine eutrophication (Roet et al. 2012)
  - Freshwater eutrophication (Melmes et al., 2012, Tirado-Seco, 2005)
LCA upscaling assumptions Italian case study

- **Process changes:**
  - Change of drying process: Spray drying instead of vacuum evaporator (capacity, product quality) and gas as thermal energy source.
  - Different mix ratio of sidestreams (5:1 → 7:1 mollusc : fish waste) → more water needed to be heated removed again for concentrated hydrolysate production (Petrova et al., 2018)

- **Size scaling**
  - Larger machines → Less processing duration (machinery use) / kg of output (mechanical processes; biochemical processes have same length).
  - Increased machinery utilization (8 h / 365 days / year | 24 h / 365 days / year for drying equipment).
  - Average industrial building use (ecoinvent)

- **Minimizing waste / processing inputs:**
  - Re-use of unused syngas from pyrolysis for drying of solid fraction of hydrolysis (instead of lab oven; Andreola et al., 2023) incl. changed emissions to air.

- **External factors:**
  - Removal of odor emissions with biofilter (Neri et al., 2018) to obtain operation / construction permit.