ライフサイクルアセスメント
生命週期評估
전 과정 평가
வாழ்க்கை வட்டப் பகுப்பாய்வு
ارزیابی چرخه عمر
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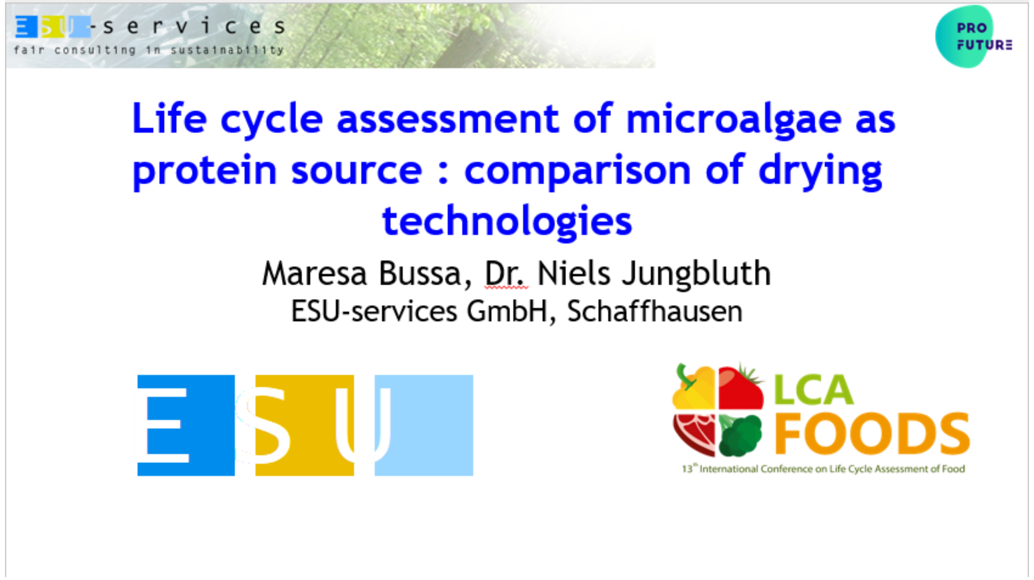
Evaluarea Ciclului de Viață
Posuzování Životního Cyklu
Penilaian Daur Hidup
Lífsferilsgreining
Levenscyclusanalyse
Livscyklusvurdering



Life cycle assessment of microalgae as protein source : comparison of drying technologies

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Introduction

- Microalgae have been recognized as promising protein source
- Previous life cycle assessment studies have shown disadvantageous results when compared the other protein sources
- Main reason: high energy demand of the production processes
- Research question: Can innovative drying technologies help microalgal protein to compete with other protein sources?
- Funding: European Commission, Horizon 2020, https://www.pro-future.eu/

Methodology and Data

- Studied species:
  - Chlorella vulagris (32% protein), heterotrophic cultivation
  - Tetreaselmis chui (40% protein), photo-autotrophic cultivation
- LCI includes: cultivation, harvesting and drying
- LCIA method: European Footprint 3.0
- Background data: ecoinvent 3.8 cut-off and ESU food database
- Functional unit: dry powder containing 1 kg protein

Product system

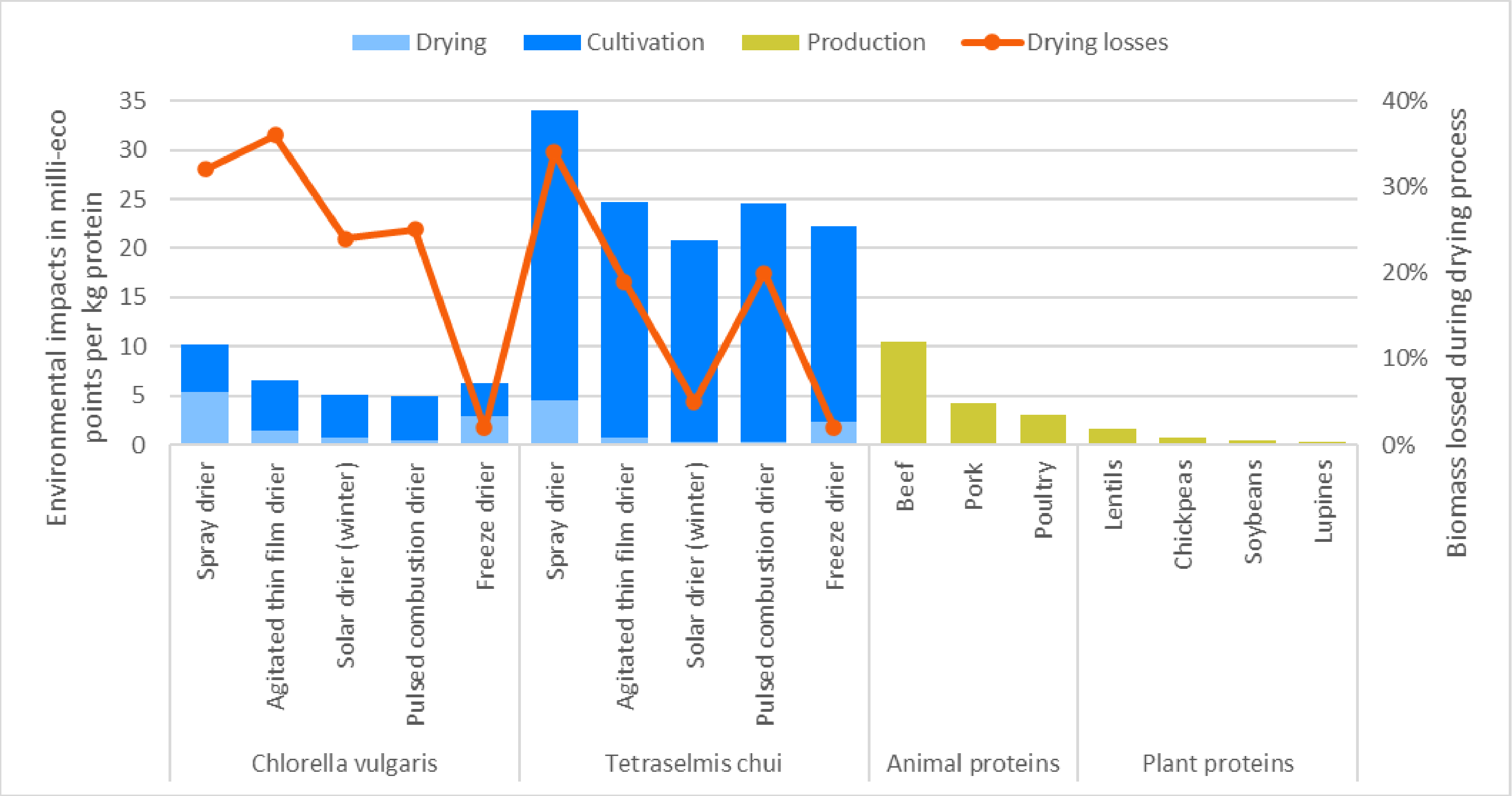
Chlorella vulgaris:
Hetrotrophic cultivation in fermenter
Harvesting by membrane filtration

Cultivation — Harvesting

- Spray drier
- Freeze drier
- Solar drier
- Agitated thin film drier
- Pulsed combustion drier

Tetraselmis chui:
Photo-autotrophic in photobioreactor
Harvesting by centrifugation

Environmental impacts per kg protein



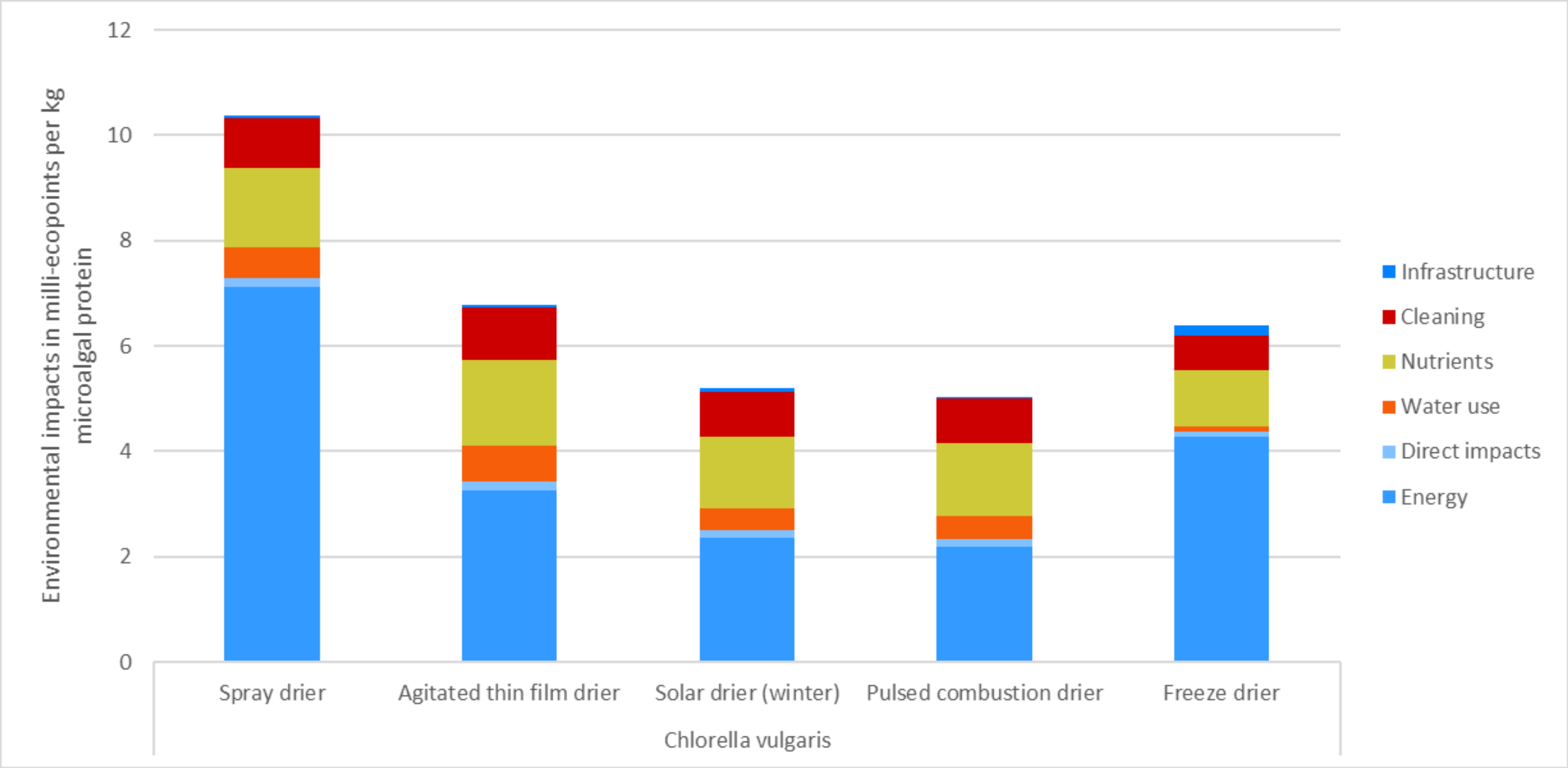
- Microalgae not competitive with plant proteins, Chlorella comparable to animal proteins
- Drying yield most important parameter

Midpoint results: Chlorella vulgaris

Impact category	Pork	Poultry	Beef	Spray drier	Agitated thin film drier	Solar drier	Pulsed com-bustion drier	Freeze drier
Climate change	6%	5%	24%	100%	59%	45%	45%	62%
Ozone depletion	2%	2%	2%	100%	74%	59%	65%	64%
Ionising radiation	5%	5%	4%	100%	49%	35%	31%	60%
Photochemical ozone formation	9%	7%	14%	100%	66%	51%	49%	62%
Particulate matter	30%	22%	100%	81%	65%	53%	51%	54%
Human toxicity, non-cancer	12%	8%	-20%	100%	72%	57%	54%	63%
Human toxicity, cancer	7%	5%	4%	86%	68%	49%	46%	100%
Acidification	24%	18%	80%	100%	66%	52%	49%	63%
Eutrophication, freshwater	2%	2%	3%	100%	57%	41%	37%	56%
Eutrophication, marine	24%	17%	25%	100%	93%	65%	65%	44%
Eutrophication, terrestrial	29%	22%	100%	58%	45%	36%	35%	37%
Ecotoxicity, freshwater	7%	5%	7%	100%	80%	63%	61%	61%
Land use	41%	32%	100%	65%	53%	46%	42%	43%
Water use	32%	20%	34%	100%	71%	56%	54%	64%
Resource use, fossils	3%	3%	3%	100%	61%	46%	46%	62%
Resource use, minerals and metals	2%	1%	3%	100%	87%	74%	69%	70%

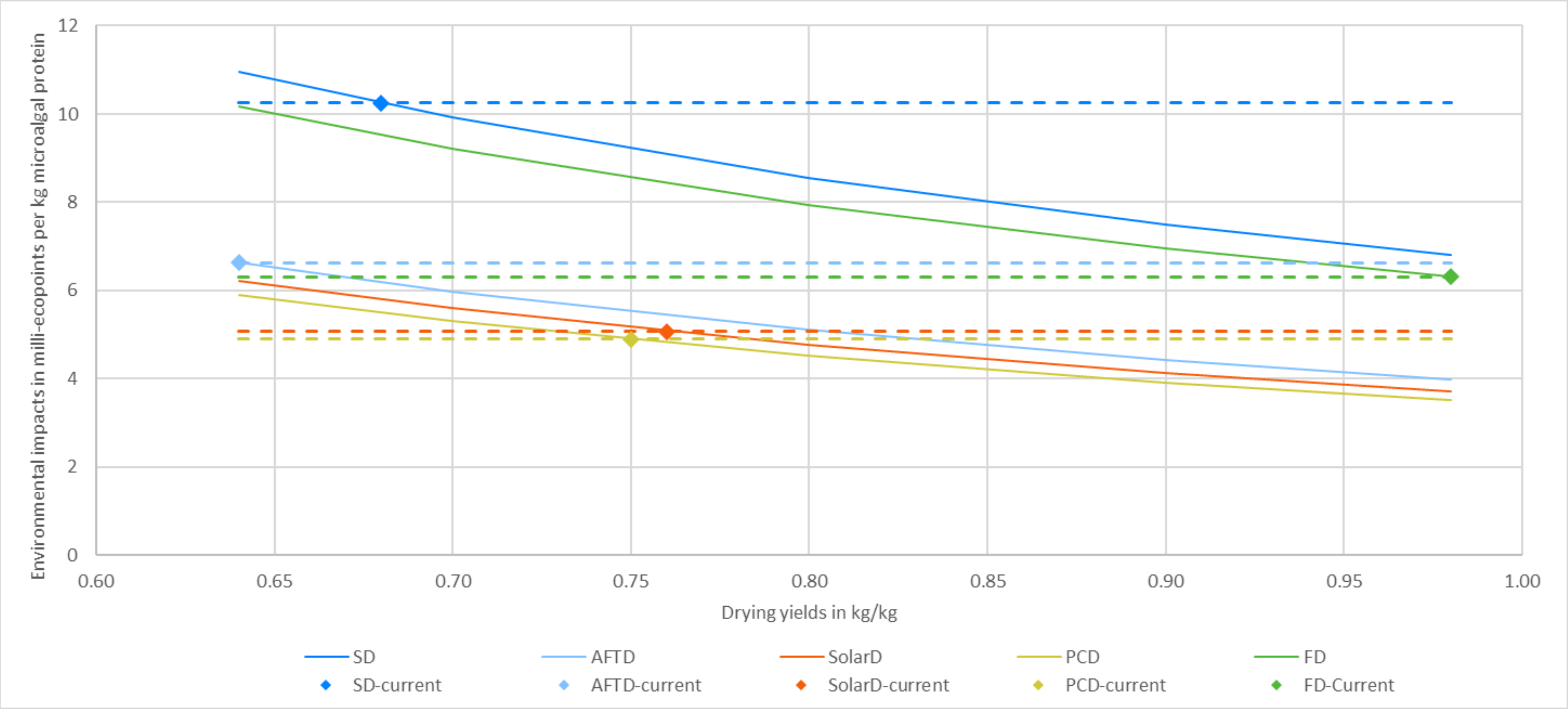
- Climate change impacts worse than beef, few indicators show lower results than beef
- Land use impacts for new drying technologies comparable to pork

Hotspot analysis: Chlorella vulgaris



- ➢ Electricity use is most important driver
- ➢ Nutrition (glucose) and cleaning (propane) are important as well

Sensitivity analysis: Chlorella vulgaris



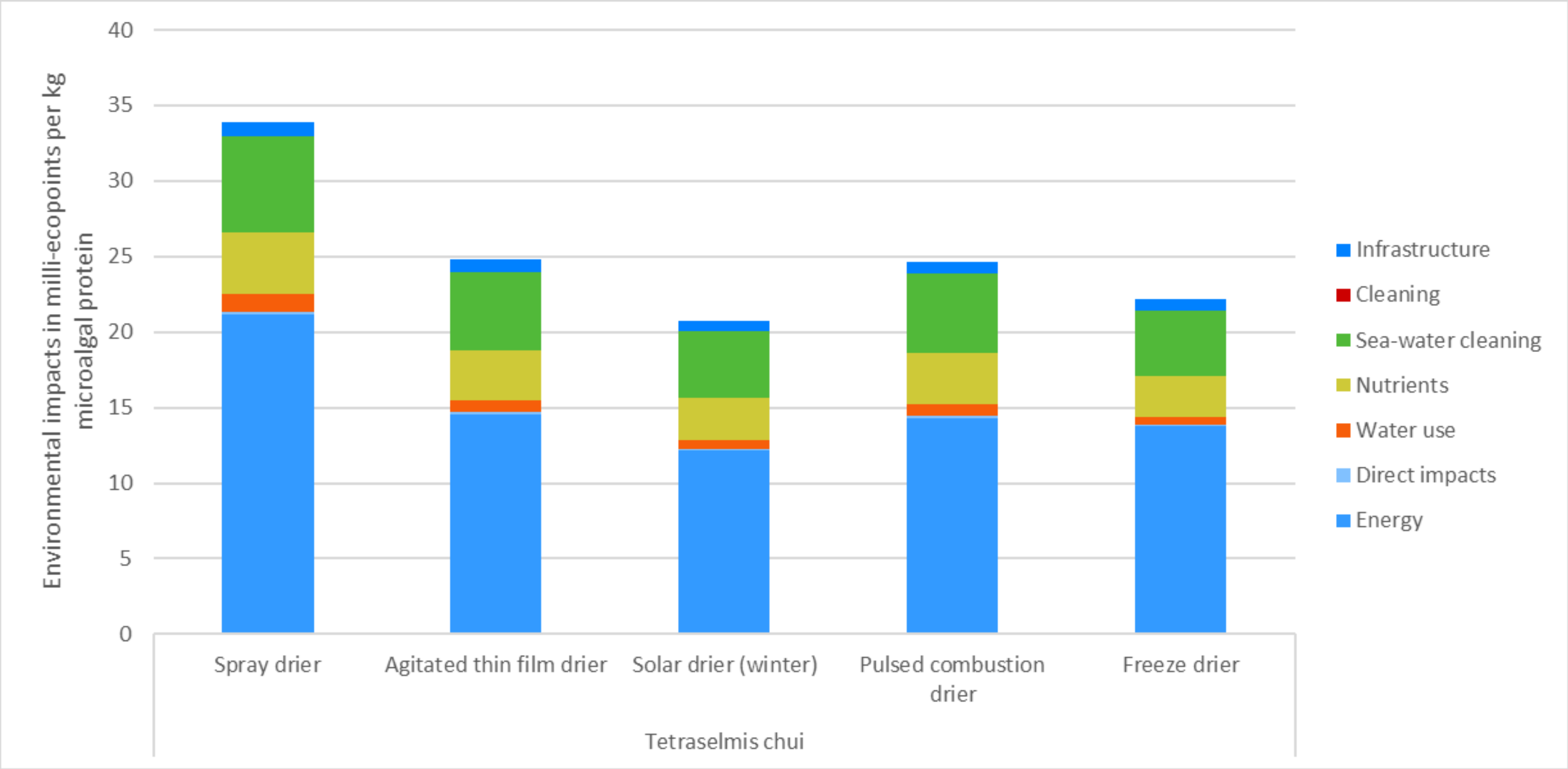
- Reduction to approximately 4 milli-ecopoints per kg protein possible
- Reminder: Animal protein 3-10 milli-ecopoints, plant protein 0.3-1.6 milli-ecopoints per kg protein

Midpoint results: Tetraselmis chui

Impact category	Pork	Poultry	Beef	Spray drier	Agitated thin film drier	Solar drier	Pulsed com-bustion drier	Freeze drier
Climate change	2%	1%	7%	100%	73%	61%	73%	66%
Ozone depletion	0%	0%	0%	100%	77%	65%	78%	66%
Ionising radiation	2%	2%	1%	100%	70%	58%	68%	65%
Photochemical ozone formation	3%	2%	4%	100%	73%	62%	73%	66%
Particulate matter	8%	6%	26%	100%	78%	66%	78%	67%
Human toxicity, non-cancer	3%	2%	-5%	100%	75%	63%	75%	66%
Human toxicity, cancer	2%	2%	1%	100%	75%	62%	74%	78%
Acidification	5%	4%	18%	100%	76%	64%	75%	66%
Eutrophication, freshwater	1%	1%	1%	100%	70%	58%	68%	64%
Eutrophication, marine	12%	9%	13%	100%	70%	55%	70%	56%
Eutrophication, terrestrial	22%	16%	75%	100%	73%	61%	73%	65%
Ecotoxicity, freshwater	2%	2%	2%	100%	75%	62%	74%	65%
Land use	26%	20%	62%	100%	75%	64%	75%	67%
Water use	5%	3%	5%	100%	78%	66%	78%	67%
Resource use, fossils	1%	1%	1%	100%	71%	60%	71%	65%
Resource use, minerals and metals	0%	0%	1%	100%	78%	67%	78%	67%

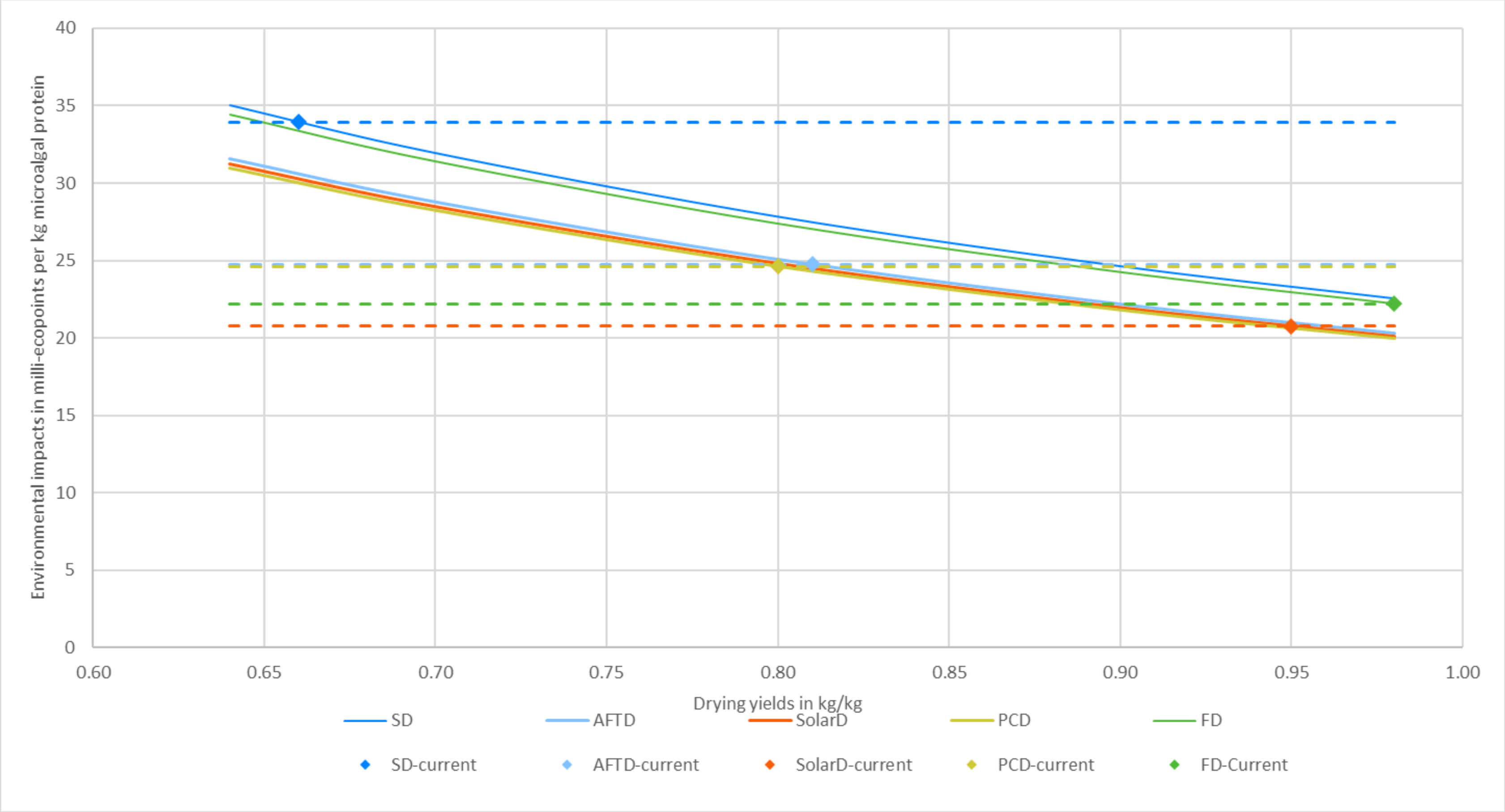
- Climate change impacts around one order of magnitude higher than for beef
- Lower results for terrestrial eutrophication when compared to beef

Hotspot analysis: Tetraselmis chui



- ➢ Energy use is most important driver
- ➢ Sea-water cleaning (sodium nitrate and thiosulfate) and nutrition (CO_2) are important as well

Sensitivity analysis: Tetraselmis chui



- Reduction to approximately 20 milli-ecopoints per kg protein possible
- Reminder: Animal protein 3-10 milli-ecopoints, plant protein 0.3-1.6 milli-ecopoints per kg protein

Conclusion

- Innovative drying technologies can reduce the environmental impacts of microalgal protein for Chlorella vulgaris to an order of magnitude comparable to animal protein
- Drying yield has the highest influence on the result of the drying technologies
- For both species measures should be tested to reduce the electricity consumption of the cultivation stage.
- Nutrient-rich waste streams should be evaluated as alternative to fertilizers/glucose..

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