LIFE CYCLE ASSESSMENT

paleo

As the first European venture capital fund, Planet A relies on its own scientific team to assess the environmental and climate impact of an innovation. Prior to an investment, a life cycle assessment, like this one, is conducted and integral part of the investment decision. All assessments as well as the methodology is published for maximum transparency.

Terminology and abbreviations

BMGY	Buffered glycerol-complex medium
CED_f	Cumulative fossil energy demand
CO_2-eq.	Carbon dioxide equivalents
DIASS	Digestible indispensable amino acid score
Functional unit	Quantified performance of a product system for use as a reference unit
FAME	Fatty methyl esther
GHG	Greenhouse gas
GMO	Genetically modified organisms
LCA	Life Cycle Assessment
PCDAAS	Protein digestibility-corrected amino acid score

About Paleo

The Belgian company Paleo researches and develops new functional ingredients to improve plant-based meat and fish alternatives. Through precision fermentation (currently using yeast), Paleo produces specific meat and fish proteins which are 100% bio-identical to animal proteins and 100% free of genetically modified organisms (GMO). Their primary focus is on myoglobin, a heme protein present in animal muscle tissue. Adding myoglobin makes plant-based foods look, taste and smell more like “real” meat or fish (color, smell, taste, aromatic experience) and provides added nutritional value, such as iron (essential nutrients).

Version 1.0 - February 24 2023

Summary

Conventional animal products are widely used as a source for essential nutrients and proteins. Their production and consumption has multifold negative implications for the environment and human health. Agriculture accounts for a high share of anthropogenic GHG emissions, ranging from 24 to 37% of total anthropogenic GHG emissions if all impacts of meat production are included (Xu et al. 2021). Up to 57% of these emissions can be attributed to livestock. Aside from GHG emissions, livestock has many negative effects on biodiversity, water use and pollution as well as land use and land use change. In contrast, alternative proteins, such as proteins contained in or derived from plants, fungi, bacteria or insects offer a more sustainable protein supply.

Paleo offers myoglobin can be added to alternative protein products to enhance the quality and taste of such alternatives. Additionally, and most importantly with regard to the potential environmental (and health) impact, Paleo's myoglobin addresses key market barriers to the wider adoption of alternative protein products. By addressing these barriers, a wider adoption of alternative protein sources and a decrease in demand for conventional animal-based proteins can be expected resulting in substantial benefits to the environment.

Our analysis shows that changing the protein source from a conventional meat protein to an alternative protein results in:

- **net GHG savings ranging from 21 to 296 kg CO_2-eq. per kg of protein,**
- **a reduction in land demand between 42 and 854 m^2a per kg of protein, and**
- **net water savings ranging from 8 to 56 m^3 of water saved per kg protein.**

The contribution of Paleo's myoglobin product to the overall impact of alternative protein products is very small. Therefore, Paleo's myoglobin can provide a powerful lever to reduce the impact of human food production by promoting a shift towards more sustainably sourced proteins.

About this study

This study is divided into three parts. **Part I** provides a brief insight into the market for alternative proteins, existing market barriers and how Paleo addresses these barriers. In **Part II**, a Life Cycle Assessment of Paleo is presented. **The LCA addresses the question how environmental impacts change if consumers switched from conventional meat-based proteins to alternatives.** The LCA assesses Paleo's impact in detail and provides a broader view on the systemic change of a diet shift. In **Part III**, other environmental impacts of conventional meat consumption are discussed. Lastly, a **summary** combines the key findings of all chapters to provide an overview on the environmental implications of the systemic change that Paleo can actively contribute to.

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1. Part I: Alternative proteins - market prospects and barriers

1.1. The alternative protein market

In the last years the overall alternative protein sales increased by 38% (Joseph et al. 2020). This increase is mainly due to meat-eating consumers who are open to trying alternative proteins every now and then (Jahn et al. 2021). This consumer group is called “Flexitarians”. As they still have meat cravings but do include plant-based meat alternatives in their diets, they are the main target group for Paleo . Across the global market 36% of the consumers intended to consume more alternative proteins (Joseph et al. 2020). Nevertheless, the same study revealed that 21% want to consume fewer alternative proteins. Other studies show that up to 60% of consumers are open to eating more plant-based proteins (Ibrahimi Jarchlo and King 2022; Grasso et al. 2019). Witte et al. (2021) estimate that by 2035, after alternative proteins reach full parity in taste, texture, and price with conventional animal proteins, 11% of all the meat, seafood, eggs, and dairy eaten around the globe is very likely to be from alternative sources (Witte et al. 2021). With a push from regulators and step changes in technology, that number could reach 22% in 2035. By then, Europe and North America will have reached the point of “peak meat,” and consumption of animal proteins will begin to decline. More than 30% would fully switch their diets to alternative proteins if doing so would have a major positive impact on climate. Overall 76% of consumers are familiar with alternative proteins. However, certain barriers existit preventing a faster adoption of alternative and more sustainable protein sources.

The investment in companies working on fermentation animal-cells based meat (lab grown meat) rose by 150% to $1.7 billion in 2021 and the European substitute market is projected to reach 3,5 bn by 2027 (Morach et al. 2022). The increased attention to alternative proteins is expected to improve taste, texture and price of alternative protein sources (Morach et al. 2022).

Agriculture accounts for a high share of anthropogenic GHG emissions, ranging from 24 to 37% of total anthropogenic GHG emissions if all impacts of meat production are included (Xu et al. 2021). Up to 57% of these emissions can be attributed to livestock. More than 30% of people that are currently partly consuming alternative proteins would completely change their diet if it would have a positive impact on climate. The positive impact on climate is therefore, next to animal welfare and health, one of the main motivators for their consumption.

1.2. Market barriers

To increase the market share of alternative sources of proteins and decrease the consumption of meat, several barriers must be addressed on the consumer side:

- The main reason for flexitarians to not switch entirely to a plant-based diet is the love and craving for the taste of meat (Jahn 2021).
- Consumers who are using plant-based meat alternatives less than five times a week are looking for products who look, taste, feel, cost and behave similar to meat (Joseph et al. 2020).
- Meat is not only valued for its taste and other sensory aspects but also for its nutritional value (Jahn et al. 2021; Cheah et al. 2020). Another barrier is therefore (perceived) lack of nutrients, especially iron. The common belief across meat eating consumers is that animal products contain nutrients that are important for our diets but cannot be easily substituted.

- Health concerns also arise because meat alternatives are viewed as highly processed foods with a lot of ingredients. Customers value products with fewer ingredients and better nutritional value.

Aside from consumer-related barriers, other obstacles exist:

- Another barrier to the wider adoption of vegan proteins is **cost**. Currently, many alternative protein sources are more expensive than animal-based proteins, which can make them less accessible to consumers. Reducing the cost of production and improving economies of scale will be important to making these products more accessible and competitive in the market.
- There are also **regulatory challenges** that must be addressed to support the growth of the alternative protein market. For example, there may be restrictions on the labeling and marketing of these products, which can limit consumer awareness and understanding of these products. Addressing these regulatory challenges will be important to promoting the growth of the alternative protein market.

In conclusion: a significant improvement in taste, color, texture, cost and ingredients of alternative protein products can alleviate barriers to consuming less meat. It is estimated that there could be an +100% increase in exclusive or near-exclusive consumers of plant based proteins if the main barriers are resolved (BCG 2022).

1.3. How Paleo addresses market entry barriers

Fermentation proteins, such as the ones Paleo develops, can significantly improve taste and color. Paleo's myoglobin creates a red-pink color which turns brown when being cooked while delivering a meaty flavor. In addition, Paleo's myoglobin allows the reduction in ingredients of meat alternatives, such as iron supplements, flavorings and ingredients affecting the appearance of alternative meat products. Iron contained in Paleo's myoglobin is highly bioavailable, similar to iron contained in conventional animal-based myoglobin. To achieve all these characteristics, only very low quantities of Paleo's myoglobin need to be added (between 0.1 and 1% of product weight).

2. Part II: LCA of Paleo's myoglobin

In the following chapters, we describe the system and explain the data inventory used.

2.1. System description

Paleo's myoglobin can be used to enhance the quality of alternative protein sources (see Part I). The aim of this LCA study is to assess the potential systemic changes in environmental impacts of a switch in diets from conventional animal-based proteins to other protein sources. To assess the impact on the environment, a consequential LCA approach was applied. The approach evaluates marginal changes within the overall economy as a consequence of a change in the market structure (e.g. entry of a new market participant such as Paleo), production modalities, demands as well as political, consumer or any other decision affecting the former aspects (Ekvall et al. 2016). To account for marginal changes, marginal data is used wherever possible, e.g. marginal suppliers are identified and the change in their production output is considered (in contrast to using market averages).

Paleo's product addresses several barriers existing regarding the market uptake of alternative protein products (see Part I). Thus, Paleo is likely to promote an increase in demand for alternative protein products and a decrease in the demand for conventional meat products. On a systemic level, this change comprises an increase in all production processes related to Paleo's myoglobin production, additional production processes to produce alternative protein products, and less demand for conventional meat (Figure 1). Additionally, the demand for glycerol, used in the fermentation medium of Paleo, might trigger additional market responses (Figure 1 and section 2.1.3.)

2.1.1. Functional unit and assessed indicators

The LCA comprises three main elements: The impact of Paleo's myoglobin production, the impact of protein supply and the systemic change in environmental impacts resulting from a change in protein consumption. The functional unit used to determine the impact of Paleo's myoglobin production, of other protein supply and the systemic change is **one kg of protein** (Paleo's myoglobin, other conventional animal proteins and alternative proteins).

The system is assessed using the indicators **climate change** (Intergovernmental Panel on Climate Change (IPCC) 2014) and several indicators related to resource use, **cumulative fossil energy demand** - CED_f (Verein Deutscher Ingenieure (VDI) (ed.) 2012), **land demand** and **water demand** - WSI (Pfister, Koehler, and Hellweg 2009).

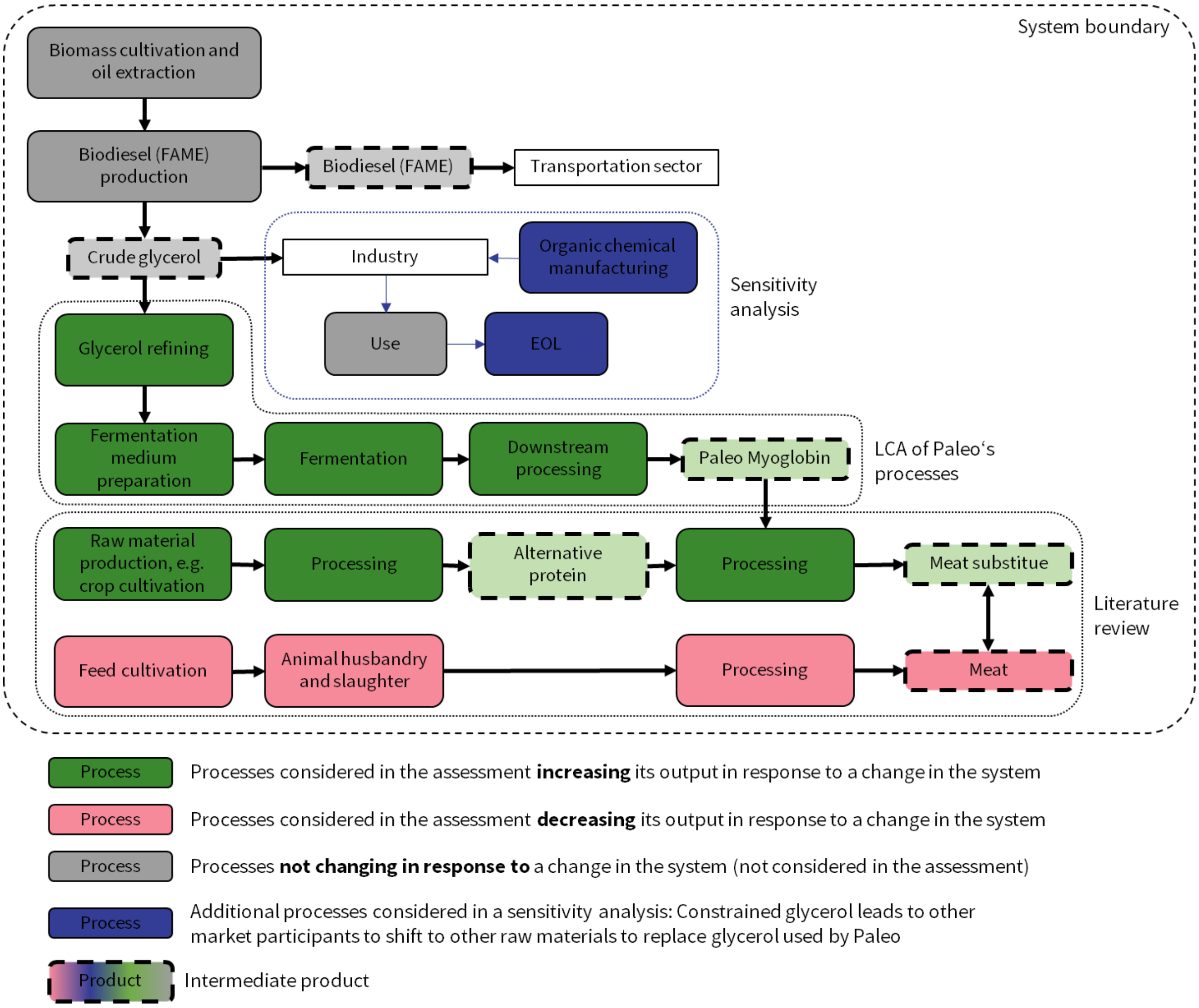

Figure 1 *Depiction of system boundaries. The gray process steps do not change in response to a shift from meat-based proteins to alternative protein sources. Green processes will increase their output, while red processes reduce their output. Additional processes (blue) are considered in a sensitivity analysis (see section 2.1.3.).*

2.1.2. Paleo's myoglobin production

Paleos production process consists of the following elements which were considered in the LCA:

- Medium preparation: The fermentation medium used in the process contains multiple ingredients. The complete list of ingredients is known to Planet A. A cut-off was applied to exclude all nutrients contained in trace quantities. All ingredients of at least 0.1% concentration (1g per L) were considered in the assessment.
- Inoculum production: A seed train is used to produce inoculum containing the microorganisms to start the fermentation process. The inoculum medium, energy requirements as well as technical parameters, such as cell density of inoculation medium, nutrient demand etc. were considered in the assessment. The medium used is a buffered glycerol-complex medium (BMGY).
- Fermentation: Most important parameters, such as fermentation time, myoglobin titer, nutrient demand, technical specifications as well as the demand for energy and auxiliary materials were considered in the assessment.
- Downstream processing: In several downstream processing steps, myoglobin is purified, concentrated and preserved by either drying or freezing. Downstream processing includes biomass removal, concentration and purification by successive microfiltration and ultrafiltration steps.

- Additional activities: Equipment sanitation and transportation of the product is included. A transport of 500 km by truck is assumed.
- Infrastructure and its operation: The assessment includes infrastructure that needs to be installed and its operation. The facility was modeled by using a proxy (ethanol production facility contained in the ecoinvent database scaled according to the size of Paleo's plant). The operation of warehouses, offices and refrigerated storage facilities requires energy. The energy demand for buildings is included in the assessment.

2.1.3. Overview of the glycerol market and its implications for the assessment of Paleo's impact

Paleo uses glycerol as a carbon source for the microorganisms to produce myoglobin. Glycerol is a co-product of processes using fatty acids to produce biodiesel/ fatty acid methyl ester (FAME). Therefore, the glycerol market was heavily supply driven: the increasing production of biodiesel resulted in large quantities of glycerol that were supplied to the market. In the future, the demand for biodiesel (FAME) is predicted to increase globally (International Energy Agency (IEA) 2023). The increase in demand for biodiesel is driven by legislation globally. The increasing supply of glycerol has led researchers and the industry to developing high-value uses of glycerin (Liu, Zhong, and Lawal 2022).

A scaling of Paleo in the upcoming years is likely to coincide with the increase in supply of glycerol. The glycerol demand by Paleo can be fully met by the increase in supply of glycerol triggered by the increase in biodiesel (FAME) production worldwide. Hence, all impacts associated with the production of biodiesel (FAME) and glycerol can be attributed to the political decision to increase biodiesel (FAME) use. Therefore, a scaling of Paleo is unlikely to trigger any additional processes and activities with regard to the supply of glycerol. This approach follows the logic of consequential LCAs (section 2.1). It is assumed that glycerol is refined. The refining step is attributed to Paleo. Researchers also demonstrated that crude glycerol can be directly used as a carbon source for fermentation without intermediate refining (Luo et al. 2018). Results presented in this study therefore present a conservative scenario assuming refining is required.

In the sensitivity analysis, an alternative scenario is assessed, assuming that glycerol used by Paleo will lead to a shift from glycerol to other feedstock in another supply chain. Because these markets have yet to develop and applications for glycerol are still developed, a generic organic chemical is used as a proxy. The considered substitution effect includes the production of a generic organic chemical substance, as well as the release of the carbon contained into the atmosphere in the form of CO_2.

2.1.4. Impact assessment of conventional and alternative protein sources

This assessment of the environmental implications of conventional meat production and alternative protein production is a comprehensive evaluation of the existing literature. The aim is to provide a thorough understanding of the potential environmental implications of different approaches to protein production. The information presented in this assessment has been gathered from a wide range of peer-reviewed studies and reports, and is based on the latest available data and analyses (Table 1). This approach was chosen over an assessment of individual production systems in order to cover the widest range of production modalities and data sources possible.

Table 1 *Overview of studies included in this assessment.*

Reference	Protein source(s)/product(s) included in this assessment	Content of the study
(Poore and Nemecek 2018)	Conventional animal meat, tofu	Comprehensive study assessing the impact of food production comprising ~38,700 commercially viable farms in 119 countries.
(Smetana et al. 2021) and (Smetana et al. 2015)	Plant-based, mycelium (F. venenatum), insect (buffalo worm)	LCA of different ready-to-eat commercially available meat substitutes (e.g. Beyond Meat, Quorn and Rügenwalder), Insect burger.
(Sinke and Odegard 2021)	Tofu, wheat-based protein product, lab grown meat	LCA of different ready-to-eat meat substitutes.
(Van Mierlo, Rohmer, and Gerdessen 2017)	Plant-based flours, protein concentrates and isolates (chickpea, kidney bean, lentil, lupine, pea, soy, wheat), insects (mealworm, superworms)	Development of a linear computation model to compose meat replacers containing similar nutritional properties as beef and chicken. LCA of all products, including nutrient fortifications.
(Upcraft et al. 2021)	Mycelium (F. venenatum)	Process modeling and LCA of mycoprotein production
(Sillman et al. 2020)	Microbial proteins	LCA of a power-to-food system utilizing CO_2 as a carbon source, energy and nutrients to produce microbial proteins from autotrophic hydrogen-oxidizing bacteria.
(Järviö et al. 2021)	Microbial proteins	LCA of proteins from autotrophic hydrogen-oxidizing bacteria.
(Tuomisto, Ellis, and Haastrup 2014; Tuomisto and Teixeira de Mattos 2011)	Lab grown meat	LCA of in vitro meat cultivation
(Sinke et al. 2023)	Lab grown meat	Ex-ante LCA of commercial-scale lab grown meat production in 2030
(Mattick et al. 2015)	Lab grown meat	Ex-ante LCA of lab grown meat

2.1.5. Protein digestibility

The digestibility of proteins is an important factor to consider when evaluating their nutritional value. Not all proteins are equally digestible, and the ability of the body to absorb and utilize a protein can vary significantly between different sources. This is why it is important to consider not only the balance of essential amino acids in a protein, but also its digestibility when evaluating its nutritional quality.

To account for differences in protein digestibility, two methods are widely used: the Protein Digestibility Corrected Amino Acid Score (PDCAAS) and the Digestible Indispensable Amino Acid Score (DIASS). Both methods provide a way to compare the nutritional quality of different proteins by taking into account their amino acid composition and digestibility:

- The PDCAAS method considers two factors in determining the quality of a protein: the balance of essential amino acids and the digestibility of the protein (Schaafsma 2000). Essential amino acids are those that cannot be synthesized by the body and must be obtained through the diet. The PDCAAS score is calculated by comparing the amino acid composition of a reference, and correcting for differences in digestibility. The selected reference is the essential amino acid requirement of preschool-age children. A PDCAAS score of 1.0 is the highest possible score, indicating that the protein has an ideal balance of essential amino acids and is highly digestible. A score of less than 1.0 indicates that the protein may be deficient in one or more essential amino acids or have low digestibility.
- The DIASS is a method used to evaluate the quality of proteins based on their amino acid composition and digestibility. It is a newer approach compared to the more widely used PDCAAS and provides a more detailed analysis of protein digestibility. DIASS calculates the digestibility of individual amino acids in a protein and provides a score based on the availability of these essential amino acids for the body. The score is determined by comparing the amino acid composition of a protein to a reference pattern, such as the pattern of essential amino acids required by the human body. A DIASS score of 1.0 indicates that the protein provides the ideal balance of essential amino acids for the body, and that all of these amino acids are highly digestible. A score less than 1.0 indicates that the protein may be deficient in one or more essential amino acids, or that the digestibility of one or more amino acids is low.

By using these methods, it is possible to evaluate the nutritional quality of proteins and to determine the quantity of protein intake required. In order to achieve an equivalent protein use of the body, consumers might adapt the protein intake accordingly. Yet, limitations are pointed out by researchers arguing that the presented methods alone are not fully sufficient to provide guidance on the optimal protein intake, cf. (Derbyshire 2022; Boye, Wijesinha-Bettoni, and Burlingame 2012; Schönfeldt and Gibson Hall 2012). Scientists demonstrated that a combination of different plant-based proteins can provide similar protein profiles as meat, even for demanding nutritional profiles (Dimina et al. 2022).

A compilation of PDCAAS and DIASS of protein sources included in this study is provided in Table A.1. in the Annex. In the sensitivity analysis an assessment is included that accounts for the PDCAAS and DIASS by adjusting the quantity of any protein needed according to the PDCAAS and DIAAS (section 2.2.1.5.3). It should be noted that this is a simplification: a combination of different foods with PDCAAS or DIASS lower than 1.0 could provide a total score of 1.0 if contained proteins complement each other. Additionally, this approach simply assumes that more of a respective protein is consumed. This might lead to an oversupply of certain nutrients.

2.2. Results

In the following section, the environmental impacts of Paleo myoglobin production are assessed in detail. Subsequently, an overview of the assessed indicators is provided for different protein sources. Lastly, both outcomes are combined by assessing the overall impact of switching from a diet based on conventional animal proteins (beef, mutton, lamb, pig and poultry) to other protein sources that are enhanced with Paleos myoglobin.

2.2.1. Environmental impact of Paleo myoglobin

2.2.1.1. Climate change

The production of Paleo's myoglobin results in GHG emissions of 41.1 kg CO_2-eq. (final product is dried) and 24.4 kg CO_2-eq. (final product is frozen) per kg protein in the base case (Figure 2). In the upside case, the GHG emissions amount to 24.4 and 18.2 kg CO_2-eq. per kg protein in case the final product is dried or frozen, respectively.

If the product is dried, downstream processing is the largest contributing factor to GHG emissions, accounting for 47 and 34% of GHG emissions in the base and upside case, respectively. The high impact of product drying reveals that reducing the moisture to be removed from the product stream for drying, a reduction in energy consumption of the drying step, as well as the GHG intensity of drying present the biggest levers to reduce overall GHG emission reductions of Paleo's operations. Instead of drying using natural gas, drying could be accomplished using biogenic energy sources, such as biogas.

The second and third largest contribution arises from ingredients of the fermentation medium other than glycerol and glycerol, ranging from 21 to 39% and 13 to 22% of total GHG emissions in case of the ingredients other than glycerol and glycerol, respectively. All other processes, activities and materials only contribute to a minor share of GHG emissions. Researchers demonstrated that crude glycerol can serve as a carbon source (section 2.1.3.). In such a case, the impact of Paleo decreases by 5.5 and 3.3 kg CO_2-eq. per kg myoglobin. Aside from drying, most GHG emissions are emitted upstream by processes providing materials needed by Paleo. A decrease in supply chain GHG emissions (scope 3) will result in a substantial reduction in GHG emissions associated with Paleo's myoglobin production.

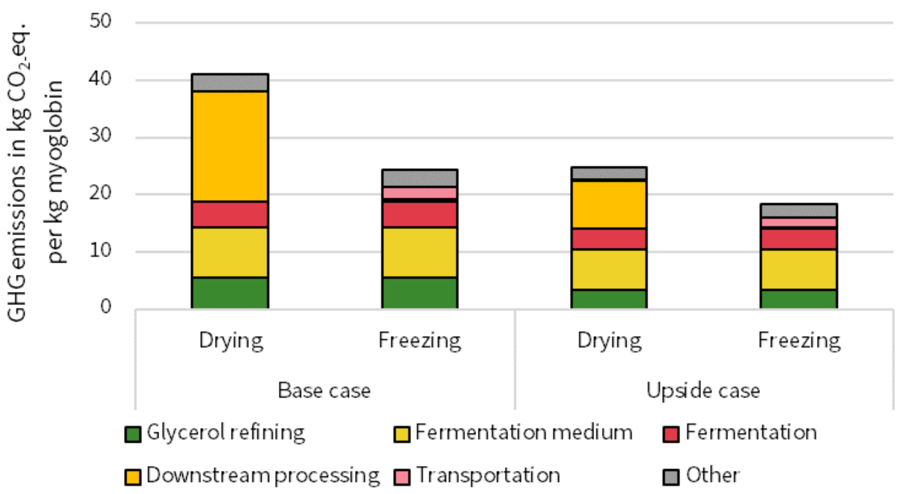

Figure 2 *GHG emissions of Paleo's myoglobin production in kg CO_2-eq. per kg myoglobin (dry mass).*

2.2.1.2. Fossil energy demand

The production of Paleo's myoglobin results in GHG emissions of 640.0 kg CO_2-eq. per kg protein in the base case (final product is dried) and 373.4 kg CO_2-eq. per kg protein (final product is frozen) (Figure 3). In the upside case, the GHG emissions amount to 373.4 and 278.5 MJ per kg protein in case the final product is dried or frozen, respectively. The assessment of the fossil energy demand mirrors findings of the climate change impacts: the largest demand of fossil energy arises from drying, followed by the production of ingredients of the fermentation medium as well as refined glycerol. This indicates again a high potential for reducing the demand for fossil fuels and associated GHG emissions.

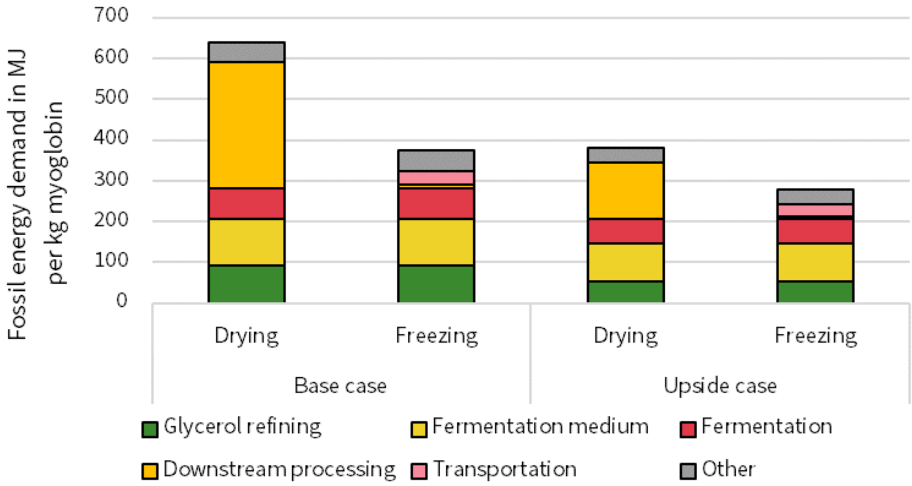

Figure 3 *Fossil energy demand of Paleo's myoglobin production in MJ per kg myoglobin (dry mass).*

2.2.1.3. Land use

The production of Paleo's myoglobin results in GHG emissions of 5.8 m^2a per kg protein in the base case if the final product is dried and 4.6 m^2a per kg protein if the final product is frozen (Figure 4). In the upside case, the GHG emissions amount to 4.0 and 3.6 m^2a per kg protein in case the final product is dried or frozen, respectively. The land-use indicator is dominated by the land use for the ingredients of the fermentation medium.

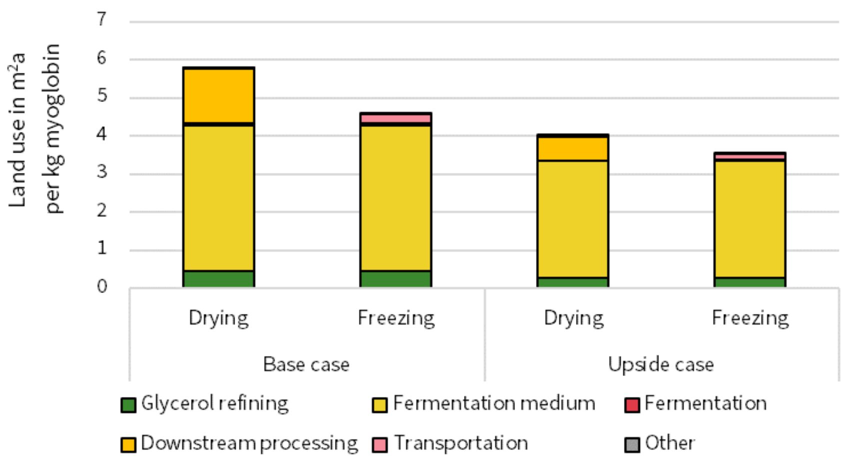

Figure 4 *Land use of Paleo's myoglobin production in m2a per kg myoglobin (dry mass).*

2.2.1.4. Water demand

The production of Paleo's myoglobin results in GHG emissions of 3.5 m^3 per kg protein in the base case if the final product is dried and 3.6 m^3 per kg protein if the final product is frozen (Figure 5). In the upside case, the GHG emissions amount to 2.9 and 2.8 m^3 per kg protein in case the final product is dried or frozen, respectively. The water demand is dominated by ingredients of the fermentation medium, accounting for 60 to 63% of the total water demand. All other processes and activities contribute only a minor share to the total water demand.

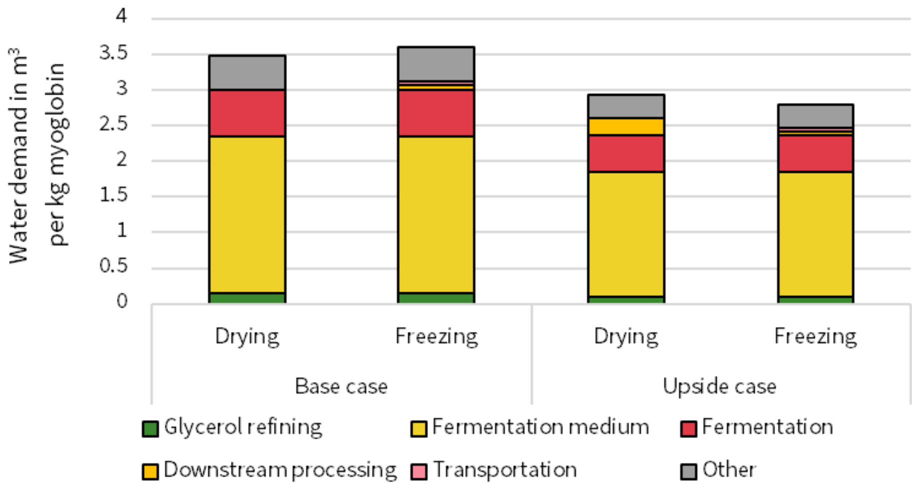

Figure 5 *Water demand of Paleo's myoglobin production in m^3 per kg myoglobin (dry mass).*

2.2.1.5. Sensitivity analysis: displacement effects and parameter variation

In the sensitivity analysis, two different aspects are assessed: the potential displacement effects that could arise if the demand for glycerol outpaces the increase in supply and the impact of important process parameters.

- **Displacement effects:** The supply of biodiesel (FAME) is projected to increase in future years. This will result in a substantial increase in crude glycerol production. Yet, researchers and the industry are searching for high value applications of glycerol. If the demand for glycerol exceeds the supply, an increase in demand for glycerol triggered by Paleo might result in other market participants to switch to other raw materials. Due to the high number of applications of glycerol, it cannot be predicted which application will replace glycerol. We thus used a generic dataset reflecting the 20 most commonly used organic chemicals of the ecoinvent database to model the production of organic chemicals that could be used instead of glycerol. The assessment includes the oxidation of carbon contained in the organic chemicals, i.e. the conversion of carbon contained in the organic chemicals into CO_2. If glycerol used by Paleo triggers other market participants to switch to other organic chemicals, GHG emissions increase by 32.7 and 24.5 kg CO_2 per kg protein (Figure 6). Note: this assessment is based on a generic dataset and the production of individual organic chemicals might differ from the generic dataset.

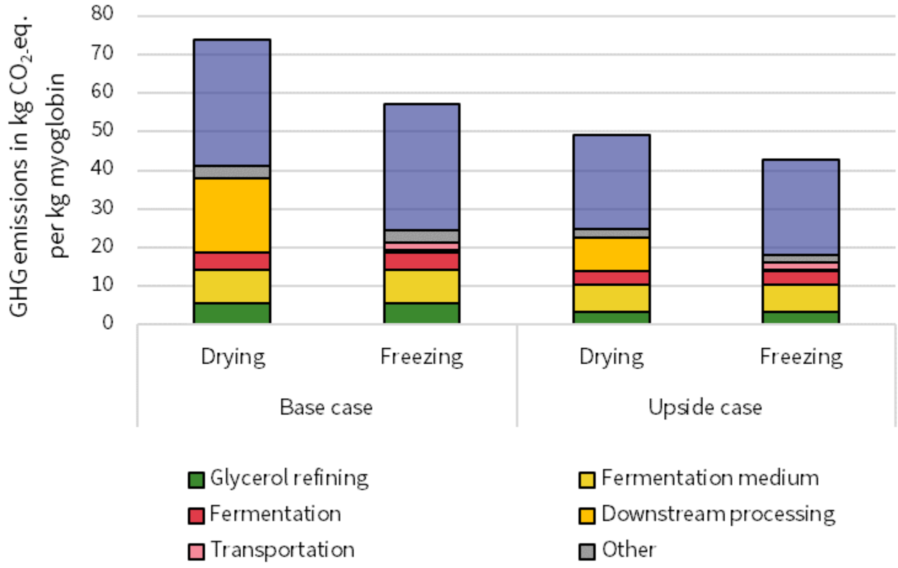

Figure 6 *GHG emissions of Paleo's myoglobin production in kg CO_2-eq. per kg myoglobin (dry mass) with additional consideration of potential market effects of glycerol use.*

- **Parameter variation:** The results of the parameter variation show that the drying set-up is strongly dependent on the final concentration of myoglobin in the product. Scenarios 1 to 4 differ in the final myoglobin titer in the fermentation broth (Figure 7). Due to the high influence of the energy demand, the drying setup is most affected by a change in this parameter. A further decrease in energy demand for drying and higher myoglobin titers result in even lower GHG emissions and other impacts in comparison with the base case scenario (scenarios 5 and 6).

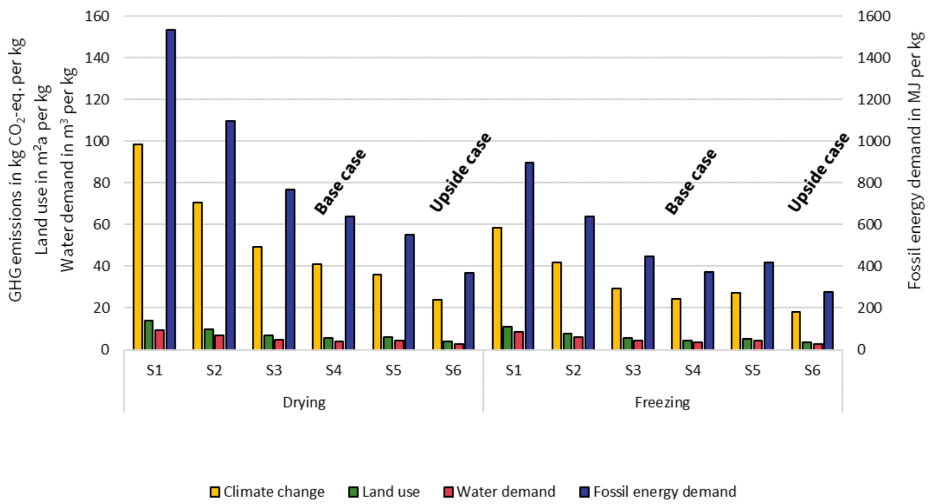

Figure 7 *Parameter variation and its impact on results. All impacts expressed per kg protein (dry mass).*

2.2.2. Environmental impact of different protein sources

The comparison of literature values of different types of animal- and plant-based proteins shows that plant-based proteins perform much better than animal proteins in terms of environmental impact (Table 2, Figure 8). Novel protein sources, such as lab grown meat, mycelium, insects and microbial proteins are also included in the assessment. In almost all cases they perform better than animal proteins.

Lab grown meat shows a comparably wide range of results indicating a worse performance than other non–conventional animal based protein sources. This is most likely because most studies are an ex-ante assessment of future production systems. Since many technical difficulties associated with lab grown meat have to be solved, most assessments rely on assumptions. The reader is referred to the abundant scientific literature on different protein sources and their sustainability for a comparison of these types of protein sources.

Table 2 *Comparison of GHG emissions, fossil energy demand, land use and water use of different protein sources. All values per kg protein (dry mass). The impact of Paleo's myoglobin is listed, too. The ranges presented refer to all scenarios discussed in section 2.2.3.1. Additionally, values for the base case scenario are provided. Note: The final ready-to-eat product will contain between 0.1 and 1% Paleo myoglobin. Abbr.: Max - maximum, Min - minimum, N - number of values included in the assessment. Data derived from all sources stated in Table 1.*

	Climate change (kg CO_2-eq.)				**Fossil energy demand (MJ)**				**Land use (m2a)**				**Water use (m^3)**			
	N	Median	Min	Max	N	Median	Min	Max	N	Median	Min	Max	N	Median	Min	Max
Bovine Meat (beef herd)	724	302.71	188.42	1350.00	0				724	854.41	353.11	4564.19	724	3.71	01.03	956.85
Bovine Meat (dairy herd)	490	172.95	75.63	287.13	0				490	131.41	62.16	538.86	490	13.24	213.65	1085.21
Lamb & Mutton	757	202.95	118.44	300.65	0				757	636.73	239.13	3621.44	757	2.30	1.29	2974.90
Pig Meat	116	65.33	42.71	147.03	0				116	83.07	45.67	210.69	116	11.19	0.32	941.47
Poultry Meat	326	43.42	22.81	120.21	0				326	63.57	37.30	117.78	326	2.14	0.12	381.32
Tofu	354	16.13	8.81	45.44	0				354	21.31	9.81	36.69	354	0.04	0.08	196.77
Lab grown	25	17.79	7.26	2814.29	17	186.84	9.70	2828.57	17	11.53	2.42	157.14	21	1.32	0.00	4.44
Microbial proteins	5	1.57	0.81	11.56	2	16.97	9.70	24.24	5	0.04	0.00	0.47	5	9.70	01.01	24.24
Mycelium	5	19.16	7.90	55.50	2	310.49	20.29	600.70	5	3.84	0.35	7.90	3	22.32	0.74	714.24
Insects	4	12.32	5.23	21.04	4	156.54	11.13	320.00	4	15.01	4.44	18.07	0			
Plant based	27	5.19	1.90	21.76	25	61.70	11.12	397.00	27	16.36	1.14	55.00	0			
Paleo myoglobin	12	67.89	42.76	98.61	12	596.46	278.53	1534.89	12	5.89	3.55	13.87	12	4.28	2.79	
				Drying: 41.11 Freezing: 24.39				Drying: 639.99 Freezing: 373.42				Drying: 5.78 Freezing: 4.57				Drying: 3.99 Freezing: 3.60

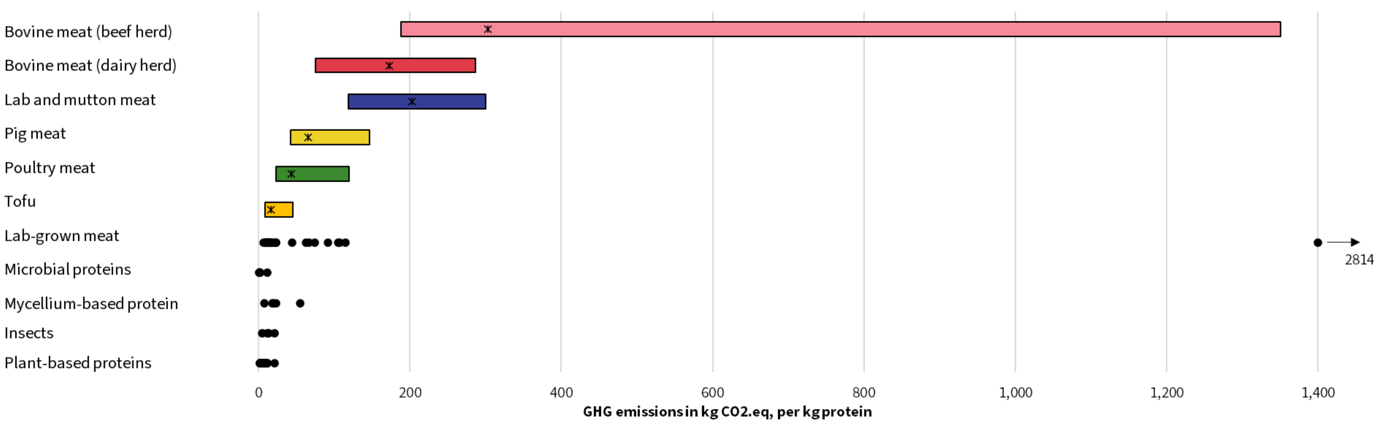

Figure 8 *GHG emissions of different protein sources in kg CO_2-eq. per kg protein.*

2.2.3. Impact of a change in protein supply

Final ready-to-eat products contain between 0.1 and 1% Paleo myoglobin. Changing the protein source from a conventional meat protein to an alternative results in **net GHG savings ranging from 21 to 296 kg CO_2-eq. per kg of protein** (Table 3). Values in Table 3 are provided per kg protein as the protein content is the major nutritional decision criterion to consume meat or any alternatives. The overall influence of Paleos myoglobin is negligible in comparison with the net reductions in GHG emissions that can be achieved by switching from conventional meat proteins to any other of the alternatives depicted here. These values only include direct impacts of protein supply. **If additional carbon sequestration by restoration of natural vegetation is considered that could take place on land no longer needed for livestock or feed production, an estimated 809 Gt CO_2 are removed from the atmosphere over a period of 100 years** (Poore and Nemecek 2018). This equates to all anthropogenic GHG emissions emitted between 1996 and 2021 or an annual average net removal equal to 22% of global GHG emissions emitted in 2022 (own calculation based on (Ritchie and Roser 2022; World Economic Forum 2022)). A 50% reduction in the consumption of animal products translates into a net removal of 551 Gt CO_2 over a period of 100 years (Poore and Nemecek 2018). These high savings in GHG emissions and potential net removal of CO_2 by a restoration of natural vegetation arises from the high land demand for livestock and animal based products.

***Table 3** Net change in GHG arising from a shift from one protein source to another in kg CO_2-eq. per kg of protein. Calculations based on median GHG emissions of different products. Alternative protein sources (*) contain myoglobin. Each product contains Paleo's myoglobin (1% of its fresh mass). The value of myoglobin is the base case scenario incl. drying of myoglobin. Green shaded values depict net reductions in GHG emissions. Red shaded values depict a net increase in emissions. Abbr.: bh - beef herd; dh - dairy herd.*

	Shift from…										
Shift to…	Bovine (bh)	Bovine (dh)	Lamb & Mutton	Pig	Poultry	Tofu*	Lab	Microbial*	Mycelium*	Insects*	Plant based*
Bovine (bh)	0	130	100	237	259	284	285	301	280	289	296
Bovine (dh)	-130	0	-30	108	130	155	155	171	151	159	167
Lamb & Mutton	-100	30	0	138	160	185	185	201	181	189	197
Pig	-237	-108	-138	0	22	47	48	63	43	51	59
Poultry	-259	-130	-160	-22	0	25	26	41	21	29	37
Tofu*	-284	-155	-185	-47	-25	0	1	16	-4	4	12
Lab	-285	-155	-185	-48	-26	-1	0	16	-4	4	12
Microbial*	-301	-171	-201	-63	-41	-16	-16	0	-20	-12	-4
Mycelium*	-280	-151	-181	-43	-21	4	4	20	0	8	16
Insects*	-289	-159	-189	-51	-29	-4	-4	12	-8	0	8
Plant based*	-296	-167	-197	-59	-37	-12	-12	4	-16	-8	0

* Additional impact of Paleo's myoglobin included (Table A3)-

Switching from any type of conventional meat to alternative protein sources reduces the land demand between 42 and 854 m^2a per kg of protein (Table 3). These high net savings arise from the fact that meat is a highly inefficient source of proteins in terms of land-use. Livestock occupies 77% of agricultural land while only supplying 37% of the global protein supply (Figure 9). The weighted average efficiency of protein-to-protein conversion of meat consumed in the United States is 8% . It should be noted that not all land is suitable for crop cultivation, nor is it always desirable from an environmental point of view to switch from pasture to cropland (see Part III). However, 81% of protein originating from cultivated feed crops depicted in Figure 9 would be suitable for human consumption. Considering the low efficiency of protein-to-protein conversion of animals, these crops could provide 12.5 times more protein to humans than by feeding these proteins to animals. Even if the lower protein digestibility of plant-based proteins is considered, these crops fed to animals could provide around 6 times more protein to humans (or reduce the land demand for these feed crops by a factor of 6).

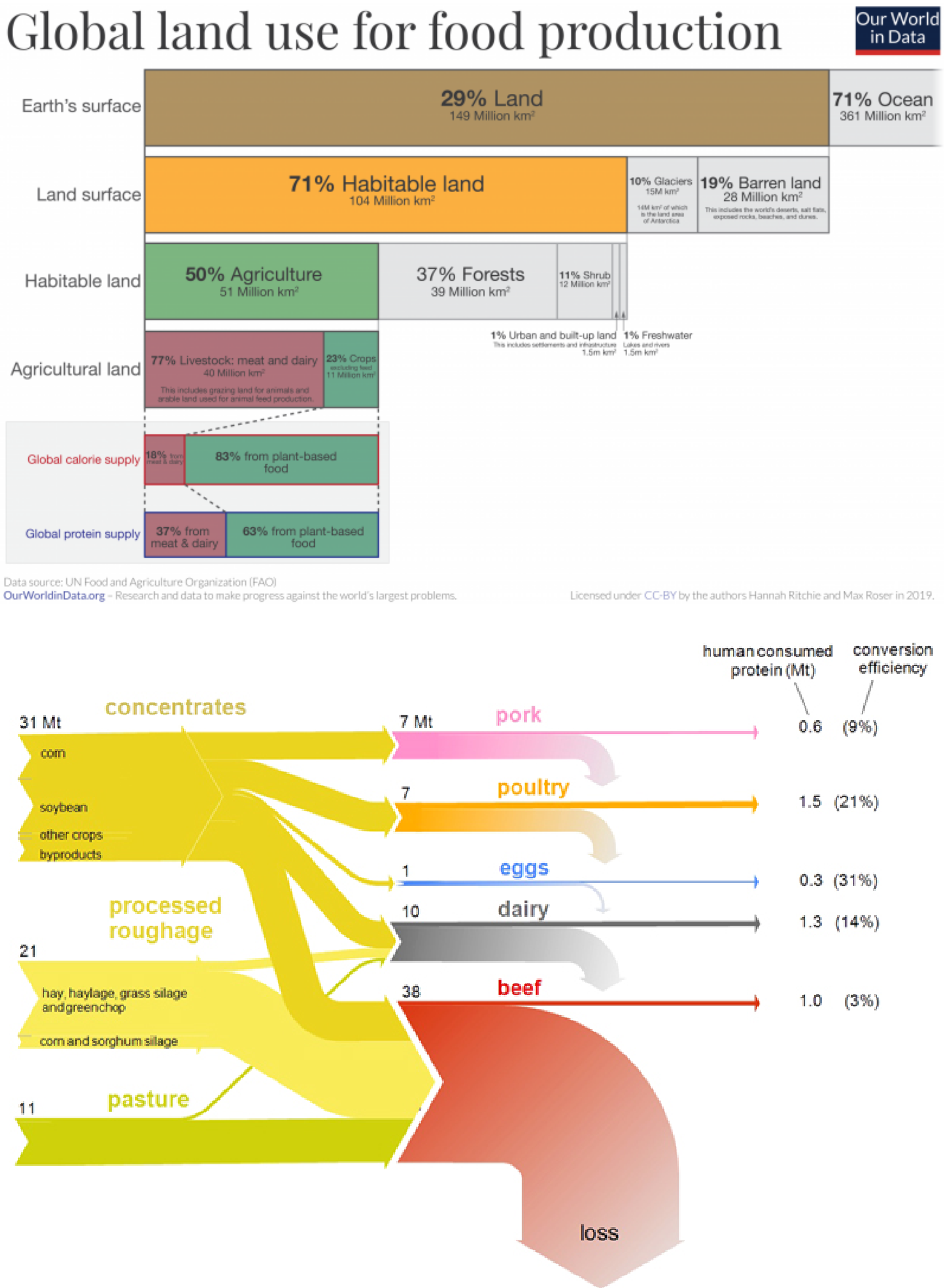

Figure 9 *Top: Global land use for food production. Figure and caption taken from (Ritchie and Roser 2017), provided under a CC BY license. Bottom: The US feed-to-food protein flux from the three feed classes (left) into edible animal products (right). On the right, parenthetical percentages are the food-protein-out/feed-protein-in conversion efficiencies of individual livestock categories. Protein values are in Mt (10^9 kg). Figure and caption taken from (Shepon et al. 2016), provided under a CC BY license.*

Table 3 *Net change in land use from a shift from one protein source to another in m^2 per kg of protein. Calculations based on median land use of different products. Alternative protein sources (*) contain myoglobin. Each product contains Paleo's myoglobin (1% of its fresh mass). The value of myoglobin is the base case scenario incl. drying of myoglobin. Green shaded values depict net reductions in GHG emissions. Red shaded values depict a net increase in emissions. Abbr.: bh - beef herd; dh - dairy herd.*

	Shift from…										
Shift to…	Bovine (bh)	Bovine (dh)	Lamb & Mutton	Pig	Poultry	Tofu*	Lab	Microbial*	Mycelium*	Insects*	Plant based*
Bovine (bh)	0	723	218	771	791	833	843	854	850	839	838
Bovine (dh)	-723	0	-505	48	68	110	120	131	127	116	115
Lamb & Mutton	-218	505	0	554	573	615	625	637	632	621	620
Pig	-771	-48	-554	0	19	61	72	83	79	68	67
Poultry	-791	-68	-573	-19	0	42	52	63	59	48	47
Tofu*	-833	-110	-615	-61	-42	0	10	22	17	6	5
Lab	-843	-120	-625	-72	-52	-10	0	11	7	-4	-5
Microbial*	-854	-131	-637	-83	-63	-22	-11	0	-4	-15	-16
Mycelium*	-850	-127	-632	-79	-59	-17	-7	4	0	-11	-12
Insects*	-839	-116	-621	-68	-48	-6	4	15	11	0	-1
Plant based*	-838	-115	-620	-67	-47	-5	5	16	12	1	0

* Additional impact of Paleo's myoglobin included (Table A3)-

The literature used to compile data did not include values for water demand of plant-based proteins. Mekonen and Hoekstra (2010) show that average vegetables have a substantially lower water footprint than beef, lamb, pig and chicken meat (Mekonnen and Hoekstra 2010). The data of Mekonnen and Hoekstra (2010) shows **net water savings ranging from 8 to 56 m³ of water saved per kg protein by switching from meat to vegetables.** In conclusion: shifting from a meat-based diet to other alternatives has a significant positive impact on the environment.

2.2.3.1. Sensitivity analysis: protein digestibility

The inclusion of the protein digestibility (section 2.1.5) has only a small influence on most substitution cases. The change in comparison with results shown in Table 3 is provided in Tables A.4. and A.5. in the Annex. Among assessed alternative proteins, mycelium is most affected by an inclusion of the PDCAAS and the DIASS due to its low scores. Only in one single case (PDCAAS-corrected GHG emissions, shift from poultry to mycelium) a net reduction in emissions becomes a net increase. In most other cases, results are only affected to a minor extent that does not change the overall outcome of this assessment: displacing conventional animal protein supply with alternatives results in substantial net savings in GHG emissions (and other environmental impacts).

2.2.4. Limitations and uncertainties

The assessment conducted in this study is subject to certain limitations:

- Paleo's myoglobin production is yet to be scaled to full scale. To account for uncertainties related to this ex-ante assessment of Paleo's myoglobin production, a parameter variation was conducted and several scenarios were considered.
- The environmental impacts of conventional meat production are based on available published literature. While the impacts of conventional meat are taken from a very comprehensive review/analysis of the impact of conventional meat production comprising hundreds of studies

and data points, alternative proteins, such as lab grown meat, microbial proteins and mycelium-based proteins are mostly not yet produced at commercial scale. Therefore, the evaluated studies are mostly ex-ante assessments of potential (future) production systems.

- The reviewed literature of conventional meat production and alternative protein production is exclusively relying on the attributional LCA methodology. The methodology usually allocates environmental impacts to all products a system provides, e.g. dairy cows produce milk and meat. Displacing meat from dairy cows also reduces milk production and products derived therefrom. The proteins and nutrients supplied by these co-products would need to be provided by other means, if less dairy cow meat is demanded by consumers. Such displacement effects are not considered in this study. The reason for doing so is to include the widest possible literature foundation in the analysis to cover the full spectrum of livestock systems. As available literature is predominantly based on the attributional LCA methodology, this shortcoming could not have been overcome.
- The reviewed literature of conventional meat production and alternative protein does not distinguish between ready-to-eat products and products that need to be further processed. For example, plant-based proteins included in the assessment contain protein concentrates and protein isolates which need additional processing steps and the addition of further ingredients, e.g. spices, nutrients, etc. to achieve a product comparable with conventional ready-to-eat meat. Previous studies show that nutrients, e.g. B12, zinc and iron fortifications only have an insignificant impact on the environmental impact of meat alternatives (Van Mierlo, Rohmer, and Gerdessen 2017). The processing requires energy, water and other resources. Overall, processing accounted for less than 0.5 kg CO_2-eq. per kg of product, corresponding to 26 and 30% of the total GHG emissions of meat replacers in case of chicken and beef replacers, respectively (ibid.). If these emissions are added to the unprocessed meat alternatives reviewed in this study, they still perform substantially better than any conventional meat assessed in this study.
- Our market analysis shows that Paleo addresses key market barriers and an increase in demand for alternative protein sources is likely. To what extent consumers eat less meat if better, tastier and healthier meat alternatives are available is hard to predict. The potential net change in environmental impacts will then depend on what other product is consumed less.

3. Part III: Other impacts of animal husbandry and animal products

In 1950, the global average per capita consumption of meat was 22.8 kg per person per year (Ritchie, Rosado, and Max 2019). The average per capita meat consumption has more than doubled until today and differs strongly between different countries (Figure 10). The per capita meat consumption has increased in the past decades due to a number of factors, including economic growth, urbanization, and changes in consumer preferences and dietary habits. Statistics show that the consumption of meat is clearly correlated with the average income.

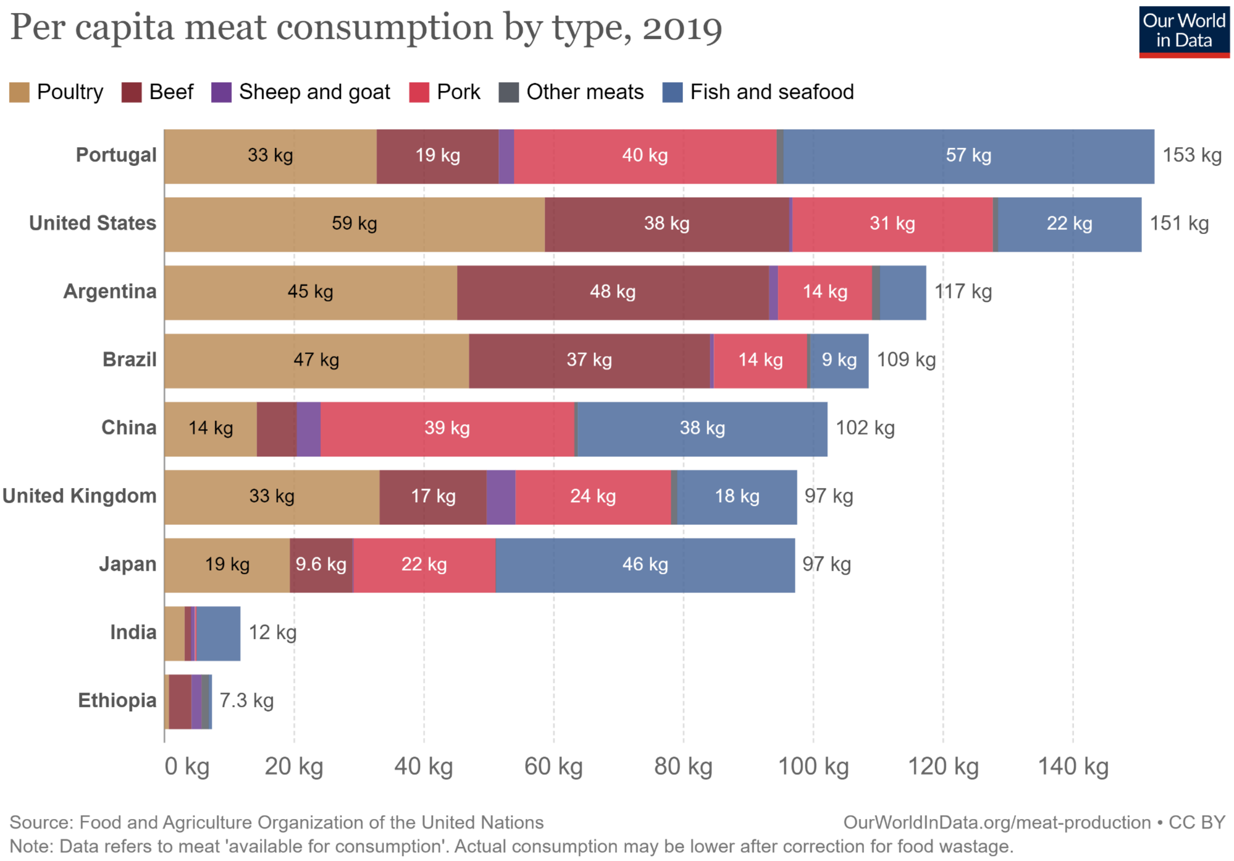

Figure 10 *Per capita meat consumption in 2019 in selected countries. Provided by [Our World in Data](), licensed under a CC BY license (Ritchie, Rosado, and Max 2019)*.

The demand for meat and other animal products is supplied by a staggering number of more than 72 billion (!) animals being killed annually (Orzechowski 2022). In the European Union, 142 million pigs, 76 million bovine animals, 60 million sheep and 11 million goats were kept in December 2021 alone (Eurostat 2022). Keeping, using, killing and consuming such a vast number of animals has numerous implications going far beyond the assessed indicators:

- **Land use and land degradation:** The large areas of land required for animal grazing and feed production are leading to overgrazing and soil erosion, causing long-term degradation of the land and loss of biodiversity (Thornton and Herrero 2010). In addition, the production of animal feed crops often requires the use of fertilizers and pesticides, which can contaminate the soil and water supplies. The UN Food and Agriculture Organization estimates that land-based agricultural expansion is driving almost 90% of global deforestation: expansion of cropland and livestock grazing account for 50 and 38.5% of deforestation (Food and Agriculture Organization of the United and Nations (FAO) 2022). Another study estimates that between 1994 and 2011, 86% of the increase in land demand was driven by the increase in demand for animal products (Alexander et al. 2015). The main drivers for the increase in animal products are population growth and changing diets.

- **Water demand pollution:** The large amounts of waste produced by animal husbandry operations are leading to the pollution of rivers and lakes, as well as groundwater aquifers (Hooda et al. 2000). Most importantly, manure contains nutrients and the spreading of nutrients causes eutrophication (Abascal et al. 2022). In addition, chemicals, pharmaceuticals and bacterial contamination occurs related to livestock farming (Bartelt-Hunt et al. 2011; Kivits et al. 2018). This pollution can be toxic to aquatic life and harmful to human health.

- **Biodiversity:** Animal husbandry and the over-exploitation of wild animals is a major driver of biodiversity loss (Filazzola et al. 2020; Machovina, Feeley, and Ripple 2015):
  - In many cases, animal livestock can lead to habitat loss and degradation, particularly in an intensive agricultural system (Carmona et al. 2020; Tsiafouli et al. 2015). This can result in the loss of important wildlife habitat and the displacement of wildlife populations. The effects of livestock grazing can be noticed even decades to centuries after it ended: Filazzola et al. (2020) report that it takes 10 to 20 years of absence of grazing animals for biodiversity to recover. Another study describes legacy effects of grazing in the US in the early 1900s still observable today (Svejcar et al. 2014). Global trade of agricultural products increases food security, but also involves the risk of burden shifting: The imports of agricultural products to Western European countries, North America as well as China and other Asian countries cause biodiversity loss elsewhere (Schwarzmueller and Kastner 2022). Note, these are all countries with high and above-average meat per capita meat consumption (Figure 10).

    In certain circumstances animal husbandry can provide habitat for wildlife, particularly grass-fed animals (Godfray et al. 2010). Grazing livestock can help to maintain grasslands and support populations of grassland birds and other species. Not all areas used for grazing are suitable for crop cultivation. Additionally, converting grassland to cropland could have adverse effects on the environment, including biodiversity loss. In specific areas, such as mountainous regions, extensive grazing maintains open habitats. Such habitats are inhabited by endemic species that could be threatened by a change in the habitat, e.g. loss of the open habitat caused by an abandonment of extensive grazing (Sartorello et al. 2020).
  - Overgrazing by livestock can lead to habitat degradation and loss, as well as soil erosion and degradation of water quality. This can reduce the overall diversity of plant and animal species in a given area (Sartorello et al. 2020).
  - The over-exploitation of wild animals, e.g. fish stocks, can lead to a rapid decline in animal populations, which can result in a loss of biodiversity and the decline of important ecosystem services such as pollination and seed dispersal. Over-exploitation can also result in the unsustainable harvest of animals, which can lead to the depletion of important food sources for local communities and the decline of livelihoods that depend on these resources.

  Changing use of sea and land, climate change, pollution, direct exploitation of organisms as well as invasive species are the so-called “Big five” accounting for an estimated 95% of total biodiversity loss. Animal husbandry and the exploitation of natural animal resources, e.g. fish stocks, are a major contributor to these most important drivers of biodiversity loss (Brondizio et al. 2019).

- **Health issues:** High levels of meat consumption have been linked to an increased risk of chronic diseases such as cardiovascular disease, certain types of cancer, and type 2 diabetes (N. González et al. 2020). This is due in part to the high levels of saturated fat and cholesterol found in many types of meat, as well as the presence of potentially harmful substances such as heterocyclic amines and polycyclic aromatic hydrocarbons that are formed during the cooking process (National Cancer Institute 2017). In addition, meat is often energy-dense and high in calories, which can lead to weight gain and increased risk of obesity (Wang and Beydoun 2009; You and Henneberg 2016).

- **Antibiotic resistance:** The widespread use of antibiotics in animal husbandry has led to the development of antibiotic-resistant strains of bacteria, which can be transmitted to humans through contaminated food or direct contact with the animals (Chatterjee et al. 2018; Monger et al. 2021). This can make it more difficult to treat bacterial infections, and poses a significant threat to public health.

- **Zoonotic diseases:** Animal husbandry operations can be a source of zoonotic diseases, which are diseases that can be transmitted from animals to humans. Of a total of 1415 species of infectious organisms known to be pathogenic to humans identified in a literature review, 61% are zoonotic diseases (Taylor, Latham, and Woolhouse 2001). Some of the most significant zoonotic diseases associated with animal husbandry include avian influenza, swine flu, and mad cow disease.

- **Ethical implications:** Raising, keeping, using and killing animals for human consumption and other purposes in general, as well as the way it is done, are accompanied by numerous ethical and moral concerns as well as animal rights issues. Such aspects should not be neglected in the debate on conventional animal-based proteins and their alternatives. A discussion of these ethical considerations goes beyond the scope of this research paper. The reader is referred to available literature on the matter, cf. (Gremmen 2020; Sandøe and Christiansen 2008).

The presented list is far from exhaustive. Yet it gives an indication of the implications of the current system of animal husbandry and exploitation of wild animals. While the benefits of animal husbandry as a source of food cannot be ignored, it is important to mitigate these impacts e.g. reducing and improving waste management practices, and developing alternative, more sustainable food production systems. By far the most impactful way of mitigating negative consequences of animal husbandry is switching to more sustainable diets containing less meat (Alexander et al. 2017; Emery 2018; Schiermeier 2019).

4. Conclusion

Our assessment of market barriers shows that there are still market barriers in place preventing a wider adoption of alternative proteins. Paleo's myoglobin addresses several of these barriers, such as taste, smell and appearance of alternative protein products. In addition, **Paleo's myoglobin allows the reduction in ingredients of meat alternatives, such as iron supplements, flavor ingredients and ingredients affecting the appearance of alternative meat products. By addressing these barriers, a wider adoption of alternative protein sources can be expected.** Such a shift in protein supply can have major positive impacts on the environment and human health. The current livestock industry combined with the high consumption of meat results in high GHG emissions, a high demand for land and water and pollution of water bodies and a substantial negative impact on biodiversity. Agriculture accounts for a high share of anthropogenic GHG emissions, ranging from 24 to 37% of total anthropogenic GHG emissions if all impacts of meat production are included (Xu et al. 2021). Up to 57% of these emissions can be attributed to livestock. The livestock industry is a major driver of biodiversity loss by affecting the most important contributors to biodiversity loss.

The most effective and efficient way to counteract these negative impacts is to drastically reduce the consumption of animal products. Alternative proteins, such as proteins contained in or derived from plants, fungi, bacteria or insects offer a more sustainable protein supply. **Our analysis shows that changing the protein source from a conventional meat protein to an alternative protein results in:**

- **net GHG savings ranging from 21 to 296 kg CO_2-eq. per kg of protein,**
- **a reduction in land demand between 42 and 854 m^2a per kg of protein, and**
- **net water savings ranging from 8 to 56 m^3 of water saved per kg protein.**

These results demonstrate that Paleo can have a substantial impact by promoting a shift from unsustainable protein supply towards a more sustainable supply or proteins. Because major barriers to the adoption of alternative proteins are addressed by only adding very small amounts of Paleo’s myoglobin, Paleo’s myoglobin is a powerful lever for fundamentally changing the impact of our global food supply.

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A. Annex

A.1. Additional data

Table A1 *PDCAAS and DIASS of different protein sources.*

Protein	PDCAAS	DIAAS	Reference
Bovine Meat	0.92	1.11	(Hoffman and Falvo 2004; Wickersham and Sawyer n.d.)
Lamb & Mutton	1	1.16	(Wickersham and Sawyer n.d.)
Pig Meat	1	1.14	(Bailey et al. 2020)
Poultry Meat	1	1.08	(Phillips 2017)
Plant-based proteins			
Tofu	0.56	0.52	(Phillips 2017)
Soy	0.91 - 1.00	0.90-0.91	(Hoffman and Falvo 2004; Rutherfurd et al. 2015; Phillips 2016)
Gluten	0.24		(Petrusán, Rawel, and Huschek 2016)
Pea (Beyond meat)			
Meatless (wheat based)			
Chickpea flour	0.84		(Nosworthy et al. 2020)
Chickpea protein concentrate			
Chickpea	0.74	0.83	(Phillips 2017)
Kidney			
Kidney bean protein concentrate	0.55		(Nosworthy and House 2017)
Kidney bean protein isolate			
Lentil a flour			
Lentil protein concentrate	0.68		(Marinangeli, Mansilla, and Shoveller 2018)
Lentil protein isolate	0.43		(Marinangeli, Mansilla, and Shoveller 2018)
Lupine flour	0.51		(Regina Pereira Monteiro et al. 2014)
Lupine protein concentrate			
Lupine protein isolate			
Pea flour	0.69		(Petrusán, Rawel, and Huschek 2016)
Pea protein concentrate	0.72	0.82	(Petrusán, Rawel, and Huschek 2016; Phillips 2017)
Pea protein isolate	0.89	0.82	(Phillips 2016)
Soy flour	0.77		(Cassiday 2018)
Soy protein concentrate	0.99	0.98	(Petrusán, Rawel, and Huschek 2016; Phillips 2017)
Soy protein isolate	1		(van Vliet, Burd, and van Loon 2015)
Wheat flour	0.40		(Boye, Wijesinha-Bettoni, and Burlingame 2012)
Wheat protein concentrate	1	0.97	(Rutherfurd et al. 2015)
Wheat protein isolate	1	1.09	(Rutherfurd et al. 2015)
Instects			
Beetle	0.89		(Churchward-Venne et al. 2017)
Silkworm	0.86		(Churchward-Venne et al. 2017)
Mycelium	0.36-0.70		(A. González et al. 2020)
Microbial proteins			

Table A2 *Protein content of protein sources*

Protein source	Median protein content of fresh mass
Bovine Meat (beef herd)	20%
Bovine Meat (dairy herd)	20%
Lamb & Mutton	20%
Pig Meat	16%
Poultry Meat	17%
Tofu	16%
Lab grown	19%
Microbial proteins	57%
Mycelium	12%
Insects	20%
Plant based	36%

A.2. Additional results

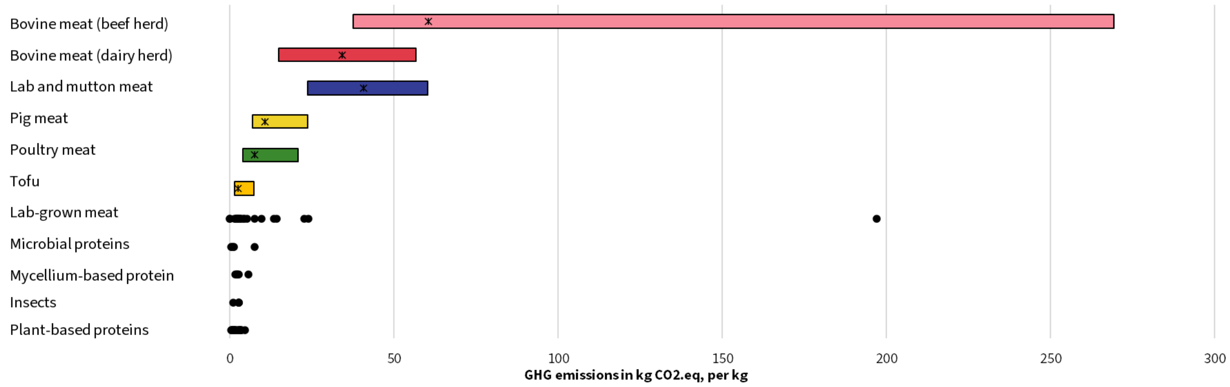

Figure A1 *GHG emissions of different protein sources in kg CO_2-eq. per kg product.*

Table A3 *Additional GHG emissions in kg CO_2-eq. per kg product (fresh mass) caused by adding between 0.1 and 1% myoglobin to the listed product.*

	0.1%	**0.2%**	**0.3%**	**0.4%**	**0.5%**	**0.6%**	**0.7%**	**0.8%**	**0.9%**	**1.0%**
Tofu	0.23	0.45	0.68	0.91	1.13	1.36	1.59	1.81	02.04	2.27
Lab grown	0.19	0.38	0.57	0.76	0.95	1.15	1.34	1.53	1.72	1.91
Microbial proteins	0.06	0.13	0.19	0.25	0.32	0.38	0.45	0.51	0.57	0.64
Mycelium	0.31	0.62	0.93	1.24	1.55	1.86	2.17	2.48	2.79	3.10
Insects	0.18	0.36	0.53	0.71	0.89	01.07	1.25	1.43	1.60	1.78
Plant based	0.10	0.20	0.31	0.41	0.51	0.61	0.71	0.81	0.92	01.02

Table A4 *Change in results if the PDCAAS of different proteins is considered (section 2.1.5). Substitution quantities were adjusted according to the PDCAAS (section 2.1.5). All values as percentage of the results without consideration of the PDCAAS, i.e. switching from bovine meat to plant based proteins results in a 0.5% lower net saving if the PDCAAS if plant based proteins and bovine meat is included in the assessment in comparison with results without the consideration of the PDCAAS. A value below 0% indicates a change from a decrease in emissions to an increase, i.e. a switch from poultry to mycelium-based protein results in a net increase if the PDCAAS is considered. Alternative protein sources (*) contain myoglobin. Each product contains Paleo's myoglobin (1% of its fresh mass). The value of myoglobin is the base case scenario incl. drying of myoglobin. Abbr.: bh - beef herd; dh - dairy herd.*

	Shift from…										
Shift to…	Bovine (bh)	Bovine (dh)	Lamb & Mutton	Pig	Poultry	Tofu*	Lab	Microbial*	Mycelium*	Insects*	Plant based*
Bovine (bh)		100.0%	126.4%	111.1%	110.2%	58.3%	104.6%		44.8%	94.3%	82.2%
Bovine (dh)	100.0%		49.9%	114.0%	111.6%	56.1%	104.8%		41.2%	94.1%	81.9%
Lamb & Mutton	116.3%	45.9%		100.0%	100.0%	51.5%	95.6%		38.1%	86.0%	75.2%
Pig	102.2%	104.9%	100.0%		100.0%	38.4%	94.5%		15.8%	83.3%	73.4%
Poultry	101.3%	102.7%	100.0%	100.0%		22.7%	93.2%		-15.1%	80.6%	71.9%
Tofu*	95.8%	92.2%	92.0%	68.5%	40.6%		1584.1%		192.2%	337.5%	154.1%
Lab	100.3%	100.5%	99.6%	98.4%	97.1%	924.1%			293.6%	51.8%	67.6%
Microbial*											
Mycelium*	91.5%	84.2%	84.6%	35.0%	-33.6%	239.1%	626.3%			353.7%	195.7%
Insects*	99.7%	99.5%	98.9%	95.8%	92.6%	217.2%	57.1%		183.0%		77.3%
Plant based*	99.5%	99.2%	99.0%	96.6%	94.6%	113.5%	85.4%		115.8%	88.5%	

* Additional impact of Paleo's myoglobin included (Table A3)-

Table A5 *Change in results if the DIASS of different proteins is considered (section 2.1.5). Substitution quantities were adjusted according to the DIASS (section 2.1.5). All values as percentage of the results without consideration of the DIASS, i.e. switching from bovine meat to plant based proteins results in a 0.5% lower net saving if the DIASS if plant based proteins and bovine meat is included in the assessment in comparison with results without the consideration of the DIASS. A value below 0% indicates a change from a decrease in emissions to an increase. Alternative protein sources (*) contain myoglobin. Each product contains Paleo's myoglobin (1% of its fresh mass). The value of myoglobin is the base case scenario incl. drying of myoglobin. Abbr.: bh - beef herd; dh - dairy herd.*

	Shift from…										
Shift to…	Bovine (bh)	Bovine (dh)	Lamb & Mutton	Pig	Poultry	Tofu*	Lab	Microbial*	Mycelium*	Insects*	Plant based*
Bovine (bh)		100.0%	114.1%	102.7%	96.2%	43.1%	85.1%				82.1%
Bovine (dh)	100.0%		73.1%	103.5%	95.7%	40.1%	84.4%				81.8%
Lamb & Mutton	109.1%	69.9%		96.5%	90.4%	38.9%	80.5%				78.1%
Pig	100.6%	101.3%	98.8%		84.3%	23.8%	78.3%				78.6%
Poultry	99.4%	98.9%	97.8%	89.0%		8.9%	81.2%				82.6%
Tofu*	92.5%	86.1%	87.4%	52.2%	18.6%		1858.1%				216.5%
Lab	99.0%	98.1%	97.9%	93.0%	91.3%	1006.5%					93.5%
Microbial*											
Mycelium*											
Insects*											
Plant based*	99.5%	99.2%	99.1%	97.4%	97.0%	122.3%	97.6%		138.9%	179.4%	

* Additional impact of Paleo's myoglobin included (Table A3)-

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