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Microalgae, are they really “green”?

Evaluating environmental impacts with Life Cycle Assessment

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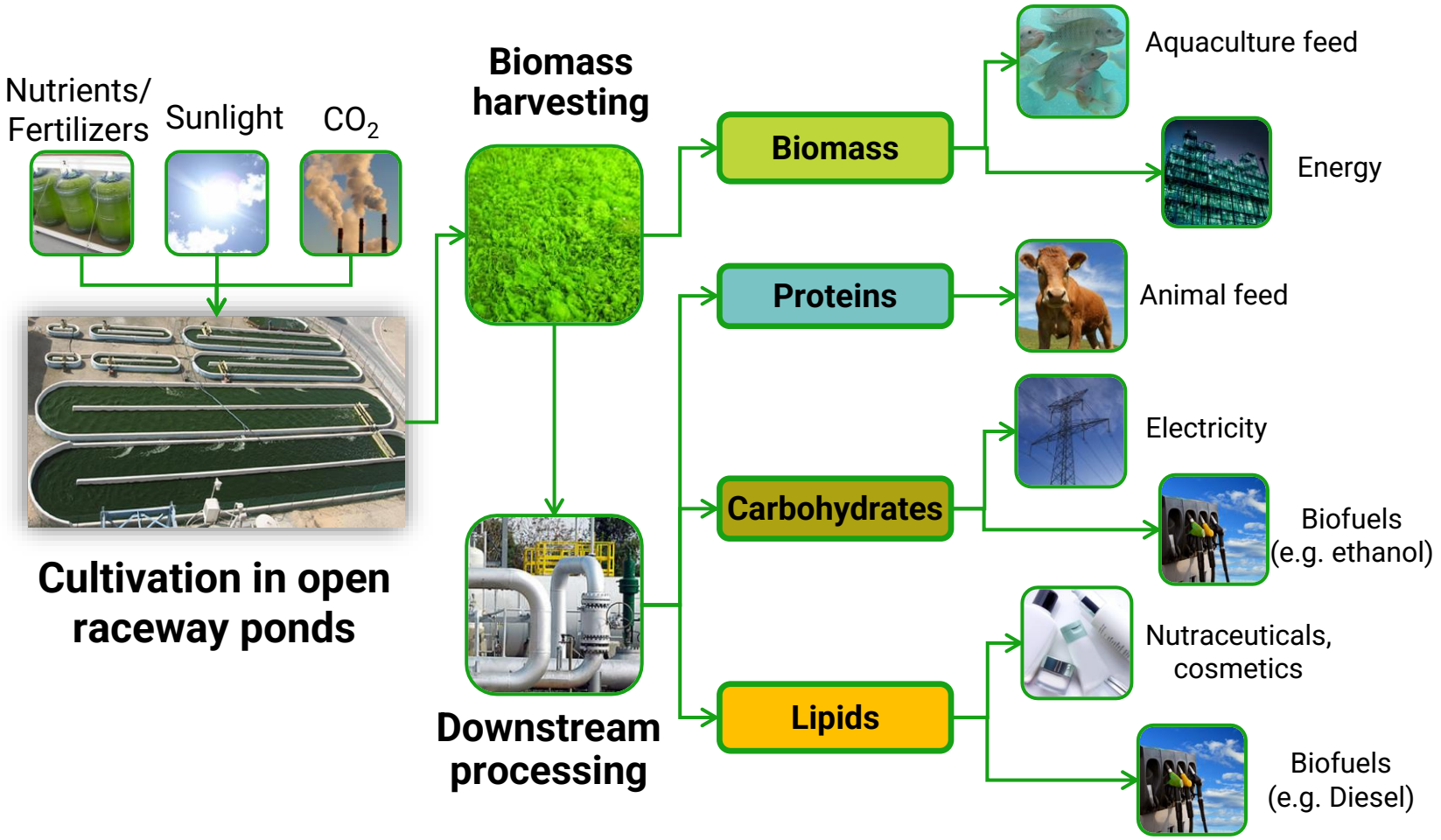
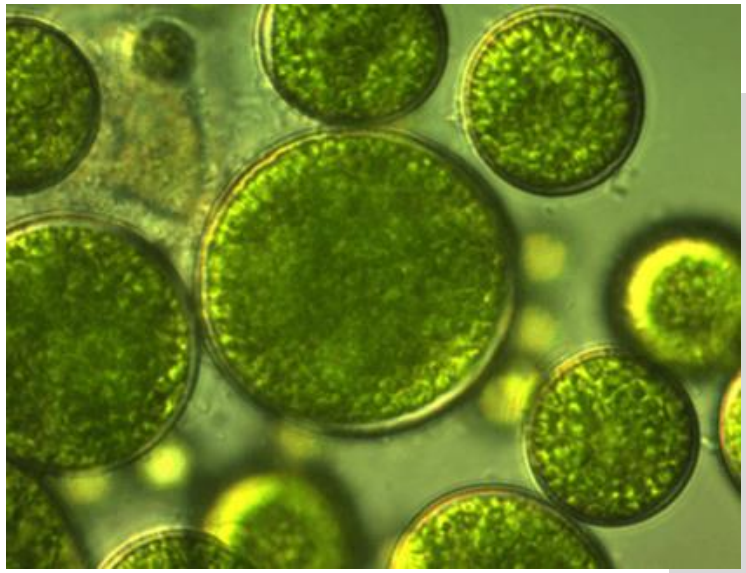
MICROALGAE: A PROMISING RESOURCE



- Renewable source of multiple products
- Higher solar energy to biomass conversion efficiency than terrestrial crops
- No need for arable land
- Possibility to couple with waste streams treatment
- ....

BEING A BIORESOURCE, MICROALGAE SHOULD HAVE NO ENVIRONMENTAL IMPACTS, SHOULDN'T THEY?



https://www.nature-et-forme.com/page /dossier/la-chlorella-fabuleuse-micro-algue

MAYBE, BUT…

- Both culture and downstream processing require energy
- Culture needs water and nutrients
- Downstream may need solvents
- Raw materials and products have to be transported
- …

→

Energy demand

Greenhouse gas emissions

Water consumption

Water emissions of N and P leading to eutrophication

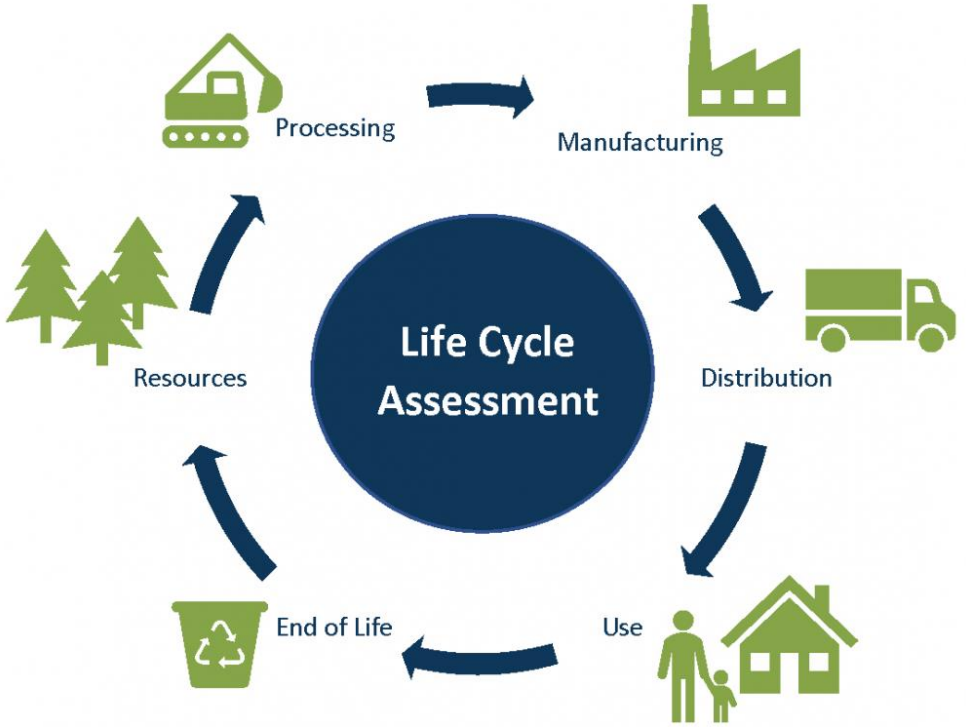
Water emissions of organic compounds

…

LIFE CYCLE ASSESSMENT: A HOLISTIC ENVIRONMENTAL TOOL

Life Cycle Assessment (LCA) is an environmental management tool that *"addresses the **environmental aspects** and **potential environmental impacts** throughout a product's life cycle, from the raw material acquisition through production, use, end-of-life treatment, recycling and final disposal"*.

ISO 14040 (2006)



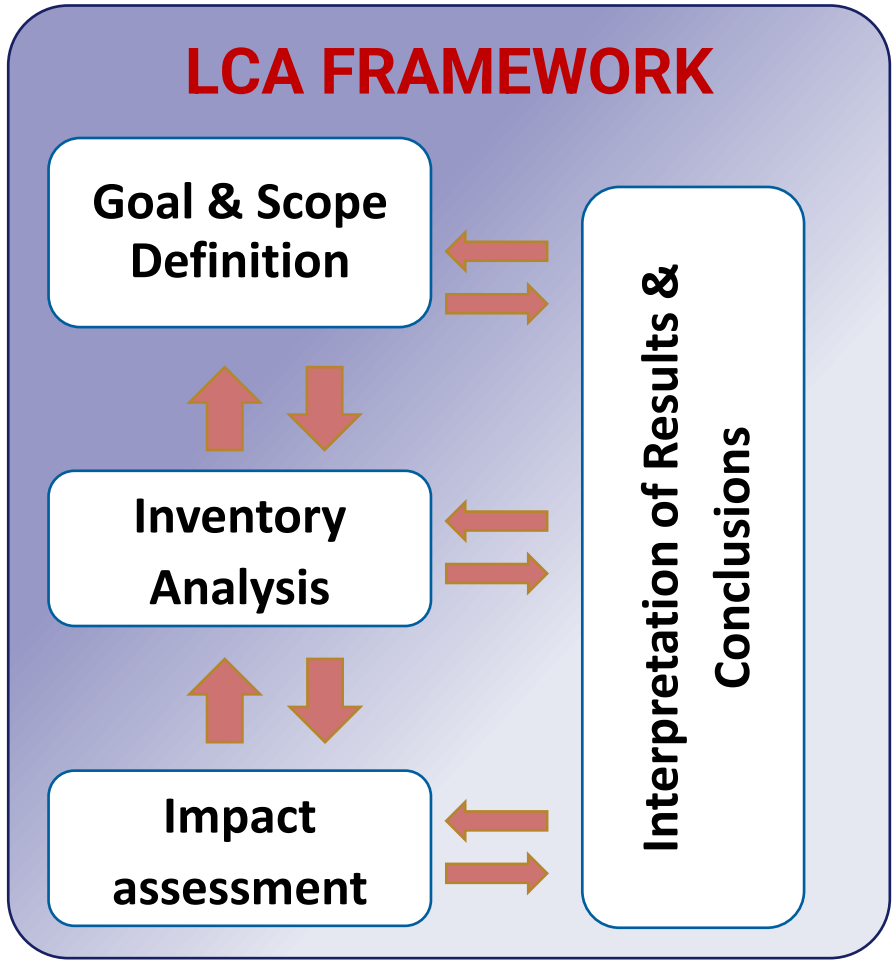
Source: *https://www.ncasi.org/technical-studies/sustainable-manufacturing/life-cycle-assessment/*

LIFE CYCLE ASSESSMENT: A HOLISTIC ENVIRONMENTAL TOOL

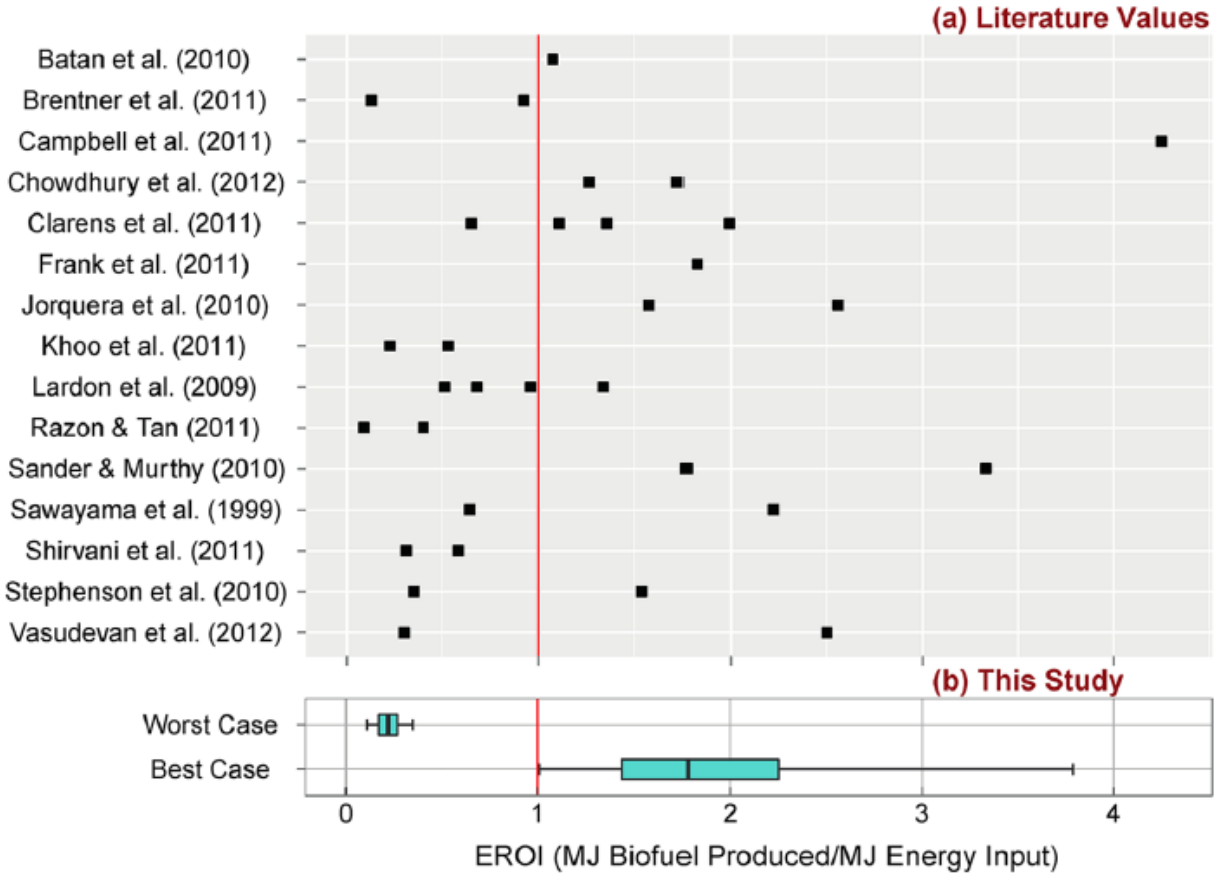
ADVANTAGES

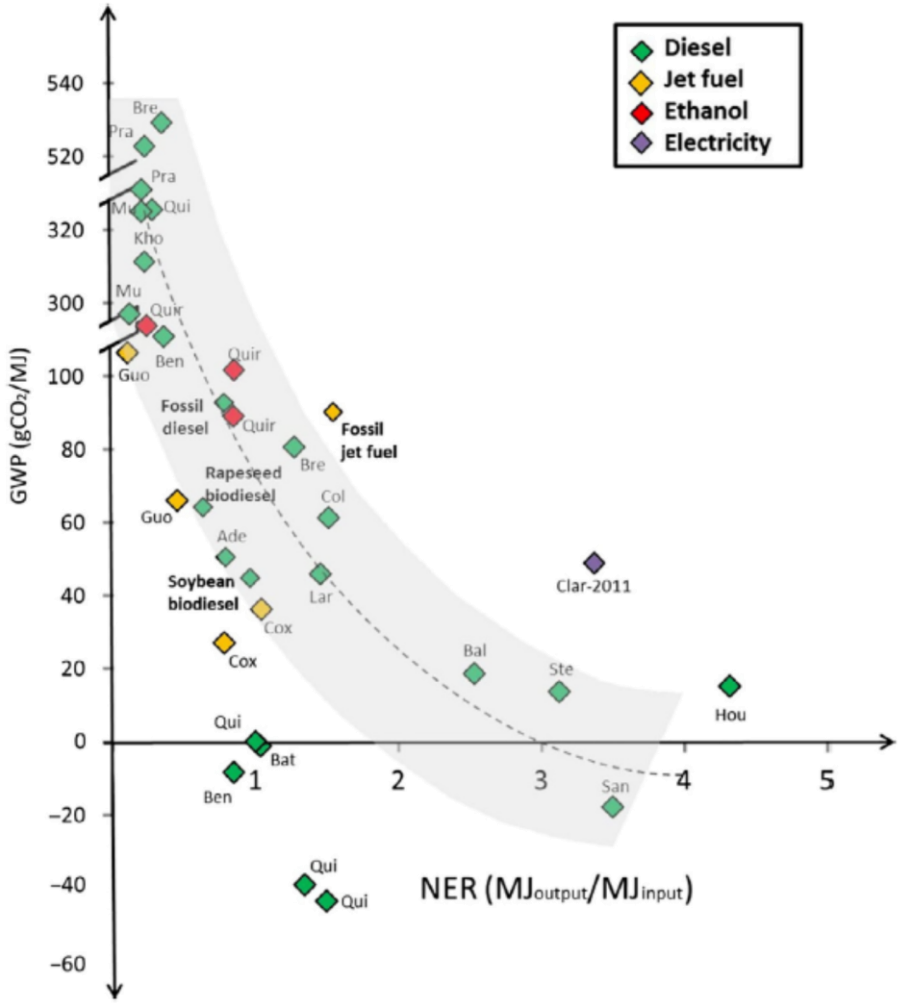
- ✓ Product-oriented systematic approach
  - All stages considered
  - Avoids sub-optimization
  - Avoids potential burden shifting between impact categories or life cycle stages
- ✓ Quantitative
- ✓ Multi-criteria: many different impact categories evaluated
- ✓ Recommended by the EU and worldwide accepted

ISO 14040 (2006)



MANY LCA STUDIES, MANY DIFFERENT OUTCOMES





Source : Sills (2013)

Source : Morales et al (2019)

CHALLENGES OF LCA MODELLING FOR MICROALGAE SYSTEMS

- Importance of functional unit, depends on goal (1 kg biomass? 1 MJ heat or elect? 1 m2 surface?)
- System boundaries to be defined clearly to ensure representativeness and comparability
- Co-products modelling challenges → allocation approach?
- CO2 capture: between 0.5 and 2.5 kg CO2/kg DM → BUT to be compared with indirect emissions
- Life cycle impact assessment → multi-criteria approach needed (climate change, land use, water use, ….)
- Uncertain results due to:

Often, only average scenario → Dynamic approaches needed

- Scarcity of large-scale data due to low TRLs
- Variability of weather (e.g. solar radiation, temperature) and other surrounding conditions → effect on operation (requirements and biomass yield) affecting inventory
- Uncertainties of LCA databases and impact assessment methods
- Climate change effects → affecting characterization factors for impact assessment phase

CASE STUDY: ENVIRONMENTAL PERFORMANCE OF MICROALGAE IN THE NETHERLANDS UNDER AVERAGE SUMMER CONDITIONS

Goal & scope

- FU = 1 kg algal biomass
- 3 real pilot cultivation systems
- Comparative assessment under average summer conditions (1,5 months total operation)
- Identification of hot spots

Vertical tubular PBR
0.56 m^3

Horizontal tubular PBR
0.56 m^3

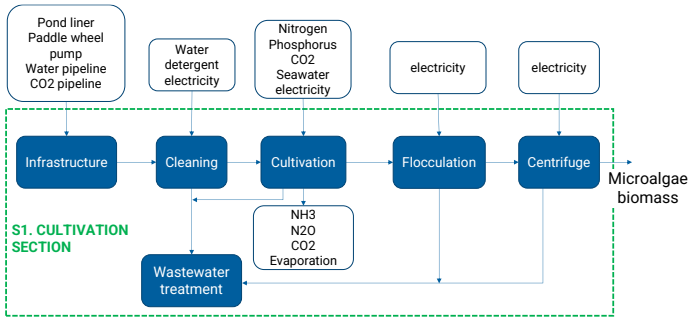
Open raceway pond
4.73 m^3

Source : Pérez-López et al (2017)

CASE STUDY: ENVIRONMENTAL PERFORMANCE OF MICROALGAE IN THE NETHERLANDS UNDER AVERAGE SUMMER CONDITIONS

Goal & scope

- Functional unit for culture: 1 kg biomass harvested
- System boundaries: cradle to gate



- Scenarios

Inventory analysis

Emission quantification

Inputs/Outputs

CH_4
CO_2

PO_4^{-3}
NO_3^-
COD

NH_3
SO_2

Impact assessment

Classification into impact categories

Characterization

Climate change → $CO_{2\,(eq)}$

Eutrophication → $PO_4^{-3}{}_{(eq)}$

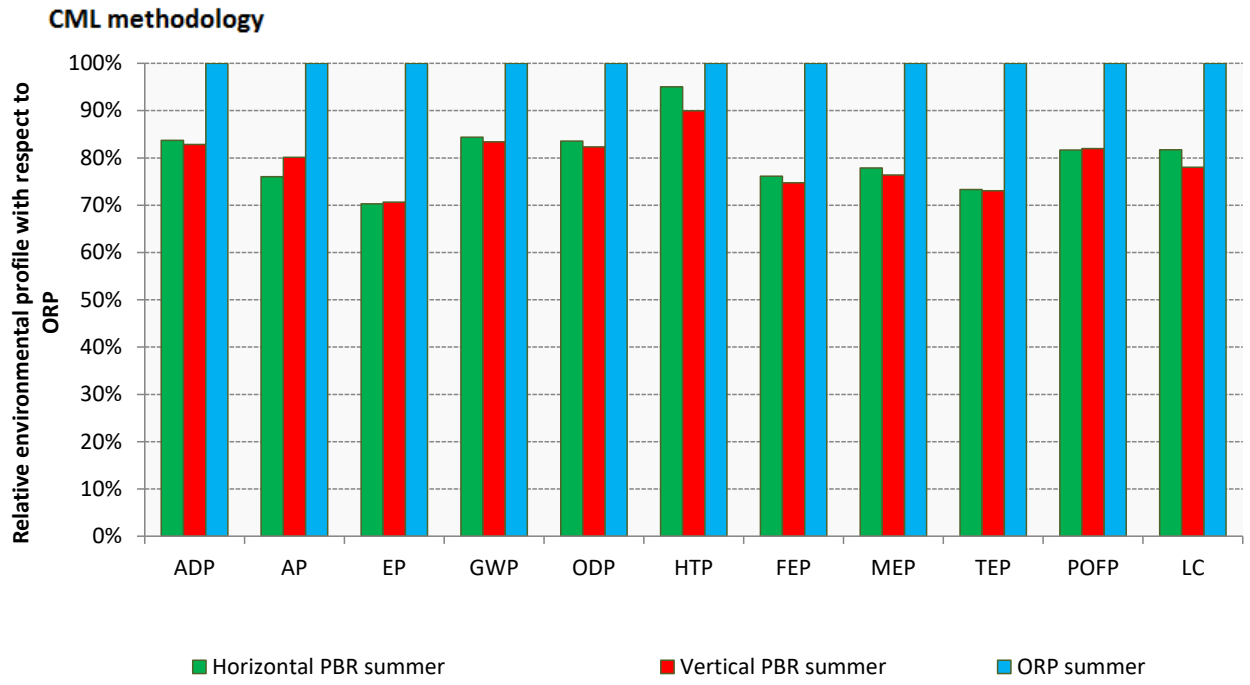
Acidification → $SO_2^-{}_{(eq)}$

Characterization factors

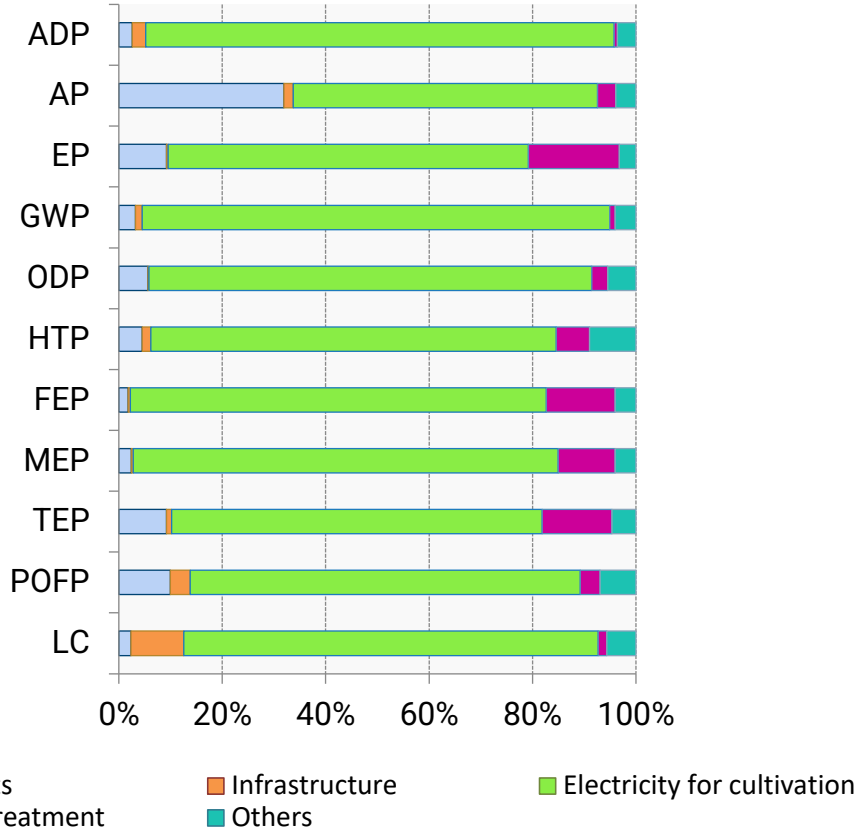
Interpretation

CASE STUDY: ENVIRONMENTAL PERFORMANCE OF MICROALGAE IN THE NETHERLANDS UNDER AVERAGE SUMMER CONDITIONS

Relative results of pilot systems with respect to ORP (100%)



Hotspots for ORP



Source : Pérez-López et al (2017)

CASE STUDY: ENVIRONMENTAL PERFORMANCE OF MICROALGAE IN THE NETHERLANDS → WHAT IF CONDITIONS CHANGE?

3 scenarios

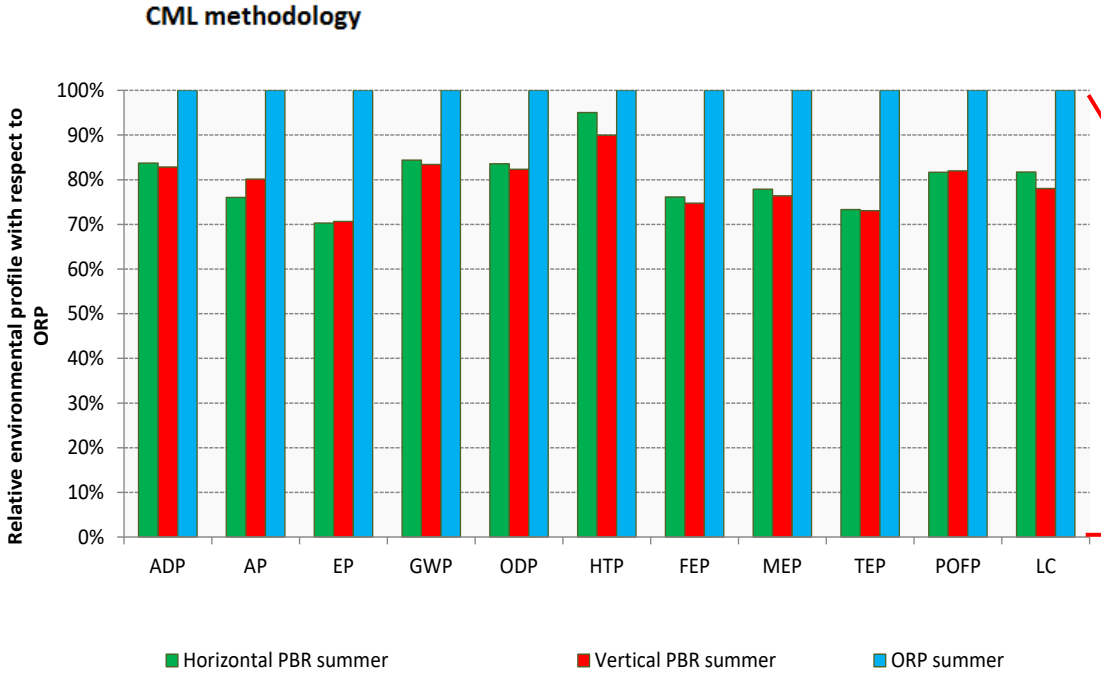
SUMMER CONDITIONS
- ↑ irradiance
- ↑ temperature
- ↓ precipitations
- ↑ growth rate

FALL CONDITIONS
- ↓ irradiance
- ↓ temperature
- ↑ precipitations
- ↓ growth rate

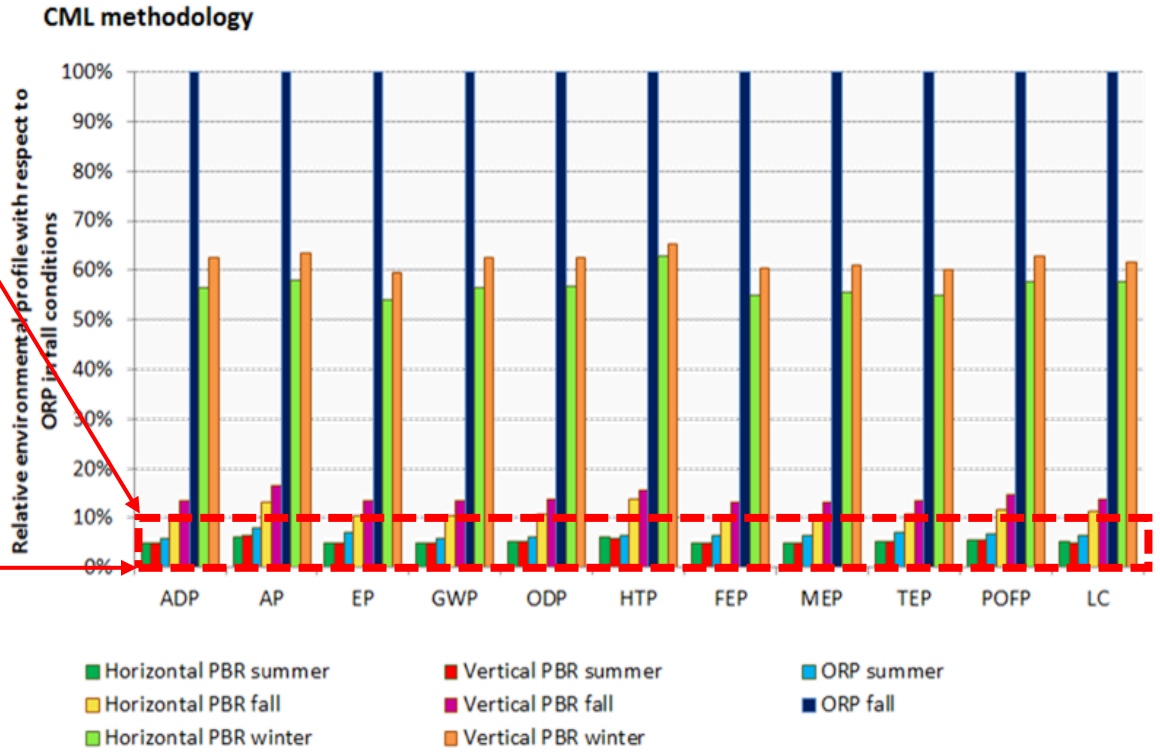
WINTER CONDITIONS
- ↓↓ irradiance
- ↓↓ temperature
- ↑ precipitations
- ↓↓ growth rate

CASE STUDY: ENVIRONMENTAL PERFORMANCE OF MICROALGAE IN THE NETHERLANDS IN DIFFERENT SEASONS

Relative results of pilot systems with respect to ORP (100%)



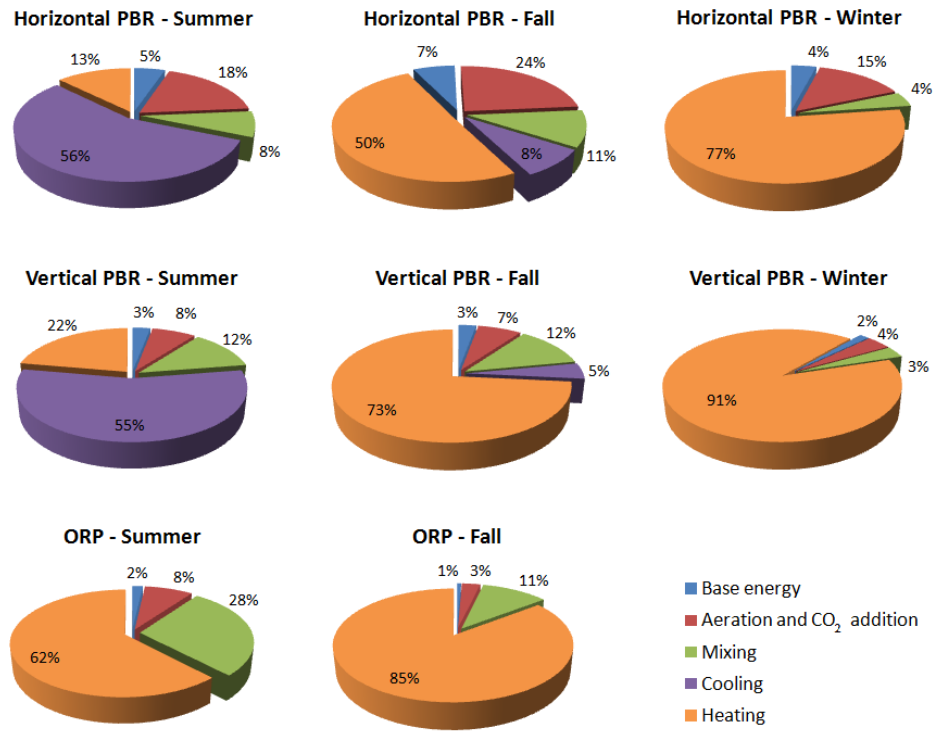
Relative results of pilot systems with respect to ORP in fall (100%)



Source : Pérez-López et al (2017)

CASE STUDY: ENVIRONMENTAL PERFORMANCE OF MICROALGAE IN THE NETHERLANDS IN DIFFERENT SEASONS

Hotspot: Electricity (~ 70-95%)



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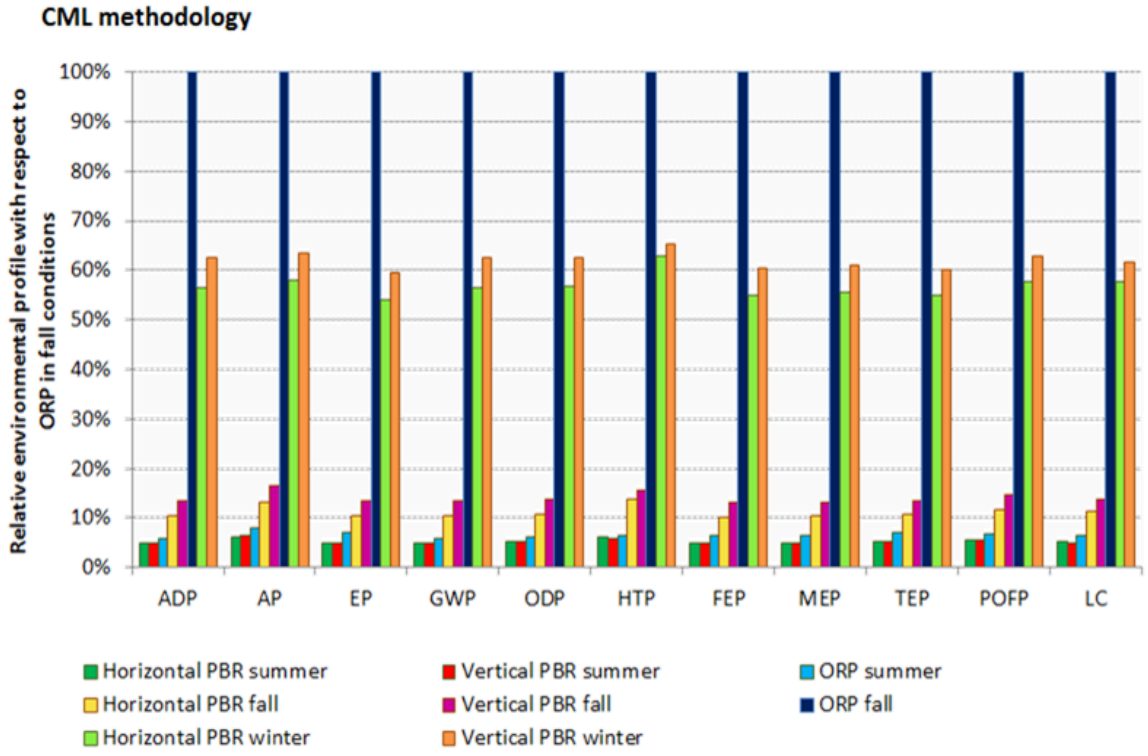
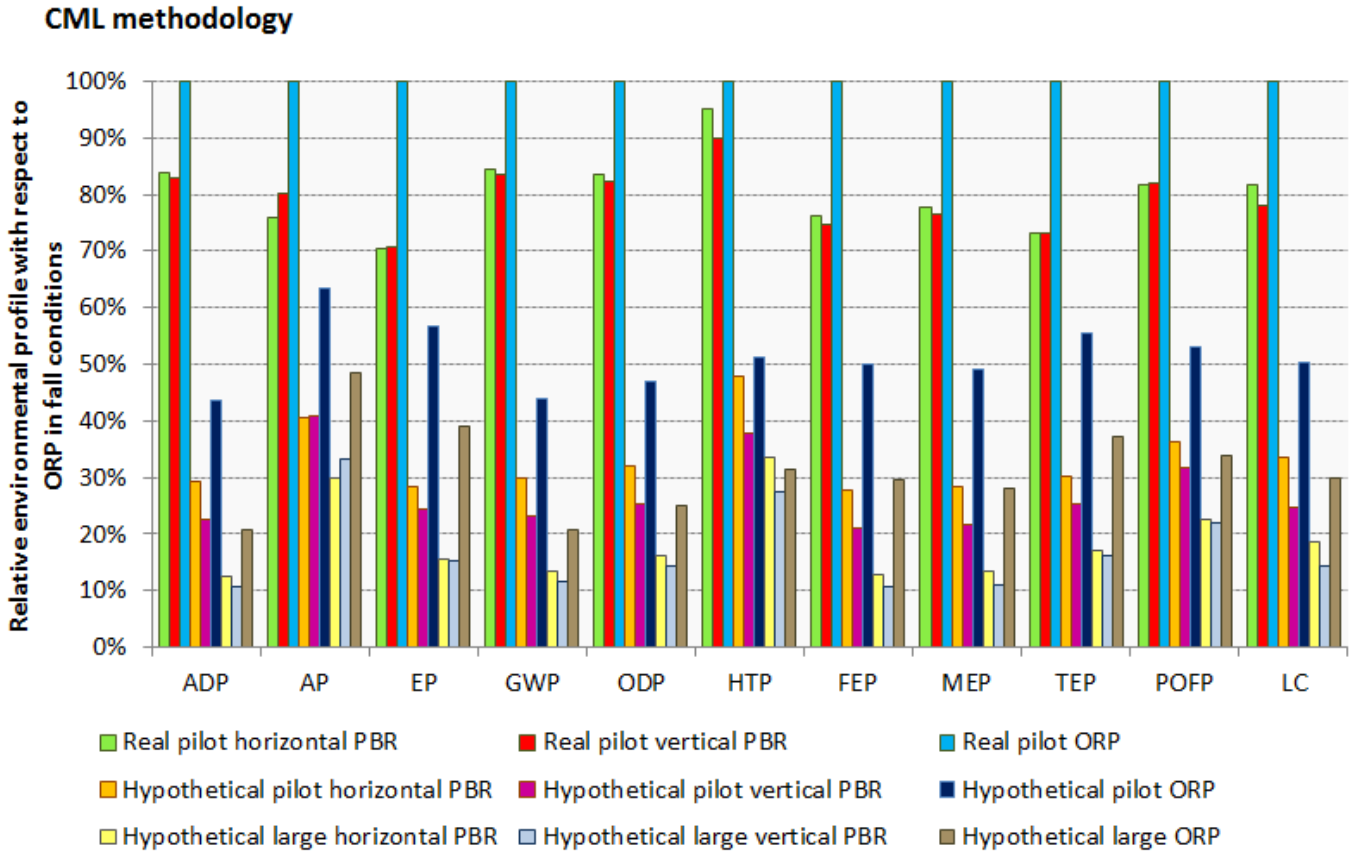


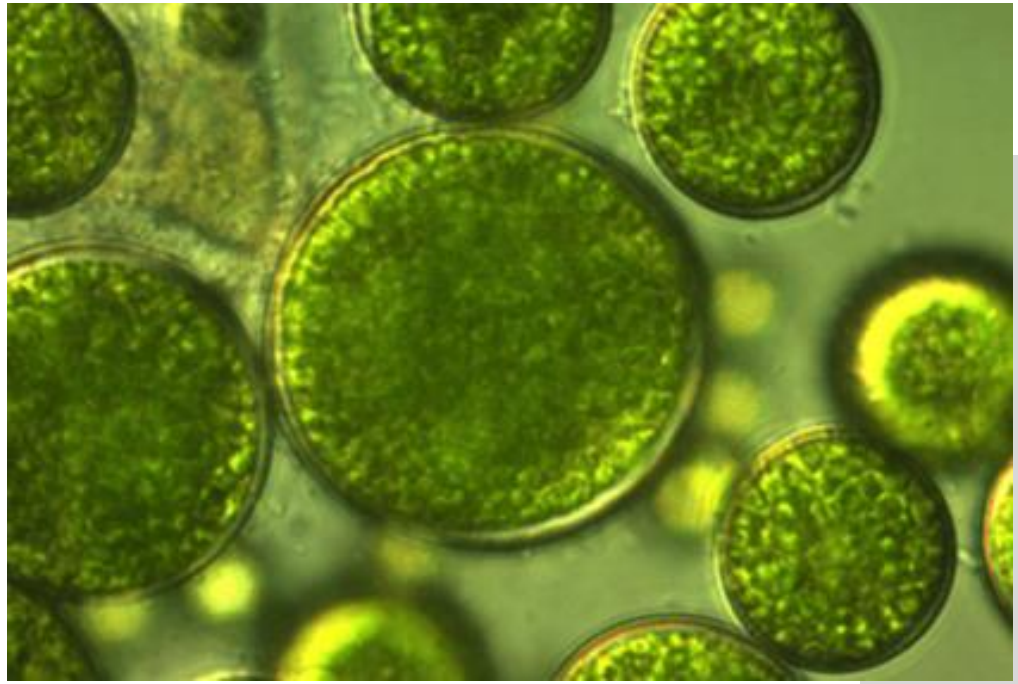
Source : Pérez-López et al (2017)

CASE STUDY: ENVIRONMENTAL PERFORMANCE OF MICROALGAE IN THE NETHERLANDS IN DIFFERENT SEASONS

Pilot vs hypothetical large scale scenarios in summer conditions



IN CONCLUSION, ARE MICROALGAE GREEN OR NOT?



https://www.nature-et-forme.com/page /dossier/la-chlorella-fabuleuse-micro-algue

IT DEPENDS

- On the weather
- On the geographical location of the site
- On the operation conditions
- On the species
- On the target product and co-products
- On the scale of production
- On LCA-related methodological choices
- …

SO WHAT?

LCA still serves …

- to identify environmental hotspots
- to compare scenarios/alternatives
- to focus on key parameters
- overall, to identify opportunities for improvement and provide information for decision-making

IT DEPENDS

- On the weather
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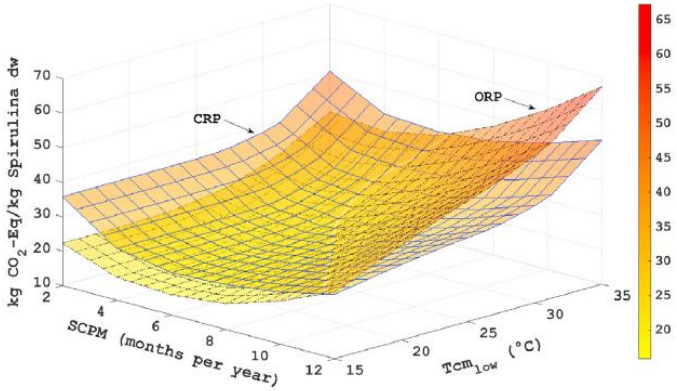
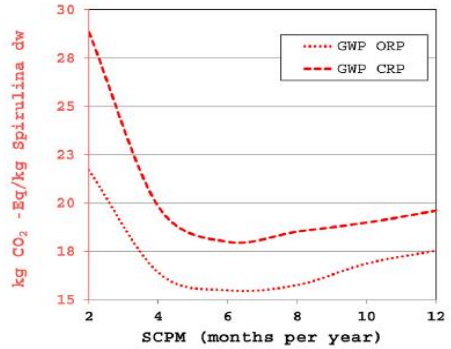
PERSPECTIVES

- Dynamic approaches



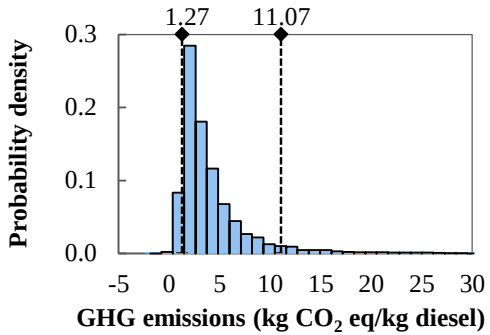
(a) with thermal regulation

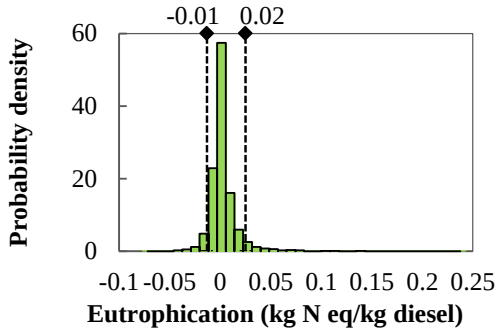


(b) w/o thermal regulation

Source : Quintero et al (2021)

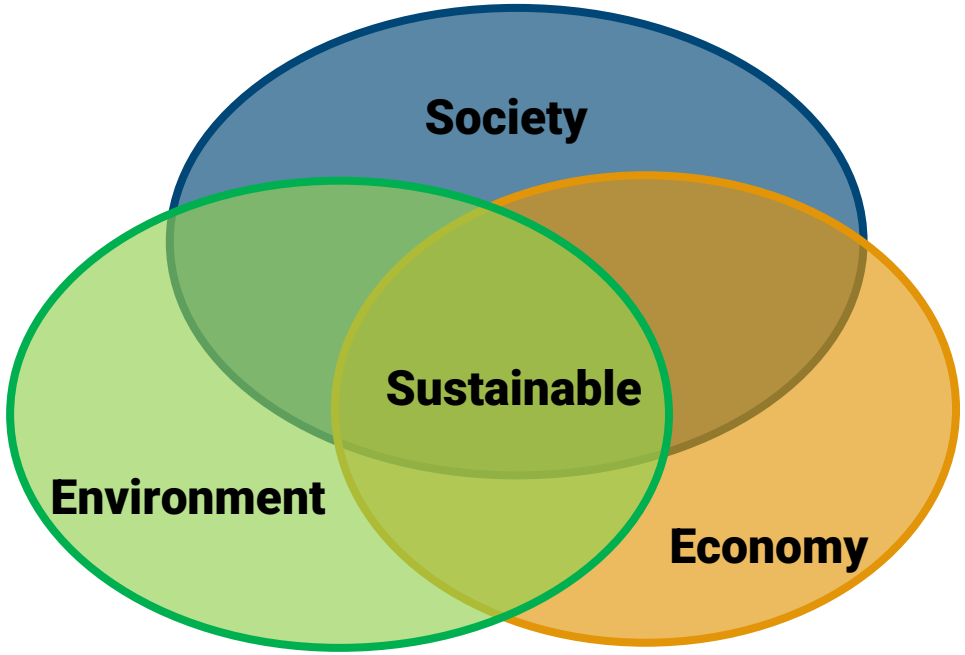
- Comprehensive sensitivity analyses





Source : Pérez-López et al (2018)

- Accounting for other aspects of sustainability, namely social and economic dimensions



Source : Rajaonison (2022)

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