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Is recombinant milk a better alternative for the environment?

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Background

Current milk production system[1,2]

Environmental: Milk is ranked second after cattle/sheep meat among all food commodities in regards to their CO_2 footprints.

Public health: Animal husbandry likely promotes the spread of antibiotic resistance and zoonotic diseases.

Ethical: Animal welfare is disrupted by the large-scale production industries and farming practices.

Current alternatives

Plant-based products have altered taste, functionality and nutritional content compared to cow's milk, leaving open space for innovation and improvements.[3] **Mammalian cell cultures** are limited by scalability and extensive media requirements.

Our approach and research questions

Precision fermentation technology for the production of milk proteins.

- Is it possible to produce milk proteins recombinantly?
- Is precision fermentation technology a sustainable solution to the problems of the food industry?
- Which are the bottlenecks and hotspots in the process?
- How can we improve the environmental performance?

Goal and scope definition

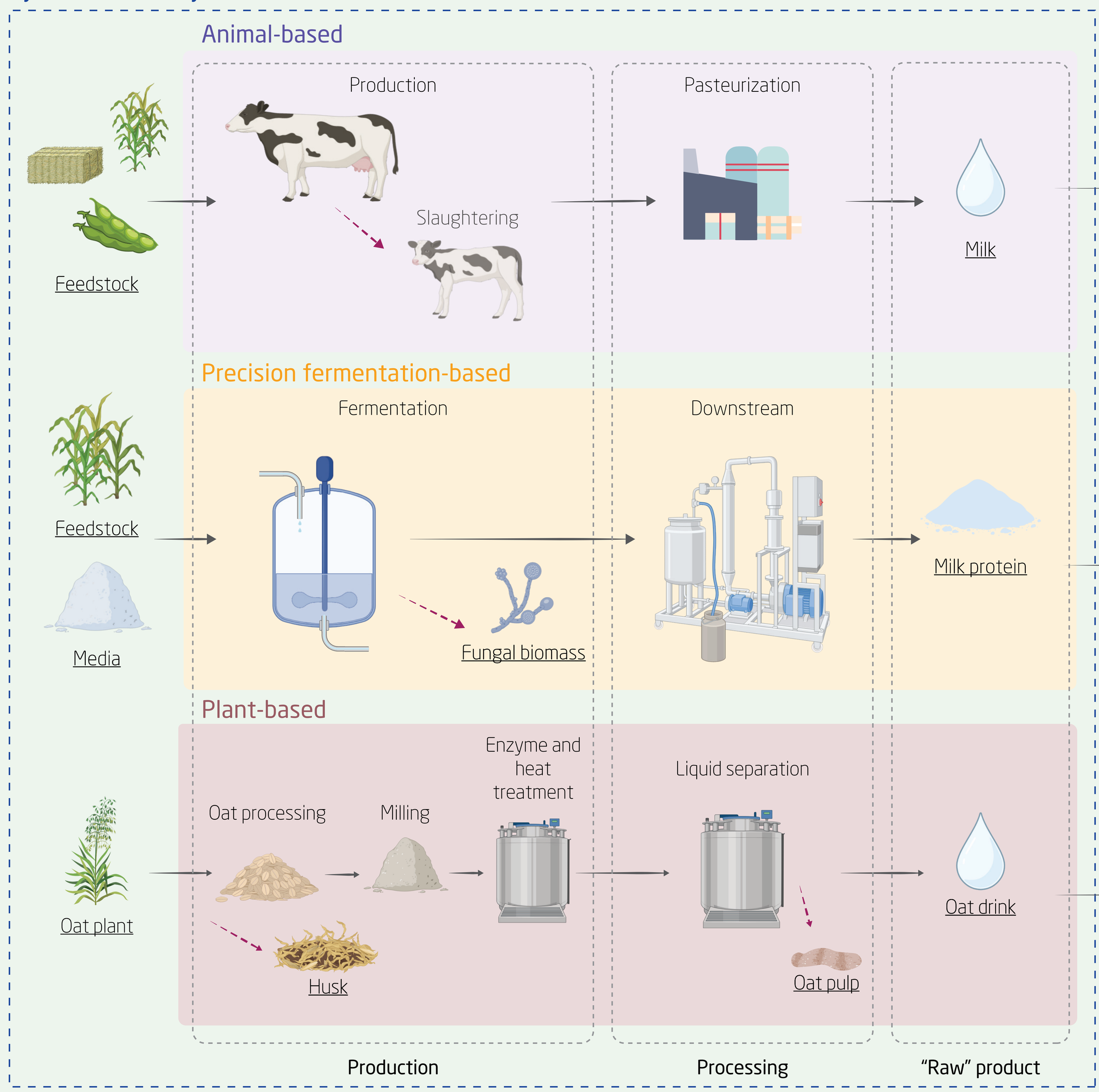

Figure 1. Precision fermentation, animal and plant-based systems including the systems boundary for the LCA. The main input and output flows of the process are underlined.

Aim:

- Understand the environmental impact of recombinant milk production and identify **bottlenecks** and **hotspots** contributing to the environmental footprint
- Identify recombinant protein production **scenarios** optimised towards sustainable production and propose the **most optimal** one
- **Compare** the impact to animal-based and plant-based drinks

Base case

- Functional unit: 1 kg of protein
- Feedstock: glucose
- Titre: 15 g/L
- Purity: 90 % (chromatographic step)
- Energy: fossil-fuel based (United States)
- Fungal biomass: biowaste (biogas)

Scenarios and sensitivity cases

Energy: semi-renewable (Denmark) and renewable (Iceland)

Titre: 50 g/L and 100 g/L
Purity: 80 % (no chromatographic step)

Feedstocks: waste media (Brewer's spent yearst + molasses)

Fungal biomass: used as animal feed (economic allocation)

Double product: 80 % casein (15g/L)
20% whey (50 g/L)

Life cycle impact assessment

Midpoint impact category	Unit	Glucose	Media	Fermentation	Downstream
Fine particulate matter formation	kg PM2.5 eq	3.07%	3.56%	91.56%	1.81%
Fossil resource scarcity	kg oil eq	32.79%	25.86%	18.47%	22.88%
Freshwater ecotocixity	kg 1,4-DCB	18.05%	66.36%	4.69%	10.90%
Freshwater euthropication	kg P eq	22.38%	35.77%	23.82%	18.03%
Global warming	kg CO2 eq	25.12%	21.67%	29.35%	23.86%
Human carcinogenic toxicity	kg 1,4-DCB	20.48%	46.02%	8.09%	25.41%
Human non-carcinogenic toxicity	kg 1,4-DCB	3.63%	78.93%	6.05%	11.39%
Ionizing radiation	kBq Co-60 eq	20.83%	18.94%	48.96%	11.26%
Land use	m2a crop eq	88.83%	6.17%	1.44%	3.56%
Marine ecotoxicity	kg 1,4-DCB	17.12%	67.12%	4.72%	11.04%
Marine euthropication	kg N eq	68.71%	19.78%	2.27%	9.24%
Mineral resource scarcity	kg Cu eq	14.82%	71.63%	1.72%	11.82%
Ozone formation, human health	kg NOx eq	33.22%	36.81%	9.86%	20.11%
Ozone formation, terrestrial ecosystems	kg NOx eq	33.22%	36.82%	9.85%	20.10%
Stratospheric ozone depletion	kg CFC11 eq	46.57%	3.20%	17.88%	32.35%
Terrestrial acidification	kg SO2 eq	2.79%	2.65%	93.48%	1.09%
Terrestrial ecotoxicity	kg 1,4-DCB	17.97%	68.38%	1.95%	11.70%
Water consumption	m3	30.86%	36.63%	15.04%	17.47%

0 % — 100 %

Figure 2. Hotspot analysis of the base case. The table shows the contribution of each main unit of the recombinant process to the total impact on each category.

- **Main contributors**: glucose and media (especially ammonium sulfate)
- **Feedstock**: responsible for almost 90% of the land use, which highlights the need for alternative feedstocks
- **Electricity**: it highly contributes to the global warming and resource scarcity categories (>10%)
- **Fermentation**: most of the impacts are derived from the gas emissions of the biological process

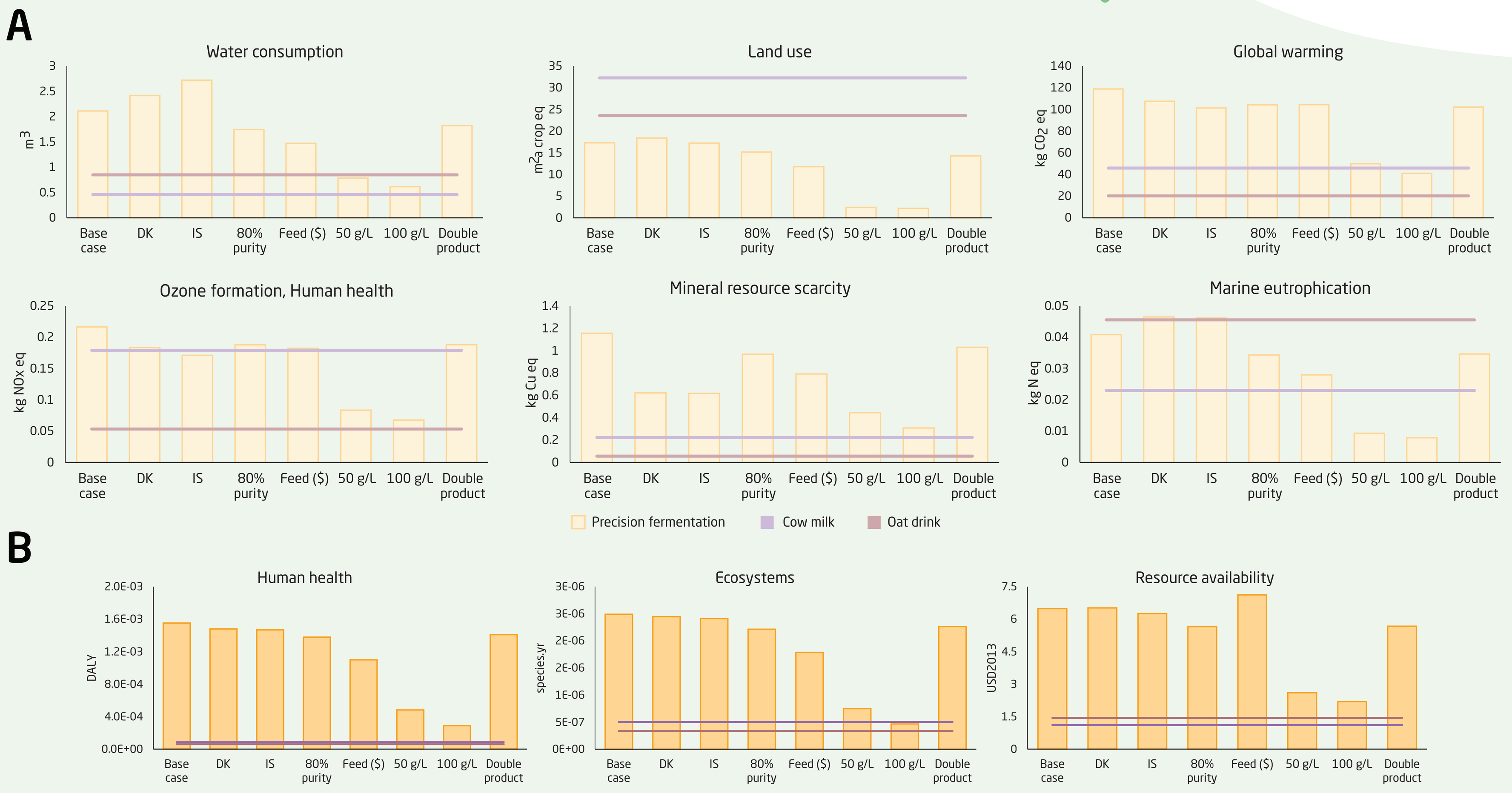

Figure 3. Environmental impact assessment of selected midpoint (A) and endpoint (B) categories according to the ReCiPe 2016 H method. Functional unit for all of the cases, including the cow milk and oat drink, is 1 kg of protein.

- **Overall impact:** oat drink or cow milk << recombinant milk protein
- **Sensitivity analysis:** titre is a high leverage point and has high potential for reduction of environmental impacts
- **Burden shifting:** renewable energies can decrease the impact (fx resource scarcity and ecotoxicity); however, they can also be detrimental (fx water consumption)

Future steps

Techno-economical assessment (TEA)

Which are the main cost drivers in the process?
Is it economically viable to produce milk proteins recombinantly?
What are the trade-offs between the economic and enviromental dimensions?

Absolute sustainability (AESA)

Calculate the **share of the Safe Operating Space** of the dairy industry, precision fermentation system and oat-drink
Explore different **allocation** and **upscaling** methods

Partial substitution of animal-based dairy with precision fermentation and plant-based milk
Pair the analysis to regional **technical** and **social** resources

Is there any **scenario** of recombinant milk that is overall environmentaly better than the animal milk?
Is there any **burden-shifting** and if so, could we balance the impacts out by a combination of cow milk and precision fermentation?
How much **investment** would it be required to make a change in the impact from the dairy industry?

Do you have any input or feedback?
Is there anything that would be interesting to research or be included in this project?
I would love to hear your opinion!

LET'S GET IN TOUCH AND DISCUSS THE POTENTIALS AND CHALLENGES OF RECOMBINANT MILK

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1- FAO. (2020). World Food and Agriculture - Statistical Yearbook 2020
2- Steinfeld, H. (2006). Frontiers in Ecology and the Environment (Vol. 5, Issue 1)
3- Chalupa-Krebzdak, S., Long, C. J., & Bohrer, B. M. (2018). International Dairy Journal (Vol. 87, pp. 84–92)

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