Prospective LCA in the context of cultivated meat

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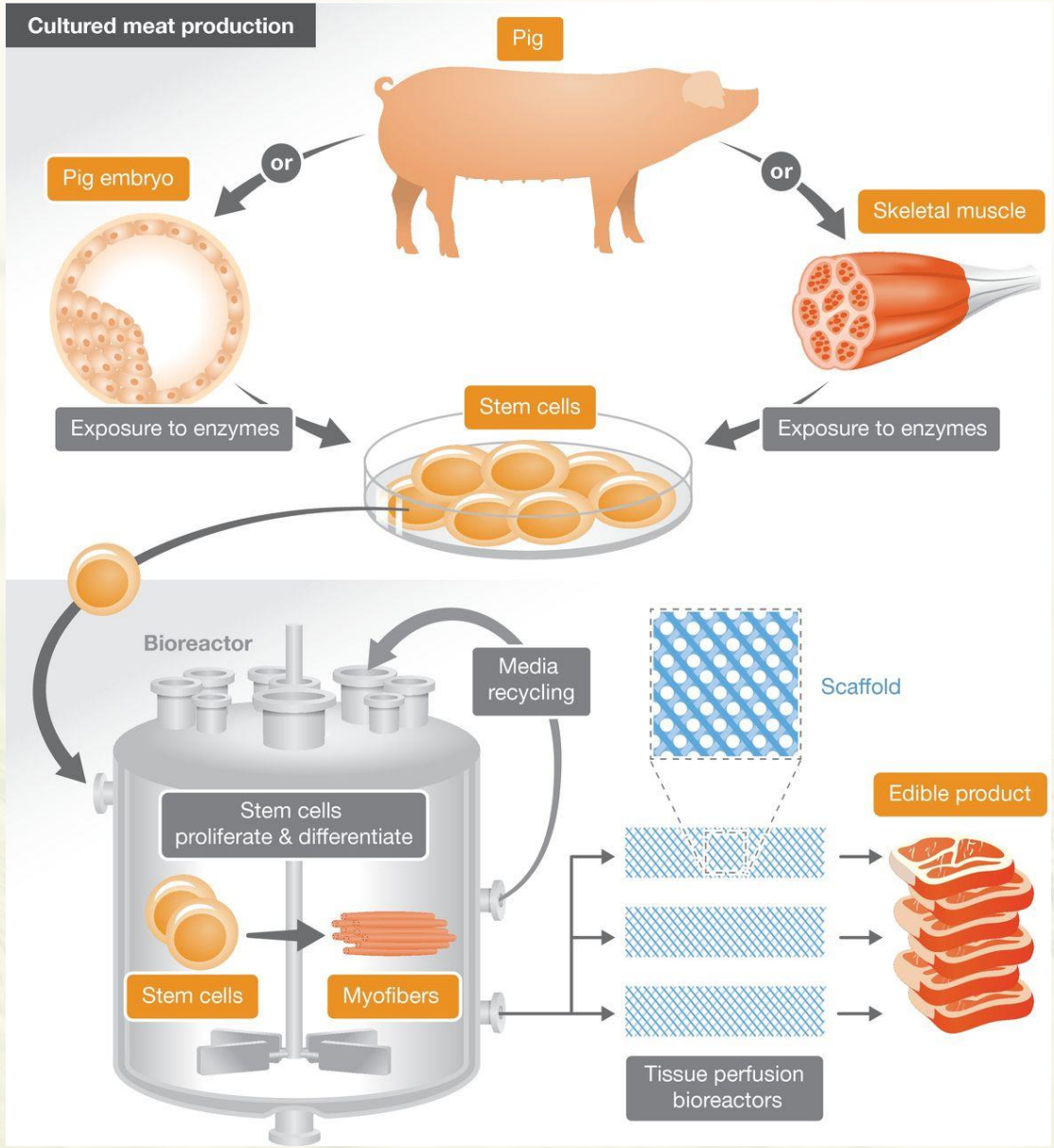
Background picture: Unplash

Cultivated meat



Tuomisto (2018) The eco-friendly burger. EMBO reports e47395

Different names used:
Cultured meat
Cultivated meat
Clean meat
in vitro meat
Artificial meat
Cell-based meat
Laboratory-meat
Synthetic meat

MILESTONES OF CULTIVATED MEAT DEVELOPMENT

First pilot product was presented to media 2013

culturedbeef.net, Photo: David Parry / PA Wire

Permission to cell cultivated meat as food in Singapore 2020

Photo: Eat Just

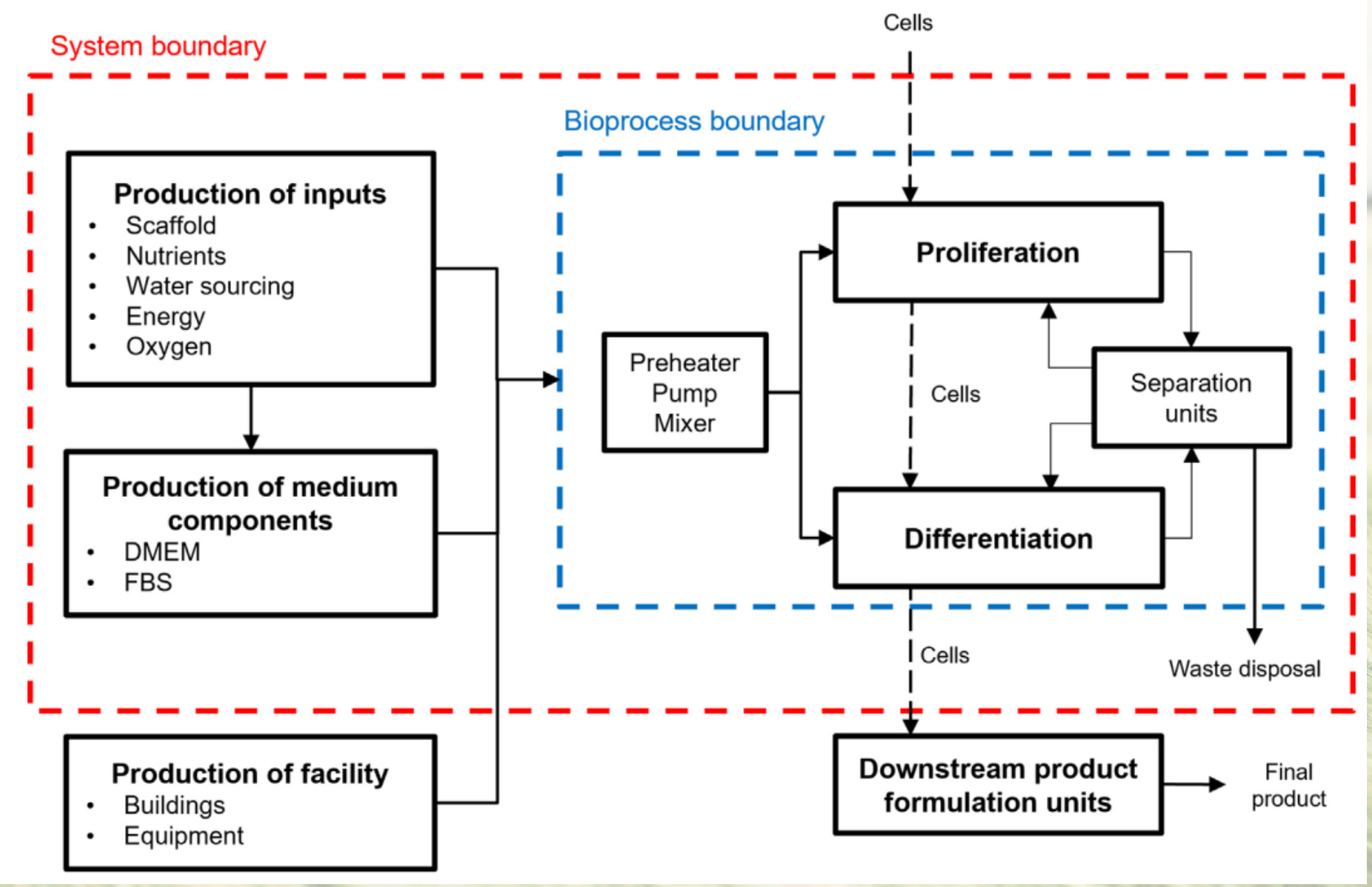
First cultivated meat novel foods application submitted to the European Food Safety Authority (EFSA) in 2024

Environmental life cycle assessment studies of cultivated meat

	Carbon footprint (kg CO_2-eq/kg)	Land use (m^2/kg)	Details
Tuomisto et al. (2011)	1.9-2.2	0.2	Cyanobacterial based medium, stir-tank bioreactor, “screening assessment”, data based on expert estimates, similar technologies, own calculations
Smetana et al. (2015)	23.9-24.6	0.4-0.8	Data from Tuomisto et al., but cyanobacteria produced in bioreactors instead of open ponds
Mattick et al. (2015)	3.0-25.5	1.5-9.5	Chinese Hamster Ovarian cells, standard serum-free culture medium, stir-tank bioreactors, more sophisticated system model,
Tuomisto et al. (2022)	4.9-25.2	1.8-6.9	C2C12 cells, standard culture medium with FBS and without, hollow fiber bioreactors, data based on experiments and modelling
Sinke et al. (2023)	2.9-14.3	2.5	Aggregated data from companies (many cell types and medium ingredients)
Kim et al. (2023)	3.8	9.5	Primary bovine cells, standard culture medium, data from a company, product is a burger patty
Risner et al. (2025)	12-1508	-	Used data from techno economic assessments. The worse case scenarios include energy intensive purification steps for the medium ingredients.

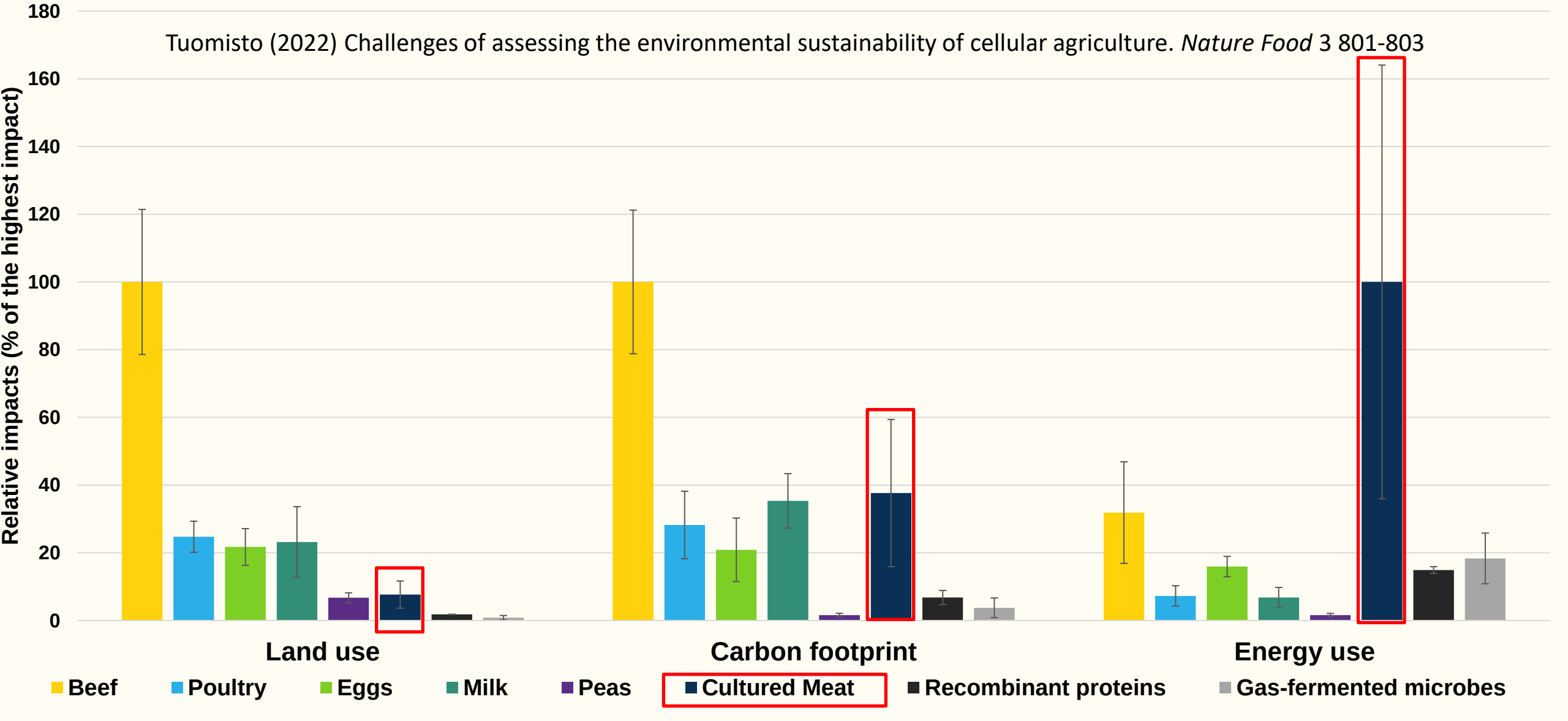
Tuomisto & Teixeira de Mattos (2011) Environmental Science & Technology 45 6117-6123, Smetana et al. (2015) International Journal of Life Cycle Assessment 20 1254-1267, Mattick et al. (2015) Environmental Science & Technology 49 11941-11949, Tuomisto et al. (2022) Science of the Total Environment 851 158051, Sinke et al. (2023) International Journal of Life Cycle Assessment 28 234-254, Kim et al. (2022) Sustainability 14 16133,
Risner et al. (2025) ACS Food Sci. Technol. 5, 61-74

System boundaries of life cycle assessment of cultivated meat



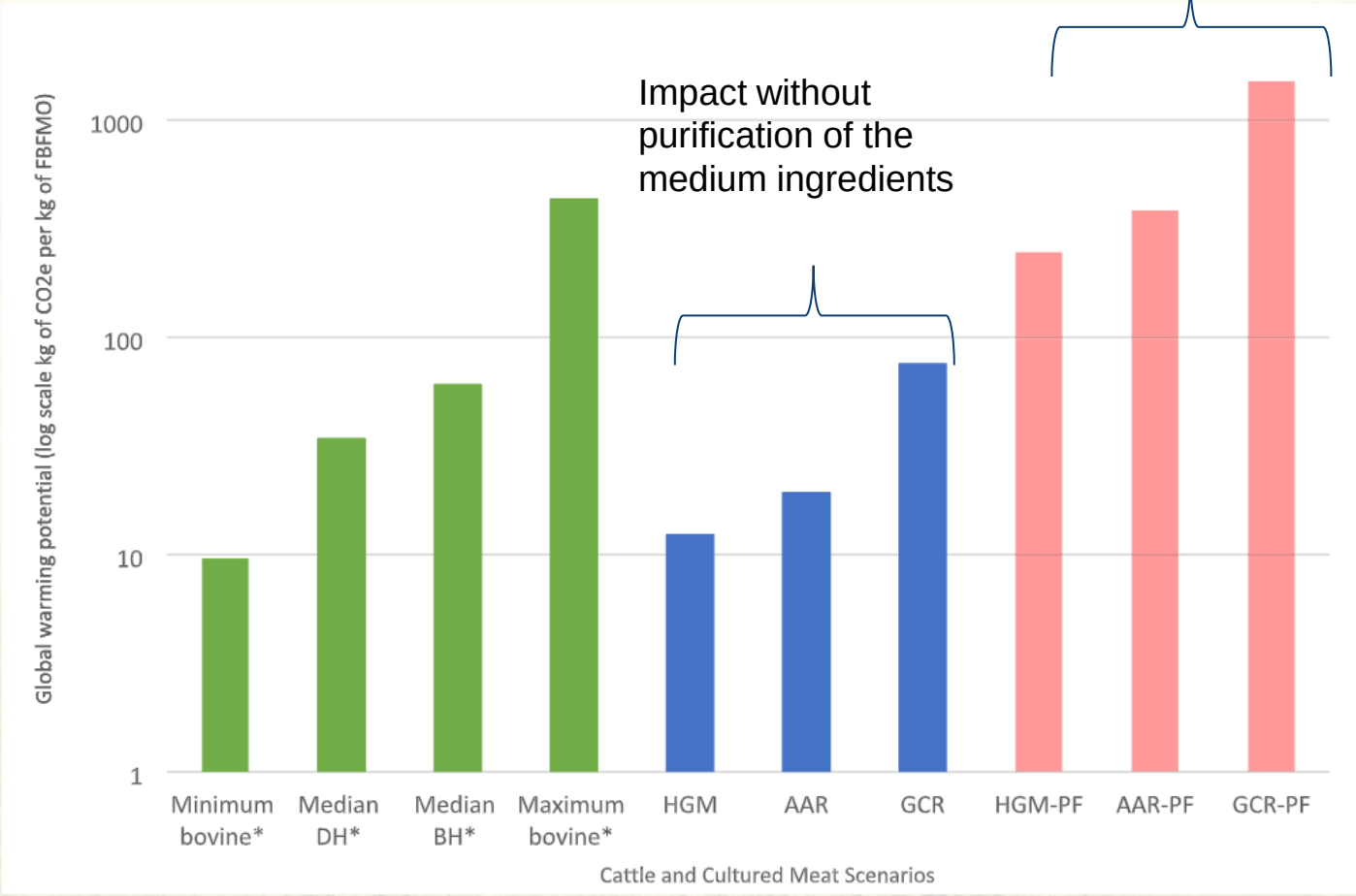
Tuomisto et al. (2022) Science of the Total Environment 851 158051

Environmental impacts and resource use of alternative protein sources (per unit of protein)



Including purification of the medium ingredients

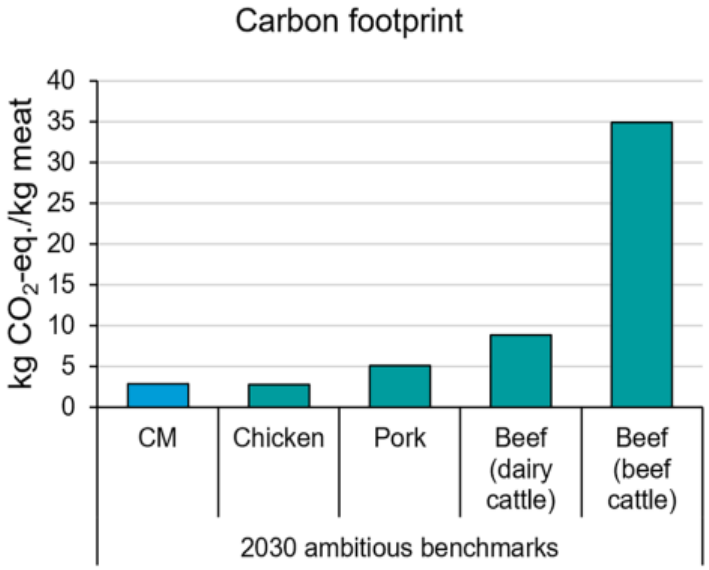
- Included an energy intensive purification process for the culture medium ingredients to make them pharmaceutical grade
- >90% of the impact is due to culture medium
- Even though food and feed grade ingredients are suitable for cultured meat production, this paper aimed at showing the impact of using pharma grade ingredients.

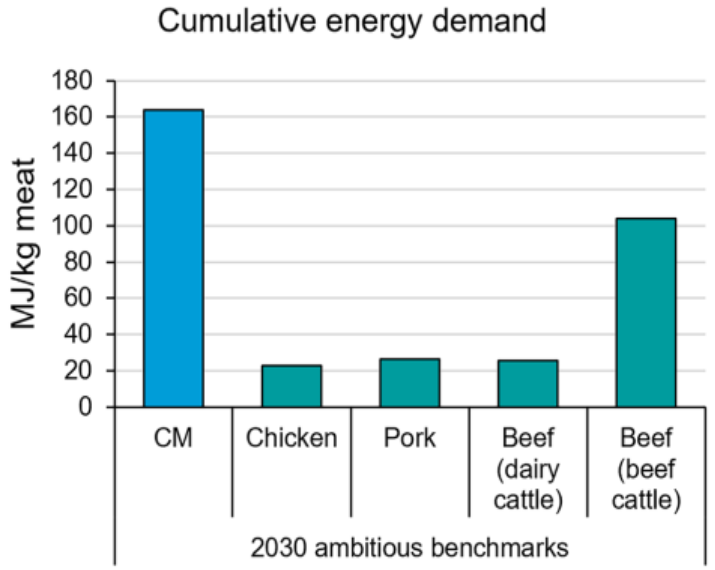


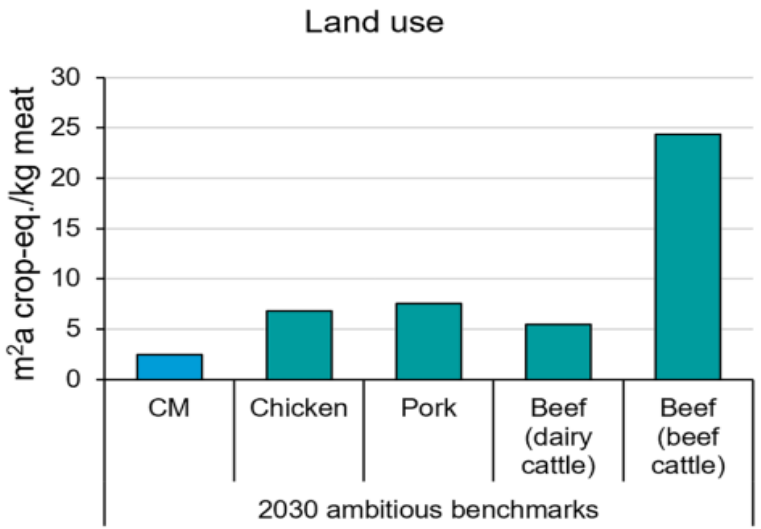
Climate impact of cultivated meat versus bovine meat when including and excluding pharma grade purification of the culture medium ingredients for cultivated meat (HGM, AAR & GCR = scenarios for cultivated meat, DH = dairy heard, BH = beef heard), (Risner et al. 2025, ACS Food Sci. Technol. 5, 61-74)

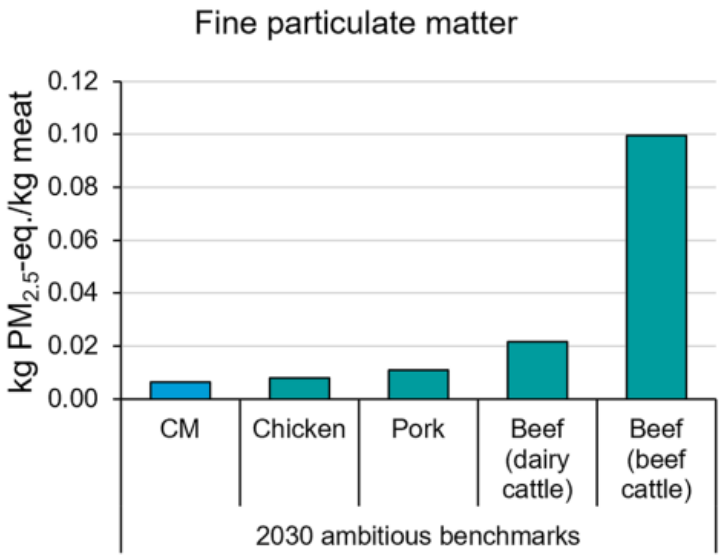
Environmental impacts of cultured meat (CM)

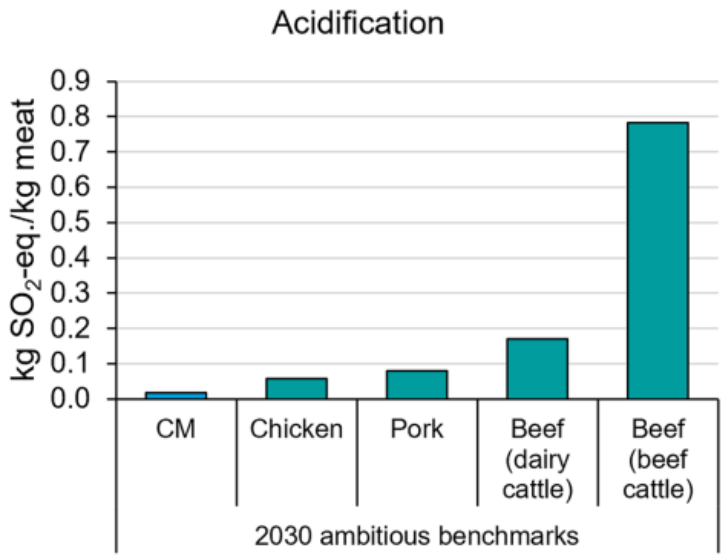
Sinke et al. (2023) International Journal of Life Cycle Assessment 28 234-254

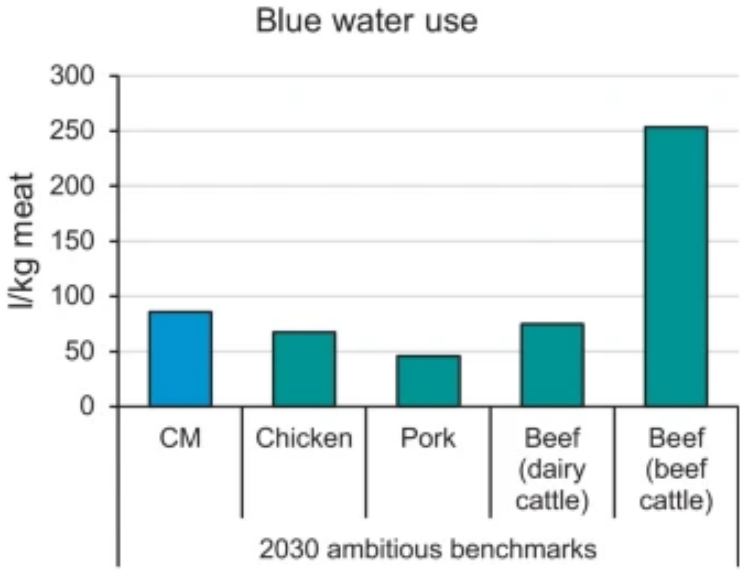




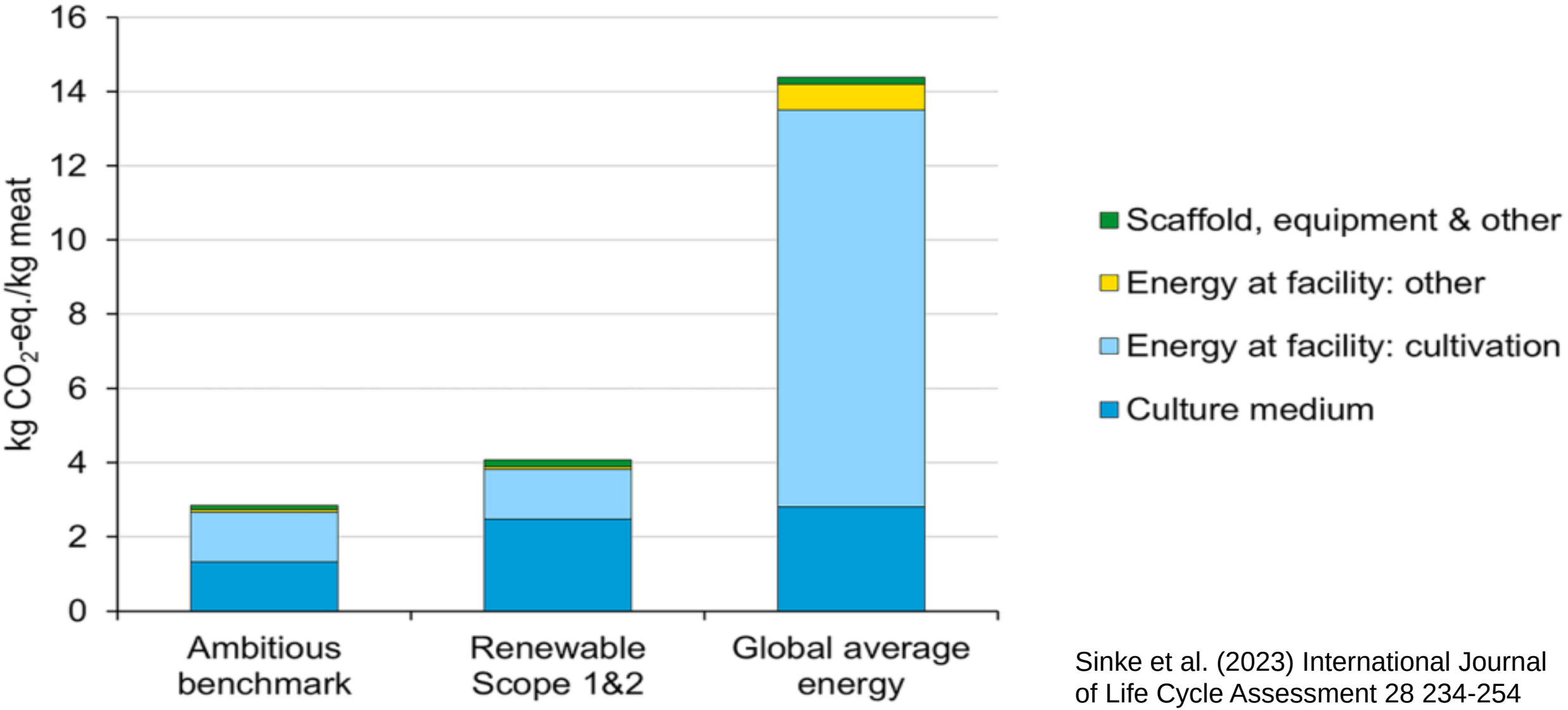








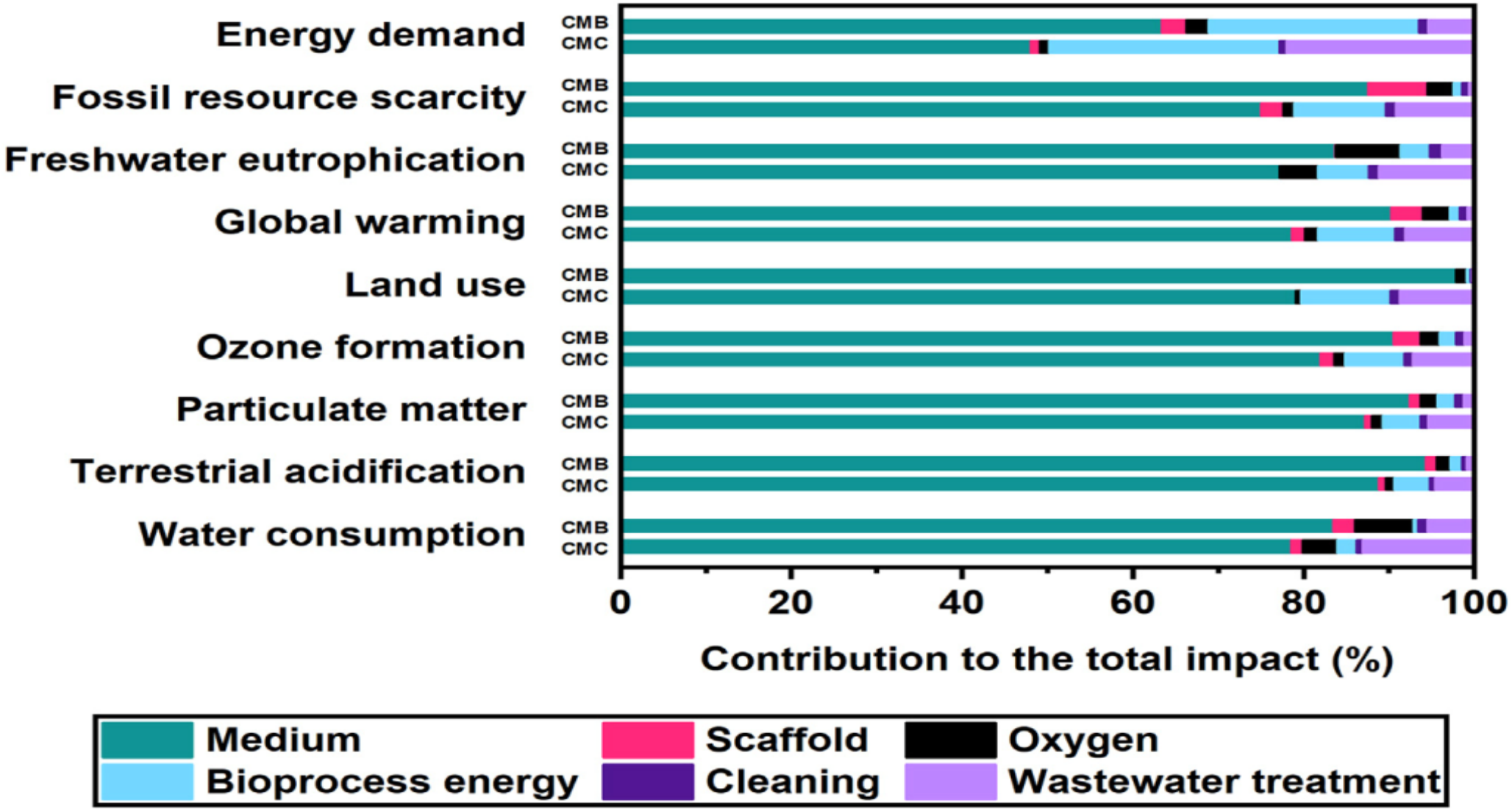
Culture medium and bioprocess energy use the main contributors to carbon footprint of cultivated meat



Sinke et al. (2023) International Journal of Life Cycle Assessment 28 234-254

Contribution of different processes on environmental impacts of cultured meat

Tuomisto, Allan & Ellis (2022) Science of the Total Environment 851 158051



Amino acids and glucose the main contributors to impacts of medium

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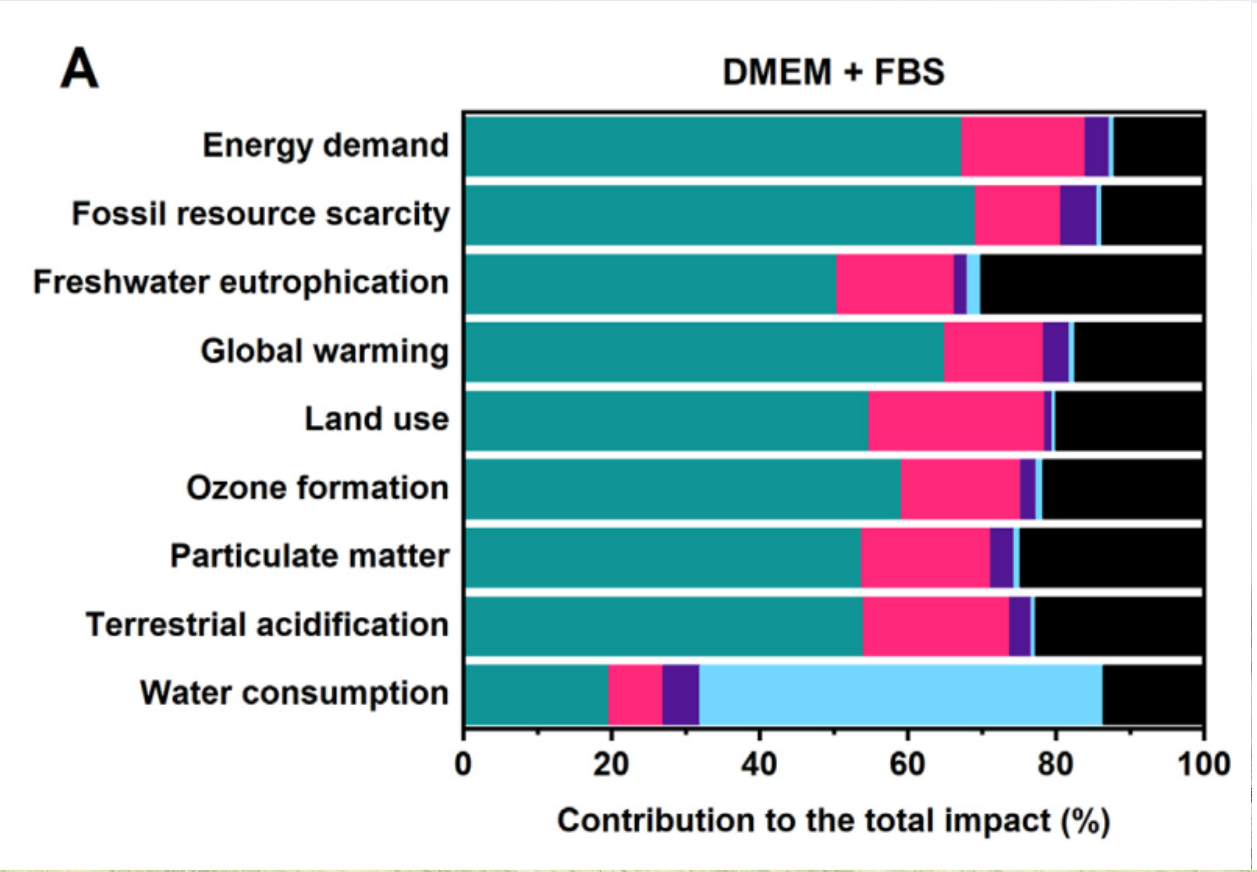
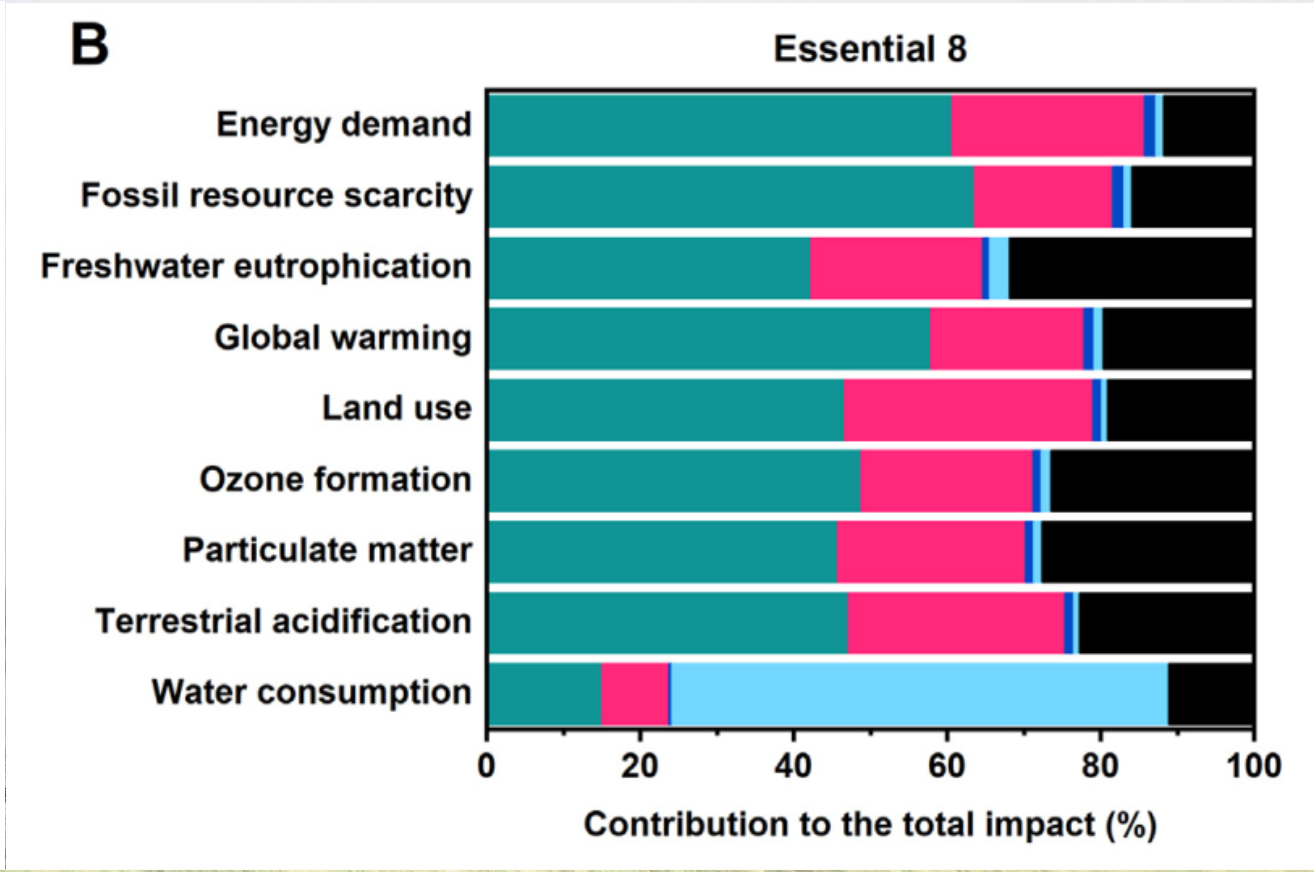
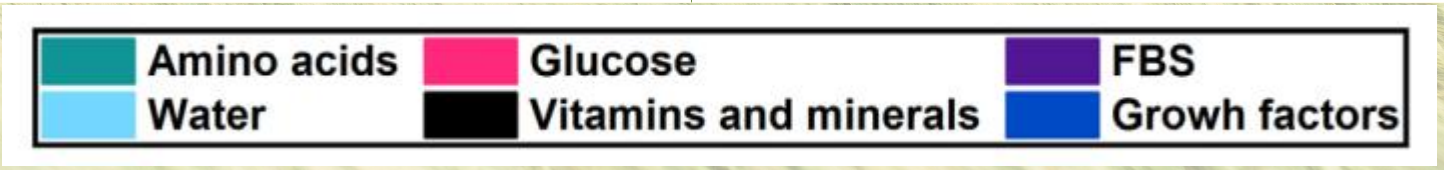






CHALLENGES OF PROSPECTIVE LCA

-SYSTEM BOUNDARIES

What to include and exclude?

How to know what processes are important to include?

- Even if an ingredient is used in small quantity, it can have large impact
  - For instance, growth factors in cultivated meat production
- Product Environmental Footprint (PEF) guidance states that capital goods should be included if evidence states their relevance
  - If evidence not available -> should be included to provide evidence
- In prospective LCAs, better to have broad system boundaries to identify all possible hotspots
  - Energy use at the facility for lighting, A/C, heating, etc.
- What processes needs to be included in comparative LCAs to have fair comparisons?
  - Inclusion of processing to final product, packing, distribution (cool chain), use, waste management (also unused products)

CHALLENGES OF PROSPECTIVE LCA

-DATA QUALITY

Quality of activity data

Data for quantity of inputs and output of the process can be based on:

- Large-scale process modelling based on laboratory scale data
  - Uncertainties whether the process will actually work at that scale
- Similar processes used in other industries
  - Uncertain how similar the processes are
- Data provided by a company
  - Uncertain how reliable the data is

Challenges in the context of cultivated meat LCAs

- Uncertainties regarding: culture media volumes and ingredients, energy consumption of the large-scale processes, possibilities to recycle culture media components, possibilities to utilise side-streams for other processes

Quality of LCI data for inputs

LCI data for input production can be based on:

- LCI data for the specific product found in LCI databases or literature
  - Uncertainties can be caused if production location or system is different (considering also improvements in the technologies in the future)
    - LCI data can be modified to improve suitability
- Proxy data based on other similar products
  - Challenging to determine which products are sufficiently similar
- Data obtained from input producers
  - Uncertain how reliable the data is
- Modelling based on literature data of the production processes
  - Often time consuming

Challenges of LCI data for inputs in the context of cultivated meat

- The life cycle inventory data for inputs (especially culture medium ingredients) lacking and/or poor quality
- Often proxies based on similar production method needs to be used
- Need to improve the data quality
  - More LCAs for medium ingredients with different purity levels, production in different countries, inclusion of packaging and transportation (including cool chain)
    - Meanwhile development of better proxies

- Most studies use culture media inventory from Mattick et al. (2015) with small modifications

Vitamins	**Proxy data**
Choline chloride	Hydrolysis product
D-Panthothenic Acid * 1/2Ca	Hydrolysis product
Folic Acid	Fermentation product
Niacinamide	Hydrolysis product
Pyridoxine * HCL	Hydrolysis product
Riboflavin	Fermentation product
Thiamine hydrochloride	Hydrolysis product
i-Inositol	Hydrolysis product

Tuomisto, H.L., Allan, S.J., Ellis, M.J., 2022. Prospective life cycle assessment of a bioprocess design for cultured meat production in hollow fiber bioreactors. Science of The Total Environment 851, 158051

CHALLENGES OF PROSPECTIVE LCA

-LIFE CYCLE IMPACT ASSESSMENT

Suitability of LCIA methods for prospective LCA

Should emission factors be different for prospective LCAs?

- How to predict the development of emissions factors to 30 years of future?
  - Water scarcity factors, others?
- Would different emission factors change conclusions compared to using the current ones?

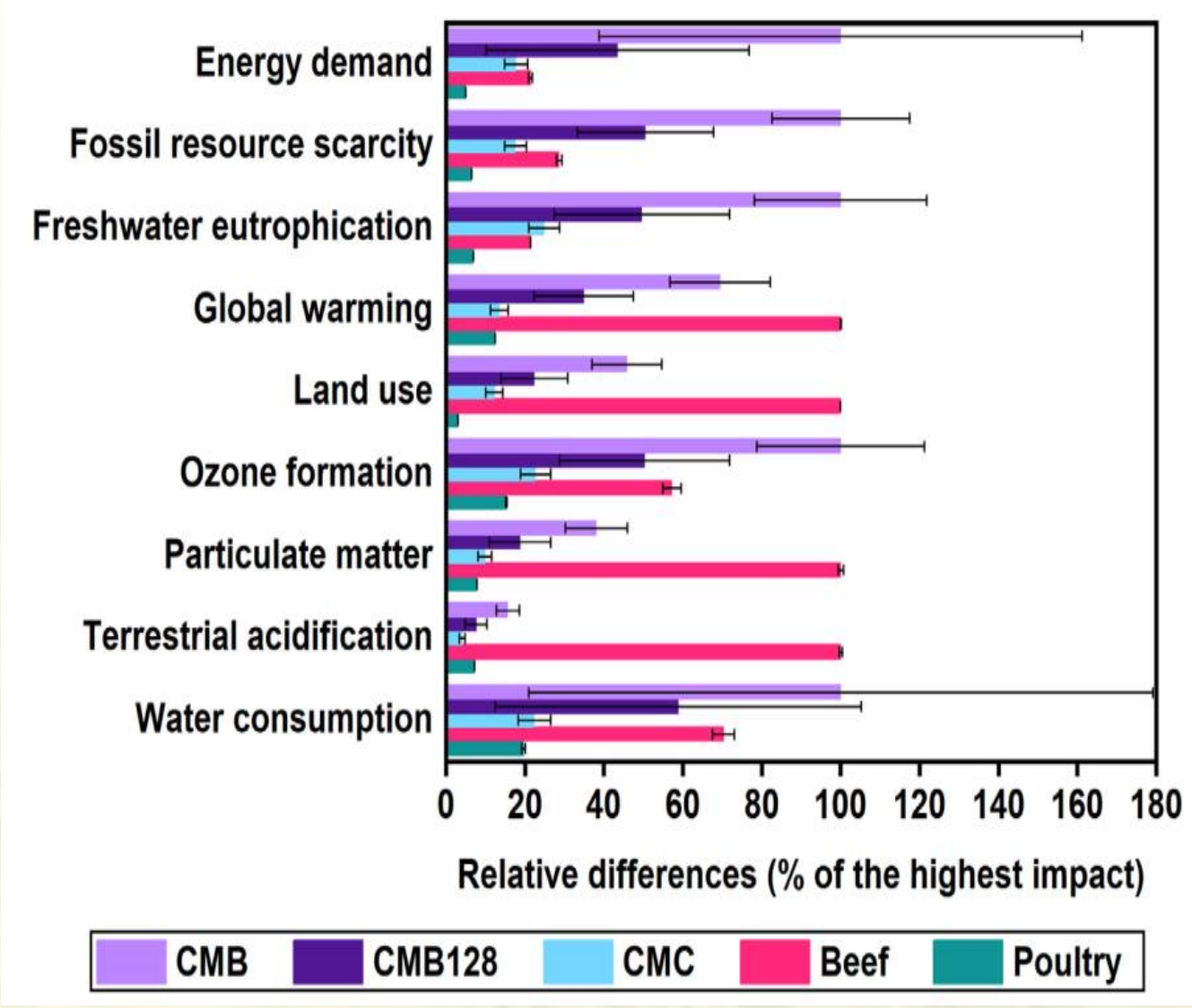
CHALLENGES OF PROSPECTIVE LCA

-UNCERTAINTY ASSESSMENTS

Monte Carlo analysis

- Monte Carlo analysis can yield wide uncertainty ranges
- Heijungs (2020, Int. J. LCA, 25, 394-402): “When input parameters are not estimated using samples, … , the Monte Carlo approach should not be used at all”.

  -> Recommended to use the predigree matrix method instead (Ciroth et al. 2016, Int. J. LCA, 21, 1338-1348)



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Sensitivity and scenario assessments

- Sensitivity and scenario assessments can be used for assessing uncertainties

Examples for cultivated meat

- Different system designs, bioreactors, medium ingredients
- Optimisation of medium
- Possibilities to extract components from medium and recycle medium ingredients
- Different cell types (primary cells, fat tissue, species)
- Data about dry matter increase in differentiation/maturation phase and protein content & quality of the cells

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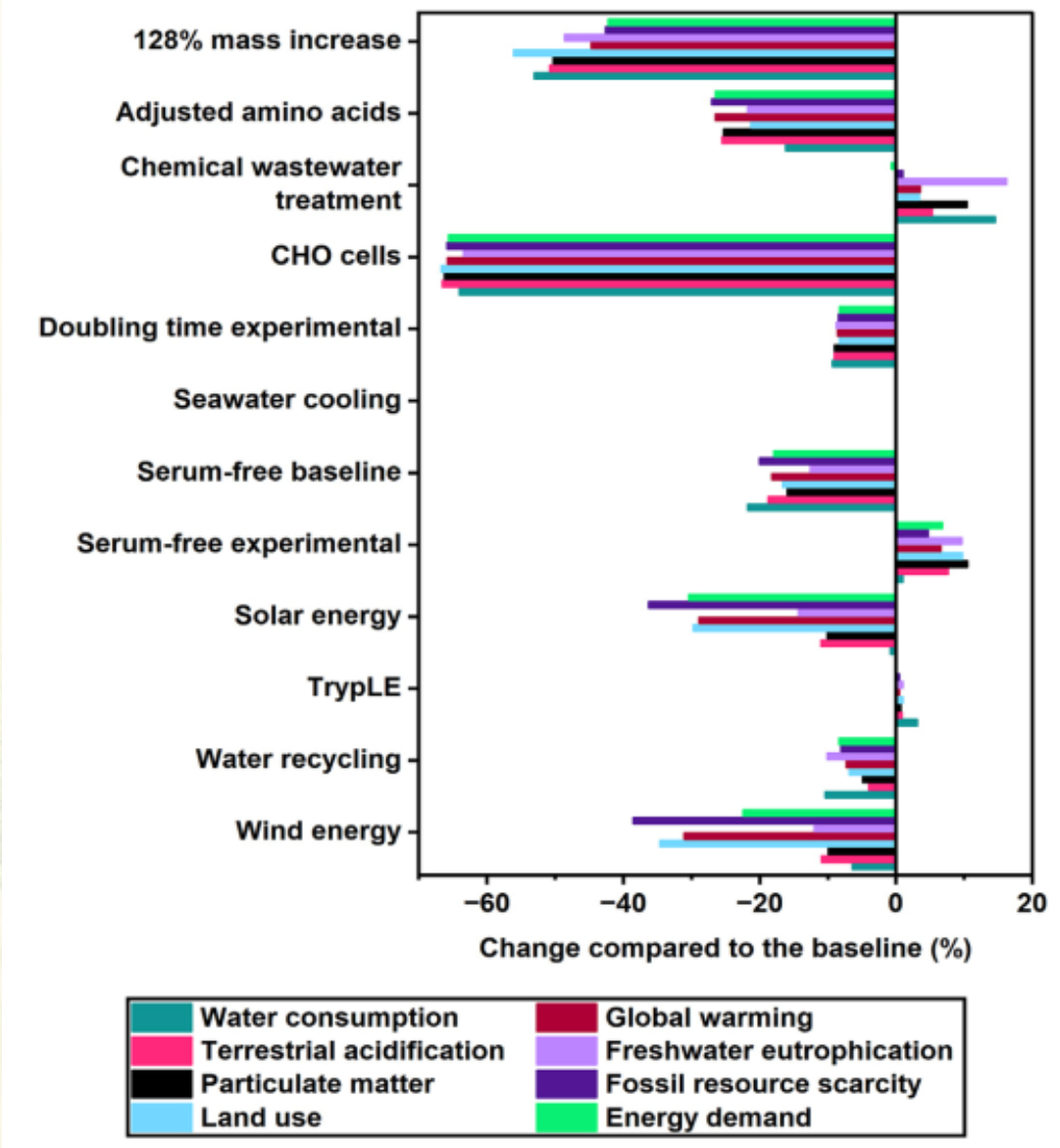

Conclusions: ways forward to improve prospective life cycle assessments (LCA) of cultivated meat

- Development of harmonized method guidance for conducting LCAs for cultivated meat
  - Working group of LCA experts led by Nicole Blackstone (Tuffts University) and Hanna Tuomisto has started to develop the guidelines
- Improvements in LCA datasets for medium ingredients and other input materials
  - More LCAs for the inputs
  - Development of centralized database where companies can provide anonymous data that will be pooled together
  - Provide recommendations for better proxy data
- More LCAs for different cultivated meat production processes
  - Different cell types, bioreactors, media, process design
  - Wider system boundaries (capital goods, facility energy)
  - More environmental impact categories (biodiversity)

Acknowledgements

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All collaborators, colleagues and friends!

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