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The environmental sustainability of meat-based versus vegan pet food

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Rapid climate change is one of humanity's most pressing global challenges, and we must urgently address unsustainable practices in all sectors to mitigate its most devastating effects. The pet food sector is a large and growing global industry that feeds about one billion dogs and cats. Moreover, its production is closely linked to the livestock sector, to which at least 25% of all anthropogenic greenhouse gas (GHG) emissions to date are attributable, and probably substantially more. Globally, dogs and cats consume 9% of livestock animals. In the US, this rises to 20%. This review collates and analyses studies on the environmental impacts of pet food, and recommends mitigation strategies. All reviewed studies agree that pet food is associated with at least non-negligible environmental impacts that must be accounted for and addressed: in the US, 25–30% of the environmental impacts of animal production have been attributed to companion animal diets. Studies have estimated a wide range of environmental "paw prints" for dog and cat diets; in some cases, the environmental impacts of some canine diets compare to or exceed those of human diets. Within pet food, ingredient selection is the most important factor. The most effective measure we can currently take to mitigate these impacts is to transition to non animal-based (vegan) pet food, where this has been formulated to be nutritionally sound. Such a transition could achieve very significant GHG and land use savings. In wealthy nations with high rates of companion animal guardianship, the benefits of this transition are demonstrably equivalent to one quarter to one third of the environmental benefits achievable through human dietary change. A transition to nutritionally sound vegan pet food represents a significant extant climate change mitigation strategy which warrants immediate implementation.

KEYWORDS

pet food, environmental impacts, sustainability, animal byproducts, vegan, pet, dog, cat

Introduction

The pet food sector is a significant and growing global industry. Over 50% of all households worldwide have a dog or cat (Alexander et al., 2020). Global populations of dogs and cats were estimated in 2024 as reaching about one billion animals (Gupta, 2024). Global data from 2018 showed that dogs slightly outnumbered cats, with approximately 471 million pet dogs and 373 million pet cats kept worldwide in that year (Knight, 2023).

The US has the largest national pet population. In the US, approximately two-thirds of US households care for at least one companion animal (Acuff et al., 2021), with an estimated 89.7 million dogs and 73.8 million cats kept nationally in 2024 (AVMA, 2024). According to the Global

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Animal Health Association, the top three dog populations exist within the US (85 million), China (74 million), and Brazil (54 million). For cats, the largest populations exist within China (67 million), the US (65 million), and Brazil (24 million) (Global Animal Health Association, 2022). When considering pet food, the focus on these two species is warranted: dog and cat diets constitute 95% of global pet food sales (Euromonitor, 2019).

The size of this industry can partly be explained by the simple fact that people like having companion animals. Companion animals can also provide health and wellbeing benefits to their guardians, many of whom develop strong emotional bonds with their animals (Su and Martens, 2018). The growth of this industry has also been attributed to economic, cultural, and demographic trends, in addition to population growth. As countries develop, family sizes decrease and income levels increase. Younger generations in high-income countries have fewer children later in life, or choose not to have children at all. In the absence of children and with more expendable income, companion animal guardianship often increases (Alexander et al., 2020).

The growth of disposable income directed towards companion animal guardianship (Rizvi et al., 2022) has also led to increased demand for higher-quality, "human-grade" pet foods (Cleaver, 2024). This has also resulted in over-feeding and the development of pet foods that exceed the nutritional requirements recommended for companion animals (Alexander et al., 2020). The growth in popularity of raw meat-based diets has likely exacerbated this trend, as these diets tend to contain particularly high amounts of meat that far exceed the recommended protein allowances for dogs and cats. In addition to their sustainability concerns, many veterinarians and other specialists caution against the use of raw meat-based diets due to a relative lack of evidence supporting health benefits compared to strong evidence of pathogenic hazards and nutritional imbalances (e.g., Lyu et al., 2025).

The sustainability of companion animal diets is also an increasing, and important, concern. As the global population increases and low-income countries (in particular) continue to develop, dog and cat populations are expected to increase. Concurrently, the pet food industry is projected to grow significantly. This is demonstrated within pet food sales trends. The global pet food ingredients market is expected to increase from \$32.2–\$44.5 billion from 2022 to 2027: a compound annual growth rate (CAGR) of 6.7% (Rizvi et al., 2022).

In the context of rapid climate change and environmental breakdown, the sustainability of such a large and growing global industry is of crucial importance. The environmental impacts of food production for companion animals have received much less attention than those of human food systems. Indeed, they are actively dismissed by some. Acuff et al. (2021) has described "many aspects of the pet food industry" as "sustainable," while Huitson (2022) has argued that we could view the pet food industry as "offsetting" the impacts of human food production, since animal byproducts (ABPs) used in pet food would otherwise be "discarded to landfill."

The assumption that the pet food industry has a negligible impact on environmental sustainability is common, but unwarranted. Domestic dogs have a collective biomass of around 20 million tonnes, approximately equal to the combined biomass of all remaining wild terrestrial mammals. Cats have a total biomass of two million tonnes (Greenspoon et al., 2023). The dietary requirements and environmental impacts of such large (and growing) populations are vast. Moreover, the notion that the industry's use of ABPs reduces or negates associated environmental impacts is contested (Knight, 2023).

These impacts are important and cannot be ignored: we face critical threats posed by rapid climate change, and there is an urgent need to mitigate global climate disaster. By 2025 we had only a short period of time—6–7 years—to enact meaningful change before reaching ecological tipping points that would render the effects of climate breakdown irreversible. Failure to act will result in increased extreme weather events, mass movement of climate refugees, widespread famine and disease, and political instability (Feigin et al., 2023).

Food systems have been estimated to account for 34% of all anthropogenic GHG emissions annually (Feigin et al., 2025). Animal agriculture, which the pet food sector is highly reliant on, is responsible for a significantly outsized proportion of these emissions. In 2013, the FAO estimated that the livestock sector was responsible for 14.5% of annual GHG emissions (Gerber et al., 2013). More recently, in 2021, Xu et al. found that at least 20% of annual GHG emissions were attributable to the livestock sector; since their estimates were conservative, it is likely that the true proportion was higher. The percentage share of GHG emissions from livestock varies by country: for example, the US Environmental Protection Agency calculated agriculture (including livestock production) to contribute 10% of annual US GHG emissions (EPA, 2024).

When considering total GHG emissions to date, at least 25% of anthropogenic GHG emissions are attributable to livestock. Others have calculated that as much as a third of emissions to date are attributable to the livestock sector (Hayek et al., 2021; Eisen and Brown, 2022). In 2025, Wedderburn-Bisshop (2025) used the most modern climate change accounting techniques to demonstrate that agriculture—and particularly animal agriculture, as the leading land use sector—has contributed the majority of GHGs to date, and is the leading cause of climate change.

It is clear that animal agriculture is a significant, and neglected, driver of environmental breakdown. The GHG emissions from livestock production have been estimated to be up to 2.5 times higher than the emissions from all forms of global transportation combined (Feigin et al., 2023).

Despite this, we, and by extension our companion animals, are currently consuming livestock at unsustainable levels. Consumption of animal products has increased dramatically in recent decades: we now slaughter an estimated 92 billion land animals, 124 billion farmed fish and 1.1–2.2 trillion wild fish (in addition to various other aquatic animals) globally, each year (Block, 2023; Mood et al., 2023; Mood and Brooke, 2024). While, in some countries, rates of veganism and flexitarianism have risen somewhat in recent years (Ward, 2025), it is clear that most people are not reducing their consumption of animal products in a manner proportionate to the environmental threats posed by animal agriculture. Indeed, consumption levels are projected to significantly increase, not decrease, in coming decades. It is estimated that the meat industry will expand by 50–73% by 2050 to meet rising demand from a projected global population of nine billion (Feigin et al., 2023). The diets of our significant and growing dog and cat populations must be taken into account when considering climate change mitigation strategies.

Despite the significant contribution of the pet food industry to rapid climate change, there is to date only a limited (although growing) body of literature examining the environmental impacts of pet food, and how these can be mitigated. There are also growing alternative protein pet food options that use a variety of novel protein sources—driven in part by consumer concerns around the sustainability of conventional (meat-based) pet food. However, it is not always clear what the environmental impacts of pet food are, nor the potential mitigation benefits offered by various alternative protein sources. There also remain widespread misconceptions regarding the environmental impacts of ABPs, a key ingredient in most pet foods. Accordingly, the following review collates and analyses recent evidence concerning these topics.

Methodology

This study sought to locate scientific studies quantifying the environmental impacts of pet food. We aimed to include studies at both global and national levels, as well as Life Cycle Assessments (LCAs) of specific pet food types/products. Consistent with best practice guidelines (Gusenbauer and Haddaway, 2020), the bibliographic databases Scopus, Web of Science, and Google Scholar were chosen for this study. Web of Science was chosen due to its extensive scientific database, with over 217 million records dating back to 1864 (Clarivate, n.d.). Scopus was chosen due to its large database with comprehensive coverage of the life sciences, with over a quarter of its 97.3 million records focused on this field (Elsevier, n.d.). Google Scholar was chosen primarily for its breadth of coverage and usefulness as a supplementary database where necessary.

Having conducted a pilot search to confirm that our search phrase and databases successfully retrieved all of the key studies we aimed to include, we used the search phrase "environmental impacts" AND "pet food" to locate studies. Studies were located between 13 and 25 November 2024. We assessed all articles from the bibliographic databases Web of Science and Scopus that were returned with this search phrase. We did not assess all articles returned with this search phrase from Google Scholar since, as noted, it was primarily intended to serve as a supplementary database, and many of these articles were not relevant to our research topic. Additional studies were sourced after scrutinising the reference lists of retrieved articles. Studies were chosen based on their relevance to our research topic: the environmental sustainability of meat-based versus vegan pet food. Studies were excluded for various reasons. Some studies were excluded due to a lack of focus on our research topic—for example, those analysing the environmental impact of specific animal supply chains without reference to pet food, or those investigating other aspects of pet food, such as their nutritional quality or safety. A small selection was excluded because these studies were not written in English, or because the full text was not available.

Studies investigating insect-based pet food were excluded for various reasons. Firstly, there are concerns regarding the scalability of insect farming to significantly mitigate the environmental impacts of the pet food industry (Lundy and Parrella, 2015). Secondly, there is a lack of conclusive evidence concerning insect sentience, and it is still highly plausible that farmed insect species have the ability to feel pain, raising ethical concerns regarding their intensive farming (Barrett and Fischer, 2023). These concerns are made more profound due to the size of individual insects, which are much smaller than animals conventionally farmed for meat, meaning many more insects would need to be farmed to meet demand. Additionally, stocking densities tend to be higher and environmental enrichment lower than those used for conventionally-farmed species, potentially worsening welfare impacts. Given the questionable benefits and significant concerns regarding insect farming, it is most appropriate to treat the practice with scepticism, unless compelling evidence demonstrating practical benefits without adverse animal welfare impacts emerges.

Results

Our search phrase retrieved 16 articles from Web of Science, 41 from Scopus and 3,250 from Google Scholar, although as noted, most of the latter articles were not relevant to our research topic. After examining relevant studies and study reference lists, we included 21 studies in our review, based on their relevance to our research topic. Companion animals contribute to various environmental impacts, through the food they consume, the waste they generate, and the production of accessories and services designed for them. Pet food production is the main driver of environmental impacts associated with companion dogs and cats. This is generally followed by impacts from pet faeces, although this is marginal compared to that of diet and ingredient choice (Yavor et al., 2020).

Studies on the environmental impacts of pet food, which include various LCAs, identify impacts connected to a range of stages of the pet food production and consumption processes. Regarding formulation, Pedrinelli et al. (2022) identified wet foods as having much greater environmental impacts compared to dry foods, and found that a diet consisting solely of wet food emits almost eight times as much CO_2-eq (CO_2 equivalent GHGs) compared to dry food. Manufacturing and its associated energy costs were identified as the fifth most GHG intensive process in Rushforth and Moreau's (2013) LCA, with transitioning to renewable energy sources suggested as a mitigating measure. The European Pet Food Industry Federation (FEDIAF) deemed packaging and manufacturing to be the least impactful stages in the pet food production process (Huitson, 2022). Distribution has also been identified as relatively insignificant: Costa et al. (2024) found distribution to account for less than 1% of the total environmental impacts of a Brazilian pet food.

Food waste was repeatedly identified as an exacerbating factor, particularly in the form of overconsumption. Guardians can serve generous portions of food and treats, often driven by misplaced affectionate behaviour towards their animals (Acuff et al., 2021). Moreover, driven by consumer demand and perceptions of companion animal health and wellbeing, the protein levels of some pet foods are much higher than required (Bittel, 2021). This can contribute to overfeeding by guardians, and consequent overproduction. Companion animal obesity is now a major problem: 50% of dogs in various geographical regions are now obese (German et al., 2018), with similar percentages cited for cats (Tarkosova et al., 2016).

Impacts from companion animal waste (faeces and urine) were also identified as significant (in absolute terms; as noted, compared to diet and ingredient choice, these impacts are marginal), particularly regarding freshwater eutrophication. Even disposal via landfill (which is the current preferred method) results in GHG emissions. In the US alone, 5.1 million tonnes of cat/dog faeces are produced annually (Yavor et al., 2020).

However, ingredient selection has by far the largest effect on the environmental impacts of a pet food (Yavor et al., 2020). In Costa et al.'s (2024) LCA study of a Brazilian pet food, at least 70% of the total environmental impacts of the pet food production process came from raw material (ingredient) selection. Hence, we focus hereafter on the impacts of various ingredient selections, including meat-based, cultivated (i.e., derived from cell-cultivated, or "lab grown", meat), and vegan (i.e., non-animal origin, usually plant-based but occasionally based on fungi or microorganisms). The latter may include yeast and emerging alternatives such as those derived from precision fermentation of bacteria.

Meat-based diets: environmental impacts

Meat-based pet food is currently the most conventional diet globally. Based on data from Knight (2023), in the US, just under half—46.9%—of the ingredients used in dog and cat food are non-animal based. These include whole and milled grains, soy products, fruits and vegetables, root products, vegetable oils, and sweeteners. The remaining 53.1% are animal-based ingredients, including human consumable (HC) ingredients such as meat, fish, dairy, and egg products, and non human-consumable (NHC) ingredients (i.e., ABPs), predominately meat and bone meal. NHC ingredients are usually significantly cheaper to source. In the US, NHC ingredients comprise 52.6% of all animal-sourced ingredients for dog food, and 50.8% for cat food. Globally, however, NHC ingredients comprise 74.9% of all animal-sourced ingredients in pet food. This is likely because the US is a particularly wealthy country, with consumers more able to afford HC animal-sourced ingredients (which are normally considered more desirable), than the global average.

The vast majority of studies on the environmental impacts of pet food calculate impacts using conventional meat-based pet food. In part because of the confusion surrounding the impacts of ABPs, discussed below, the range of estimates vary significantly. This is also to be expected given the diversity within any global industry, where variations in national contexts, product formulations, and other factors are all relevant.

Despite this range, all current estimates reveal significant environmental impacts associated with feeding conventional diets to companion animals. The ecological footprint (EF) is a widely used tool for assessing environmental sustainability by measuring the demand placed on natural resources through human activities, such as the production, consumption, and disposal of goods, including food. The environmental paw print (EPP) adapts the EF concept to measure the environmental impacts of companion animal resource consumption (Su and Martens, 2018). The following studies have estimated the environmental impacts of pet food in countries including the US, China, Japan, and Netherlands.

Okin's (2017) US study provided key estimates of the environmental impacts of pet food in a wealthy nation with high rates of companion animal guardianship. In the US, dogs and cats consumed as much dietary energy as ~62 million Americans, roughly one-fifth of the population. While companion animals consumed about 19% (+/− 2%) of the dietary energy of humans, their diets were also high in animal products, meaning they consumed 33% (+/− 9%) of the animal derived energy consumed nationally. This meant that, if companion animals' dietary consumption was included in environmental calculations, the US would be a country with an equivalent human population of 380 million in terms of raw dietary energy consumed, and 690 million in terms of animal derived energy consumed (using data from 2017).

The proportionally larger consumption of animal products within companion animal diets compared to humans results in very significant environmental impacts. Okin found that 25–30% of the environmental impacts of livestock production within the US were attributable to dog and cat diets. In another study of the US sector, Rushforth and Moreau (2013) estimated that a pet food manufacturer required 1.17 hectares of land to produce one tonne of dog food (11.72 m^2 per kilogram).

Dog and cat consumption and environmental impact data for China, Japan, and Netherlands are reproduced from Martens et al. (2019) in Tables 1, 2. Vale and Vale, reported by Ravilious (2008), estimated an EPP of 0.84 hectares for a medium dog, and 1.1 hectares for a large dog (country unspecified).

As stated, there are significant differences among these national estimates, and such regional variability is to be expected. The dietary EPP of a dog on commercial dry food in Netherlands and China was about double that of a dog in Japan, for example. This could in part be due to overconsumption: companion dogs in China were found to consume more food than they actually needed, which resulted in higher environmental impacts. However, this was also noted of companion dogs in Japan. Hence, other factors, such as the average size of a dog in each country, and the specific formulations fed, are likely also relevant. The environmental impacts of pet food are most pronounced in high-income countries, where there are higher rates of companion animal guardianship and more established commercial pet food industries using a high proportion of animal products.

Despite the range in estimates, however, these impacts are undeniably significant and should not be disregarded. In their study of the environmental impacts of pet food in Japan, Su and Martens (2018) found that the dietary EPP of one medium-sized dog was higher than the dietary EF of one Japanese person, and that the dietary EPP of two medium-sized dogs or one large dog was equivalent to the entire EF of one Japanese person. In high pet-owning countries like the US, the benefits achieved by transitioning dogs away from meat-based diets are often equivalent to one quarter to one third of the environmental benefits achievable through human dietary change (Knight, 2023). Another study calculated that in high-income countries, a dog has around 7% the annual climate change impact of an average EU citizen (Yavor et al., 2020). These represent very significant climate change mitigation opportunities.

Globally, environmental impacts from pet food are relatively reduced, due to lower per capita levels of companion animal

TABLE 1 Companion animal numbers and their commercial dry food consumptions in China, Japan, and The Netherlands (after Martens et al., 2019, Table 2).

Animal	Country	Per capita food consumption (kg/year)	Total numbers (millions)	Total food consumption (millions of kg/year)
Dog	China	48–243	27.4	1,308–6,656
	Japan	19–123	10.35	194–1,271
	Netherlands	61–247	1.8	109–445
Cat	China	20–34	58.1	1,168–1954
	Japan	18–31	9.96	178–311
	Netherlands	20–33	3.2	64–106

TABLE 2 Per capita dietary EPP and GHG emissions for average sized dogs in China, Japan, and The Netherlands (after Martens et al., 2019, Table 3).

Category	Country	EPP (hectares)	GHG emission (tons)
Annual impacts	China	0.82–4.19	0.313–1.592
	Japan	0.33–2.19	0.127–0.831
	Netherlands	0.90–3.66	0.349–1.424
Lifetime impacts	China	9.89–50.32	3.756–19.104
	Japan	4.01–26.28	1.522–9.972
	Netherlands	10.77–43.93	4.488–17.087
Total dogs	China	22.5 million–114.8 million	8.576 million–43.621 million
	Japan	3.40 million–22.70 million	1.312 million–8.596 million
	Netherlands	1.62 million–6.59 million	0.608 million–2.480 million

An average-size dog weighed 10–20 kilograms in this study.

guardianship. This is partially offset by the higher proportion of NHC ingredients used globally compared to the US (75% versus ~50%), which, as discussed below, have greater environmental impacts compared to HC ingredients. Globally, canine dietary change would generally achieve one fifth to one tenth impact of human dietary change (Knight, 2023).

However, while average impacts of pet food production in wealthy nations are higher than the global average, they are likely to portend future global impacts, given demographic trends that show increases in companion animal guardianship as countries develop. For example, it has been estimated in China that dog and cat populations will increase by 10% annually, at a compound rate (Su et al., 2018). Moreover, they are still significant, even now.

Two studies have attempted to calculate the global environmental impacts of pet food: Knight (2023), discussed below, and Alexander et al. (2020). Alexander et al.'s findings were lower than most national estimates. They found that global dry food production was associated with 56–151 megatons of CO_2-eq emissions (1.1–2.9% of global agricultural emissions) and 41–58 megahectares of agricultural land (0.8–1.2% of global agricultural land use). These impacts were equivalent to a global EPP twice the size of the UK's land area. If emissions from global dry pet food production were from a country, it would be the 60th highest emitting country, on par with total GHG emissions from Mozambique or the Philippines.

However, various methodological flaws resulted in significant underestimations of environmental impacts. Firstly, Alexander et al. assumed ABPs have lower environmental impacts compared to HC meat products. To account for this, they used an economic allocation model that weighted the environmental impacts of animal-based ingredients according to their market value. This approach significantly reduced the estimated environmental impacts of global pet food production. Compared to calculations using a mass allocation model (as was employed in other studies), the economic allocation model yielded results that were less than half as impactful. It is important to note that there are also limitations to a mass allocation model, which unrealistically generalises the environmental impacts of HC and NHC animal products. However, it is not clear that there is any direct correlation between the economic value of animal-based ingredients and their environmental impacts. Further, other studies (discussed below) have found the opposite of Alexander et al.'s assumption: cheaper ABPs appear to have *greater* environmental impacts. Hence, Alexander et al.'s decision to use economic value allocation when modelling these impacts was flawed, particularly for ABPs, and significantly underestimated the global impacts of pet food production.

Additionally, Alexander et al. also recognised that these findings only referred to impacts related to dry pet food. When taking into account other pet food formulations including wet food, raw meat-based food, and table scraps/home cooked food, these impacts are likely to increase. While it is unclear by exactly how much, increases would likely be substantial: 80% of pet food is dry, but the remaining 20% (notably wet food) can have much higher environmental impacts (Pedrinelli et al., 2022).

Conventional meat-based pet food is therefore associated with a broad range of environmental impact estimates. Regardless of the variety in results, all authors agree that the impacts of pet food production are at least non-negligible, cannot be ignored, and should be accounted for when measuring and attempting to mitigate the environmental impacts of the food industry more broadly. However, as noted, there is particular confusion in many studies and among the general public regarding the environmental impacts of ABPs. Given that ABPs are a primary protein source in most pet foods, and play a significant role in pet food's overall environmental footprint, their specific environmental impacts warrant more detailed study.

Meat-based diets: animal byproducts

ABPs typically come from NHC sources, and are often considered to be waste products from meat production for human consumption. These include principal byproducts—such as ears, snouts, foetuses, horns, hides, hairs, and many others that are harvested directly from the animal—and secondary byproducts—such as meat meal, bone meal, fats, intestinal linings, and protein hydrolysates that are derived from principal byproducts.

There is a widespread and commonly accepted misunderstanding that ABPs are associated with reduced environmental impacts due to their status as waste products from human meat production, that would otherwise be discarded. Many authors assume this to be the case (Costa et al., 2024; Vasconcellos et al., 2023; Huitson, 2022; Okin, 2017), and others have similar assumptions affecting their calculations, significantly impacting their results (Alexander et al., 2020).

Some go further, suggesting that use of ABPs in pet food offsets the impacts of the human food industry, since these products would otherwise be wasted in landfill, which is associated with its own environmental impacts (Huitson, 2022; Acuff et al., 2021). This argument is the official line of the US National Renderers Association, which claimed in an infographic (Figure 1) in 2014 that "a single decomposing dairy cow releases 1.2 metric tons of carbon dioxide" and that "rendering avoids this!" The infographic concluded that

FIGURE 1
A 2014 infographic from the US National Renderers Association titled "Rendering Is Recycling".

"rendering is sustainable" and "protects the environment" (Wilkinson, 2014).

These claims are frequently made without any supporting evidence, and are broadly taken for granted within relevant literature. They assume, crucially, that ABPs would be discarded in landfill if not used in pet food.

Importantly, however, only 25% of all ABPs produced in high-income countries like the US are used within pet food. As a minority user of ABPs, the pet food industry competes for these ingredients with various other industries, including the livestock industry (for livestock feed), the energy industry (for energy generation), and the pharmaceutical industry (Figure 2) (Knight, 2023). Moreover, many ABPs can be used within the human food industry, since the definition of a NHC ABP is often relative to cultural and aesthetic factors, in addition to whether a byproduct is actually edible. This is acknowledged by some authors. Swanson et al. (2013) and Su et al. (2018) both argue that there is direct competition for some ingredients between the human and animal food industries.

Hence, it is not the case that ABPs are the majority protein source within pet food globally because such use beneficially recycles products that would otherwise be wasted. Additionally, ABPs generate significant value for the livestock sector. As Jayathilakan et al. (2012) notes: "efficient utilisation of meat by-products is important for the profitability of the meat industry." 11.4% of the gross income from beef is from byproducts, and 7.5% for pork. ABPs are used in pet food production because they are significantly cheaper than HC ingredients such as lean meat. A variety of other industries (among which pet food is often a minority user) would use these ABPs if not used for pet food (Halpin et al., 1999). As such, their use in pet food increases demand for ABPs, and therefore for livestock production.

Some studies have disputed the common assumption that ABPs reduce environmental impacts and would be wasted if not used in pet food, finding instead that the use of APBs inflicts *greater* environmental damage. In their Economic Input Output LCA, Rushforth and Moreau (2013) found that using lean meat in pet food was environmentally preferable to ABPs. This was largely because ABPs had a much poorer nutritional profile: while lean beef has an average w/w protein content of 24%, beef's average offal protein content is less than half, at 11%. For sheep, the figures are 16 and 11%, respectively. They concluded their study with the recommendation: "utilize a greater portion of lean meat in product formulation … [since] lean meat has a greater concentration of protein and therefore has a lower GWP [global warming potential] than offal." Since their model relied on data that did not distinguish between specific product

FIGURE 2
Main social applications of animal byproducts (Knight, 2023).

formulations, their environmental impact calculations are subject to some uncertainty. However, their finding that ABPs have a greater GWP than lean meat was a direct result of protein content calculations and associated environmental impacts, and this remains a valid conclusion despite the model's limitations.

In a recent study by one of us (Knight, 2023), we found that, on average, ABPs make up a minority of each animal carcass used for pet food production: meat meals (the largest ABP ingredient in pet food, which can be considered a proxy for ABPs more broadly) constitute on average only 39.2% of an animal carcass used for dog food, and 31.3% for cat food. A much greater proportion of the carcass is available to produce human-grade meat. Consequently, when ABPs are used instead of human-grade meat, then in order to produce the same quantity of animal-based ingredients, more average livestock carcasses are required. For dog food, using ABPs rather than human-grade meat requires 1.4 times more livestock carcasses, and for cat food, 1.9 times more. Hence ABPs are less efficient to produce, than human-grade meat. Their production requires significantly more livestock carcasses. This has the potential to increase the numbers of livestock animals required, and the associated environmental impacts.

A related point is how we view ABPs. Arguably, the standard nomenclature is misleading. In regulatory terms, Acuff et al. (2021) notes that a byproduct is "merely the secondary product produced from manufacturing the primary product." Importantly, that does not mean that the secondary product must be or is usually wasted, nor does it mean that the secondary product lacks value. In this light, it is more reasonable, as Acuff et al. suggest, to view ABPs more as a coproduct rather than a byproduct of human meat production. This reframes these ingredients as valuable commodities in and of themselves, rather than as externalised byproducts that can be excluded from environmental impact calculations.

In short, ABPs support demand for livestock farming and contribute to its profits. Moreover, as shown by Rushforth and Moreau (2013) and Knight (2023), ABPs used in pet food have greater environmental impacts compared to HC meat. It is therefore unreasonable to externalise or diminish the environmental impacts of these ingredients, merely because they are categorised as "byproducts." Viewing them as coproducts which have economic and environmental impacts in their own right is more appropriate.

Vegan diets

Because ingredient choice is the most significant factor in determining the environmental impacts of pet food, various authors have concluded that the most effective way to reduce the impacts of the pet food industry is to reduce or eliminate animal products from pet food production (Su and Martens, 2018; Martens et al., 2019; Knight, 2023; Acuff et al., 2021; Huitson, 2022; Jarosch et al., 2024).

This has historically been viewed as a controversial position due to concerns regarding the nutritional suitability of vegan pet food. However, there is now strong and growing evidence that well formulated vegan diets for both dogs and cats can be nutritionally sound, and moreover that dogs and cats fed vegan diets generally experience health outcomes as good as or better than those achieved by conventional meat-based diets. By early 2025 there were 12 studies exploring the health effects of vegan or vegetarian diets on dogs, 11 of which supported the use of these diets (Knight et al., 2024; Linde et al., 2024; Dodd et al., 2024; Dodd et al., 2022; Knight et al., 2022; Davies, 2022; Cavanaugh et al., 2021; Kiemer, 2019; Knight and Leitsberger, 2016; Semp, 2014; Brown et al., 2009; Yamada et al., 1987). There were three studies exploring the health effects on cats, all of which supported the use of vegan or vegetarian cat food (Knight et al., 2023; Dodd et al., 2021; Wakefield et al., 2006). One additional study from Leon et al. (1992) showed that a vegetarian diet deficient in potassium produced clinical signs of hypokalaemia—potassium deficiency, which resolved when a similar diet was fed, supplemented with potassium. An additional systematic literature review of vegan companion animal diets published in 2023 concluded that "there was no overwhelming evidence of adverse effects arising from use of these diets and there was some evidence of benefits" (Domínguez-Oliva et al., 2023).

Knight (2023) published the second global study on the environmental impacts of pet food, and calculated the relative environmental benefits of vegan diets for cats and dogs (in addition to humans). Globally, dogs and cats were found to consume 9% of livestock animals, which rose to 20% in the US. As a result, very large impact reductions were associated with transitioning dogs and cats to vegan diets.

In the scenario of a global transition towards vegan diets for dogs and cats, land savings larger than the total land of Mexico and Germany combined would be achieved. GHG emissions greater than total annual emissions from the UK and New Zealand combined would also be eliminated. Moreover, the estimates used within this study, such as the number of dogs and cats globally, and dog and cat energy requirements, were conservative. In reality, the environmental impact reductions associated with a transition to vegan companion animal diets can be expected to be even larger (Knight, 2025).

Another study by Jarosch et al. (2024) found that when a vegan wet food was compared with a meat-based dog food, the vegan food was associated with reductions in the environmental impact categories climate change, smog, and acidification. However, it was also associated with higher impacts for land use and eutrophication. Importantly though, the study used an economic allocation model to calculate these impacts, which is likely to have significantly underestimated the impacts of ABPs in meat-based pet food.

As such, given these diets' ability to significantly reduce the substantial environmental impacts associated with meat-based pet food production, it seems reasonable to immediately support a global transition towards sustainable and nutritionally sound vegan diets.

Various companies worldwide are already established players in the vegan pet food industry, which is growing at a CAGR of 7%, faster than the pet food industry as a whole (Future Market Insights, 2023). These companies generally use a variety of plant-based protein sources including soy, beans, potatoes, and other ingredients to formulate nutritionally complete vegan pet food. A non-exhaustive list of companies is available at www.sustainablepetfood.info. Seaweed is also a potential ingredient that can be used to produce nutritionally sound vegan pet food. The World Bank recently identified pet food as an emerging market for seaweed ingredient use that demonstrated a competitive value proposition, limited scaling challenges, and low processing complexity (Janke, 2024).

Emerging alternatives

In addition to vegan pet foods formulated with plant-based proteins, several other vegan pet food ingredients have emerged in recent years. While these ingredients are mostly in early stages of development and/or distribution, and subsequently have more limited data on environmental benefits, some offer huge potential.

Protein grown via precision fermentation is one such emerging alternative. Here, microorganisms are used within carefully controlled fermentation processes (sometimes referred to as microbial fermentation) to efficiently produce specific proteins with optimized yield and precision. This can include the genetic modification (GM) of microorganisms to produce specific animal proteins, such as casein or haemoglobin, that replicate the functional and nutritional properties of conventional meat. It also includes the cultivation of non-GM microorganisms such as bacteria, algae, or specific fungi such as moulds or yeasts, to produce high-quality protein biomass. Products are already being developed by pet food companies, including Bond Pet Foods, who produce chicken protein (free from livestock production), and Calysta, who produce protein derived from the fermentation of a naturally-occurring bacterium. They have the potential to offer protein divorced from conventional livestock production at a small fraction of the land use, water use, and GHG emissions. Calysta claims its plant can produce 100,000 tonnes of product with just 10 hectares of developed land. By comparison, an equivalent quantity of soy production would require 250,000 hectares of land (Calysta, n.d.). Conventionally produced animal protein would require vastly greater amounts of land.

Another alternative is cultivated meat where animal cells are grown without raising animals (also termed "cellular agriculture"). The process involves extracting stem cells from a source animal and cultivating them in a controlled environment with nutrients and growth factors, to produce "cultivated" meat that is biologically identical to conventional meat.

In addition to vegan pet food formulated with plant-based proteins, pet food ingredients derived from precision fermentation, and products using these ingredients, are already available at commercial scale (Calysta, 2024). The first pet food (a dog food) using these ingredients was marketed by German company Marsapet in late February 2025 (Pet Food Industry, 2025). This is in comparison to pet food made with cultivated meat. The first cultivated meat-based pet food (also a dog food) was produced by UK biotech company Meatly partnering with UK dog food company THE PACK, and was marketed earlier in February 2025. However, it is expected to take some years until cultivated meat-based pet food becomes available at industrial scale (Meatly, 2024). Moreover, whether cultivated meat will emerge as a widely used and commercial alternative to conventionally farmed meat in the near future is still uncertain.

These emerging alternatives represent the increasingly realised potential for a diverse range of sustainable pet food protein sources that can accommodate a broad range of production methods and consumer preferences. All of these emerging alternatives appear to offer significant, and in some cases extremely large, reductions in environmental impacts.

Policy responses

Given the very significant and comparatively neglected environmental impacts of the pet food industry, measures to reduce the dietary "paw prints" of our companion animals warrant urgent adoption. The most significant contributor to the pet food industry's environmental impacts is its ingredient selection—namely, its strong reliance on animal-based ingredients, and especially ABPs. As such, the most straightforward and impactful mitigation measure is to transition dogs and cats onto nutritionally sound vegan diets (Su and Martens, 2018). On average, dogs and cats fed such vegan diets appear to enjoy them as much as meat-based diets (Knight and Satchell, 2021). Modern, commercially available vegan pet diets are normally formulated to be of equivalent or superior quality and nutritional soundness to meat-based pet foods (Knight and Light, 2021). Hence, there is no longer any sound reason not to support such a dietary transition, particularly given the strong and growing body of evidence demonstrating equivalent or superior health outcomes when nutritionally sound vegan pet diets are used.

In addition to this, it is also important to address the other contributors to the sizable environmental impacts associated with the pet food industry. Perhaps most obviously, large dogs have a much larger dietary EPP than smaller dogs [nine times as large as a small dog, and 12 times as large as a cat (Su and Martens, 2018)]. Hence, choosing to care for small companion animals over larger ones (if at all), would dramatically reduce associated environmental impacts. Moreover, choosing to adopt or rescue existing companion animals rather than breeding and buying new animals can also reduce pet overpopulation in many countries.

Preventing overfeeding would also prevent food waste, as well as safeguarding companion animal health. This could be encouraged via informational campaigns targeted at companion animal guardians (encouraging weighing of food, for example). However, as Su and Martens (2018) note, efforts to reduce energy consumption to more appropriate levels will be easily outpaced by the rising dietary energy requirements of the growing global companion animal population. Hence, while important, such strategies are complementary to the more structural and significant transition towards more sustainable ingredient selection from non-animal sources, that is clearly necessary.

Additionally, governments, environmental NGOs, and other stakeholders would be prudent to recognise the substantial environmental impacts currently inflicted by the pet food industry, and concurrently, the significant extant opportunities to reduce these impacts. The first step is to communicate to companion animal guardians the best ways of reducing the environmental impacts of feeding their animals. Given the very significant climate change mitigation potential associated with companion animal diet change, societal awareness concerning this topic is shockingly and unacceptably low.

Various policy responses have been suggested in the reviewed studies. Governments and the mass media could carry out large-scale communication campaigns to make guardians aware of the environmental impacts of different pet food types, and how best to mitigate impacts arising from companion animal diets. This could include information on the health and environmental benefits of nutritionally sound vegan pet food, guidance on how to reduce food waste and overconsumption, and encouragement to adopt or rescue a pet rather than buy one (Su and Martens, 2018). We would add that consumers who are initially resistant to the idea of completely vegan diets could be encouraged to transition gradually and feed, for example, 50% vegan and 50% meat-based pet foods. Even a 50% reduction in meat-based pet food consumption would still significantly mitigate the environmental impacts of pet food production. In addition, increased public and private investment in alternative protein production technologies, both for human and companion animal consumption, is key to facilitating a swift and sustainable protein transition (Su and Martens, 2018).

These responses—in particular a rapid transition away from animal-based ingredients to sustainable alternatives, represent an opportunity to substantially mitigate the environmental impacts of the large and increasing global pet food industry.

Further research on this topic could quantify these impact reductions at the national level, or further investigate the influence of ABPs on the environmental impacts of pet food. As this study did not systematically review studies in this field, a systematic review could provide a more comprehensive account of current knowledge.

Conclusion

Humanity stands at what may be its most critical and precarious juncture to date. We are living through a sixth mass extinction event, predominantly human-made in origin (Feigin et al., 2023). We must act immediately and comprehensively to mitigate the effects of rapid climate change and avoid crossing tipping points that trigger ecological and societal disaster (Feigin et al., 2023).

The food system, and the pet food industry in particular, have so far been relatively neglected foci of environmental reform. This is despite our food system contributing 34% of global GHG emissions (Feigin et al., 2025), and the livestock sector—upon which the pet food industry currently relies—contributing at least 20% of global GHG emissions annually (Xu et al., 2021). In this context, the environmental impacts of pet food production must be urgently addressed. Companion animal populations are predicted to significantly increase in coming years, and so mitigation strategies must fundamentally redress unsustainable practices.

The most obvious and effective step we can take to substantially reduce the environmental impacts of companion animal diets, is to transition away from animal-sourced ingredients, and towards nutritionally sound vegan pet foods. A global transition would free up land larger than Mexico and Germany combined, and reduce GHG emissions greater than all those emitted by the UK and New Zealand combined (Knight, 2023).

Many companies are already producing good quality, nutritionally-sound vegan diets for dogs and cats. The sector is expected to grow significantly in the coming years. In addition to diets formed from plant-based or yeast-based proteins, proteins sourced from precision fermentation or cultivated meat are also emerging. Given the very large potential of this transition to mitigate climate change and environmental breakdown, rapid support from government and industry is warranted.

Author contributions

BN: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. AK: Conceptualization, Funding acquisition, Methodology, Visualization, Writing – review & editing.

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Conflict of interest

BN was employed by pet food company Omni.

The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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