Environmental impacts of animal and plant-based food

October 2020

blue horizon

Pure play impact with tasty, healthy, sustainable food for everyone

Dear readers,

Science and society have long been concerned with the monetisation of environmental costs. Many of these costs will increase with climate change. The question is: What would the theoretical monetary value be of clean air, unpolluted water, healthy seas and soil? Measuring economic efficiency provides a basis for an objective discussion about the economic and financial impact of food production and climate change.

In the case of food, these prices are currently distorted. Agriculture is heavily subsidised worldwide. Environmental costs are not internalised. Hence meat, dairy and many other food products are traded in most markets at prices not reflecting their true costs. At the same time, the environmental damage caused by the animal protein industry like meat and dairy is becoming increasingly visible. The related problems are becoming more pressing. Today's food production is unsustainable. Consumers and investors keep a close eye on these developments, and increasingly are demanding change. The COVID crisis is adding even more pressure on global food supply chains and is acting as an accelerator for consumer change away from animal protein towards sustainable options.

As a pure play impact investor, Blue Horizon is measuring and managing the impact of its investments with sustainability tools combined with proprietary methodology. This study is a response to Blue Horizon's aim to better understand the environmental impacts of animal-based products and its plant-based alternatives. Blue Horizon targets to shed light on this topic, as the market needs environmental data in monetarised form. We therefore mandated PwC to combine academic input as well as impact data in this study "Environmental impacts of animal and plant-based food".

With this study, Blue Horizon extends its domain expertise and provides valuable data. We are convinced that this is a true breakthrough, as it enables all stakeholders to factor in external costs into food prices in order to correctly assess the risks and future opportunities. This study provides detailed and robust data and the real prices of consumption of animal proteins and their plant-based alternatives, in a consistent framework across different meat categories and geographies. The impressive numbers in this study clearly demonstrate that there is an enormous potential to disrupt mass markets by supporting the transition of the global food industry through replacing animal proteins with healthy, alternative protein sources across the global supply chain.

We hope that this study will have an eye-opening effect and encourage you to join us on our journey to master the challenges and exploit the opportunities that lie ahead.

Yours sincerely,

Roger Lienhard
Founder & Chairman

Björn Witte
CEO & Managing Partner

Contents

Disclaimer

This document is the overall responsibility of Blue Horizon. PwC has contributed to the contents of this document by analysing the environmental data and valued environmental impacts of GHG emissions, water use and land use for animal proteins and plant-based alternative proteins. PwC's contribution has been prepared only for Blue Horizon and solely for the purpose and on the terms agreed with Blue Horizon. PwC accepts no liability (including for negligence) to anyone else in connection with the PwC contents of this document.

Executive summary

Introduction

The future of food

In the last century, global meat production and consumption has increased dramatically. Across all animal products, production has more than quadrupled in the last 50 years,[1] swelling to 327 million tonnes in 2018.[2] Although the rate of increase is slowing, global production is still expected to increase by a further 13% by 2028* to support a growing world population, increasing life expectancy, and increasing incomes, particularly in developing economies.[3] Meat consumption per capita is higher than ever before, ranging from less than 5kg per person per year in India, to over 100kg in the United States.[4]

The impact on the environment is significant. Food production accounts for around 25% of global greenhouse gas emissions, with meat and animal products making up over half of that – despite accounting for less than 20% of the calories we consume.[5] Meanwhile, half of all habitable land is used for agriculture, of which 77% is used for livestock production (including production of crops for animal feed).[6] This is leading to the degradation of natural ecosystems and a reduction in biodiversity and other ecosystem services, including carbon sequestration. Additionally, over 92% of the world's freshwater footprint is associated with agriculture, with almost a third relating to animal products.[7]

Increased understanding of the environmental costs of animal consumption is one of the key drivers behind the exploration into affordable, nutritious protein alternatives, which can be produced at scale. The alternative meat industry has been projected to grow to almost 10% of the size of the global meat industry by 2030.[8] This report aims to provide an evidence base to explore and compare the environmental impacts of both animal products and their plant-based alternatives.

Overview of this study

This report measures the environmental impacts of four different animal products (chicken, egg, pork, and beef) and compares these impacts to substitutes produced using plant-based protein alternatives. The analysis explores the environmental impacts of greenhouse gas emissions, land use, and water consumption. These were chosen as they were deemed to be the most material environmental impacts arising from food production. This is not an exhaustive evaluation of environmental impacts from meat production – for example it does not include other air pollutants, water pollutants and waste. However, it provides a robust method for comparing material environmental impacts across geographies and farming systems.

This study reports environmental impacts in the following units: GHGs are measured in kg of CO_2 equivalent (CO_2e,), land use is measured in hectares (ha), and water consumption is measured in m^3. These environmental quantities are also converted into monetary values to allow comparison between the different types of impact on a single scale. Valuation is a measure of the cost to society of different types of impact.

The purpose of this report is not to advocate any particular solution, but to provide a set of metrics to aid the comparison of products and farming systems. The scope is limited to environmental impacts; other factors, such as health, animal welfare, disease management, and economic and social factors are not considered.

This work is an important step in helping people to understand how the decisions we make about our protein consumption impact our environment. To further the development of this approach, we welcome the comments and views of experts in this field.

*Note: These projections were made prior to the COVID-19 pandemic and resulting economic crisis. Although this may affect the rate of consumption growth, overall global meat consumption is still expected to grow.

Scope (1/2)

Animal and plant-based alternative products

This study examines the environmental footprints of four animal-based products: pulled chicken, pork mince, beef mince, and eggs. Globally, cattle, poultry, and pig products make up over 92% of global meat production.[9] Over 82 million tonnes of eggs are produced annually.[10]

The specific products were selected as the raw ingredients of consumer products, which are often replaced by plant-based alternatives. Pulled chicken is usually made from chicken breast, a high-value (expensive) cut of meat, whilst pork and beef mince is usually made from low-value (cheaper) cuts. This is important as the methodology used in this study assigns a lower environmental impact to lower value cuts of meat, in the same way that carbon accounting assigns fewer emissions to economy airplane seats compared to first class seats. For further details, please see page 64.

For each product, the environmental impact was examined for three different locations: Europe, the United States, and China. In addition, as the world's second-largest producer of beef, we calculated the environmental footprint of cattle in Brazil.

The study also compares the environmental impacts of a range of different farming systems: conventional (in most cases industrial), free-range/grazing, and organic. These farming systems are described in more detail on page 12 and in the "Detailed results by animal product" section from page 18 onwards.

Table 1: Scope of products, locations, and systems

Country	Chicken – *pulled*	Pork – *mince*	Beef – *mince*	Eggs
Europe United States China	• Conventional (industrial) • Free range • Organic • Plant-based alternatives	• Conventional (industrial) • Grazing • Organic • Plant-based alternative	• Conventional (mixed) • Grazing • Organic • Plant-based alternatives	• Conventional (industrial) • Free range • Organic • Plant-based alternative
Brazil	-	-	• Conventional (grass-fed)	-

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

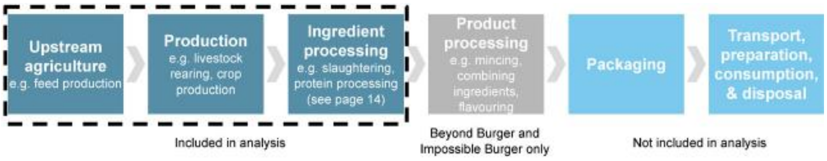
Finally, we considered up to 4 different plant-based alternatives for each product. The recipes for these were provided by Blue Horizon investee companies, and were not independently verified. In the case of two alternatives (Beyond Burger and Impossible Burger), we did not analyse recipe data but took aggregate results directly from independently conducted studies.

The unit of comparison is 1kg of finished product. It is worth noting that the finished products may differ in their nutritional content; this means that the amount of product a person would need to consume to achieve a given protein intake may vary (see details on protein content on page 13).

Scope (2/2)

Value Chain

Table 1: Scope of products, locations, and systems



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

The analysis includes impacts along the value chain, from crop farming (including for animal feed production) to the whole, processed ingredients which are used to make the final product. We do not include impacts from processing the ingredients into the final product (e.g. mincing, combining, forming patties, flavouring), except for two of the plant-based alternatives: the Beyond Burger and Impossible Burger. This is because the impact data for these products was taken directly from studies looking into the whole burger patty and it was not possible to separate out ingredient processing from product processing. See page 68 for further details. For all products, we do not include transport emissions or downstream environmental impacts such as those from the preparation or cooking of the products, as these are assumed to be similar for both animal and plant-based products.

Environmental impacts

The study examines the impacts of animal and plant-based alternatives on three different environmental indicators:

Table 2: Description of environmental impacts

Environmental impact	Description	Units of measurement
Greenhouse gases	Greenhouse gases (GHGs) are atmospheric compounds that absorb and re-emit infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. This property causes the greenhouse effect, where heat is trapped within the Earth's surface-troposphere system. Livestock farming primarily contributes towards the production of three main GHGs: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).	kg CO_2 equivalent ($kgCO_2e$)
Land use	Natural land areas, often rich with biodiversity, provide essential services to society which regulate our environment, provide goods and services that support livelihoods, offer opportunities for recreation, and provide cultural and spiritual enrichment. By converting natural land for agricultural purposes, we lose access to a portion of these ecosystem services, depending on the type of land use. For example, grazing will have a lower impact on the natural land than crop monoculture, which will in turn be less detrimental than intensive barn/feedlot systems.	Hectares (ha)
Water consumption	Water consumption is the volume of water that is evaporated, incorporated into a product or polluted to the point where the it becomes unusable. Consumption of water reduces the amount of water available for other uses, which, depending on the level of competition and the socio-economic context, can have consequences for the environment and people.	Cubic meters (m^3)

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

These impacts were selected as the most material environmental impacts from food production.

Note: health and social impacts are not included in this analysis. Additional areas which could be explored include labour, animal welfare, and the dietary health impacts of plant- and animal- based proteins. See page 15 for further details.

Methodology

Our methodology included the following key steps:

1

Data collection

Table 3: Summary of main data sources

Data collected		Sources
Animal products	The quantities of GHG emissions, water consumption, and land use of each animal protein, location and farming system.	Publicly available, peer-reviewed Life Cycle Assessments (LCAs)
Plant-based alternatives	Recipes for the alternative products.*	Blue Horizon
	The quantities of GHG emissions, water consumption and land use of each ingredient used in the recipes.	Publicly available, peer-reviewed Life Cycle Assessments (LCAs)

*Note: for two of the beef alternatives (Beyond Burger and Impossible Burger), results were taken directly from independent LCA studies for the final burger without separately analysing recipe data. For more details, please see page 68.

2

Data analysis

- Where data was not available for particular location, system, or ingredient, we estimated impacts using conservative assumptions from the closest alternative. This was most relevant for free-range/grazing and organic animal products from China and the United States, as well as mung bean protein isolate and soy textured vegetable protein (TVP).
- Data was converted into a consistent functional unit for comparison: [1 kg of animal product (carcass weight) or plant-based alternative].
- For the alternative products, the recipe and impact data was combined to calculate overall impact for each alternative.
- For animal products, we used an economic allocation to allocate environmental impacts between different cuts of meat proportionally to their economic value. Lower value cuts of meat are assigned a lower proportion of the environmental impact.

3

Valuation

- The final step involved converting the environmental data into monetised values. This allows comparison between the three different types of impact – GHGs, water consumption, and land use.
- To value the impacts, we applied PwC's location-specific valuation coefficients. These coefficients represent the cost to society from environmental emissions and resource use. The methodology underlying these coefficients is publicly available on the PwC website.[11]

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

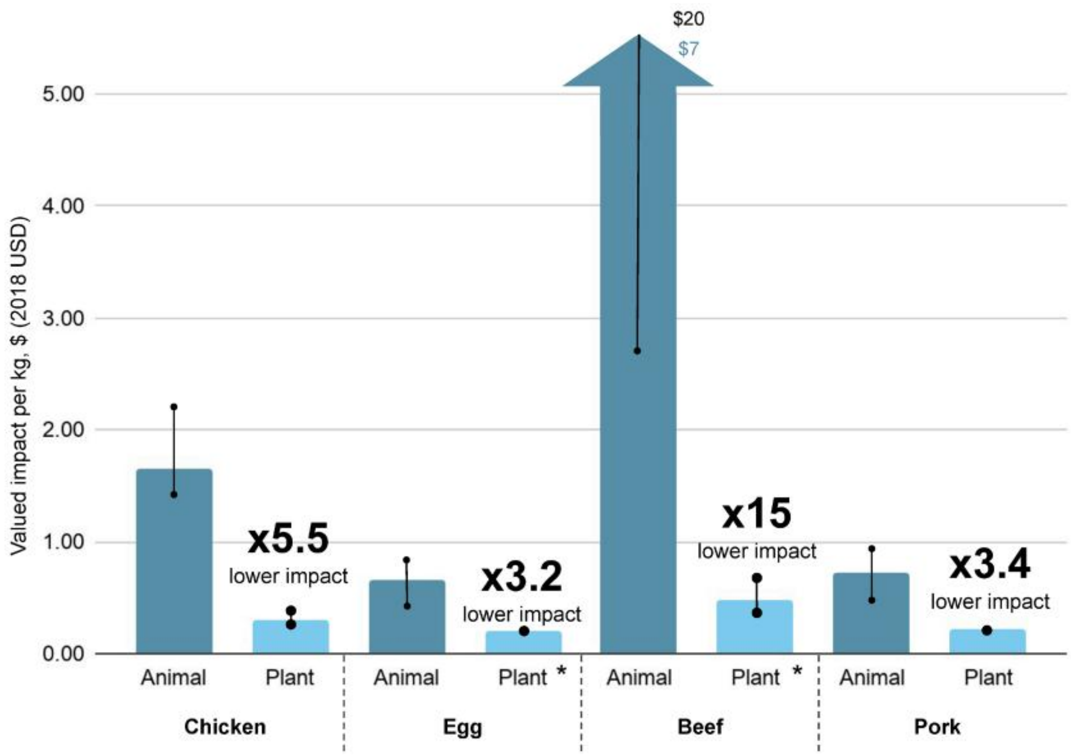
Environmental impacts

Key findings

Our analysis illustrates that plant-based alternative protein sources consistently have a lower overall environmental footprint than their animal counterparts. The difference is starkest for beef mince – where the impact of alternative protein is 15x lower than conventionally farmed beef. However, even for egg (the animal-based product with the lowest environmental footprint) the impact of the alternative was more than 3x lower than conventionally farmed egg.

These results are illustrated in the graph below. Ranges illustrate variation in the impact of animal products based on different locations, systems, and cuts. In every case, the alternative product had a lower environmental impact than the animal-based counterpart, even when the animal was farmed in the most environmentally-friendly way, in the lowest impact location.

Figure 2: Valued environmental impact ($) of animal products and plant-based alternatives
(equivalent cuts; predominant farming system in producing countries; weighted average by annual animal production in 2018; ranges indicate variation between locations of the study)



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

What is driving the impact?

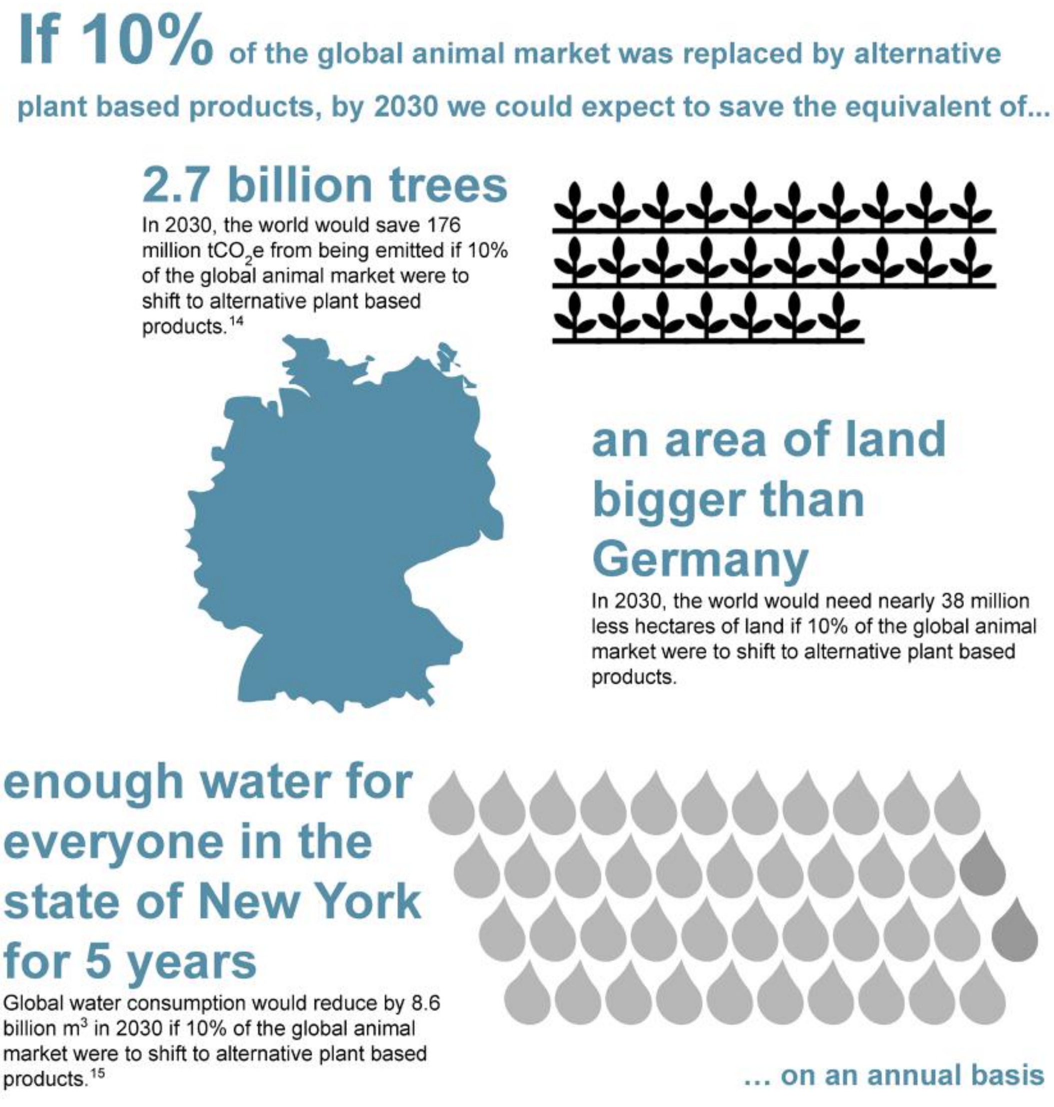
On average across the products, greenhouse gases account for around a third of the impact. These are emitted from from the use of chemical fertilizers, fuel, and electricity as well as methane production from enteric fermentation, and methane and nitrous oxide from manure. Land use accounts for just over half of the environmental footprint, and comes mainly from the clearing of natural land for crops and animals. Water use for crop production, animal consumption, and electricity makes up the smallest proportion of the impact. production in 2018; ranges indicate variation between locations of the study)

*Note: The complete environmental profiles of the plant-based proteins for the two of the four beef products containing soy TVP and egg (containing mung bean protein isolate) were not available. Conservative estimates have been used to model these impacts. The impacts of soy TVP have been modelled based on the impacts of soy flour. The impacts of mung bean protein isolate have been modelled based on the impacts of pea protein isolate. For full details see pages 13 & 14.

Switching at scale

Global production of chicken, eggs, cattle and pigmeat exceeded 291 million tonnes in 2018.[12] According to our analysis, this accounts for at least 1.7 gigatonnes CO_2e emissions, occupies 380 million hectares of land and requires almost 87 billion m^3 of water to produce.[13] As part of this study we analysed several scenarios looking at the potential impact of switching animal products for more sustainable alternatives. These are illustrated in detail on page 54. The results show that, based on FAO predictions for the growth of the global meat and egg market, just over 16% of total production would need to switch to alternatives by 2030 for the world to see a net fall in each environmental impact category against 2018.

Figure 3: Potential environmental gains of switching away from meat products



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Variation in animal products (1/2)

Location

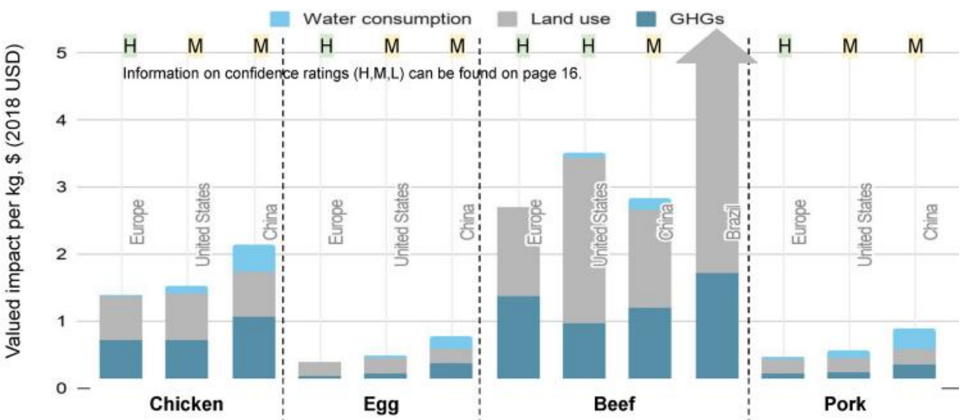
The environmental impact of meat and dairy products varies considerably by location. This is mainly driven by differences in the nature and intensity of farming practices across the world, as well as differences in the environment and social cost of environmental resources (land use and water consumption) in different locations. This is reflected in the valuation coefficients applied – see Table 4 below for further explanation.

Our analysis finds that:

- For all four products, when looking at a conventional system, the impact is lowest in Europe.
- Impact is higher in the US and, in most cases, higher still in China. This reflects differences in the nature of the farming systems in different locations.
- For beef, the highest impact is in Brazil. This is driven by the high land use requirements for feed production and grazing relative to beef farming in other locations, as well as the high social value of the land used for Brazilian beef farms, which is often created by clearing land area from the Amazon.*

Figure 4: Variation in environmental impact of animal by location (predominant system)

Note: in Brazil, the predominant beef farming system is a grazing system. For all other locations and products, the predominant system is conventional. Impact is shown for the cuts specified on page 6.



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

The table below explains why each indicator might vary by location.

Table 4: Variation in the environmental impact of animal products by location

Indicator	Factors affecting indicator
Greenhouse gases	• Differences in the nature and intensity of farming practices. • Types and quantities of fuel used in the crop-farming and production steps. • Use of electricity and grid emission factors. For example, China's electricity grid uses a much higher proportion of coal compared to an average European country. Therefore, the same amount of electricity would produce more emissions if generated in China compared to Europe.
Water consumption	• Differences in the nature and intensity of farming practices. • Local rainfall levels. This will affect the amount of irrigation required. • Local water scarcity. For example, on average, water is more scare in China than Europe, so industrial water use in China represents a larger cost to society than in Europe. This is reflected in the valuation coefficients used.
Land use	• Differences in the nature and intensity of farming practices. • Local ecosystems. For example, beef produced in Brazil involves clearing land in the Amazon; rainforest ecosystems provide a wide range of benefits and services to humanity, and so the loss is valued highly.*

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

*Note: due to the importance of the ecosystems services provided by the Amazon rainforest, our valuation methodology assigns a high social cost to the use of Brazilian land.

Variation in animal products (2/2)

Farming system

The environmental impact of animal products also varies significantly depending on the farming system used. These systems are described below.

Table 5: Description of farming systems included in study

System	Description
Conventional	• For eggs and chicken, a conventional system is a caged system, where the birds are kept indoors. This represents the majority of egg and chicken production in all three locations. • For beef, a conventional system is mixed: cattle are first raised on pasture before being fattened more intensively. • For pork, the conventional systems differs by geography; this is detailed in the "Detailed results by animal product" section.
Free range and grazing	• For eggs and chicken, a free range system implies that the birds can move and feed freely in an area of open ground. • Similarly, with pork production, the pigs have an outdoor run and part of their diet is from forage. • For beef, a grazing system means that the cows are kept outside and are almost entirely pasture fed.
Organic	• For all proteins, an organic farming system promotes soil fertility and biological diversity. Therefore, it prohibits the use of synthetic pesticides, fetilisters, antibiotics, and hormones.

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Our analysis finds that:

- For all four products, when considering an average location, the impact is lowest for a conventional system. It is worth noting that this analysis excludes impacts such as animal welfare, use of hormones and antibiotics and water pollution, which are likely to have a high impact in conventional systems.

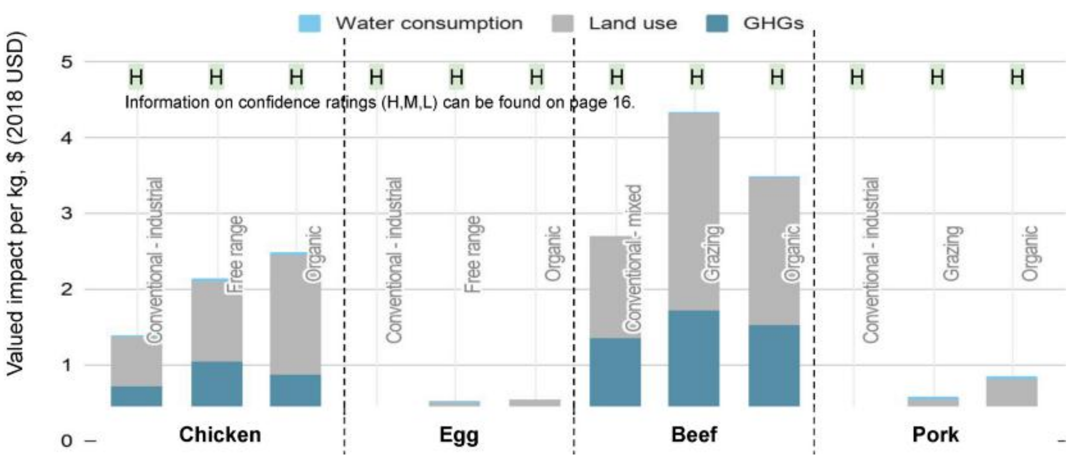
- Free-range and grazing systems have a higher impact, and organic systems have a higher impact still, with the exception of beef farming.

- These differences are driven mainly by the large land use requirements of organic and free range farming due to the lower intensity. This also increases the inputs required and hence GHG emissions.

Note that other impacts, such as animal welfare, use of hormones and antibiotics and water pollution likely to be more significant for conventional / intensive farming.

Figure 5: Variation in environmental impact of animal by farming system (Europe)

Note: impact is shown for the cuts specified on page 6.

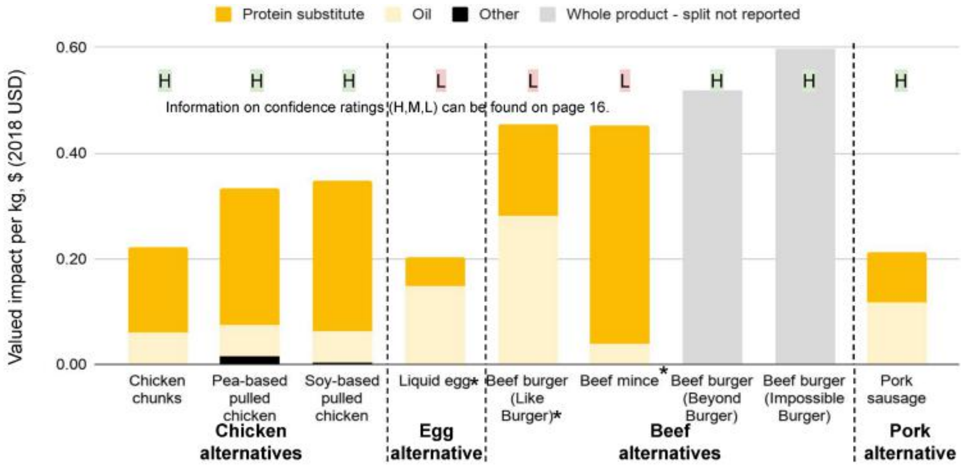


Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Variation in alternative products (1/2)

Although there is much less variation in the impact of plant-based alternatives compared to animal products, there are still some significant differences – ranging from $0.18 to $0.60 of impact per kg. This is illustrated below.

Figure 6: Valued environmental impact ($) of plant-based animal alternatives (average location)



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

The two products with the highest environmental impact are the Beyond Burger and the Impossible Burger. This is likely because these results were calculated using a different methodology from the other products. The results were taken directly from independent LCA studies for the aggregate burger; they will therefore include ingredients which were excluded for other products (such as flavourings and preservatives), as well as impacts from the final processing of separate ingredients into a burger patty.

Variation between the environmental impact of alternatives is primarily caused by the choice of protein substitute ingredient included in the recipe, which can make up by weight anything from 15 to 45% of the product. Protein substitute ingredients can be made from a variety of vegetable crops, and may be in the form of flours, concentrates, textured vegetable proteins (TVP), and protein isolates. These ingredients are described in further detail on the following page. Protein ingredients vary significantly in their environmental impacts. Additionally, where oils make up a large proportion of the recipe (e.g. Like Burger) the environmental footprint can increase significantly. Some key information about each alternative is described in the next table.

Table 6: Overview of protein alternative products considered in this study

Product	Brand name	Form	Protein substitute ingredient	Overall protein content	Protein content of equivalent animal product
Chicken alt. 1	Like Chicken Chunks	Chunks	Soy protein concentrate	19%	31%
Chicken alt. 2	N/A	Pulled	Pea protein isolate	21%	31%
Chicken alt. 3	N/A	Pulled	Soy protein isolate	23%	31%
Egg alt.	Just Egg	Liquid	Mung bean protein isolate*	12%	13%
Beef alt. 1	Like Burger	Burger	Soy textured vegetable protein (TVP)	9%	22-29%
Beef alt. 2	Like Hack	Mince	Soy textured vegetable protein (TVP)	22%	22-29%
Beef alt. 3	Beyond Burger	Burger	Pea protein isolate	17%	22-29%
Beef alt. 4	Impossible Burger	Burger	Soy textured vegetable protein (TVP), potato protein, heme	17%	22-29%
Pork alt.	Like Bratwurst	Sausage	Soy protein concentrate	11%	23-32%

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

*Note: The complete environmental profiles of the plant-based proteins for the two beef products containing soy TVP and egg (containing mung bean protein isolate) were not available. Conservative estimates have been used to model these impacts. The impacts of soy TVP have been modelled based on the impacts of soy flour. The impacts of mung bean protein isolate have been modelled based on the impacts of pea protein isolate.

Variation in alternative products (2/2)

Protein substitute ingredients can be made from a variety of crops, and can come in a range of different forms. The ingredients investigated in this study are described below.

Table 7: Overview of protein substitute ingredients

Protein Ingredient	Form	Production method	Protein content
Soy	Concentrate	Soy protein concentrate is prepared from high quality, dehulled soybean seeds by removing most of the oil and water soluble non-protein constituents.	70%
	Textured vegetable protein (TVP)*	Soy is the most common ingredient in textured TVP. TVP can be made by either thermoplastic extrusion or fibre spinning: • Thermoplastic extrusion: soy flour or soy protein concentrate is mixed with water, sodium chloride, and other ingredients. This is then passed under pressure through a cooker extruder to form the protein into various shapes and sizes. • Fibre spinning: soy protein isolates are used as the starting material. These proteins are then spun into fibres.	51%
	Isolate	Soybeans are dehulled and milled to a powder. The powder is then washed in water or alcohol to remove the non-protein components (fibres and starches). The remaining protein is dried and converted to a powder.	90%
Pea	Isolate	Raw peas are dehulled and milled into a flour before solubilisation of the proteins in water, alkali, or acid. The solubilised proteins are then separated from fibres and starch by wet filtration. The extracted proteins are neutralised and dried.	82%
Mung bean	Isolate*	Raw beans are dehulled and milled to produce a flour, which is then solubilised, filtered, washed, pasteurized and spray-dried (a process which involves chemical processing).	88%

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

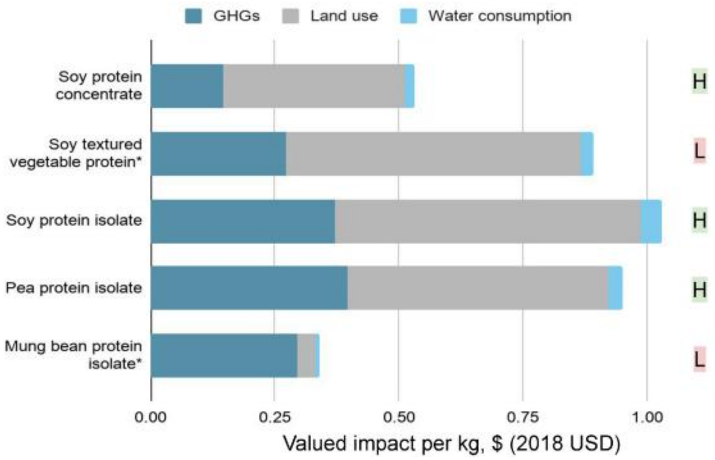
The environmental impact of each protein substitute depends on:

1. **The crop used:** Crops with high yields such as mung bean use less land per kg than soy and pea.
2. **The level of processing:** Protein concentrates are typically the least processed, followed by textured vegetable proteins. Isolates are the most highly processed. See Table 7 above for more detail.

In general, the environmental impacts of plant-based alternatives have been studied in less detail than their animal counterparts. For a detailed review, please see the "Methodology" section, pages 56-69.

The graph below illustrates the environmental impact of each protein substitute ingredient. It is worth bearing in mind that a variety of other factors including texture, flavour, and nutrition (including protein content) will affect the choice of protein substitute ingredient.

Figure 7: Valued environmental impact per kg of protein substitute ingredient (Europe)



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Information on confidence ratings (H,M,L) can be found on page 16.

*Note: The complete environmental profiles of the plant-based proteins for the two of the four beef products containing soy TVP and egg (containing mung bean protein isolate) were not available. Conservative estimates have been used to model these impacts. The impacts of soy TVP have been modelled based on the impacts of soy flour. The impacts of mung bean protein isolate have been modelled based on the impacts of pea protein isolate.

Areas for future study

Plant based-alternatives

We have had to make a number of assumptions on the environmental impacts of animals and plant-based alternatives, where data was not available. In general, there is significantly more data available on the environmental impacts of animal products compared to plant-based alternatives. We would welcome further research in these areas, including formal Lifecycle Assessments, to test and validate our assumptions. In particular, we would welcome further research into:

- The impacts of **protein substitute ingredients** such as mung bean protein isolate and soy textured vegetable protein.
- **Variation in the impacts of protein substitute ingredients** in different locations and using different methods.

Other alternatives

This study focuses on animal and plant-based alternatives. It does not consider a variety of other traditional or newly developing sources of alternative protein, including:

- **Traditional alternatives** such as tofu and tempeh
- **Mycoprotein-**based alternatives
- **Cultured animal protein** (popularly known as "lab grown meat")
- Proteins from **algae**

Other impacts and considerations

This study focuses on three of the most material environmental impacts arising from animal production. However, in order to calculate the full environmental footprint of animals and their alternatives, it would be important to consider the impact on the following:

- **Air pollution**
- **Waste production**
- **Water pollution**

Of course, in addition to the environmental impacts, there are many other factors which will affect the choices we make about what proteins to include in our diets. This report does not consider:

- The **health and dietary impacts** of different animal products and their alternatives. The past decade has seen increased global attention to the potential health implications of animal consumption, most notably the association of red meat and processed meat with increased risk of of cardiovascular disease, diabetes, and cancer.[16]
- Differences in **animal welfare** of different products and farming systems.
- The spread of **disease** amongst farmed animals.
- The **cost effectiveness and commercial viability** of animal-based meats and their alternatives.
- The **scalability** of plant-based protein production.
- The **economic and social consequences** of switching from animal-based products to alternatives, including the impact on jobs and communities.
- Differences in **tastes and textures** of products.
- The **cultural value** of certain ingredients and recipes.

Note on results

Confidence

We have provided confidence ratings throughout this report, in order to be clear about where we have had to make additional assumptions about a particular product, location or system due to limitations in data availability. The key for these confidence ratings is:

H	*Results calculated based on data for the stated product, system and location, taken from peer-reviewed Life Cycle Assessments or other reliable sources with limited adjustments.*
M	*Results calculated based on data for the stated product from peer-reviewed Life Cycle Assessments. Data may be for a different system or location; in some cases reasonable adjustments have been made based on conservative assumptions to adjust impact to required system/location.*
L	*Results calculated based on data from peer-reviewed Life Cycle Assessments. Significant adjustments have been made to adjust impact to required product, based on conservative assumptions.*

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Our overall confidence level for each product, system and location is provided in the table below.

Animal products: We were generally able to source good data for European systems, and for US and Brazilian beef. In other locations, we were usually able to find GHG data for conventional systems, but free range, grazing and organic systems and land use impacts were less well documented.

Plant-based alternatives: Alternatives which contain soy textured vegetable protein or mung bean protein isolate are rated as low confidence, as our analysis is based on other ingredients (soy flour and pea protein isolate), with various adjustments to estimate the impact of soy TVP and mung bean. Other plant-based products are rated as high confidence in the country where the data was taken from (Europe for chicken and pork alternatives and the United States for the Beyond Burger and Impossible Burger), and medium confidence elsewhere.

For more details on the assumptions used to make these adjustments, please see pages 58-70.

Table 8: Overall confidence rating for each product, system and location

Product	System / alternative	Confidence rating			
		Europe	United States	China	Brazil
Chicken	Conventional	H	M	M	N/A
	Free range	H	M	M	N/A
	Organic	H	M	M	N/A
Egg	Conventional	H	M	M	N/A
	Free range	H	M	M	N/A
	Organic	H	M	M	N/A
Pork	Conventional	H	M	M	N/A
	Grazing	H	M	M	N/A
	Organic	H	M	M	N/A
Beef	Conventional	H	H	M	H
	Grazing	H	H	M	N/A
	Organic	H	H	M	N/A
Alternatives	Chicken alt. 1	H	M	M	N/A
	Chicken alt. 2	H	M	M	N/A
	Chicken alt. 3	H	M	M	N/A
	Egg alt.	L	L	L	N/A
	Beef alt. 1	L	L	L	N/A
	Beef alt. 2	L	L	L	N/A
	Beef alt. 3	N/A	H	N/A	N/A
	Beef alt. 4	N/A	H	N/A	N/A
	Pork alt.	H	M	M	N/A

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Detailed results by animal product

Chicken

Chicken: locations and systems

Poultry is the most commonly farmed meat globally, with 123.9 million tonnes produced in 2018,[17] and output expected to increase by a further 20 million tonnes over the next ten years.[18] An estimated 70% of all birds on the planet are farmed poultry, with chicken being by far the most common bird.[19] The United States is the world's largest poultry producer, with 18% of global output, followed by China, Brazil, and Russia.[20]

Locations[21]

The following locations were considered in our analysis:

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Systems

The following farming systems were included in our analysis:

Table 9: Chicken farming systems

System	Description	% Total production		
		Europe[22]	United States[23]	China[24]
Conventional	A conventional system is a caged system, where the birds are kept indoors. This represents the majority of chicken production in all three locations.	~90%	Unknown but the vast majority.	~90%
Free range	A free range system implies that the birds can move and feed freely in an area of open ground for at least part of the day.	~5%	Unknown but small.	~10%
Organic	An organic farming system promotes soil fertility and biological diversity. It therefore prohibits the use of synthetic pesticides, fetilisters, antibiotics, and hormones.	~1%	Unknown but small.	Unknown but small.

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Chicken: products

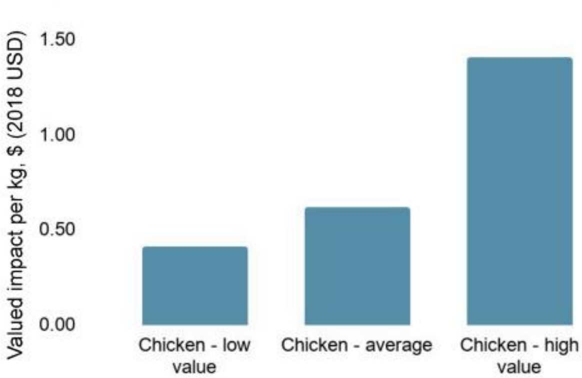
Cuts of meat

Our analysis focused on pulled chicken, which is most commonly made from chicken breast – a high value (expensive) cut of meat. This is important as the methodology used in this study assigns a lower environmental impact to lower value cuts of meat, in the same way that carbon accounting assigns fewer emissions to economy airplane seats compared to first class seats. This is known as an economic allocation.

The economic allocation has a highly significant impact on the overall results. This is illustrated in the example on the right, which shows the difference between the valued impact of low value, high value and average chicken, for a conventional system in Europe.

For more details, please see page 64.

Figure 8: Valued impact of different cuts of chicken (Europe)



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Alternatives

Our analysis considers three different plant-based chicken alternatives: a soy protein concentrate called Like Chicken Chunks, and two generic recipes which contain soy protein isolate and pea protein isolate, respectively. These are described in the table below, with their recipes.

Table 10: Plant-based chicken alternatives

Product	Brand name	Form	Overall protein content	Protein content of equivalent animal product	Ingredients	%
Chicken alternative 1	Like Chicken Chunks	Chunks	19%	31%	Soy protein concentrate	27%
					Sunflower oil	3%
					Water	66%
					Other	4%
Chicken alternative 2	N/A	Pulled	21%	31%	Pea protein isolate	25%
					Sunflower oil	3%
					Pea fiber	17%
					Water	55%
Chicken alternative 3	N/A	Pulled	23%	31%	Soy protein isolate	25%
					Sunflower oil	3%
					Soy fiber	17%
					Water	55%

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Chicken: results, valued impacts

$1.66 average environmental impact per kg conventionally farmed pulled chicken,

compared to **$0.30** per kg of plant based alternative

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

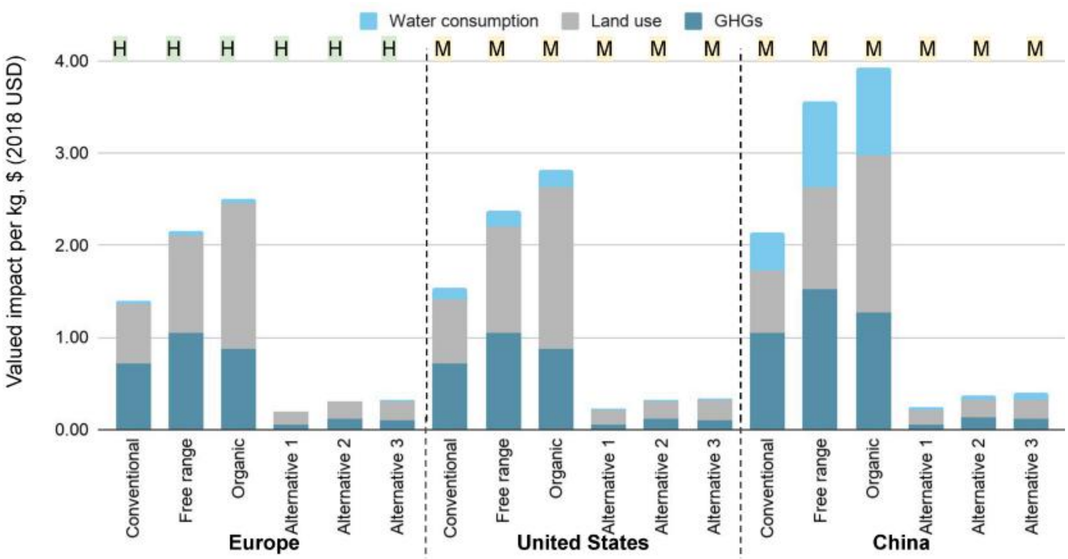
• On average, conventionally farmed chicken breast has 5.5x higher environmental impact than the plant-based alternatives.

• Organic farming systems have nearly twice the environmental impact of conventional ones, driven mainly by the need for increased land to produce the same number of birds.

• However, location has a more significant impact on the results: a conventional farming system in China has a similar overall environmental footprint to a free range system in Europe.

• If an average cut of meat was used instead of high-value cut, impact would be 2.3x smaller.

Figure 9: Valued impacts of pulled chicken and plant-based alternatives, $ (2018 USD)



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Table 11: Valued impacts of pulled chicken and plant-based alternatives, $ (2018 USD)

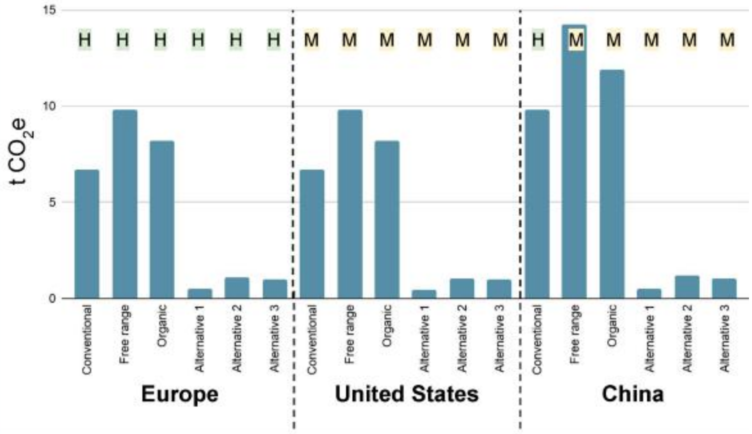
Country	Conventional	Free range	Organic	Alternative 1	Alternative 2	Alternative 3
Europe	1.40	2.16	2.50	0.20	0.31	0.32
United States	1.54	2.39	2.82	0.22	0.33	0.34
China	2.15	3.57	3.92	0.25	0.37	0.40

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Chicken: results, environmental quantities

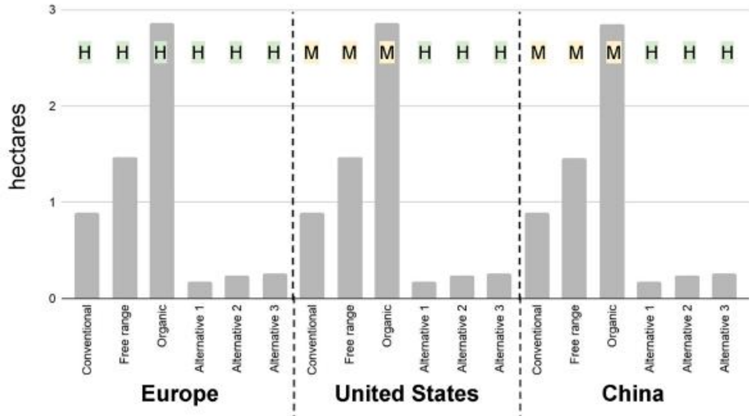
7.6 tCO_2e per tonne average conventionally farmed pulled chicken, compared to **0.9** tCO_2e per tonne of alternative

Figure 10: GHG emissions per tonne of pulled chicken and plant-based alternatives



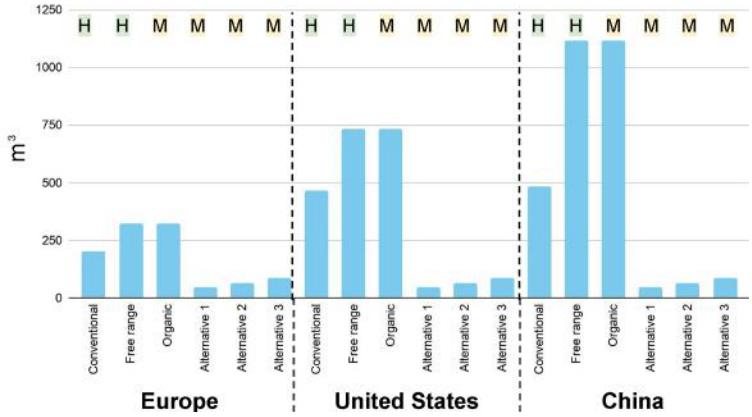
0.89 hectares land use per tonne average conventionally farmed pulled chicken, compared to **0.23** ha per tonne of alternative

Figure 11: Land use per tonne of pulled chicken and plant-based alternatives



378m^3 water consumption per tonne average conventionally farmed pulled chicken, compared to **67**m^3 per tonne of alternative

Figure 12: Water consumption per tonne of pulled chicken and plant-based alternatives



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Egg

Egg: locations and systems

Over 82 million tonnes of eggs are produced globally every year.[25] China is the world's largest egg producer by far, with 42% of the market; the next biggest producer is the United States with just 7%.[26]

Locations[27]

The following locations were considered in our analysis:

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Systems

The following farming systems were included in our analysis:

Table 12: Egg farming systems

System	Description	% Total production		
		Europe	United States[31]	China[32]
Conventional	A conventional system is a caged system, where the birds are kept indoors. This represents the majority of egg production in all three locations.	Varies significantly by country, from ~50% in the UK to 99% in Spain.[28]	>95% total production	>85% total production
Free range	A free range system implies that the birds can move and feed freely in an area of open ground for at least part of the day.	Varies significantly by country, up to ~50% in the UK.[29]	<5% total production	~10%
Organic	An organic farming system promotes soil fertility and biological diversity. It therefore prohibits the use of synthetic pesticides, fetilisters, antibiotics, and hormones.	Varies significantly by country, up to ~13% in France.[30]	<5% total production	<5% total production

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Egg: products

Animal product

Our analysis is for whole eggs. No economic allocation is applied.

Alternatives

Our analysis considers one plant-based alternative egg recipe, Just Egg, which contains mung bean protein isolate. This is described in the table below, with its recipe.

Table 13: Plant-based egg alternative

Product	Brand name	Form	Overall protein content	Protein content of equivalent animal product	Ingredients	%
Egg alternative	Just Egg	Liquid	12%	13%	Mung bean protein isolate	14%
					Canola oil	11%
					Water	73%
					Other	1%

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Egg: results, valued impacts

$0.65 average environmental impact per kg conventionally farmed egg, compared to **$0.20** per kg of plant based alternative

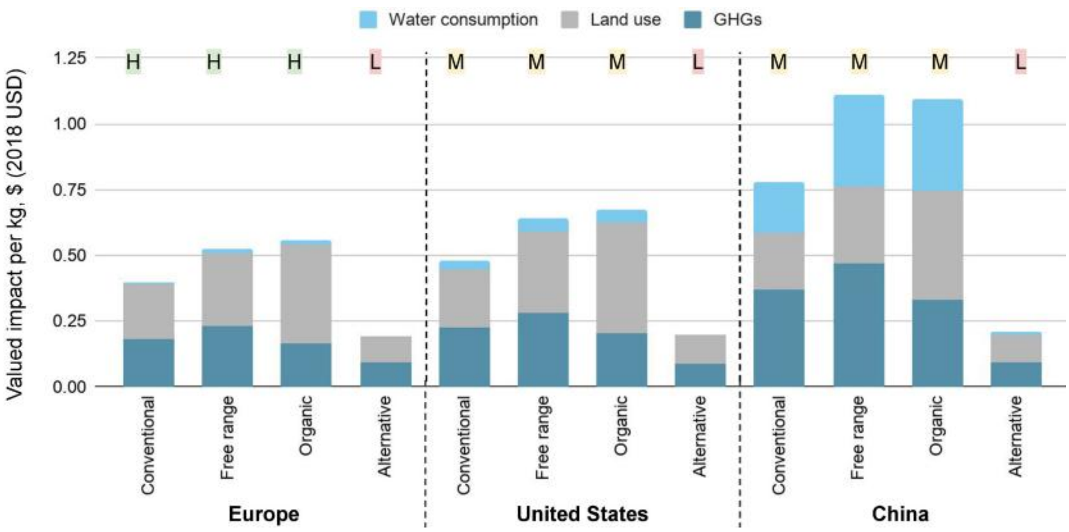
Source: PwC analysis prepared in connection with “Environmental impacts of animal and plant-based food” prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

- On average, conventionally farmed egg has 3.2x higher environmental impact than the plant-based alternative.

- A conventional egg farming system in China has 2.5x the impact of its equivalent in Europe. The difference is even greater for free range and organic systems. Chinese farming systems produce more GHGs and use more water per kg of egg. This is particularly relevant with China dominating the global egg market.

- Of all the animal products studied, egg had the lowest environmental impact per kg.

Figure 13: Valued impacts of egg and plant-based alternatives, $ (2018 USD)



Source: PwC analysis prepared in connection with “Environmental impacts of animal and plant-based food” prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Table 14: Valued impacts of egg and plant-based alternative, $ (2018 USD)

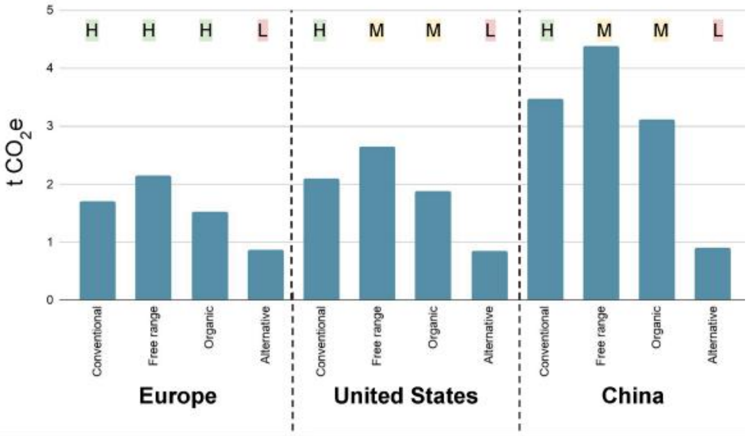
Country	Conventional	Free range	Organic	Alternative
Europe	0.40	0.53	0.56	0.19
United States	0.48	0.64	0.67	0.20
China	0.78	1.11	1.10	0.21

Source: PwC analysis prepared in connection with “Environmental impacts of animal and plant-based food” prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Egg: results, environmental quantities

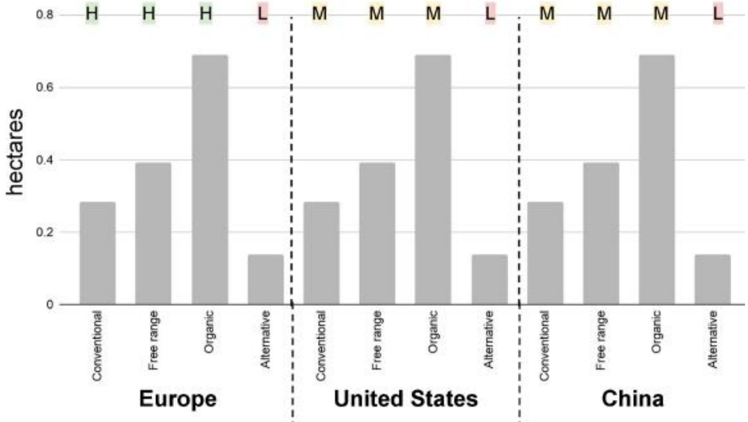
2.9 tCO_2e per tonne average conventionally farmed egg, compared to **0.9** tCO_2e per tonne of alternative

Figure 14: GHG emissions per tonne of egg and plant-based alternative



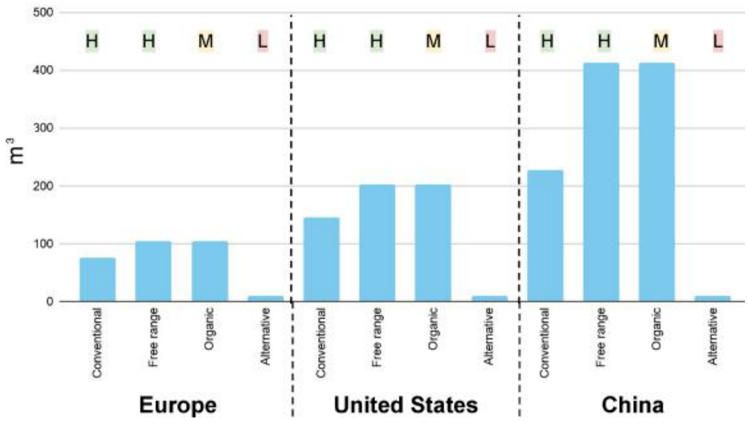
0.28 hectares land use per tonne average conventionally farmed egg, compared to **0.14** ha per tonne of alternative

Figure 15: Land use per tonne of egg and plant-based alternative



182m^3 water consumption per tonne average conventionally farmed egg, compared to **10**m^3 per tonne of alternative

Figure 16: Water consumption per tonne of egg and plant-based alternative



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Beef

Beef: locations and systems

Global production of beef rose to 71.1 million tonnes in 2018,[33] and is expected to exceed 80 million tonnes in the next decade.[34] The United States produces nearly a fifth of the world's beef, followed by Brazil, the European Union, and China.[35] The environmental impacts of beef production have come under particular scrutiny in recent decades, due to the high methane footprint from enteric fermentation, and the fact that cattle ranching is one of the key drivers of deforestation globally. A single cow can produce up to 120kg of methane per year – and there are around 1.5 billion cattle kept worldwide, for meat and dairy purposes.[36]

Locations[37]

The following locations were considered in our analysis:

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Systems

The following farming systems were included in our analysis:

Table 15: Beef farming systems

System	Description	% Total production			
		Europe[33]	United States[39]	China[40]	Brazil[41]
Conventional	In Europe, the United States and China the conventional system is mixed: cattle are first raised on pasture before being fattened more intensively.	Unknown but the majority.	>95%	~85%	<20%
Grazing	A grazing system means that the cows are kept outside and are almost entirely pasture fed. Grazing systems are assumed to be extensive with no/limited rotational grazing or other land management practices.	Unknown but <50%.	<5%	<15%	~80%
Organic	An organic farming system promotes soil fertility and biological diversity. It therefore prohibits the use of synthetic pesticides, fetilisters, antibiotics and hormones. This study does not consider organic beef farming systems in Brazil, as they are relatively uncommon.	<5%	Unknown but small.	Unknown but small.	Unknown but small.

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Beef: products

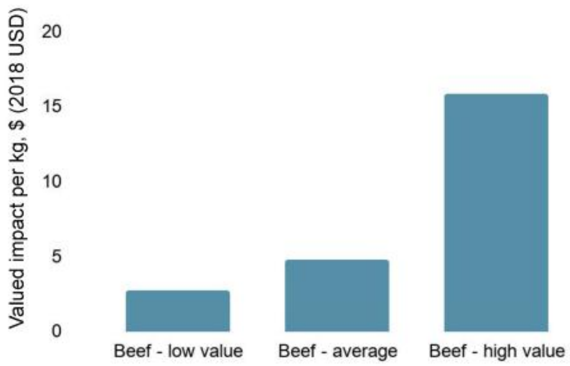
Cuts of meat

Our analysis focused on beef mince, which is usually made from low value (cheap) cuts of meat. This is important as the methodology used in this study assigns a lower environmental impact to lower value cuts of meat, in the same way that carbon accounting assigns fewer emissions to economy airplane seats compared to first class seats.

The economic allocation has a highly significant impact on the overall results. This is illustrated in the example on the right, which shows the difference between the valued impact of low value, high value and average beef, for a conventional system in Europe.

For more details, please see page 64.

Figure 17: Valued impact of different cuts of beef (Europe)



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Alternatives

Our analysis considers four different plant-based beef alternatives: a mince alternative called Like Hack and three different burger alternative (Like Burger, Beyond Burger and Impossible Burger). These are described in the table below. We did not analyse the individual ingredients used in the Beyond Burger or Impossible Burger as the results were taken from independent LCA studies for the burger patties as a whole.

Table 16: Plant-based beef alternatives

Product	Brand name	Form	Overall protein content	Protein content of equivalent animal product	Ingredients	%
Beef alternative 1	Like Burger	Burger	9%	22-29%	Soy textured vegetable protein	18%
					Sunflower oil	10%
					Coconut oil	6%
					Water	56%
					Other	10%
Beef alternative 2	Like Hack	Mince	22%	22-29%	Soy textured vegetable protein	43%
					Sunflower oil	2%
					Water	50%
					Other	5%
Beef alternative 3	Beyond Burger*	Burger	17%	22-29%	Individual ingredients not analysed	
Beef alternative 4	Impossible Burger*	Burger	17%	22-29%	Individual ingredients not analysed	

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

*Note that impacts from the Beyond Burger and Impossible Burger are higher than the other alternatives. This is because Beyond Burger and Impossible Burger impacts are taken from LCA studies which include impacts from flavourings and preservatives, as well as from processing the ingredients into a burger patty. These impacts are excluded for other products.

Beef: results, valued impacts

$7.26 average environmental impact per kg predominant farming system for beef mince, compared to **$0.48** per kg of plant based alternative

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

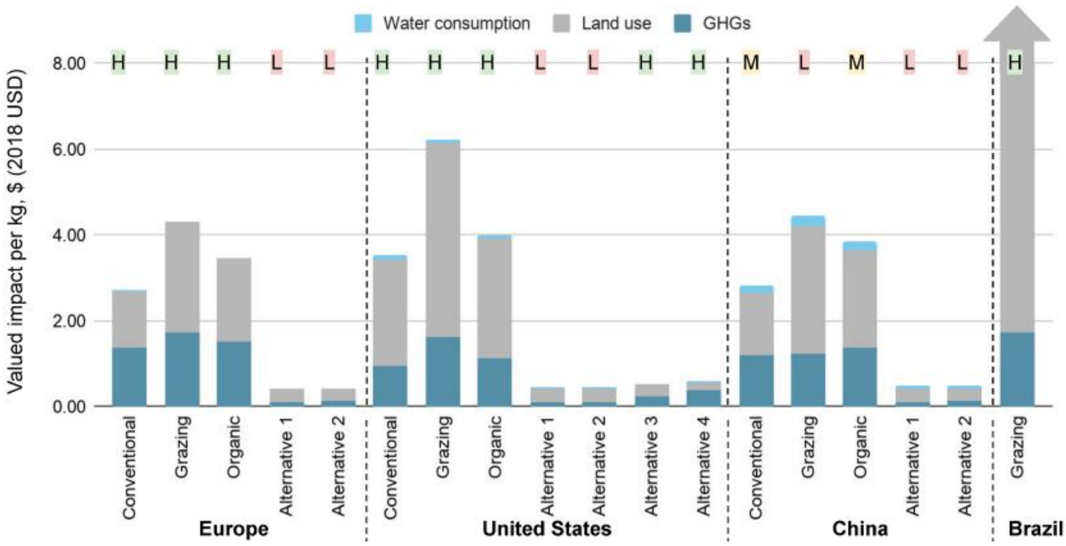
- On average, beef mince farmed by the predominant system in each location in this study has 15x higher environmental impact than the plant-based alternatives.

- Brazilian beef farming has by far the largest footprint, at nearly $20 per kg. This is due to the large areas of land deforested from the Amazon for cattle farms.*

- Grazed beef has the highest impact followed by organic and then conventionally farmed beef. This is because of the large areas of land used for pasture. Although pastureland is used less intensively than land used for intensive agriculture, there is still some loss of ecosystem services. For more details, see page 71.

- If an average cut of meat was used instead of low-value cut, impact would be 1.8x bigger.

Figure 18: Valued impacts of beef mince and plant-based alternatives, $ (2018 USD)



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Table 17: Valued impacts of beef mince and plant-based alternatives, $ (2018 USD)

Country	Conventional	Grazing	Organic	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Europe	2.71	4.34	3.49	0.42	0.42	-	-
United States	3.51	6.24	4.00	0.46	0.46	0.52	0.60
China	2.85	4.46	3.87	0.51	0.50	-	-
Brazil	-	19.34	-	-	-	-	-

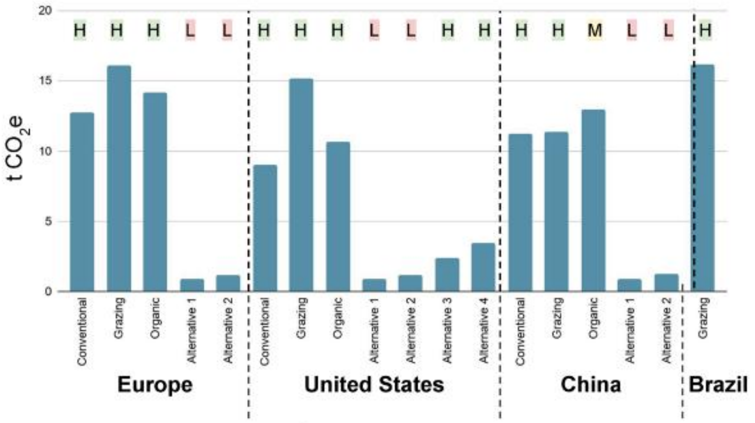
Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

*Note: due to the importance of the ecosystems services provided by the Amazon rainforest, our valuation methodology assigns a very high social cost to the use of Brazilian land.

Beef: results, environmental quantities

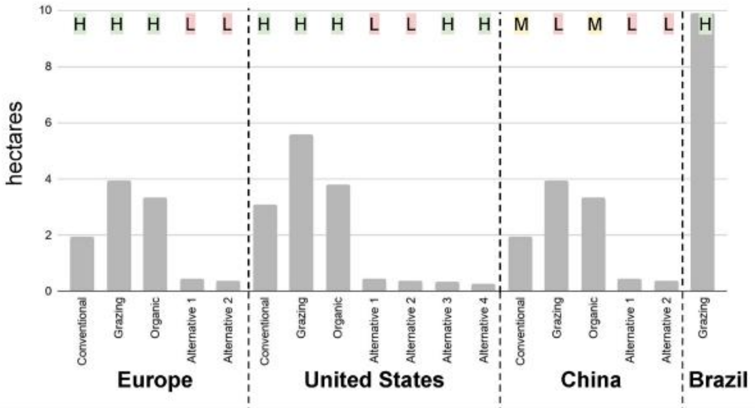
12.2 tCO_2e per tonne average predominant farming system for beef mince, compared to **1** tCO_2e per tonne of alternative

Figure 19: GHG emissions per tonne of beef mince and plant-based alternatives



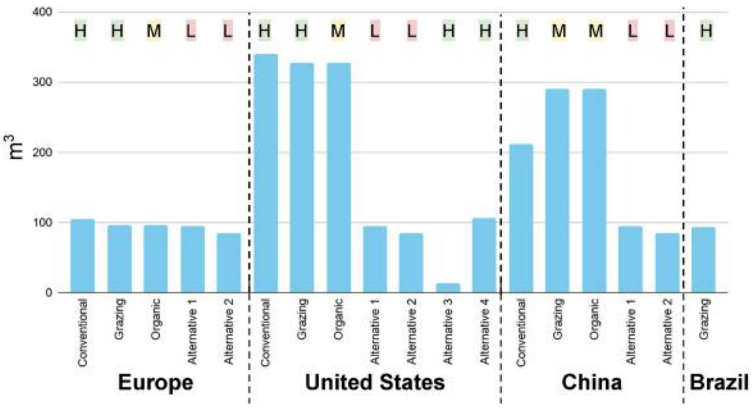
4.3 hectares land use per tonne average predominant farming system for beef mince, compared to **0.40** ha per tonne of alternative

Figure 20: Land use per tonne of beef mince and plant-based alternatives



193m^3 water consumption per tonne average predominant farming system for beef mince, compared to **90**m^3 per tonne of alternative

Figure 21: Water consumption per tonne of beef mince and plant-based alternatives



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Pork

Pork: locations and systems

Until very recently, pork was the most commonly eaten meat in the world.[42] Global production in 2018 was 120.5 million tonnes[43] – an overall increase from 2018, despite major pork-producing regions including China being affected by a major outbreak of African swine fever virus, and is projected to reach 133 million tonnes by 2028.[44] China produces a staggering 46% of global pigmeat production, followed by the European Union and United States.[45]

Locations[46]

The following locations were considered in our analysis:

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Systems

The following farming systems were included in our analysis:

Table 18: Pork farming systems

System	Description	% Total production		
		Europe[47]	United States[49]	China[50]
Conventional	In the case of pork, the conventional farming system differs by geography: • In Europe and the United States, the conventional system is industrial: the pigs are raised indoors and intensively, on a crop-based diet. • In China, the conventional system is mixed: the pigs are first raised on pasture before being fattened more intensively.	Varies by country; ~60% in UK	~90%	~90%
Grazing	A grazing system means the pigs have an outdoor run and part of their diet is from forage. Grazing systems are assumed to be extensive with no/limited rotational grazing or other land management practices.	Varies by country; ~40% in UK	~3%	<10%
Organic	An organic farming system promotes soil fertility and biological diversity. It therefore prohibits the use of synthetic pesticides, fetilisters, antibiotics, and hormones.	Unknown but small.[48]	Unknown but small.	Unknown but small.

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Pork: products

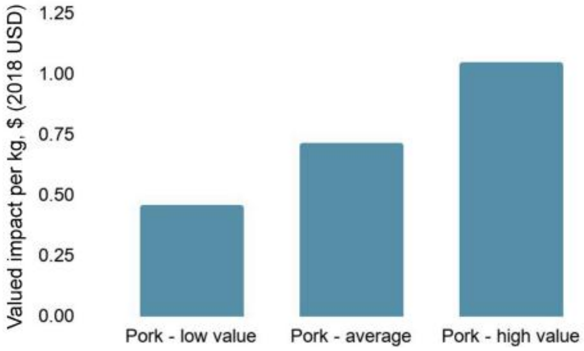
Cuts of meat

Our analysis focused on pork mince, which is usually made from low value (cheap) cuts of meat. This is important as the methodology used in this study assigns a lower environmental impact to lower value cuts of meat, in the same way that carbon accounting assigns fewer emissions to economy airplane seats compared to first class seats.

The economic allocation has a highly significant impact on the overall results. This is illustrated in the example on the right, which shows the difference between the valued impact of low value, high value and average pork, for a conventional system in Europe.

For more details, please see page 64.

Figure 17: Valued impact of different cuts of pork (Europe)



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Alternatives

Our analysis considers one plant-based pork alternative: a sausage recipe containing soy protein concentrate called Like Bratwurst. This is described in the table below, with the recipe.

Table 19: Plant-based pork alternatives

Product	Brand name	Form	Overall protein content	Protein content of equivalent animal product	Ingredients	%
Pork alternative	Like Bratwurst	Sausage	11%	23-32%	Soy protein concentrate	15%
					Sunflower oil	2%
					Coconut oil	5%
					Fiber	3%
					Water	69%
					Other	6%

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Pork: results, valued impacts

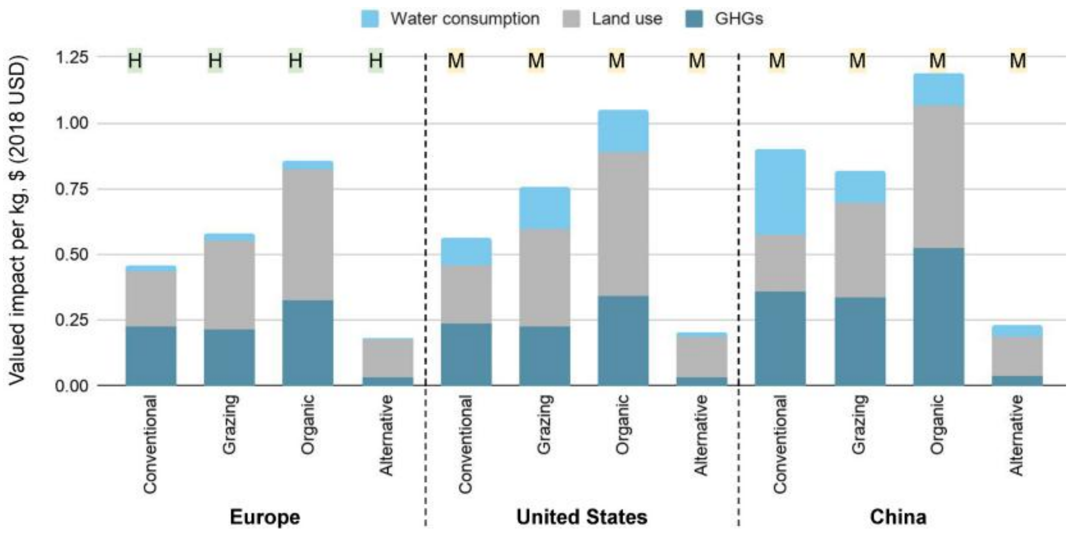
$0.72 average environmental impact per kg conventionally farmed pork mince,

compared to **$0.21** per kg of plant based alternative

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

- On average, conventionally farmed pork mince has 3.4x higher environmental impact than the plant-based alternatives.
- Organic farming systems have nearly two thirds higher environmental impact of conventional ones, driven mainly by the increased greenhouse gas emissions and land use requirements.
- However, location has a more significant impact on the results: a conventional farming system in China has a 20% higher overall environmental footprint than an organic system in Europe.
- If an average cut of meat was used instead of a low-value cut, impact would be 1.6x bigger.

Figure 23: Valued impacts of pork mince and plant-based alternative, $ (2018 USD)



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Table 20: Valued impacts of pork mince and plant-based alternative, $ (2018 USD)

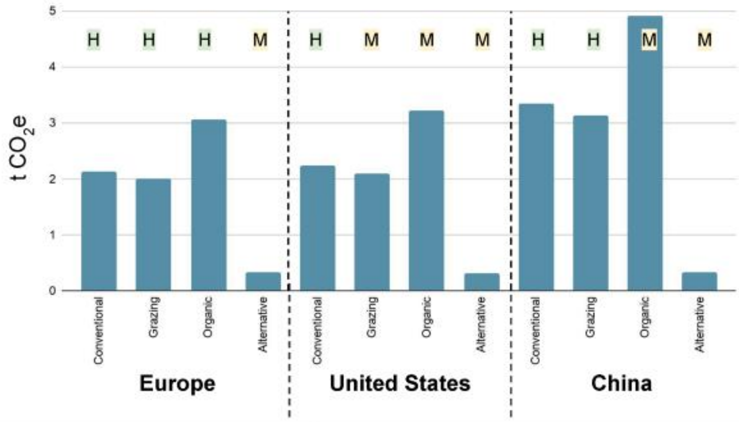
Country	Conventional	Grazing	Organic	Alternative
Europe	0.46	0.58	0.86	0.18
United States	0.56	0.76	1.05	0.20
China	0.90	0.82	1.19	0.23

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Pork: results, environmental quantities

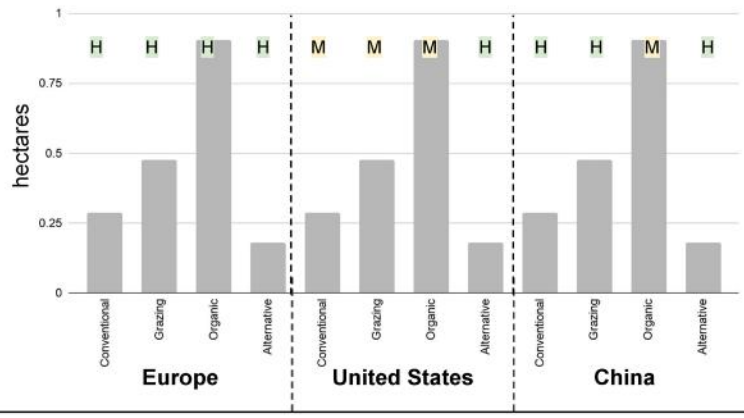
2.8 tCO_2e per tonne average conventionally farmed pork mince, compared to **0.3** tCO_2e per tonne of alternative

Figure 24: GHG emissions per tonne of pork mince and plant-based alternatives



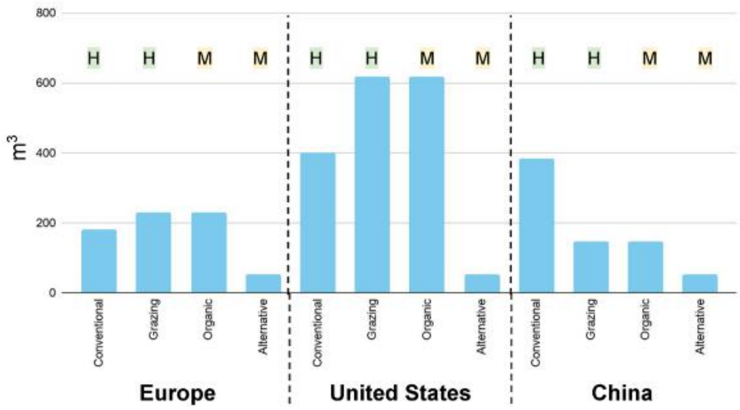
0.29 hectares land use per tonne average conventionally farmed pork mince, compared to **0.18** ha per tonne of alternative

Figure 25: Land use per tonne of pork mince and plant-based alternatives



323 m^3 water consumption per tonne average conventionally farmed pork mince, compared to **52** m^3 per tonne of alternative

Figure 26: Water consumption per tonne of pork mince and plant-based alternatives



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Plant-based alternatives

Plant-based alternatives: recipes

The plant-based alternative meat market is valued at over $10billion USD, and is projected to more than triple in the next decade.[51] Currently, soy-based products make up approximately two thirds of the market, although alternatives are also made from mycoprotein, wheat, pea and other ingredients.[52]

This study considers seven different recipes for plant-based alternative meat products. In the case of two alternatives (Beyond Burger and Impossible Burger), we did not analyse recipe data but took aggregate results directly from independently conducted LCA studies. Further details and recipes for each product are provided in the table below.

In general, most products studied contain some combination of plant-based protein substitute (in the form of a concentrate, textured vegetable protein or isolate); oil (sunflower, coconut and/or canola); fibre (usually from soy or pea); and water.

Salt, flavourings, preservatives and other ingredients which make up <=2% of the overall product were excluded from the analysis. As they are also likely to be added to animal products, they have been excluded here to maintain comparability between products. Note: they are likely to be immaterial to the overall footprint.

Key
Plant-based protein substitute
Oil
Fiber
Water
Other (salt, flavourings, preservatives, other <=2% of recipe)

Table 21: Recipes for plant-based proteins

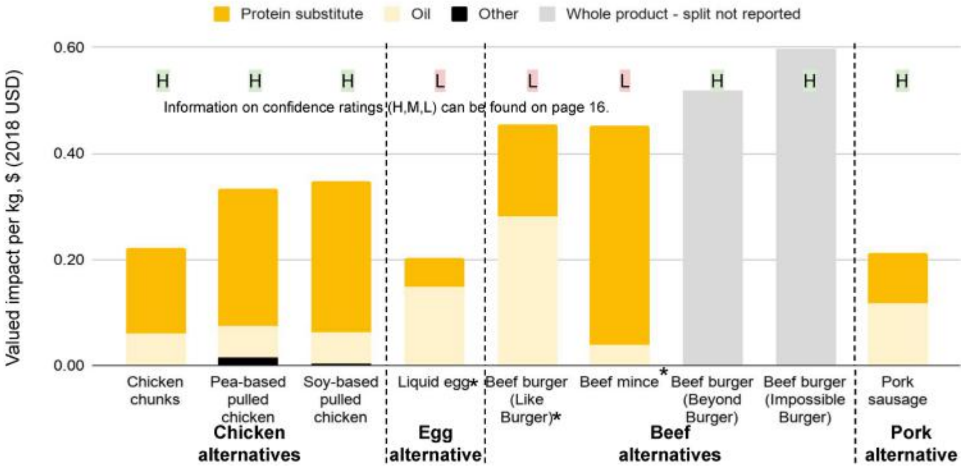
Product	Brand name	Form	Overall protein content	Protein content of equivalent animal product	Ingredients	%
Chicken alt. 1	Like Chicken Chunks	Chunks	19%	31%	Soy protein concentrate	27%
					Sunflower oil	3%
					Water	66%
					Other	4%
Chicken alt. 2	N/A	Pulled	21%	31%	Pea protein isolate	25%
					Sunflower oil	3%
					Pea fiber	17%
					Water	55%
Chicken alt. 3	N/A	Pulled	23%	31%	Soy protein isolate	25%
					Sunflower oil	3%
					Soy fiber	17%
					Water	55%
Egg alt.	Just Egg	Liquid	12%	13%	Mung bean protein isolate	14%
					Canola oil	11%
					Water	73%
					Other	1%
Beef alt. 1	Like Burger	Burger	9%	22-29%	Soy textured vegetable protein	18%
					Sunflower oil	10%
					Coconut oil	6%
					Water	56%
					Other	10%
Beef alt. 2	Like Hack	Mince	22%	22-29%	Soy textured vegetable protein	43%
					Sunflower oil	2%
					Water	50%
					Other	5%
Beef alt. 3	Beyond Burger	Burger	17%	22-29%	Individual ingredients not analysed	
Beef alt. 4	Impossible Burger	Burger	17%	22-29%	Individual ingredients not analysed	
Pork alt.	Like Bratwurst	Sausage	11%	23-32%	Soy protein concentrate	15%
					Sunflower oil	2%
					Coconut oil	5%
					Fiber	3%
					Water	69%
					Other	6%

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Plant-based alternatives: results, valued impacts

Although there is much less variation in the impact of plant-based alternatives compared to animal products, there are still some significant differences – ranging from $0.18 to $0.60 of impact per kg. This is illustrated in the graph below.

Figure 27: Valued environmental impact ($) of plant-based animal alternatives (average location)



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

The two products with the highest environmental impact are the Beyond Burger and the Impossible Burger. This is likely because these results were calculated using a different methodology from the other products. The results were taken directly from independent LCA studies for the aggregate burger; they will therefore include ingredients which were excluded for other products (such as flavourings and preservatives), as well as impacts from the final processing of separate ingredients into a burger patty.

Variation in environmental impact is primarily caused by the protein substitute and quantity included in the recipe for the alternative, which can make up anything between 15 and 45% of the product based on product specifications. These ingredients are described in further detail on the following page.

Note on regional data: Data for protein substitutes was limited to European studies, with adjustments made based on the relative emissions intensities of the electricity grid in each location, for GHG impacts only. Since only a small proportion of the GHG emissions for each ingredient was associated with electricity use, the overall difference between locations is small. Impacts from oil were also based on global studies so do not vary between locations.

Table 22: Valued impacts of plant-based alternatives, $ (2018 USD)

Country	Chicken alt. 1	Chicken alt. 2	Chicken alt. 3	Egg alt.	Beef alt. 1	Beef alt. 2	Beef alt. 3	Beef alt. 4	Pork alt.
Europe	0.20	0.31	0.32	0.19	0.42	0.42	-	-	0.18
United States	0.22	0.33	0.34	0.20	0.46	0.46	0.52	0.60	0.20
China	0.25	0.37	0.40	0.21	0.51	0.50	-	-	0.23

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

*Note: The complete environmental profile of the plant based proteins for beef (soy TVP) and egg (mung bean protein isolate) were not available. Conservative estimates have been used to model these impacts. The environmental impacts of soy TVP have been modelled based on the impacts of soy flour. The environmental impacts of mung bean protein isolate have been modelled based on the impacts of pea protein isolate.

Protein substitute ingredients: overview

For plant-based alternatives, the majority of the environmental impact came from the protein substitute ingredient, which can make up anything between 15 and 45% of the product. Protein substitute ingredients can be made from a variety of vegetable crops, and may be in the form of flours, concentrates, textured vegetable proteins, and. Different protein ingredients have very different environmental impacts.

Table 23: Protein substitute ingredients

Protein Ingredient	Form	Production method	Protein content
Soy	Concentrate	Soy protein concentrate is prepared from high quality, dehulled soybean seeds by removing most of the oil and water soluble non-protein constituents.	70%
	Textured vegetable protein (TVP)*	Soy is the most common ingredient in textured TVP. TVP can be made by either thermoplastic extrusion or fibre spinning: • Thermoplastic extrusion: soy flour or soy protein concentrate is mixed with water, sodium chloride, and other ingredients. This is then passed under pressure through a cooker extruder to form the protein into various shapes and sizes. • Fibre spinning: soy protein isolates are used as the starting material. These proteins are then spun into fibres.	51%
	Isolate	Soybeans are dehulled and milled to a powder. The powder is then washed in water or alcohol to remove the non-protein components (fibres and starches). The remaining protein is dried and converted to a powder.	90%
Pea	Isolate	Raw peas are dehulled and milled into a flour before solubilisation of the proteins in water, alkali, or acid. The solubilised proteins are then separated from fibres and starch by wet filtration. The extracted proteins are neutralised and dried.	82%
Mung bean	Isolate*	Raw beans are dehulled and milled to produce a flour, which is then solubilised, filtered, washed, pasteurized and spray-dried (a process which involves chemical processing).	88%

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

The environmental impact of each protein substitute depends on:

1. **The crop used:** Crops with high yields such as mung bean use less land per kg than soy and pea.
2. **The level of processing:** Protein concentrates are typically the least processed, followed by textured vegetable proteins. Isolates are the most highly processed. See Table 23 above for more detail.

In general, the environmental impacts of plant-based alternatives have been studied in less detail than their animal-based counterparts. We therefore had to make a number of assumptions where data was not available for a particular product or location. Our estimates are intentionally conservative to avoid overstating the benefits of switching to plant-based alternatives.

• **Soy textured vegetable protein:** Impacts have been modelled based on the impact of soy flour, with adjustments made for protein content.
• **Mung bean protein isolate:** Impacts from mung bean are modelled based on the impacts of pea protein isolate, with adjustments made for protein content, yield, time to maturity and water consumption.
• **Impacts in the United States and China:** Data for all protein substitute ingredients was taken from a European study. To model impacts in the US and China, adjustments were made based on electricity in the production phase, and the relative emissions intensities of the grid.

For a detailed description of the adjustments, please see pages 66 and 68.

The graphs on the following pages illustrate the environmental impact of each protein substitute ingredient. It is worth bearing in mind that a variety of other factors including texture, flavour, and nutrition (including protein content) will affect the choice of protein substitute ingredient.

*Note: The complete environmental profiles of the plant-based proteins for the two of the four beef products containing soy TVP and egg (containing mung bean protein isolate) were not available. Conservative estimates have been used to model these impacts. The impacts of soy TVP have been modelled based on the impacts of soy flour. The impacts of mung bean protein isolate have been modelled based on the impacts of pea protein isolate.

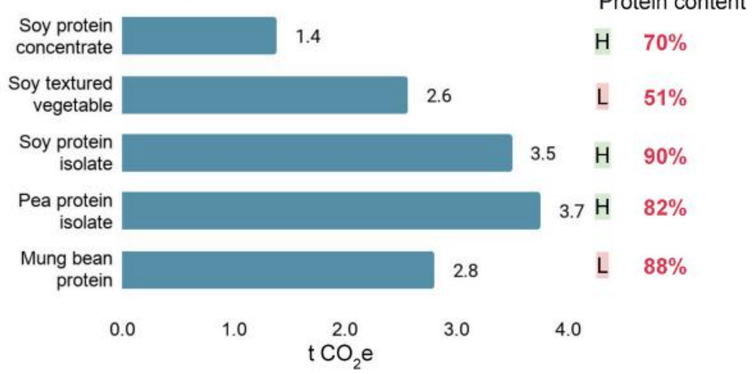
Protein substitute ingredients: results, environmental quantities

When comparing protein substitutes, it is important to bear in mind the protein content of different ingredients, as this will affect the volume required in the recipe. For example, more concentrate than isolate would be required to get the same overall protein content in a product.

1.4 to 3.7 tCO_2e per tonne protein substitute (average location)

The more highly processed an ingredient, the higher the GHG emissions produced. On average, protein isolates have the highest impacts, followed by textured vegetable protein, and then concentrates.

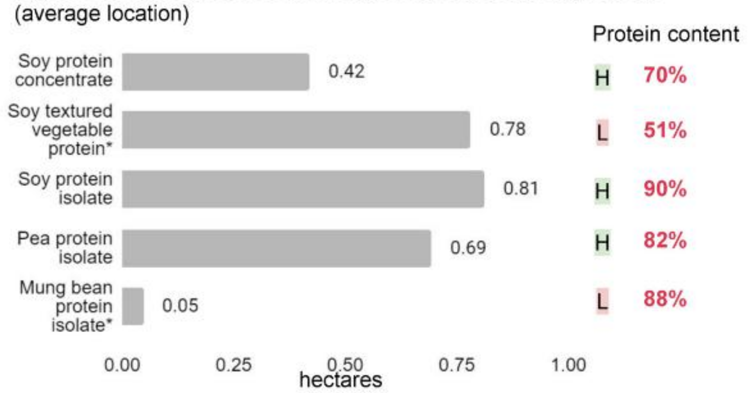
Figure 28: GHG emissions per tonne of protein substitute ingredient (average location)



0.05 to 0.81 hectares land use per tonne protein substitute (average location)

Land use is affected by both the yield of the crop, and the protein content of the final ingredient. Isolates have the highest protein content, so require more crop per tonne of ingredient than textured vegetable proteins and concentrates.

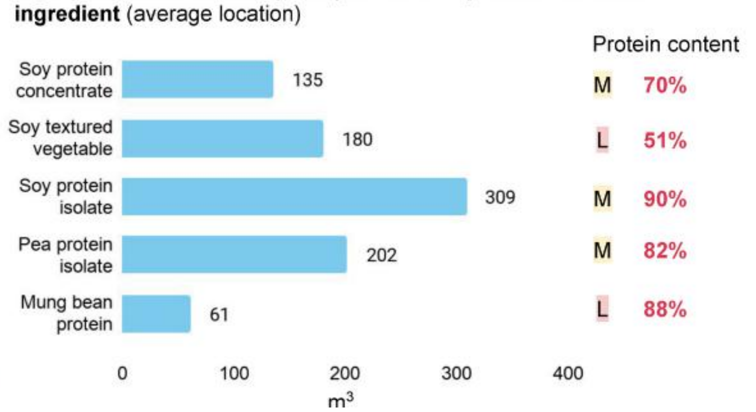
Figure 29: Land use per tonne of protein substitute ingredient (average location)



61 to 309m³ water consumption per tonne protein substitute (average location)

Water consumption is affected by both the water intensity of the crop, and the protein content of the final ingredient – as with land use (see above). We assume there is no water consumption in the processing step.

Figure 30: Water consumption per tonne of protein substitute ingredient (average location)



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

*Note: The complete environmental profiles of the plant-based proteins for the two beef products containing soy TVP and egg (containing mung bean protein isolate) were not available. Conservative estimates have been used to model these impacts. The environmental impacts of soy TVP have been modelled based on the impacts of soy flour. The environmental impacts of mung bean protein isolate have been modelled based on the impacts of pea protein isolate.

Comparison of products by environmental impacts

Overview

The following section compares the GHG, land use and water consumption impacts per tonne of each animal product and plant-based alternative, across all locations and farming systems included in the study.

Impacts are provided in environmental quantities, and are not valued – i.e. tCO_2e, hectares of land use, and m^3 of water consumption, not $. This means that the graphs represent differences in the magnitude of different impacts only, not differences in their cost to society.

Two graphs are provided for each environmental indicator. The first shows impact for an average cut of meat. The second shows the impact for the particular cuts examined in the study. These cuts are listed below, and were selected as the raw ingredients of consumer products which are often replaced by plant-based alternatives.

Table 24: Cuts of meat in scope of study

Animal product	Cut	Value of cut
Pulled chicken	Chicken breast	High value
Egg	Not applicable	Not applicable
Beef mince	Off cuts of pork loin, shoulder, belly and leg	Low value
Pork mince	Beef huck, rib, loin, round, flank	Low value

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Adjustments are made based on both the mass and value of different cuts. The value of the cut is important as the methodology used in this study assigns a lower environmental impact to lower value cuts of meat, in the same way that carbon accounting assigns fewer emissions to economy airplane seats compared to first class seats. This does not mean that chicken breast produces more emissions per tonne than chicken thighs, wings, and leg, but that a higher proportion of the impact of a chicken is assigned to the chicken breast. For a detailed description of the economic allocations applied, please see pages 64-69.

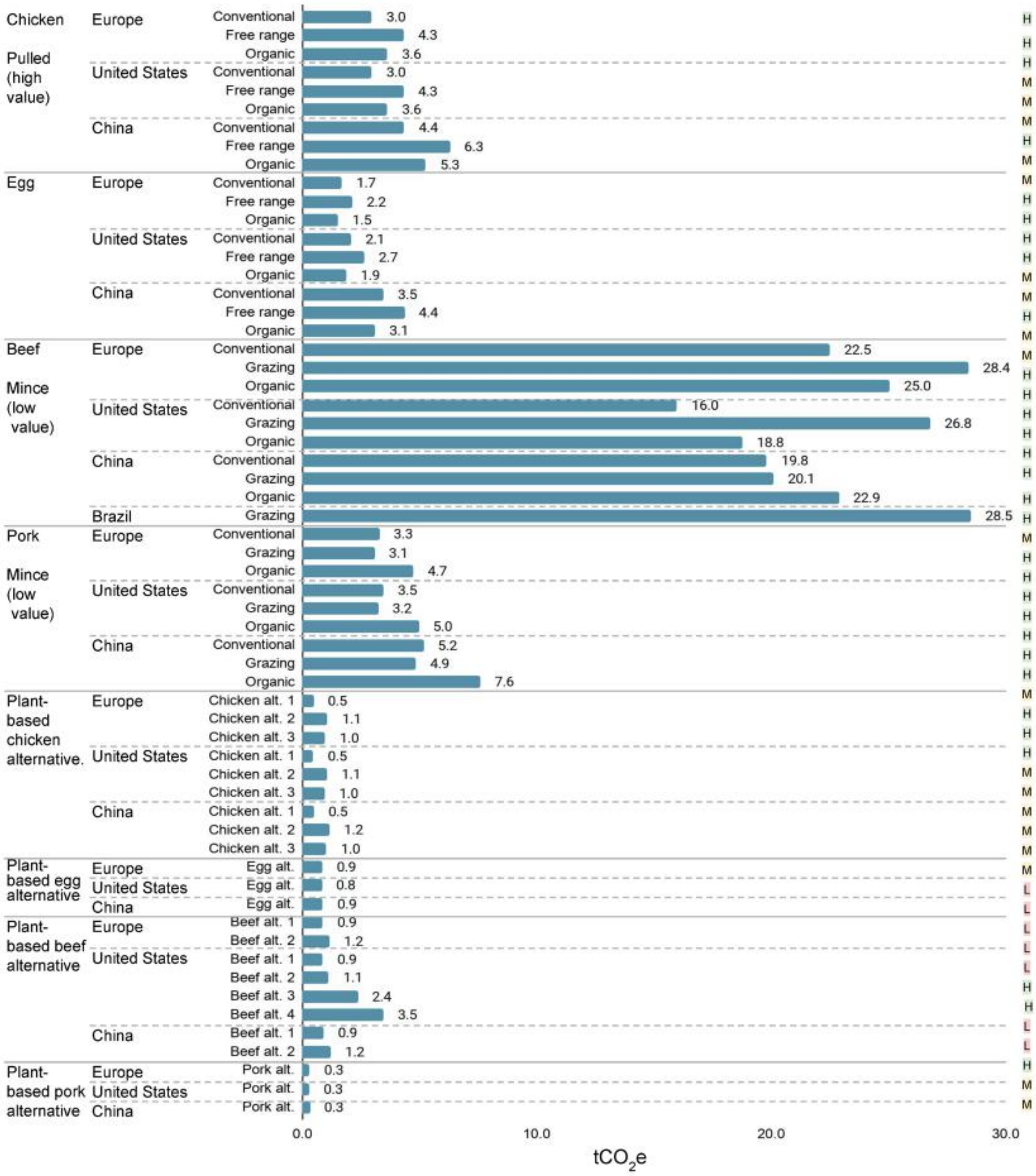
Note that this study is comparing the impact for a high value cut of chicken to low value cuts of beef and pork. As this section will show, the choice of cut has a significant impact on the final results.

Environmental impacts: average cuts of meat

Greenhouse gas emissions: animal-based proteins, average cuts

As expected, for all locations and systems, beef produces far more greenhouse gas emissions per tonne than any other animal product in the study. For an average cut, pork produces just slightly more GHG emissions per tonne than chicken, with egg producing the lowest. All plant-based products have lower impacts than the lowest impact animal product. Plant products vary slightly by country due to the adjustments made for the emissions intensities of different grid systems – see page 64.

Figure 31: GHG emissions per tonne of animal-based protein (average cut)

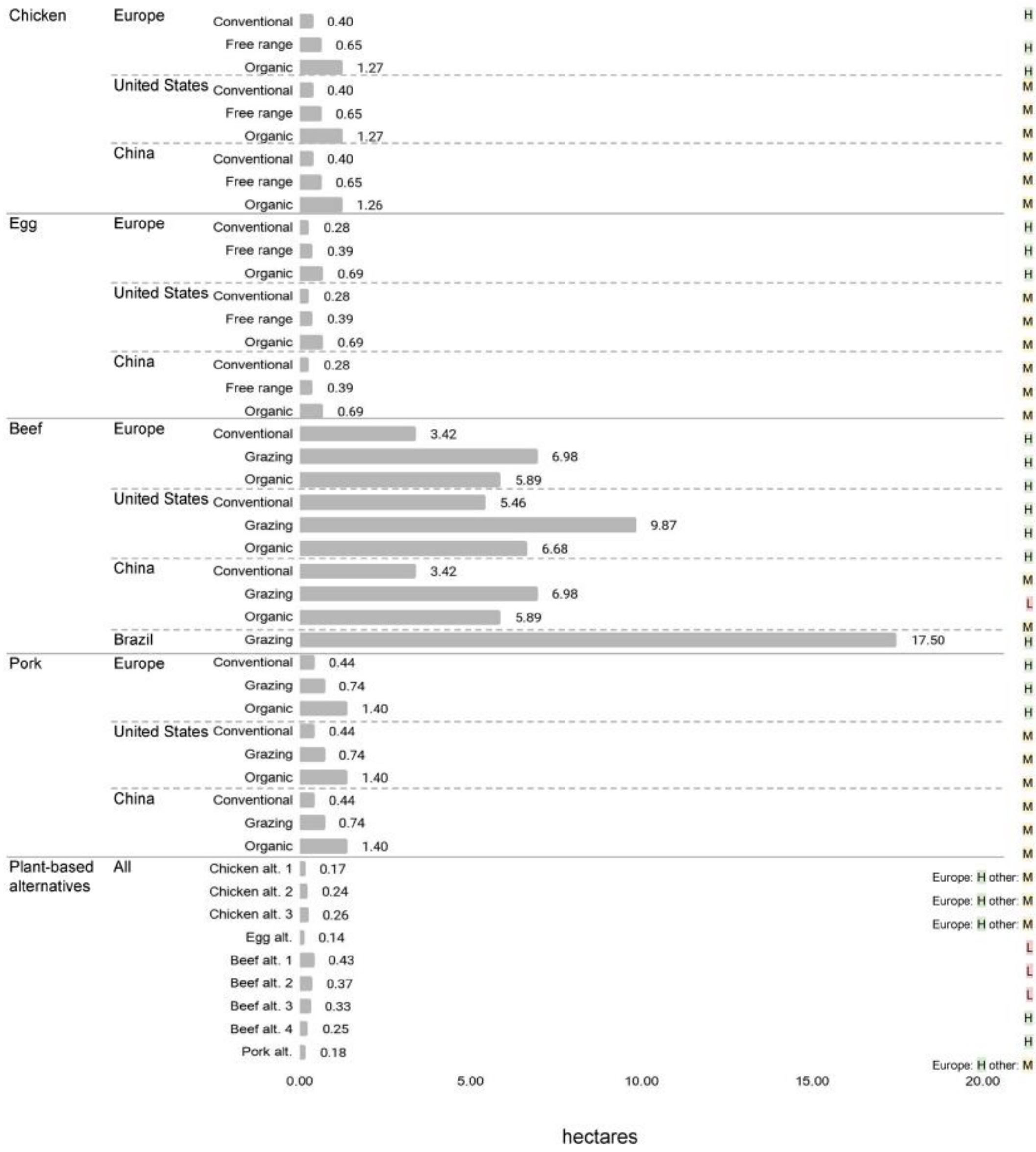


Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Land use:
animal-based proteins, average cuts

As expected, for all locations and systems, beef uses more hectares of land per tonne than any other animal product in the study. In particular, Brazilian beef systems use almost twice as much land per tonne than any other location. Again, pork and chicken have similar land use requirements, and egg has the lowest land use impact of all products. All plant-based products have lower impacts than the lowest impact animal product. Due to limitations in data availability, we assume that the land use impacts of plant products do not vary by location.

Figure 32: **Land use per tonne of animal-based protein** (average cut)

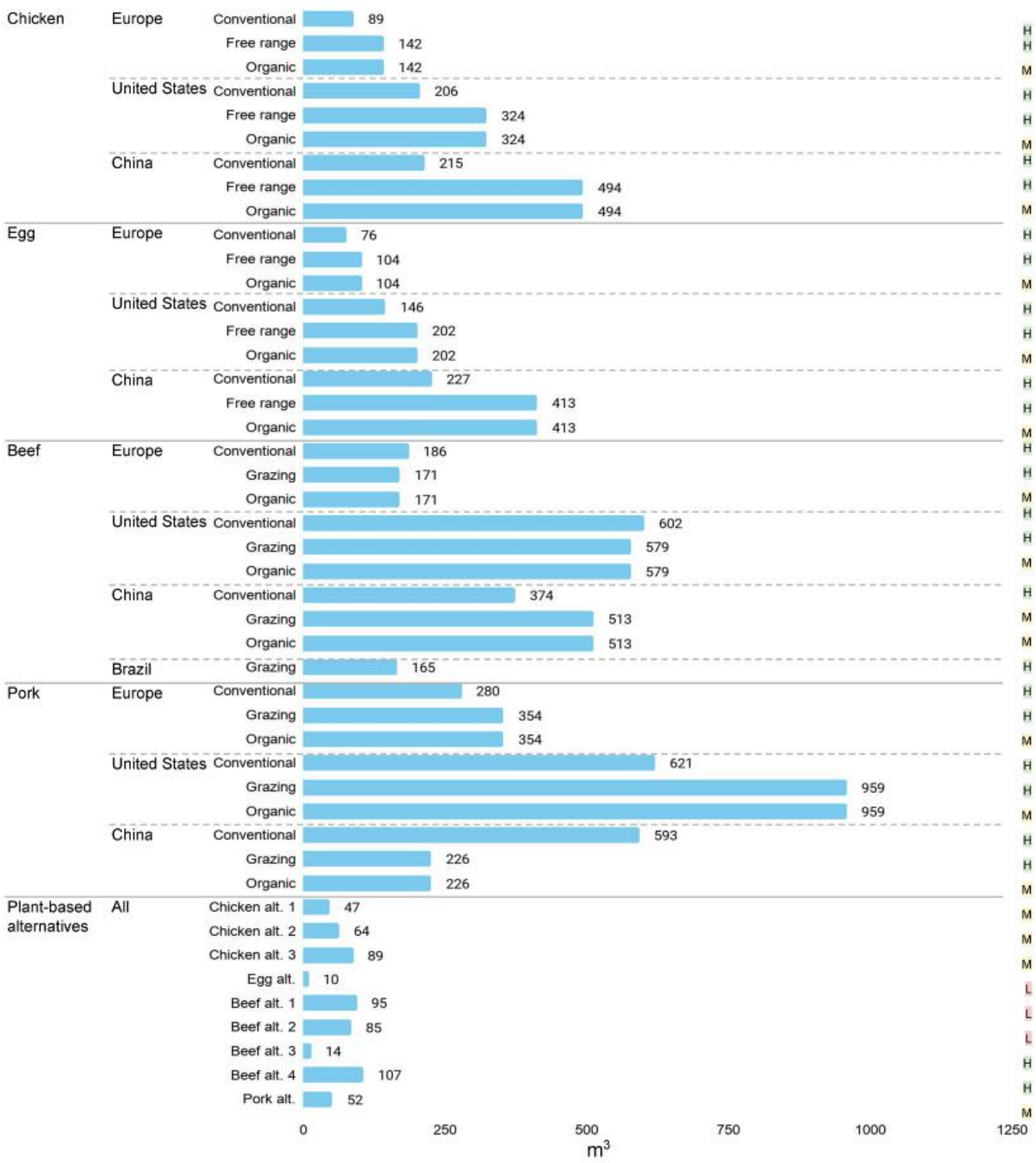


Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Water consumption: animal-based proteins, average cuts

The water consumption impacts of organic systems are assumed to be the same as those of grazing systems, due to limitations in data availability – see page 67-69. The overall picture for water consumption is very different to that for GHGs and land use. On average, pork requires the most water per tonne, followed by beef and then chicken. However, it is important to note that the impact from water consumption makes up only a small proportion of an animal product's environmental footprint. All plant-based products have lower impacts than the lowest impact animal product. Note that for plant-based products, we use global coefficients.

Figure 33: Water consumption per tonne of animal-based protein (average cut)



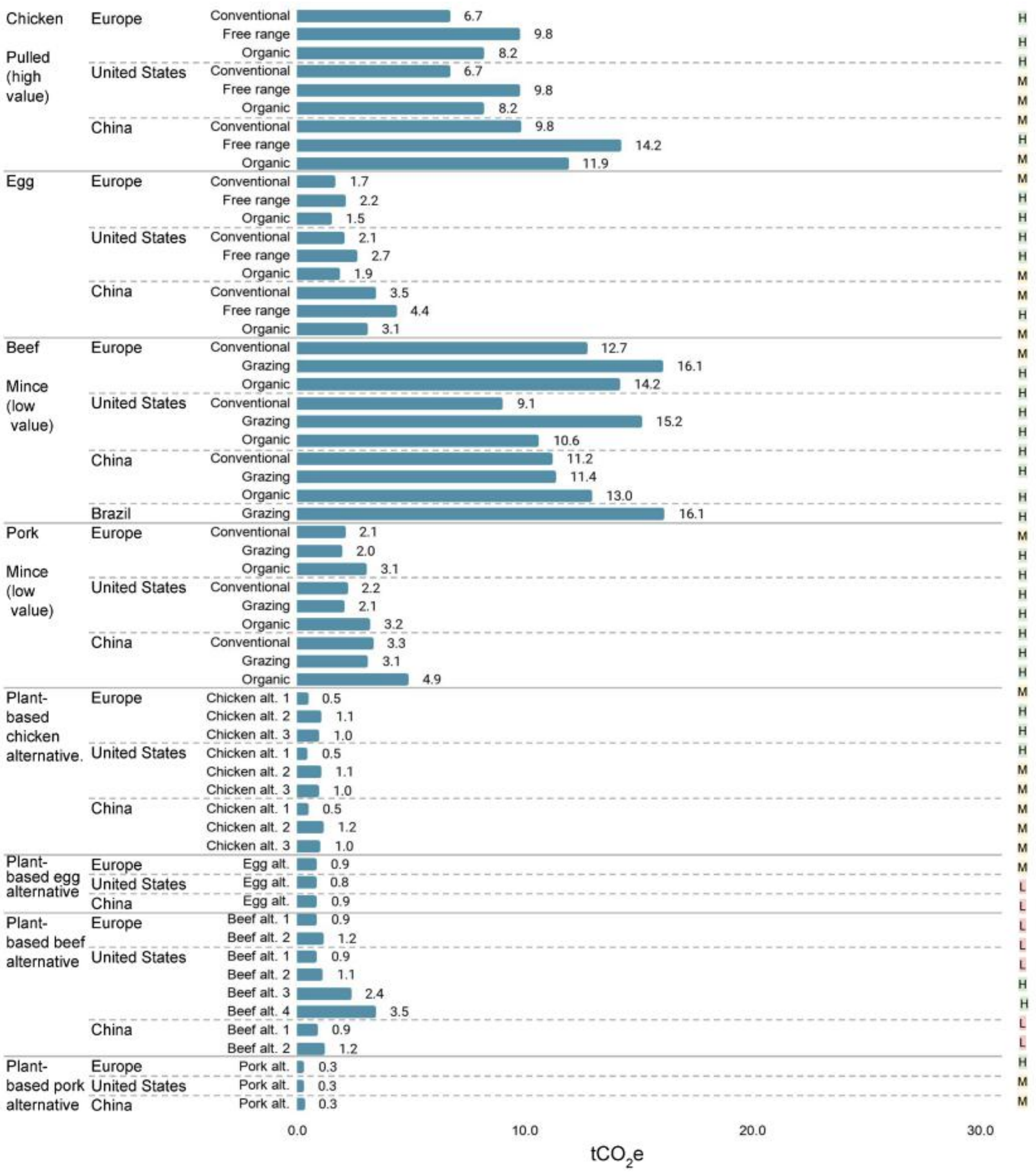
Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Environmental impacts: specific cuts of meat used in this study

Greenhouse gas emissions: animal-based proteins, cuts used in study

When looking at the particular cuts used in this study, beef still has the highest GHG footprint for every system / location. However, because we are comparing a high value cut of chicken to low value cuts of beef and pork, chicken has a significantly higher environmental impact than pork, and nearly as high an impact as beef. By this method, pork mince has a similar GHG impact to eggs. All plant-based products have lower impacts than the lowest impact animal product. Plant products vary slightly by country due to the adjustments made for the emissions intensities of different grid systems – see page 64.

Figure 34: GHG emissions per tonne of animal-based protein (cuts used in study)

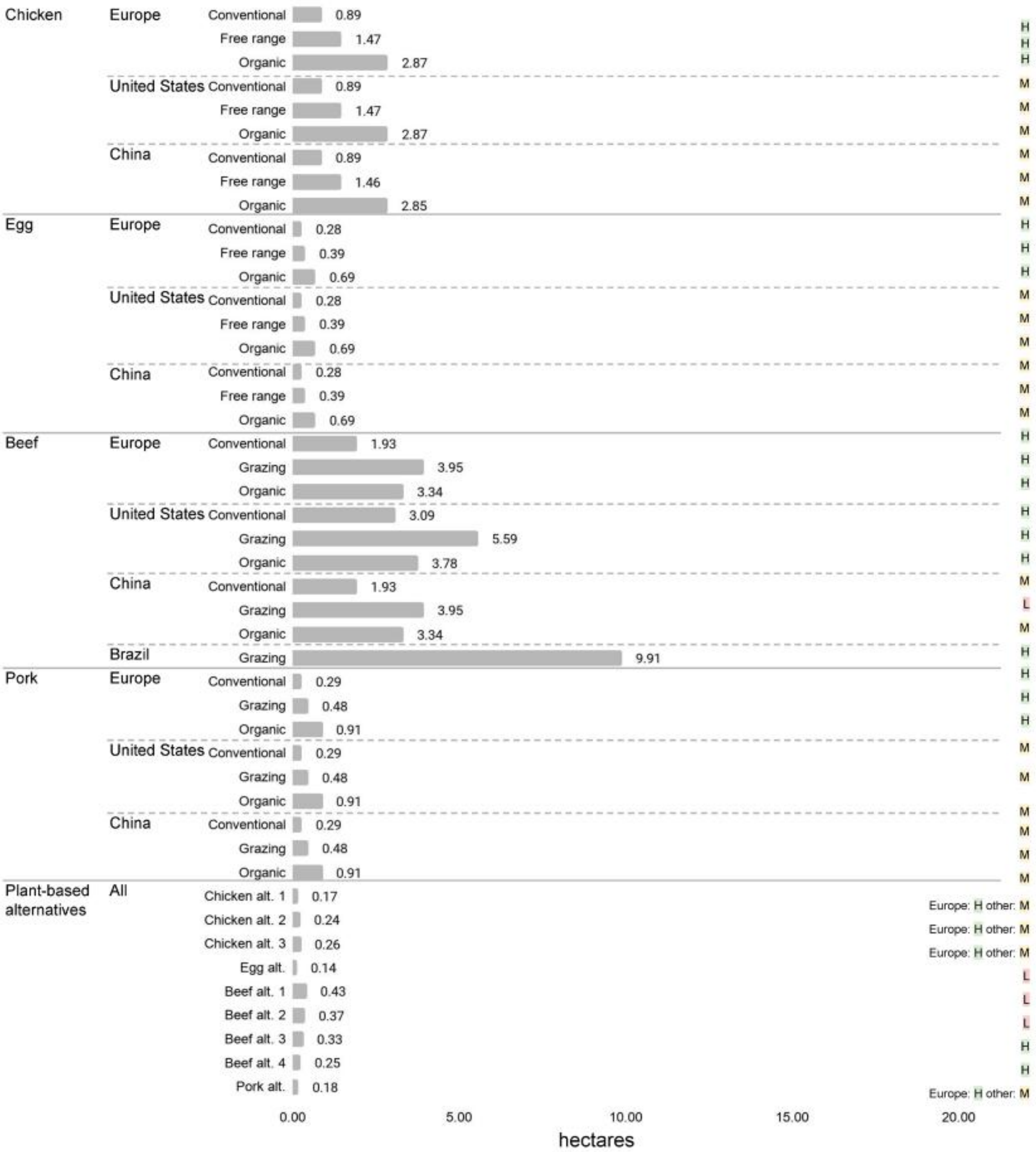


Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Land use:
animal-based proteins, cuts used in study

Beef still has the highest land use footprint for every system / location. However, because we are comparing a high value cut of chicken to low value cuts of beef and pork, chicken has a significantly higher environmental impact than pork, and nearly as high an impact as beef. All plant-based products have lower impacts than the lowest impact animal product.

Figure 35: Land use per tonne of animal-based protein (cuts used in study)

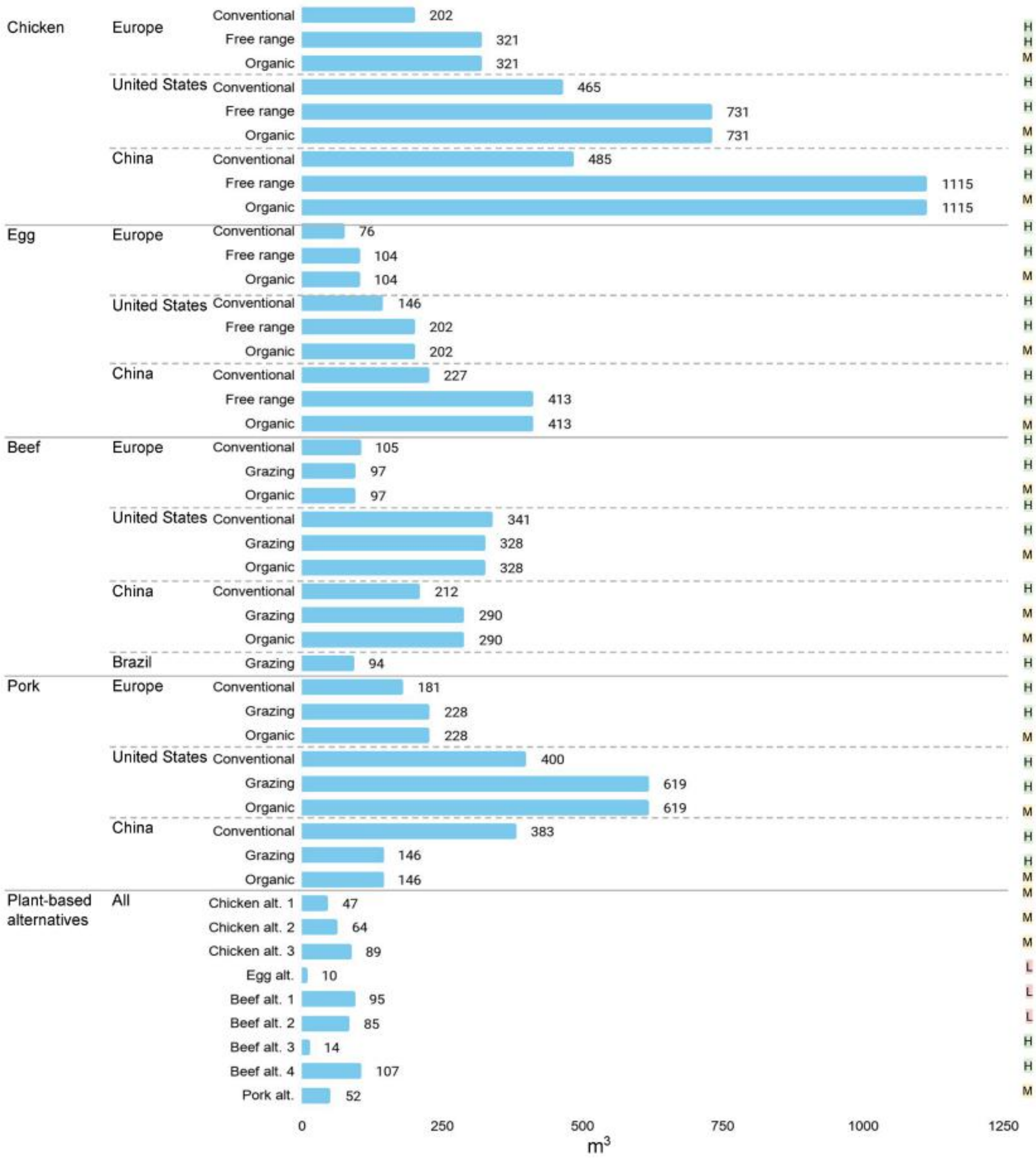


Source: PwC analysis prepared in connection with “Environmental impacts of animal and plant-based food” prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Water consumption: animal-based proteins, cuts used in study

The water consumption impacts of organic systems are assumed to be the same as those of grazing systems, due to limitations in data availability – see page 67-69. Because of the methodology applied, chicken breast has the highest water use footprint, followed by pork mince, beef mince, and finally egg. All plant-based products have lower impacts than the lowest impact animal product.

Figure 36: Water consumption per tonne of animal-based protein (cuts used in study)



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Switching at scale

Global overview

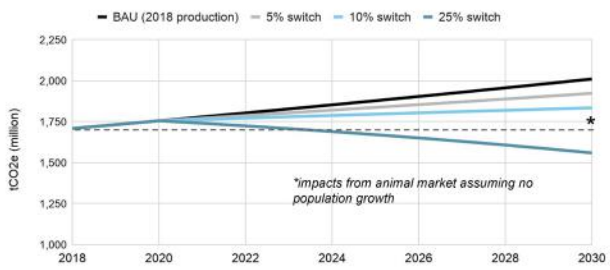
The diagrams below give an indication of the scale of potential environmental benefits from switching from animal products to plant-based alternatives on a global scale. As well as BAU growth, three scenarios have been modelled: a 5%, 10% and 25% switch to plant-based alternatives by 2030. The results show that just over 16% of the market would need to switch to alternatives by 2030 for the world to see a fall in each environmental impact category compared to today.

With a 10% switch to plant-based alternatives:

176 million tCO2e avoided emissions per year by 2030

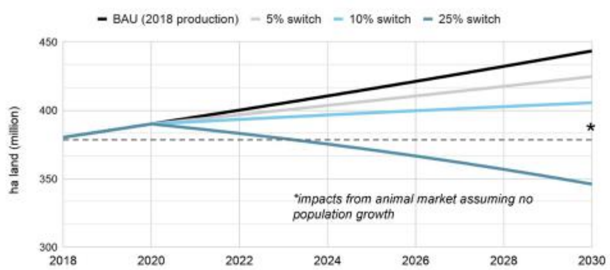
Note: the estimates for current and BAU global GHG emissions from animal products reported here are smaller than those found in previous FAO studies.[53] This is partially because we only consider a limited number of animal products, and partially because of differences in estimated emissions intensities due to the use of different data sources.

Figure 37: GHG emissions over time under 3 'switching' scenarios



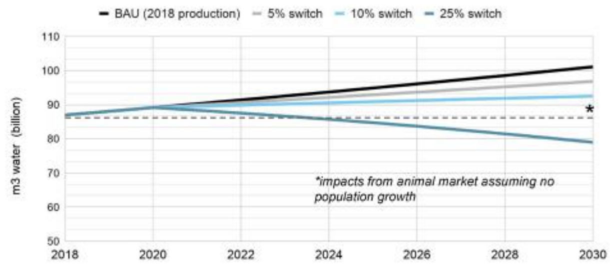
38 million hectares of land freed up per year by 2030

Figure 38: Land use over time under 3 'switching' scenarios



8.6 billion m^3 water saved per year by 2030

Figure 39: Water consumption over time under 3 'switching' scenarios



Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Note: the analysis takes into consideration an increase in overall animal production over time in line with FAO projections.[54] The analysis includes only the animal products that were considered in the main study (i.e. beef, pig, chicken, egg). Average global environmental impacts are extrapolated based upon locations used in the study.

Methodological notes

Methodology

Our methodology included the following key steps. Each of these are described in more detail in this section.

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

This section also describes the assumptions used in this study, in response to some of the key challenges described below. We would welcome further research in these areas.

1. Data gaps in the literature

Despite an extensive review of the LCA literature available for the protein sources, locations, and farming systems in scope, there were some clear gaps in the data collection:

• Organic and free range systems are less well documented than conventional systems.
• Less literature was available for regions outside Europe, with China being the most difficult country to source data for.
• Land use impacts are less commonly reported than GHGs and LCA methodologies more commonly differ in their scope.
• Plant-based proteins are less well studied. In particular, no LCA data was found for mung bean protein isolates and textured vegetable proteins.

On this basis, we have been required to estimate these environmental impacts using the environmental quantities for other locations and systems. The assumptions used can be found on page 59-69.

2. Matching farming systems to consumer products

All studies selected report environmental impacts in different units, system boundaries, and final protein products. Therefore, a major part of the calculation process has been to standardise these impacts.

For some studies this has involved conversion to a standard carcass weight of each animal, followed by an economic allocation to the cut of meat required. This cut represents the closest form of each protein to the ingredient used in the consumer product e.g. beef mince to be used in a beef burger.

The results are particularly sensitive to the economic allocation applied and so it has been important to highlight how the distribution of the results can change based on the value of the cut of meat required for the consumer product.

3. Variability in beef farming systems

It was relatively straightforward to gather data on an average conventional system for eggs, chicken, and pork. For beef, however, systems show far greater variability in size, breed and type of cow (dairy or beef bred), feed, and number of stages of production. We have tried to represent conventional farming in each country, but this has been constrained by the system assumptions in each study.

For beef production in Europe, we have made assumptions about the average types of cows going to slaughter in France. This is based on the proportion of dairy versus beef cows in the country and the average calf, heifer, cull cow ratio for a farm. The impact is, therefore, a blend of all of these.

Data collection

Studies selected (1/4)

This section lists the main studies used in this paper. They were selected based on the following criteria: representativeness of the desired location and farming systems; reputation of the publication; degree of peer review; date of publication; and comparability of system boundaries between studies. Outlier studies have been removed from consideration.

Data gaps: Where we were not able to find data for a particular ingredient, location, or system, we have described the assumptions we made to estimate these impacts. We have highlighted these data gaps according to the key below, and would welcome further research in these areas.

Key:

LCA data available

Assumed to be equivalent to data from an LCA for a different region or farming system

Adjusted based on ratio of data for a European system

Adjusted LCA for a different region based on relative emissions intensity of electricity grids

Adjusted LCA data for a different ingredient/product

Adjusted based on volume of base crop required to produce ingredient

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Table 25: Data sources

Ingredient	Location	Environmental indicator	Selected study
Eggs	EU	GHGs	Agribalyse (2015)
		Land use	Agribalyse (2015)
		Water consumption	Mekonnen and Hoekstra (2010) Grazing value has been used as a proxy for organic systems
	USA	GHGs	Pelletier (2013) Grazing and organic adjusted based on ratios from Agribalyse (2015)
		Land use	Proxied using Agribalyse (2015)
		Water consumption	Mekonnen and Hoekstra (2010) Grazing value has been used as a proxy for organic systems
	China	GHGs	Luo (2015) Grazing and organic adjusted based on ratios from Agribalyse (2015)
		Land use	Proxied using Agribalyse (2015)
		Water consumption	Mekonnen and Hoekstra (2010) Grazing value has been used as a proxy for organic systems
Chicken	EU	GHGs	Agribalyse (2015), Prudêncio et al (2012)
		Land use	Agribalyse (2015), Prudêncio et al (2012)
		Water consumption	Mekonnen and Hoekstra (2010) Grazing value has been used as a proxy for organic systems
	USA	GHGs	Agribalyse (2015), Prudêncio et al (2012)
		Land use	Proxied using Agribalyse (2015), Prudêncio et al (2012)
		Water consumption	Mekonnen and Hoekstra (2010) Grazing value has been used as a proxy for organic systems
	China	GHGs	FAO (2013) Organic adjusted based on ratios from Agribalyse (2015)
		Land use	Proxied using Agribalyse (2015), Prudêncio et al (2012)
		Water consumption	Mekonnen and Hoekstra (2010) Grazing value has been used as a proxy for organic systems

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Studies selected (2/4)

Ingredient	Location	Environmental indicator	Selected study
Beef	EU	GHGs	Agribalyse (2015), Desjardins et al (2012)
		Land use	Agribalyse (2015)
		Water consumption	Mekonnen and Hoekstra (2010) Grazing value has been used as a proxy for organic systems
	USA	GHGs	Capper (2012)
		Land use	Capper (2012)
		Water consumption	Mekonnen and Hoekstra (2010) Grazing value has been used as a proxy for organic systems
	China	GHGs	Du (2018) Organic adjusted based on ratios from Agribalyse (2015)
		Land use	Proxied using Agribalyse (2015)
		Water consumption	Mekonnen and Hoekstra (2010). Grazing value has been used as a proxy for organic systems
	Brazil	GHGs	Cederberg (2009), Desjardins et al (2012)
		Land use	Cederberg (2009)
		Water consumption	Mekonnen and Hoekstra (2010). Grazing value has been used as a proxy for organic systems
Pork	EU	GHGs	Agribalyse (2015), Nguyen et al. (2011)
		Land use	Agribalyse (2015)
		Water consumption	Mekonnen and Hoekstra (2010) Grazing value has been used as a proxy for organic systems
	USA	GHGs	Pelletier (2010), Nguyen et al. (2011) Grazing and organic adjusted based on ratios from Agribalyse (2015)
		Land use	Proxied using Agribalyse (2015)
		Water consumption	Mekonnen and Hoekstra (2010) Grazing value has been used as a proxy for organic systems
	China	GHGs	FAO (2013) Organic adjusted based on ratios from Agribalyse (2015)
		Land use	Proxied using Agribalyse (2015)
		Water consumption	Mekonnen and Hoekstra (2010) Grazing value has been used as a proxy for organic systems

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Studies selected (3/4)

Ingredient	Location	Environmental indicator	Selected study
Pea protein isolate and pea fiber	EU	GHGs	Blonk consultants (2016)
		Land use	Blonk consultants (2016)
		Water consumption	Mekonnen and Hoekstra (2011)
	USA	GHGs	Adjusted based on Blonk consultants (2016)
		Land use	Blonk consultants (2016)
		Water consumption	Mekonnen and Hoekstra (2011)
	China	GHGs	Adjusted based on Blonk consultants (2016)
		Land use	Blonk consultants (2016)
		Water consumption	Mekonnen and Hoekstra (2011)
Soy protein isolate and soy fiber	EU	GHGs	Blonk consultants (2016)
		Land use	Blonk consultants (2016)
		Water consumption	Mekonnen and Hoekstra (2011)
	USA	GHGs	Adjusted based on Blonk consultants (2016)
		Land use	Blonk consultants (2016)
		Water consumption	Mekonnen and Hoekstra (2011)
	China	GHGs	Adjusted based on Blonk consultants (2016)
		Land use	Blonk consultants (2016)
		Water consumption	Mekonnen and Hoekstra (2011)
Mung bean protein	EU	GHGs	Adjusted based on Blonk consultants (2016) pea protein isolate data
		Land use	Adjusted based on Blonk consultants (2016) pea protein isolate data
		Water consumption	Mekonnen and Hoekstra (2011)
	USA	GHGs	Adjusted based on Blonk consultants (2016) pea protein isolate data
		Land use	Adjusted based on Blonk consultants (2016) pea protein isolate data
		Water consumption	Mekonnen and Hoekstra (2011)
	China	GHGs	Adjusted based on Blonk consultants (2016) pea protein isolate data
		Land use	Adjusted based on Blonk consultants (2016) pea protein isolate data
		Water consumption	Mekonnen and Hoekstra (2011)
Soy protein concentrate	EU	GHGs	Blonk consultants (2016)
		Land use	Blonk consultants (2016)
		Water consumption	Mekonnen and Hoekstra (2011)
	USA	GHGs	Adjusted based on Blonk consultants (2016)
		Land use	Blonk consultants (2016)
		Water consumption	Mekonnen and Hoekstra (2011)
	China	GHGs	Adjusted based on Blonk consultants (2016)
		Land use	Blonk consultants (2016)
		Water consumption	Mekonnen and Hoekstra (2011)
Soy textured vegetable protein	EU	GHGs	Adjusted based on Blonk consultants (2016) soy flour data
		Land use	Adjusted based on Blonk consultants (2016) soy flour data
		Water consumption	Mekonnen and Hoekstra (2011)
	USA	GHGs	Adjusted based on Blonk consultants (2016) soy flour data
		Land use	Adjusted based on Blonk consultants (2016) soy flour data
		Water consumption	Mekonnen and Hoekstra (2011)
	China	GHGs	Adjusted based on Blonk consu (2016) soy flour dataltants
		Land use	Adjusted based on Blonk consultants (2016) soy flour data
		Water consumption	Mekonnen and Hoekstra (2011)

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Studies selected (4/4)

Ingredient	Location	Environmental indicator	Selected study
Sunflower oil	EU	GHGs	Poore et al (2018)
		Land use	Poore et al (2018)
		Water consumption	Mekonnen and Hoekstra (2011)
	USA	GHGs	Poore et al (2018)
		Land use	Poore et al (2018)
		Water consumption	Mekonnen and Hoekstra (2011)
	China	GHGs	Poore et al (2018)
		Land use	Poore et al (2018)
		Water consumption	Mekonnen and Hoekstra (2011)
Coconut oil	EU	GHGs	Mulvaney (2014)
		Land use	Dumelin (2009)
		Water consumption	Mekonnen and Hoekstra (2011)
	USA	GHGs	Mulvaney (2014)
		Land use	Dumelin (2009)
		Water consumption	Mekonnen and Hoekstra (2011)
	China	GHGs	Mulvaney (2014)
		Land use	Dumelin (2009)
		Water consumption	Mekonnen and Hoekstra (2011)
Rapeseed oil	EU	GHGs	Poore et al (2018)
		Land use	Poore et al (2018)
		Water consumption	Mekonnen and Hoekstra (2011)
	USA	GHGs	Poore et al (2018)
		Land use	Poore et al (2018)
		Water consumption	Mekonnen and Hoekstra (2011)
	China	GHGs	Poore et al (2018)
		Land use	Poore et al (2018)
		Water consumption	Mekonnen and Hoekstra (2011)
Beyond Burger	USA	All	Heller and Keoleian (2018)
Impossible Burger	USA	All	Khan et al (2019)

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Data analysis

Adjustments to raw data

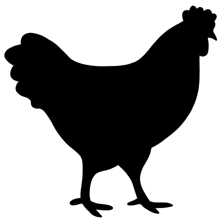
Key adjustments made to the raw LCA data are described below. The actual adjustments made for each product are listed on the following pages, with sources provided on pages 59-62.

Economic allocations

An economic allocation is an adjustment made to assign environmental impact between different parts of a product. Impacts are assigned proportionally to economic value: high value parts of the product are assigned more of the impact than low value parts.This accounts for differences in the desirability of different the different parts. For example, byproducts are assigned a very low proportion of the impact. A well-known use of this methodology is in carbon accounting of plane emissions: fewer emissions are assigned to economy airplane seats compared to first class seats.

In this study, we make economic allocations based on the value of different cuts of meat. For example, chicken breast - a high value cut, is assigned more of the impact. This is illustrated below. In the case of meat products, the economic allocation can account for differences in both the mass and value of different cuts.

Figure 40: Example economic allocation



Chicken breast
21% by total chicken mass
48% of total chicken value

Economic allocation = (1/0.21) x 0.48 = 2.26

Source: PwC analysis prepared in connection with “Environmental impacts of animal and plant-based food” prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

This does not mean that chicken breast produces more emissions per tonne than chicken thighs, wings, and leg, but that a higher proportion of the impact of a chicken is assigned to the chicken breast. The cuts used in this study are listed below, and were selected as the raw ingredients of consumer products which are often replaced by plant-based alternatives.

Table 26: Cuts of meat in scope of study

Animal product	Cut	Value of cut
Pulled chicken	Chicken breast	High value
Egg	Not applicable	Not applicable
Beef mince	Off cuts of pork loin, shoulder, belly and leg	Low value
Pork mince	Beef huck, rib, loin, round, flank	Low value

Source: PwC analysis prepared in connection with “Environmental impacts of animal and plant-based food” prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Carcassweight adjustment

Some LCAs provided data for a given liveweight of meat. To ensure comparability, we applied standard adjustments for each meat, to adjust the impact to the appropriate carcassweight.

Location adjustment

We sometimes used an LCA for a different country to estimate the environmental impacts of an ingredient in a particular location. In some cases, we made an adjustment to the greenhouse gas emissions, based on the amount of electricity used in production, and the relative grid emissions of different countries.

Crop adjustment

In some cases we used an LCA for a different crop to estimate the environmental impacts of a particular ingredient. Where this was the case, we made adjustments based on various factors, including protein content, yield, water consumption and time to maturity.

Translation of environmental data to a set of common products (1/2)

The following adjustments were made to translate the raw environmental data from LCA studies into a set of common products which could be compared across systems and locations. Sources for these adjustments can be found in the following section.

Animal proteins

Ingredient	Raw data	Slaughter weight adjustment	Economic allocation	Mass conversion
Eggs (kg eggs)	LCA environmental data per kg of eggs	N/A	N/A	N/A
Chicken (kg chicken breast)	LCA environmental data per kg of live chicken	Adjust from live weight to carcass weight (if required) X 1.43	Adjust for economic allocation of chicken breast meat X 0.48	Adjust weight from 0.21kg to 1kg breast meat X 4.67
Pork (kg pork mince)	LCA environmental data per kg of live pig	Adjust from live weight to carcass weight (if required) X 1.32	Adjust for economic allocation of cuts which go into pork mince X 0.2	Adjust weight of pork mince cuts from 0.31kg to 1kg mince X 3.23
Beef (kg beef mince)	LCA environmental data per kg live cow	Adjust from live weight to carcass weight (if required) X 1.82	Adjust for ratio of beef mince economic allocation to average beef cut economic allocation X 0.57	

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Translation of environmental data to a set of common products (2/2)

Plant-based proteins

Ingredient	Raw data	Location adjustment	Crop adjustment	Economic allocation
Soy protein isolate (kg)	LCA environmental data per kg of soy protein isolate	Electricity adjustments made by region for GHG impacts	Adjust from soybean water consumption **x1.13**	N/A
Soy protein concentrate (kg)	LCA environmental data per kg of soy protein concentrate	Electricity adjustments made by region for GHG impacts	Adjust from soybean water consumption **x0.50**	N/A
Soy textured vegetable protein (kg)	LCA environmental data per kg of soy flour	Electricity adjustments made by region for GHG impacts	Adjust from soy flour to soy textured vegetable protein **x2**	N/A
Pea protein isolate (kg)	LCA environmental data per kg of pea protein isolate	Electricity adjustments made by region for GHG impacts	Adjust from pea water consumption **x0.46**	N/A
Mung bean protein isolate (kg)	LCA environmental data per kg of pea protein isolate	Electricity adjustments made by region for GHG impacts	Adjust from pea protein to mung bean protein based on overall protein content, yield, time to maturity and water consumption	N/A
Coconut oil (kg)	LCA environmental data per kg of coconut oil	N/A	N/A	N/A
Rapeseed oil (kg)	LCA environmental data per kg of rapeseed oil	N/A	N/A	N/A
Sunflower oil (kg sunflower oil)	LCA environmental data per kg of sunflower oil	N/A	N/A	N/A
Soy fiber (kg)	LCA environmental data per kg of soy protein isolate	Electricity adjustments made by region for GHG impacts	Adjust from soy water consumption **x1.13**	Adjust for economic allocation for soy protein isolate **x0.09**
Pea fiber (kg)	LCA environmental data per kg of pea protein isolate	Electricity adjustments made by region for GHG impacts	Adjust from pea water consumption **x1.13**	Adjust for economic allocation for pea protein isolate **x0.02**
Water (kg)	LCA environmental data per kg of water	N/A	N/A	N/A

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Key assumptions (1/3)

Animal-based proteins

In our analysis of animal proteins, we made a number of assumptions where there were data gaps in the literature. This mainly applied to grazing and organic farming systems outside of Europe. We also list here sources for the adjustments made to translate the raw LCA data into standardised units.

Table 27: Key assumptions (animal-based proteins)

Ingredient(s)	Assumption	Source
All	**Scope:** The analysis includes impacts along the value chain, from crop farming (including for animal feed production) to the whole, processed ingredients which are used to make the final product. We do not include impacts from processing the ingredients into the final product (e.g. mincing, combining, forming patties, flavouring), transport emissions or downstream environmental impacts such as those from the preparation or cooking of the products, as these are assumed to be similar for both animal and plant-based products.	N/A
Data gaps (all products)	**Estimation of unavailable data:** Where data was not available for free range/grazing or conventional systems in the United States or China, we estimated the impact using the ratio between European systems.	N/A
Eggs, pork, beef	**Estimation of unavailable data:** Land use in processing phase (after the farm gate) is excluded on the basis of materiality, where data gaps exist in the literature.	N/A
All organic products	**Estimation of unavailable data:** Reported blue water consumption for grazing systems used to proxy water consumption for organic farming.	Mekonnen and Hoekstra (2010)
Eggs	**Estimation of unavailable data:** The ratio between upstream crop farming and the direct operations of the farming systems in Europe is used to distribute values between these phases of production, where data gaps exist in the literature.	N/A
Beef, China	**Estimation of unavailable data:** Global average blue water consumption value is used to model the impact of grazing and organic beef, as China specific blue water consumption is not reported in the study.	Mekonnen and Hoekstra (2010)
Chicken	**Economic allocation:** Pulled chicken is made of chicken breast. The economic applied is 0.483, calculated using the price and % weight information for chicken cuts from Jiang (1998).	Jiang (1998)
Pork	**Economic allocation:** Pork mince is made from off cuts of pork loin, shoulder, belly and leg. The economic allocation applied is 0.2.	FAO (2018)
Beef	**Economic allocation:** Beef mince is made of cuts of chuck, rib, loin, round, and flank. The economic allocation applied is 0.566, based on the ratio between the average beef mass allocation footprint (31.8 kg CO2e/kg) and the economic allocation of minced meat (18 kg CO2e/kg) data from Eymann (2015).	Eymann (2015)
Chicken	**Slaughter weight adjustment:** The live-weight to carcass-weight conversion is 1.43. This is the inverse of the killing out percentage provided in Williams (2006).	Williams (2006)
Pork	**Slaughter weight adjustment:** The live-weight to carcass-weight conversion is 1.32. This is the inverse of the killing out percentage provided in FAO (2013).	FAO (2013)
Beef	**Slaughter weight adjustment:** The live-weight to carcass-weight conversion is 1.82. This is the inverse of the killing out percentage provided in Williams (2006).	Williams (2006)
Beef, France	French beef production is based on a mix of suckler and dairy cows. As per Deblitz (2005), the proportions used are 48% suckler and 52% dairy cow. A conventional French beef system is assumed to include: 3 36 weaners, 8 heifers, 11 cows (55 animals).	Deblitz (2005)

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Key assumptions (2/3)

Plant-based alternatives

In general, the environmental impacts of plant-based alternatives have been studied in less detail than their meat counterparts. We have therefore had to make some key assumptions in our analysis of certain ingredients, due to limitations in data availability. Our assumptions are based on reasonable adjustments, and we have been deliberately conservative in order to avoid overstating the benefits of switching to alternatives. The most significant assumptions are described in the table below.

Table 28: **Key assumptions** (plant-based proteins)

Ingredient(s)	Assumption	Source
All	**Scope:** The analysis includes impacts along the value chain, from crop farming to the whole, processed ingredients which are used to make the final product. We do not include impacts from processing the ingredients into the final product (e.g. mincing, combining, forming patties, flavouring), except for two of the plant-based alternatives: the Beyond Burger and Impossible Burger. This is because the impact data for these products was taken directly from studies looking into the whole burger patty and it was not possible to separate out ingredient processing from product processing. See below for further details. For all products, we do not include transport emissions or downstream environmental impacts such as those from the preparation or cooking of the products, as these are assumed to be similar for both animal and plant-based products.	N/A
Beyond Burger	**Modelling approach:** The impacts of the Beyond Burger have been taken from Heller and Keoleian (2018). In order to mirror the scope of processes included for other products (as described on page 7) as closely as possible, only the impacts from the "Ingredients" and "Processing" stages were included. However, the impacts reported for the Beyond Burger will still include some impacts excluded elsewhere, including: 1) impacts from flavourings and other ingredients which made up <2% of the product; 2) impacts from processing the ingredients into a burger patty.	Heller and Keoleian (2018)
Impossible Burger	**Modelling approach:** The impacts of the Impossible Burger have been taken from Khan et al (2018). In order to mirror the scope of processes included for other products (as described on page 7) as closely as possible, only the impacts from the "Impossible Burger Mix" and "Production" stages were included. However, the impacts reported for the Impossible Burger will still include some impacts excluded elsewhere, including: 1) impacts from flavourings and other ingredients which made up <2% of the product; 2) impacts from processing the ingredients into a burger patty.	Khan et al (2018)
Mung bean protein isolate	**Estimation of unavailable data:** We were not able to find a study on the environmental impacts of mung bean protein isolate. We therefore modelled mung bean impacts using a study on pea protein isolate, adjusting for differences in: • Overall protein content • Yield • Time to maturity • Water consumption	N/A
Soy textured vegetable protein	**Estimation of unavailable data:** We were not able to find a study on the environmental impacts of soy textured vegetable protein (TVP). Since TVP is produced by refining soy flour or soy protein concentrate, we modelled the impact as double that of soy flour. This is a conservative estimate, and, as expected, the estimated impact is somewhere in between that of a soy protein concentrate and a soy protein isolate. It should also be noted that even if we modelled TVP as soy protein isolate - the most protein substitute ingredient with the most intense environmental impact – the impact of the final alternative product would still be significantly less than that of its meat counterpart.	N/A

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Key assumptions (3/3)

Ingredient(s)	Assumption	Source
All protein substitute ingredients	**Estimation of unavailable data:** GHG and land use data on all protein substitute ingredients was from Europe. To estimate the impact in the United States and China, we adjusted the GHG emissions produced by each ingredient based on the kWh of electricity used in the processing phase, and the relative emissions intensities of the national grids. Land use impacts have not been adjusted to different regions.	BP (2019), IEA (2019), PwC analysis
All protein substitute ingredients	**Estimation of unavailable data:** We were not able to find a study on the water consumption impacts of the protein substitute ingredients. Therefore, water consumption is estimated based on the blue water consumption of the whole ingredient (e.g. soybean, pea) and scaled up based on the weight of raw input required to produce a kg of product. We assume that water consumption in the processing phase is immaterial.	N/A
All plant-based products	**Estimation of unavailable data:** Impacts from combining the individual ingredients within each recipe to produce the alternative are excluded from the analysis, due to lack of data availability.	N/A
All protein substitute ingredients	We assume that all farming for protein substitute ingredients are assumed to be a conventional system.	N/A
All protein substitute ingredients	We assume that all ingredients are produced locally and/or the transport impacts of producing the ingredients is negligible to the overall impact.	N/A
All protein substitute ingredients	We assume that 80% of the land use impact occurs in the crop farming phase and 20% occurs within the production phase. Adjusting this assumption makes very little difference to the overall impact.	N/A
Oils (sunflower, coconut, rapeseed)	Global values have been used for all oil ingredients. No electricity adjustments for GHG emissions have been made, as electricity consumption data was not provided in the studies.	N/A

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

Valuation

Impact valuation

To enable comparison between different types of environmental impact (GHGs, land use, and water consumption), this study converts environmental quantities into monetary units using PwC's location-specific valuation coefficients. These coefficients represent the cost to society from different types of environmental emissions and resource use. Detailed papers describing the methodologies behind these coefficients is publicly available on the PwC website. The methodologies have been reviewed by the Independent Methodology Review Panel established by the Natural Capital Coalition.

A brief overview of each impact methodology used in this paper provided below. For more details, please refer to the methodology papers on the PwC website, linked above.

Table 29: Impact valuation approaches

Environmental impact	Description	Valuation approach	Variation by location
Greenhouse gases 	Agriculture, deforestation, electricity generation, fuel use, and other activities produce greenhouse gases, which contribute to global heating. Climate change resulting from this global heating leads to numerous impacts on human health, ecosystem services, and economic productivity.	PwC uses a Social Cost of Carbon ("SCC") to value the damage from current and future climate change attributable to each tonne of carbon dioxide equivalent ("tCO_2e") released in a given year. The approach involves a meta-analysis of estimates of the SCC from a range of peer reviewed studies.	Not applicable. The SCC is a global coefficient, which does not vary by location.
Land use 	Natural ecosystems provide essential services which support economic activity and human wellbeing. These services include: stable, predictable climate; crop pollination; fertile soils; clean water; recreation and tourism; food; fuel; and fibre. A proportion of the annual flow of these services is lost if natural ecosystems are converted or degraded. This will vary by the type of land use: for example, grazing will have a lower impact on the land than crop monoculture, which will in turn be less detrimental than intensive barn/feedlot systems.	PwC's valuation approach draws on peer-reviewed literature to value different types of natural ecosystems in different locations. It then estimates the proportion of these ecosystem services lost compared to natural state ecosystems. The impact of each type of land use is modelled based on changes in biomass, species richness, and soil organic carbon.	The social cost of land use will vary depending on the natural ecosystem(s) in a particular location. Coefficients are calculated at a country level based on an average ecosystem; intra-country variation is not accounted for.
Water consumption 	Domestic, agricultural, and industrial water consumption can lead to reduced water availability for other purposes, particularly in areas where water scarcity is an issue. This has resulting health and economic impacts.	PwC's valuation approach measures how increased water stress can result in higher rates of waterborne disease and malnutrition, due to reduced availability of clean water for drinking and agriculture. These health impacts are then valued using the Value of a Statistical Life. The methodology also captures the cost of replenishing reduced groundwater stocks.	The social cost of water consumption will vary depending on the level of water stress in a particular location. Coefficients are calculated at a country level based on average water stress; intra-country variation is not accounted for.

Source: PwC analysis prepared in connection with "Environmental impacts of animal and plant-based food" prepared solely for the purpose and on the terms exclusively agreed with Blue Horizon.

References

Footnotes (1/4)

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12. FAOSTAT Statistical Database (2020)

13. Figures calculated by applying the environmental impact intensities from this study to FAO global meat consumption data.

14. Based on the assumption that 15 trees sequester 1 tonne of CO_2e. https://carbonneutral.com.au/faqs/

Footnotes (2/4)

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