LIFE CYCLE ASSESSMENT

SUSTAINABLE MEAT ALTERNATIVES

PROJECT EADEN

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 are published for maximum transparency.

Terminology and abbreviations

bc	Beef cattle
BM	Beef meat
CO_2-eq.	Carbon dioxide equivalents
dc	Dairy cattle
DIASS	Digestible indispensable amino acid score
L	Lamb
LCA	Life Cycle Assessment
LT	Long-term (scenario)
M	Mutton
MT	Mid-term (scenario)
PDCAAS	Protein digestibility-corrected amino acid score
PM	Pork meat
PS	Pork sausage

About Project Eaden

Project Eaden, a Berlin-based startup, developed an innovative technology to produce plant-based meat alternatives mimicking the texture and feel of animal products. The novel technology produces meat alternatives with mouthfeel and texture of conventional meat products. This achievement addresses a key barrier of meat alternatives and is likely to accelerate the market uptake of planet-based meat alternatives paving the way to more sustainable diets.

Version 1.02 - Jan 16 2025

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 24 to 37% of total anthropogenic GHG emissions if all impacts of meat production are included. 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.

Project Eadens technology converts plant-based proteins to meat alternatives with texture and mouthfeel similar to conventional meat products. This technological advancement addresses one of the major market entry barriers of meat substitutes. By overcoming this barrier, a wider and accelerated adoption of meat alternatives can be expected.

Our analysis shows that switching from conventional pork products (pork meat and pork sausages, the products currently mimicked by Project Eaden's products) could lead to

- **a net reduction in GHG emissions of 10 to 14 kg CO_2-eq. per kg in the mid-term and 8 to 20 kg CO_2-eq. per kg in the long-term.**
- **a net reduction in water-stress weighted water use ranging from 43 to 56 m^3/kg in the mid-term and in the long-term.**
- **a net reduction in land-use of 9 to 20 m^2/kg in the mid-term and 9 to 18 m^2/kg in the long-term.**

If beef or lamb and mutton are replaced even higher net emission reductions can be achieved. **In all production and substitution scenarios, as well as the use of minimum and maximum impacts reported from hundreds of different life cycle assessments (LCAs) lead to a net reduction in impacts if consumers switch from meat to Project Eaden's vegan alternatives.**

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 Project Eaden addresses these barriers. In **Part II**, a Life Cycle Assessment (LCA) of Project Eaden is presented **addressing the question how environmental impacts change if consumers switch from conventional meat-based proteins to Project Eaden's vegan meat alternatives.** The LCA assesses Project Eadens'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 Project Eaden can actively contribute to.

Note: This is a shortened version of the full LCA report. Until market launch of the assessed products, the detailed ingredients list and descriptions of how processes were modeled remains undisclosed. Once available in the market, an updated version of this report will be available containing the full ingredient list of all assessed products.

Table of Contents

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

1.1. The alternative protein market

Data from the Good Food Institute shows that in 2023, plant-based meat and seafood's share was only 1.8 % of total retail packaged meat dollar sales or 0.9 % of the total meat category (Ignaszewski et al., 2024). Market research shows that many meat-eating consumers 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 Project Eaden. Across the global market 21% of the consumers want to consume fewer alternative proteins, while 36% intend to consume more alternative proteins (Joseph et al. 2020). Other studies show that up to 60% of consumers are open to eating more plant-based proteins (Ibrahimi Jarchlo & 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 up to 22% in 2035. By then, Europe and North America might have reached the point of "peak meat," and consumption of animal proteins will begin to decline (ibid.). 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 positive impact on climate is therefore, next to animal welfare and health, one of the main motivators for their consumption. In a survey, the climate impact was mentioned by more than 30% of respondents (2nd highest rating) as the main reason to eat alternative meat products (Ibrahimi Jarchlo & King, 2022).

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 on alternative proteins is expected to improve taste, texture and price of alternative protein sources.

Overall 76% of consumers are familiar with alternative proteins (Morach et al., 2022). Forecasts by Bloomberg Intelligence suggest that plant-based meat sales could reach $74–118 billion by 2030, while Credit Suisse predicts sales to reach $88–263 billion by 2030 (Caputo et al., 2024). However, certain barriers exist in preventing a faster adoption of alternative and more sustainable protein sources.

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** (Malila et al., 2024; Jahn et al., 2021).
- Consumers who are using plant-based meat alternatives less than five times a week are looking for products that **look, taste, feel, cost and behave similar to meat** (Malila et al., 2024). Mouthfeel and texture are fundamental sensory attributes, which along with taste and smell, determines the overall flavor of a food item. Many studies report that the lack of similarity in texture and mouthfeel of products based on alternative protein sources is a major market entry barrier.
- 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 plant-based proteins is **cost**. Currently, many products based on 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).

2. Part II: LCA of a shift from conventional meat to Project Eaden's products

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

2.1. System description

Project Eaden's technologies allows the production of plant-based products with similar texture and mouthfeel than conventional meat products (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 products to Project Eaden's products. To assess the impact on the environment, we applied a consequential LCA approach. We evaluated marginal **changes within the overall economy as a consequence of a change in the market** (e.g. entry of a new market participant such as Project Eaden), 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). This approach reflects potential effects arising from the market entry and scaling of Project Eaden. The aim of this study is therefore to evaluate the potential net changes in environmental impacts as a result of a scale-up of Project Eaden.

By addressing a key market entry barrier, Project Eaden 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 Project Eaden's manufacturing process, additional production processes to produce alternative protein products, and less demand for conventional meat (Figure 1). Certain processes remain (in sum) unchanged, e.g. food packaging, slicing, etc. of an animal-based ham is similar to Project Eaden's ham. Therefore, these processes do not change, more precisely, a new process replaces a similar one if consumers switch from animal-sourced products to Project Eaden's products. Whenever a new process replaces a similar process in the conventional meat processing industry, the net change in environmental impacts is zero. Therefore, these processes are excluded. The resulting net changes in emissions reflect the sum of all additional processes, e.g. increase in plant-based protein supply and Project Eaden's processes, minus all processes that are required less, e.g. conventional protein supply by animal husbandry.

2.1.1. System boundaries

The assessed system comprises process in the supply chain of Project Eaden, Project Eaden's processes and processes in the wider economy that might be affected by the changes initiated by a scaling of Project Eaden (Figure 1):

- Project Eaden requires energy and ingredients. In this study, the impact of a market response to an increase in the demand for energy and ingredients is assessed. In certain cases, the supply of ingredients used cannot be ramped up because of market constraints.

In such a case, other marginal suppliers will provide oils/fats to the market in order to replace the fat/oil used by Project Eaden.

- The increase in demand for certain ingredients might trigger a number of further changes in the market. For example, certain ingredients used by Project Eaden are produced together with other edible and non-idible products, e.g. the extraction of proteins often yields co-products, such as starch and shells/husks. The extraction of vegetable oils and fats usually produces another product (the remainder of the oil extraction step), that can be used for other purposes. Increasing the demand for and production of vegetable proteins or vegetable oil/fats will increase the supply of other products. The supply of these co-products to the market entails certain consequences, such as a potential decrease in other production processes.
- Project Eaden produces vegan alternatives to conventional meat. The taste, mouthfeel and texture of real meat products is mimicked. It is therefore likely that Project Eaden replaces conventional meat products in the market.
- The assessment aims at including all upstream and downstream processes involved related to the processes mentioned above.
- Processes that are similar to the conventional meat processing industry are not part of the assessment of systemic changes because they are considered similar, i.e. refrigerated storage, cleaning activities, retail and use at the consumer.

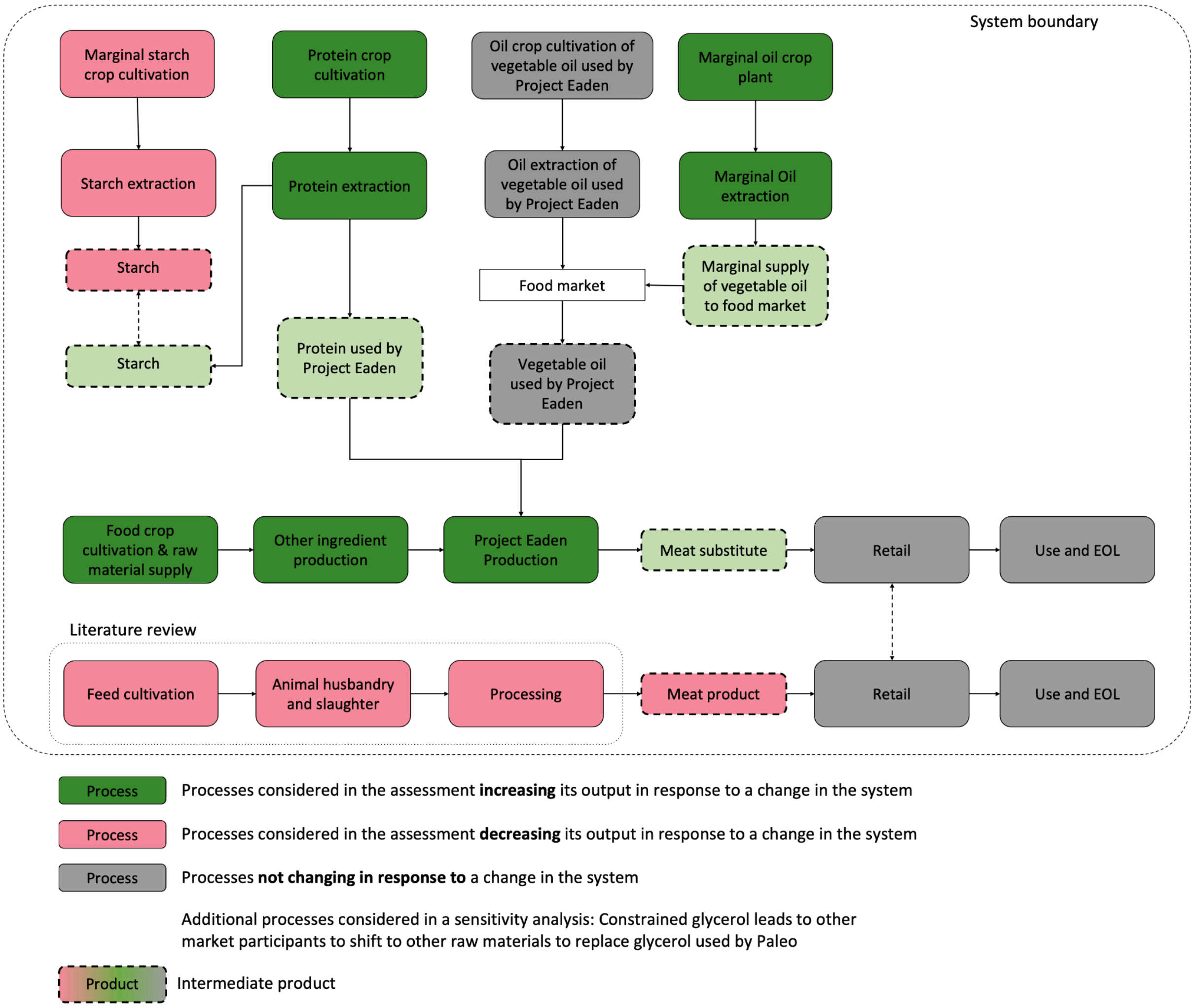
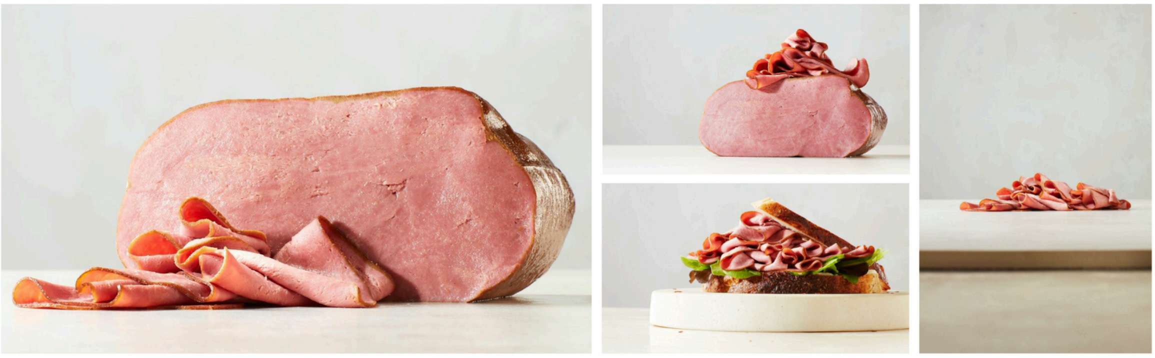


Figure 1 *Depiction of system boundaries. The gray process steps do not change in response to a shift from meat-based proteins to alternative protein sources. Green processes will increase their output, while red processes reduce their output. Additional processes (blue) are considered in a sensitivity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

2.1.2. Functional unit and assessed indicators

The LCA comprises three main elements: The impact of Project Eaden's production processes, the impact of protein supply and the systemic change in environmental impacts resulting from a change in protein consumption. The system is assessed using the indicators **climate change** (Intergovernmental Panel on Climate Change (IPCC), 2014) and several indicators related to resource use, **land demand** and **water demand** - WSI (Pfister et al., 2009).

The functional unit chosen is **1 kg packed consumer products**. At the moment, Project Eaden plans to offer three product categories based on plant proteins: Cold cuts, Sausages (*Bratwurst*) and filet (Figure 2). For this review, we selected three representative products: a cooked ham, a coarse sausage, and a pork filet.



Cooked ham

Coarse sausages (*Bratwurst*)

BEEF-STYLE FLANK STEAK

PORK-STYLE FLANK STEAK

Filet

Figure 2 *Assessed products in this study.*

2.1.3. Impact assessment of conventional and alternative protein sources

The provision of vegan meat alternatives that mimic texture, mouthfeel and taste of conventional meat products is likely to incentivise customers to switch to those alternatives from meat consumption. Conventional meat can be produced under many different circumstances. To cover the widest range of production modalities and data sources possible, hundreds of different LCAs of meat production systems were included (Poore & Nemecek, 2018). Poore et al. report impacts of different meat types without further processing. A hypothetical pork sausage was modeled assuming a maximum water content of 20% to allow a fair comparison. This hypothetical pork sausage presented in the results is an estimate and results in 20% lower impacts than pork meat.

2.1.4. Projecte Eaden's impact assessment

The **ingredients** of Project Eaden's vegan meat alternatives were assessed using scientific literature and data derived from the Ecoinvent database. Overall, at least 96% of all ingredients per product (by weight) were included in the assessment (Table 1). The remainder was not included due to the lack of appropriate LCA studies to model the impacts related to their production. **Note: The ingredients list will be undisclosed until the market launch of products.**

Table 1 *Ingredient composition in g/100g and nutritional value of assessed products. All ingredients listed in italic are not included in the assessment.*

Cooked Ham			**Coarse sausage**			**Filet**	
Ingredient	**MT**	**LT**	**Ingredient**	**MT**	**LT**	**Ingredient**	**MT**
Values undisclosed until product launch							
Nutrition value			Nutrition value			Nutrition value	
Protein content			Protein content			Protein content	

The use of these ingredients might lead to a number of systemic effects. The products and the corresponding systemic impacts are modeled in the following manner:

- **Note:** The ingredient list remains undisclosed until the market launch of the product. Once the products are available to the market, a description on how ingredient supply was modeled, will be included here.
- In all cases of agricultural products, it is assumed that the marginal supply will happen on the world markets. The life cycle data of all processes was taken from the peer-reviewed scientific literature stated above and complemented with data from the Ecoinvent database. The change in biogenic carbon stocks and all other relevant parameters is modeled according to the system model applied in the ecoinvent database. More information can be found in (Wernet et al., 2016). All other ingredients not mentioned above, such as table salt and drinking water are exclusively modeled with the Ecoinvent database.

Project Eaden developed an innovative **production process** that creates fibers from proteins and, subsequently, a meat substitute from protein fibers. The technology can be applied to plant- and mycelium-based proteins, as well as proteins produced by precision fermentation and cultivation. After the mixing of ingredients, fibers are spun. These fibers are then mixed with additional ingredients and processed to produce a vegan meat alternative mimicking the texture, mouthfeel and flavor of meat counterparts. The current product range (cold cuts, coarse sausage and filet) are closest to pork meat. The process requires electricity and water. The data is confidential and cannot be reported in this report. The GHG emissions associated with Project Eaden's operations are compared with literature values to provide insights into the plausibility of results (section 2.2.2.).

2.1.5. Sensitivity analysis

A number of **scenarios** are assessed in this study to cover a range of potential future design choices and to cover a number of different market effects to see robustness of results in dependence of assumptions made in this study. Overall, 24 scenarios were calculated based on a combination of these different scenarios:

- **Two scenarios on ingredient production**. A scenario using **conventional** and a scenario using **organic** ingredients was assessed.

- **Two future production scenarios.** A **mid-term scenario** models the first scaled-up production line. In this scenario, Project Eaden buys protein isolates on the market (triggering the displacement effects discussed above). In a **long-term scenario**, less energy is required and Project Eaden uses more raw materials, e.g. flour instead of protein isolates and starch.

- **Two substitution scenarios.** Two different substitution scenarios were assessed in which either potato starch or maize starch are replaced (Figure 1). These scenarios are used to cover two most important starch types in two world markets, the European Union and the United States.

In addition to these scenarios, the systemic impact of project Eaden is assessed using a different approach to quantify the quantities of potentially replaced conventional meat: protein digestibility. Consumers might not displace conventional meat with Project Eadens products based on weight, but potentially also based on the protein content and nutritional value of these proteins.

2.1.6. 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 et al., 2012; Schönfeldt & 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.

2.2. Results

In the following section, we first present the environmental impacts of conventional meat. Thereafter, we will showcase the net change in environmental impact of switching from conventional animal products (beef, mutton, lamb, pig and poultry) to the vegan products offered by Project Eaden.

2.2.1. Environmental impact of conventional meat production

Table 2 and Figure 3 show the environmental impacts of different types of meat products. All values obtained from (Poore & Nemecek, 2018). Additionally, we list the number of observations included in the literature review. The high number of observations indicate that a wide range of possible production modalities are covered by the data. In addition to these products, a hypothetical pork sausage was modeled (section 2.1.3.).

__Table 2__ Comparison of GHG emissions, land use and water use of different meat types. All values per kg fresh mass. Data taken from (Poore & Nemecek, 2018) Abbr.: Max - maximum, Min - minimum, N - number of values included in the assessment.

GHG Emissions (kg CO_2-eq./kg)	**5th**	**10th pctl**	**Mean**	**Median**	**90th pctl**	**95th pctl**	**Number of observations**
Bovine Meat (beef cattle)	37.6	40.4	99.5	60.4	209.9	269.2	724
Bovine Meat (dairy cattle)	14.9	17.9	33.3	34.1	50.9	56.7	490
Lamb & Mutton	23.7	24.5	39.7	40.6	54.4	60.2	757
Pig Meat	6.9	7.4	12.3	10.6	22.3	23.8	116
Poultry Meat	4.0	4.2	9.9	7.5	20.1	20.8	326

Land Use (m^2/FU)	**5th**	**10th pctl**	**Mean**	**Median**	**90th pctl**	**95th pctl**	**Number of observations**
Bovine Meat (beef cattle)	70.4	82.8	326.2	170.4	735.1	910.1	724
Bovine Meat (dairy cattle)	12.3	14.4	43.2	25.9	64.1	106.4	490
Lamb & Mutton	47.9	60.1	369.8	127.4	442.3	724.7	757
Pig Meat	7.4	7.8	17.4	13.4	31.1	34.1	116
Poultry Meat	6.5	6.7	12.2	11.0	16.0	20.4	326

Stress-Weighted Water Use (L/FU)	**5th**	**10th pctl**	**Mean**	**Median**	**90th pctl**	**95th pctl**	**Number of observations**
Bovine Meat (beef cattle)	205	242	34733	441	89872	190796	724
Bovine Meat (dairy cattle)	42175	46309	119805	122177	181963	214221	490
Lamb & Mutton	259	259	141925	259	540906	595278	757
Pig Meat	51	54	66867	54243	134395	152330	116
Poultry Meat	21	21	14178	334	49727	66045	326

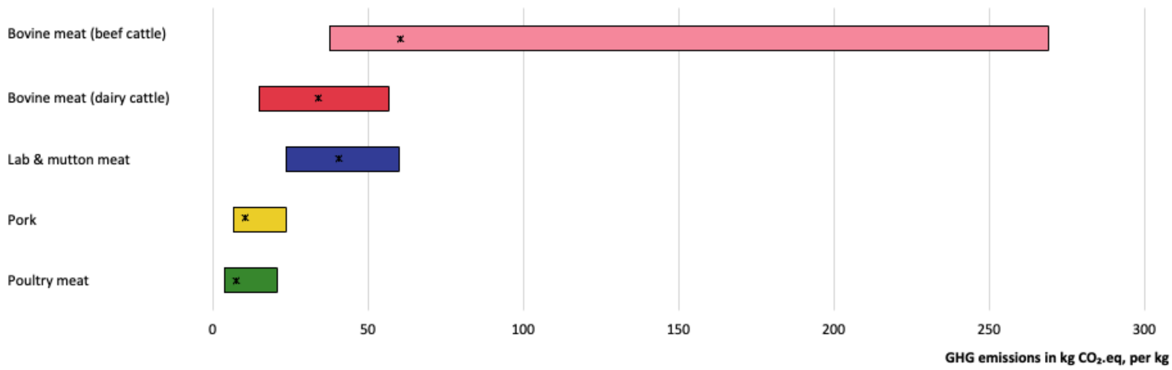


__Figure 3__ GHG emissions of different protein sources in kg CO_2-eq. per kg. Black Xs denote median values. Values taken from (Poore & Nemecek, 2018).

2.2.2. Impact of a change from conventional meat to Project Eaden's products

Switching from pork or pork sausages to Project Eaden's vegan meat alternatives leads to a net reduction in GHG emissions of 10 to 14 kg CO_2-eq. per kg in the mid-term scenario (Table 3). If project Eaden uses organic ingredients, the saving is slightly higher than if conventional products are used (ca. 0.5 kg CO_2-eq.). Across all types of meat products assessed, the net reduction in GHG emissions ranges from 3 to 271 kg CO_2-eq./kg. **In the long-term scenario, the switch from pork meat and pork sausages to Project Eaden's products might reduce GHG emissions between 8 and 20 kg CO_2-eq. per kg.** The main differences in emission changes in these scenarios comes from the lower energy demand of Project Eaden and a change in recipe. The use of flour (instead of protein isolates), reduces efforts to extract proteins and alters substitution effects. The range of net changes in GHG emissions is from 5 to 916 kg CO_2-eq./kg across all meat types. In general, highest net reduction arises if consumers use vegan alternatives instead of beef. The smallest reductions can be achieved if poultry is substituted with vegan alternatives. In a scientific study assessing vegan meat replaces processing accounts for less than 0.5 kg CO_2-eq. per kg of product (Van Mierlo et al., 2017). This is in the same range as GHG emissions associated with the operations of Project Eaden.

In this study, only peer-reviewed scientific papers are considered as data sources or reference points (apart from primary data obtained from Project Eaden). The GHG emissions of conventional meat products in the used scientific paper is higher than what is reported by some documents published by industry players. For instance, a large manufacturer of poultry products claims GHG emissions of 1.8 kg CO2-eq./kg. We did not include such studies, because data is inaccessible and the studies did not undergo a scientific review process. Yet, if this value is assumed as the minimum GHG intensity of poultry, there is still a potential net saving of ca. 1 kg CO2-eq. per kg.

To put the massive land demand for livestock and animal based products into perspective: **An estimated 809 Gt CO_2 would be removed from the atmosphere over a period of 100 years if all land currently occupied by livestock or feed production would be renaturated** (Poore & 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 & Roser, 2022; World Economic Forum, 2022)). **A 50% reduction in the consumption of animal products would translate into a net removal of 551 Gt CO_2 over a period of 100 years** (Poore & Nemecek, 2018).

***Table 3** Net change in GHG arising from a shift from animal proteins source to Project Eadens vegan meat products in kg CO_2-eq. per kg of protein. Calculations based on median, minimum and maximum GHG emissions of different products. Abbr.: bc - beef cattle, BM - beef meat, dc - dairy cattle, L - lamb, LT - long-term (scenario), M - mutton, MT - mid-term (scenario) P - poultry, PM - pork meat, PS - pork sausage.*

	Switching from →	Median						Min						Max					
	To ↓	**PM**	**PS**	BM-bc	BM-dc	L&M	P	**PM**	**PS**	BM-bc	BM-dc	L&M	P	**PM**	**PS**	BM-bc	BM-dc	L&M	P
MT	**Conventional**																		
	Cooked Ham	**-14**	**-11**	-90	-23	-30	-12	**-6**	**-5**	-37	-14	-23	-3	**-22**	**-17**	-268	-55	-59	-19
	Sausage	**-13**	**-11**	-102	-36	-42	-11	**-8**	**-7**	-39	-16	-25	-5	**-22**	**-18**	-268	-55	-59	-19
	Filet	**-14**	**-10**	-101	-34	-41	-13	**-10**	**-9**	-41	-18	-27	-7	**-22**	**-17**	-268	-55	-58	-19
	Organic																		
	Cooked Ham	**-14**	**-12**	-101	-35	-42	-12	**-9**	**-8**	-40	-17	-26	-6	**-25**	**-20**	-270	-58	-61	-22
	Sausage	**-13**	**-11**	-100	-34	-40	-11	**-8**	**-7**	-39	-16	-25	-5	**-24**	**-19**	-269	-57	-60	-21
	Filet	**-14**	**-11**	-101	-35	-41	-11	**-10**	**-9**	-41	-18	-27	-7	**-25**	**-21**	-271	-58	-62	-22
LT	**Conventional**																		
	Cooked Ham	**-11**	**-8**	-168	-24	-125	-9	**-7**	**-5**	-70	-11	-47	-6	**-30**	**-24**	-906	-103	-721	-17
	Sausage	**-12**	**-9**	-169	-25	-126	-10	**-7**	**-6**	-70	-12	-48	-6	**-32**	**-25**	-908	-104	-722	-18
	Filet	**-12**	**-9**	-169	-24	-126	-9	**-7**	**-5**	-70	-11	-47	-6	**-30**	**-23**	-906	-102	-720	-16
	Organic																		
	Cooked Ham	**-20**	**-17**	-177	-32	-134	-17	**-15**	**-14**	-78	-20	-56	-14	**-39**	**-32**	-915	-111	-729	-25
	Sausage	**-18**	**-15**	-175	-30	-132	-15	**-13**	**-11**	-76	-18	-53	-12	**-37**	**-31**	-913	-110	-728	-24
	Filet	**-20**	**-17**	-176	-32	-134	-17	**-16**	**-15**	-79	-21	-57	-15	**-40**	**-33**	-916	-112	-730	-26

The reduction in water-stress weighted water use ranges from 43 to 56 m^3/kg in the mid-term scenario and the long-term scenarios (Table 4). The high net reduction comes from the very high water demand and use of pork meat production (median value of pork, Table 2). Across all meat types, the lowest net change in water-stress weighted water use is 9 L/kg in the mid-term and 422 L/kg in the long term scenario. The net reduction in water-stress weighted water is highest (597 m^3/kg) if mutton or lamp is replaced. Mutton and lamb exhibit a very high water-stress weighted water demand if produced in arid countries.

Table 4 *Net change changes in water-stress weighted water demand arising from a shift from conventional meat to Project Eaden's vegan meat products in m³ per kg of protein. Calculations based on median, minimum and maximum water-stress weighted water use . A value of 0 in the table is a net change less than 0.5m³. See main text for lowest values. Abbr.: bc - beef cattle, BM - beef meat, dc - dairy cattle, L - lamb, LT - long-term (scenario), M - mutton, MT - mid-term (scenario) P - poultry, PM - pork meat, PS - pork sausage.*

	Switching from →	Median						Min						Max					
	To ↓	**PM**	**PS**	BM-bc	BM-dc	L&M	P	**PM**	**PS**	BM-bc	BM-dc	L&M	P	**PM**	**PS**	BM-bc	BM-dc	L&M	P
MT	**Conventional**																		
	Cooked Ham	**-54**	**-43**	0	-122	0	0	**0**	**0**	0	-42	0	0	**-152**	**-121**	-190	-214	-595	-65
	Sausage	**-54**	**-43**	0	-122	0	0	**0**	**0**	0	-42	0	0	**-152**	**-121**	-190	-214	-595	-66
	Filet	**-54**	**-43**	0	-122	0	0	**0**	**0**	0	-42	0	0	**-152**	**-121**	-190	-214	-595	-65
	Organic																		
	Cooked Ham	**-56**	**-45**	-2	-124	-2	-2	**-2**	**-2**	-2	-44	-2	-2	**-155**	**-124**	-193	-217	-598	-68
	Sausage	**-56**	**-45**	-2	-123	-2	-2	**-1**	**-1**	-1	-43	-1	-1	**-154**	**-123**	-192	-216	-597	-68
	Filet	**-56**	**-45**	-2	-124	-2	-2	**-2**	**-2**	-2	-44	-2	-2	**-155**	**-125**	-194	-217	-598	-69
LT	**Conventional**																		
	Cooked Ham	**-54**	**-43**	0	-122	0	0	**0**	**0**	0	-42	0	0	**-152**	**-122**	-191	-214	-595	-66
	Sausage	**-54**	**-43**	0	-122	0	0	**0**	**0**	0	-42	0	0	**-152**	**-122**	-191	-214	-595	-66
	Filet	**-54**	**-43**	0	-122	0	0	**0**	**0**	0	-42	0	0	**-152**	**-122**	-191	-214	-595	-66
	Organic																		
	Cooked Ham	**-56**	**-45**	-2	-124	-2	-2	**-1**	**-1**	-1	-43	-1	-1	**-154**	**-124**	-193	-216	-597	-68
	Sausage	**-55**	**-44**	-1	-123	-1	-1	**-1**	**-1**	-1	-43	-1	-1	**-153**	**-123**	-192	-215	-596	-67
	Filet	**-55**	**-44**	-1	-123	-1	-1	**-1**	**-1**	-1	-43	-1	-1	**-154**	**-123**	-192	-215	-596	-67

The net reduction in land-use is 9 to 20 m²/kg in the mid-term scenario and 9 to 18 m²/kg in the long-term scenario (Table 5). Again, if other types of meats are included in the assessment, the potential net benefits substantially increase to 5 to 919 m²/kg and 5 to 914 m²/kg in the mid-term and long-term scenario. 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 4). 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 4 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).

Table 5 *Net change in land use from a shift from meat to Project Eaden's vegan meat products in* m^2 *per kg of protein. Calculations based on median land use of different products. Abbr.: bc - beef cattle, BM - beef meat, dc - dairy cattle, L - lamb, LT - long-term (scenario), M - mutton, MT - mid-term (scenario) P - poultry, PM - pork meat, PS - pork sausage.*

	Switching from →	Median						Min						Max					
	To ↓	**PM**	**PS**	BM-bc	BM-dc	L&M	P	**PM**	**PS**	BM-bc	BM-dc	L&M	P	**PM**	**PS**	BM-bc	BM-dc	L&M	P
MT	**Conventional**																		
	Cooked Ham	**-11**	**-9**	-168	-24	-125	-9	**-7**	**-5**	-70	-11	-47	-6	**-30**	**-24**	-906	-103	-721	-17
	Sausage	**-12**	**-9**	-169	-25	-126	-10	**-7**	**-6**	-70	-12	-48	-6	**-32**	**-25**	-908	-104	-722	-18
	Filet	**-12**	**-9**	-169	-24	-126	-9	**-7**	**-5**	-70	-11	-47	-6	**-30**	**-23**	-906	-102	-720	-16
	Organic																		
	Cooked Ham	**-20**	**-17**	-177	-32	-134	-17	**-12**	**-11**	-75	-17	-53	-11	**-42**	**-35**	-918	-114	-732	-28
	Sausage	**-18**	**-15**	-175	-30	-132	-15	**-11**	**-9**	-74	-16	-51	-10	**-40**	**-33**	-916	-112	-730	-26
	Filet	**-20**	**-17**	-177	-32	-134	-17	**-13**	**-11**	-76	-18	-53	-12	**-43**	**-36**	-919	-115	-734	-29
LT	**Conventional**																		
	Cooked Ham	**-12**	**-9**	**-168**	**-24**	-126	-9	**-6**	**-5**	-70	-11	-47	-6	**-31**	**-24**	-907	-103	-722	-18
	Sausage	**-13**	**-10**	**-170**	**-26**	-127	-11	**-8**	**-6**	-71	-13	-48	-7	**-33**	**-26**	-909	-106	-724	-20
	Filet	**-13**	**-10**	**-170**	**-25**	-127	-10	**-7**	**-5**	-70	-12	-47	-6	**-32**	**-25**	-908	-104	-723	-18
	Organic																		
	Cooked Ham	**-18**	**-15**	-175	-30	-132	-15	**-13**	**-11**	-76	-18	-53	-12	**-38**	**-31**	-914	-110	-728	-24
	Sausage	**-16**	**-13**	-173	-28	-130	-13	**-10**	**-9**	-73	-15	-51	-9	**-36**	**-29**	-912	-108	-726	-22
	Filet	**-16**	**-13**	-173	-29	-130	-14	**-11**	**-10**	-74	-16	-52	-10	**-36**	**-30**	-912	-109	-727	-23

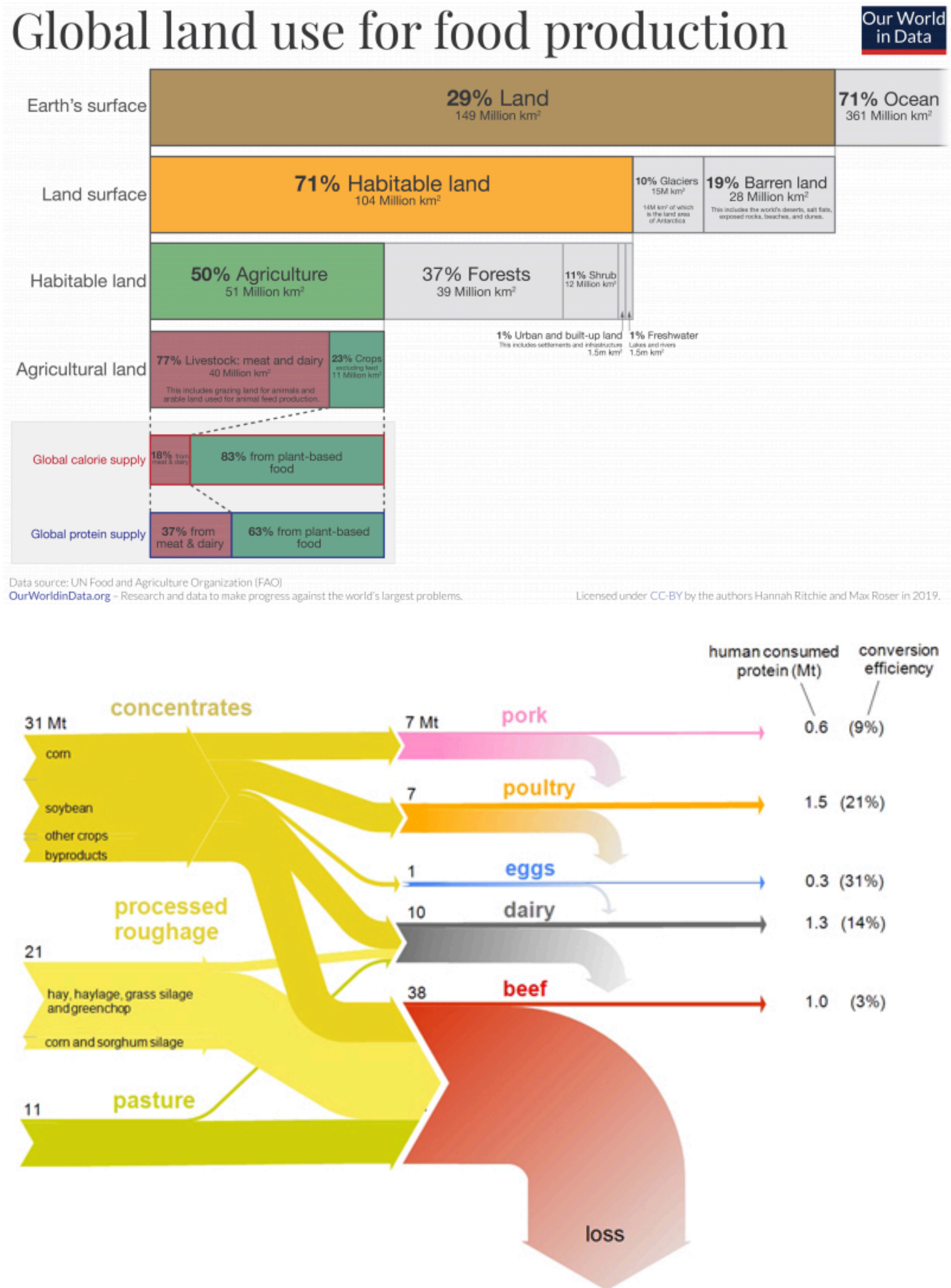


Figure 4 <u>Top:</u> *Global land use for food production. Figure and caption taken from (Ritchie & Roser, 2017), provided under a CC BY license.* <u>Bottom:</u> *The US feed-to-food protein flux from the three feed classes (left) into edible animal products (right). On the right, parenthetical percentages 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.*

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 & Hoekstra, 2010). The data of Mekonnen and Hoekstra (2010) shows **net water savings ranging from 8 to 56 m^3 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. Sensitivity analysis: protein digestibility

The inclusion of the protein digestibility (section 2.1.5) has only a minor influence on the assessment. If protein digestibility is taken into account (Tables A.2 in the Annex) only minor changes in outcomes can be observed: The values without taking protein digestibility into account and results including protein digestibility differ by less than 2.5%.

2.2.4. Limitations and uncertainties

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

- Project Eaden production is yet to be scaled to full scale. To account for uncertainties related to this ex-ante assessment of Project Eaden, two different scenarios were considered: a mid-term scenario and a long-term scenario. These scenarios cover the upcoming scale up and future targets.

- The data used in this study was taken from peer-reviewed scientific papers and the Ecoinvent database. No data was found on the purification of proteins, i.e. concentration of proteins to produce isolate. This process step is missing in the assessment. Yet, the additional efforts are very unlikely to change the overall indication of high net reduction in GHG emissions, water use and land-use.

- Likewise, the processing of meat products to edible products, manufacturing of sausages is excluded. Again, the additional efforts required and related environmental impacts will only increase the net positive impact achieved by a switch to vegan products offered by Project Eaden.

- The reviewed literature of conventional meat production relies 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.

- Our market analysis shows that Project Eaden 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. In case, consumers switch from other alternative meat products, no substantial change in impacts can be expected. The total potential to replace conventional meat depends on the price of products, too. Likewise, the magnitude of changes in the food market, e.g. protein, gluten and oil, depends on many factors. To increase the confidence in results, several scenarios were calculated.

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 et al., 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.

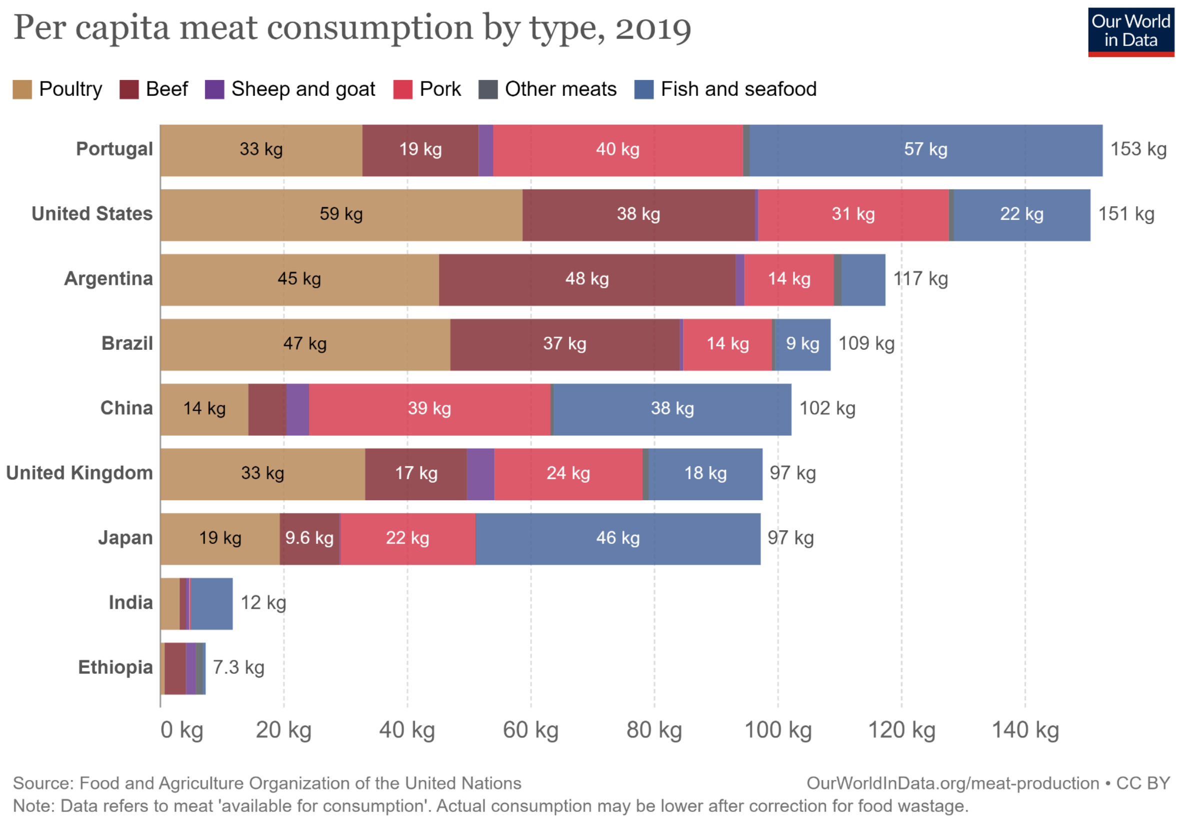


Figure 10 *Per capita meat consumption in 2019 in selected countries. Provided by Our World in Data, licensed under a CC BY license* (Ritchie et al., 2019).

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 & 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 & 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 et al., 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 & 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 (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 & Beydoun, 2009; You & 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 et al., 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 & 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 market barriers in place preventing a wider adoption of alternative proteins. Project Eaden products address several of these barriers, such as the texture and mouthfeel of alternative protein products. **By addressing these barriers, a wider adoption of alternative protein sources can be expected.** A change in consumption behaviors 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 switching from conventional pork products (pork meat and pork sausages, the products currently mimicked by Project Eaden's products) could lead to**

- **a net reduction in GHG emissions of 10 to 14 kg CO_2-eq. per kg in the mid-term and 8 to 20 kg CO_2-eq. per kg in the long-term.**
- **a net reduction in water-stress weighted water use ranges from 43 to 56 m^3/kg in the mid-term and the long-term.**
- **a net reduction in land-use is 9 to 20 m^2/kg in the mid-term and 9 to 18 m^2/kg in the long-term.**

If other meat types are replaced, a wider range of net savings can be achieved. The common observable trend is: lower net reduction if poultry is replaced and substantially higher net reductions in impacts if beef or lamb and mutton are replaced. **In any case, all production and substitution scenarios, as well as the use of minimum and maximum impacts reported from hundreds of different LCAs lead to a net reduction in impacts if consumers switch from meat to Project Eaden's vegan alternatives.**

References

Abascal, E., Gómez-Coma, L., Ortiz, I., & Ortiz, A. (2022). Global diagnosis of nitrate pollution in groundwater and review of removal technologies. *Science of The Total Environment*, *810*, 152233. https://doi.org/10.1016/j.scitotenv.2021.152233

Alexander, P., Brown, C., Arneth, A., Dias, C., Finnigan, J., Moran, D., & Rounsevell, M. D. A. (2017). Could consumption of insects, cultured meat or imitation meat reduce global agricultural land use? *Global Food Security*, *15*, 22–32. https://doi.org/10.1016/j.gfs.2017.04.001

Alexander, P., Rounsevell, M. D. A., Dislich, C., Dodson, J. R., Engström, K., & Moran, D. (2015). Drivers for global agricultural land use change: The nexus of diet, population, yield and bioenergy. *Global Environmental Change*, *35*, 138–147. https://doi.org/10.1016/j.gloenvcha.2015.08.011

Bailey, H. M., Mathai, J. K., Berg, E. P., & Stein, H. H. (2020). Pork Products Have Digestible Indispensable Amino Acid Scores (DIAAS) That Are Greater Than 100 When Determined in Pigs, but Processing Does Not Always Increase DIAAS. *The Journal of Nutrition*, *150*(3), 475–482. https://doi.org/10.1093/jn/nxz284

Bartelt-Hunt, S., Snow, D. D., Damon-Powell, T., & Miesbach, D. (2011). Occurrence of steroid hormones and antibiotics in shallow groundwater impacted by livestock waste control facilities. *Journal of Contaminant Hydrology*, *123*(3–4), 94–103. https://doi.org/10.1016/j.jconhyd.2010.12.010

Boye, J., Wijesinha-Bettoni, R., & Burlingame, B. (2012). Protein quality evaluation twenty years after the introduction of the protein digestibility corrected amino acid score method. *British Journal of Nutrition*, *108*(S2), S183–S211. https://doi.org/10.1017/S0007114512002309

Brondizio, E. S., Settele, J., Díaz, S., & Ngo, H. T. (2019). *Summary for policymakers of the global assessment report on biodiversity and ecosystem services* (Intergovernmental Science-Policy Platform On Biodiversity And Ecosystem Services, Ed.). Zenodo. https://doi.org/10.5281/ZENODO.3553579

Caputo, V., Sun, J., Staples, A. J., & Taylor, H. (2024). Market outlook for meat alternatives: Challenges, opportunities, and new developments. *Trends in Food Science & Technology*, *148*, 104474. https://doi.org/10.1016/j.tifs.2024.104474

Carmona, C. P., Guerrero, I., Peco, B., Morales, M. B., Oñate, J. J., Pärt, T., Tscharntke, T., Liira, J., Aavik, T., Emmerson, M., Berendse, F., Ceryngier, P., Bretagnolle, V., Weisser, W. W., Bengtsson, J., & Seymour, C. (2020). Agriculture intensification reduces plant taxonomic and functional diversity across European arable systems. *Functional Ecology*, *34*(7), 1448–1460. https://doi.org/10.1111/1365-2435.13608

Chatterjee, A., Modarai, M., Naylor, N. R., Boyd, S. E., Atun, R., Barlow, J., Holmes, A. H., Johnson, A., & Robotham, J. V. (2018). Quantifying drivers of antibiotic resistance in humans: A systematic review. *The Lancet Infectious Diseases*, *18*(12), e368–e378. https://doi.org/10.1016/S1473-3099(18)30296-2

Derbyshire, E. (2022). Food-Based Dietary Guidelines and Protein Quality Definitions—Time to Move Forward and Encompass Mycoprotein? *Foods*, *11*(5), 647. https://doi.org/10.3390/foods11050647

Dimina, L., Rémond, D., Huneau, J.-F., & Mariotti, F. (2022). Combining Plant Proteins to Achieve Amino Acid Profiles Adapted to Various Nutritional Objectives—An Exploratory Analysis Using Linear Programming. *Frontiers in Nutrition*, *8*, 809685. https://doi.org/10.3389/fnut.2021.809685

Ekvall, T., Azapagic, A., Finnveden, G., Rydberg, T., Weidema, B. P., & Zamagni, A. (2016). Attributional and consequential LCA in the ILCD handbook. *The International Journal of Life*

Cycle Assessment, *21*(3), 293–296. https://doi.org/10.1007/s11367-015-1026-0
Emery, I. (2018). Without animals, US farmers would reduce feed crop production. *Proceedings of the National Academy of Sciences*, *115*(8). https://doi.org/10.1073/pnas.1720760115
Eurostat. (2022). *Livestock population in numbers*. Eurostat. https://ec.europa.eu/eurostat/de/web/products-eurostat-news/-/ddn-20220517-2
Filazzola, A., Brown, C., Dettlaff, M. A., Batbaatar, A., Grenke, J., Bao, T., Peetoom Heida, I., & Cahill, J. F. (2020). The effects of livestock grazing on biodiversity are multi-trophic: A meta-analysis. *Ecology Letters*, *23*(8), 1298–1309. https://doi.org/10.1111/ele.13527
Food and Agriculture Organization of the United & Nations (FAO). (2022). *FRA 2020 Remote Sensing Survey*. FAO. https://doi.org/10.4060/cb9970en
Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M., & Toulmin, C. (2010). Food Security: The Challenge of Feeding 9 Billion People. *Science*, *327*(5967), 812–818. https://doi.org/10.1126/science.1185383
González, N., Marquès, M., Nadal, M., & Domingo, J. L. (2020). Meat consumption: Which are the current global risks? A review of recent (2010–2020) evidences. *Food Research International*, *137*, 109341. https://doi.org/10.1016/j.foodres.2020.109341
Grasso, A. C., Hung, Y., Olthof, M. R., Verbeke, W., & Brouwer, I. A. (2019). Older Consumers' Readiness to Accept Alternative, More Sustainable Protein Sources in the European Union. *Nutrients*, *11*(8), 1904. https://doi.org/10.3390/nu11081904
Gremmen, B. (2020). Ethics views on animal science and animal production. *Animal Frontiers*, *10*(1), 5–7. https://doi.org/10.1093/af/vfz049
Hoffman, J. R., & Falvo, M. J. (2004). Protein—Which is Best? *Journal of Sports Science & Medicine*, *3*(3), 118–130.
Hooda, P. S., Edwards, A. C., Anderson, H. A., & Miller, A. (2000). A review of water quality concerns in livestock farming areas. *Science of The Total Environment*, *250*(1–3), 143–167. https://doi.org/10.1016/S0048-9697(00)00373-9
Ibrahimi Jarchlo, A., & King, L. (2022). *Survey of consumer perceptions of alternative, or novel, sources of protein*. Food Standards Agency. https://doi.org/10.46756/sci.fsa.ncn554
Ignaszewski, E., Pierce, B., Gernter, D., & Leet-Otley, T. (2024). *Analyzing plant-based meat & seafood sales (gfi—Good Food Intitute)*. https://gfi.org/resource/analyzing-plant-based-meat-and-seafood-sales/
Intergovernmental Panel on Climate Change (IPCC) (Ed.). (2014). *Climate Change 2013—The Physical Science Basis*. Cambridge University Press. https://doi.org/10.1017/CBO9781107415324
Jahn, S., Furchheim, P., & Strässner, A.-M. (2021). Plant-Based Meat Alternatives: Motivational Adoption Barriers and Solutions. *Ststainability*, *13*(23). https://doi.org/10.3390/su132313271
Kivits, T., Broers, H. P., Beeltje, H., van Vliet, M., & Griffioen, J. (2018). Presence and fate of veterinary antibiotics in age-dated groundwater in areas with intensive livestock farming. *Environmental Pollution*, *241*, 988–998. https://doi.org/10.1016/j.envpol.2018.05.085
Machovina, B., Feeley, K. J., & Ripple, W. J. (2015). Biodiversity conservation: The key is reducing meat consumption. *Science of The Total Environment*, *536*, 419–431. https://doi.org/10.1016/j.scitotenv.2015.07.022
Malila, Y., Owolabi, I. O., Chotanaphuti, T., Sakdibhornssup, N., Elliott, C. T., Visessanguan, W., Karoonuthaisiri, N., & Petchkongkaew, A. (2024). Current challenges of alternative proteins as future foods. *Npj Science of Food*, *8*(1), 53. https://doi.org/10.1038/s41538-024-00291-w
Mekonnen, M., & Hoekstra, A. Y. (2010). *The green, blue and grey water footprint of farm animals and animal products.*
Monger, X. C., Gilbert, A.-A., Saucier, L., & Vincent, A. T. (2021). Antibiotic Resistance: From Pig to Meat. *Antibiotics*, *10*(10), 1209. https://doi.org/10.3390/antibiotics10101209

Morach, B., Clausen, M., Rogg, J., Brigl, M., Schulze, U., Dehnert, N., Hepp, M., Yang, V., Kurth, T., von Koeller, E., Burchardt, J., Witte, B., Obloj, P., Koktenturk, S., Grosse-Holz, F., & Stolt-Nielsen Meinl, O. (2022). *The Untapped Climate Opportunity in Alternative Proteins*. Boston Consulting Group (BCG) and blue horizon.
National Cancer Institute. (2017). *Chemicals in Meat Cooked at High Temperatures and Cancer Risk*. https://www.cancer.gov/about-cancer/causes-prevention/risk/diet/cooked-meats-fact-sheet
Orzechowski, K. (2022). *Global Animal Slaughter Statistics & Charts: 2022 Update*. Faunalytics. https://faunalytics.org/global-animal-slaughter-statistics-charts-2022-update/
Pfister, S., Koehler, A., & Hellweg, S. (2009). Assessing the Environmental Impacts of Freshwater Consumption in LCA. *Environmental Science & Technology*, *43*(11), 4098–4104. https://doi.org/10.1021/es802423e
Phillips, S. M. (2017). Current Concepts and Unresolved Questions in Dietary Protein Requirements and Supplements in Adults. *Frontiers in Nutrition*, *4*, 13. https://doi.org/10.3389/fnut.2017.00013
Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science*, *360*(6392), 987–992. https://doi.org/10.1126/science.aaq0216
Ritchie, H., Rosado, P., & Max, R. (2019). *Meat and Dairy Production*. https://ourworldindata.org/meat-production#number-of-animals-slaughtered
Ritchie, H., & Roser, M. (2017). *How much of the world's land would we need in order to feed the global population with the average diet of a given country?* Our World in Data. https://ourworldindata.org/agricultural-land-by-global-diets
Ritchie, H., & Roser, M. (2022). *CO2 emissions*. Our World in Data. https://ourworldindata.org/co2-emissions
Sandøe, P., & Christiansen, S. B. (2008). *Ethics of animal use*. Blackwell.
Sartorello, Y., Pastorino, A., Bogliani, G., Ghidotti, S., Viterbi, R., & Cerrato, C. (2020). The impact of pastoral activities on animal biodiversity in Europe: A systematic review and meta-analysis. *Journal for Nature Conservation*, *56*, 125863. https://doi.org/10.1016/j.jnc.2020.125863
Schaafsma, G. (2000). The Protein Digestibility–Corrected Amino Acid Score. *The Journal of Nutrition*, *130*(7), 1865S-1867S. https://doi.org/10.1093/jn/130.7.1865S
Schiermeier, Q. (2019). Eat less meat: UN climate-change report calls for change to human diet. *Nature*, *572*(7769), 291–292. https://doi.org/10.1038/d41586-019-02409-7
Schönfeldt, H. C., & Gibson Hall, N. (2012). Dietary protein quality and malnutrition in Africa. *British Journal of Nutrition*, *108*(S2), S69–S76. https://doi.org/10.1017/S0007114512002553
Schwarzmueller, F., & Kastner, T. (2022). Agricultural trade and its impacts on cropland use and the global loss of species habitat. *Sustainability Science*, *17*(6), 2363–2377. https://doi.org/10.1007/s11625-022-01138-7
Shepon, A., Eshel, G., Noor, E., & Milo, R. (2016). Energy and protein feed-to-food conversion efficiencies in the US and potential food security gains from dietary changes. *Environmental Research Letters*, *11*(10), 105002. https://doi.org/10.1088/1748-9326/11/10/105002
Svejcar, T., Boyd, C., Davies, K., Madsen, M., Bates, J., Sheley, R., Marlow, C., Bohnert, D., Borman, M., Mata-Gonzàlez, R., Buckhouse, J., Stringham, T., Perryman, B., Swanson, S., Tate, K., George, M., Ruyle, G., Roundy, B., Call, C., … Havstad, K. (2014). Western Land Managers will Need all Available Tools for Adapting to Climate Change, Including Grazing: A Critique of Beschta et al. *Environmental Management*, *53*(6), 1035–1038. https://doi.org/10.1007/s00267-013-0218-2
Taylor, L. H., Latham, S. M., & Woolhouse, M. E. J. (2001). Risk factors for human disease emergence. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *356*(1411), 983–989. https://doi.org/10.1098/rstb.2001.0888

Thornton, P., & Herrero, M. (2010). *The Inter-Linkages between Rapid Growth in Livestock Production, Climate Change, and the Impacts on Water Resources, Land Use, and Deforestation. World Bank Policy Research Working Paper No. 5178, Available at SSRN: https://ssrn.com/abstract=1536991*.

Tsiafouli, M. A., Thébault, E., Sgardelis, S. P., de Ruiter, P. C., van der Putten, W. H., Birkhofer, K., Hemerik, L., de Vries, F. T., Bardgett, R. D., Brady, M. V., Bjornlund, L., Jørgensen, H. B., Christensen, S., Hertefeldt, T. D., Hotes, S., Gera Hol, W. H., Frouz, J., Liiri, M., Mortimer, S. R., … Hedlund, K. (2015). Intensive agriculture reduces soil biodiversity across Europe. *Global Change Biology*, *21*(2), 973–985. https://doi.org/10.1111/gcb.12752

Van Mierlo, K., Rohmer, S., & Gerdessen, J. C. (2017). A model for composing meat replacers: Reducing the environmental impact of our food consumption pattern while retaining its nutritional value. *Journal of Cleaner Production*, *165*, 930–950. https://doi.org/10.1016/j.jclepro.2017.07.098

Wang, Y., & Beydoun, M. A. (2009). Meat consumption is associated with obesity and central obesity among US adults. *International Journal of Obesity*, *33*(6), 621–628. https://doi.org/10.1038/ijo.2009.45

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., & Weidema, B. (2016). The ecoinvent database version 3 (part I): Overview and methodology. *The International Journal of Life Cycle Assessment*, *21*(9), 1218–1230. https://doi.org/10.1007/s11367-016-1087-8

Wickersham, T. A., & Sawyer, J. E. (n.d.). *Protein Supplementation of Beef Cattle to Meet Human Protein Requirements*.

Witte, B., Przemek, O., Koktenturk, S., Brigl, M., Rogg, J., Schulze, U., Walker, D., von Koeller, E., Dehnert, N., & Grosse-Holz, F. (2021). *The Protein Transformation*. Boston Consulting Group (BCG) and blue horizon.

World Economic Forum. (2022). *Analysis: Global CO2 emissions from fossil fuels hits record high in 2022*. https://www.weforum.org/agenda/2022/11/global-co2-emissions-fossil-fuels-hit-record-2022

Xu, X., Sharma, P., Shu, S., Lin, T.-S., Ciais, P., Tubiello, F. N., Smith, P., Campbell, N., & Jain, A. K. (2021). Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods. *Nature Food*, *2*(9), 724–732. https://doi.org/10.1038/s43016-021-00358-x

You, W., & Henneberg, M. (2016). Meat consumption providing a surplus energy in modern diet contributes to obesity prevalence: An ecological analysis. *BMC Nutrition*, *2*(1), 22. https://doi.org/10.1186/s40795-016-0063-9

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 & Falvo, 2004; Wickersham & Sawyer, n.d.)
Lamb & Mutton	1	1.16	(Wickersham & Sawyer, n.d.)
Pig Meat	1	1.14	(Bailey et al., 2020)
Poultry Meat	1	1.08	(Phillips, 2017)

Values undisclosed until product launch

A.2. Additional results

Table A2 *Sensitivity analysis taking protein digestibility (PCDAA and DIAAS) into account. Tabulated values are the net change in GHG emissions arising from a shift from conventional meat products to Project Eadens meat alternatives in kg CO_2-eq. per kg of protein. Only conventional scenarios are calculated in the sensitivity analysis. Calculations based on median, minimum and maximum GHG emissions of different products. Abbr.: bc - beef cattle, BM - beef meat, dc - dairy cattle, DIASS - digestible indispensable amino acid score, L - lamb, LT - long-term (scenario), M - mutton, MT - mid-term (scenario), P - poultry, PCDAA - protein digestibility corrected amino acid score, PM - pork meat, PS - pork sausage.*

Switching from →	PCDAA						DIASS					
To ↓	**PM**	**PS**	BM-bc	BM-dc	L&M	P	**PM**	**PS**	BM-bc	BM-dc	L&M	P
Mid-team												
Cooked Ham	**-14**	**-11**	-101	-34	-41	-11	**-14**	**-11**	-101	-35	-41	-11
Sausage	**-13**	**-10**	-100	-34	-40	-10	**-13**	**-10**	-100	-34	-40	-10
Filet	**-14**	**-11**	-101	-35	-41	-12	**-14**	**-11**	-101	-35	-42	-12
Long-team												
Cooked Ham	**-12**	**-9**	-99	-33	-39	-9	**-12**	**-9**	-99	-33	-39	-9
Sausage	**-12**	**-9**	-99	-33	-39	-9	**-12**	**-9**	-99	-33	-39	-9
Filet	**-12**	**-9**	-99	-33	-39	-9	**-12**	**-9**	-99	-33	-39	-9

www.planet-a.com