Life cycle assessment of microalgae: Challenges and lessons learned

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fair consulting in sustainability since 1998

INTRODUCTION: LCA AND ESU

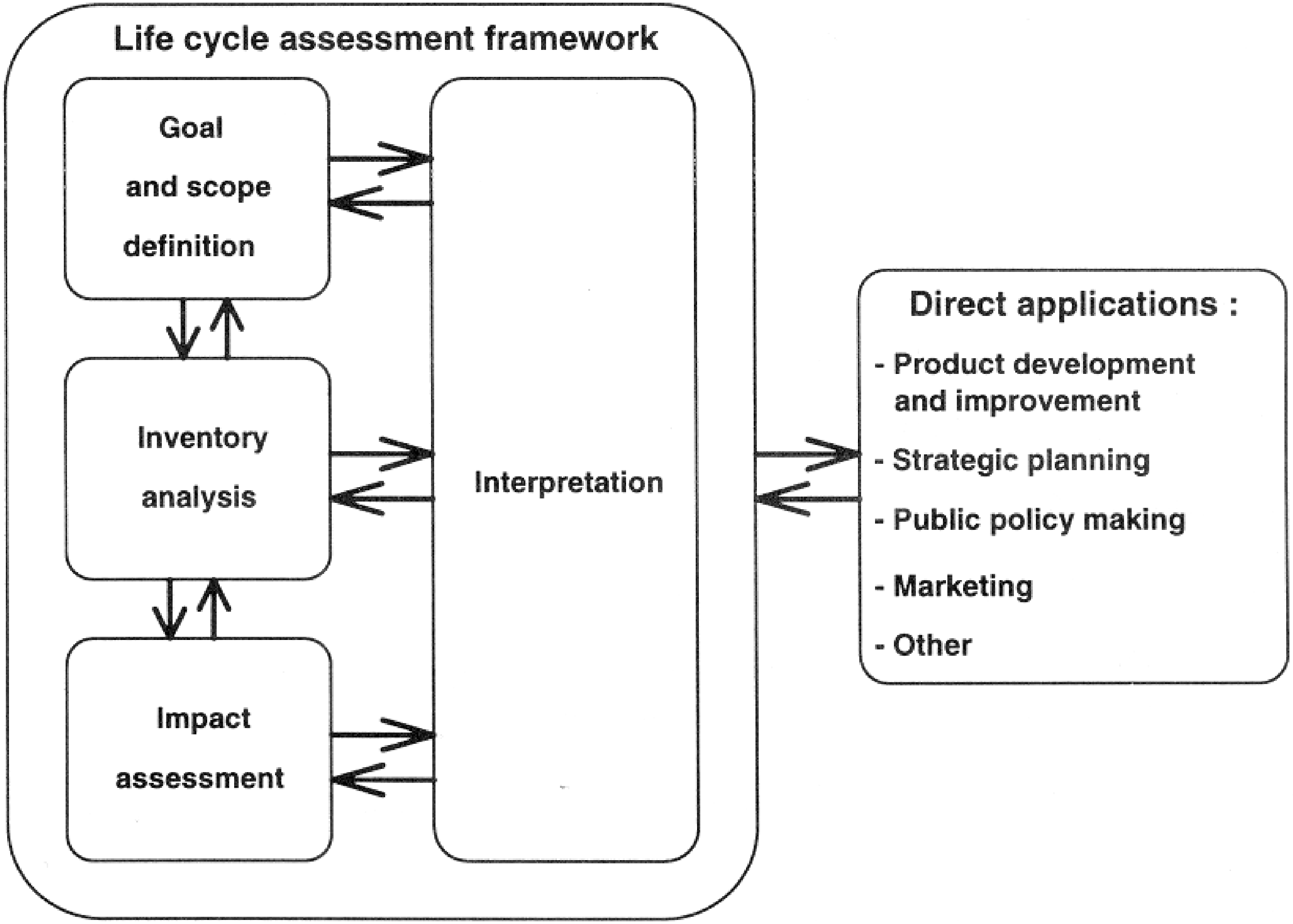
What is an LCA ?

- A model: depiction of reality
  - A model of the full life cycle of a product or service and its environmental impact.
  - A model that shows consequences of these environmental impacts on our health, the ecosystem (plants, animals and fungi) the economy, etc.
- Each model is a simplification of reality

Overview Life Cycle Assessment

- Life cycle from cradle to grave
- Goal and Scope Definition
- Balance of all in- and outputs according to the defined system boundaries & functional unit → Inventory
- Assessment of different environmental impacts (e.g. climate change, eutrophication, summer smog, etc…)
- Improvement and comparison of production processes

ISO standard 14040: LCA



Dr Niels Jungbluth

Founded 1998 @ETHZ

Samuel Solin, Christoph Meili, Maresa Bussa, Martin Ulrich

Clients from industry, NGOs, administration, universities

25+ years and 350+ projects experience in life cycle assessment

Company database with more than ten thousands of datasets

All economic sectors coved

In more detail

Our offer	Features	Price start at (CHF/€)	Months
Assess existing data	E.g. CO2-eq/kg for one product	200	<1
Screening LCA	Short report and first analysis for internal use, based on data for your product	9000	2-6
Full LCA	Comparison of your products, detailed analysis, suitable for publication	15000	3-9
Parameter model	Play around and see selected results when modifying key parameters of your process	10000	2-6
ISO compliant LCA	Full comparative LCA, peer reviewed by a third party	20000	4-12
Do it yourself	SimaPro Software, training and coaching	9000	1-6
Review	Review, Validation, Verification	2500	1

LCA OF MICROALGAE: CHALLENGES AND LESSONS LEARNED

Challenges: Emerging technology

- Technologies are often tested with small capacities and low technology-readiness-level
  - Optimum production parameter still to be determined
  - Less efficient

> LCA results can be used to identify hotspots and improve technology
> LCA results are often used to benchmark microalgae against reference products

Challenges: Comparisons

- Common benchmark products
  - Energetic use (e.g. biodiesel, bioethanol):
    - Diesel
    - Rape, Palm, Soybean, Sunflower
  - Feed and food:
    - Soybean, Rape, Pea, Whey
    - Egg, Fishmeal

➢ Compared systems differ in scale and matureness
➢ Unfavourable for microalgae

Case Study: Spray drier

- Microalgae Protein - Ingredients for the Food and Feed of the Future
- Two species:
  - Chlorella vulgaris: heterotrophic cultivation
  - Tetraselmis chui: autotrophic cultivation
- Functional unit: biomass with 1 kg protein
- Scope: cultivation and drying

	Electricity consumption	Yield
Pilot-scale	8.8	68%
Industrial-scale	2.1	88%

Case study: C. vulgaris

PRO FUTURE

Impact category	Unit	Pilot-scale	Reduced electricity consumption		Increased yield		Combined	
Ionising radiation	kBq U-235 eq	40.500	20.212	-50%	31.047	-23%	15.370	-62%
Human toxicity, non-cancer	CTUh	1.067E-6	7.453E-7	-30%	7.98E-7	-25%	5.495E-7	-49%
Eutrophication, marine	kg N eq	0.199	0.168	-16%	0.119	-40%	0.095	-52%
Ozone depletion	kg CFC11 eq	6.346E-6	4.584E-6	-28%	4.84E-6	-24%	3.479E-6	-45%
Water use	m3 depriv.	67.737	39.055	-42%	51.772	-24%	29.609	-56%
Resource use, minerals and metals	kg Sb eq	4.934E-4	4.092E-4	-17%	3.721E-4	-25%	3.071E-4	-38%
Resource use, fossils	MJ	1856.873	1120.679	-40%	1422.201	-23%	853.324	-54%
Land use	Pt	558.348	438.248	-22%	427.381	-23%	334.576	-40%
Ecotoxicity, freshwater	CTUe	1579.496	1208.941	-23%	1150.120	-27%	863.782	-45%
Acidification	mol H+ eq	0.517	0.338	-35%	0.394	-24%	0.255	-51%
Particulate matter	p inc.	2.321E-6	1.804E-6	-22%	1.756E-6	-24%	1.356E-6	-42%
Climate change	kg CO2 eq	85.990	50.930	-41%	65.506	-24%	38.415	-55%
Human toxicity, cancer	CTUh	4.561E-8	3.57E-8	-22%	3.31E-8	-27%	2.545E-8	-44%
Eutrophication, terrestrial	mol N eq	1.052	0.787	-25%	0.798	-24%	0.593	-44%
Photochemical ozone formation	kg NMVOC eq	0.204	0.131	-36%	0.154	-25%	0.098	-52%
Eutrophication, freshwater	kg P eq	0.084	0.047	-44%	0.061	-27%	0.033	-60%

- Larger reduction can be achieved with reduced electricity consumption
- In total, impacts can be reduced by ~ 50%

Case study: T. chui

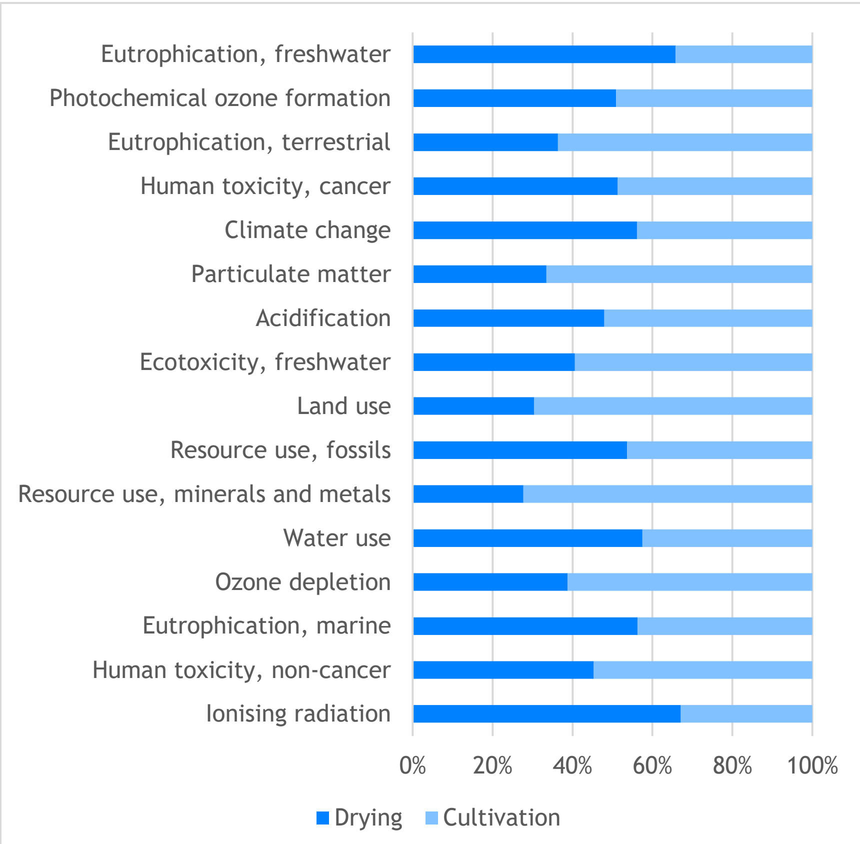
PRO FUTURE

Impact category	Unit	Pilot-scale	Reduced electricity consumption		Increased yield		Combined	
Ionising radiation	kBq U-235 eq	126.631	109.909	-13%	96.979	-23%	84.146	-34%
Human toxicity, non-cancer	CTUh	3.998E-6	3.733E-6	-7%	3.047E-6	-24%	2.843E-6	-29%
Eutrophication, marine	kg N eq	0.389	0.364	-7%	0.271	-30%	0.251	-35%
Ozone depletion	kg CFC11 eq	2.757E-5	2.612E-5	-5%	2.111E-5	-23%	1.999E-5	-27%
Water use	m3 depriv.	310.343	286.702	-8%	237.704	-23%	219.561	-29%
Resource use, minerals and metals	kg Sb eq	0.002	0.002	-4%	0.001	-24%	0.001	-26%
Resource use, fossils	MJ	5356.295	4749.492	-11%	4100.285	-23%	3634.599	-32%
Land use	Pt	1384.009	1285.017	-7%	1058.814	-23%	982.844	-29%
Ecotoxicity, freshwater	CTUe	4661.545	4356.118	-7%	3519.835	-24%	3285.437	-30%
Acidification	mol H+ eq	2.291	2.143	-6%	1.754	-23%	1.640	-28%
Particulate matter	p inc.	1.113E-5	1.071E-5	-4%	8.515E-6	-24%	8.187E-6	-26%
Climate change	kg CO2 eq	297.705	268.807	-10%	227.701	-24%	205.524	-31%
Human toxicity, cancer	CTUh	1.601E-7	1.519E-7	-5%	1.211E-7	-24%	1.148E-7	-28%
Eutrophication, terrestrial	mol N eq	2.422	2.204	-9%	1.847	-24%	1.679	-31%
Photochemical ozone formation	kg NMVOC eq	0.691	0.632	-9%	0.528	-24%	0.482	-30%
Eutrophication, freshwater	kg P eq	0.245	0.215	-12%	0.185	-24%	0.162	-34%

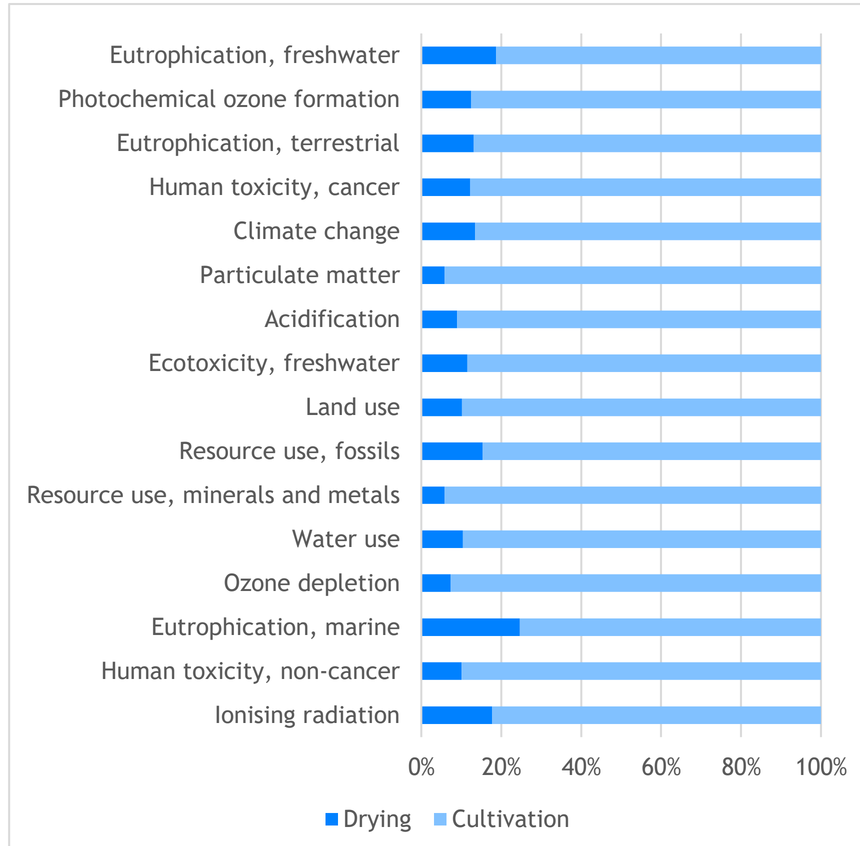
- Larger reduction can be achieved with increased yield
- In total, impacts can be reduced by ~ 30%

Case study: Spray drier

C. vulgaris



T. chui



Lessons learned: General

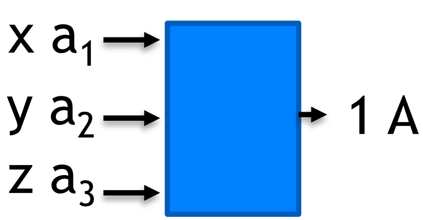
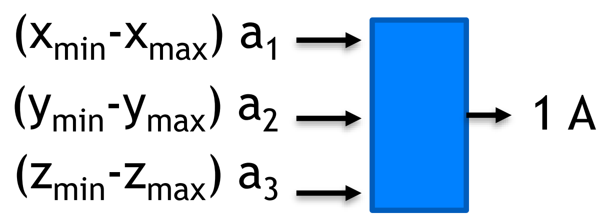
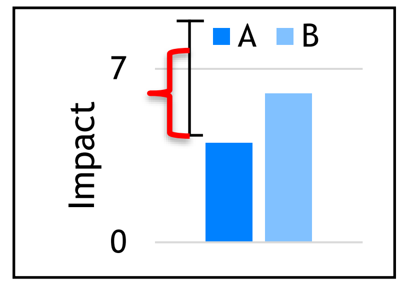
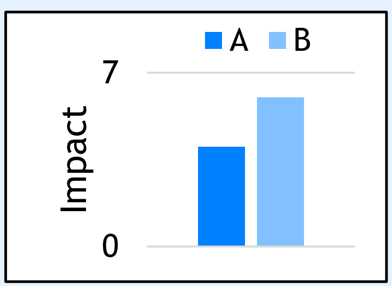
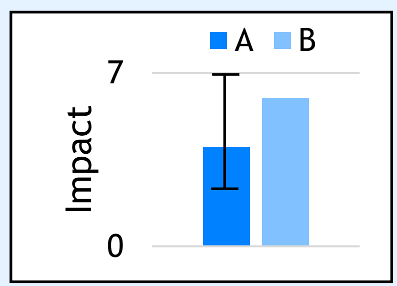
- Electricity consumption is a key driver of environmental impacts
- Cultivation is important
  - Increase yield of downstream processes
  - Test waste-streams as nutrition/carbon source
- Results cannot always be transferred from one specie to another

Lessons learned: Functional unit

- Especially relevant for food and feed sector
- Often a mass-based functional unit is used
- Might give wrong incentives if nutritional value differs considerably
- Main function of food is to provide nutrients

> at least present information about the content of main nutrients
> allows the reader to judge if different options really can be perceived as equal for the intended function in the diet

Lessons learned: Comparisons

Name	Life Cycle Assessment	Monte-Carlo Simulation (MCS)	MCS backwards
Research question	Is A better than B?		When is A better than B?
Starting point			
Result			x y z R_1 x_1 x_1 z_1 R_n x_n y_n z_n x_{lim} y_{lim} z_{lim}

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