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LCA of a next-generation microalgae cultivation system: Eco-design approach for emerging technologies

Penaranda, Diego | Morales, Marjorie | Guihéneuf, Freddy | Bernard, Olivier

Penaranda, et al., 2023.

BACKGROUND

Microalgae cultivation technologies

Conventional culture systems



Raceways & Photobioreactors

Next-generation culture systems



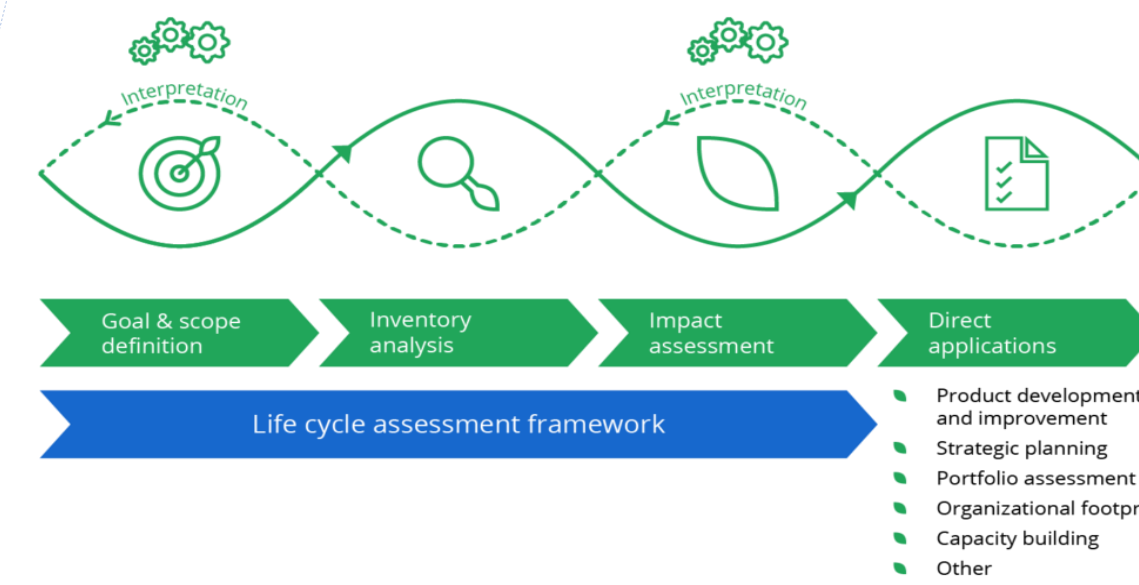
Rotative biofilms

Rotating algal biofilm has several advantages :

- **Higher cell concentrations:**
 - Avoid concentrations processes (energy and cost demanding)
 - Provide a ready-to-use product
- **Higher biomass productivities:**
 - Productivities more higher in RAB than ORP.
- **Reduced water body:**
 - Improve CO₂ mass-transfer rates.
 - Reduced doses of pesticides or antibiotics (contamination control)

Based on: Morales, et al., 2020.

Life cycle assessment and Eco-design



LCA of new technologies

Problems

- Lack of large-scale data
- Data based on largely theoretical knowledge (lab-scale, pilot-scale)

Solutions

Eco-design strategies:

- Selection of low impact material
- Optimal raw materials use.
- Reduction of energy requirements.
- Optimization of production techniques
- Optimization of initial lifetime
- Reduction of impact during use
- Reduction of end-of-life system

- **Upscaling to projected industrial scale level**
- **Optimization, uncertainty and sensitivity analysis of parameters**

Main objective

To carry out an LCA study with an eco-design approach to minimize the environmental life cycle impacts of a rotating cylinder biofilm technology for the cultivation of *Tetraselmis suecica*.

Specific objectives

- Implement a contribution analysis of process stages (or substances) to the environmental impacts.
- Identify the sensitive parameters that specify the design of the rotating cylinder biofilm system and their influence on the subsequent environmental burdens.
- Compare the environmental impacts of the protein meal produced in the rotating biofilm system with other protein sources, such as soymeal and fishmeal.
- Compare Inalve technology to other microalgae cultivation technologies, such as open raceways and rotative carpet biofilm.

MATERIALS AND METHODS

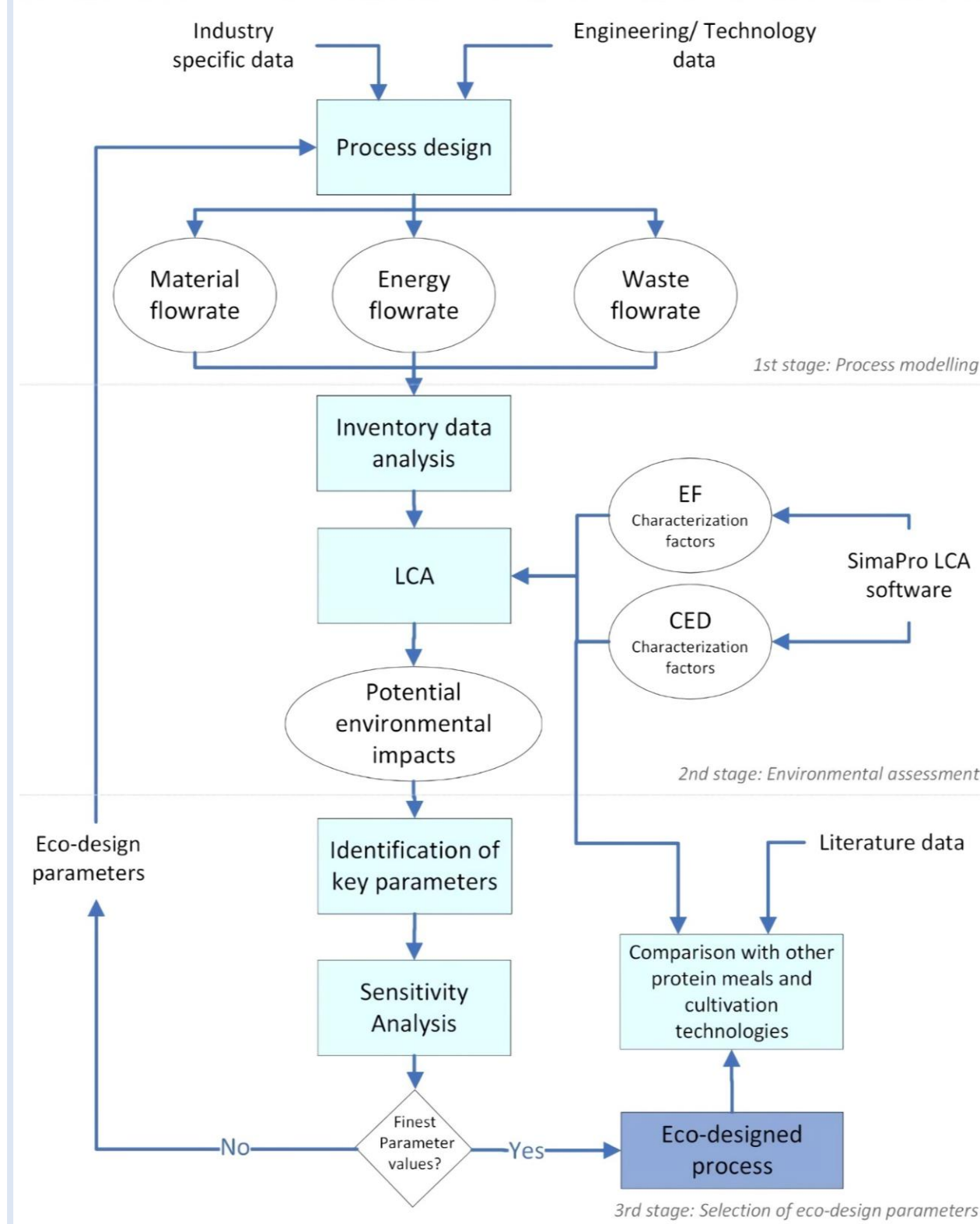


Fig.1. Research methodology

Discussion with experts

Discussion between experts in technology and LCA to explore how the pilot scale technology would differ from up-scaled technology

Physical calculations

Calculation based on mathematical and physical equations, stoichiometric relationships, scaling factors, etc.

Process simulation software

Data estimation methods that involve the use of simulation software and database.

Use of proxy

Approximate data by using information from already existing technology that shows high resemblance with the new technology.

Eco-design

Process design based on environmental, technical and economic aspects.

Recycling

Process design considering re-use and/or treatment of residues, e.g. WWT

Methodology source: Tsoy et al., 2020.

Fig.2. Extrapolation methods

The research methodology (Fig. 1) includes:

- 1st stage - process modeling; where, in addition to the conventional extrapolation methods, new objectives (eco-design and recycling) were included (see Fig. 2).
- 2nd stage - environmental assessment: at the system boundaries, water treatment and recycling were included (Fig. 3).
- 3rd stage - selection of eco-design parameters: the processes and parameters with the higher contribution by impact category were identified (see Fig. 4); an iterative sensitivity analysis to the parameters identified for the eco-design was performed (see Fig. 5); finally, the eco-designed technology and its product were compared with existing technologies (see Fig. 6).

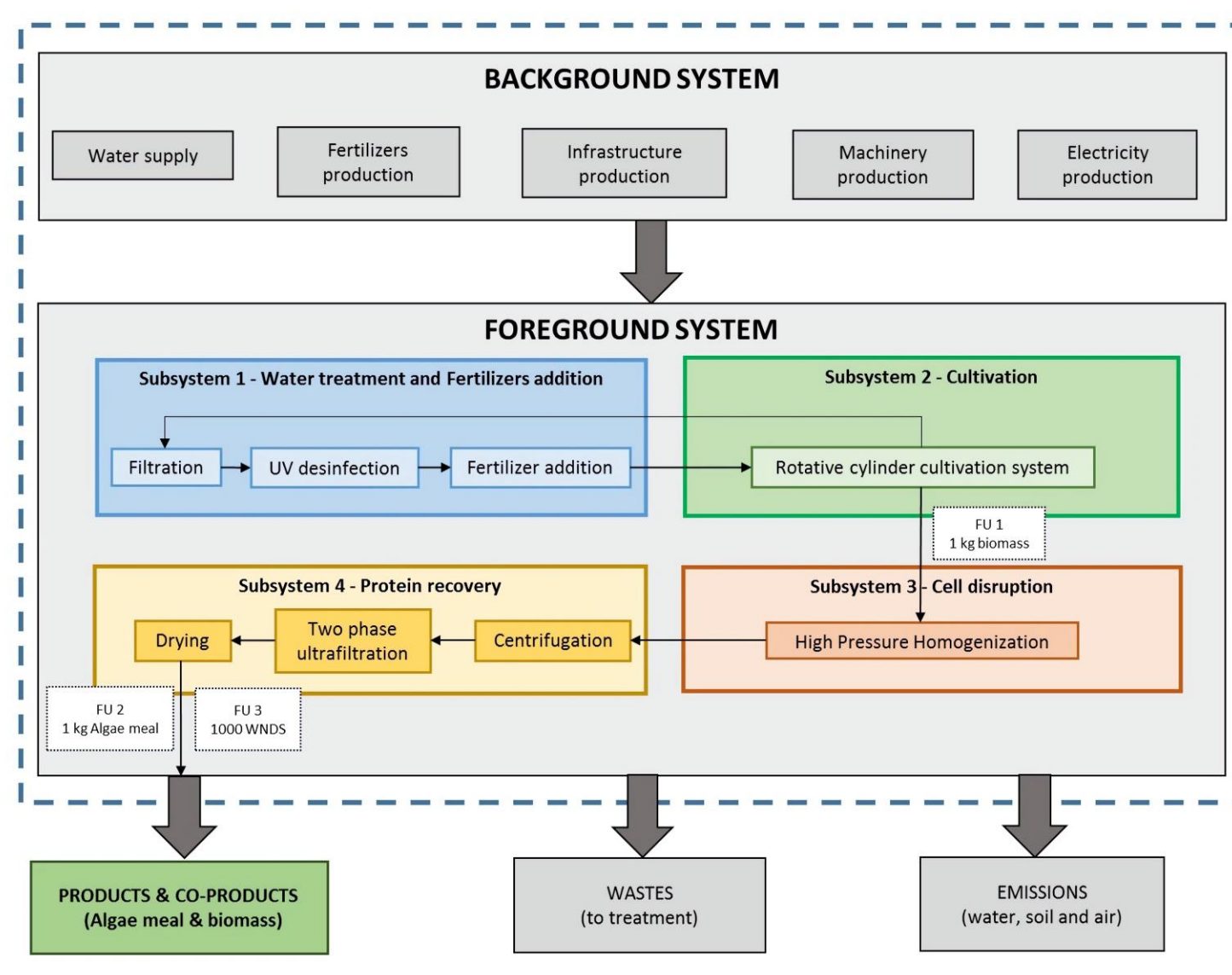


Fig.3. Pond to gate system boundaries.

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CONCLUSIONS

- This study proposes an eco-design approach dedicated to technologies at early design stages, for which extrapolation at industrial scale is necessary.
- The most impacting eco-design parameters are: NH₃ emission factor, Power blower, power rotator, Plastic used in the cylinder: Thickness and lifespan, Fabric material source and lifespan.
- Sensitivity analysis of these parameters shows environmental impact reduction between: 25% and 27.6% for CC, RI, A, 65.7% for LU, 88.3% for WS and 50.3% CED method.
- Algae meal from eco-designed rotating biofilm has an environmental impact reduced by at least 70.8% in comparison to conventional aquafeeds (fishmeal and soymeal).
- The methodology used in this work can be adapted and implemented to analyze other emerging technologies at early design stages, through the analysis, identification and selection of key parameters according to their environmental loads.

RESULTS

Subsystem	Process	CC	RI	A	ET	LU	WS	CED total	CED fossil
S1	Water consumption	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Machinery production	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
	Pipelines production	0.00	0.33	0.26	0.10	0.00	0.00	0.92	1.56
	Nutrients production	18.46	11.43	9.40	7.73	4.52	0.09	9.98	16.75
	Electricity consumption	0.06	0.02	0.01	0.01	0.04	0.03	0.57	0.05
S2	Cylinder production	0.00	3.17	2.50	0.97	0.00	0.00	8.83	15.01
	Pond concrete production	2.67	0.70	0.46	0.37	2.32	0.17	0.94	1.41
	Greenhouse production	0.60	0.28	0.13	0.07	0.19	0.00	0.22	0.38
	Machinery production	0.06	0.02	0.02	0.01	0.08	0.02	0.06	0.11
	Electricity consumption	1.25	0.40	0.29	0.13	0.74	0.64	11.31	1.07
S3	Machinery production	0.06	0.02	0.01	0.01	0.02	0.00	0.02	0.04
	Electricity consumption	0.05	0.02	0.01	0.01	0.03	0.03	0.47	0.04
	Machinery production	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Electricity consumption	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Machinery production	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Fig. 4. Environmental contributions (%) to EF and CED categories / process. FU: 1 kg algae meal

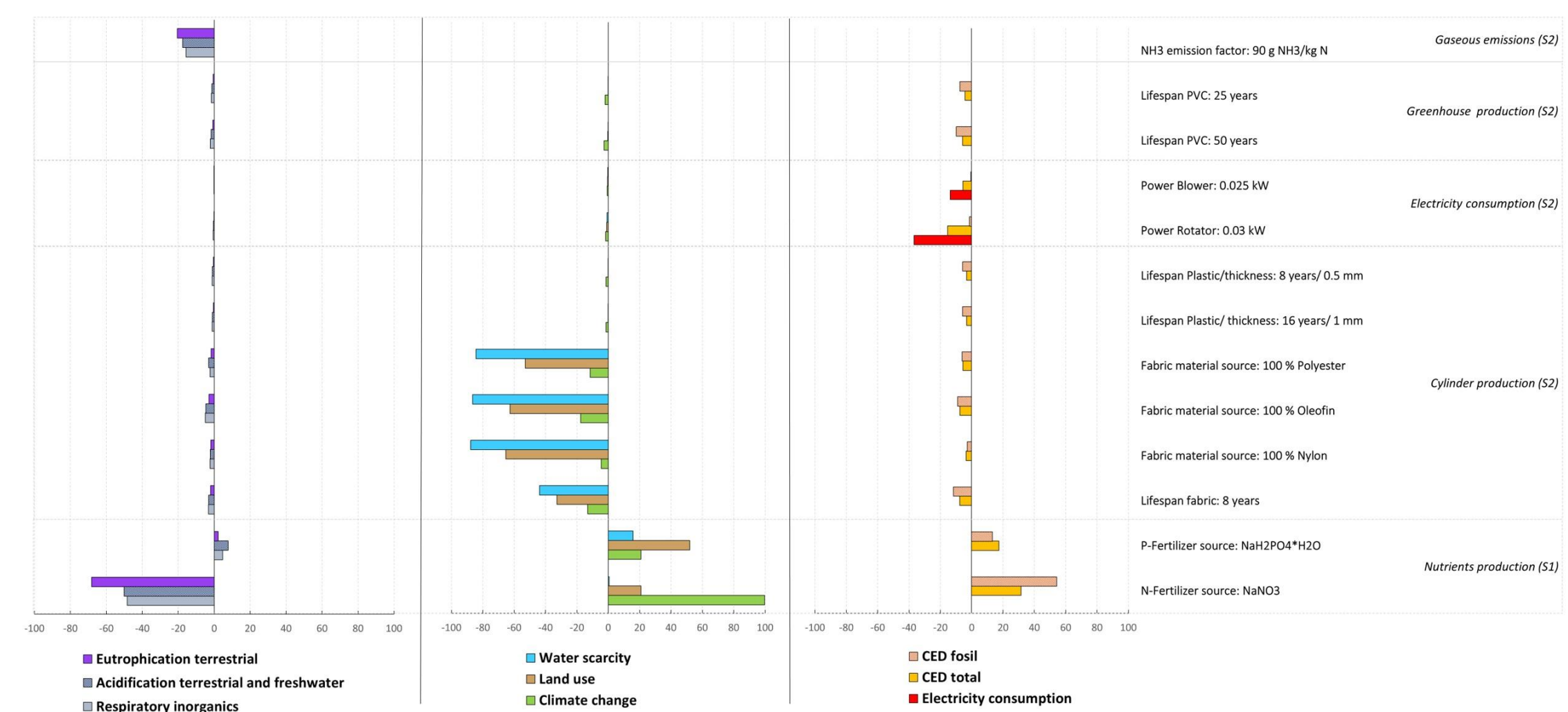


Fig. 5. Sensitivity Analysis of the key parameters.

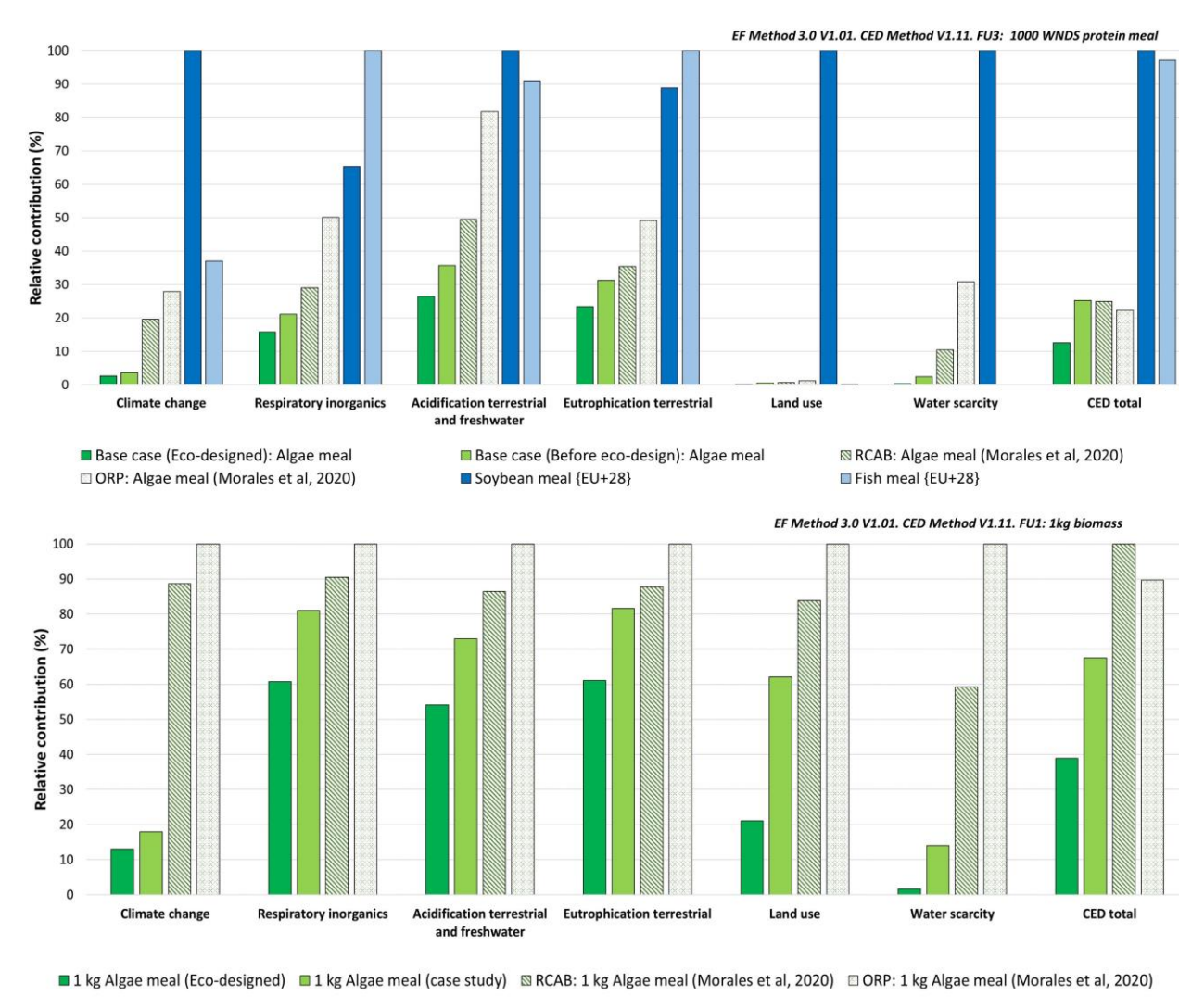


Fig. 6. Comparison of eco-designed algae meal production system versus conventional protein meals (a) and production systems (b).

The processes with contribution over 10% by impact category were NH₃ production, P₂O₅ production, cotton production, polyester production, rotator motor and blower electricity, and NH₃ emissions (Fig. 4).

The parameters identified for the eco-design were NH₃ emission factor, lifespan PVC, blower and rotator power, lifespan and thickness plastic, fabric material source, lifespan fabric, P-fertilizer source, and N-fertilizer source (Fig. 5).

The algae meal produced by the eco-designed system obtained reductions > 70.8%, in all the categories evaluated, compared to conventional protein meals (Fig. 6).