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Animal board invited review: Animal source foods in healthy, sustainable, and ethical diets – An argument against drastic limitation of livestock in the food system

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ABSTRACT

Animal source foods are evolutionarily appropriate foods for humans. It is therefore remarkable that they are now presented by some as unhealthy, unsustainable, and unethical, particularly in the urban West. The benefits of consuming them are nonetheless substantial, as they offer a wide spectrum of nutrients that are needed for cell and tissue development, function, and survival. They play a role in proper physical and cognitive development of infants, children, and adolescents, and help promote maintenance of physical function with ageing. While high-red meat consumption in the West is *associated* with several forms of chronic disease, these associations remain uncertain in other cultural contexts or when consumption is part of wholesome diets. Besides health concerns, there is also widespread anxiety about the environmental impacts of animal source foods. Although several production methods are detrimental (intensive cropping for feed, overgrazing, deforestation, water pollution, etc.) and require substantial mitigation, damaging impacts are not intrinsic to animal husbandry. When well-managed, livestock farming contributes to ecosystem management and soil health, while delivering high-quality foodstuffs through the upcycling of resources that are otherwise non-suitable for food production, making use of marginal land and inedible materials (forage, by-products, etc.), integrating livestock and crop farming where possible has the potential to benefit plant food production through enhanced nutrient recycling, while minimising external input needs such as fertilisers and pesticides. Moreover, the impacts on land use, water wastage, and greenhouse gas emissions are highly contextual, and their estimation is often erroneous due to a reductionist use of metrics. Similarly, whether animal husbandry is ethical or not depends on practical specificities, not on the fact that animals are involved. Such discussions also need to factor in that animal husbandry plays an important role in culture, societal well-being, food security, and the provision of livelihoods. We seize this opportunity to argue for less preconceived assumptions about alleged effects of animal source foods on the health of the planet and the humans and animals involved, for less top-down planning based on isolated metrics or (Western) technocratic perspectives, and for more holistic and circumstantial approaches to the food system.

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Implications

Policy makers and influencers are increasingly calling for a far-reaching substitution of animal source foods by plant alternatives. These offer opportunities to investors but should not be seen as fully equivalent products when viewed beyond nutritional reductionism. There are possibilities to formulate healthy, sustainable, and ethical diets, wherein plant-based formulations may play a role to replace animal source foods in some cases, especially at the lower quality end. Yet, *exclusion* or heavy restriction of animal source foods may lead to a more fragile food system and societal damage. As for the production of any food, the true challenge is to promote best practices and limit harm.

Introduction

During the last decennia, the place of animal source foods in human diets has rapidly become an ideological battleground. Whereas some authors believe such foods are intrinsically unhealthy, unsustainable, and/or unethical (Barnard & Leroy, 2020; Deckers, 2013), others claim that they are not (Leroy et al., 2020a; Provenza et al., 2021). Whether any food production system or commodity consumption pattern is net harmful or benign is, however, context and praxis specific and highly heterogeneous at the geographical and cultural level. The reason why this important nuance is often missed in mainstream (and mostly Western) discourses seems to be catalysed by an intermixture of anxieties within the general population, a desire to simplify the global narrative, animal rights activism, vested interests of food corporations, political opportunism by policy makers, and mass media distortions due to *post-truth* dynamics within the attention economy (Leroy, 2019; Leroy et al., 2018a; 2020b).

A number of controversies have underlined to which degree such polarisation has become problematic, also for scientific integrity. In 2019, a consortium of scientists (NutriRECS) claimed that the totality of the evidence of linking red meat consumption with cardiovascular disease and cancer is too weak to recommend lower consumption (Johnston et al., 2019). To do so, they scrutinised the data using the GRADE approach, which is a well-accepted transparent framework for developing and presenting summaries of evidence (Guyatt et al., 2011). Yet, activists and academics who disagreed with these findings went to the point of trying to preemptively retract the publication of these studies (cf. Rubin, 2020 for an overview). This is obviously not in the best interest of stimulating scientific debate. Respectful dialogue, however, is needed to resolve the conflict between those who claim that GRADE criteria do not lend themselves to this type of research (Qian et al., 2020), and those who are of the opinion that standards of evidence across health fields should be identical (Vernooij et al., 2021).

At policy level, another symptomatic example is provided by the call for an interventionist Great Food Transformation by the EAT-Lancet Commission (Willett et al., 2019) and its wider network of public–private partnerships, hyperbolically identifying red meat as an 'unhealthy food' choice that is also portrayed as far more environmentally harmful than other foods (Leroy & Hite, 2020; Leroy et al., 2020b). By doing so, the Commission proposes a semi-vegetarian reference diet with a vegan option, allowing for small amounts of animal source foods (proposed at 14% of the caloric intake). It prescribes amounts of red meat (14 g/d and 30 kcal/d, with a broader window of 0–28 g/d) or eggs (13 g/d and 19 kcal/d; 0–25 g/d) that are even lower than the recommendation for sugar (31 g/d and 120 kcal/d; 0–31 g/d), triggering methodological criticism (*e.g.*, Zagmutt et al., 2021). Furthermore, such approaches seem to be at odds with the Commission's own acknowledgement of the need for carefully designed solutions that incorporate diversity and specific realities (also, *cf*., Iannotti et al., 2021).

As a result, much of the complexity of the food system is ignored and reduced to three intertwined narratives stating that consumption of animal source foods causes harm to (1) human health, (2) the planet, and (3) the animals. Although these simplified messages resonate well with virtue-signalling policy makers and citizens in the urban West, especially in the upper middle classes (Leroy & Hite, 2020), genuine concerns also play an important role. There are indeed strong overtones of social justice involved, which are related to health hazards, climate change, and animal welfare. Such concerns, unfortunately, can also lead to serious distortion of information and neglect of nuance (so-called "white-hat bias", fuelled by feelings of righteous zeal; cf. Cope & Allison, 2010), or even assaults to livestock agriculture (Provenza et al., 2021).

Instead, we argue that what should top policy agendas worldwide is the tackling of (1) nutrient deficiencies (Nelson et al., 2018) and overconsumption of energy-rich, nutrient-poor, and ultra-processed diets (Hall et al., 2019), (2) the excessive use of fossil fuels and hyper-extractive business models (Max-Neef, 2010), (3) the lowering of environmental impacts of all forms of crop and animal agriculture (Herrero et al., 2016; Lark et al., 2020), and (4) the urban disconnect with the rural food chain, paralleling perturbed human-animal interactions (Leroy & Praet, 2017). It is primordial to underline that the most suitable approaches will vary by context and cannot be structured into a unified global model.

The present work is to be read as a call for evidence-based interpretations of the scientific data and contextual thinking. More balanced and informed decisions can only be obtained by steering away from isolated and overemphasised metrics and by embracing the wider and varied aspects of nutrition, landscapes, and culture. Policy making would benefit from using approaches that are less top-down oriented, as this generally tends to favour harmful reductionism (Scott, 1998). In particular, food policy would do well with more bottom-up and community-derived insights and wisdom from people that are *practically* invested in health care, agriculture, landscape management, and food security (Leroy et al., 2020b). Since anti-livestock positions rely heavily on the mutual reinforcement of the health, environment, and animal welfare narratives, it is essential to address all three of them on their own merits and failures (Leroy et al., 2020a). Yet, it also has to be taken into account that animal production yields highly heterogeneous categories of foods (*i.e*., eggs, dairy, meats, and fish), each produced and prepared according to a wide variety of practices, displaying dissimilar biochemical and nutritional properties, produced in regions with different ecological contexts, and consumed by populations with specific nutritional, economic, and cultural needs. The fact that intake levels of animal source foods differ substantially between geographical regions and socio-economic categories should also be at the heart of global policy development and rebalancing scenarios.

Due to constraints in format, we restrict ourselves to generating a perspective that favours concepts over details and methodological data. We also specifically prioritise our arguments in view of the calls for a drastic food system transformation away from livestock, rather than focussing on more reasonable modifications such as a shift to more regenerative and humane production practices. We hope that this overview can nonetheless help to shape the debate and dialogue, as well as the minds of those interested in personal, academic, social, and political discourses around livestock and animal source foods.

Animal source foods in healthy diets

Why the nutritional case against animal source foods may be overstated

One of the most heated debates in today's nutritional sciences is whether the intake of animal source foods should be restricted because of their alleged link with chronic disease (*e.g.*, Naghshi et al., 2020), with some even arguing for their total elimination (Barnard & Leroy, 2020). Unprocessed red meat and processed meats are particularly targeted, as well as the saturated fat that is present in many animal source foods such as whole dairy and eggs (Willett et al., 2019). Even though advocacy for moderate to heavy restriction is echoed by various public heath institutions worldwide, suggesting apparent consensus, the scientific debate is not settled as the evidence has been challenged by various scientists, both for red meat (Truswell, 2009; Hite et al., 2010; Alexander et al., 2015; Klurfeld, 2015; Kruger & Zhou, 2018; Händel et al., 2020; Hill et al., 2020; Johnston et al., 2019; Leroy and Cofnas, 2020; Sholl et al., 2021) and saturated fat, which is not exclusive to animal source foods (Astrup et al., 2020; Krauss & Kris-Etherton, 2020).

Among other concerns, one of the objections is that pleas for restriction are based on conflicting findings and observational relationships that are not necessarily causal, suffering from confounding and bias (Grosso et al., 2017; Händel et al., 2020; Hill et al., 2020; Leroy & Barnard, 2020; Nordhagen et al., 2020). Unwarranted use of causal language is nonetheless widespread in the interpretation of nutritional epidemiological data, thereby posing a systemic problem and undermining the field's credibility (Cofield et al., 2010; Ioannidis, 2018). Moreover, the associations between red meat and metabolic disease have not only been evaluated as weak, translating into small absolute risks based on low to very low certainty evidence (Johnston et al., 2019), but also differ according to geographical regions and cultural contexts, even if this may also reflect different economic and medical conditions (*e.g.*, Grosso et al., 2017; Iqbal et al., 2021). Associations are particularly noticeable in North America, where meat is often consumed through a fast-food window and where high-meat consumers tend to also eat less healthy diets and follow less healthy lifestyles in general. In a Canadian study, eating more meat was only associated with more all-cause cancer incidence for the subpopulation eating the lowest amounts of fruits and vegetables (Maximova et al., 2020). Several large-scale population-based studies, performed in individuals with 'healthy lifestyles', such as the Oxford-EPIC Study (Key et al., 2003) and the 45-and-Up Study (Mihrshahi et al., 2017), also find that the negative effects of red meat consumption on all-cause mortality become benign. If red meat were indeed causally driving the associations, one would anticipate finding stronger effects in systematic reviews looking specifically at red meat intake (able to evaluate a large intake gradient) compared to dietary pattern studies (smaller intake gradient) (Johnston et al., 2018). On the contrary, the absolute risk reductions from both reviews specific to intake versus dietary pattern (Johnston et al., 2019) were very similar in their magnitude of effect, indicating the possibility that, even after adjustment, a multitude of other diet or lifestyle components may be confounding the associations irrespective of whether they are negative or positive (Zeraatkar & Johnston, 2019).

While such troubling incongruity can be partially ascribed to differences in methodological set-up between studies, it has been hypothesised that the associations found in the West could at least partially be seen as cultural constructs generated by responses to norms of *eating right* (Hite, 2018). An important question to consider, therefore, is "whether intake of animal and plant proteins is a marker of overall dietary patterns or of social class" (Naghshi et al., 2020). Upper-middle classes, who are particularly sensitive to the ideologies of eating virtuous, tend to eat less red meat and saturated fat because of what they *symbolise*, and because of what they are being told by authorities and moralising societal discourse (Leroy & Hite, 2020). However, those same people are also more educated, wealthier, and healthier in general (Leroy & Cofnas, 2020). Even if multivariable models are used to account for such confounding effects as smoking, alcohol consumption, or obesity, it may not be possible to disentangle the effects of *all* dietary and lifestyle factors involved, especially given the low certainty of evidence. Therefore, WHO (2015) mentions that eating unprocessed red meat "has not yet been established as a *cause* of cancer" (emphasis added), while IARC (2015) stated that "chance, bias, and confounding could not be ruled out" with respect to the association between red meat intake and colorectal cancer. According to some (*e.g.*, Hite, 2018), nutritional epidemiology of chronic disease is thus at risk of capturing cultural artefacts and health beliefs within observational relationships, rather than reliably quantifying actual health effects. Such observations are then used to reinforce dietary advice, potentially creating a positive feedback loop (Leroy & Hite, 2020). This problem is further underlined by the lack of support from intervention trials (O'Connor et al., 2017; Turner & Lloyd, 2017; Leroy & Cofnas, 2020), which are designed to account for known and unknown confounders, and the fact that the mechanistic rationale for red meats remains speculative at best (Delgado et al., 2020; Leroy & Barnard, 2020).

Taken together, various public health organisations make a case for the reduction of animal source foods based on their interpretation of the prevailing scientific evidence. Others, however, argue that conclusive proof for (some of) these recommendations is missing, particularly given the contribution of animal source foods to closing essential micronutrient gaps (Leroy & Barnard, 2020). Arguing for strong reductions contradicts common-sense approaches, especially from an anthropological perspective (Gupta, 2016; Leroy et al., 2020a). Meat, marrow, and seafood are evolutionary components of the human diet, even if they may have displayed some nutritional and biochemical differences compared to what is produced today in intensified operations, *e.g.*, with respect to fat composition (Kuipers et al., 2010; Manzano-Baena & Salguero-Herrera 2018) and the presence of phytochemicals (van Vliet et al., 2021a, and 2021b). The health impact of these differences may be significant but remains difficult to quantify, though polyunsaturated fatty acids/saturated fatty acids and omega 3/6 ratios of wild ruminants living in current times are similar to pasture-raised (grass-fed) beef, but dissimilar to grain-fed beef (Cordain et al., 2002b). Be that as it may, the abundant consumption of animal source foods over 2.5 million years has resulted in an adapted human anatomy, metabolism, and cognitive capacity that is divergent from other apes (Milton, 2003; Mann, 2018). Also, many hunter-gatherer populations consume far larger amounts of meat and other animal source foods (sometimes > 300 kg/p/y), than what is now consumed in the West (around 100 kg/p/y). This is likely still much below what was once valid for early humans preying on megafauna (Ben-Dor & Barkai, 2020). On a caloric basis, the animal:plant ratio of Western diets (about 1:2 in the US; Rehkamp, 2016) is the inverse of most pre-agricultural diets (mean of 2:1; Cordain et al., 2000). Such high amounts of animal source foods are not necessarily indicative of a health advantage, but it can be assumed that animal source foods are at least compatible with good health. So-called "diseases of modernity" were rare in ancestral communities, in contrast to what is now seen in regions where Western diets rich in energy-dense foods and (sedentary) lifestyles prevail. In the US, 71% of packaged foods are ultra-processed (Baldridge et al., 2019), whereas children in the Anglosphere now obtain >50% of their caloric intake from such foods as crisps, biscuits, juices, and sodas (Khandpur et al. 2020). Moreover, contemporary cultures that have maintained traditional diets and lifestyles typically have low burdens of chronic disease (*e.g.*, Kaplan et al., 2017). Even if this has been described as a "paradox" (Cordain et al., 2002a), it mainly indicates that today's assumptions about healthy diets, as being *de facto* low in red meat and saturated fat, are flawed and represent a romanticised Western viewpoint.

To sum up, although animal source foods are primary components of the Western diet, they are also evolutionary foods to which the human body is anatomically and metabolically adapted, up to the level of the microbiome (Sholl et al., 2021), and has always obtained key nutrients from. Although further research may be needed, their role in chronic diseases could as well be a mere artefact based on *association* with the actual damage from other dietary and lifestyle factors. It is uncertain yet possible that high intake of red meat could become problematic in a contemporary Western context. Whereas co-consumption of plants that are rich in phytochemicals and fibre could potentially be protective, low intake of fruits and vegetables combined with high intake of ultra-processed foods could amplify disease risk associated with red meat consumption (Van Vliet et al., 2021b), as will be discussed below.

Why there is still reason for concern

To be clear, the arguments in the previous section do not imply that the consumption of all animal source foods will be invariably benign. Besides that, there may be interindividual differences in harmful physiological responses or intolerances to eating *any* food or nutrient, both from plants (*e.g.*, anti-nutritional factors, gluten, and lectins) and animals (*e.g.*, lactose, saturated fat, or haem iron). Much will depend on *how* the food was produced, prepared, and incorporated into dietary patterns. The nutritional profile of meat from free-ranging livestock, for instance, may show tangible biochemical improvements (Manzano-Baena & Salguero-Herrera, 2018; van Vliet et al., 2021b). But more clearly still, a beef stew contains different components than an overly charred steak, while ripened traditional salami and cooked ham are very different from deep-fried chicken nuggets (Leroy et al., 2018b).

Uncertainty remains with respect to the health effects of processing, but concerns about harsh curing, smoking, or heat treatments seem reasonable and merit further investigation, as they may lead to the accumulation of nitrosylated compounds, polycyclic aromatic hydrocarbons, and heterocyclic amines (IARC, 2015; Demeyer et al., 2016). Although this justifies caution, the actual impact on public health is often unclear as a lot also depends on the dose and the attenuating factors in the general diet (Turner & Lloyd, 2017; Key et al. 2020). For example, potential deleterious compounds formed in meat with high-temperature cooking can be several-fold reduced when marinated or co-consumed with phytochemically rich plant foods (Smith et al., 2008; Van Hecke et al., 2017). Overall dietary composition and quality, including the type of processing, is what matters most for health, not specific targets for individual minimally processed food groups (*e.g.*, eggs or red meat) or the ratio of animal-to-plant source foods. Indeed, both plant- and animal-derived foods can be formulated as either healthy or unhealthy dietary components, and risk associations with chronic disease should ideally be broken down as such (Satija et al., 2017; Asnicar et al., 2021). The leap from "hazard" (cf. IARC, 2015) to "risk" requires a risk assessment, which turns out to be reassuring "at usual dietary intakes of red meat in the context of a normal diet" (Kruger & Zhou, 2018). Be that as it may, the processing of food can have both beneficial and harmful consequences (Leroy et al., 2018b), with the case against excessive consumption of ultra-processed foods in Western hyperpalatable diets building up (Hall et al., 2019; Lane et al., 2021).

The problem with eliminating animal source foods

While the argument for a restriction of animal source foods for health reasons is a debate on its own (see above), some wish to go further and argue that the avoidance of chronic disease requires diets that are devoid of animal source foods (Barnard & Leroy, 2020). Although adequate vegan and vegetarian diets are possible, at least for some individuals, they are arguably not physiologically optimal for everyone in the mid- or long term (Leroy & Barnard, 2020; Dinu et al., 2017). A systematic review has underlined the weakness and heterogeneity of studies on vegetarian children (Schürman et al., 2017). Moreover, there is a quasi-absence of data on vegan children, who may even suffer more often from vitamin A, B12, and D deficiency (unless supplemented), as well as iron-deficiency anaemia and low ferritin, choline, and Docosahexaenoic acid (**DHA**) levels compared to omnivores (Wallace et al., 2018; Desmond et al., 2021; Hovinen et al., 2021). Little is known on the health effects of adopting vegan diets on population wide-levels, from conception to old age. Moreover, such diets require careful planning and supplementation and/or consumption of adequately fortified foods, which can be difficult to achieve for many within the population. This is particularly the case when living in locations where such foods are inaccessible or unaffordable, or when adhering to other dietary restrictions that exclude important plant staples such as grains, peas, or nuts, for instance due to allergies and intolerances (Protudjer & Mikkelsen, 2020). This, combined with a common lack of nutritional knowledge and diligence, leads to a lower dietary robustness, may reduce the intake of important nutrients, and increases the risk of undernutrition, including stunting (Ingenbleek & McCully, 2012: Fayet et al., 2014; Woo et al., 2014; Pawlak et al., 2016; Brantsæter et al., 2018; Naik et al., 2018; Leroy & Cofnas, 2020; Nordhagen et al., 2020). Indeed, four out of the eight food groups contributing to the WHO minimum dietary diversity score for children are of animal origin; in settings with poor diets, they have a critical role in filling in nutrient gaps (Keeley et al., 2019). Finally, intra-individual differences in nutrient metabolism may very well preclude portions of the population to thrive on (near) plant-exclusive diets no matter how well the diet is "designed" (cf., for instance, Burdge, 2006; Tang, 2010).

While diets based on wholesome plant-based meals may be possible for some, the current trend is often one towards excessively engineered foods. A recurring concern of nutritionism and "engineered" replacements (such as meat, egg, and dairy replacements) is the focus on only a handful of nutrients, mostly those that appear on food labels and nutrition databases (*e.g.*, protein, fats, and some of the main vitamins and minerals), which underestimate the true complexity and health benefits of ingesting nutrients as part of complex whole food matrices (Jacobs & Tapsell, 2007; Barabási et al. 2020). These nutrients represent only a small fraction of the more than 70 000 unique compounds found in foods (FooDB, 2020) - many of which are found exclusively in animal foods (*e.g.*, creatine, anserine, taurine, cysteamine, 4-hydroxyproline, carnosine, and the long-chain omega-3 fatty acid eicosapentaenoic acid and docosahexaenoic acid, to name only a few) (van Vliet et al., 2021b). Many of these compounds are considered non-essential or conditionally essential (depending on life-stages), not unlike dietary fibre and polyphenols (*e.g.*, Rodriguez-Mateos et al., 2019); however, all of these nutrients impact metabolism and human health throughout the life-span (Swanson et al., 2012; Paul & Snyder, 2019; Wu, 2020) and their importance should not be downplayed simply because they are not considered indispensable. Compounds present in the whole food matrix also synergistically impact metabolism; consuming isolated nutrients often does not confer similar benefits (Chen et al., 2019), in part due to the absence of co-factors, and can carry risks such as toxicity (*e.*

g., liposoluble vitamins) or exacerbating infection (*e.g.*, iron). Thus, the reductionist approach of fortification and supplementation with isolated nutrients to engineer replacements (whether it be animal or plant foods) does not truly replicate the whole food matrix and the health benefits they are likely to provide. This is not an "appeal to nature" and certainly fortification (*e.g.*, iron, folate, iodine, or vitamins A, B12, and D) has an important role in contributing to nutrient adequacy of populations (see, for instance, Berner et al., 2014). A food-first approach (with a complementary role of food fortification) should nonetheless be emphasised, as obtaining nutrients from foods (as opposed to supplemental forms) is primarily responsible for the health effects ascribed to individual nutrients (Lichtenstein & Russell, 2005; Jacobs & Tapsell, 2007; Chen et al., 2019).

Whether increase or reduction of animal source foods can or should be promoted is context-specific, and dependent on the characteristics of the population, such as micronutrient status. Although low- and middle-income countries are particularly vulnerable to limitations in the intake of animal source foods due to economic and logistic constraints (Headey et al., 2017; Adesogan et al., 2020), the problem also exists in the West (Leroy & Cofnas, 2020). It is often related to high market prices and price elasticities in low-income families (Green et al., 2013) or to ideological motivations, such as strict vegetarianism. This is particularly concerning given the higher prevalence of nutrient deficiencies in pregnant women (Koebnick et al., 2004), as well as infants and children (Cofnas, 2019), translating into a long list of clinical case reports in the medical literature (*e.g.*, Giannini et al., 2006; Guez et al., 2012). In contrast to the position paper of the Academy of Nutrition and Dietetics (Melina et al., 2016), of which the authors represent ethical veganism or Seventh-Day Adventism (cf. Banta et al., 2018), many professional (paediatric and medical) associations - such as the Belgian Royal Academy of Medicine (2019) or the Swiss Federal Commission for Nutrition (2018) – now explicitly discourage veganism and vegetarianism for young populations. In a joint position paper, Italian paediatric organisations have stated that vegan and vegetarian diets are inadequate for neuro-psychomotoric development and may cause deficiencies and irreversible damage (Barberi et al., 2017). This may not be surprising, given that animal source foods have played a foundational role in evolutive brain development (Gupta, 2016). Inadequate vitamin B12 intake during the early years of life can lead to persistent cobalamin deficiency and impaired cognitive functions in later life (van Dusseldorp et al., 1999; Louwman et al., 2000; Pawlak et al., 2016). In adolescents and young adults, (strict) vegetarian diets frequently parallel eating disorders and depression, although it is not known if this link is causal or due to reversed causality (Kapoor et al., 2017; Barthels et al., 2018; Zickgraf et al., 2020).

Animal source foods provide high-quality protein and various key nutrients that are highly bioavailable and more difficult or impossible to obtain via plant foods only, requiring fortification and supplementation (Bakaloudi et al. 2020; Beal et al. 2021; Leroy & Barnard, 2020). Various long-chain fatty acids (*e.g.*, Eicosapentaenoic acid (**EPA**) and DHA), minerals (*e.g.*, zinc and iron), and vitamins (*e.g.*, vitamin D and vitamin B12) are either (nearly) absent or less bioavailable in plants, where anti-nutritional factors may further complicate absorption and metabolic use. For example, compared with ruminant liver, young children would need more than 100 times the portion size of pulses to achieve a similar proportion of requirements for commonly lacking micronutrients—iron, zinc, vitamin A, vitamin B12, folate, and calcium (Fig. 1). As an excellent source of unique nutritional compounds with critical roles in development, functioning, and survival, animal-sourced foods have the potential to combat stunting and improve the thriving and cognitive development of infants and children worldwide (Hulett et al., 2014; Tang & Krebs, 2014; Grace et al. 2018; Adesogan et al., 2020), and prevent or treat malnutrition and sarcopenia in the elderly (Shibata, 2001; Phillips, 2012; Rondanelli et al., 2015).

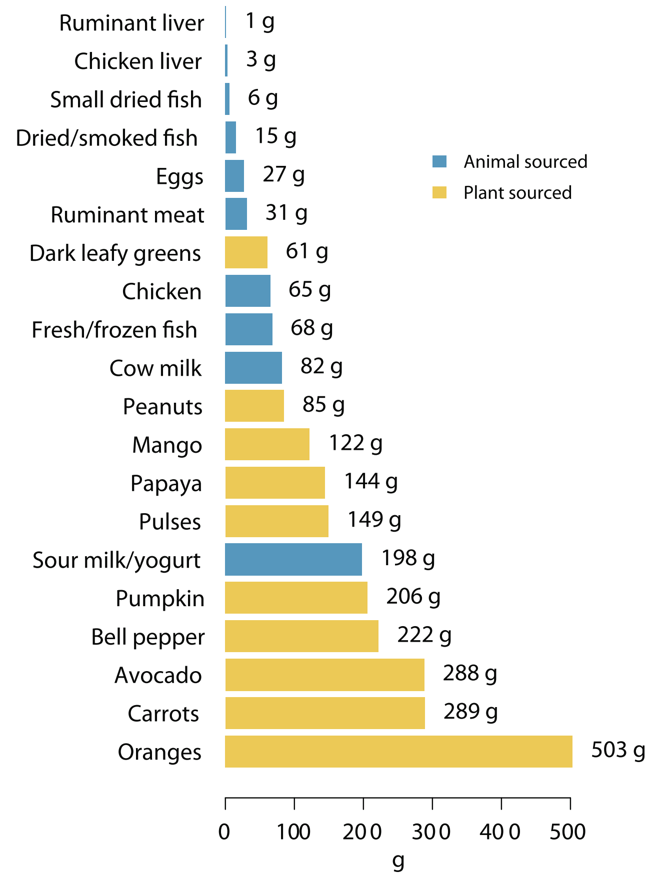

Fig. 1. Portion size needed to achieve an average of 33.3% of requirements for iron, vitamin A, zinc, folate, vitamin B_{12}, and calcium, key micronutrients that are commonly lacking in the diets of low- and middle-income countries (Beal et al. 2021: White et al., 2021), from complementary foods in Kenya (each micronutrient capped at 100% of daily requirements). The proportion of micronutrient requirements from complementary foods was assumed to be 0.98 for iron, 0.87 for zinc, 0.65 for calcium, 0.17 for vitamin A, 0.70 for vitamin B12, and 0.60 for folate (Dewey, 2001). Iron and zinc requirements were adjusted for bioavailability. For iron, it was assumed that there was 15% dietary iron bioavailability from animal source foods and 10% from plant foods; for zinc, it was assumed that there was 50% dietary zinc bioavailability from animal source foods and 30% from legumes, nuts, and seeds (WHO/FAO, 2004). Nutrient densities are from the Kenya Food Composition Table (Mwai et al., 2018). The average share of requirements calculation followed Beal et al. (2021). Ruminant meat is a mix of beef, lamb, and goat; eggs are chicken eggs; fish are a mix of various local species; smoked/dried fish is nile perch; small dried fish are a mix of species from Eastern Africa.

In conclusion, except for specific cases, health is not a proper foundation to argue for a shift away from omnivory, well on the contrary. In addition, raising livestock is intrinsic to many cultures, culinary traditions, livelihoods, and food security worldwide, which cannot and should not be uncoupled from health concerns.

Animal source foods in sustainable diets

Why the sustainability case against animal source foods may be overstated

Animal husbandry is commonly portrayed in both mainstream discourse and policy documents as being a wasteful practice due to its high requirements of water, feed, and land, and as detrimental for the climate, biodiversity, and the environment at large. As was the case for the effects of animal source foods on health, livestock's role in sustainable food systems requires contextualisation on all fronts. Debates should abandon the binary approach, whereby animal source foods are disproportionally presented as mostly environmentally unfriendly and plants as mostly benign (Leroy & Hite, 2020; Leroy et al., 2020b; Provenza et al., 2021). Given the vastness of the topic, it is not possible to be comprehensive at this point, but the few examples below should suffice to illustrate the problem.

As a response to the widespread claim that one kg of beef consumes over 15 000 litres of water, it needs to be clarified that such data derive from Water Footprint (**WF**) metrics (Boulay et al., 2021), where almost 90% of the water used by livestock is to be categorised under rainfall not contributing to runoff, i.e. "green water". Consequently, WF of grass-fed livestock will only reflect how rainy the local climate is. Unsurprisingly, the percentage is even higher (94%) for grazing ruminants (Mekonnen & Hoekstra, 2010). The WF will showcase a particularly high value in some marginal lands not fit for cultivation but with high rainfall, such as mountains. In these contexts, none of that water use is competitive with crops or human consumption, and water will fall anyway from the sky and incorporate itself into the natural water cycle regardless of the presence of livestock. In some livestock systems, levels of extractive water ("blue water") for feed production are indeed of concern, but in others, they are comparable to (or lower than) what is needed for crops. Life Cycle Analyses (**LCAs**) aimed at measuring Water Productivity (Boulay et al., 2021) have shown that in documented cases of Australian lamb and beef production, requirements are situated between 5 and 500 litres of water per kg of meat (Peters et al., 2010; Ridoutt et al., 2012a; 2012b). For US beef, the need for extractive water averages 2 000 litres per kg of carcass weight, but this depends strongly on the region and the needs for crop irrigation, and can be as low as 100 litres (Rotz et al., 2019). Such differences highlight the importance of carefully contextualising footprint values when making general conclusions about livestock's role in water wastage. When comparing the main water consumption metrics, *i.e.*, the Water Footprint Network approach on the one hand, and LCA/ISO approaches on the other, the latter address actual water scarcity and ecological impact of water use rather than total water use (Pfister et al. 2017; Boulay et al., 2021) – a more realistic evaluation of its impact. Besides water use as such, livestock farming of course also comes with issues of water quality, partly captured in grey water assessments but also requiring their own contextual evaluations and adjustments.

A second commonly heard argument states that animal feed competes with crops that would otherwise be directly suitable for the human diet. This is partially true (provided that supply chains would follow that logic), but also requires nuance. Exaggerated estimates claim that 6–20 kg grain is needed to produce one kg of meat, while in reality, this is around 3 kg of grain (Mottet et al., 2018). More importantly, debates should take into account that 86% of livestock feed encompasses forage, crop residues, and all sorts of by-products that are *not* suitable for human consumption in the first place and would otherwise form an environmental burden. For ruminants, especially, only 5% of the global feed intake consists of grains and soybean meal that are in direct competition with the human diet (Mottet et al. 2018). It is true, however, that the degree of feed-food competition is contextual and varies between and within geographical regions, depending on praxis. Ideally, this would be further reduced to the benefit of true industrial by-products (*i.e.*, those that would be produced anyway such as agri-waste and crop residues) and away from the current cultivation of feed with the sole intent of providing it to livestock. Because cattle's primary asset is to upcycle inedible materials to high-quality nutrition based on their rumen-centred metabolism, they function as net contributors to the production of human-edible protein worldwide. As a matter of fact, ruminants need less protein from human-edible feed (0.6 kg) than what they deliver as one kg of human-edible, high-quality protein (Mottet et al., 2017 and 2018; FAO, 2018).

A reasonable case can be made for reconsideration of some of the crop land that is now used for feed production, by shifting it to grow crops for direct human consumption. However, calls allowing for a further conversion of pasture into crops (for food or bioethanol) (*cf.* Willett et al., 2019; Williams et al., 2020) are myopic to existing examples of ecosystem damage and loss of wildlife habitat (Wright et al., 2017; Alemu et al., 2020). They ignore the problems with expansion of cropping into marginal land, downplaying the reality that agricultural lands are of differing quality. For example, in the US alone, over a million acres/year of native grasslands have been converted to croplands between 2008 and 2016, with nearly 70% of newly founded croplands producing yields below the national average at the detriment to birdlife (Lark et al., 2020). High-productivity lands are already under crop production, and they happen to be areas hosting relatively low biodiversity (Huston, 2005). Perennialisation and properly managed livestock can help maintain high levels of biodiversity in many contexts, above and below ground, by grazing unploughed, less productive areas (Provenza et al., 2015; Manzano-Baena & Salguero-Herrera, 2018; Neal et al., 2020), while being economically more efficient. About a quarter of the global agricultural surface comprises marginal land, unsuitable for cropping and consisting of non-convertible pastures and rangelands (1.3 billion ha; Mottet et al., 2018). If policy makers would adopt the idea of leaving such land "unexploited", one option would be to (partially) convert it into forest and/or rewild it. This may be appropriate in some contexts but appeals to a (mostly Western) romanticised notion of forested landscapes and a Nature *versus* Culture paradigm, ignoring the open, non-forested character of many such landscapes (Pausas & Bond, 2019) and that humans have shaped most of the terrestrial nature for at least 12 000 years. As noted by Ellis et al. (2021), "current biodiversity losses are caused not by human conversion or degradation of untouched ecosystems, but rather by the appropriation, colonisation, and intensification of use in lands inhabited and used by prior societies". It must be noted that viewing agriculture and nature as somehow separate entities is problematic to begin with. This is evidenced by the practices of silvopastoralism and agroforestry – a mutually beneficial integration of livestock, forage/crops, and trees – of which there is considerable scientific certainty regarding its high sequestration rates and food security (Lal, 2020). It also overlooks the complementarity of fire and grazing as factors sculpting the landscape (Bond, 2019), and how abandonment scenarios may lead to landscapes not very different from current ecosystems grazed by livestock (Manzano & White, 2019). The latter perspective not only opens an interesting debate on what should be considered *natural* but also brings us to what is the most mediatised issue in public discourse, that of climate change.

The contribution of livestock to total greenhouse gas (**GHG**) emissions globally has been estimated at 14.5%, which is mostly ascribed to feed production (45% of contribution) and enteric fermentation by ruminants (39%) (Gerber et al., 2013). Nuance is needed, however, as this global number is often erroneously referred to when discussing specific local systems. It is primordial to point out that this number masks a vast regional heterogeneity. Moreover, arguments stating that animal source foods lead to higher emissions than foods from plant origin (*e.g.*, Xu et al. 2021) overlook that estimations of the saving effects of a dietary shift within carbon budgets are not straightforward as they will have to respect agricultural and nutritional constraints. For instance, reducing animal source foods implies that more of other foods will need to be produced and consumed to meet nutritional needs, generating their own impact. Also, any benefit of dietary carbon savings will have to be judged on its merit within *total* carbon footprints, dominated by fossil fuel consumption. Taking out livestock from the US food system would thus lead to a reduction in emissions of approximately 3%, depending on underlying assumptions (White & Hall, 2017 and 2018). On an individual level, the same order of magnitude is found. A 60% flexitarian decrease in meat consumption, a vegetarian diet, and a vegan diet would lead to a 0.2, 0.5, and 0.8 t CO_2-eq/p/y reduction, respectively (Meier & Christen 2013; Hallström et al. 2015; Wynes & Nicholas 2017). On a *total* lifestyle footprint of a Western individual (*e.g.*, 12 t CO_2-eq/p/y), this would translate into a 2–6% decrease (Fig. 2), which may arguably need to be halved to 1–3% due to rebound effects (Grabs, 2015). A similar reduction magnitude has been found for a lifetime's total reduction in consumption-based emissions when adopting a meat-substituted diet in New Zealand (Barnsley et al. 2021). Given that most (>80%) vegetarians and vegans rapidly revert to omnivore diets, often within months (Faunalytics, 2014), such effects are mostly insignificant on a lifetime basis. Intake of animal source foods could potentially be lower than was the case before experimenting with vegan or vegetarian diets; however, robust data on this are missing.

In addition to the context needed with conventional accountancy, methane is disproportionately evaluated in these calculations as a much more harmful GHG than CO_2, in view of its global warming potential (**GWP**). Recent research presenting a modified GWP approach (**GWP***) has, however, shown that both gases follow fundamentally different kinetics and should be treated differently. Whereas methane is a short-lived climate pollutant, CO_2 is a long-lived stock pollutant that accumulates in the atmosphere (Allen et al., 2018; Cain et al., 2019). Additionally, methane from ruminants is part of a historical and biological cycle whereas CO_2 represents the one-directional mobilisation of fossil carbon that took millions of years to form (Thompson & Rowntree, 2020). The implication is that ruminants will not contribute to global warming if herd sizes do not expand and biogenic methane is mitigated to a reasonable extent through better feed, veterinary care, and herd management. There is considerable margin for global mitigation, especially with respect to some of the ruminant systems in Latin America, Sub-Saharan Africa, and South Asia that still display low productivity (Gerber et al., 2013). Moreover, what emission-based statistics overlook is that animal agriculture also sequesters carbon, to the point that dedicated grazing management systems can potentially offset emissions to a substantial degree (Gerber et al., 2013; Teague et al., 2016; Stanley et al., 2018; Rowntree et al., 2020).

The potential detrimental outcomes and side-effects of a mitigation policy based on abandoning grass-fed livestock are commonly ignored. This will not only compromise the world's nutrient supply but also lead to a sharp increase in other methanogenic animals that are less efficient in converting feed (Manzano & White, 2019). It is very likely that emissions would be replaced or even increased by the ones of wild counterparts, as enterogenic methane production today may be relatively comparable to historical levels produced by wild animals, including bison, and the Palaeolithic megafauna, such as mammoths and aurochs (Hristov, 2012; Zimov and Zimov, 2014), as well as termites. Updated calculations cited in Manzano & White (2019) indicate that prehuman herbivore density may indeed be much higher than assumed by some authors [*e.g.*, Bar-On et al. (2018), derived from estimates by Barnosky (2008)].

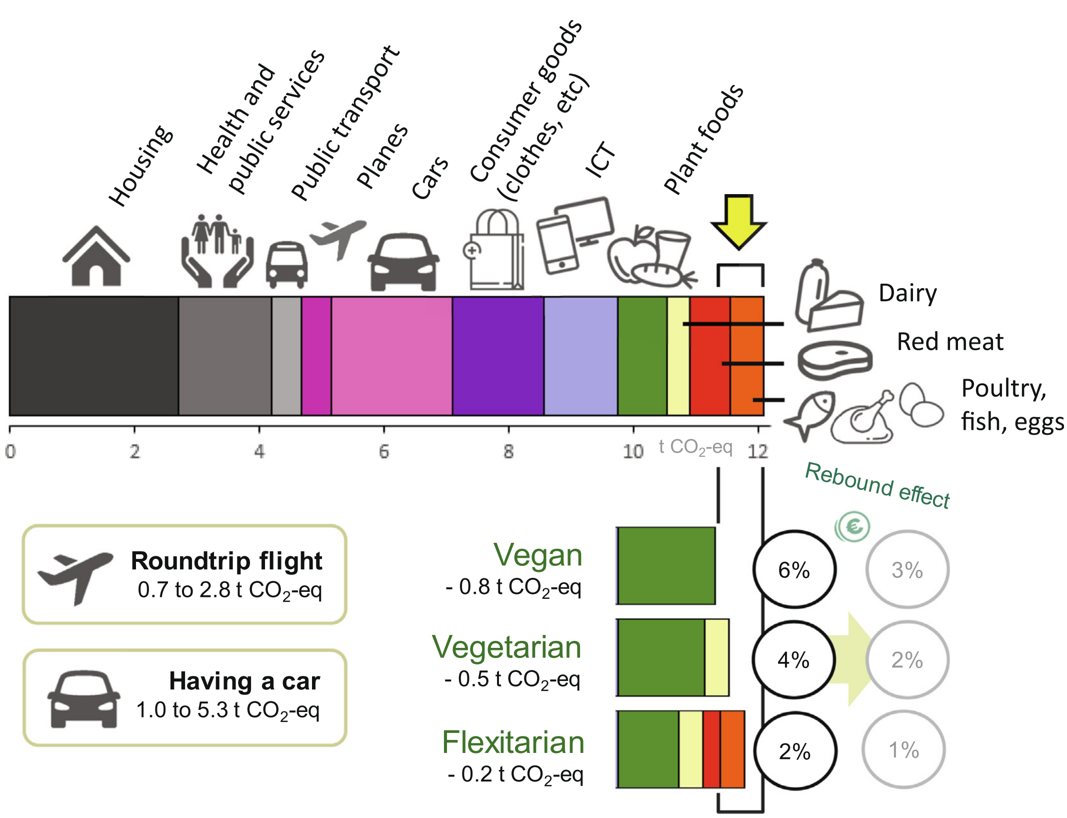

Fig. 2. Effect of dietary shifts on the yearly greenhouse gas emissions (in CO_2-eq) of a Western individual (example for the average Frenchmen; after https://ravijen.fr/?p=440), taking into account the dietary effects of veganism and vegetarianism (Hallström et al., 2015; Wynes & Nicholas, 2017) and flexitarianism (a 60% decrease in meat intake, from 200 to 80 g/p/d), as well as potential rebound effects (Grabs, 2015). Transportation data (car and flights) are obtained from Wynes and Nicholas (2017). ICT = information and communications technology.

Finally, comparisons should also be fair on a nutritional basis, avoiding reductionist metrics such as CO_2-eq per kg or per kcal. Such approaches stem from the historical interpretation of nutrition as a manner to address food shortages or fill caloric gaps, whereas the nutritional benefits relate to their spectrum and density of essential nutrients. When comparing foods, the aim should be to factor in adequate essential nutrition (Werner et al., 2014; Drewnowski et al., 2015; Tessari et al., 2016). The global dietary challenges of mid-century are not related solely to food quantities or calories but particularly to essential nutrients, many of which are generally contained in higher densities and/or more bioavailable forms in animal source foods, including essential amino acids, long-chain omega-3 fatty acids, vitamin B12, vitamin D, iron, zinc, and calcium (Simopoulos, 1999; Wu et al., 2014; Semba et al., 2016; Leroy & Barnard, 2020; Smith et al., 2021). Plant source foods may sometimes contain higher amounts of some of these key nutrients, as is often true for iron, yet lead to lower bioavailability nonetheless. Even "protein", as a unit of comparison, does not acknowledge the qualitative aspects of digestibility and essential amino acid content, which are more optimal in animal source foods (cf. Tessari et al., 2016; Marinangeli & House, 2017). Combined with the fact that animal source foods contain many other beneficial components that are not found in plants (Wu, 2020), such as taurine, creatine, and growth factors, the common belief that they are simply interchangeable with pulses is an oversimplification. Any environmental comparison that neglects nutritional adequacy is insufficient and not to be considered as a good basis for policy-making.

Why there is still reason for concern

Although exaggerated claims about livestock's effect on planetary health are not warranted, it is important to understand and acknowledge that reality is highly contingent on the region, ecosystem, and practices involved. At the same time, this implies that animal husbandry is often suboptimal and requires substantial improvements at many levels. This could, for instance, relate to further productivity improvements (*e.g.*, through breeding technologies and veterinary care), better protection of waterways, adjustment of grazing patterns and their management (in terms of frequency and intensity of defoliations, as well as taxonomically diverse wards, and in turn, biochemically diverse herbage canopies and rhizospheres in views to increase ecosystem services; Gregorini et al., 2017), and a better integration in the circular bioeconomy (Mottet et al., 2018; Leroy et al., 2020b). For ruminants, a larger shifting of grain feeding to grazing may turn out to be beneficial, whereas improved channelling of by-streams and recycling of food waste holds potential for efficient conversion by monogastrics (Fairlie, 2011; Schurson, 2020). There are also trade-offs, as regenerative grass-based systems tend to require more land. Yet, available land is often deteriorated from harmful monoculture cropping practices and can sustain greater biodiversity, healthier topsoil, and enhanced carbon sequestration with the presence of well-managed livestock (Rowntree et al., 2020).

The problem with eliminating animal source foods

Arguments for the decimation or even abolishment of livestock and the large-scale rewilding of marginal lands could only find root in a postindustrial Western context (cf. Leroy et al., 2020b). Its proponents neglect all services that livestock provide worldwide and their role in social sustainability (Dominguez-Salas et al., 2019). It would be fair policy to address and mitigate those practices within global animal production that give rise to concern because of a net negative impact on humans, animals, and the environment. However, when done well, animal husbandry plays a key role in the generation of food security, the manure-fertilisation of cropland and grassland, traction, carbon sequestration and topsoil formation, rural development, asset savings, livelihoods, and the empowerment of women, which in turn can result in improved nutrition security (Mottet et al., 2018). The environmental importance of livestock-mediated herbivory is attested by livestock-abandoned landscapes to show consistently less biodiversity than pastoralist cultural landscapes, as well as by other services such as wildfire prevention or soil restoration (Manzano-Baena & Salguero-Herrera, 2018). Advocating for total livestock abandonment is also not substantiated as coexistence with wildlife is possible, often even facilitating big game species (Schieltz & Rubenstein, 2016).

In addition, making food supply systems livestock-free would result in nutrient shortages which will have to be compensated in other ways (White & Hall, 2017). The risk is that this may as well reinforce disastrous forms of monocropping that are reliant on fossil fuel-derived fertilisers, result in further topsoil depletion, biodiversity losses, bioreactor foods, and apocalyptic greenhouse landscapes (as currently found in Almeria, Spain; MailOnline, 2013). Cultivated crops would also have to increase their surface (Peters et al., 2016). Given that crop expansion tends to occupy first lands that are less biodiverse, and then shifts into more biodiverse areas (Huston, 2005), the negative effects on biodiversity would increase sharply. Degradation of croplands in the US had led to a widescale conversion of native grasslands to croplands (88% of all newly converted croplands between 2008 and 2016), which has produced marginal crop yields at high cost to wildlife (Lark et al., 2020). Similar to the argument for livestock production, this does not imply that we should not grow crops, but implies that we should improve management practices in all forms of agriculture. Although there are global challenges to be addressed, such as water pollution and disruption of biochemical flows, livestock manure is also an important sustainable source of fertility for agricultural soils that would have to be replaced by more problematic mineral fertilisation in the case of drastic livestock reduction (Bouwman et al., 2013; Manzano-Baena & Salguero-Herrera, 2018). In fact, regenerative livestock production practices hold the potential to restore lands degraded from unsustainable crop production (Rowntree et al. 2020).

The loss of valuable, biodegradable textile products such as leather or animal fibres would come with its own environmental impacts. The use of artificial fibres is spreading microplastics in oceans and beyond, with very worrying potential effects (UNEP, 2016). Cold-isolating textile is one of the largest microplastic sources (Boucher & Friot, 2017), and natural fibre alternatives are mainly based on wool (Laing, 2009). Their comfort also has positive outcomes on physical and psychological well-being (Laing & Swan, 2016).

It should not be forgotten that true sustainability goes beyond the concept of "Planet" and also involves "Prosperity" and "People". The environmental impact of livestock needs to be assessed in relation to the alternative livelihoods for those populations that rely on livestock as the pathway out of poverty.

Animal source foods in ethical diets

Why the ethical case against animal source foods may be overstated

Ethics represent standards of what is generally to be expected from each other and from ourselves in specific situational settings. This, at its core, requires social transactions and accords. Thus, the need for animal welfare standards has been established as morally justified (Grandin & Cockram, 2020). Many animal rights advocates, however, wish to move conceptually beyond welfare criteria.

They are supportive of the elimination of any form of use of animals for food or other by-products, or for research. Considering that some theorists are in favour of legal coercion to impose veganism on society (*e.g.*, Deckers, 2013), the debate touches upon freedom of dietary choice. It is, therefore, pertinent to explore what lies at the origin of this evolution and to which degree animal source foods still maintain a justifiable role in ethical diets.

Being a nutritional foundation of our ancestral diets (Mann, 2018), animal source foods have always been strongly linked to ideas of strength, abundance, generosity, and other communitarian values (Leroy & Praet, 2015). These original connotations are increasingly being inverted by the vegan movement into ones of deterioration, death, infertility, debauchery, selfishness, disgust, and abnormality (Leroy et al., 2020b). The depiction of *all* of animal husbandry as an immoral system of "exploitation" that requires "liberation", rather than as one of sustenance and nourishment, is however a relatively recent moral construct becoming gradually more important since the 19th Century (Leroy & Hite, 2020). This cannot be uncoupled from the *commodification* of animals during that period, and the often rightful protest this may have generated with respect to animal welfare. Yet, it also relates to a variety of other sociohistorical dynamics. In brief, the latter relate to the beliefs and anxieties of the (upper) middle classes in the urban West, and their expression through *moral eating* and dietary *purity* [for a detailed discussion, we refer to Leroy (2019), Leroy & Hite (2020), and Leroy et al. (2020b)]. Also, the kill is perceived as a "dark event", offering a challenge to human empathy, especially when it is amplified by anthropomorphic projection and no longer culturally embedded in ritual and meaning (Leroy & Praet, 2017).

Despite what is commonly presumed, global suffering may not decrease with the elimination of animal husbandry and animal source foods. Although its prevalence may become less directly measurable and visible, the need for killing animals would not be abolished by the termination of livestock farming. What is usually left unaddressed in veganism's reliance on utilitarian philosophy, besides biodiversity loss from the envisaged land use change, is that the number of sentient animals that are killed as field deaths during crop production (via pest control, ploughing, harvesting machines, etc.), may even exceed the number obtained with animal husbandry per unit of food, especially when factoring in nutritional value and when compared to large animals (Davis, 2003; Archer, 2011). Estimates are highly uncertain (Fischer & Lamey, 2018), however, but it is clear that *all* food production comes with a death toll (Provenza et al., 2021).

Some of the problems may not be visible enough to ignite a critical debate. While animal activists are openly concerned about the welfare of marine mammals in zoological gardens, sea pollution by microplastics – mainly shed by synthetic clothing (UNEP, 2016) – is a more serious concern for the conservation of such species (Panti et al., 2019) than zoo keeping. Yet, this is not an important element in animal rights advocacy because the derived illness and death of wildlife remain invisible.

As an alternative to what is now often presented as exploitation, livestock farming can instead be valued as a *symbiotic* relationship between humans and animals, to the benefit of both (Leroy et al., 2020a). To be clear, the latter is only valid when animal welfare standards are in place and livestock receive a dignified life and a fast death. In comparison to their counterparts living a much more ferocious life in the wild, livestock animals receive shelter, are better fed during winter, receive veterinary care, are protected from predators, and do not die after a long agony. To state, therefore, that farming would be against livestock's interests or "nature", or that animals have self-regarding desires about their own futures, is an anthropocentric assumption (Baggini, 2014; Belshaw, 2015).

Compared to the straightforward benefits that can be obtained from a sound welfarist approach, utilitarian vegan claims remain unsupported and entail risk. Advocating for radical change towards both a new diet and food production system for humankind requires extraordinary evidence of safety. It is far from guaranteed that human suffering may not potentially increase in fragile populations. Vegan diets, which have been tested mostly on non-representative samples of Western adult populations in non-controlled studies, are probably not physiologically optimal for everyone and may potentially lead to long-term adverse effects. Abolishment of animal agriculture, which is critical in many regions of the world, opens the door to social and economic harm and the weakening of food security.

Why there is still reason for concern

In pre-industrial models, based on hunter-gathering or pastoralism, humans display rich interactions with animals and a respectful attitude, especially during the act of killing and the sharing and eating of the obtained foods. Asking forgiveness for the kill and a restitution to nature of what was taken through ritual is common practice, especially for hunter-gatherers (Leroy & Praet, 2017; Leroy et al., 2020b). It has been argued that a disconnection from ancestral activities and the commodification of animals and animal source foods during the era of industrialisation has caused much of the current moral crisis (Leroy 2019). By removing farming, slaughtering, and butchering scenes from their daily lives, Western citizens have also lost moral involvement and direct control over these processes. Moreover, breeding efforts to increase production and efficiency have typically resulted in less robust animals, which in some ways can have negative effects on well-being (Rauw, 2016). Although standards of animal welfare are in place in many areas and an increasing amount of work is being done to uphold them, they often fail to be covered at all stages and by all players in the livestock sector. Animal rights advocates rightly point out existing inhumane animal welfare practices, which require improved standards and regulation. But there are also many exemplary cases of livestock production, whose practices should be recognised and incentivised.

The problem with eliminating animal source foods

Given that even plant production comes with a large death toll, the only path towards a human food supply system that does not require animal killing would be one based on a radical fencing off of plant agriculture or on the development of bioreactor foods produced by "precision fermentation". In such cases, however, the already problematic Nature/Culture barrier will be heightened to the maximum. Also, the granting of human-like rights to non-human animals would eventually result in an enlargement of the sphere of individuals that are positioned *outside* Nature (Plumwood, 2004), failing to recognise ecological embeddedness of both human and non-human animals. Worse still, it would amplify the Life/Death binary as well. Some vegetarians already perceive death as a "contaminant essence" (Testoni et al., 2017), invading a biocentric and utopian Garden-of-Eden image (Sánchez Sábaté et al., 2016). While this would be impossible to uphold, the most extreme vegan theorists argue for a further far-reaching *purification* of what is left of the Nature compartment (cf., Verchot, 2014; Gyurko, 2016; Moen, 2016; Bramble, 2020).

Since animal source foods trace back to a rich cultural heritage, they will likely need to be replaced by plant-derived "imitations" to meet consumer demands. Generally, this has already been welcomed by food multinationals worldwide as a new business model in a market that was facing stagnation and reaching its limits of innovation potential. It not only allows for "greenwashing" and "nutri-washing" but also offers a perfect fit with existing industrial expertise: the (ultra)processing of inexpensive materials into added-value foods (Leroy et al., 2020b). The attribution of symbolic value to products of inferior quality via (lifestyle) branding thus exploits a consumerist need to accumulate "cultural" capital (Baudrillard, 1970; Ulijaszek et al., 2012). Besides accelerating a devolution towards nutritionism (*i.e*., the reduction of the cultural and nourishing values of food to a set of nutrients, "protein" in particular), and the loss of food sovereignty and centralisation in the hands of a few corporations, this will likely not be helpful to an already disastrous situation of public and planetary health.

With respect to public health, it is not only a potential enhancement of chronic disease that is of ethical concern but also a further undermining of adequate essential nutrition in already vulnerable populations, as discussed above. According to Hunt (2019), there is "moral reason for parents to not raise their child on a vegan diet because a vegan diet bears a risk of harm to both the physical and the social well-being of children". Giannini et al. (2006) agree: "it is alarming in a developed country to find situations in which a child's health is put at risk by malnutrition, not through economic problems but because of the ideological choices of the parents". In addition, vulnerable members of society would further suffer from the elimination of animal husbandry, due to the many other societal benefits it generates globally (livelihoods, use of by-products for medicine, etc.) Lastly, it would undermine our best chances on a resilient food system, integrating the best of plant and animal agriculture (Leroy et al., 2020b). Leaving such potential untapped would be unethical in its own manner.

Conclusions

Although there is a considerable margin for correction and improvement that can result in a substantial decrease of environmental burden and advances in animal welfare, we argue that animal source foods are compatible with the concept of healthy, sustainable, and ethical diets, and thereby foodscapes and landscapes. There may be a need to reduce animal source foods in some contexts and increase them in others, but contrary to what some high-profile global analyses have suggested, there is no robust evidence-based universal target amount of animal source foods that every population should adhere to (Nordhagen et al., 2020; Ridoutt et al., 2017). A prescribed optimal amount of animal source foods in the diet in any population will depend on numerous health, environmental, and social factors as well as production methods that vary considerably by context and are arguably difficult to capture in simplified metrics, given competing priorities, values, and inevitable trade-offs.

Of course, there is an urgent need for more efficient and environmentally sensitive livestock production methods, especially in view of providing the Global South with better access to the nutritional benefits of animal source foods. Generally, top-down planification of system properties and the quantification of planetary boundaries and safe-operating spaces from empirical data are highly unreliable due to overall complexity and uncertainty (cf. Hillebrand et al., 2020). Instead, we argue that future policies should start from robust premises: drawing red lines where needed (*e.g*., deforestation, water and air pollution, poor animal welfare, etc.) and incentivising those practices that are net beneficial, to amplify a bottom-up dynamic driven by practical agroecological and societal benefits (Leroy et al., 2020b).

In conclusion, animal husbandry, when done well and in alignment with local ecosystems and social contexts, should be part of the solution to improve public health and environmental resilience. Portraying it as a "problem" is counterproductive and will reinforce the Nature/Culture divide, risking to launch a mass experiment with unpredictable outcomes and with an entire new set of ethical concerns. It would also magnify internal inconsistency and imbalance within already problematic foodscapes and thoughtscapes (Leroy et al., 2020b). Rather than continuing along a trajectory that portrays animal source foods as harmful and plant source foods as beneficial, the future discourse would benefit from a renewed focus on such healthy foundations as nourishment and commensality. At policy level, notions of power, participation, and accountability need to be urgently addressed to prevent a future in which agriculture and the way we experience food are directly shaped by such vested interests as the public–private partnerships centred around investors and (agri-food) corporations (Canfield et al. 2021; Fakhri et al. 2021). In the scientific domain, this may also imply that we need to address white-hat bias (Cope & Allison, 2010) and conflicts of interests, both financial and ideological (Ioannidis & Trepanowski, 2018).

Ethics approval

Not applicable.

Data and model availability statement

Not applicable.

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Declaration of interest

All authors follow omnivorous diets. FL is a non-remunerated board member of various academic non-profit organisations including the Belgian Association for Meat Science and Technology (president), the Belgian Society for Food Microbiology (secretary), and the Belgian Nutrition Society. On a non-remunerated basis, he also has a seat in the scientific committee of the Institute Danone Belgium, the World's Farmers Organization, and the Advisory Commission for the "Protection of Geographical Denominations and Guaranteed Traditional Specialties for Agricultural Products and Foods" of the Ministry of the Brussels Capital Region. PM is a non-remunerated member of the Spanish Platform for Extensive Livestock and Pastoralism. SvV reports financial renumeration for academic talks, but does not accept honoraria, consulting fees, or other personal income from food industry groups/companies.

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