PLANT BASED ALTERNATIVES

The environmental sustainability and health implications of plant-based proteins and plant-based meat alternatives

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CONTENTS

EXECUTIVE SUMMARY

Plant-based alternatives to meat and dairy products are increasing in popularity and have been identified as having an important role in the much-needed transition from production and consumption of animal proteins to more plant-based proteins. Along with this increase
in popularity is the need to assess the environmental and health implications of these products in the context of healthy and sustainable diets, compared with animal-based equivalents.

These products can play a role in shifting the protein transition and sustainable food systems owing to their convenience and the variety they can provide within the context of a balanced diet. However, these products are not a silver bullet solution and consideration should be given to how they are produced and how they are used in products and meals, as with any other food products. Food businesses, manufacturers and citizens must not lose sight of the benefits and importance of minimally processed plant-based proteins (e.g., legumes, pulses, nuts, grains) amid the hype of new innovations. This report provides a high-level insight into the basis of some of the key sustainability and nutritional aspects of five best-selling plant-based meat and dairy alternative products, five minimally processed plant-based proteins and three common secondary ingredients found in alternatives.

Substituting animal-based protein products (such as sausages, burgers, milk, meatballs and chicken pieces) with plant-based protein alternatives offers significant environmental benefits and is linked to limited social sustainability issues such as land rights or fair labour practices. These benefits span many indicators, including lower greenhouse gas emissions, more efficient land and water use, and reduced habitat loss and energy use.

The extent of environmental savings varies by plant-based alternative product and by environmental indicator chosen. Overall, the environmental savings associated with substituting meat with plant-based protein alternatives are most acute for beef burgers and pork sausages, with water and land use reduced by over 90% and 85% respectively.

Diets high in unprocessed plant-based foods have been demonstrated to have positive impacts on several health outcomes, including type 2 diabetes, cardiovascular health, and premature mortality[1,2,3]. However, plant-based meat and dairy alternatives are often awarded a 'health halo', as many believe the presence of plant ingredients signifies a healthier way of eating when this is not always the case.

Generally, plant-based products are higher in fibre, good sources of protein and lower in fat (e.g., mycoprotein sausage outperforms pork sausages, nutritionally). However, some plant-based products have high levels of fat, sugar and/or salt – ingredients that are problematic for our health if overconsumed, as was seen in the meatball and chicken pieces examples given later.

Certain essential micronutrients may be easily missed when removing or limiting meat and/or dairy from one's diet. Therefore, when choosing more plant-based products, these micronutrients need to be considered and well planned.

'Whole foods' in a diet are more nutritious and can help to increase diversity in our diets than more processed plant-based products. However, we found that more processed plant-based products can play a role in helping to reduce the consumption of food products with high environmental impact (meat and dairy), while increasing convenience and variety within the diet. But, as with the 'less but better' approach to animal-based products, plant-based should also come from better production systems that use agroecological regenerative and sustainable agricultural practices.

"Agroecological approaches to food and agricultural systems can protect, manage, and restore nature, while providing healthy food and securing livelihoods[4]."

RECOMMENDATIONS

Demand for plant-based meat and dairy alternatives is rising and, while many food companies (retailers, food service and manufacturers) are already starting to diversify their protein sales and procurement, the pace of change needs to increase to provide the added stimulus to the much-needed behavioural shift. Food companies selling plant-based alternatives to animal products to meet their emission targets (e.g., greenhouse gas emissions) must also consider what impact they can have on other environmental indicators as well as meeting nutritional requirements and health concerns. The outcomes of this research are intended to inform food companies' strategies to encourage the adoption of healthier and more sustainable eating in their businesses.

MENU AND PRODUCT DEVELOPMENT

Pay attention to the potential of pulses.

Minimally processed plant proteins, such as lentils, peas, or soy, performed better nutritionally and environmentally in this research. So, minimising the processing of ingredients and improving nutritional criteria (e.g., lower salt and saturated fats, micronutrient enrichment) should be prioritised when purchasing or developing new products. While not part of the research, more traditional replacements such as tofu and tempeh are also good options.

Diversify menus and prioritise plant-based meat alternative substitutions.

This research has demonstrated that environmental savings can be achieved by substituting animal products with plant-based alternatives. However, the potential savings differ depending on the product, the country of origin, and the environmental indicator that is used. Substitutions should be prioritised where the savings are greatest. From the five plant-based alternatives examined in this research, the biggest savings came from beef substitution, and this should therefore be a first step, where feasible and appropriate.

Stay abreast of innovation and development.

The market for plant-based alternatives that can help to shift reliance on animal products is moving quickly, with new companies and innovations constantly arriving on the market. Businesses should stay abreast of these innovations, their potential improved or increased impact on environmental and health impacts and their development towards healthier alternatives and consider which products to invest in and scale up.

Consider health and safety.

Allergens and health risks of novel plant-based alternatives should be considered and integrated into menu decisions, especially as many plant-based products may still contain ingredients such as dairy milk or eggs.

Understand and manage trade-offs.

This research has shown that trade-offs do exist, when making plant-based and animal-based product substitutions, between achieving environmental savings, optimising nutrition, and minimising the level of processing of products. Businesses should work with internal and external stakeholders to identify environmental and nutritional-related sourcing issues and develop solutions and positions that consider and managed the trade-offs.

STRATEGY DEVELOPMENT

Harness purchasing practices and strategies.
For each environmental indicator examined in this research (greenhouse gas emissions, land use, habitat loss and water use), every plant-based alternative offers a different level of savings. Each market and its supply chain will have a different level of importance attached to each environmental indicator. However, businesses need oversight of the environmental indicators and to develop mechanisms within their sourcing strategies and/or tools that will help to identify all environmental indicators, prevent their impact and/or correct for them. This oversight needs to incorporate both the primary protein and secondary ingredients in the plant-based alternatives.

Incorporate nutrition into decisions around plant-based alternatives.
While this research only focuses on a small number of alternatives, it shows that caution should be exercised around levels of salt and saturated fat content in products, as well as products such as plant-based milk where fortification is necessary. These considerations should be incorporated into plant-based alternative product development, due diligence work and procurement principles. Companies should collaborate with and employ dietitians and registered nutritionists to set thresholds that meet nutritional recommendations for plant-based alternatives in their specific countries, and work with suppliers to improve the nutritional quality of these products (e.g., reformulation, reduction in salt content).

Avoid the 'health halo' and support positive communication around wholefood plant-based ingredients.
It is often believed that the presence of plant ingredients makes products healthier, adding a 'health halo' effect to plant-based terminology and products. However, this isn't always the case. The health halo effect happens when a product's healthfulness is overestimated based on a single claim, such as its plant-based ingredients. This often results in people gravitating to, and potentially overconsuming, certain foods deemed 'healthy'.

Some people might regard plant-based burgers or hot dogs as healthier than their meat counterparts owing to their plant-based ingredients. But as well as being clear about the amount and types of plant-based ingredients and the processing methods, it's important to consider the health impacts of the context in which these products are likely to be consumed. For example, plant-based burgers or hot dogs are often served with refined buns, very few vegetables, sauce and chips. In addition to clear communication that helps to avoid any undeserved 'health halo' around products, there should be positive narratives about plant-based eating that focus on reducing animal-based products and increasing plant-based products, prioritising wholefood alternatives and championing diversity of plant-based ingredients.

Support better farming practices.
Even for plant-based alternatives and minimally processed products, businesses can ensure that they and their suppliers are helping to accelerate the transition towards food systems based on agroecological principles. They can do this by looking for opportunities in the market to procure plant-based alternatives and raw/minimally processed commodities that are produced using regenerative farming practices. In addition, they can support farmers who are already engaged in regenerative agriculture practices, and farmers who are not currently engaged in agroecology practices, to develop business plans to integrate agroecology into their production.

Low-cost, equitable plant-based alternatives.
In the short term it is important to focus on the immediate needs of those most affected by the cost-of-living crisis. Yet, if we don't get long-term solutions in place, we will continue to go from one crisis to the next, where the most hard-pressed households will time and again pay the price for future shocks. Working with academia and civil society, businesses need to identify affordable and equitable plant-based alternative options and help citizens access these

TRAINING

Cultivate a sustainability mindset.

From managers to front-of-house staff, and from culinary and product developers to suppliers, people should be supported and trained to understand and manage the trade-offs between environmental impact, nutrition content, and degree of processing in plant-based meat alternatives and how to communicate this to clients and consumers.

Harness chefs' culinary skills.

Chefs around the world have unique culinary skills that can be further advanced to develop delicious and nutritious plant-based recipes that rely on more minimally processed plant-based alternatives (legumes, pulses etc.), as these perform better on environmental and nutritional impacts. For chefs, training should be available, or tools to provide training, on identifying healthy and sustainable alternatives and creating healthy and balanced meals (e.g., identifying salt levels in products or good sources of plant-based proteins).

INTRODUCTION

We know that what we eat and how it is produced has consequences for the health of the planet. Previous research has shown that food systems are responsible for approximately 30% of global greenhouse gas emissions[4] and use about 71% of the world's habitable land for agriculture[3] – more specifically for livestock such as cattle and pigs, and for the crops that feed both us and the livestock. This land use is the most significant cause of deforestation and habitat loss, making it the single largest threat to biodiversity[6]. We need to fix our food system to ensure we can produce healthy and affordable food sustainably.

The remarkable diversity and abundance of species we share this planet with help to form healthy and sustainable food systems globally however, business-as-usual puts this biodiversity risk and is leading to potentially irreversible damage around the world. However, there is something that all citizens and businesses can do to ease the pressure on biodiversity and nature – they can shift towards healthier, more sustainable diets that emphasise foods from plants, based around whole grains, fruits, vegetables, nuts, and legumes. Such diets may include meat and dairy but in significantly smaller proportions in high-consuming countries from agroecological, regenerative and higher animal welfare systems[3].

Plant-based meat and dairy alternatives have been called critical innovations for transforming global diets in that they can promote healthier diets and help diversify protein supply. There is growing public interest in plant-based meat and dairy alternatives, with countries such as the UK, Germany and Austria seeing large spikes in plant-based and vegan trends[6].

This is especially so after the most popular Veganuary to date, where more than half a million people attempted a vegan diet in January 2022[8]. However, this rapid increase in available plant-based products and the increase in consumption is raising questions regarding the environmental and, especially, health credentials of such products.

Some research on the environmental impacts of these products does exist[9,10]. For example, the Beyond Meat-commissioned Life Cycle Assessment found that the Beyond Burger generates 90% fewer greenhouse gas emissions, requires 46% less energy, 99% less water, and 93% less land use than a burger made from US beef[11].

However, questions regarding other aspects of the environmental sustainability (such as biodiversity, energy use, etc.) and the production methods of the primary ingredients of these animal protein alternatives warrant closer attention.

Consumers also have legitimate concerns about the safety and health impact of new food ingredients and data is currently lacking on the nutritional qualities and health impacts of these foods. In addition, many health professionals are concerned about the high levels of fat, salt, and free sugar (sugar added to food or drinks and which should be limited in diets) some of these products may have, which could have unknown consequences on diet-related non-communicable diseases.

This research looked at the environmental and nutritional implications of five best-selling plant-based protein alternative products and their raw or minimally processed plant-based equivalents in five priority markets (see Table 1 on page 7).

Table 1.
Overview of product categories, primary and secondary ingredients, and key markets

Product categories	Branded product	Primary plant protein ingredient	Secondary ingredient	Major markets with confirmed product availability
Plant-based milk alternative	Alpro or Almond-based drink	Water	Almond	UK, Ireland, France, Italy
Sausages	Quorn	Mycoprotein	Rapeseed, palm oil	US, UK, Ireland, France, Italy
Burgers	Beyond Burger	Pea	Rapeseed, coconut oil	US, Canada, UK, France, Italy
Meatballs	Future Farm	Chickpea	Coconut oil	US, Canada, UK, France, Italy, Brazil
Chicken	Vegetarian Butcher	Soy	n/a	US, Canada, UK, Ireland, France, Italy, Brazil
Minimally processed wholefoods	n/a	Soy, chickpea, pea, lentil, almond	n/a	

WHAT IS A PLANT-BASED MEAT ALTERNATIVE?

The plant-based meat and dairy alternatives sector has experienced exceptional growth over the last few years, owing to increased consumer awareness, acceptance, and demand for these products, especially within the context of increasing health and environmental concerns linked to the over-consumption of meat. However, plant-based alternatives to animal-based foods are not a new phenomenon: tofu has been a viable meat substitute in China since 535BCE. Crops including soy (used to make tofu), peas and wheat are being used to create different plant-based alternatives. Other sources, such as fungi (mycoprotein) and pulses (chickpeas, kidney beans, lentils), also exist. However, a new generation of plant-based alternatives is emerging, appearing to mimic the texture, flavour and/or nutrient profiles of meat products, appealing more towards mainstream omnivores. These products generally rely on purified plant protein as their primary ingredient, and include fats such as coconut, palm, or rapeseed oil as their secondary ingredients.

Protein rich plants
(legumes, pulses, whole grains, nuts, seeds)

Traditionally processed products not meant
to mimic meat (tempeh, tofu)

Plant-based meat/dairy alternatives
made to have similar sensory properties
as animal products

COUNTRY CASE STUDY UK:

WHAT IS THE CURRENT CONSUMPTION IN THE UK?

The UK represents a popular and growing market for the consumption of plant-based proteins, with 39% of UK meat eaters reporting that they reduced the amount of meat they consumed in 2019[12]. The UK government collects detailed annual data on UK dietary trends, including consumption of plant-based food groups, in the Defra Family Food dataset.

This dataset showed that plant-based consumption remains significantly below that of meat protein. In 2019, the average Briton purchased a total of 438g/day of animal-based protein products and, while this was a 15% reduction since 1990, this still represents intakes above the recommended quantity of between 45 and 56g/person/day for the average adult in the UK. Plant-based protein purchases have increased by around 24% since 1990 – however, given that the rates of plant-based consumption are still low, this increase only equates to an additional 7g/person/day since 1990, increasing the total to 36g/person/day. While this is in line with the minimum of 33g of plant-based protein per day that WWF's Livewell Plate calls for, it is still a low intake and is even projected to decrease slightly by 2030 (Figure 1).

Animal protein consumption linear trends to 2030

Grams purchased/person/day

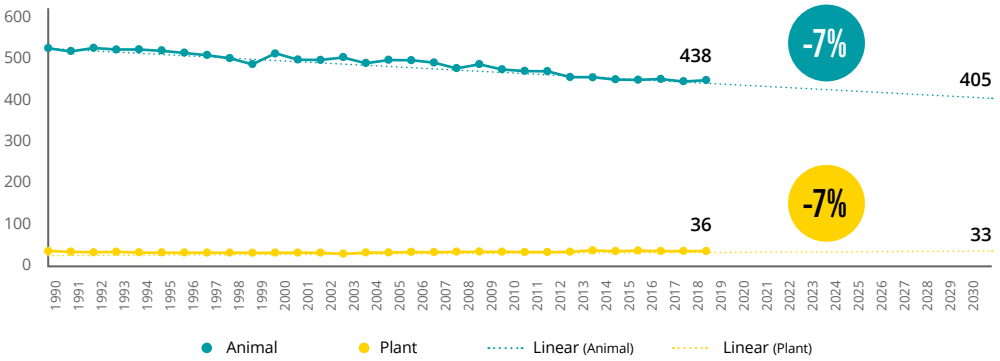

Figure 1:
Grams of animal and plant-based consumption per average UK person per day from 1990–2019 and projected to 2030.[1]

While overall purchasing of animal-based protein is decreasing and the purchasing of plant-protein products is increasing, recent data from the UK shows that the number of people who report eating and drinking plant-based alternatives has nearly doubled from 6.7% (2008–2011) to 13.1% (2017–2019)[13]. However, such increases and decreases are not seen universally across all animal and plant-based product categories. For plant-based products, dairy alternatives are the only product where significantly increased purchasing is observed (Figure 2). Projections to 2030 show that wholefoods, minimally processed legumes, nuts and oilseeds will decrease (Figure 2).

Plant protein consumption linear trends to 2030

Grams purchased/person/day

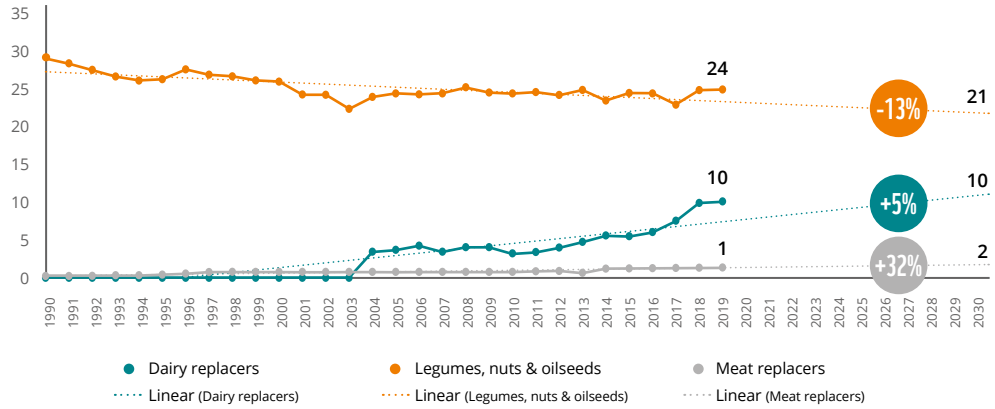

Figure 2:
Purchasing of plant-based protein products per average UK person per day, 1990–2019, and projects to 2030.[2]

While the overall purchasing of animal-based protein products decreased between 1990 and 2019, this downward trend is not true for all types of animal-based protein products. Purchasing of processed meat, poultry and eggs increased between 2009 and 2019 by 8%, 5% and 22% respectively. These increases represent large challenges because, if trends continue for processed meat, a reduction of 77% would be required to reach the recommended 4g/person/day (see Figure 3).

[1] Sum of grams of a certain type of food, not the actual protein content.

[2] Sum of grams of a certain type of food, not the actual protein content.

Animal protein consumption linear trends to 2030

Grams purchased/person/day

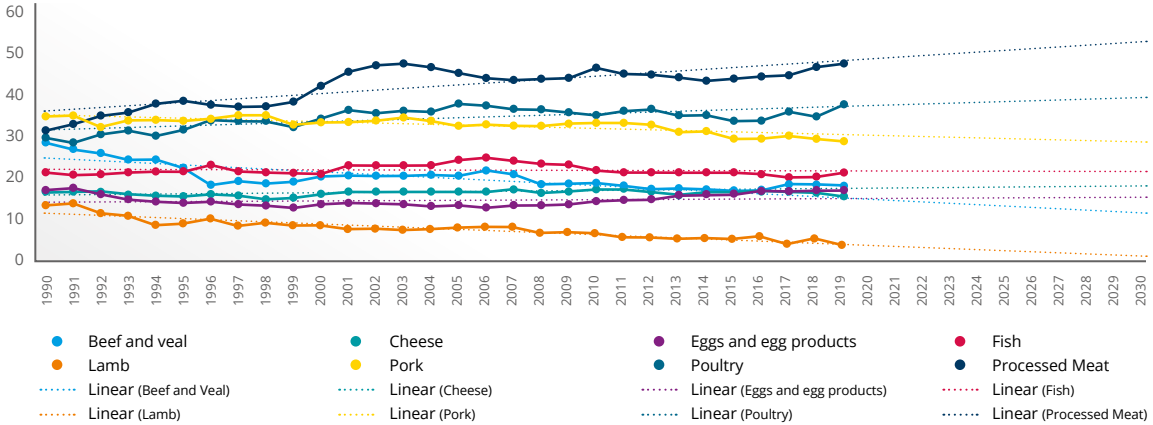

Figure 3:
Purchasing of animal-based protein products per average UK person per day, 1990–2019, with trend line continued to 2030.[3]

This research also investigated whether purchasing of plant-based proteins differed according to age and location. The more processed alternatives had higher rates of purchasing among younger people, whereas purchasing was skewed towards nuts, legumes, and oilseeds in older individuals.

Dairy replacements	Rates of purchasing were higher among younger people and slightly higher for rural populations. For example, the under 30s age category purchases 53% more dairy replacements than the 65–74 age group, and the rural population purchased 9% more than their urban counterparts.
Nuts, legumes, oilseeds	Purchasing is skewed towards older individuals, and slightly more towards urban populations. The under 30s purchased 30% less of this food category than the 65–74 age group, and the urban population purchased 5% less than the rural population.
Meat replacements	Rural or urban location did not impact purchasing of meat replacements in the UK. However, purchasing was much higher among the young, with the under 30s age group purchasing double the quantity of meat replacements than the 65–74 age group.

Table 2.
Demographic trends of plant-based protein consumption

[3] Sum of grams of a certain type of food, not the actual protein content; dairy is excluded from the chart since consumption is much higher.

ENVIRONMENTAL IMPACT

Plant-based meat and dairy alternatives are often promoted for their lower environmental footprint compared with animal products. However, these benefits will depend on a number of factors including the primary ingredients, environmental impact assessed and location. This analysis found that substituting animal-based protein products (such as sausages, burgers, milk, meatballs and chicken pieces) with plant-based protein alternatives offers significant environmental benefits (see table 3, orange indicates reductions of plant-based products compared to animal-based products).

The substitution of European pork with mycoprotein, US conventional beef with Beyond Burgers, and Brazilian meatballs with pea-based meatballs, offered very high levels of greenhouse gas savings – 81%, 89% and 89% respectively. Savings from exchanging dairy milk for almond-based milk were more modest but still significant, with savings of 43–47%, depending on the production system (conventional vs organic). Similarly, substituting chicken with What the Cluck chicken resulted in a saving of 48–64% of greenhouse gas emissions.

Water use reduction was most dramatic when comparing conventional US beef with Beyond Burgers, where 99% of water use is saved from a substitution (the equivalent of 217 litres per burger). Pork substitution with mycoprotein also offered significant savings, at 87% or 5,219 litres per kg.

Substituting Brazilian beef meatballs with pea-based meatballs offered the highest percentage of land saving, at 97%. Substituting conventional US beef with Beyond Burgers also offered large savings on land use, with reductions of 85%, or 3.5 square metres per burger. This is unsurprising, given that beef production requires very large quantities of land. Pork substitution with mycoprotein also reduced land use by 85%. Large land savings with mycoprotein are also unsurprising, given that mycoprotein is industrially produced in large containers.

Habitat loss is an issue within all livestock production systems via, for example, deforestation and/or land degradation leading to direct loss of ecosystems and wildlife habitats. However, some organic or agroecological livestock systems do mitigate this risk to a large extent. All plant-based ingredients are likely to have some impact on local habitat loss, whether it be through monocrop farming, fertiliser use or land use change.

However, mycoprotein seemed to have lower impacts on land use change and, therefore, habitat loss as it is produced and manufactured within factories. But these impacts are much lower and less wide-ranging compared with the equivalent animal-based protein products.

For many plant-based products, information was not available on energy use, leaving significant data gaps. However, for those products where information was available, the picture is mixed. For example, Beyond Burgers offer an energy saving of 46% compared with conventional US burgers; while energy use for almond drink either matches or is higher than the animal-based protein equivalent.

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	Almond drink vs conventional dairy[4]	Vegetarian sausage[5] vs conventional pork (European)[6]	Beyond Burger vs conventional beef burger	Pea-protein meatball[7] vs Irish beef meatballs	Pea-protein meatball vs Brazilian beef meatballs	Vegan chicken vs conventional chicken[8]
Greenhouse gas emissions	-43% (0.6 CO_2e per kg)	-81% (6.7 CO_2e per kg)	-89% (3.3kg CO_2e per burger)	-84% (2.8kg CO_2e per 100g)	-89% (4.1kg CO_2e per 100g)	-48 to -59%[9] (0.9–1.4kg CO_2e per kg)
Water use	-10 to -74% (81–581 litres per kg)	-87% (-89% green, -92% blue, -60% grey) (5,219 litres per kg: 4,531 green, 381 blue, 307 grey)	-99% (217.3 litre per burger)	-74% (760 litres per 100g)	-59% (160 litres per 100g)	Unclear
Land use	-31 to -92% (0.4–1.2 sq m per kg)	-85% (10.2 sq m per kg)	-92% (3.5 sq m per burger)	-88% (316 'points' per 100g)[10]	-97% (1,148 'points' per 100g)	Very significant reduction in risk of deforestation and land use change in South American countries from soy
Habitat loss	Although habitat losses are incurred from almond drink production, these are less pervasive than conventional dairy	Pork production is one of the largest consumers of soy from South America, a hotspot for deforestation. Mycoprotein substitution mitigates this risk	Significant savings of habitat loss from plant-based substitution	Reduction in risk to habitat loss	Very significant reduction in risk to habitat loss	Unclear
Energy demand	No savings	Unclear	-46% (5.3MJ per burger)	-44% (6.8MJ per 100g)	-56% (11.2MJ per 100g)	Unclear

Table 3.
Differences in impact of plant-based products and animal-based products from conventional production

[4] This is an approximation based on the ingredient profile for an almond drink consumed in Sweden.

[5] Comparison to mycoprotein, key 'pork' ingredient, not whole sausage, for which information was unavailable.

[6] Comparison is to pork (N.B. not pork sausages) from typical European housed farming.

[7] No information was found on the environmental impact of Future Farm Meatballs or textured soy protein – its primary protein ingredient. However, it does contain protein from peas and chickpeas and, therefore, the next best option for comparison in the literature was meatballs made from pea protein.

[8] Figures are whole carcass weight chicken.

[9] Figures cover only soy protein concentrate, which accounts for 88% of What the Cluck Chicken ingredients. Assumes soy is sourced from Canada, but company sourcing geographies are not clear. Canadian CO2e per kg of soybean is higher than other non-South American producing countries, such as the US, Italy, China and Ukraine, and can therefore be considered the upper limit, and the figure is likely to present the minimum possible CO2e savings.

[10] Authors are not clear on how land use 'points' are calculated, so we were not able to translate back to a land equivalent.

SUSTAINABLE SOURCING

Many plant-based alternatives include agricultural crops such as soy, palm oil and almonds, among others, which are grown in diverse regions around the world. These ingredients have been controversial – for example, palm oil and soy production can lead to deforestation, while growing almonds can lead to droughts. As such, this analysis examined the likely provenance and certification schemes for key markets, and high-level key sustainable sourcing issues, such as deforestation or labour rights. Overall, each of these products is fairly low-risk in terms of environmental and social issues and they are available with organic certification in the majority of key markets this analysis looked at, although there are some potential environmental issues associated with soy and almond production.

	Soy	Lentils	Chickpeas	Almonds	Peas	Mycoprotein
Summary	High quality protein commonly used in animal feed and as meat-alternative for human consumption. 75% of global soy output is used in animal feed, 25% is used for human consumption, biofuels and other industrial purposes	Part of the legume family and widely available as dried, canned ingredients or in processed protein alternatives. There are many different lentils with different uses as protein alternatives – brown, green, red lentils	Not widely used in processed protein alternatives. There are two main types of chickpeas (Desi chickpeas – for chickpea flour; Kabuli chickpeas – for canned or cooked chickpeas)	Nut tree, most commonly used in dairy milk substitutes	Part of the legume family, green peas and yellow split peas are mainly used for alternatives. Similar to lentils, they create fewer greenhouse gas emissions than other crops and can sequester carbon in soil	Widely used protein source in Quorn products with a number of new brands emerging *(3F BIO, Mycorena, EnyTech)*
Methods of processing for plant-based alternatives	Mince, protein isolates and concentrates	Processed, raw form, dried, canned, extruded for dairy milk substitute	Crushed chickpeas or chickpea flour	Ground and extruded for dairy milk substitute	Protein isolate	Protein made from fermented fungi spores of *Fusarium venenatum* fungus and fed on glucose and other nutrients

Key sourcing regions	South America (i.e. Amazon and Cerrado) (animal feed) China, India, Canada, Europe (human consumption, likely in plant-based alternatives)	Canada (largest producer in world) supplies all key regions Turkey supplies to Europe and North America	Europe is limited Australia, India (Desi chickpeas) North America (Kabuli chickpea)	North America (80%), Australia, Spain (smaller percentages)	More commonly sourced domestically. Top five producing countries: China, India, US, France, Egypt Limited data available on sourcing countries for pea as a protein alternative	Available in all four key markets (UK and Ireland, France, Australia, North America), except Brazil
Certification	Widely used and wide range (e.g. RTRS, Organic)	Organic, Fair Trade	Organic	Organic, however water issues are not addressed by organic certification	Organic	N/A, use free-range eggs in UK market
Social issues	Land rights	No significant social/ labour issues. Some countries (e.g. India and Turkey) are relatively high risk for labour issues	No significant issues found	No significant issues found	No significant issues found	No significant issues found
Environmental issues	Deforestation and land use change (e.g. Amazon and Cerrado) Biodiversity and pesticide use (monoculture involving heavy use of pesticides)	Nitrogen fixers and so require fewer chemical inputs Do not require irrigation and well suited to arid/dry climates without unsustainable water use	Nitrogen fixers and so require fewer chemical inputs Insect-pollinated, responsible planting could boost wildlife and biodiversity in growing areas Higher water footprint than other pulses, issue in places where rainfall isn't sufficient (in parts of west Asia and north Africa)	California has made progress on reducing amount of water through more efficient irrigation techniques. However, there is still an issue with water use, pesticide use and damage to bee population	Pesticide usage. However, this is not as significant as other crops owing to nitrogen fixation capabilities	Fed on glucose (wheat-corn) which has certain pesticide issues Water footprint higher than other protein alternative products, but owing to manufacturing processes still 10 times less than water footprint of beef and chicken

Table 4.
Overview of sustainable sourcing issues for primary ingredients in plant-based alternatives

	Palm Oil	Coconut Oil	Rapeseed
Summary	Secondary ingredient in alternatives to bind ingredients and enhance flavour	Secondary ingredient in alternatives to bind ingredients and enhance flavour	Also known as rape or oilseed rape, favoured due to affordability and versatility. Secondary ingredient in alternatives to bind ingredients and enhance flavour
Methods of processing	Palm oil, palm kernel	Coconut oil or fat, coconut milk is used as a dairy milk replacement, coconut flesh can be eaten or processed into oil or drinks, inner liquid is used as coconut water	
Certification	Roundtable on Sustainable Palm Oil (RSPO)	Still lacks a unified process available to customers in key markets. Fairtrade USA launched coconut certification	Organic certification is widely available
Key sourcing regions	Indonesia and Malaysia are the main sourcing regions, with smaller quantities coming from Papua New Guinea, Thailand and the Philippines	Indonesia, the Philippines and India are the main producers of coconuts	All key markets produce rapeseed oil domestically. Canada is the largest global producer, while Brazil produces modest quantities
Social issues	Issues with land use rights of Indigenous Peoples (e.g., Indonesia), forced and child labour (Indonesia and Malaysia) and migrant labour conditions (wages, health and safety, gender discrimination)	Mostly produced by smallholder farmers. Coconut pickers often receive little income and many are below the poverty line (in the Philippines earning less than a dollar a day) Some issues of monkey labour in Thai coconut production	No significant labour issues
Environmental issues	Deforestation and land use, especially of peat land through palm oil cultivation	Mainly grow on sandy and coastal soils, causing minimal impact on deforestation. However, they are linked to biodiversity loss as many regions are home to unique species	Not linked to deforestation but some studies suggest it causes worse impacts on acidification, eutrophication and smog compared with palm oil, owing to less productive use of land than palm and soy oil production High usage of fertilisers, insecticides and pesticides

Table 5.
Overview of sustainable sourcing issues for secondary ingredients in plant-based alternatives

PLANT-BASED DIETS

There is scientific consensus that prioritising plants in the diet can lead to better outcomes for the health of people and the planet[3]. However, plant-based diets need to be well-planned to meet dietary needs. There are nutrients that are either not present, present at low quantities, or less bioavailable in plants, which may easily be missed when removing or limiting meat and/or dairy from the diet. These include essential amino acids, calcium, iron, zinc, iodine, and vitamin B12 (see tables 6 and 7).

It is a common misconception that plant based diets do not provide all essential amino acids (building blocks of protein which our bodies cannot make and therefore have to be supplied by the diet). However, whilst some plant protein foods don't contain all essential amino acids (incomplete), it is perfectly possible to get the full spectrum if protein is consumed from a variety of different plant sources and from those that will complement for the limited amino acids in certain plant based foods[14]. There is often concern that reducing meat and dairy intake will lead to reduced protein intake, but studies consistently demonstrate that the UK average protein intake exceeds recommendations for all age groups, including by vegans[15].

Food	Limited Amino Acid	Complementary food
Beans	Methionine	Grains, nuts, seeds
Grains	Lysine, threonine	Legumes
Nuts/seeds	Lysine	Legumes
Vegetables	Methionine	Grains, nuts, seeds
Corn	Tryptophan, lysine	Legumes

Table 6.
Examples of pairing complementary amino acid sources

The bioavailability of nutrients is also important to consider in the context of plant-based diets. This refers to the body's ability to utilise a specific type of nutrient. As such, high bioavailability means that a protein is easy to digest, absorb and convert into other proteins.

It is important to note that there are varying differences in the bioavailability of some micronutrients within a food (e.g., a natural component) compared with those added in as a supplement (e.g., fortification).

For example, if a product contains a good source of iron, the absorption of this could be inhibited if the recipe also contains a high polyphenol ingredient, such as spinach.

Conversely, if it contains vitamin C, this will increase the absorption of iron. In a similar way, the lactose in dairy milk aids the absorption of calcium. The absorption of calcium can be further assisted through fortification of plant-based milk with vitamin D, alongside calcium. The oxalate in almonds may also influence the bioavailability of calcium, but almond drink has such low quantities that this should not pose a problem (Alpro Almond only contains 2.3% almonds). Interestingly, there is some evidence to suggest that individuals can adapt their ability to absorb nutrients once their plant-based eating habits become established[16].

The context in which plant-based alternatives are eaten is also relevant. For example, if a product such as a plant-based burger is within healthy eating criteria (e.g., low in fat, salt and sugar), this may not be the case when it is actually consumed, as products such as burgers, hotdogs, and so on, tend to be eaten with chips and condiments high in sugar, salt and fat.

Nutrient	Function	Plant/animal comparison	Additional information
Protein	Essential for growth, maintenance, repair of all body cells. Provides energy and essential amino acids.	Animal-based 'complete proteins' contain all nine essential amino acids (EAA). Many plant-based proteins contain all EAA but lysine and methionine are often present in lower amounts.	Elderly and those with greater muscle synthesis (athletes) need greater proportion of protein if coming solely from plants. UK consumption exceeds recommendations in all age groups, including vegans.
Fats	Required for a range of bodily processes and to maintain the normal structure of cells in the body. They also carry essential fat-soluble vitamins and are important for their absorption.	Essential fats are predominantly found in oily fish. There are some plant-based sources (linseeds, flax seeds, chia seeds, hemp seeds, walnuts, rapeseed oil, soybeans and soybean oil), but the amounts contained are considerably limited.	On average, all age groups consume less than the recommended amount of oily fish, even those not following a vegan or vegetarian diet. In the UK, much of the UK population are exceeding the guideline maximum intakes of total and saturated fats.
Iron	Helps to make red blood cells, which carry oxygen around the body. It also helps the immune system to work as it should. It helps the brain to function normally and supports growth and development in childhood.	Good sources of iron include red meat, beans, pulses, nuts and seeds, fish, quinoa, wholemeal bread and dried fruit. Iron from plant sources is often less bioavailable. It is inhibited by phytates, polyphenols and tannins naturally found in some plant foods. There are a number of ways to optimise consumption.	The main sources of iron in UK diets, across all age groups, are cereal foods (41–55% of total iron intake) and meat (12–21% contribution). Men are unlikely to struggle to meet iron requirements from plant sources due to relatively lower iron requirements. However, in more vulnerable groups, such as toddlers, teenage girls and women of childbearing age, low iron intake is a concern.
Vitamin B12	Helps the body to keep the nervous system healthy, makes red blood cells, metabolises folate and helps the body use energy.	Found exclusively in animal-based foods. Many plant-based products are now fortified with vitamin B12, including some breakfast cereals, plant-based drinks and yoghurt alternatives.	Can be a nutrient of concern for vegan diets. Nutritional yeast flakes or yeast extract are good sources of vitamin B12, however can be high in salt.
Calcium	Helps build strong bones and teeth, is important for muscle contraction and ensures the blood clots properly.	Milk and milk-based products supply much of the UK population's calcium intake. However, it is also found in white and brown flour milled in the UK (which legally must be fortified with calcium) and associated cereal products. Some vegetables also contain small amounts of calcium.	Soya foods such as calcium-set tofu have similar bioavailability to milk and so can be considered good alternatives to dairy.

Zinc	Involved in a multitude of biological processes.	Animal-based foods (meat, milk and milk products) are a significant source of zinc in the UK diet. However, good plant sources of zinc include mycoprotein, fortified breakfast cereals, soaked beans and lentils.	Zinc intakes can be compromised in teenage girls.
Iodine	Important in the production of thyroid hormones and plays a vital role in the cognitive development of a growing foetus and young children.	Data can vary significantly between products as iodine content is highly variable, depending on seasons and farming practices. Iodine in milk is a by-product of iodine added to animal feed. It is advisable that any plant-based drinks are fortified with iodine (in addition to vitamin B12, calcium and vitamin D). Seaweed is a plant based source but iodine content is highly variable and can reach dangerous levels in kelp particularly.	UK is a mildly iodine deficient country. Girls and women of child bearing age, as well as UK vegans, are vulnerable to deficiency.
Vitamin D	Helps regulate calcium and phosphate in the body which keeps teeth, bones and muscles healthy.	Few dietary sources. The UK government recommends everyone (regardless of diet) takes a 10mcg supplement of vitamin D during the autumn and winter months.	
Selenium	Protects the cells in our bodies against damage. It also helps the immune and thyroid systems to work as they should, helps maintain normal nails and hair and normal fertility in males.	Most selenium in UK diets comes from cereals, meat and seafood, and intakes may be compromised if animal-based foods are limited.	The elderly and those following plant based diets can be at risk of deficiency.
Fibre	Keeps the digestive system healthy.	Plant-based foods contain much higher levels of fibre.	UK diets are well below the recommended daily intake of 30g
Sodium/salt	Balances the amount and distribution of water in our bodies, a key role in the control of blood pressure.	Found naturally in some foods (e.g. dairy), added to others (e.g. cured meats) – most commonly used as table salt.	Recommended intake for adults is no more than 2.4g sodium/day (equivalent to 6g salt/ day). In the UK, most people consume more than the recommended daily amount.

Table 7.
Summary of key nutrients relevant to plant-based foods, their functions, and their availability in plant-foods compared with animal foods.

NUTRITION IMPLICATIONS

Similarly to conventional animal products, all plant-based meat and dairy alternatives are composed of water, protein, fat and micronutrients. However, the exact nutritional values are dependent on the recipes and the varying amounts of these nutrients used to create these products. Using well-established nutrition profiling models (Traffic light, High Fat Salt and Sugar, and the European Food Safety Authority (EFSA) protein claims), we analysed the nutritional values of the plant-based alternative products and minimally processed commodities (appendix).

Per 100g of product	Traffic light labelling				Advertising pre-9pm?	Protein claim?	NOVA* classification
	Fat	Sat Fat	Sugar	Salt			
Alpro Almond drink	Low	Low	Low	Low		None	Group 4
Dairy milk	Medium	Medium	Medium	Low		High in protein	Group 3
Quorn sausages	Medium	Low	Low	Medium		High in protein	Group 4
Pork sausages	High	High	Low	High		Source of protein	Group 3
Beyond Burger	High	High	Low	Medium		High in protein	Group 4
Beef burgers	High	High	Low	Medium		High in protein	Group 3
Future Farm meatballs	Medium	High	Low	Medium		High in protein	Group 4
Beef meatballs	Medium	High	Low	Medium		High in protein	Group 3
What the Cluck chicken	Medium	Low	Low	Medium		High in protein	Group 4
Chicken breast	Low	Low	Low	Low		High in protein	Group 3
Quorn Chicken pieces	Low	Low	Low	Medium		High in protein	Group 4
Soy beans	Medium	Low	Low	Low		High in protein	Group 1
Chickpeas	Low	Low	Low	Low		High in protein	Group 1
Peas	Low	Low	Low	Low		High in protein	Group 1
Lentils	Low	Low	Low	Low		High in protein	Group 1
Almonds	High	High	Low	Low		Source of protein	Group 1

Key (see appendix for definitions and thresholds):

	High in stated nutrient
	Medium in stated nutrient
	Low in stated nutrient
High in protein	At least 20% energy from food/drink is protein
Source of protein	At least 12% energy from food/drink is protein
Group 1	Product considered part of Group 1 (minimally processed) in NOVA classification
Group 4	Product considered part of Group 4 (ultra-processed) in NOVA classification

Table 8.
Overview of plant-based products and nutrition profiling models

* See page 24 for definition of NOVA classification

PLANT-BASED MILK

Plant-based milk alternatives can often be perceived as healthy alternatives to dairy. However, most are largely composed of water with varying amounts of solids from the plant material (soy and oat milk alternatives typically contain about 10% solids, and nut alternatives typically contain around 2–3%). Consequently, plant-based milk alternatives are not, in their natural form, nutritionally comparable with dairy milk.

Many companies fortify their products to include some of the main micronutrients lacking in non-fortified versions (regulatory standards mean this is not possible with organic varieties). However, this is variable across the marketplace, and there is currently no standard composition or labelling required for these products.

Ideally, they should be, at a minimum, fortified with calcium, vitamin D, vitamin B12 and iodine. Soy and pea milk are the closest nutritionally to dairy milk as they contain higher levels of complete protein and would therefore be the most preferable substitute from an overall nutritional perspective.

While not represented in the products, it can be noted that oat-based milk alternatives contain free sugars (whose quantity it is recommended to limit) from the processing of the oats, even though they may be labelled as 'no added sugar' or 'unsweetened'.

PLANT-BASED SAUSAGE

The plant-based product from Quorn in this analysis is made of mycoprotein. The main ingredient is Fusarium venenatum, a type of fungus that occurs naturally in the soil. *Fusarium venenatum* is fed with human-grade carbohydrate in large air-lift fermenters before the liquid is separated by centrifugation to leave behind the mycoprotein 'dough', closely resembling bread dough.

Fungi are separate from plants and animals, and include mushrooms as well as a huge variety of micro-fungi species, such as Fusarium and yeasts.

Mycoprotein sausage products are a preferable alternative to pork sausages owing to high levels of protein and lower levels of saturated fat. Similar to animal-based products, mycoprotein is a complete protein and so contains all the essential amino acids that our bodies cannot make themselves (and therefore have to be provided by food or drink). As with all processed products, salt content is a problem. The Quorn sausage is lower in salt and in fat and saturated fat than the pork sausage, however it is has medium content on fat and salt, according to the UK government's criteria, which may be exacerbated by the likelihood that these products will be cooked and served with oils and sauces with similarly high levels of salt, fat and/or sugar.

PLANT-BASED BURGERS

Beyond Burger is a plant-based burger that is designed to look, cook and taste like beef. Both products are high in fat and saturated fat, and medium in salt, according to the UK government's criteria, which may be exacerbated by the likelihood that these products will be cooked and served with oils and sauces with similarly high levels of salt, fat and/or sugar. Therefore, neither could be regarded as a 'healthy product' and neither would be suitable for advertising on UK TV pre 9pm, online, or via the London Transport network (and, in future, possibly other cities).

The nutritional advantages of the Beyond Burger are that it contains fewer calories and, although the fat and saturated fat content is rated high, it is still lower than the beef equivalent. Ultimately, Beyond Burgers should be regarded as something to eat occasionally, rather than routinely – similar, in fact, to the guidance for standard burgers.

PLANT-BASED MEATBALLS

Future Farm products are classified as high in fat, salt and sugar, according to the Government nutrient profiling model and are becoming increasingly known for their ability to 'bleed' just like animal products. Similar to the burger category, both of the meatball products (beef and chickpea protein-based meatballs) are high in saturated fat, medium in fat and salt. However, unlike the burgers, neither can be deemed nutritionally better than the other. For example, although the beef meatballs contain higher levels of fat than predominantly chickpea protein-based Future Farm meatballs, when this is broken into types of fat, levels of saturated fat are actually lower in beef meatballs. While the Future Farm meatballs are lower in salt (also a key public health concern), this is not at a low level.

PLANT-BASED CHICKEN PIECES

What the Cluck chicken is mainly based on a soy structure (water and soy protein concentrate), with only a couple of other ingredients. Although commonly reported, soy does not disrupt hormones. The phytoesterols in soy, which have a similar structure to human oestrogen, act differently in the body than oestrogen and have been associated with lowering cholesterol[17]. From a nutritional perspective, chicken is a great source of complete protein, and low in fat, sugar and salt. The What the Cluck product does not fare as well nutritionally because of its significantly higher levels of salt. The salt content would be a key concern, especially as this tends to rate as a fairly bland product, so it is likely that additional seasoning would be added. Following this original analysis, authors have been made aware that the What the Cluck chicken pieces product has been reformulated to address the issues with salt levels (changed from 1.7 g/100g to 1.1 g/100g) *(see technical report for link).*

WHOLE FOOD PLANT-BASED PRODUCTS

Whole food plant-based products, or minimally processed ingredients such as soybeans, chickpeas, lentils, peas and almonds, are all excellent nutritional options and there are many opportunities to include more of these ingredients and products in our diet. The products featured in this report are naturally low in salt and sugar, and all, other than almonds, are naturally low in fat. They provide a range of macro and micronutrients and are good sources of plant-based protein and fibre, especially soy, which is a 'complete protein' as it contains all essential amino acids.

Almonds are highly energy dense and, as such, score high for fat. However, this is because the scoring model is based on 'per 100g' of product. They contain a large proportion of monounsaturated fat, which helps to protect the heart by maintaining levels of HDL (good) cholesterol and reducing levels of LDL (bad) cholesterol. The recommended daily portion size for nuts is 30g.

ADDITIVES

The inclusion of additives in plant-based meat and dairy alternatives has generated some scepticism regarding these products. Of the products assessed in this report, many of the processed options have fairly similar additives to their meat counterparts (e.g., sausages and burgers). However, a few plant-based versions contain more ingredients, such as gums, flavours, preservatives and emulsifiers, all used to impart flavour, colour and texture to the products. The tables below list the ingredients of some of the plant-based products; the rest of the products analysed can be found in the technical report. All the products contain additives, with the largest difference being between the plant-based almond drink alternative and dairy milk, which has one labelled ingredient (milk). The plant-based drink has water, almonds, sugar, calcium (tri-calcium phosphate), sea salt, stabilisers (locust bean gum, gellan gum), emulsifier (lecithins – sunflower), natural flavouring, vitamins (B2, B12, E, D2) (Table 9).

It is important to note, especially with fortified plant-based drinks, that additives help with the dispersion of the micronutrients throughout the product and help reduce misuse (such as consumers failing to shake a container to disperse settled micronutrients). All the food additives in the products assessed are permitted and considered safe to use under EU and UK regulations. While citizens may be concerned and are seeking out products with 'clean labels', it should be noted that there should not be any concerns about additives approved by the European Food Safety Authority (EFSA) and Food Standards Agency (FSA). Any health implication would only arise with excessive continued consumption. It is interesting to note there is some controversy regarding certain additives (e.g., sodium nitrite and titanium dioxide, though these are not found in the report's products), acknowledgement of limited research on the potential interactions between additives and their affect on the human body[19], as well as examples of certain food additives not being tolerable to some consumers for example causing gastrointestinal reactions[20].


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FOOD ADDITIVES

Manufacturers must provide information on any additives used in their food products. All ingredients on labels must be stated in descending order of weight when present at more than 2% in the product. In the EU and similarly in the UK, new food additives must be approved for use in foods. The Food Standards Agency (FSA) provides further guidance on food additive authorisation in the UK and also provides a list of approved additives and E numbers[18, 19].

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Table 9.
Ingredients in Alpro Almond Original

Ingredient	Common use / other information
Water	The vast majority of the product is water
Almonds	Only 2.3% of the finished product is almonds, so minimal nutritional benefit
Sugar	Added for flavour but there are also 'no sugar' variants available
Calcium (tri-calcium phosphate)	This is the manual addition of calcium to the recipe (some reports have shown this is less bioavailable than calcium carbonate, but this is difficult to verify)
Sea salt	Dairy milk has a naturally occurring salty flavour; this mimics it
Stabilisers (locust bean gum, gellan gum)	These help to thicken the liquid and help with texture. Gellan gum is similar to gelatine, but is plant based
Emulsifier (lecithins – sunflower)	This helps consistency, especially keeping the water and the oil from the almonds blended together, and also helps extend shelf life
Natural flavouring	It is not known which one is used, but it is likely to be an almond flavour to enhance the taste perception of the product
Vitamins (B2, B12, E, D2)	These are vitamins that have been added manually to the recipe to imitate the nutritional composition of animal-based milk. The plant-based drink does not contain iodine, which would be optimal

Table 10.
Ingredients in Quorn sausage

Ingredient	Common use / other information
Mycoprotein	41% of the recipe
Rehydrated free range egg white	To bind the ingredients together *(Quorn vegan sausages without egg are also available)*
Vegetable oils	Rapeseed and palm
Onion	For flavour
Rusk	Made from wheat flour, yeast and salt. Helps to control moisture
Natural flavouring	For flavour
Casing	Made from sodium alginate (extracted from brown seaweed), cellulose (a fibre) and starch
Textured wheat protein	This is wheat flour plus a stabiliser (sodium alginate). It can help to stabilise and/or thicken the ingredients
Firming agents	Help to keep the product together and extend the shelf-life: calcium chloride, calcium acetate
Seasoning	Herbs for flavouring (sage and parsley) mixed with a little rapeseed oil
Pea fibre	Used as a bulking agent, but also helps to increase the fibre of the recipe
Barley malt extract	Used as a flavour enhancer
Natural caramelised sugar	To balance the recipe

Table 11.
Ingredients in What the Cluck chicken pieces

Ingredient	Common use / other information
Soy structure	88%; made of water and soy protein concentrate
Spice extracts	For flavour
Natural flavourings	For flavour

PROCESSING

Food processing has an essential role in providing safe, nutritious and edible foods, as well as allowing for food preservation, which can help reduce food waste. However, the term 'processing' is very general, relating to processes that can bring risks or benefits to food products depending on their context. Helpful processing includes heat treatment, which reduces microbial activity and improves digestibility and bioavailability of certain nutrients. Processes that hinder include the formation of undesirable compounds in starchy foods such as acrylamide, a likely carcinogenic by-product of the Maillard reaction, which results in the browning of foods[20].

All the processed products investigated in the report can be classified as either Group 3 for 'processed food' or Group 4 for 'ultra-processed food. As demand is increasing for ultra-processed plant-based alternatives, this may have implications for health. A recent analysis of the healthiness and environmental sustainability of ultra-processed foods found that per 100kcal, ultra-processed and processed foods in the UK had lower nutritional quality, regardless of their total fat, salt and/or sugar content[21]. However, the system has received some criti-cism that ultra-processed foods are a varied group of products, with some products such as shop-bought hummus or wholegrain or enriched bread being classified as ultra-processed, while still be-ing considered nutritious[22, 23]. In terms of health outcomes, obser-vational analysis has found that ultra-processed foods were linked to an increased risk of obesity and overweightness in adults and children[24]. A randomised control trial found that ultra-processed foods led to increased energy intake and weight gain compared with whole foods[25]. However, the mechanisms behind the links between ultra-processed foods, excessive energy intake and negat-ive health outcomes still need investigating, especially considering the trends in consumption. Whether these outcomes are due to the levels of processing, sensory properties or to the average poorer nutritional quality of ultra-processed foods is not clear[20, 26, 27]. Health concerns from ingredients such as gums and flavours com-monly used in these products are unlikely to cause any major health concerns unless there is excessive and continuous con-sumption above EFSA recommendations.

NOVA CLASSIFICATION

NOVA food classification is a system that classifies foods into four groups based on their levels of processing. Group 4 foods are defined as 'ultra-processed', which include snacks, drinks, ready meals and many other products derived from substances that are not used in home kitchens (e.g., protein isolates), and/or cosmetic additives (e.g., emulsifiers). Group 2 represents processed culinary ingredients, such as plant oils (e.g., olive oil, coconut oil), animal fats, sugar, honey, salt, etc. This categorisation is the most widely used in the literature and does provide some benefits in understanding the wide ranges in processed foods. However, care must be taken as the system has received some criticism around the variety of products found in ultra-processed foods (Group 4) while considered nutritious, can be classified as ultra-processed foods (e.g., shop-bought hummus).

Example of NOVA classification processing of Corn[26]

Corn cob Group 1	**Corn oil** Group 2	**Canned corn** Group 3	**Corn snack** Group 4
Unprocessed or minimally processed	Processed culinary ingredients	Processed food	Ultra-processed food
Corn prepared to eat either raw, boiled or grilled without any added culinary ingredients	Obtained from corn by industrial processes	Corn preserved via canning	Corn snack made from ingredients exclusive to industrial processes with sugar, oils and fats, salt, flavours and additives to prolong product life added to product

AREAS FOR FURTHER RESEARCH

This report has identified a number of areas for further research, outlined below. Ultimately, this is a topic on which customer attitudes are evolving rapidly, and new and more sophisticated plant-based products are regularly being launched. Staying abreast of these developments is crucial.

- **Define criteria of acceptable nutritional thresholds that plant-based alternatives should meet to be considered a nutritionally viable substitute.** This is important, especially given that some plant-based alternatives contain high levels of saturated fat, sugar and, especially, salt.

- **Explore cultural acceptance and appetite for plant-based alternatives in each priority market.** Some markets may be more receptive than others to the substitution of meat with plant-based alternatives. For example, Germany and the UK are significant European markets for the consumption of plant-based alternatives, but in France these products have faced a backlash, with meat-related terms, such as 'sausage', being prohibited from use on plant-based alternative product labels. Explore whether an increase in plant-based alternatives links to a substitutive effect in animal-based products.

- **Understand health implications.** Further research is required into the health implications of eating highly processed plant-based alternatives, to examine their role in the complexity of healthy sustainable diets beyond their protein, fat, vitamin and mineral content. All additives used in plant-based products are tested to ensure they are safe, but this still leaves questions regarding the health and safety implications of eating a high volume of these products regularly. Additional caution should be taken by vulnerable populations – children, women of childbearing age and the elderly, who may be at risk of suboptimal nutritional status with lower intakes of animal foods and higher intakes of ultra-processed foods.

- **Investigate any unintended consequences of upscaling plant-protein.** This research found no significant sustainable sourcing issues around plant-based protein products. Further research is required to understand how scaling up the production of plant-based alternatives will affect primary and secondary ingredient production and how the level of displacement of animal-based consumption with plant-based alternatives may affect environmental factors, as well as other actors and groups along the supply chain.

- **Understand price implications of plant-based ingredients and products.** Further research should be conducted to understand price implications of substituting meat ingredients or products with plant ingredients or products. It's likely there would be a range of price implications, given that some plant-based ingredients are relatively cheap, such as soy, whereas others, such as nuts, can be very expensive.

- **Stay abreast of developments around plant-based proteins.** Customer attitudes to and market availability of plant-based protein ingredients and products are changing rapidly. A system should be developed to stay on top of these developments.

- **Expand the scope of research.** This research has focused on a limited number of plant-based products and ingredients. While this sample has provided many useful insights, expanding this further to include more products and ingredients would be valuable for confirming current findings, and may offer potential new findings.

- **Look at food waste.** Food waste is an important metric to look at when evaluating the environmental sustainability of products. Further analysis could compare whether citizens are more likely to waste plant-based meat alternatives compared with animal-based products, whether more plant-based meat alternatives are wasted from lack of uptake (e.g., if they aren't sold, or have shorter sell-by dates). It would also be interesting to understand if any side streams come from these products, and if there are any innovative ways of repurposing these.

- **Support regenerative farming techniques.** Look at opportunities in the market for supporting products or raw commodities that are produced using regenerative farming practices.

CONCLUSION

Purchases of plant-based protein alternatives are increasing in many developed countries. With this increase in demand come concerns around the environmental and nutritional implications of these products. This report found that more processed plant-based alternatives can play an important role in driving healthier and more sustainable diets. The environmental benefits of all plant-based alternative products investigated (Alpro almond drink, Quorn mycoprotein sausages, Beyond Burgers, Future Farm Meatballs and What the Cluck chicken) are unambiguous and significant, whereas the health comparisons show a slightly more nuanced picture. Some plant-based products, such as mycoprotein sausages, are clearly preferable, nutritionally, to meat equivalents. On the other hand, plant-based milks offer inferior nutrition on a number of indicators and should, at a minimum, be fortified with essential micronutrients (calcium, iodine, vitamin B12 and vitamin D).

Wholefood plant-based proteins performed well overall in terms of sustainable sourcing issues in supply chains, and nutrition credentials. One exception to this is almonds, where production uses significant water quantities in drought-prone regions, particularly in California, and fat content means that portion size for almond nuts should be limited to 30 grams. While soy used for livestock feed is strongly linked to deforestation and land use change in South America, this is much less likely to be the case for soy directly consumed by humans, mainly due to legislation in European markets prohibiting direct human consumption of GMO crops. Soy also performs well nutritionally, is low in saturated fat, and is a particularly good source of protein. The research did not raise any significant concerns around allergens, food-borne diseases, or use of additives or gums in plant-based foods, although it should be noted that exclusively plant-based diets should be carefully planned to ensure all micronutrient needs are met.

While this research compared the environmental and health characteristics of five best-selling plant-based meat alternatives, and five minimally processed plant-based proteins, its aim is to provide an insight into the pertinent issues based on a sample of best-selling options. It is not a complete comparison of all the plant-based alternative products and ingredients that are available, nor an in depth look at all the complex health and environmental issues that could arise from substitution. It identifies several other areas for further research, including understanding the level of cultural acceptance of plant-based alternatives across different global markets, as well as greater research into any health implications of excessive consumption of highly processed plant-based


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food products. Ultimately, this is a topic on which customer attitudes are evolving rapidly. New and more sophisticated plant-based products are regularly being launched, and a system should be put in place to stay abreast of these developments.

Despite the promising potential of plant-based protein alternatives, particularly for environmental savings, their consumption still lags behind that of meat. In the UK in 2019, the volume of purchases of plant-based protein products was equal to just 8% of the volume of animal-based protein products. While in the UK market the purchasing of plant foods is increasing, and that of meat products is overall decreasing (with some exceptions such as processed meats), the pace of change is not yet fast enough for there to be even comparable consumption levels in the near future for these two sets of products. More processed plant-based alternatives can play an important role in the much-needed protein transition for convenience and variety within the context of a balanced diet. However, such alternatives are not a silver bullet solution and should be approached with similar considerations as with other foods. Food businesses, manufacturers and citizens must not lose sight of the benefits and importance of minimally processed plant-based proteins (e.g., legumes, pulses, nuts, grains) amid the hype of these new innovations.

APPENDIX

METHODS AND SCOPE

Five best-selling plant-based meat alternative products, five minimally processed plant-based protein and three common secondary ingredients found in plant-based meat alternatives were selected to compare their environmental impact, sustainable sourcing, and nutritional composition. Products were selected to cover a range of product categories, commodity ingredients, and availability across key markets. This analysis therefore provides an insight into the basis of these specific five products and ingredients and is not a comprehensive comparison of all the plant-based meat alternative products and ingredients that are available.

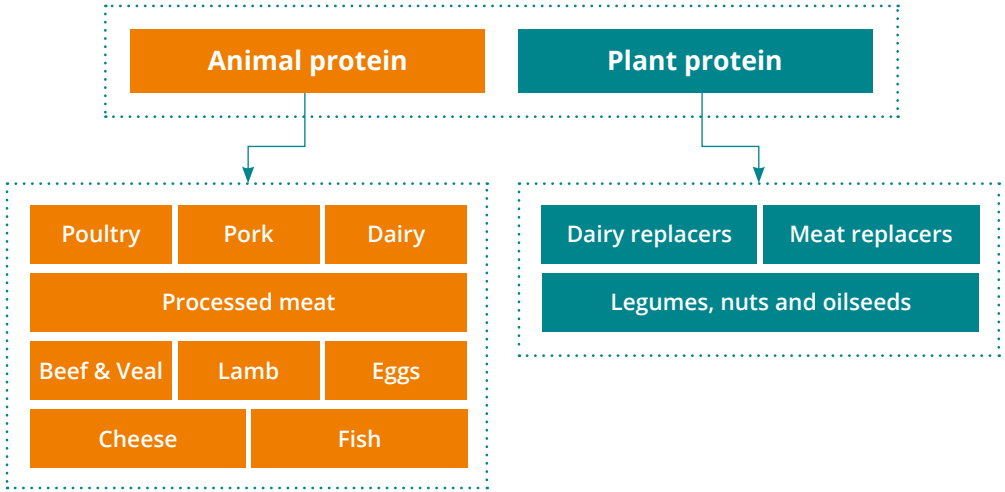

Table 12:
Categories of animal-based and plant-based protein

UK PLANT-BASED CONSUMPTION

The data from the Department for Environment, Food & Rural Affairs (Defra) Family Food dataset contains statistics on the average quantity of each food and drink category purchased per average person per week from 1974 to 2019. The dataset is comprehensive, covering hundreds of different food product categories and is updated annually. Data from 1990–2019 on all food products that fit into 12 animal and plant-based categories (dairy replacements, meat replacements, legumes and nuts and seeds, poultry, pork, dairy, processed meat, beef and veal, lamb, eggs, cheese and fish), as well as demographic data (age, location) were downloaded. A trend line was drawn to show projections to 2030. The Defra dataset is limited to food product purchases and does not represent actual consumption, as it does not account for household food product waste (for example, purchased salad leaves are more likely to go off and not be consumed than digestive biscuits) or how food products are processed or cooked before consumption. Tables 12 and 13 include the 12 categories and full list of products from the family food survey included in each category respectively.

	Food category	Family Food survey data foods
Animal-based protein	Beef and veal	Beef joints, beef steak, minced beef, all other beef and veal, ox liver, corned beef, beef sausages
	Pork	Pork joints, pork chops, pork fillets and steaks, all other pork, pig's liver, bacon and ham joints, bacon and ham rashers, uncooked pork sausages
	Lamb	Mutton, lamb joints, lamb chops, all other lamb, lamb's liver
	Poultry	Chicken and turkey, takeaway chicken, whole chicken or chicken pieces, poultry other than chicken or turkey
	Fish	White fish, blue fish, salmon, shellfish, takeaway fish and fish products, tinned salmon, other tinned or bottled fish, ready meals and other fish products
	Eggs and egg products	Eggs
	Processed meat	Other cooked and canned meat and meat products, meat pies, sausage rolls, burgers, complete meat-based ready meals, other convenience meat products, pate, delicatessen-type sausages, pasties and puddings, meat pastes and spreads, takeaway sausages, saveloys, and miscellaneous meat
	Dairy	Evaporated milk, infant milks, instant dried milk, school milk, welfare milk, whole milks, skimmed milks, yoghurt, fromage frais, cream, dried milk products, dairy desserts, milk drinks and other milks
	Cheese	Hard cheese, cottage cheese, soft natural cheese, processed cheese
Plant protein	Legumes, nuts and oilseeds	Fresh beans, baked beans, other canned beans and pulses, dried pulses other than air-dried, frozen beans, nuts and edible seeds, peanut butter
	Meat replacements (novel protein foods)	Soy and novel protein foods
	Dairy replacements (plant-based milks)	Non-dairy milk substitutes

Table 13:
Full breakdown of Family Food data included in each of the 12 food categories

ENVIRONMENTAL IMPACT

Data was collected from a combination of Life Cycle Assessments within academic literature and publicly available information from company websites. Where information was available, direct comparisons were made on a product's greenhouse gas emissions, water use, land use, impact on habitat loss, and energy use. The environmental impacts of an animal-based protein product can vary significantly, depending on production system and location. For each animal-based protein product where mainstream conventional production systems can vary significantly (e.g., chicken, beef, dairy) and where information was available, two contrasting environmental impact figures were given from each production system (e.g., conventional vs organic), as well as between countries or regions (e.g., Brazilian beef vs Irish beef).

Some data gaps existed either on specific brands or on environmental indicators, which limited the extent to which plant-based meat alternatives can be compared directly with equivalent animal-based products. Where information was limited, data on primary protein ingredient or secondary protein ingredient was used. For example, Quorn sausage footprint data had not been released, therefore this study used data for mycoprotein to compare with pork. Additionally, no studies detailing the environmental impact of Future Farm Meatballs or What the Cluck chicken were found. To counter this, analysis compared the environmental impact of the primary ingredients, pea-based protein and soy protein isolate respectively.

Category	Reference
Milk category comparison	Potter, H.K., et al. (2020). Environmental impact of plant-based foods – data collection for the development of a consumer guide for plant-based foods. https://pub.epsilon.slu.se/17699/1/Report112.pdf (accessed 30/6/2021) Thomassen, M.A., et al. (2008). Life cycle assessment of conventional and organic milk production in the Netherlands. https://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=877842968193E1B2F0E19583A18DE56D?doi=10.1.1.460.5507&rep=rep1&type=pdf (accessed 30/6/2021)
Sausage category comparison	Hsu, K., et al. (2018). Quorn footprint comparison report. https://www.quorn.co.uk/assets/files/content/Carbon-Trust-Comparison-Report-2018.pdf (accessed 30/6/2021)
Burger category comparison	Heller, M.C., Keoleian, G.A. (2018). Beyond Meat's Beyond Burger Life Cycle Assessment: A detailed comparison between a plant-based and an animal-based protein source. https://css.umich.edu/sites/default/files/publication/CSS18-10.pdf (accessed 30/6/2021)
Chicken category comparison	Kroes, H., Kuepper, B. (2015). Mapping the soy supply chain in Europe. https://d2ouvy59p0dg6k.cloudfront.net/downloads/mapping_soy_supply_chain_europe_wwf_2015.pdf (accessed 30/6/2021)
	Wiedemann, S, et al. (2012). Using life cycle assessment to quantify the environmental impact of chicken meat production. Australian Government Rural Industries Research and Development Corporation. https://www.agrifutures.com.au/wp-content/uploads/publications/12-029.pdf (accessed 30/6/2021)
	Blonk Consultants. (2020). The environmental footprint of soy: life cycle assessment. https://www.proterrafoundation.org/news/information-sharing-environmental-footprint-of-soy-life-cycle-assessment-lca/ (accessed 30/6/2021)
	RTRS. 2020. Technical supporting document. https://issuu.com/rtrs/docs/rtrs_calculadora_eng_?fr=sOWUyYjM5MDM2MDc (accessed 15/03/2022)
Meatballl category comparison	Saget, C., et al. (2021). Substitution of beef with pea protein reduces the environmental footprint of meat balls whilst supporting health and climate stabilisation goals. Journal of Cleaner Production, 297:126447. doi: https://doi.org/10.1016/j.jclepro.2021.126447

SUSTAINABLE SOURCING

Six primary ingredients commonly used in plant-based meat alternatives were analysed: five are agricultural crops (almonds, lentils, chickpeas, soy and peas) and one is an industrial product (mycoprotein). Data on domestic sourcing regions and likely provenance for five markets were obtained from FAOSTAT (Food and agricultural data from the Food and Agriculture Organisation) and UN COMTRADE (International trade statistics from the United Nations), unless otherwise specified. Key sustainable sourcing issues and available certifications were also obtained through literature review (including sources from academic and grey literature).

NUTRITIONAL COMPOSITION

The nutritional values for the products and commodities were sought from on-pack labelling, manufacturer or retailer websites, or published nutritional datasets. All values are shown as 'per 100g' of product and were compared against three well-established nutrition profiling models.

Profiling models	Description	Reference
High in Fat, Salt and Sugar (HFSS) legislation	Used for UK advertising to ascertain whether a product is overall 'high in fat, salt, sugar' (HFSS) or 'not high in fat, salt, sugar' (non HFSS). Currently this model is used for programmes with a large child audience and also by Transport for London across its transport network (advertising on tube platforms, buses, etc). HFSS policies were originally intended to be implemented by October 2022. However, recent changes mean current HFSS policies are set to be implemented: 1) Restrictions on volume price promotions by October 2023, 2) Banning of HFSS adverts on TV before 9 pm and paid-for adverts by January 2024, 3) Location restriction preventing HFSS items in front of store, gondola ends, checkouts and online equivalents by October 2022.	https://www.gov.uk/government/publications/the-nutrient-profiling-model https://www.gov.uk/government/news/government-delays-restrictions-on-multibuy-deals-and-advertising-on-tv-and-online
Traffic Lights	Used for packaging labelling purposes. It gives a green (low), amber (medium) or red (high) rating for levels of fat, saturated fat, sugar and salt. It is currently a voluntary scheme for retailers and manufacturers. However, now that nutrition labelling legislation is governed by the UK (owing to Brexit), it is likely that this, or a similar labelling system, will become mandatory.	https://www.food.gov.uk/sites/default/files/media/document/fop-guidance_0.pdf
Protein claims	Used to establish whether a protein claim is permittable on packaging or other communication materials. High in protein = at least 20% energy from food/drink is protein. Source of protein = at least 12% energy from food/drink is protein.	https://food.ec.europa.eu/safety/labelling-and-nutrition/nutrition-and-health-claims_en
NOVA	System to classify foods into four groups depending on level and purpose of ingredient processing. Group 1 = unprocessed or minimally processed; Group 2 = processed culinary ingredients; Group 3 = processed foods, Group 4 = ultra-processed foods.	https://pubmed.ncbi.nlm.nih.gov/28322183/ https://pubmed.ncbi.nlm.nih.gov/34677812/

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