

<https://helda.helsinki.fi>

---

Animal board invited review: Animal source foods in healthy,  
pysustainable, and ethical diets An argument aga  
limitation of livestock in the food system

Leroy, Frédéric

2022-02-11

---

Leroy , F , Abraini , F , Beal , T , Domínguez-Salas , P , Gregorini , P , Manzano , P ,  
Rowntree , J & van Vliet , S 2022 , ' Animal board invited review: Animal source foods in  
pysustainable, and ethical diets An argument against drastic l  
the food system ' , Animal , vol. 16 , no. 3 , 100457 . <https://doi.org/10.1016/j.animal.2022.100457>

---

<http://hdl.handle.net/10138/341833>

<https://doi.org/10.1016/j.animal.2022.100457>

---

cc\_by\_nc\_nd

publishedVersion

---

*Downloaded from Helda, University of Helsinki institutional repository.*

*This is an electronic reprint of the original article.*

*This reprint may differ from the original in pagination and typographic detail.*

*Please cite the original version.*



# Animal

## The international journal of animal biosciences



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



Frédéric Leroy<sup>a,\*</sup>, Fabien Abraini<sup>b</sup>, Ty Beal<sup>c,d</sup>, Paula Dominguez-Salas<sup>e,f</sup>, Pablo Gregorini<sup>g,h</sup>, Pablo Manzano<sup>i,j,k</sup>, Jason Rowntree<sup>l</sup>, Stephan van Vliet<sup>m</sup>

<sup>a</sup> Industrial Microbiology and Food Biotechnology (IMDO), Faculty of Sciences and Bioengineering Sciences, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels, Belgium

<sup>b</sup> UMR CNRS 6240 LISA, Università di Corsica Pasquale Paoli, France

<sup>c</sup> Global Alliance for Improved Nutrition (GAIN), Washington, DC, USA

<sup>d</sup> Department of Environmental Science and Policy, University of California, Davis, CA, USA

<sup>e</sup> Natural Resources Institute, University of Greenwich, Kent ME4 4TB, UK

<sup>f</sup> International Livestock Research Institute (ILRI), Nairobi, Kenya

<sup>g</sup> Pastoral Livestock Production Lab, PO Box 85084, Lincoln University, Lincoln 7647, Christchurch, New Zealand

<sup>h</sup> Centre of Excellence for Designing Future Productive Landscapes, PO Box 85084, Lincoln University, Lincoln 7647, Christchurch, New Zealand

<sup>i</sup> Global Change and Conservation Lab, Organismal and Evolutionary Biology Research Programme, Faculty of Biological and Environmental Sciences, University of Helsinki, P.O. Box 65, FI-00014 Helsinki, Finland

<sup>j</sup> Helsinki Institute of Sustainability Science (HELSUS), Faculty of Biological and Environmental Sciences, University of Helsinki, P.O. Box 65, FI-00014 Helsinki, Finland

<sup>k</sup> Basque Centre For Climate Change (BC3), Edificio Sede, Campus EHU, Barrio Sarriena, S/n, 48940 Leioa, Spain

<sup>l</sup> Department of Animal Science, Michigan State University, East Lansing, MI, USA

<sup>m</sup> Center for Human Nutrition Studies, Utah State University, Logan, UT, USA

#### ARTICLE INFO

##### Article history:

Received 11 January 2021

Revised 6 January 2022

Accepted 7 January 2022

Available online 11 February 2022

##### Keywords:

Dairy

Meat

Plant-based

Vegan

Vegetarian

#### 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.

© 2022 The Authors. Published by Elsevier B.V. on behalf of The Animal Consortium. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

\* Corresponding author.

E-mail address: [Frederic.Leroy@vub.be](mailto:Frederic.Leroy@vub.be) (F. Leroy).

## 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 health 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 ([Mihirshahi 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 ([Baldrige 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” (Kruiger & 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

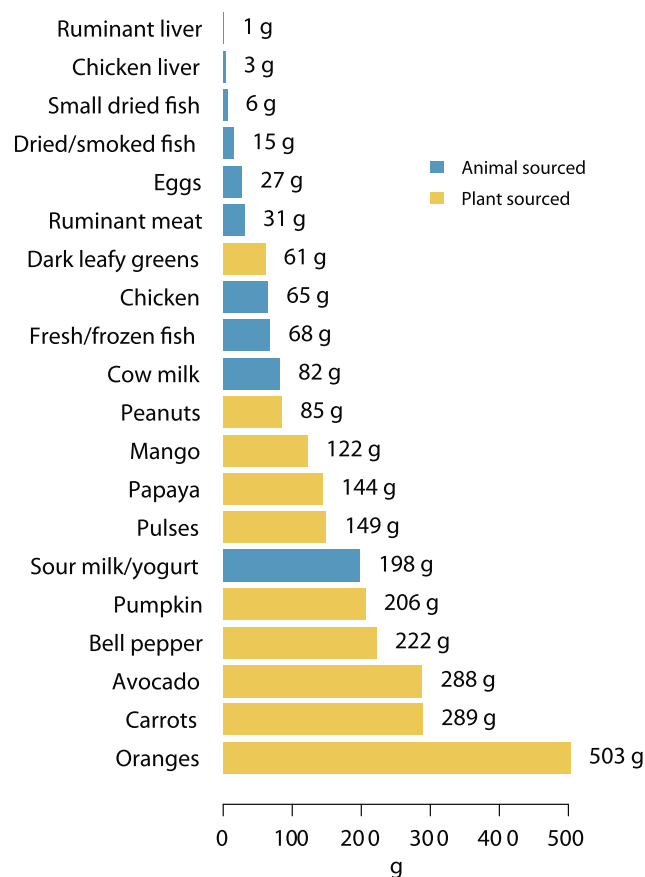
While the argument for a restriction of animal source foods for health reasons is a debate on its own (see above), some wish to go further and argue that the avoidance of chronic disease requires diets that are devoid of animal source foods (Barnard & Leroy, 2020). Although adequate vegan and vegetarian 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 (FoodDB, 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;



**Fig. 1.** Portion size needed to achieve an average of 33.3% of requirements for iron, vitamin A, zinc, folate, 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.

Adesogan et al., 2020), and prevent or treat malnutrition and sarcopenia in the elderly (Shibata, 2001; Phillips, 2012; Rondanelli et al., 2015).

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 disproportionately 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 bird-life (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 mediated issue in public discourse, that of climate change.

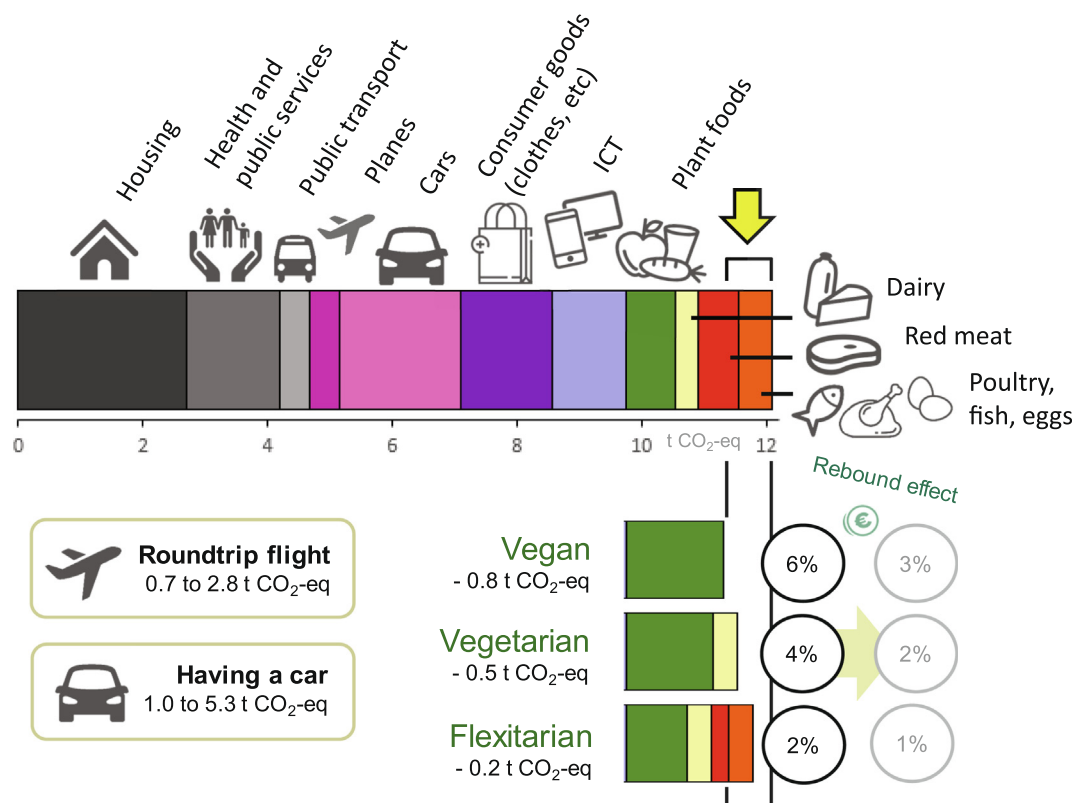
The contribution of livestock to total greenhouse gas (GHG) emissions globally has been estimated at 14.5%, which is mostly ascribed to feed production (45% of contribution) and enteric fermentation by ruminants (39%) (Gerber et al., 2013). Nuance is needed, however, as this global number is often erroneously 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<sub>2</sub>-eq/p/y reduction, respectively (Meier & Christen 2013; Hallström et al. 2015; Wynnes & Nicholas 2017). On a *total* lifestyle footprint of a Western individual (e.g., 12 t CO<sub>2</sub>-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<sub>2</sub>, 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub>-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; Wynnes & 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 Wynnes and Nicholas (2017). ICT = information and communications technology.



Finally, comparisons should also be fair on a nutritional basis, avoiding reductionist metrics such as CO<sub>2</sub>-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; Drownowski 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 (Schielz & 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 thoughts (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.

## Author ORICDs

**Frédéric Leroy:** <https://orcid.org/0000-0001-8682-9626>

**Fabien Abraini:** <https://orcid.org/0000-0003-2457-6269>

**Ty Beal:** <https://orcid.org/0000-0002-0398-9825>

**Paula Dominguez-Salas:** <https://orcid.org/0000-0001-8753-4221>

**Pablo Gregorini:** <https://orcid.org/0000-0002-7084-5223>

**Pablo Manzano:** <https://orcid.org/0000-0002-6071-2670>

**Jason Rowntree:** <https://orcid.org/0000-0003-4182-7592>

**Stephan van Vliet:** <https://orcid.org/0000-0001-8992-555X>

## Author contributions

**Frédéric Leroy:** Conceptualization, Writing – Original Draft.

**Fabien Abraini:** Writing – Review and Editing.

**Ty Beal:** Writing – Review and Editing.

**Paula Dominguez-Salas:** Writing – Review and Editing.

**Pablo Gregorini:** Writing – Review & Editing.

**Pablo Manzano:** Writing – Review & Editing.

**Jason Rowntree:** Writing – Review and Editing.

**Stephan van Vliet:** Writing – Review & Editing.

## 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 remuneration for academic talks, but does not accept honoraria, con-



sulting fees, or other personal income from food industry groups/companies.

## Acknowledgements

We thank Theresa Ryckman for her support with data analysis for Fig. 1, and Agustín del Prado for assisting in the interpretation of some references.

## Financial support statement

FL acknowledges financial support of the Research Council of the Vrije Universiteit Brussel, including the SRP7 and IOF342 projects, and in particular, the Interdisciplinary Research Program “Tradition and naturalness of animal products within a societal context of change” (IRP11). PM acknowledges financial support of the Helsinki Institute of Sustainability (HELSUS) through the project “Understanding pastoralism sustainability through an interdisciplinary lens”. PG and FL acknowledge financial support of the project “Grazing for environmental and human health” funded by the New Zealand Royal Society’s Catalyst Seeding Fund. SvV acknowledges grant support from the North Dakota Beef Association to study the health effects of red meat in relation to diet quality. SvV reports additional grant support from USDA-NIFA-SARE (2020-38640-31521; 2021-67034-35118), the Turner Institute of Ecoagriculture, the Dixon Foundation, and the Greenacres Foundation for projects that link agricultural production systems (including livestock and crops) to the nutritional/metabolite composition of foods and human health.

## References

Adesogan, A.T., Havelaar, A.H., McKunec, S.L., Ellittäd, M., Dahl, G.E., 2020. Animal source foods: sustainability problem or malnutrition and sustainability solution? Perspective matters. *Global Food Security* 25, 100325.

Alemu, W.G., Henebry, G.M., Melesse, A.M., 2020. Land cover and land use change in the US Prairie Pothole Region using the USDA Cropland Data Layer. *Land* 9, 166.

Alexander, D.D., Weed, D.L., Miller, P.E., Mohamed, M.A., 2015. Red meat and colorectal cancer: A quantitative update on the state of the epidemiologic science. *Journal of the American College of Nutrition* 34, 521–543.

Allen, M.R., Shine, K.P., Fuglestedt, J.S., Millar, R.J., Cain, M., Frame, D.J., Macey, A.H., 2018. A solution to the misrepresentations of CO<sub>2</sub>-equivalent emissions of short-lived climate pollutants under ambitious mitigation. *npj Climate and Atmospheric Science* 1, 16.

Archer, M., 2011. Ordering the vegetarian meal? There’s more animal blood on your hands. Retrieved on 10 December 2020, from <http://theconversation.com/ordering-the-vegetarian-meal-theres-more-animal-blood-on-your-hands-4659>.

Asnicar, F., Berry, S.E., Valdes, A.M., Nguyen, L.H., Piccinno, G., Drew, D.A., et al., 2021. Microbiome connections with host metabolism and habitual diet from 1,098 deeply phenotyped individuals. *Nature Medicine* 27, 321–332.

Astrup, A., Magkos, F., Bier, D.M., Brenna, J.T., de Oliveira Otto, M.C., Hill, J.O., et al., 2020. Saturated fats and health: A reassessment and proposal for food-based recommendations: JACC State-of-the-Art Review 2020. *Journal of the American College of Cardiology* 76, 844–857.

Baggini, J., 2014. *The virtues of the table*. Granta Publications, London, UK.

Baldrige, A.S., Huffman, M.D., Taylor, F., Xavier, D., Bright, B., Van Horn, L.V., et al., 2019. The healthfulness of the US packaged food and beverage supply: a cross-sectional study. *Nutrients* 11, 1704.

Banta, J.E., Lee, J.W., Hodgkin, G., Yi, Z., Fanica, A., Sabate, J., 2018. The global influence of the Seventh-Day Adventist church on diet. *Religions* 9, 251.

Barabási, A.-L., Menichetti, G., Loscalzo, J., 2020. The unmapped chemical complexity of our diet. *Nature Food* 1, 33–37.

Barberi, S., Bergamini, M., Bernardo, L., Berni Canani, R., Biasucci, G., Bona, G., et al., 2017. Position paper SIPPS-FIMP-SIMP. Diets vegetarian in gravidanza ed età evolutive. Retrieved on 10 December 2020, from [https://www.researchgate.net/publication/320004250\\_POSITION\\_PAPER\\_SIPPS-FIMP-SIMP\\_DIETE\\_VEGETARIANE\\_IN\\_GRAVIDANZA\\_ED\\_ETÀ\\_EVOLUTIVA](https://www.researchgate.net/publication/320004250_POSITION_PAPER_SIPPS-FIMP-SIMP_DIETE_VEGETARIANE_IN_GRAVIDANZA_ED_ETÀ_EVOLUTIVA).

Barnard, N.D., Leroy, F., 2020. Children and adults should avoid consuming animal products to reduce risk for chronic disease: YES. *The American Journal of Clinical Nutrition* 112, 926–930.

Barnsley, J.E., Chandrakumar, C., Gonzalez-Fischer, C., Eme, P.E., Bourke, B.E.P., Smith, N.W., et al., 2021. Lifetime climate impacts of diet transitions: A novel climate change accounting perspective. *Sustainability* 13, 5568.

Barthels, F., Meyer, F., Pietrowsky, R., 2018. Orthorexic and restrained eating behaviour in vegans, vegetarians, and individuals on a diet. *Eating and Weight Disorders* 23, 159–166.

Bakaloudi, D.R., Halloran, A., Rippin, H.L., Oikonomidou, A.C., Dardavesis, T., Williams, J., et al., 2020. Intake and adequacy of the vegan diet. A systematic review of the evidence. *Clinical Nutrition*. <https://doi.org/10.1016/j.clnu.2020.11.035>. Published online by Elsevier 7 December 2020.

Barnosky, A.D., 2008. Colloquium paper: Megafauna biomass trade-off as a driver of Quaternary and future extinctions. *Proceedings of the National Academy of Sciences* 105, 11543–11548.

Bar-On, Y.M., Phillips, R., Milo, R., 2018. The biomass distribution on Earth. *Proceedings of the National Academy of Sciences* 115, 6506–6511.

Baudrillard, J., 1970. *The Consumer Society, Myths and Structures*. Gallimard, Paris, France.

Beal, T., White, J.M., Arsenault, J.E., Okronipa, H., Hinnouhu, G.-M., Torlesse, H., et al., 2021. Micronutrient gaps during the complementary feeding period in South Asia: A Comprehensive Nutrient Gap Assessment. *Nutrition Reviews* 79 (Suppl 1), 26–34. <https://doi.org/10.1093/nutrit/nuaa144>.

Belgian Royal Academy of Medicine, 2019. Régimes végétariens et végétaliens administrés aux enfants et adolescents. Retrieved on 10 December 2020, from [http://www.armb.be/index.php?eID=tx\\_nawsecuredl&u=0&g=0&hash=9d0545dbd4fbb309ce0f2417c2c3d44a782de9a&file=fileadmin/sites/armb/upload/armb\\_super\\_editor/armb\\_editor/pdf/Avis/2019/ARMB\\_re\\_g\\_ve\\_ge\\_talien\\_version\\_complete.pdf](http://www.armb.be/index.php?eID=tx_nawsecuredl&u=0&g=0&hash=9d0545dbd4fbb309ce0f2417c2c3d44a782de9a&file=fileadmin/sites/armb/upload/armb_super_editor/armb_editor/pdf/Avis/2019/ARMB_re_g_ve_ge_talien_version_complete.pdf).

Belshaw, C., 2015. Meat. In: Bramble, B., Fischer, B. (Eds.), *The Moral Complexities of Eating Meat*. Oxford University Press, Oxford, UK. <https://doi.org/10.1093/acprof:oso/9780199353903.001.0001>.

Ben-Dor, M., Barkai, R., 2020. The importance of large prey animals during the Pleistocene and the implications of their extinction on the use of dietary ethnographic analogies. *Journal of Anthropological Archaeology* 59, 101192.

Berner, L.A., Keast, D.R., Bailey, R.L., Dwyer, J.T., 2014. Fortified foods are major contributors to nutrient intakes in diets of US children and adolescents. *Journal of the Academy of Nutrition and Dietetics* 114, 1009–1022.e8.

Bond, W.J., 2019. Open Ecosystems: ecology and evolution beyond the forest edge. Oxford Scholarship Online. Retrieved on 18 November 2021 from doi: 10.1093/oso/9780198812456.001.0001.

Boucher, J., Friot, D., 2017. Primary microplastics in the oceans: a global evaluation of sources. IUCN, Gland, Switzerland. <https://doi.org/10.2305/IUCN.CH.2017.01.en>.

Boulay, A.M., Drastig, K., Amanullah, Chapagain, A., Charlon, A., Civit, B., et al., 2021. Building consensus on water use assessment of livestock production systems and supply chains: Outcome and recommendations from the FAO LEAP Partnership. *Ecological Indicators* 124, 107391.

Bouwman, L., Goldewijk, K.K., Van Der Hoek, K.W., Beusen, A.H., Van Vuuren, D.P., Willems, J., et al., 2013. Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period. *Proceedings of the National Academy of Sciences* 110, 20882–20887.

Bramble, B., 2020. Painlessly killing predators. *Journal of Applied Philosophy* 2020. <https://doi.org/10.1111/japp.12461>. Published online by Wiley Online Library 15 September.

Brantsæter, A.L., Knutsen, H.K., Johansen, N.C., Nyheim, K.A., Erlund, I., Meltzer, H. M., et al., 2018. Inadequate iodine intake in population groups defined by age, life stage and vegetarian dietary practice in a Norwegian convenience sample. *Nutrients* 10, E230.

Burdge, G.C., 2006. Metabolism of alpha-linolenic acid in humans. *Prostaglandins, Leukotrienes, and Essential Fatty Acids* 75, 161–168.

Cain, M., Lynch, J., Allen, M.R., Fuglestedt, J.S., Frame, D.J., Macey, A.H., 2019. Improved calculation of warming-equivalent emissions for short-lived climate pollutants. *npj Climate and Atmospheric Science* 2, 29.

Canfield, M., Anderson, M.D., McMichael, P., 2021. UN Food Systems Summit 2021: Dismantling democracy and resetting corporate control of food systems. *Frontiers in Sustainable Food Systems* 2021. <https://doi.org/10.3389/fsufs.2021.661552>. Published online by Frontiers on 13 April.

Chen, F., Du, M., Blumberg, J.B., Chui, K.K.H., Ruan, M., Rogers, R., et al., 2019. Association among dietary supplement use, nutrient intake, and mortality among U.S. adults: A cohort study. *Annals of Internal Medicine* 170, 604–613.

Cofield, S.S., Corona, R.V., Allison, D.B., 2010. Use of causal language in observational studies of obesity and nutrition. *Obesity Facts* 3, 353–356.

Cofnas, N., 2019. Is vegetarianism healthy for children? *Critical Reviews in Food Science and Nutrition* 59, 2052–2060.

Cope, M.B., Allison, D.B., 2010. White hat bias: Examples of its presence in obesity research and a call for renewed commitment to faithfulness in research reporting. *International Journal of Obesity* 34, 84–183.

Cordain, L., Brand Miller, J., Boyd Eaton, S., Mann, N., Holt, S.H.A., Speth, J.D., 2000. Plant-animal subsistence ratios and macronutrient energy estimations in worldwide hunter-gatherer diets. *American Journal of Clinical Nutrition* 71, 682–692.

Cordain, L., Eaton, S.B., Brand Miller, J., Mann, N., Hill, K., 2002a. The paradoxical nature of hunter-gatherer diets: Meat-based, yet non-atherogenic. *European Journal of Clinical Nutrition* 56, S42–S52.

Cordain, L., Watkins, B.A., Florant, G.L., Kelher, M., Rogers, L., Li, Y., 2002b. Fatty acid analysis of wild ruminant tissues: Evolutionary implications for reducing diet-related chronic disease. *European Journal of Clinical Nutrition* 56, 181–191.

Davis, S.L., 2003. The least harm principle may require that humans consume a diet containing large herbivores. *Journal of Agricultural and Environmental Ethics* 16, 387–394.



- Deckers, J., 2013. In defence of the vegan project. *Bioethical Inquiry* 10, 187–195.
- Delgado, J., Ansoren, D., Van Hecke, T., Astiasarán, I., De Smet, S., Estévez, M., 2020. Meat lipids, NaCl and carnitine: Do they unveil the conundrum of the association between red and processed meat intake and cardiovascular diseases? *Meat Science* 171, 108278.
- Demeyer, D., Mertens, B., De Smet, S., Ulens, M., 2016. Mechanisms linking colorectal cancer to the consumption of (processed) red meat: a review. *Critical Reviews in Food Science and Nutrition* 56, 2747–2766.
- Desmond, M.A., Sobiecki, J.G., Jaworski, M., Phudowski, P., Antoniewicz, J., Shirley, M. K., et al., 2021. Growth, body composition, and cardiovascular and nutritional risk of 5- to 10-y-old children consuming vegetarian, vegan, or omnivore diets. *American Journal of Clinical Nutrition* 2021. <https://doi.org/10.1093/ajcn/nqaa445>. Published online by Oxford Academic on 19 March.
- Dewey, K.G., 2001. Nutrition, growth, and complementary feeding of the breastfed infant. *Paediatric Clinics of North America* 48, 87–104.
- Dinu, M., Abbate, R., Gensini, G.F., Casini, A., Sofi, F., 2017. Vegetarian and vegan diets and multiple health outcomes: A systematic review with meta-analysis of observational studies. *Critical Reviews in Food Science and Nutrition* 57, 3640–3649.
- Dominguez-Salas, P., Omore, A., Omosa, E., Ouma, E., 2019. Agrifood Systems in Low- and Middle-Income Countries: Status and Opportunities for Smallholder Dairy in LMIC. In: Ferranti, P., Berry, E.M., Ferranti, P., Berry, E.M. (Eds.), *Encyclopedia of Food Security and Sustainability*, vol. 3. Elsevier, Amsterdam, the Netherlands, pp. 326–339.
- Drewnowski, A., Rehm, C.D., Martin, A., Verger, E.O., Voinnesson, M., Imbert, P., 2015. Energy and nutrient density of foods in relation to their carbon footprint. *American Journal of Clinical Nutrition* 101, 184–191.
- Ellis, E.C., Gauthier, N., Goldewijk, K.K., Bird, R.B., Boivin, N., Díaz, S., et al., 2021. People have shaped most of terrestrial nature for at least 12,000 years. *Proceedings of the National Academy of Sciences of the United States of America* 118, e2023483118.
- Fairlie, S., 2011. *Meat: a benign extravagance*. Permanent Publications, East Meon, UK.
- Fakhri, M., Elver, H., De Schutter, O., 2021. The UN Food Systems Summit: How not to respond to the urgency of reform. Retrieved on 3 April 2021, from <http://www.ipsnews.net/2021/03/un-food-systems-summit-not-respond-urgency-reform/>.
- FAO (2018). More fuel for the food/feed debate. Retrieved on 3 January 2021, from [http://www.fao.org/ag/againfo/home/en/news\\_archive/2017\\_More\\_Fuel\\_for\\_the\\_Food\\_Feed.html](http://www.fao.org/ag/againfo/home/en/news_archive/2017_More_Fuel_for_the_Food_Feed.html).
- Faunalytics (Human Research Council), 2014. Study of current and former vegetarians and vegans. Initial findings. Retrieved on 3 January 2021, from <https://faunalytics.org/study-of-current-and-former-vegetarians-and-vegans/>.
- Fayet, F., Flood, V., Petocz, P., Samman, S., 2014. Avoidance of meat and poultry decreases intakes of omega-3 fatty acids, vitamin B12, selenium and zinc in young women. *Journal of Human Nutrition and Dietetics* 27, 135–142.
- Federal Commission for Nutrition, 2018. *Vegan diets: Review of nutritional benefits and risks*. Expert report of the FCN. Federal Food Safety and Veterinary Office, Bern, Switzerland.
- Fischer, B., Lamey, A., 2018. Field deaths in plant agriculture. *Journal of Agricultural and Environmental Ethics* 31, 409–428.
- FoodB, 2020. Compounds. Retrieved on 12 December 2020, from <https://foodb.ca/compounds>.
- Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., et al., 2013. Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy <http://www.fao.org/3/a-i3437e.pdf>.
- Giannini, A., Mirra, N., Patria, M.F., 2006. Health risks for children raised on vegan or vegetarian diets. *Pediatric Critical Care Medicine* 7, 188.
- Grace, D., Dominguez-Salas, P., Alonso, S., Lannerstad, M., Muunda, E., Ngwili, N., et al., 2018. The influence of livestock-derived foods on nutrition during the first 1,000 days of life ILRI Research Report 44. International Livestock Research Institute (ILRI), Nairobi, Kenya.
- Grabs, J., 2015. The rebound effects of switching to vegetarianism. A microeconomic analysis of Swedish consumption behavior. *Ecological Economics* 116, 270–279.
- Grandin, T., Cockram, M., 2020. *The slaughter of farmed animals*, Practical ways of enhancing animal welfare. CABI Publishing, Boston, MA, USA.
- Green, R., Cornelsen, L., Dangour, A.D., Turner, R., Shankar, B., Mazzocchi, M., Smith, R.D., 2013. The effect of rising food prices on food consumption: Systematic review with meta-regression. *British Medical Journal* 346, f3703.
- Gregorini, P., Villalba, J.J., Chilibroste, P., Provenza, F.D., 2017. Grazing management: Setting the table, designing the menu and influencing the diner. *Animal Production Science* 57, 1248–1268.
- Grosso, G., Micek, A., Godos, J., Pajak, A., Sciacca, S., Galvano, F., Boffetta, P., 2017. Health risk factors associated with meat, fruit and vegetable consumption in cohort studies: A comprehensive meta-analysis. *PLoS ONE* 12, e0183787.
- Guez, S., Chiarelli, G., Menni, F., Salera, S., Principi, N., Esposito, S., 2012. Severe vitamin B12 deficiency in an exclusively breastfed 5-month-old Italian infant born to a mother receiving multivitamin supplementation during pregnancy. *BMC Pediatrics* 12, 85.
- Gupta, S., 2016. Brain food: Clever eating. *Nature* 531, S12–S13.
- Guyatt, G., Oxman, A.D., Akl, E.A., Kunz, R., Vist, G., Brozek, J., et al., 2011. GRADE guidelines: 1. Introduction—GRADE evidence profiles and summary of findings tables. *Journal of Clinical Epidemiology* 64, 383–394.
- Gyrko, Z.I., 2016. The next step for veganism is ditching our bodies and digitizing our minds. Retrieved on 10 December 2020, from [https://www.vice.com/en\\_us/article/qkxjv/the-next-step-for-veganism-is-ditching-our-bodies-and-digitizing-our-minds](https://www.vice.com/en_us/article/qkxjv/the-next-step-for-veganism-is-ditching-our-bodies-and-digitizing-our-minds).
- Hall, K.D., Ayuketah, A., Brychta, R., Cai, H., Cassimatis, T., Chen, K.Y., et al., 2019. Ultra-processed diets cause excess calorie intake and weight gain: An inpatient randomized controlled trial of ad libitum food intake. *Cell Metabolism* 30, 67–77.
- Hallström, E., Carlsson-Kanyama, A., Börjesson, P., 2015. Environmental impact of dietary change: a systematic review. *Journal of Cleaner Production* 91, 1–11.
- Händel, M.N., Rohde, J.F., Jacobsen, R., Nielsen, S.M., Christensen, R., Alexander, D.D., et al., 2020. Processed meat intake and incidence of colorectal cancer: a systematic review and meta-analysis of prospective observational studies. *European Journal of Clinical Nutrition* 74, 1132–1148.
- Headey, D., Hirvonen, K., Hoddinott, J., 2017. Animal sourced foods and child stunting. *American Journal of Agricultural Economics* 100, 1302–1319.
- Herrero, M., Henderson, B., Havlík, P., Thornton, P.K., Conant, R.T., Smith, P., et al., 2016. Greenhouse gas mitigation potentials in the livestock sector. *Nature Climate Change* 6, 452–461.
- Hill, E., Wang, Y., Clark, C., McGowen, B., O'Connor, L., Campbell, W., 2020. Red meat intake and cardiometabolic disease risk: An assessment of causality using the Bradford Hill criteria. *Current Developments in Nutrition* 4, 31.
- Hillebrand, H., Donohue, I., Harpole, W.S., Hodapp, D., Kucera, M., Lewandowska, A. M., et al., 2020. Thresholds for ecological responses to global change do not emerge from empirical data. *Nature Ecology and Evolution* 4, 1502–1509.
- Hite, A.H., Feinman, R.D., Guzman, G.E., Satin, M., Schoenfeld, P.A., Wood, R.J., 2010. In the face of contradictory evidence: Report of the Dietary Guidelines for Americans Committee. *Nutrition* 26, 915–924.
- Hite, A.H., 2018. Nutritional epidemiology of chronic disease and defining “healthy diet”. *Global Food History* 4, 207–225.
- Hovinen, T., Korkalo, L., Freese, R., Skaffari, E., Isohanni, P., Niemi, M., et al., 2021. Vegan diet in young children remodels metabolism and challenges the statuses of essential nutrients. *EMBO Molecular Medicine* 13, e13492.
- Hristov, A.N., 2012. Historic, pre-European settlement, and present-day contribution of wild ruminants to enteric methane emissions in the United States. *Journal of Animal Science* 90, 1371–1375.
- Hulet, J.L., Weiss, R.E., Bwibo, N.O., Galal, O.M., Drorbaugh, N., Neumann, C.G., 2014. Animal source foods have a positive impact on the primary school test scores of Kenyan schoolchildren in a cluster-randomised, controlled feeding intervention trial. *British Journal of Nutrition* 111, 875–886.
- Hunt, M.W., 2019. Veganism and children: physical and social well-being. *Journal of Agricultural and Environmental Ethics* 32, 269–291.
- Huston, M.A., 2005. The three phases of land-use change: implications for biodiversity. *Ecological Applications* 15, 1864–1878.
- Iannotti, L., Tarawali, S., Baltenweck, I., Ericksen, P., Bett, B., Grace, et al., 2021. *Livestock-derived foods and sustainable healthy diets*. UN Nutrition Secretariat, Rome, Italy.
- IARC, 2015. *IARC Monographs evaluate consumption of red meat and processed meat*. Press release n°240. Retrieved on 18 November 2021 from [https://www.iarc.fr/en/media-centre/pr/2015/pdfs/pr240\\_E.pdf](https://www.iarc.fr/en/media-centre/pr/2015/pdfs/pr240_E.pdf).
- Ingenbleek, Y., McCully, K.S., 2012. Vegetarianism produces subclinical malnutrition, hyperhomocysteinemia and atherogenesis. *Nutrition* 28, 148–153.
- Ioannidis, J.P.A., 2018. The challenge of reforming nutritional epidemiologic research. *JAMA* 320, 969–970.
- Ioannidis, J.P.A., Trepanowski, J.F., 2018. Disclosures in nutrition research. Why it is different. *JAMA* 319, 547–548.
- Iqbal, R., Dehghan, M., Mente, A., Rangarajan, S., Wielgosz, A., Avezum, A., et al., 2021. Associations of unprocessed and processed meat intake with mortality and cardiovascular disease in 21 countries [Prospective Urban Rural Epidemiology (PURE) Study]: a prospective cohort study. *The American Journal of Clinical Nutrition* 2021. <https://doi.org/10.1093/ajcn/nqaa448>. Published online by Oxford Academic on 31 March.
- Jacobs, D.R., Tapsell, L.C., 2007. Food, not nutrients, is the fundamental unit in nutrition. *Nutrition Reviews* 65, 439–450.
- Johnston, B.C., Alonso-Coello, P., Bala, M.M., Zeraatkar, D., Rabassa, M., Valli, C., et al., 2018. Methods for trustworthy nutritional recommendations NutriRECS (Nutritional Recommendations and accessible Evidence summaries Composed of Systematic reviews): a protocol. *BMC Medical Research Methodology* 18, 162.
- Johnston, B.C., Zeraatkar, D., Han, M.A., Vernooij, R.W.M., Valli, C., El Dib, R., Marshall, C., Stover, P.J., Fairweather-Tait, S., Wójcik, G., et al., 2019. Unprocessed red meat and processed meat consumption: dietary guideline recommendations from the Nutritional Recommendations (NutriRECS) consortium. *Annals of Internal Medicine* 171, 756–764.
- Kaplan, H., Thompson, R.C., Trumble, B.C., et al., 2017. Coronary atherosclerosis in indigenous South American Tsimane: A cross sectional cohort study. *Lancet* 389, 1730–1739.
- Kapoor, A., Baig, M., Tunio, S.A., Memon, A.S., Karmani, H., 2017. Neuropsychiatric and neurological problems among vitamin B12 deficient young vegetarians. *Neurosciences* 22, 228–232.
- Keeley, B., Little, C., Zuehlke, E., 2019. *The State of the World's Children 2019: Children, Food and Nutrition – Growing Well in a Changing World*. UNICEF, New York, NY, USA.

- Key, T.J., Appleby, P.N., Davey, G.K., Allen, N.E., Spencer, E.A., Travis, R.C., 2003. Mortality in British vegetarians: review and preliminary results from EPIC-Oxford. *American Journal of Clinical Nutrition* 78, 533S–538S.
- Key, T.J., Bradbury, K.E., Perez-Cornago, A., Sinha, R., Tsilidis, K.T., Tsubane, S., 2020. Diet, nutrition, and cancer risk: what do we know and what is the way forward? *British Medical Journal* 368, m511.
- Khandpur, N., Neri, D.A., Monteiro, C., Mazur, A., Frelut, M.-L., Boyland, E., et al., 2020. Ultra-processed food consumption among the paediatric population: an overview and call to action from the European Childhood Obesity Group. *Annals of Nutrition and Metabolism* 76, 109–113.
- Klurfeld, D.M., 2015. Research gaps in evaluating the relationship of meat and health. *Meat Science* 109, 86–95.
- Koebnick, C., Hoffmann, I., Dagnelie, P.C., Heins, U.A., Wickramasinghe, S.N., Ratnayaka, I.D., Gruendel, S., Lindemans, J., Leitzmann, C., 2004. Long-term ovo-lacto vegetarian diet impairs vitamin B-12 status in pregnant women. *Journal of Nutrition* 134, 3319–3326.
- Krauss, R.M., Kris-Etherton, P.M., 2020. Public health guidelines should recommend reducing saturated fat consumption as much as possible: NO. *The American Journal of Clinical Nutrition* 112, 19–24.
- Kruger, C., Zhou, Y., 2018. Red meat and colon cancer: a review of mechanistic evidence for heme in the context of risk assessment methodology. *Food Chemistry and Toxicology* 118, 131–153.
- Kuipers, R.S., Luxwolda, M.F., Dijck-Brouwer, D.A.J., Eaton, S.B., Crawford, M.A., Cordain, L., Muskiet, F.A.J., 2010. Estimated macronutrient and fatty acid intakes from an East African Paleolithic diet. *British Journal of Nutrition* 104, 1666–1687.
- Laing, R.M., 2009. Assessing fabrics for cold weather apparel: the case of wool. In: Williams, J.T. (Ed.), *Textiles for Cold Weather Apparel*. Woodhead Publishing Limited, Sawston, Cambridge, UK, pp. 33–55. <https://doi.org/10.1533/9781845697174.1.33>.
- Laing, R.M., Swan, P., 2016. Wool in human health and well-being. In: Fanguero, R., Rana, S. (Eds.), *Natural Fibres – Advances in Science and Technology Towards Industrial Applications*. Springer, Dordrecht, the Netherlands, pp. 19–34. <https://doi.org/10.1016/j.proeng.2017.07.015>.
- Lal, R., 2020. Integrating animal husbandry with crops and trees. *Frontiers in Sustainable Food Systems* 2020. <https://doi.org/10.3389/fsufs.2020.00113>. Published online by Frontiers on 29 July.
- Lane, M.M., Davis, J.A., Beattie, S., Gómez-Donoso, C., Loughman, A., O'Neil, A., et al., 2021. Ultraprocessed food and chronic noncommunicable diseases: A systematic review and meta-analysis of 43 observational studies. *Obesity Reviews* 22, e13146.
- Lark, T.J., Spawn, S.A., Bougie, M., Gibbs, H.K., 2020. Cropland expansion in the United States produces marginal yields at high costs to wildlife. *Nature Communications* 11, 4295.
- Leroy, F., 2019. Meat as a pharmakon: An exploration of the biosocial complexities of meat consumption. *Advances in Food and Nutrition Research* 87, 409–446.
- Leroy, F., Barnard, N.D., 2020. Children and adults should avoid consuming animal products to reduce risk for chronic disease: NO. *The American Journal of Clinical Nutrition* 112, 931–936.
- Leroy, F., Cofnas, N., 2020. Should dietary guidelines recommend low red meat intake? *Critical Reviews in Food Science and Nutrition* 60, 2763–2772.
- Leroy, F., Hite, A.H., 2020. The place of meat in dietary policy: an exploration of the animal/plant divide. *Meat and Muscle Biology* 4, 2.
- Leroy, F., Praet, I., 2015. Meat traditions: the co-evolution of humans and meat. *Appetite* 90, 200–211.
- Leroy, F., Praet, I., 2017. Animal killing and postdomestic meat production. *Journal of Agricultural and Environmental Ethics* 30, 67–86.
- Leroy, F., Brengman, M., Ryckbosch, W., Scholliers, P., 2018a. Meat in the post-truth era: mass media discourses on health and disease in the attention economy. *Appetite* 125, 345–355.
- Leroy, F., Aymersch, T., Champomier-Vergès, M.-C., Cocolin, L., De Vuyst, L., Flores, M., et al., 2018b. Fermented meats (and the symptomatic case of the Flemish food pyramid): are we heading towards the vilification of a valuable food group? *International Journal of Food Microbiology* 274, 67–70.
- Leroy, F., Ben-Dor, M., Mitloehner, F.M., 2020a. Ethical defence of eating meat: the place of meat eating in ethical diets. In: Grandin, T., Cockram, M. (Eds.), *The slaughter of farmed animals. Practical ways of enhancing animal welfare*. CABI Publishing, Boston, MA, USA, pp. 301–308.
- Leroy, F., Hite, A.H., Gregorini, P., 2020b. Livestock in evolving foodscapes and thoughts. *Frontiers in Sustainable Food Systems* 4, 105.
- Lichtenstein, A.H., Russell, R.M., 2005. Essential nutrients: Food or supplements? Where should the emphasis be? *JAMA* 294, 351–358.
- Louwman, M.W.J., van Dusseldorp, M., van de Vijver, F.J.R., Thomas, C.M.G., Schneede, J., Ueland, P.M., Refsum, H., van Staveren, W.A., 2000. Signs of impaired cognitive function in adolescents with marginal cobalamin status. *American Journal of Clinical Nutrition* 72, 762–769.
- MailOnline, 2013. Britain's vegetable garden: The sea of Spanish greenhouses as large as the Isle of Wight where the food UK eats is grown. Retrieved on 10 December 2020, from <https://www.dailymail.co.uk/news/article-2303943/Britains-vegetable-garden-The-sea-Spanish-greenhouses-large-Isle-Wight-food-eat-grown.html>.
- Mann, N.J., 2018. A brief history of meat in the human diet and current health implications. *Meat Science* 144, 169–179.
- Manzano, P., White, S.R., 2019. Intensifying pastoralism may reduce greenhouse gas emissions: wild-life dominated landscape scenarios as a baseline in life-cycle analysis. *Climate Research* 77, 91–97.
- Manzano-Baena, P., Salguero-Herrera, C., 2018. Mobile Pastoralism in the Mediterranean: Arguments and evidence for policy reform and to combat climate change. In: Zogib, L. (Ed.), *Mediterranean Consortium for Nature and Culture*. Retrieved on 18 November 2021 from <https://tinyurl.com/yalgh87o>.
- Marinangeli, C.P.F., House, J.D., 2017. Potential impact of the digestible indispensable amino acid score as a measure of protein quality on dietary regulations and health. *Nutrition Reviews* 75, 658–667.
- Max-Neef, M., 2010. The world on a collision course and the need for a new economy. Contribution to the 2009 Royal Colloquium. *Ambio* 39, 200–210.
- Maximova, K., Khodayari Moez, E., Dabravolskaj, J., Ferdinands, A.R., Dinu, I., Lo Siou, G., Al Rajabi, A., Veugeliers, P.J., 2020. Co-consumption of vegetables and fruit, whole grains, and fiber reduces the cancer risk of red and processed meat in a large prospective cohort of adults from Alberta's Tomorrow Project. *Nutrients* 12, 2265.
- Meier, T., Christen, O., 2013. Environmental impacts of dietary recommendations and dietary styles: Germany as an example. *Environmental Science and Technology* 47, 877–888.
- Mekonnen, M.M., Hoekstra, A.Y., 2010. The green, blue and grey water footprint of farm animals and animal products Value of Water Research Report Series No. 48. UNESCO-IHE, Delft, the Netherlands.
- Melina, V., Craig, W., Levin, S., 2016. Position of the Academy of Nutrition and Dietetics: vegetarian diets. *Journal of the Academy of Nutrition and Dietetics* 116, 1970–1980.
- Mirshahi, S., Ding, D., Gale, J., Allman-Farinelli, M., Banks, E., Bauman, A.E., 2017. Vegetarian diet and all-cause mortality: Evidence from a large population-based Australian cohort – the 45 and Up Study. *Preventive Medicine* 97, 1–7.
- Milton, K., 2003. The critical role played by animal source foods in human (*Homo*) evolution. *The Journal of Nutrition* 133, 3886S–3892S.
- Moen, O.M., 2016. The ethics of wild animal suffering. *Nordic Journal of Applied Ethics* 10, 91–104.
- Mottet, A., de Haan, C., Faluccia, A., Tempio, G., Opio, C., Gerber, P., 2017. Livestock: on our plates or eating at our table? A new analysis of the feed/food debate. *Global Food Security* 14, 1–8.
- Mottet, A., Teillard, F., Boettcher, P., DeBesi, G., Besbes, B., 2018. Domestic herbivores and food security: current contribution, trends and challenges for a sustainable development. *Animal* 12, s188–s198.
- Mwai, J., Kimani, A., Mbelenga, E., et al., 2018. Kenya Food Composition Tables. Retrieved on 10 January 2021, from <https://www.kilimo.go.ke/wp-content/uploads/2018/10/KENYA-FOOD-COMPOSITION-TABLES-2018.pdf>.
- Naghsh, S., Sadeghi, O., Willett, W.C., Esmaillzadeh, A., 2020. Dietary intake of total, animal, and plant proteins and risk of all cause, cardiovascular, and cancer mortality: systematic review and dose-response meta-analysis of prospective cohort studies. *BMJ* 370, m2412.
- Naik, S., Mahalle, N., Bhide, V., 2018. Identification of vitamin B12 deficiency in vegetarian Indians. *British Journal of Nutrition* 119, 629–635.
- Neal, A.L., Bacq-Labreuil, A., Zhang, X., Clark, I.M., Coleman, K., Mooney, S.J., et al., 2020. Soil as an extended composite phenotype of the microbial metagenome. *Scientific Reports* 10, 10649.
- Nelson, G., Bogard, J., Lividini, K., Arsenaault, J., Riley, M., Sulser, T.B., et al., 2018. Income growth and climate change effects on global nutrition security to mid-century. *Nature Sustainability* 1, 773–781.
- Nordhagen, S., Beal, T., Haddad, L., 2020. GAIN Discussion Paper Series 5 – The role of animal-source foods in healthy, sustainable, and equitable food systems. Retrieved on 18 November 2021 from <https://doi.org/10.36072/dp.5>.
- O'Connor, L.E., Kim, J.E., Campbell, W.W., 2017. Total red meat intake of  $\geq 0.5$  servings/d does not negatively influence cardiovascular disease risk factors: a systematically searched meta-analysis of randomized controlled trials. *American Journal of Clinical Nutrition* 105, 57–69.
- Panti, C., Baini, M., Lusher, A., Hernandez-Milan, G., Bravo Rebolledo, E.L., Unger, B., et al., 2019. Marine litter: one of the major threats for marine mammals. Outcomes from the European Cetacean Society workshop. *Environmental Pollution* 247, 72–79.
- Paul, B.D., Snyder, S.H., 2019. Therapeutic applications of cysteamine and cystamine in neurodegenerative and neuropsychiatric diseases. *Frontiers in Neurology* 10, 1315.
- Pausas, J.G., Bond, W.J., 2019. Humboldt and the reinvention of nature. *Journal of Ecology* 107, 1031–1037.
- Pawlak, R., Lester, S.E., Babatunde, T., 2016. The prevalence of cobalamin deficiency among vegetarians assessed by serum vitamin B12: a review of literature. *European Journal of Clinical Nutrition* 70, 866.
- Peters, C.J., Picardy, J., Darroutet-Nardi, A.F., Wilkins, J.L., Griffin, T.S., Fick, G.W., 2016. Carrying capacity of U.S. agricultural land: Ten diet scenarios. *Elementary Science of the Anthropocene* 4, 000116.
- Peters, G.M., Wiedemann, S.G., Rowley, H.V., Tucker, R.W., 2010. Accounting for water use in Australian red meat production. *International Journal of Life Cycle Assessment* 15, 311–320.
- Pfister, S., Boulay, A.-M., Berger, M., Hadjikakou, M., Motoshita, M., Hess, T., et al., 2017. Understanding the LCA and ISO water footprint: A response to Hoekstra (2016) "A critique on the water-scarcity weighted water footprint in LCA". *Ecological Indicators* 72, 352–359.
- Phillips, S.M., 2012. Nutrient-rich meat proteins in offsetting age-related muscle loss. *Meat Science* 92, 174–178.
- Plumwood, V., 2004. Animals and ecology: toward a better integration. In: Sapontzis, S.F. (Ed.), *Food for thought: the debate over eating meat*. Prometheus, Amherst, NY, USA, pp. 344–358.

- Protudjer, J.L.P., Mikkelsen, A., 2020. Veganism and paediatric food allergy: two increasingly prevalent dietary issues that are challenging when co-occurring. *BMC Pediatrics* 20, 341.
- Provenza, F.D., Meuret, M., Gregorini, P., 2015. Our landscapes, our livestock, ourselves: Restoring broken linkages among plants, herbivores, and humans with diets that nourish and satiate. *Appetite* 95, 500–519.
- Provenza, F.D., Anderson, C., Gregorini, P., 2021. We are the earth and the earth is us. How palates link foodscapes, landscapes, heartsapes and mindscapes. *Frontiers in Sustainable Food Systems* 5, 547822.
- Qian, F., Riddle, M.C., Wylie-Rosett, J., Hu, F.B., 2020. Red and processed meats and health risks: how strong is the evidence? *Diabetes Care* 43, 265–271.
- Rauw, W.M., 2016. Improving animal welfare through genetic selection. *Frontiers in Genetics* 7, 69.
- Rehkamp, S., 2016. A look at calorie sources in the American diet. Retrieved on 10 December 2020, from <https://www.ers.usda.gov/amber-waves/2016/december/a-look-at-calorie-sources-in-the-american-diet>.
- Ridoutt, B.G., Sanguansri, P., Freer, M., Harper, G.S., 2012a. Water footprint of livestock: comparison of six geographically defined beef production systems. *International Journal of Life Cycle Assessment* 17, 15–175.
- Ridoutt, B.G., Sanguansri, P., Nolan, M., Marks, N., 2012b. Meat consumption and water scarcity: beware of generalizations. *Journal of Cleaner Production* 28, 127–133.
- Ridoutt, B.G., Hendrie, G.A., Noakes, M., 2017. Dietary strategies to reduce environmental impact: a critical review of the evidence base. *Advances in Nutrition* 8, 933–946.
- Rodriguez-Mateos, A., Istas, G., Boschek, L., Feliciano, R.P., Mills, C.E., Boby, C., et al., 2019. Circulating anthocyanin metabolites mediate vascular benefits of blueberries: Insights from randomized controlled trials, metabolomics, and nutrigenomics. *The Journals of Gerontology (Series A)* 74, 967–976.
- Rondanelli, M., Perna, S., Faliva, M.A., Peroni, G., Infantino, V., Pozzi, R., 2015. Novel insights on intake of meat and prevention of sarcopenia: All reasons for an adequate consumption. *Nutrición Hospitalaria* 32, 2136–2143.
- Rotz, A., Asem-Hiablie, A., Place, A., Thoma, G., 2019. Environmental footprints of beef cattle production in the United States. *Agricultural Systems* 169, 1–13.
- Rowntree, J., Stanley, P.L., Maciel, I.C., Thorbecke, M., Rosenzweig, S.T., Hancock, D. W., Raven, M.R., 2020. Ecosystem impacts and productive capacity of a multi-species pastured livestock system. *Frontiers in Sustainable Food Systems* 4, 232.
- Rubin, R., 2020. Backlash over meat dietary recommendations raises questions about corporate ties to nutrition scientists. *JAMA* 323, 401–404.
- Sánchez Sábate, R., Gelabert, R., Badilla, Y., Del Valle, C., 2016. Feeding holy bodies: a study on the social meanings of a vegetarian diet to Seventh-day Adventist church pioneers. *HTS: Theological Studies* 72, UNSP a3080.
- Satija, A., Bhupathiraju, S.N., Spiegelman, D., Chiuve, S.E., Manson, J.E., Willett, W., et al., 2017. Healthful and unhealthful plant-based diets and the risk of coronary heart disease in U.S. adults. *Journal of the American College of Cardiology* 70, 411–422.
- Schieltz, J.M., Rubenstein, D.I., 2016. Evidence based review: Positive versus negative effects of livestock grazing on wildlife. What do we really know? *Environmental Research Letters* 11, 113003.
- Schürman, S., Kersting, M., Alexy, U., 2017. Vegetarian diets in children: A systematic review. *European Journal of Nutrition* 56, 1797–1817.
- Scott, J.C., 1998. Seeing like a state: How certain schemes to improve the human condition have failed. Yale University Press, New Haven, CT, USA.
- Schurson, G.C., 2020. “What a waste”—Can we improve sustainability of food animal production systems by recycling food waste streams into animal feed in an era of health, climate, and economic crises? *Sustainability* 12, 7071.
- Semba, R.D., Shardell, M., Ashour, F.A.S., Moaddel, R., Trehan, I., Maleta, K.M., et al., 2016. Child stunting is associated with low circulating essential amino acids. *EBioMedicine* 6, 246–252.
- Shibata, H., 2001. Nutritional factors on longevity and quality of life in Japan. *Journal of Nutrition, Health and Aging* 5, 97–102.
- Sholl, J., Mailing, L.J., Wood, T.R., 2021. Reframing nutritional microbiota studies to reflect an inherent metabolic flexibility of the human gut: a narrative review focusing on high-fat diets. *mBio* 12, e00579–e00621.
- Simopoulos, A.P., 1999. Essential fatty acids in health and chronic disease. *The American Journal of Clinical Nutrition* 70, 560s–569s.
- Smith, J.S., Ameri, F., Gadgil, P., 2008. Effect of marinades on the formation of heterocyclic amines in grilled beef steaks. *Journal of Food Science* 73, T100–T105.
- Smith, N.W., Fletcher, A.J., Dave, L.A., Hill, J.P., McNabb, W.C., 2021. Use of the DELTA model to understand the food system and global nutrition. *The Journal of Nutrition* 151, 3253–3261.
- Stanley, P.L., Rowntree, J.E., Beede, D.K., DeLonge, M.S., Hamm, M.W., 2018. Impacts of soil carbon sequestration on life cycle greenhouse gas emissions in Midwestern USA beef finishing systems. *Agricultural Systems* 162, 249–258.
- Swanson, D., Block, R., Mousa, S.A., 2012. Omega-3 fatty acids EPA and DHA: Health benefits throughout life. *Advances in Nutrition* 3, 1–7.
- Tang, G., 2010. Bioconversion of dietary provitamin A carotenoids to vitamin A in humans. *American Journal of Clinical Nutrition* 91, 1468S–1473S.
- Tang, M., Krebs, N.F., 2014. High protein intake from meats as complementary food increases growth but not adiposity in breastfed infants: a randomized trial. *American Journal of Clinical Nutrition* 100, 1322–1328.
- Teague, W.R., Apfelbaum, S., Lal, R., Kreuter, U.P., Rowntree, J., Davies, C.A., et al., 2016. The role of ruminants in reducing agriculture's carbon footprint in North America. *Journal of Soil and Water Conservation* 71, 156–164.
- Tessari, P., Lante, A., Mosca, G., 2016. Essential amino acids: master regulators of nutrition and environmental footprint? *Scientific Reports* 6, 26074.
- Testoni, I., Ghellar, T., Rodelli, M., De Cataldo, L., Zamperini, A., 2017. Representations of death among Italian vegetarians: an ethnographic research on environment, disgust and transcendence. *European Journal of Psychology* 13, 378–395.
- Thompson, L.R., Rowntree, J.E., 2020. Invited review: Methane sources, quantification, and mitigation in grazing beef systems. *Sustainability and Integrated Systems* 36, 556–573.
- Truswell, A.S., 2009. Problems with red meat in the WCRF2. *The American Journal of Clinical Nutrition* 89, 1274–1275.
- Turner, N.D., Lloyd, S.K., 2017. Association between red meat consumption and colon cancer: a systematic review of experimental results. *Experimental Biology and Medicine* 242, 813–839.
- Ulijaszek, S., Mann, N., Elton, S., 2012. Evolving human nutrition, Implications for human health. Cambridge University Press, Cambridge, UK.
- UNEP, 2016. Microplastics: trouble in the food chain. In: *UNEP Frontiers 2016 Report: Emerging Issues of Environmental Concern*, pp. 32–43. United Nations Environment Programme, Nairobi. Retrieved on 10 December 2020, from <http://hdl.handle.net/20.500.11822/7664>.
- van Dusseldorp, M., Schneede, J., Refsum, H., Ueland, P.M., Thomas, C.M.G., de Boer, E., van Staveren, W.A., 1999. Risk of persistent cobalamin deficiency in adolescents fed a macrobiotic diet in early life. *American Journal of Clinical Nutrition* 69, 664–671.
- Van Hecke, T., Goethals, S., De Smet, S., 2017. The potential of herbs and spices to reduce lipid oxidation during heating and gastrointestinal digestion of a beef product. *Food Research International* 102, 785–792.
- van Vliet, S., Kronberg, S.L., Provenza, F.D., 2021a. Plant-based meats, human health, and climate change. *Frontiers in Sustainable Food Systems* 2020. <https://doi.org/10.3389/fsufs.2020.00128>. Published by Frontiers on 6 October.
- van Vliet, S., Provenza, F.D., Kronberg, S.L., 2021b. Health-promoting phytonutrients are higher in grass-fed meat and milk. *Frontiers in Sustainable Food Systems* 2021. <https://doi.org/10.3389/fsufs.2020.555426>. Published by Frontiers on 1 February.
- Verchot, M., 2014. Meet the people who want to turn predators into herbivores. Retrieved on 10 December 2020, from <https://www.treehugger.com/natural-sciences/meet-the-people-who-want-to-turn-predators-into-vegans.html>.
- Vernooij, R.W.M., Guyatt, G.H., Zeraatkar, D., Han, M.A., Valli, C., El Dib, R., Alonso-Coello, P., Bala, M.M., Johnston, B.C., 2021. Reconciling contrasting guideline recommendations on red and processed meat for health outcomes. *Journal of Clinical Epidemiology* 2021. <https://doi.org/10.1016/j.jclinepi.2021.07.008>. Published by Elsevier on 14 July.
- Wallace, T.C., Blusztajn, J.K., Caudill, M.A., Klatt, K.C., Natker, E., Zeisel, S., Zelman, K. M., 2018. Choline. The underconsumed and underappreciated essential nutrient. *Nutrition Today* 53, 240–253.
- Werner, L.B., Flysjö, A., Tholstrup, T., 2014. Greenhouse gas emissions of realistic dietary choices in Denmark: the carbon footprint and nutritional value of dairy products. *Food and Nutrition Research* 58, 20687.
- White, R.R., Hall, M.B., 2017. Nutritional and greenhouse gas impacts of removing animals from US agriculture. *Proceedings of the National Academy of Sciences of the United States of America* 114, E10301–E10308.
- White, R.R., Hall, M.B., 2018. Reply to Van Meerbeek and Svenning, Emery, and Springmann et al.: Clarifying assumptions and objectives in evaluating effects of food system shifts on human diets. *Proceedings of the National Academy of Sciences of the United States of America* 115, E1706–E1708.
- White, J.M., Beal, T., Arsenault, J.E., Okronipa, H., Hinnouho, G.M., Chimanya, K., et al., 2021. Micronutrient gaps during the complementary feeding period in 6 countries in Eastern and Southern Africa: A comprehensive nutrient gap assessment. *Nutrition Reviews* 79 (Suppl. 1), 16–25.
- Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., et al., 2019. Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems. *Lancet* 393, 447–492.
- Williams, D.R., Clark, M., Buchanan, G.M., Ficetola, G.F., Rondinini, C., Tilman, D., 2020. Proactive conservation to prevent habitat losses to agricultural expansion. *Nature Sustainability* 4, 314–322.
- WHO/FAO, 2004. World Health Organization, Food and Agriculture Organization of the United Nations, eds. *Vitamin and Mineral Requirements in Human Nutrition*. 2nd ed. Retrieved on 10 December 2020, from <https://apps.who.int/iris/bitstream/handle/10665/42716/9241546123.pdf>.
- WHO, 2015. Cancer: Carcinogenicity of the consumption of red meat and processed meat. Retrieved on 4 April 2021, from <https://www.who.int/news-room/q-a-detail/cancer-carcinogenicity-of-the-consumption-of-red-meat-and-processed-meat>.
- Woo, K.S., Kwok, T.C., Celemajer, D.S., 2014. Vegan diet, subnormal vitamin B-12 status and cardiovascular health. *Nutrients* 6, 3259–3273.
- Wright, C.K., Larson, B., Lark, T.J., Gibbs, H.K., 2017. Recent grassland losses are concentrated around U.S. ethanol refineries. *Environmental Research Letters* 12, 044001.
- Wu, G., 2020. Important roles of dietary taurine, creatine, carnosine, anserine and 4-hydroxyproline in human nutrition and health. *Amino Acids* 52, 329–360.
- Wu, G., Fanzo, J., Miller, D.D., Pingali, P., Post, M., Steiner, J.L., Thalacker-Mercer, A.E., 2014. Production and supply of high-quality food protein for human consumption: sustainability, challenges, and innovations. *Annals of the New York Academy of Sciences* 1321, 1–19.

- Wynes, S., Nicholas, K.A., 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions. *Environmental Research Letters* 12, 074024.
- Xu, X., Sharma, P., Shu, S., Lin, T.-S., Ciais, P., Tubiello, F.N., et al., 2021. Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods. *Nature Food* 2, 724–732.
- Zagmutt, F.J., Pouzou, J.G., Costard, S., 2021. The EAT-Lancet Commission's dietary composition may not prevent noncommunicable disease mortality. *The Journal of Nutrition* 150, 985–988.
- Zeraatkar, D., Johnston, B.C., 2019. A novel approach to evaluating the plausibility of causal relationships from non-randomized studies. *International Society for Evidence-Based Health Care*, 26th Newsletter Edition. Retrieved on 6 April 2021, from [https://ebm.mcmaster.ca/docs/librariesprovider31/newsletters/international-society-for-evidence-based-health-care-newsletter-december-2019.pdf?sfvrsn=1bef3db2\\_4](https://ebm.mcmaster.ca/docs/librariesprovider31/newsletters/international-society-for-evidence-based-health-care-newsletter-december-2019.pdf?sfvrsn=1bef3db2_4).
- Zickgraf, H.F., Hazzard, V.M., O'Connor, S.M., Simone, M., Williams-Kerver, G.A., Anderson, L.M., Lipson, S.K., 2020. Examining vegetarianism, weight motivations, and eating disorder psychopathology among college students. *International Journal of Eating Disorders* 53, 1506–1514.
- Zimov, S., Zimov, N., 2014. Role of megafauna and frozen soil in the atmospheric C44 dynamics. *PLoS One* 9, e93331.