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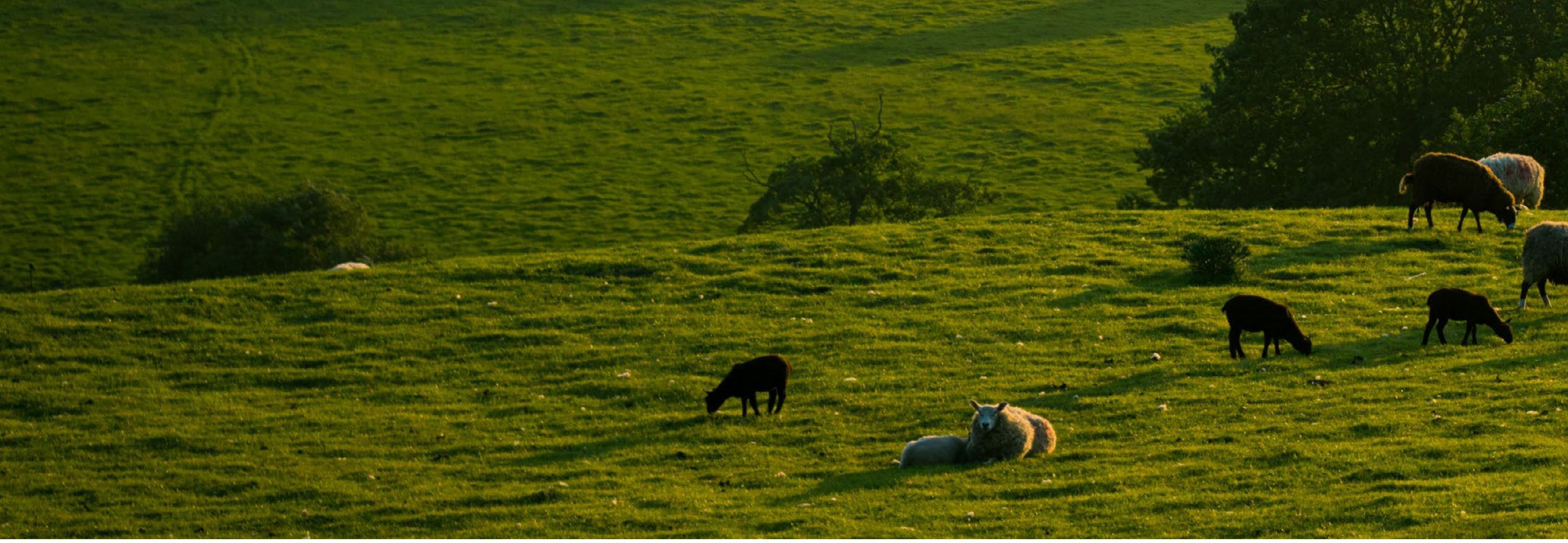
REPORT

Toward “Better” Meat?

Aligning meat sourcing strategies with corporate climate and sustainability goals

Richard Waite, Jessica Zionts, and Clara Cho



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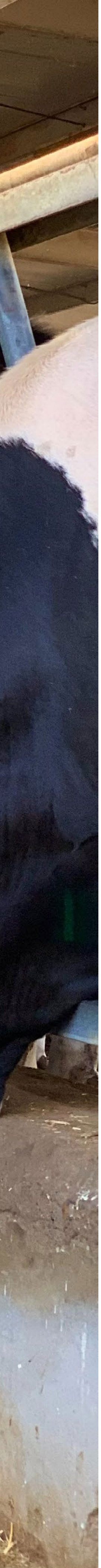

Foreword

Today, meat and dairy production contributes roughly two-thirds of all emissions from agriculture and accounts for more than three-quarters of agricultural land use. Yet, the actual consumption of these animal-based products is extremely uneven across the world, with the highest consumption among populations in the Global North. Without a significant change in how people in these high-consuming countries eat, global climate targets will remain out of reach.

The striking role of meat – particularly beef and lamb – in climate change makes clear that the world must shift toward a more plant-based diet. This will not happen overnight. In fact, many people who enjoy meat may never fully eliminate it from their plates. Luckily, a more climate friendly diet does not require everyone to become vegan or vegetarian. The reality is that even as restaurants, retailers, catering companies and other food providers work to help consumers choose lower-carbon foods, they will also continue to sell at least some meat.

Many of those companies are rightly asking: If my company does source meat, how can it be sourced in a way that is better for the animals that are being consumed, the people who are being served, the natural resources and land that are used for production, and the climate that we are actively harming? What does "better meat" mean?

Companies aiming to achieve multiple sustainability goals related to the food they purchase and serve are often faced with tradeoffs between those goals. They are forced to weigh sometimes contradictory measures – such as sourcing meat from higher-welfare production systems that use more land, but also ensuring more efficient use of earth's finite land and avoiding additional agricultural encroachment on forests.

This research provides a starting point for food providers in search of guidance, outlining six strategies to help food providers meet multiple sustainability goals, from food-related emissions measurement and sourcing strategy design to supplier engagement.

With careful planning, it is possible to source higher-welfare meat and dairy while still lowering food-related emissions and land use overall. At the same time, in cases where sourcing so-called "better meat" is likely to lead to higher environmental impacts, strategies to source "less meat" need to become strategies to source "even less meat."

To achieve their sustainability goals, food providers need robust, evidence-based information to optimize their meat sourcing strategies. Assessing the environmental and climate impacts of different food production systems, practices, and technologies with supply chain partners – and improving those impacts – is nuanced and complex work. As we move forward, companies and experts must work together even more closely to meaningfully shift diets and production practices to create a better world for people, nature, and climate.

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President & CEO

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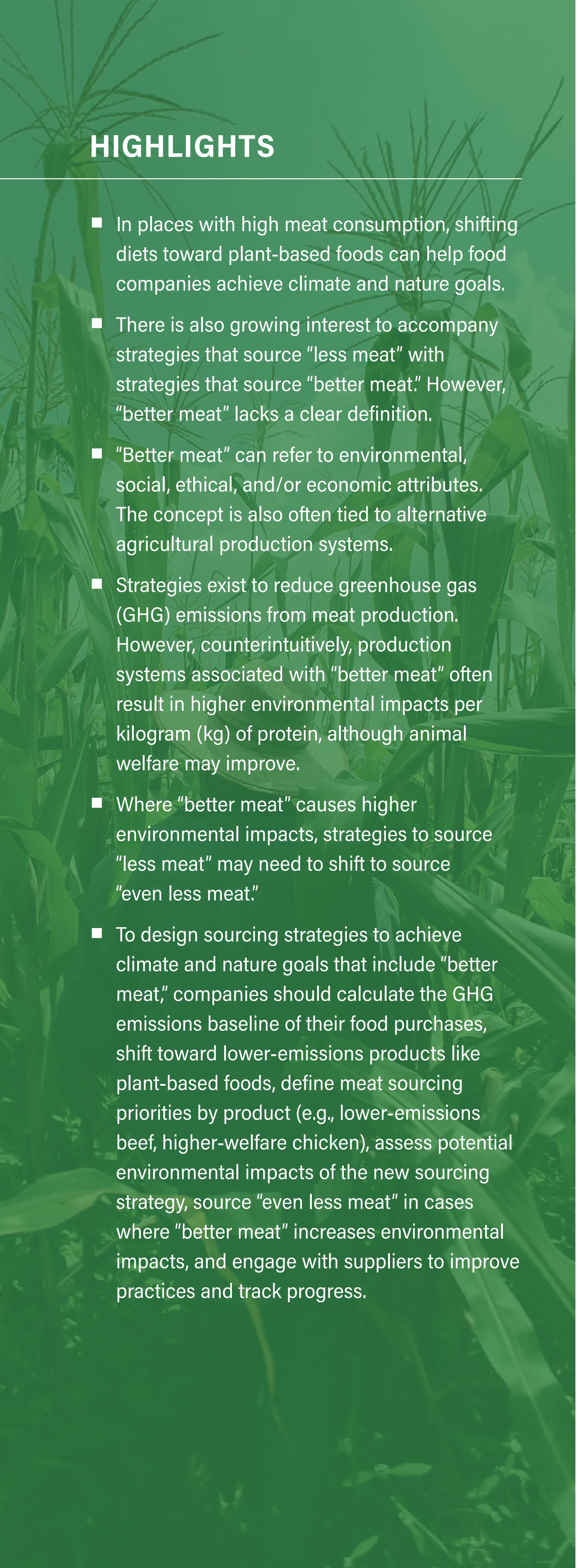
Executive summary

Terrestrial animal agriculture—including meat and dairy production—is responsible for more than three-quarters of agricultural land use, 11–20 percent of global greenhouse gas emissions, and more than 30 percent of global methane emissions. Animal agriculture is a key driver of deforestation and land-use change. As the global population grows toward 10 billion people by 2050, strategies to both shift high-meat diets toward plant-based foods and reduce GHG emissions and other environmental impacts from remaining meat production will be necessary to achieve food security in an equitable way, while meeting nature and climate targets. Furthermore, ending deforestation and achieving large-scale ecosystem restoration will only be possible if agriculture's large land footprint is reduced.



HIGHLIGHTS

- In places with high meat consumption, shifting diets toward plant-based foods can help food companies achieve climate and nature goals.
- There is also growing interest to accompany strategies that source "less meat" with strategies that source "better meat." However, "better meat" lacks a clear definition.
- "Better meat" can refer to environmental, social, ethical, and/or economic attributes. The concept is also often tied to alternative agricultural production systems.
- Strategies exist to reduce greenhouse gas (GHG) emissions from meat production. However, counterintuitively, production systems associated with "better meat" often result in higher environmental impacts per kilogram (kg) of protein, although animal welfare may improve.
- Where "better meat" causes higher environmental impacts, strategies to source "less meat" may need to shift to source "even less meat."
- To design sourcing strategies to achieve climate and nature goals that include "better meat," companies should calculate the GHG emissions baseline of their food purchases, shift toward lower-emissions products like plant-based foods, define meat sourcing priorities by product (e.g., lower-emissions beef, higher-welfare chicken), assess potential environmental impacts of the new sourcing strategy, source "even less meat" in cases where "better meat" increases environmental impacts, and engage with suppliers to improve practices and track progress.

Shifting diets toward plant-based foods is most relevant in the Global North, where per capita meat consumption is high. Animal-based foods are dense in bioavailable protein and micronutrients, and populations in some regions of the world, including South Asia and sub-Saharan Africa, could benefit from increased per capita consumption to boost nutrition. Dietary shifts toward plant-based foods are appropriate in regions like North America and Europe, where per capita meat consumption is high and affordable substitutes for animal protein are widely available.

Retailers, manufacturers, and food service providers shape the "food environment" and heavily influence consumer choices, and therefore have an important role to play. Such companies also tend to have high "scope 3" GHG emissions related to agriculture and food production (i.e., indirect emissions from supply chains linked to purchased food), and these companies are increasingly setting science-based GHG reduction targets in line with Paris Agreement goals.

In recent years, pairing strategies to source "less meat" with those to source "better meat" has emerged as a potential climate mitigation strategy, and the concept of "better meat" has gained traction as a way to describe more sustainable forms of terrestrial animal agriculture. However, the term "better meat" lacks a clear and universally agreed definition and can entail trade-offs. Our review of the literature, supplemented with interviews with food industry stakeholders in North America and Europe, shows that "better meat" can refer to meat production with a wide variety of attributes. These attributes include better environmental performance (climate, land, water use, water quality, biodiversity, soils), social and ethical performance (animal welfare, local sourcing, livelihoods, nutrition and public health, antimicrobial resistance, equity, social justice), and/or economic performance (quality, profitability). The concept of "better meat" is also often tied to specific alternative agricultural production systems and methods, such as organic, pasture-raised, grass-fed, free-range (or other animal welfare attributes), and regenerative.

Meat and dairy production—and especially production of ruminant meats such as beef and lamb—is generally more resource-intensive than production of plant-based proteins. We compared the environmental impacts of "conventional" production of animal and plant proteins in North America and Europe, finding that beef and lamb generally had the highest impacts in terms of climate, land use, and water use and pollution. Other animal-based foods (dairy, pork, poultry, eggs) have medium impacts, while plant-based proteins (pulses and soy) have the lowest impacts. For example, beef production results in an average of 310 kg of carbon dioxide equivalent (CO_2e) emissions per kg of protein, whereas poultry production emits 45 kg CO_2e and production of pulses emits 6 kg CO_2e. The high resource use of animal-based foods is due to the animals' need to convert calories and protein in crop- or grass-based feeds into human-edible calories and protein.

Shifting to production systems associated with "better meat" often results in higher environmental impacts per kilogram of protein. Within each animal protein type, we compared the environmental and animal welfare performance of "conventional" production to several alternative production systems using peer-reviewed life cycle assessment (LCA) data. Perhaps counterintuitively, systems marketed as "better" (e.g., organic, grass-fed, pasture-raised, free-range) often lead to higher environmental impacts per kg of protein than those thought of as "conventional." In our aggregate data set, environmental impacts were higher in three-quarters of alternative cases across studies. GHG emissions specifically were higher in more than 70 percent of cases. Notably, the amount of land needed under systems marketed as "better" was higher than under "conventional" systems more than 90 percent of the time. These differences for GHG emissions and land use were statistically significant for beef, dairy, pork, poultry, and eggs. This is very important from a climate and biodiversity perspective, since agricultural land expansion is the leading driver of deforestation, and agricultural land use needs to decline if the world is to restore large-scale areas to natural ecosystems for climate and nature goals. When we translated land use into "carbon opportunity costs," the total climate impacts of the alternative systems were higher than those of "conventional" systems more than 90 percent of the time. The effects of alternative systems on water use were more varied. Effects on on-farm biodiversity and soil health were not evaluated, as most LCAs do not yet account for these indicators. There is a movement to expand measurement systems beyond traditional LCAs to give a fuller accounting of the local and global impacts of agricultural production, and it will be important to take this dimension into account going forward.

A number of strategies exist to reduce GHG emissions from meat in general, and beef in particular. While many of these do not constitute major shifts to "alternative production systems"—and therefore did not appear in the above analysis of LCA data—they are important options for companies to be aware of as they work to reduce their scope 3 GHG emissions. For beef, major GHG reduction strategies include improving efficiency and productivity in ways that do not harm animal welfare; reducing enteric methane emissions ("cow burps") through better feeds and feed additives, improving manure management, and stabilizing and sequestering carbon in vegetation and soils on pasturelands. There is currently high interest in increasing soil carbon stocks as a GHG mitigation strategy, but the impacts of management practices on net carbon sequestration can be complex and hard to predict. Increasing soil carbon stocks should be explored as just one of a suite of potential mitigation options for beef production, rather than viewed as a "silver bullet" to achieve large emissions reductions.

Animal welfare is a key sustainability consideration when sourcing meat, but the impacts of animal welfare improvements on environmental performance are mixed, and there are trade-offs. One important trade-off relates to the number of animal lives per unit of protein produced. Companies might be tempted to shift purchasing from beef toward chicken for climate reasons, but to produce a ton of protein, more than 100 times as many chickens than cows need to be slaughtered. Another trade-off is related to alternative production systems. Production systems that result in animal welfare improvements also often increase the environmental impact of the system per kg of protein. Many systems that improve animal welfare require a larger land footprint (e.g., for grass-fed, pasture-raised, or free-range animals), which can increase pressure on natural ecosystems, as noted above. In addition, grazing or slow-growth animals require higher resource use over their lifetimes and—for ruminant animals like cows—result in more time spent emitting methane. Balancing animal welfare with environmental goals therefore requires careful planning for organizations sourcing meat.

If "better meat" causes higher resource use or environmental impacts per kg of protein, "less meat" must become "even less meat." The "less and better meat" approach suggests that food companies with climate and nature targets can shift the mix of what they purchase and serve away from animal-based foods ("less meat") and toward plant-based foods to reduce environmental impacts while improving animal welfare and other important attributes associated with the meat they source ("better meat"). That said, if "better meat" strategies lead to higher environmental impacts from the meat in their supply chains, our research shows this is likely to counteract the environmental gains under the "less meat" strategy. In such cases, to hit environmental targets, companies would need to reduce the amount of animal-based foods by *even more* than under a pure "less meat" strategy.

Reducing beef and lamb purchasing opens up climate "space" for sourcing from higher-welfare systems for other protein sources. Because beef and lamb have outsized emissions and land use per kg of protein, reducing purchasing of these meats can allow food companies to shift to alternative systems for the other animal proteins (e.g., cage-free eggs, organic chicken) and still realize overall reductions in the GHG emissions and land occupation of their supply chains. Care should be taken not to increase overall negative impacts on water use, water quality, and soil health. This strategy enables a company to both reduce its emissions and improve performance on animal welfare. For example, we investigated a scenario where a company reduced its beef purchases by more than half and reduced other meat sourcing by 20 percent and dairy sourcing by 15 percent, shifting toward pulses, soy, and vegetables. Because of the large reduction in beef purchasing, the company in our scenario could achieve its goal of reducing its total food-related GHG emissions by 25 percent even while shifting all of its chicken and egg purchases to higher animal welfare products.

A shift toward plant-based foods is a multiple win for climate, nature, and animal welfare. Shifts between or within animal products often lead to trade-offs. Beyond the basic trade-off in a shift from beef to chicken (lower emissions and other environmental impacts, but a much higher number of animals slaughtered), the data also indicate that improvements in animal welfare within an animal product (e.g., slower-growth chicken) tend to lead to higher climate and other environmental impacts, although not in all cases. However, these trade-offs can be reduced or avoided altogether with shifts toward plant-based foods, whose carbon footprints and other environmental impacts are usually lower than animal proteins. Both traditional plant-based foods, such as pulses and soy, as well as alternative proteins, such as plant-based meat, can be used in this shift, with the latter group appealing to consumers who desire the familiar taste of meat.

We recommend six steps that companies can take to design a sourcing strategy that will allow them to achieve climate and nature goals while also sourcing "better meat," to maximize co-benefits and minimize trade-offs:

1. *Calculate the scope 3 GHG emissions baseline of food purchases, including meat.* Establishing a scope 3 GHG emissions baseline for food purchases will allow companies to understand how much of an impact meat has on their food-related carbon footprint and enable them to pinpoint emissions hot spots.
2. *Shift from high-emissions products like beef and lamb toward lower-emissions products like plant-based foods and alternative proteins.* This type of shift is a triple win for climate, nature, and animal welfare.
3. *Define priorities around improved meat sourcing by product type.* For example, around beef, the goal might be to reduce climate and land impacts—both through sourcing less of it, and through encouraging lower-emissions production methods. For chicken and eggs, the goal might be to improve animal welfare, promote responsible antibiotic use, and minimize water pollution.
4. *Assess the potential impacts of sourcing changes on climate and other "better meat" priority goals.* The analysis should include both co-benefits and trade-offs. It could be quantitative (e.g., through analysis of potential scenarios' effects on environmental indicators, or scoring that relates to current or envisioned sustainability and marketing goals) and/or qualitative (e.g., "likely direction of travel") in nature.
5. *If a "better meat" sourcing strategy increases environmental impacts, shift to sourcing "even less meat."* If a company's analysis suggests that shifting sourcing to "better meat" will lead to higher environmental impacts from their supply chains, they should move beyond a "less meat" strategy to an "even less meat" strategy to stay on track for their environmental targets.
6. *Engage with suppliers to improve their production practices and develop more transparent emissions quantification and ways to verify other "better meat" attributes.* This step entails the most work, and it could unfold over many years. For example, companies can define standards and scoring systems for their suppliers, buy certified

products connected to attributes of interest, encourage suppliers to make voluntary commitments, and invest in on-farm projects.

We hope to work more closely with food companies and their suppliers in the future to improve the availability and quality of emissions data—and other data associated with "better meat" attributes—along food supply chains. Guidance could include how to choose metrics to account for the various attributes of "better" meat, considerations around data quality and supply chain traceability, and strategies for supplier and producer engagement. Guidance could also help companies navigate the various certifications and other labeling schemes that can identify products that have somehow "improved" an attribute of interest (high animal welfare, responsible antibiotic use, deforestation-free, lower-than-average emissions, etc.).

Further work is necessary to gather publicly available data on other environmental, social, and economic attributes of "better meat," such as for soil health, on-farm biodiversity, and agricultural livelihoods, to inform corporate decision-making. Similarly, better data are needed on alternative systems and practices related to fish and seafood production; these "blue foods" are important contributors to global food and nutrition security, but data are even scarcer for these food production systems than for terrestrial animal agriculture.

In an ideal world, "better meat" production could lead to improvements across all sustainability goals; however, our analysis shows that companies with quantitative sustainability goals need to consider both co-benefits and trade-offs across all goals when designing their meat sourcing strategies. We also show that balancing these goals is eminently possible. This analysis also confirms the critical importance of shifting diets high in animal-based foods toward plant-based foods and alternative proteins to improve both environmental and animal welfare outcomes.

FIGURE ES-1 | Six steps that companies can take to design a meat sourcing strategy

1. Calculate the scope 3 GHG emissions baseline of food purchases.

2. Shift from high-emissions products toward lower-emissions products.

3. Define priorities around improved meat sourcing by product type.

4. Assess the potential impacts of sourcing changes on climate and other "better meat" priority goals.

5. If a "better meat" sourcing strategy increases environmental impacts, shift to sourcing "even less meat."

6. Engage with suppliers to improve production practices and develop more transparent emissions quantification.

Source: Authors.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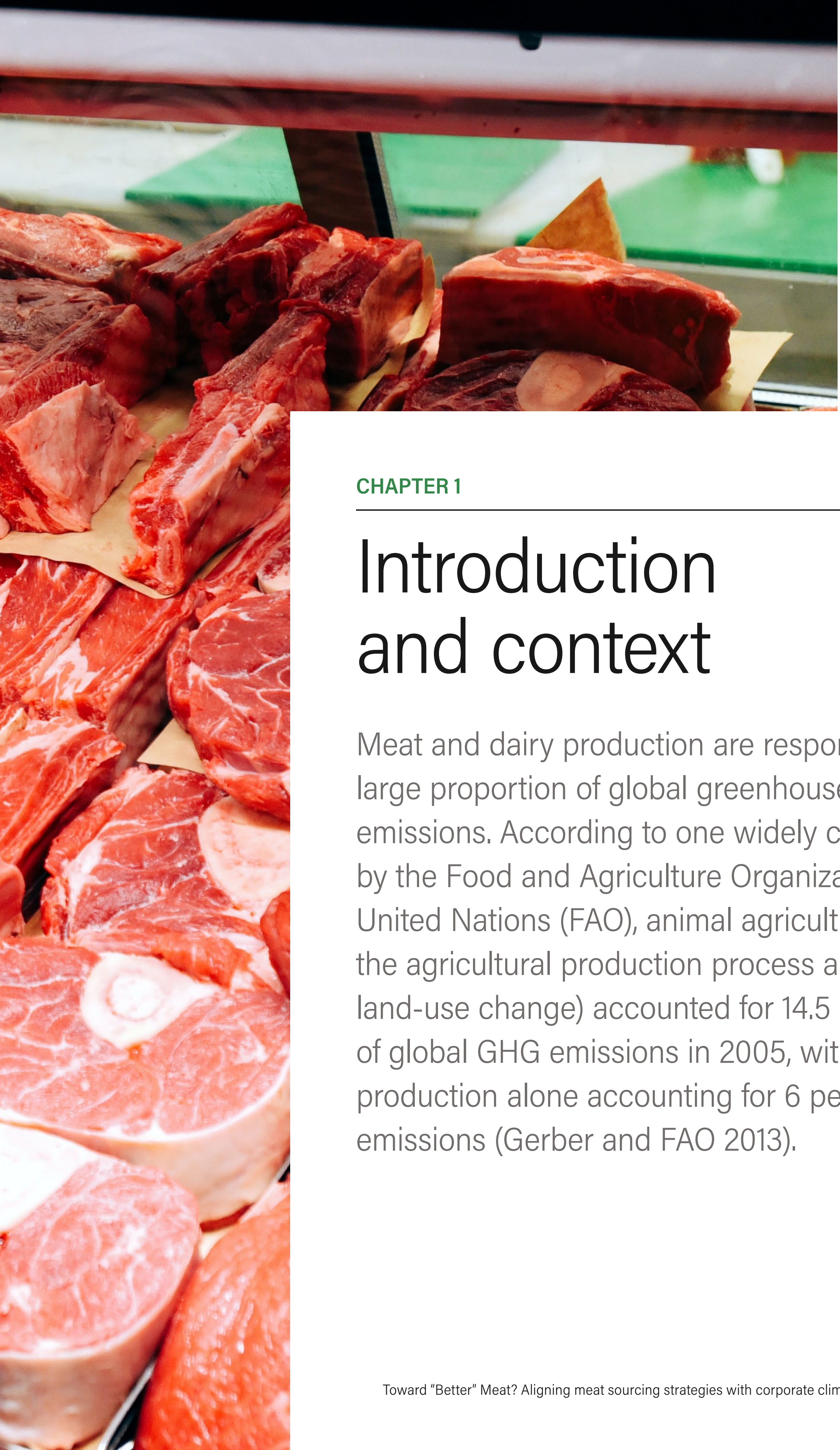

CHAPTER 1

Introduction and context

Meat and dairy production are responsible for a large proportion of global greenhouse gas (GHG) emissions. According to one widely cited estimate by the Food and Agriculture Organization of the United Nations (FAO), animal agriculture (including the agricultural production process and related land-use change) accounted for 14.5 percent of global GHG emissions in 2005, with beef production alone accounting for 6 percent of global emissions (Gerber and FAO 2013).

More recent estimates for animal agriculture's contribution to global emissions in 2010–15 are of a similar magnitude, ranging from 11 to 20 percent (e.g., Poore and Nemecek 2018; Twine 2021; Xu et al. 2021; FAO 2022a). Animal agriculture also accounted for more than 30 percent of global methane emissions in 2017 (CCAC and UNEP 2021).

Terrestrial animal agriculture is also a large user of land. Agriculture occupies approximately half of all vegetated land on the planet (FAO 2022b), with meat and dairy production (including pasturelands and croplands that grow animal feed) accounting for more than three-quarters of that land area (Searchinger et al. 2019). With this high and growing level of land use, it is not surprising that animal agriculture is a key driver of deforestation and land-use change (Goldman et al. 2020), which affect both biodiversity and the climate. High land use also means that animal agriculture has a high "carbon opportunity cost," because agricultural land in many cases could sequester much more carbon if the land were allowed to return to native vegetation (Hayek et al. 2021).

As outlined in the *World Resources Report: Creating a Sustainable Food Future* (Searchinger et al. 2019), the world needs to produce more food for a growing population on less agricultural land while simultaneously reducing greenhouse gas emissions in line with the goals of the Paris Agreement. And while animal-based foods are dense in bioavailable protein and micronutrients, and populations in South Asia and sub-Saharan Africa could benefit from increased per capita consumption to boost nutrition (Beal et al. 2023), dietary shifts toward plant-based foods are appropriate in regions like North America and Europe, where per capita meat consumption is high and affordable substitutes for animal protein are widely available.

Companies such as retailers, manufacturers, and food service providers purchase large amounts of food, and thus have an important role to play in facilitating this dietary shift. The "food environment" in retail and food service outlets has an important influence on people's eating habits. This environment includes the types of food on offer, how the food is arranged in menus and buffets, how it is advertised and promoted to consumers, and how it is priced (Attwood et al. 2020). Such companies also tend to have high "scope 3" GHG emissions related to agriculture and food production (i.e., indirect emissions from supply chains linked to purchased food) (WRI and WBCSD 2011), and they are increasingly setting GHG reduction targets in line with Paris Agreement goals.

While dietary shifts from meat toward plant-based foods can contribute significantly to mitigation in high-consuming regions, the livestock sector will continue to play an important role in food and nutrition security and rural livelihoods around the world. Achieving climate targets for the broader food system to 2030 or 2050 (SBTi 2022) will require improvements to animal agriculture, such as increasing pasture productivity, reducing enteric methane emissions ("cow burps"), improving manure management, and improving feed production and grazing practices (Searchinger et al. 2019). Food purchasing companies with climate targets related to their scope 3 agricultural emissions will therefore likely need to reduce the climate impacts of meat production in tandem with shifts in purchasing toward plants. These companies will also need to be able to credibly track reductions in meat- and dairy-related GHG emissions due to improved practices in their supply chains. They will also increasingly look to data from suppliers to justify GHG emission factors that reflect their suppliers' livestock production practices rather than "industry average" factors (e.g., emissions per kilogram [kg] of beef at the national level) commonly used for scope 3 GHG accounting.

In recent years, the concept of "better meat" (as in "better" than "average" or "conventional" meat) has gained traction among actors across food supply chains, as well as civil society organizations, to describe a pathway toward more sustainable meat production. It is sometimes paired with "less meat" as a dual goal, as in "less and better meat" (Eating Better 2021) or "less but better meat" (Resare Sahlin and Trewern 2022). While the term "better meat" lacks a clear and universally agreed definition (Henchion 2022; Resare Sahlin et al. 2020; Laestadius et al. 2014), it generally refers to changes in the meat production process that result in an improvement of any number of metrics toward a range of sustainability goals. These goals include, but are not limited to, reducing GHG emissions and improving biodiversity, water quality, animal welfare, responsible antibiotic use, the overall quality of the meat, and socioeconomic factors (Resare Sahlin and Trewern 2022; Resare Sahlin et al. 2020; Eating Better 2021).

The concept of "better meat" is also often tied to specific alternative agricultural production systems, such as organic and grass-fed ones (Resare Sahlin and Trewern 2022). The idea of "better meat" is thus much broader than climate impact, and includes other social, economic, and health priorities that companies sourcing meat may consider in their decision-making. However, the environmental and social impacts of different production systems can be highly varied within and across different types of animal-based foods. Companies sourcing food often balance multiple sustainability goals, and thus must understand the potential impacts of different foods and food production systems.

This report is intended for food retailers, manufacturers, and food service companies interested in understanding how to identify and source not only "less meat" but also "better meat" (Box 1) to make progress toward climate and other sustainability and corporate social responsibility goals. This report is relevant to companies setting GHG reduction targets through the Science Based Targets initiative (SBTi) (www.sciencebasedtargets.org), as well as companies setting targets for water, land, and other Earth systems through the Science Based Targets Network (SBTN) (www.sciencebasedtargetsnetwork.org). It is also relevant to members of WRI's Coolfood initiative (www.coolfood.org), which has worked since 2019 to help food service providers reduce the climate impact of the food they serve, with a goal of collectively reducing emissions by 25 percent by 2030 (Waite et al. 2019). Because the goal to reduce meat consumption for climate and environmental reasons is most relevant in the Global North—where there is also highest interest in the concept of "less and better meat"—our analysis uses data from North America and Europe.[1]

Chapter 2 of this report, "What is better meat?," provides an overview of the literature and food sector perspectives on the definition and attributes of "better meat." Chapter 3, "Linking 'better meat' attributes to production systems, practices, co-benefits, and trade-offs," uses the latest publicly available data to assess the co-benefits and trade-offs between climate goals and other sustainability attributes often associated with "better meat," and also looks at strategies to reduce GHG emissions from meat production. The conclusion offers recommendations for food providers to design "better meat" sourcing strategies that contribute to climate goals while navigating the co-benefits and trade-offs with other attributes important to their organizations.

BOX 1 | "Better meat" as a shorthand in this report for all improvements to terrestrial animal agriculture

Although "meat" typically refers to products such as beef, lamb, pork, and chicken, the analysis in this report considers other terrestrial animal-based foods (dairy and eggs). This is because many of the concerns, insights, and recommendations for improved sourcing and balancing of sustainability priorities are similar across all terrestrial animal-based foods. Therefore, in this report, "better meat" is a shorthand for improvements to all types of terrestrial animal agriculture. For readability, we also use "animal protein" in this report as a shorthand for all types of terrestrial animal-based foods.

While fish and seafood are not a main focus of this report, due to a thinner representation of these foods in the life cycle assessment literature, they are important to food systems and have their own environmental and social impacts, and considerations around fish and seafood are discussed elsewhere in the report.

Some people even define "better meat" as alternative proteins, such as plant-based meat and cultivated meat. Alternative proteins are mentioned in several places in the report as comparisons, but they are distinct from the report's main focus: improvements to terrestrial animal agriculture and resulting implications for climate and other sustainability goals.

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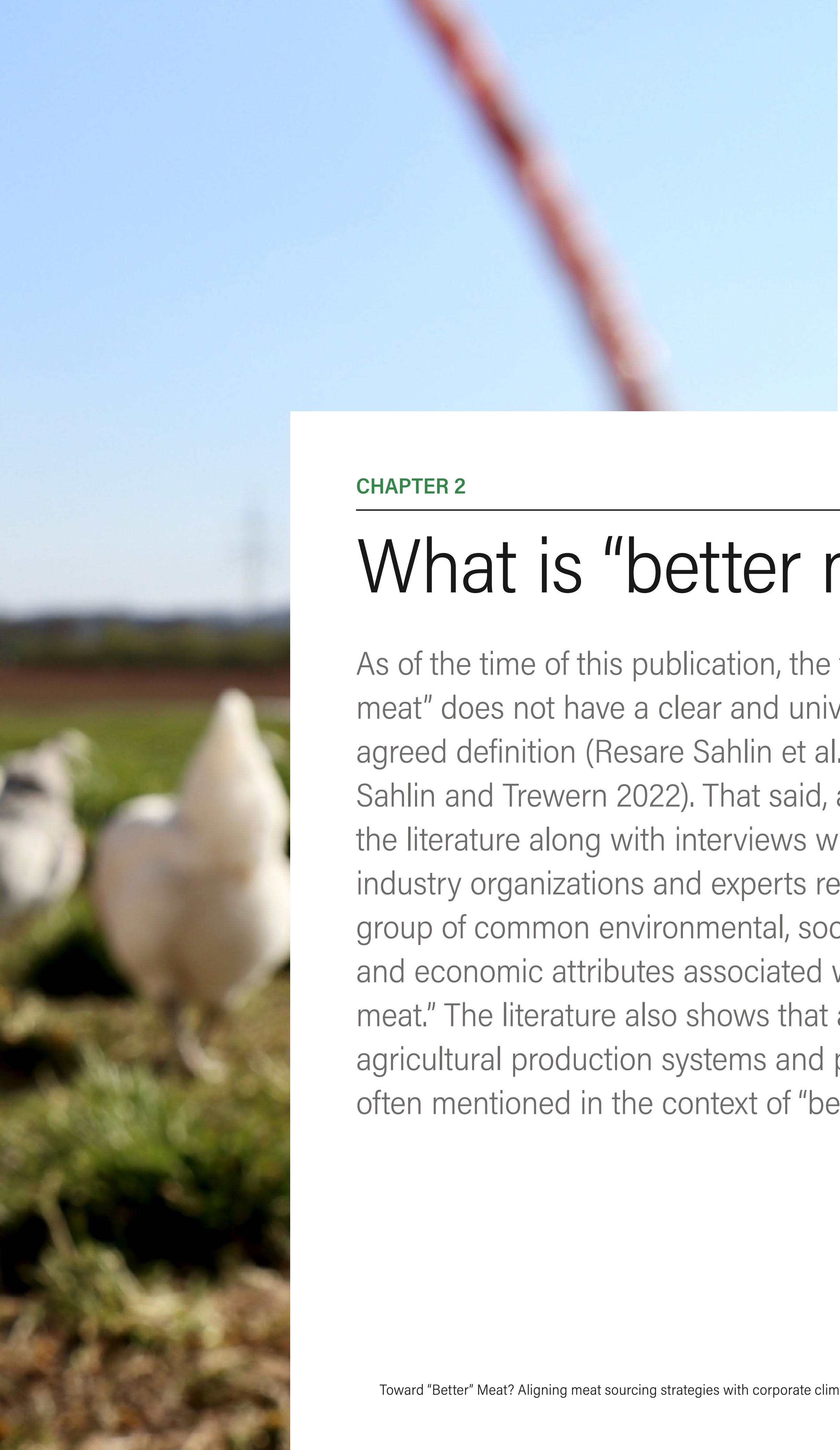


CHAPTER 2

What is “better meat”?

As of the time of this publication, the term “better meat” does not have a clear and universally agreed definition (Resare Sahlin et al. 2020; Resare Sahlin and Trewern 2022). That said, a review of the literature along with interviews with 17 food industry organizations and experts revealed a group of common environmental, social, ethical, and economic attributes associated with “better meat.” The literature also shows that alternative agricultural production systems and practices are often mentioned in the context of “better meat.”

Figure 1 shows the attributes associated with "better meat" in the literature and our interviews. In addition, the alternative production systems and practices often mentioned include organic, pasture-raised, grass-fed, extensive, intensive, small-scale, free-range, agroecological, and regenerative (Resare Sahlin and Trewern 2022). These terms are also used to signal to consumers that the food they are purchasing is "better" in some way. However, as detailed in Chapter 3 of this report, links between these alternative production systems and practices, and their effects on the attributes in Figure 1, can be complex.

Because "better meat" is loosely defined, different stakeholders may interpret it differently. Our interviews confirmed that "better meat" can have different meanings across organizations. This is particularly problematic in relation to broader sustainability priorities: without a clear definition, companies may simply define "better" in a way that fits their own current sourcing patterns, and/or to mean something very narrow, which poses a risk of greenwashing. We also found that while some organizations are not familiar with the term, they inadvertently are already pursuing some attributes of "better meat" through their own sustainability goals. Even within a single company, different products can be subject to different "better" priorities. For example, some companies expressed that their focus on beef is reducing the climate impact, while the priority for sourcing chicken is to improve animal welfare. Ultimately, as one company representative put it, "you can't meet every criterion with every purchase." In general, however, the most salient attributes of "better meat" that emerged during the stakeholder interviews focused on climate, animal welfare, local sourcing, antibiotic use, quality, and cost of purchase.

While many companies had identified several priorities around their meat sourcing strategies, they also acknowledged obstacles to implementing those priorities. For example, sourcing meat with higher animal welfare standards often comes at a higher cost. In terms of improving climate impact, many described challenges in acquiring sufficient data from their supply chains to make credible claims about changes in emissions and land use. One company representative stated that they do not "feel like any carbon-neutral claims rise up to where we would be comfortable using them, but would listen if a credible third party validated the claims," suggesting the need for not only better data collection but also data quality standards, as provided in the draft "Greenhouse Gas Protocol Land Sector and Removals Guidance" (WRI and WBCSD 2022). Because collecting data requires resources, companies probably cannot track everything from the outset, but they need to prioritize which attributes are most important to them (and their customers). Therefore, a given company's working definition of "better meat" is likely to depend on organizational priorities. One nonprofit interviewee further noted that even

FIGURE 1 | Attributes commonly associated with "better meat"

ENVIRONMENTAL	SOCIAL AND ETHICAL	ECONOMIC AND FINANCIAL
Climate	Animal welfare	Perceived quality
Land use and land-use change	Antimicrobial resistance	Cost, profitability, and consumer affordability
Biodiversity	Farmer and farmworker livelihoods	
Water use	Local sourcing	
Water quality and pollution	Nutrition and public health	
Soil health	Equity and social justice	

Source: Adapted from Resare Sahlin et al. (2020), updated via WRI interviews.

companies that have surmounted these obstacles "need to be able to communicate the changes to their meat sourcing, so there is a marketing challenge."

Finally, there is the question about how to weigh corporate climate goals against the other attributes of "better meat." Although there are numerous synergies and co-benefits between these attributes, there can also be trade-offs, such as between environmental and animal welfare indicators. Companies need to think through how to manage and minimize trade-offs to optimize meat sourcing strategies—and broader food sourcing strategies—against multiple sustainability goals.

To be able to provide guidance on how companies should develop their meat sourcing strategies, we concentrated on the attributes of "better meat" that stakeholders frequently highlighted as important in our interviews, and then matched those where possible to publicly available data. Table 1 lists the attributes included in detail in this report, which include climate, land use, water use, water quality, and animal welfare criteria. Several other attributes, including biodiversity, local sourcing, and antimicrobial resistance, are included in more minor or indirect ways in the data used in this report, and we note public data gaps in other areas.

TABLE 1 | "Better meat" attributes by category and inclusion in this report

ATTRIBUTE	INCLUDED IN REPORT?	COMMENT
Environmental		
Climate (reduced greenhouse gas emissions)	Yes	This report is meant to be used alongside food companies' existing greenhouse gas emissions calculations and climate change mitigation strategies, and emissions data are readily available in agriculture life cycle assessments (LCAs).
Land use and land-use change (and land-related GHG emissions)	Yes	LCAs also commonly include land use (also called "land occupation"), which is relevant to climate because land-use change from agricultural expansion is a key driver of deforestation. Using land for food production often creates a "carbon opportunity cost," meaning that the land cannot be restored into a higher-carbon natural ecosystem. Additionally, some LCAs include estimates of GHG emissions from recent land-use change (e.g., deforestation).
Water use	Yes	The food sector is the world's largest freshwater user, and water use is most typically included in LCAs of agriculture.
Water quality and pollution	Yes	The food sector is a key driver of water pollution through runoff of excess nutrients from farms, and LCAs measure agriculture's potential to cause eutrophication, which leads to harmful algal blooms, dead zones, and fish kills.
Biodiversity	Somewhat	Farm-level biodiversity is underrepresented in LCAs of agriculture, although work has been done to quantify species abundance, richness, and evenness (FOLU 2023). That said, land use and land-use change can be used as proxies for global biodiversity impact, because agricultural land expansion is the largest historical and current driver of biodiversity loss, and using land for food production creates a "biodiversity opportunity cost." There are also links between water metrics measured by LCA (e.g., eutrophication) and biodiversity.
Soil health	No	Soil health has important links to food security (via agricultural productivity) and on-farm biodiversity. There are a large number of complex soil health or soil quality indicators that are not easily simplified into one LCA metric that is comparable across multiple farm systems. Because of this, and the lack of a consistent definition for "soil health," we do not include metrics on soil health in this report.
Social and ethical		
Animal welfare	Yes	Stakeholder interviews identified this as a high-interest category. It includes number of animal lives, alongside the use of growth hormones, outdoor access, breeding for slower growth, and the use of cages, as well as the use of antibiotics as a separate indicator (see "Antimicrobial resistance" below).
Local sourcing	Somewhat	Stakeholder interviews identified this as a high-interest category. Box 4 offers LCA data about the climate impacts of food transportation, which are relatively small compared to those of food production, especially for terrestrial animal agriculture (Poore and Nemecek 2018). Because these impacts are small, they are not a main focus of our analysis.
Antimicrobial resistance	Somewhat	Stakeholder interviews identified this as a high-interest category, particularly regarding antibiotic overuse in animal agriculture, which can lead to the emergence of antibiotic-resistant infectious bacteria, making it a public health concern. Antibiotic use features in the broader analysis linking animal welfare and environmental impacts.
Nutrition and public health	No	Limited data are available on the impact of alternative production systems on the nutritional quality of meat. Both deforestation (linked to agricultural expansion) and intensification of animal agriculture can create the risk of infectious diseases originating from animals (Hayek 2022). Intensive animal agriculture can also lead to other public health impacts, such as poor air quality, leading to respiratory disease (Casey et al. 2015).

TABLE 1 | “Better meat” attributes by category and inclusion in this report (cont.)

ATTRIBUTE	INCLUDED IN REPORT?	COMMENT
Social and ethical (cont.)		
Farmer and farmworker livelihoods	No	There is a lack of studies linking agricultural livelihoods to “better” meat (Resare Sahlin and Trewern 2022).
Equity and social justice	No	There is a lack of studies linking equity and social justice issues to “better” meat (Resare Sahlin and Trewern 2022).
Economic and financial		
Perceived quality	No	Perceived quality includes flavor, tenderness, and juiciness (Resare Sahlin et al. 2020). Product cost, profitability, and affordability (linked to consumer price) matter variously to food companies and their customers. However, while these economic and financial attributes of “better meat” are important for corporate decision-making, studies have not clearly defined relationships with the other social and environmental attributes above.
Cost, profitability, and consumer affordability	No	

Source: Authors.

> Because collecting data requires resources, companies probably cannot track everything from the outset, but they need to prioritize which attributes are most important to them (and their customers). A given company’s working definition of “better meat” is likely to depend on organizational priorities.

CHAPTER 3

Linking "better meat" attributes to production systems, practices, co-benefits, and trade-offs

This chapter assesses how different meat production systems and practices affect several of the high-priority attributes of "better meat" identified in the literature and stakeholder interviews, and where co-benefits and trade-offs are likely to occur. The attributes emphasized include climate, land use, water use, water quality, and animal welfare.

We start with a general assessment of the relative environmental impacts of terrestrial animal-based protein sources. We then use the life cycle assessment (LCA) literature to evaluate how shifts to prominent alternative meat production systems are likely to affect these environmental impacts. Because climate is of particular concern to food companies, we then discuss options to reduce GHG emissions associated with the production of beef, a common high-impact animal protein. Finally, we link the environmental analysis with animal welfare to show how companies might achieve progress across these attributes in their meat sourcing strategies.

RELATIVE ENVIRONMENTAL IMPACTS OF ANIMAL AND PLANT PROTEINS

Different foods have different environmental impacts. This is particularly true of animal-based foods, which are relatively resource-intensive, and whose production varies widely across the world. To analyze the environmental attributes of terrestrial animal proteins, we build on Poore and Nemecek's (2018) meta-analysis, which looked at LCAs of the production of dozens of food products across more than 38,000 farms in 100 countries. The studies included in this meta-analysis were based on real farm data (rather than relying fully on models or simulations). Using these LCAs, Poore and Nemecek (2018) constructed a database containing four of the quantitative environmental indicators discussed in Chapter 2 (GHG emissions, land use, water use, and water quality). Because our analysis is focused on the Global North, where "less and better meat" is a relevant sustainability strategy, we used data points from North America and Europe only in this report.[2] We started by extracting weighted-average values for North America and Europe for each of the four environmental indicators by animal protein type (beef, lamb, dairy, pork, poultry, and eggs), calculating impacts per kg of protein produced.[3] Table 2 shows these data, with two common plant-based sources of protein (soy and pulses) for comparison.[4]

We recognize that LCAs primarily provide data on environmental (rather than social, ethical, and economic) indicators. Furthermore, LCAs generally do not yet account for certain indicators, such as on-farm biodiversity and soil health, which are closely related to the farm-level environmental consequences of food production. Indicators such as GHG emissions and land use are highly relevant to the global impacts of food production, because the world has finite "carbon budgets" and "land budgets" that must be managed to avoid dangerous levels of global warming and to halt ecosystem conversion. Halting ecosystem conversion, in turn, is important globally to halt biodiversity loss. That said, water use and water quality indicators in our analysis *are* relevant at the farm level, and land use can be locally relevant too, as it can give an indication about how much cropland and/or pastureland is likely to be needed to produce a given amount of food.

There has been a movement to expand measurement systems beyond traditional LCAs to give a fuller accounting of the local and global impacts of agricultural production. One instance of this is being spearheaded by the French government as it seeks to implement a national environmental labeling scheme (Hélias et al. 2022). Another new impact assessment tool proposed by the European Commission is the Environmental Footprint 3.0, which considers 16 different impact categories (Hélias et al. 2022). However, these environmental assessment methods are relatively new, or even yet to be finalized, meaning there is not a significant amount of published literature using these new methods. Given the ongoing development of new measurement systems for indicators such as on-farm biodiversity and soil health, and uncertainty in their results, we chose to not include these indicators in the primary analysis of this report and keep our focus on the environmental indicators most commonly found in LCAs published to date.

CHANGES TO ENVIRONMENTAL IMPACTS UNDER ALTERNATIVE PRODUCTION SYSTEMS: REVIEWING LCA STUDIES

One avenue companies have pursued to source "better meat" is meat produced in alternative production systems, such as organic, grass-fed, or free-range (Resare Sahlin and Trewern 2022). Meat produced in these systems and with these labels may be desirable to consumers, and there is often some sort of third-party certification or verification that companies can use to identify relevant suppliers or products. Here, we examine the LCA literature to see how these alternative systems affect the environmental attributes of "better meat."

TABLE 2 | Selected environmental indicators per kg protein by food type (production weighted-average, North America and Europe)

FOOD TYPE	GHG EMISSIONS (KG CO_2E)	LAND OCCUPATION (M^2*YR)	WATER USE—FRESHWATER WITHDRAWAL (L)	WATER POLLUTION—EUTROPHICATION POTENTIAL (KG $PO_4^{3-}E$)
Lamb	334	1,110	No data	1.02
Beef	310	663	11,672	1.84
Pork	92	177	16,227	0.54
Dairy	56	50	No data	0.12
Poultry	45	84	10,254	0.30
Eggs	35	59	5,263	0.19
Soy	13	20	990	0.09
Pulses	6	35	4,786	0.02

Notes: kg CO_2e = kilograms of carbon dioxide equivalent; l = liters; m^2*yr = square meter-years; kg PO_4^{3-}-e = kilograms of phosphate equivalent. North America and Europe averages are weighted by amount of production of each food type in 2018 (three-year average of 2017–19), as given in FAO (2023).

Source: WRI calculations from Poore and Nemecek (2018), converted to protein using FAO (2023).

While most of the LCA studies included in Poore and Nemecek's (2018) database evaluated "conventional" (i.e., dominant) production systems, some studies evaluated alternative ones. However, it is not straightforward to directly compare results between individual LCA studies, which were conducted by different authors, using different assumptions and system boundaries, and in different geographies and often years. That said, a smaller subset of studies in Poore and Nemecek's (2018) database compared multiple production systems (i.e., a conventional system and some alternative production system in the same study). This smaller set of studies, which we call "paired studies" below, allows for a more realistic comparison between production systems because they were each done by the same researchers, using the same assumptions and boundaries, in the same place and time. These studies each shed light on the quantitative effects of shifting production or sourcing from a conventional system to an alternative system.

Because Poore and Nemecek's (2018) database only captured studies published between 2000 and June 2016, we performed a literature review using similar search terms and study inclusion criteria to capture additional studies that were published through 2022. As Poore and Nemecek (2018) did, in some instances we performed adjustments to fill data gaps or make results more comparable between studies (e.g., estimating land use using data included in a study, making assumptions to estimate impacts from the animals' full life cycle). See Appendix A for more details on our approach to adding in more recent studies and Appendix B for the full list of "paired studies" included in our analysis below, as well as all adjustments made. The Glossary provides definitions of the various production systems.

For each quantitative environmental indicator (e.g., GHG emissions, land use) in each "paired study," we calculated the percent changes that occurred when shifting from the conventional system to the alternative production system.[5] As one example, Pelletier et al.'s (2010) "paired study" found that, compared to a conventional feedlot-finished beef production system in the United States, producing 1 kg of beef in a completely grass-fed production system led to a 17 percent increase in GHG emissions, a 36 percent increase in water pollution, and a 54 percent increase in land use. The study authors noted that the increases in emissions, land use, and water pollution per kg of beef under the grass-fed system were primarily due to the absence of low-fiber and high-energy feed ingredients (e.g., maize) that are fed to the cattle in feedlots during the final months of their lives. This difference in feed led the grass-fed cattle to have a slower growth rate than the feedlot-finished cattle, which in turn led to higher emissions from digestion and manure production throughout the animals' lives in the grass-fed system than in the conventional system. This effect translated into higher feed and land requirements, and higher manure production, per pound of beef produced, in the grass-fed system than in the "conventional" system.

Table 3 shows the broad categories of "alternative" systems, by product, included in the "paired studies."[6] In all, we used data from 45 unique studies. Because some studies included multiple alternative systems, our dataset included 85 comparisons between conventional and alternative systems. And because most studies included multiple environmental indicators, there were a total of 252 data points across the four environmental indicators.

To estimate the ranges of potential environmental impacts of shifting from "conventional" to alternative production systems, we used the average values in Table 2 to represent "conventional" production and scaled each of the data points from the alternative production systems based on the percent changes in the environmental impacts. Table 4 shows an example of our scaling method for four environmental impacts for a "paired study" in Switzerland that looked at conventional beef production (cattle finished on concentrated feeds) and organic production. Figures 2a–2d show the ranges across all of the studies, explained further below.

> These studies each shed light on the quantitative effects of shifting production or sourcing from a conventional system to an alternative system.

TABLE 3 | Alternative production systems in paired LCAs assessed

FOOD TYPE	NUMBER OF COMPARISONS BETWEEN CONVENTIONAL AND ALTERNATIVE SYSTEMS
Lamb	**5**
Organic	2
Pasture-based/grass-fed/extensive	3
Beef	**18**
No growth-enhancing technologies	1
Organic	6
Pasture-based/grass-fed/extensive	11
Pork	**14**
Free-range	4
Other animal welfare improvement	1
Organic	8
Red Label (*Label Rouge*)	1
Dairy	**25**
Local breed	1
Organic	15
Pasture-based/grass-fed/extensive	9
Poultry	**8**
Free-range	1
Organic	3
Outdoor	1
Red Label	3
Eggs	**15**
Barn	5
Free-range	3
Organic	4
Outdoor	3
Total paired studies	**85**

Note: LCA = life cycle assessment.

Source: Authors, from Poore and Nemecek (2018) supplemented by WRI literature review.

TABLE 4 | Estimated effect of shifting to an alternative production system for selected environmental indicators per kg protein (example calculation based on organic beef production in Switzerland)

	GHG EMISSIONS (KG CO_2E)	LAND OCCUPATION (M^2*YR)	WATER USE—FRESHWATER WITHDRAWAL (L)	WATER POLLUTION —EUTROPHICATION POTENTIAL (KG $PO_4^{3-}E$)
Conventional beef production (weighted average, North America and Europe)	310	663	11,672	1.84
% change for organic beef production in study	-2%	+27%	-14%	+15%
Organic beef production (scaled to conventional)	302	844	10,027	2.11

Notes: GHG = greenhouse gas; kg CO_2e = kilograms of carbon dioxide equivalent; l = liters; m^2*yr = square meter-years; kg PO_4^{3-}-e = kilograms of phosphate equivalent.
Source: Authors' analysis based on Alig et al. (2012).

Note that these results should not be used to try to derive exact estimates of the effects of shifts to alternative systems, or exact impacts of different systems (e.g., for the purpose of estimating scope 3 GHG emissions). This is partly because the calculations are based on a limited number of studies. It is also because we adapted the raw values in the "paired studies" to show what percent changes above or below average "conventional" values would look like. This approach is similar to the one taken by Seufert et al. (2012), in which the "conventional" value is set at 1 for displaying results and the values for the "alternative" systems reflect the ratio in environmental impacts between the two types of systems (e.g., organic yields were found to be 0.75 of conventional yields in that study). The difference in our approach is that instead of setting the "conventional" value at 1, we set it at the weighted average by food type to simultaneously show differences in environmental performance across and within food types. The ranges in the dots shown in the figures are illustrative to give an idea of what *might* happen when a food company shifts its sourcing from conventional toward alternative production systems, based on the published, peer-reviewed evidence. Companies that mostly rely today on "industry average" environmental impact factors to estimate the impacts of their corporate activities on the environment will need to work with suppliers or other organizations to acquire actual impact factors that best match the characteristics of the products they are purchasing.

Figures 2a–2d show the results of our analysis of the effects of switching to alternative production systems for the selected environmental indicators. These figures show the weighted averages of environmental impacts for each protein source (also shown in Table 2) as blue dots to convey the impacts of "conventional" production. The yellow dots show the estimated data points from the different studies based on the percent changes between conventional and alternative production systems. For example, Figure 2a shows that, across the "paired studies," shifting from conventional to alternative production systems tends to increase GHG emissions per kilogram of protein for beef, pork, poultry, and eggs, while the results were more variable for other animal proteins. These results are further summarized in Table 5.

We also conducted t-tests to determine the statistical significance of the above findings. For these t-tests, our null hypothesis was that there would be no difference between the conventional and alternative production systems, while the alternative hypothesis was that the alternative production systems would have mostly higher environmental impacts than the conventional systems. We conducted these tests using the paired data points for beef, lamb, dairy, pork, poultry, and eggs, for both GHG emissions and land use. (There were not enough data for water pollution and water use to conduct t-tests.) The GHG emissions results were statistically significant for beef, poultry, and eggs, with a p value <0.05. The land use results were statistically significant for beef, dairy, pork, poultry, and eggs, with a p value <0.05. Overall, the fact that the majority of these results, for GHG emissions and land use, were statistically significant reinforces the findings that alternative production systems generally have higher environmental impacts than conventional systems. There were not enough data for water pollution and water use, so the statistical significance of the water-related results could not be determined.

FIGURE 2A | Estimated effects of alternative production systems on GHG emissions by protein type

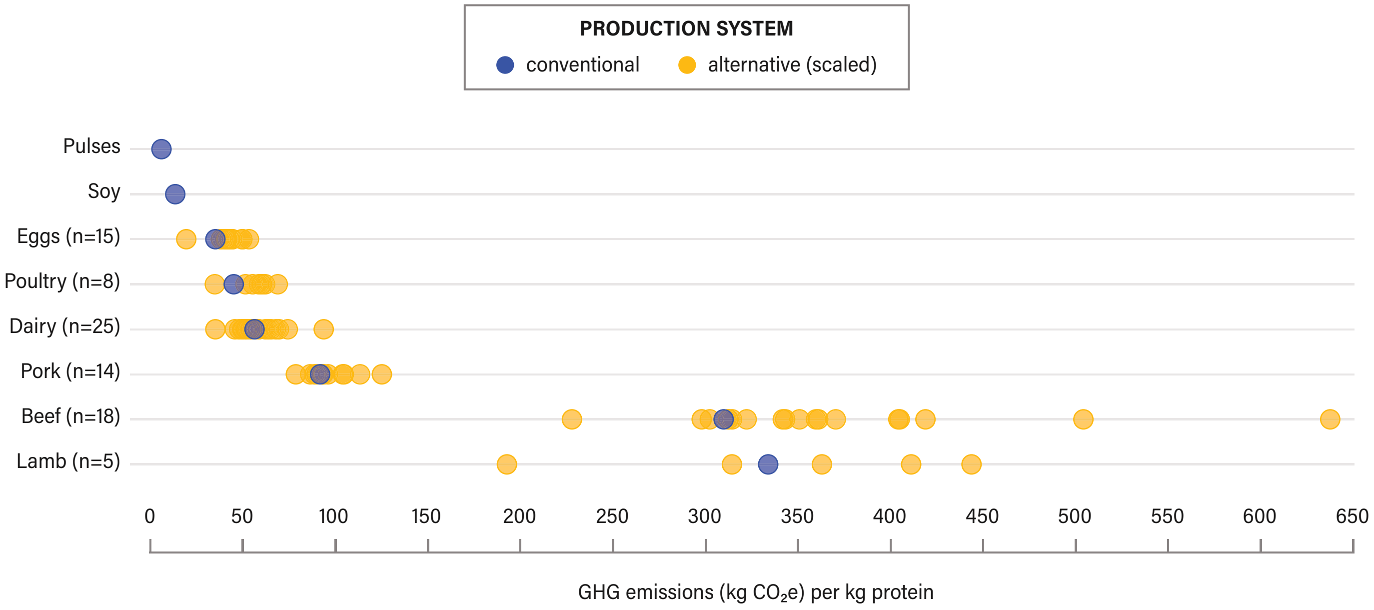


FIGURE 2B | Estimated effects of alternative production systems on land use by protein type

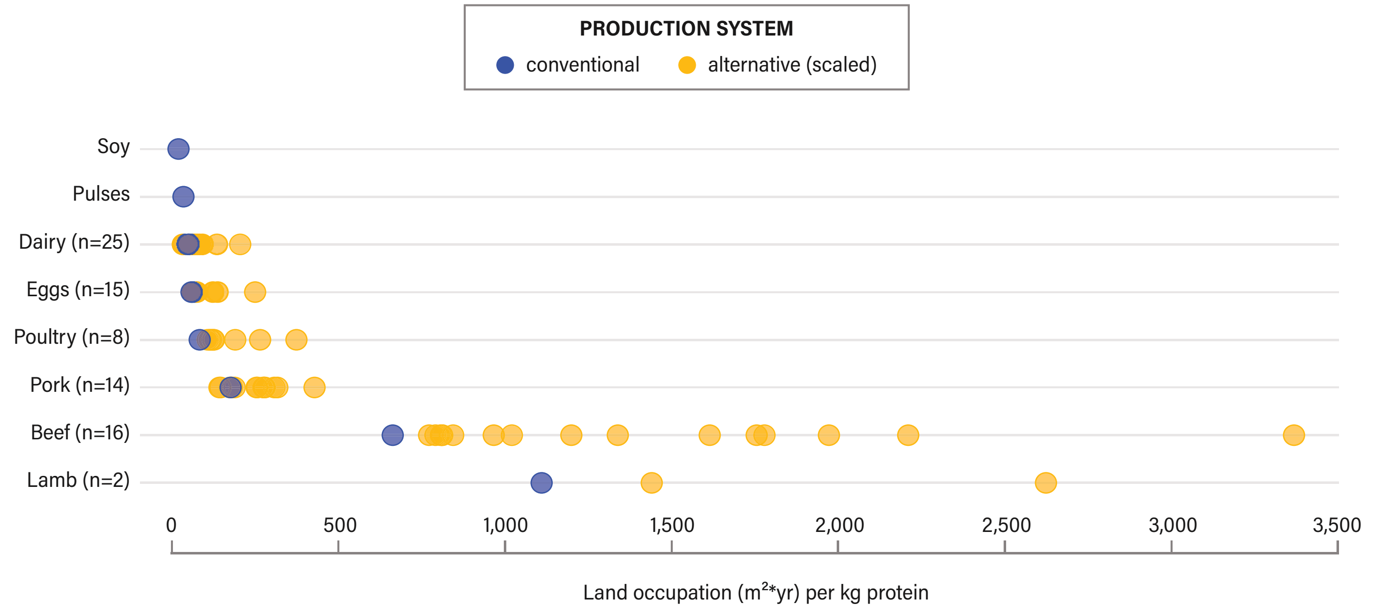


FIGURE 2C | Estimated effects of alternative production systems on water use by protein type

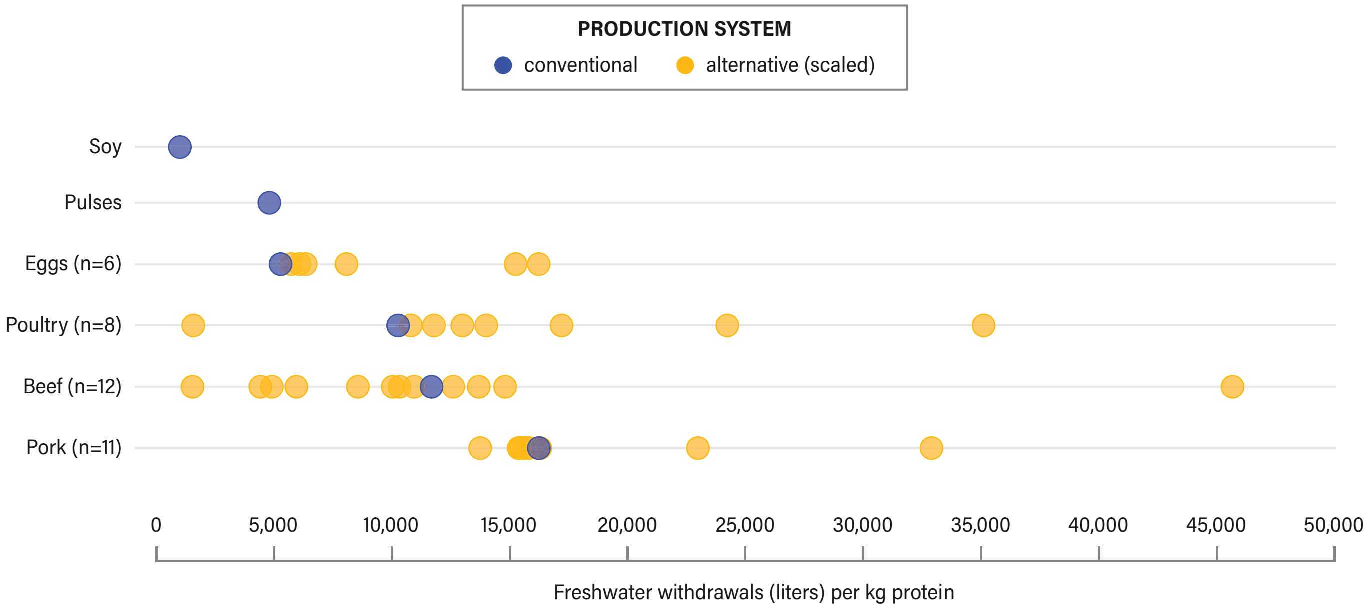
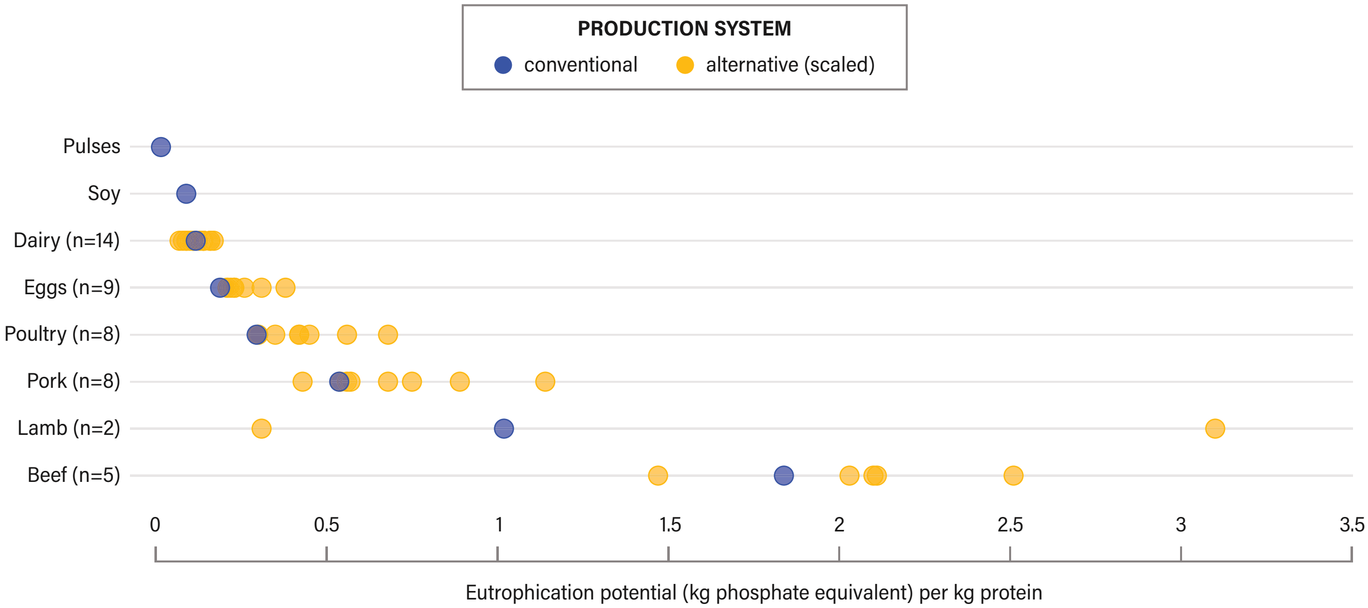


FIGURE 2D | Estimated effects of alternative production systems on water pollution by protein type



Notes: GHG = greenhouse gas; kg CO_2e = kilogram of carbon dioxide equivalent; m^2*yr = square meter-years; n = number of comparative study data points. Blue dots represent weighted average (mean) values for all production in Europe and North America. Yellow dots represent estimates (data points) from paired conventional-versus-alternative studies, scaling the average values by the effects (percent changes) of each alternative system to the conventional system in the paired study. Alternative systems, including pasture-based, extensive, grass-fed, organic, free-range, Red Label (*Label Rouge*), barn, and outdoor, were only present in a small subset of life cycle assessment studies, and thus the estimates are illustrative. GHG emissions only are shown (not carbon removals).

Source: Authors' analysis based on paired data points from Poore and Nemecek (2018), supplemented by WRI literature review.

TABLE 5 | Incidence of studies with increased estimated environmental impacts when shifting from conventional to alternative production systems for selected environmental indicators

ENVIRONMENTAL IMPACT INDICATOR (PER KG PROTEIN)	TOTAL UNIQUE DATA POINTS (ALTERNATIVE SYSTEMS)	TOTAL DATA POINTS WITH HIGHER ENVIRONMENTAL IMPACT THAN CONVENTIONAL	% OF DATA POINTS WITH HIGHER ENVIRONMENTAL IMPACT THAN CONVENTIONAL
GHG emissions (kg CO_2e)	85	60	71%
Land occupation (m^2*yr)	77	72	94%
Water use—freshwater withdrawal (l)	44	24	55%
Water pollution—eutrophication potential (kg $PO_4^{3-}e$)	46	34	73%
Total	**252**	**190**	**75%**

Notes: GHG = greenhouse gas; kg CO_2e = kilograms of carbon dioxide equivalent; l = liters; m^2*yr = square meter-years; kg PO_4^{3-}-e = kilograms of phosphate equivalent.

Overall, the LCA data on environmental impacts of alternative production systems present a mixed and perhaps counterintuitive picture. Several points are worth noting:

- *Shifting from conventional systems to alternative systems associated with "better meat" results in higher environmental impacts per kg of protein in a majority of cases in the published LCA literature.* Perhaps counterintuitively, systems marketed as "better" (e.g., organic, grass-fed, free-range) often lead to higher environmental impacts per kg of protein than those thought of as "conventional." In our aggregate data set shown in Table 5, environmental impacts were higher in three-quarters of alternative cases across studies. GHG emissions specifically were higher in more than 70 percent of cases. The least predictable outcome was the effect on water use, where 55 percent of the data points on alternative production systems had higher environmental impacts than conventional, and 45 percent had lower impacts. This result, however, varies by protein source. For example, the majority of alternative beef and pork systems saw a decrease in water use, whereas the majority of poultry and egg systems saw increased water use. Because feed (whether crop- or grass-based) is usually the largest contributor to resource use in animal-based food production, whether the croplands or pasturelands in any particular study were irrigated would highly influence the water use results of that study, and irrigation use also varies by geography.

- *Land occupation per kg of protein is usually higher in alternative systems—which is important from a climate and deforestation perspective, because "carbon opportunity costs" are also higher.* The amount of land needed to produce a kg of protein under alternative systems (associated with "better meat") was higher than "conventional" more than 90 percent of the time. This is very important from a climate perspective, since agricultural land expansion is the leading driver of deforestation and three-quarters of global agricultural land already goes to livestock production (Searchinger et al. 2019). Cattle pasture and soy are two of the main direct drivers of tropical deforestation since 2000 (Goldman et al. 2020). This suggests that, without a corresponding reduction in meat sourcing, merely shifting sourcing from conventional to alternative meat production systems would increase agriculture's pressure on remaining natural ecosystems such as forests. Although it is well known in the literature that organic and grass-fed systems are more land-intensive than conventional systems (see, e.g., Klopatek et al. 2022; Stanley et al. 2018; Seufert and Ramankutty 2017; Capper 2012; and Pelletier et al. 2010), this implication is poorly understood in discussions advocating for shifts to more extensive forms of animal agriculture. For example, Hayek and Garrett (2018) found that a nationwide shift in the United States from feedlot-finished beef to exclusively grass-finished beef, without expanding land requirements, would require a 73 percent reduction in U.S. beef production (put another way, current U.S. pasturelands could only support 27 percent of current beef production levels if finished on grass). In addition, climate goals require global agriculture to reduce, not increase, the size of its land footprint. Maintaining or increasing land dedicated to meat production means that lands previously deforested cannot be restored to natural ecosystems, leading to a large "carbon opportunity cost" (Hayek et al. 2021; Searchinger et al. 2018; Schmidinger and Stehfest 2012; Nguyen et al. 2010). This land occupation result is also relevant to global biodiversity, since agricultural expansion is also the leading driver of biodiversity loss, and expansion further increases the "biodiversity opportunity costs" of food production.

- *There are large differences in the ranges of environmental impacts between food types.* Different food types have significantly different ranges in environmental impacts per kg of protein. The products at the lower end of the impact scale (e.g., eggs, chicken, pork, and dairy) have maximum environmental impacts that are still lower than the lowest-impact beef and lamb, in terms of GHG emissions and land use, which—as noted above—are both very important for climate. That said, ranges between the food types overlap more for water use and water pollution. This result means that shifting purchasing toward lower-emitting animal products (or even better, plant-based foods) is often a more effective strategy for reducing climate impacts than sourcing even the lowest-impact beef and lamb products. Because we were unable to compare alternative fish and seafood production systems in the same way as the other animal proteins, Box 2 further delves into the environmental performance of fish and seafood. Notably, both wild and farmed fish and seafood can be relatively climate-friendly forms of animal protein, although there are wide variations across species and production methods.

BOX 2 | How do fish and seafood relate to "better meat"?

Fish and seafood provided 17 percent of the global animal protein supply in 2020 and are a particularly important source of nutrition in developing countries (FAO 2023). However, the global wild fisheries catch has plateaued since the 1990s, and the continued increase in global fish and seafood demand since then has been met by the fast growth of aquaculture (fish farming) (FAO 2022c). As of 2019, 35 percent of marine fish stocks were overfished, an all-time high (FAO 2022c).

The Poore and Nemecek (2018) database used for the environmental analysis in this report provided limited data on fish and seafood production, and we were not able to use our method to compare paired "conventional" and "alternative" systems for fish and seafood as we did for terrestrial animal protein production. However, fish and seafood are a relatively climate-friendly form of animal protein, and some more recent studies have taken a closer look at the environmental impacts of aquatic foods (also called "blue foods") (Gephart et al. 2021).

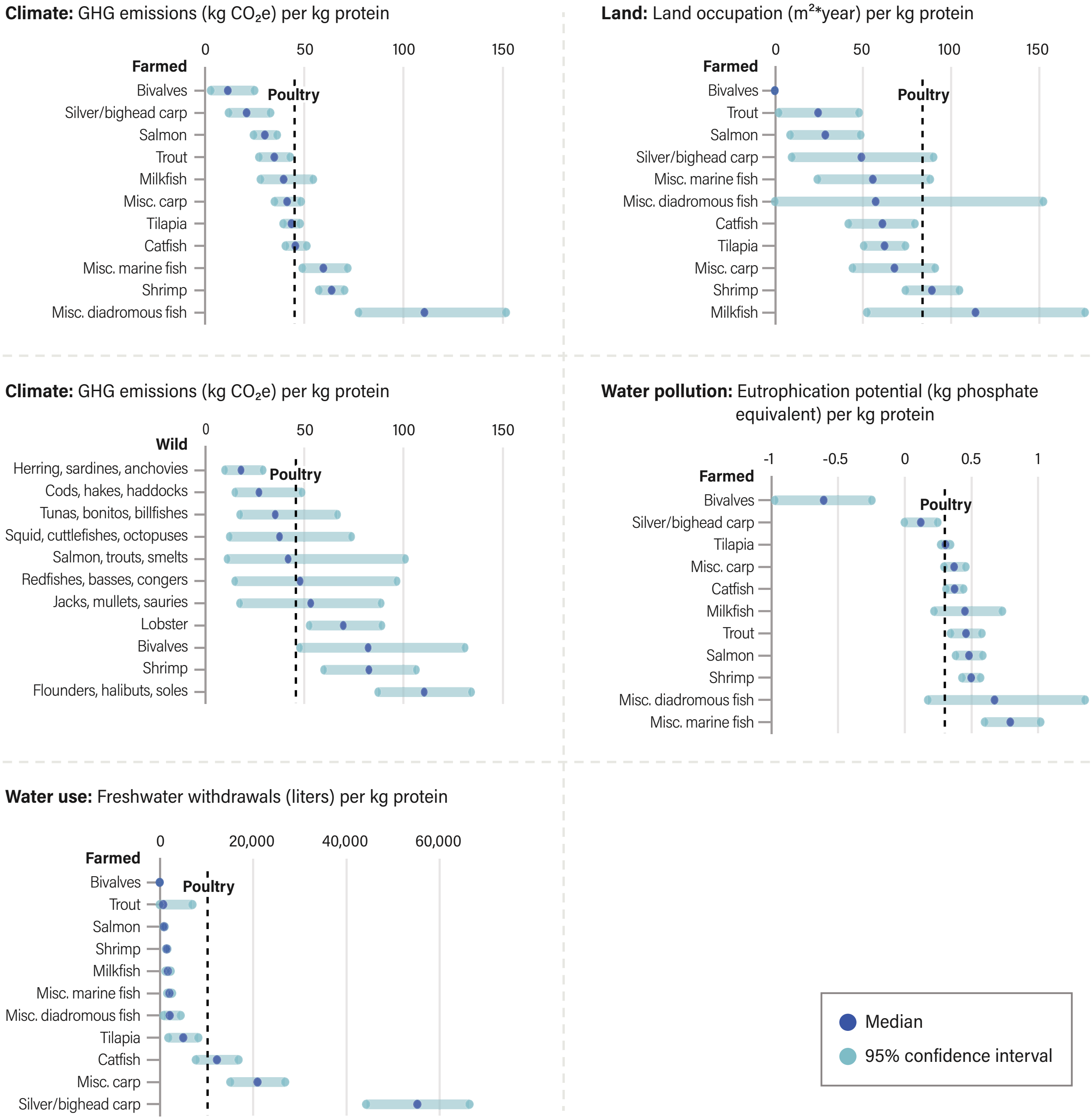
There is a large variability across species and production methods for aquatic foods in terms of environmental impact. Figure B2-1, which includes environmental indicators across GHG emissions, land use, water use, and water pollution, shows that farmed seaweeds and bivalves (clams, mussels, oysters, scallops, etc.) generally have the lowest environmental impact, followed by small wild-caught fish (herring, sardines, anchovies, etc.). Farmed bivalves even outperform plant-based proteins in that they use no land or freshwater, and can reduce water pollution, although their production area competes with other users of nearshore waters. The impacts of fish and seafood species range from lower than poultry (seaweeds, farmed bivalves, small wild-caught fish, etc.), to on par with poultry (farmed tilapia and shrimp, etc.), to higher than poultry (lobster, farmed marine fish, etc.). Overall, this places fish and seafood at the lower end of the environmental impact spectrum for animal proteins (Gephart et al. 2021) but usually still higher than plant-based proteins.

Similarly to terrestrial animal proteins, life cycle assessments of aquaculture (fish farming) have found that there are environmental trade-offs with intensification. When finfish and crustacean aquaculture systems move along the spectrum from more traditional extensive systems to more industrialized intensive systems, land use and water use per kilogram of fish declines, but water pollution and energy use per kilogram of fish grow (Bohnes et al. 2018; Waite et al. 2014; Hall et al. 2011). Effects on GHG emissions can be mixed under intensification due to the growth in energy use and land use for feeds balanced by the reduction in land use for ponds (Searchinger et al. 2019), and translation of land use into "carbon opportunity costs" can help better weigh these trade-offs. Aquaculture is also a significant user of wild fish as feed; more than 20 percent of total wild-caught fish catch in 2020 went to "nonfood" uses—mostly for fishmeal and fish oil used in aquaculture operations (FAO 2022c).

Because of aquatic foods' high nutrient density (Tigchelaar et al. 2022), dietary guidelines in Europe and North America often recommend an increase in fish and seafood consumption (e.g., USDA and USDHHS 2020; European Commission 2021), and because of their relatively low environmental impact compared to other animal proteins, increasing their share on the plate could be a "win-win" for the climate and for nutrition. That said, aquatic foods—and "better" forms of fish and seafood production—are subject to the same caveats as terrestrial animal proteins, including around livelihoods, animal welfare (which includes the high number of aquatic animals slaughtered annually for food and feed), and the other attributes shown in Figure 1 (Franks et al. 2021). In addition, curbing overfishing is critical, and it will be necessary to improve aquaculture's productivity and environmental performance over time as the sector grows (Searchinger et al. 2019). Certification schemes can help companies select fish and seafood products that meet specific environmental and social sustainability standards, such as avoiding overfishing and harm to marine ecosystems, and achieving fair and safe working conditions in seafood supply chains. And as with terrestrial animal proteins, new alternatives such as plant-based and cultivated seafood are also under development.

BOX 2 | How do fish and seafood relate to "better meat"? (cont.)

FIGURE B2-1 | Environmental impacts of aquatic foods



Climate: GHG emissions (kg CO_2e) per kg protein

Land: Land occupation (m^2*year) per kg protein

Climate: GHG emissions (kg CO_2e) per kg protein

Water pollution: Eutrophication potential (kg phosphate equivalent) per kg protein

Water use: Freshwater withdrawals (liters) per kg protein

Notes: kg CO_2e = kilogram of carbon dioxide equivalent; m^2*year = square meter-years. Values represent kilograms of edible protein and use mass allocation. Dotted vertical lines represent estimated poultry impacts from Figures 2a-2d for comparison purposes.

Source: Adapted from Gephart et al. (2021).

INCORPORATING THE "CARBON OPPORTUNITY COSTS" OF AGRICULTURAL LAND OCCUPATION TO UNDERSTAND THE CLIMATE IMPACTS OF SHIFTS TO ALTERNATIVE PRODUCTION SYSTEMS

The analysis above shows that, of the alternative production systems in the LCA literature, a shift from a conventional system to an alternative system increased GHG emissions per kg of protein produced in 71 percent of cases, while increasing land use per kg of protein produced in 94 percent of cases. But this discrepancy means that there are cases in which shifting from a conventional system to an alternative system causes GHG emissions from agricultural production to go *down*, but land use to go *up*. Given rising global food demand and ongoing deforestation, would such a trade-off between agricultural emissions and land use be better or worse for the climate? A metric called "carbon opportunity costs" allows us to weigh this trade-off by translating the change in land-use requirements into carbon dioxide equivalents, and comparing it with the change in agricultural production emissions.

Most of the world's croplands, and around 30 percent of its pasturelands, originally stored more carbon in their vegetation and soils than they do today (e.g., as forests, woody savannas, grasslands, or wetlands) (Searchinger et al. 2018). And while deforestation and other land-use changes remain a major contributor to climate change, limiting warming to below 1.5°C requires halting deforestation and achieving significant amounts of net reforestation (which would result in net carbon removals from land-use change) (IPCC 2019). Therefore, almost any productive use of land has a carbon opportunity cost.

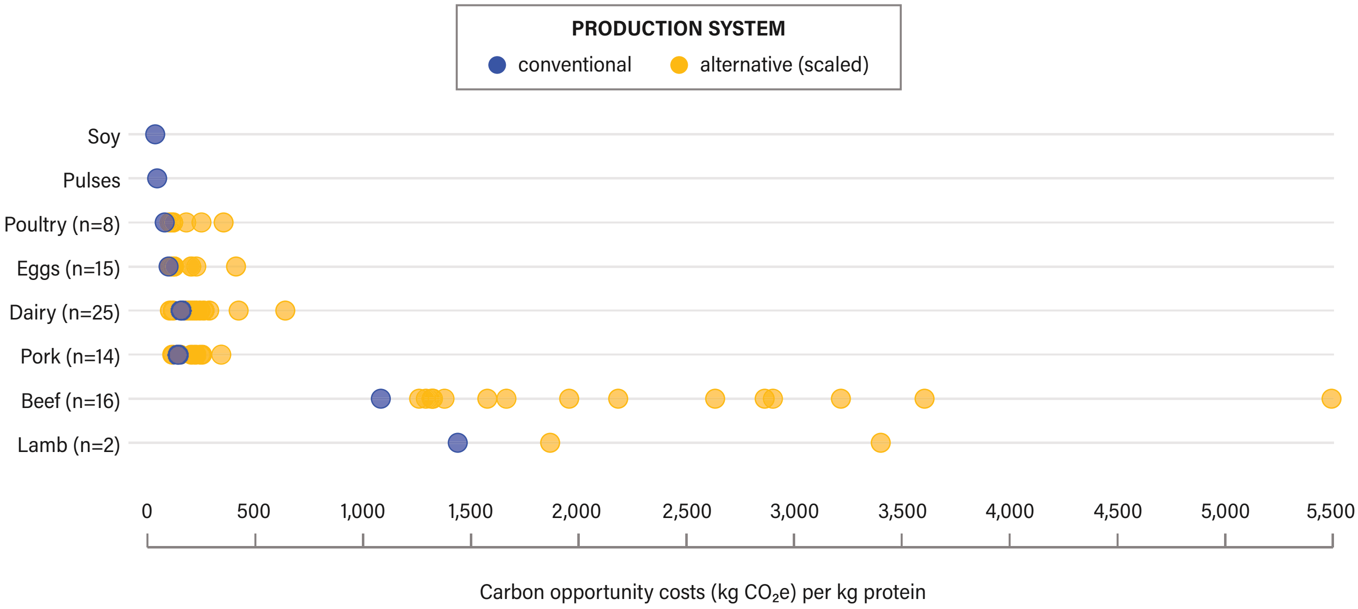
The carbon opportunity cost of a specific amount of a food is the total historical amount of carbon lost from plants and soils on agricultural lands that produce that food, divided by the total amount of that food produced (WRI and WBCSD 2022). Because soil and vegetative carbon losses occur quickly but food production can continue for many years, carbon opportunity costs are then often annualized by using a discount rate or dividing by an amortization period. Here we use the discount rate of 4 percent used in Searchinger et al. (2018), which is similar to amortizing the emissions over a period of 30–35 years.

Because animal-based foods (especially ruminant meats) require a relatively large amount of land to produce a kilogram of protein, these foods have higher carbon opportunity costs per kilogram of protein than do plant-based foods (Figure 3a). If a company's food-related land use (and carbon opportunity costs) grew over time, this growth would mean that the shift would increase pressure on the world's remaining natural ecosystems (e.g., forests) typically converted to produce those foods, and the change to the carbon opportunity cost metric from one year to the next would estimate the resulting negative effect on the climate. Conversely, if a company's land use fell over time because of a shift toward plant-based foods, the change in this metric would estimate the resulting beneficial effect on the climate, as pressure would be reduced on the world's remaining natural ecosystems.

One can also use the effects of alternative production systems on land use, shown in the yellow dots in Figure 2b, to estimate the effects of these production systems on carbon opportunity costs. Applying the percentage changes in land-use requirements between conventional and alternative systems, and scaling them relative to the average carbon opportunity costs, shows that just as land use increases in the vast majority of cases, so would carbon opportunity costs (Figure 3a). This is important, because by translating the land use amount into carbon opportunity costs one can see if, given both changes to GHG emissions from agricultural production and changes to carbon opportunity costs, a shift to a given production system would increase or decrease total "carbon costs" of meat production (i.e., be better or worse for the climate).

This sum of agricultural production emissions (from Figure 2a) and the carbon opportunity costs (from Figure 3a) is shown in Figure 3b. Overall, 94 percent of the alternative systems show up as having higher total "carbon costs" when analyzed in this way (Figure 3b). For example, four organic beef and lamb systems had lower agricultural GHG emissions than did conventional systems (e.g., because of reduced energy emissions linked to reduced use of fertilizers and concentrate feeds) but higher land use (Dakpo et al.

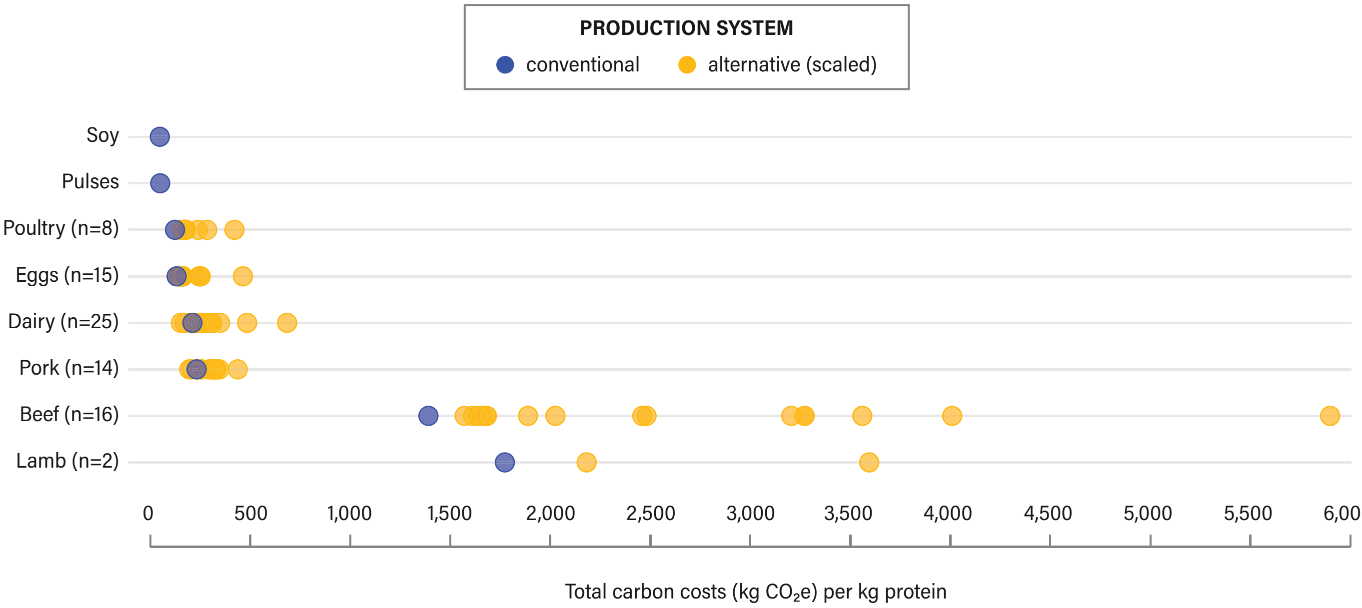
FIGURE 3A | Estimated effects of alternative production systems on carbon opportunity costs by protein type



Notes: kg CO_2e = kilograms of carbon dioxide equivalent; n = number of comparative study data points. Blue dots represent weighted average (mean) values for global production. Yellow dots represent estimates (data points) from paired conventional-versus-alternative studies, scaling the average values by the effects (% changes in land use) of each alternative system to the conventional system in the paired study. Alternative systems, including pasture-based, extensive, grass-fed, organic, free-range, Red Label (*Label Rouge*), barn, and outdoor, were only present in a small subset of life cycle assessment studies, and thus the estimates are illustrative.

Source: Authors' analysis based on paired data points from Poore and Nemecek (2018), supplemented by WRI literature review, and calculated using global carbon opportunity cost values from Searchinger et al. (2018).

FIGURE 3B | Estimated effects of alternative production systems on total carbon costs (GHG emissions plus carbon opportunity costs) by protein type



Notes: kg CO_2e = kilograms of carbon dioxide equivalent; n = number of comparative study data points. Blue dots represent weighted average (mean) summed values from Figure 2a (agricultural production emissions) and Figure 3a (carbon opportunity costs). Yellow dots represent estimates (data points) from paired conventional-versus-alternative studies, scaling the average values by the effects (percent changes) of each alternative system to the conventional system in the paired study. Alternative systems, including pasture-based, extensive, grass-fed, organic, free-range, Red Label (*Label Rouge*), barn, and outdoor, were only present in a small subset of life cycle assessment studies, and thus the estimates are illustrative. GHG emissions only are shown (not carbon removals).

Source: Authors' analysis based on paired data points from Poore and Nemecek (2018), supplemented by WRI literature review, and calculated using global carbon opportunity cost values from Searchinger et al. (2018).

2013; Alig et al. 2012; Casey and Holden 2006; Williams et al. 2006). In all four cases, when the land-use amounts were translated into carbon opportunity costs, these organic systems had higher total "carbon costs" than the conventional systems they were compared to.

Including carbon opportunity costs alongside agricultural GHG emissions therefore provides a fuller picture of the climate impacts of food purchasing decisions. It shows that the climate benefits of shifting diets high in meat toward plant-based foods are larger than commonly calculated, as such shifts produce a "double climate dividend" through both a reduction in scope 3 agricultural production emissions and a reduction in agricultural land demand (Hayek et al. 2021). Including carbon opportunity costs also shows that shifting purchasing toward more land-intensive meat production systems should be done with caution so as not to compromise corporate progress toward climate goals.

LIMITATIONS OF THE LCA REVIEW

The above analysis of the relative environmental impacts of alternative meat production systems, as captured in the LCA literature, does have some limitations:

- *LCAs generally do not account for on-farm biodiversity and soil health.* These are two "better meat" attributes that are closely related to the farm-level environmental consequences of food production. On the one hand, an overemphasis on land-use efficiency could lead to unsustainable forms of agricultural intensification (e.g., overuse of fertilizers or pesticides; overly high stocking densities) that could be detrimental to on-farm biodiversity, soil health, water quality, public health, and/or animal welfare in production areas. On the other hand, shifting to lower-yielding production systems also entails

biodiversity risks: in alternative production systems where on-farm biodiversity is improved but less meat is produced, there is a potential biodiversity trade-off when looking beyond the farm boundary, if land needs to be cleared elsewhere to make up for the meat production forgone in the alternative system (FOLU 2023).

- *LCAs do not account for animal welfare, an important "better meat" attribute*. Because of this, we analyze the links between alternative production systems and animal welfare further below, in the subsection "Linking animal welfare with the environmental impacts of meat production."
- *Not all hectares of land are the same.* Many pasturelands, for example, are not suitable for growing crops, and in these cases, ruminant meat and milk production can make use of land that would not otherwise produce food. The mere fact that land use per kg of protein is higher in beef and lamb production obscures this nuance. Furthermore, land use linked to production of animal-based foods in North America and Europe may be "offshored," such as recently deforested croplands in South America used to grow soy exported to Europe as chicken feed. That said, agricultural commodities are traded across borders, global meat production and consumption continue to rise, and tropical deforestation linked to livestock production continues apace. Because of these dynamics, land use remains an important indicator of how much pressure a food or an agricultural production system exerts on the world's remaining natural ecosystems. Furthermore, if land use is translated into "carbon opportunity costs," it can better incorporate the fact that not all hectares of land are the same in terms of former or potential future carbon storage.
- *Improvements within meat production systems can reduce environmental impacts, but these are not captured in these paired LCA studies.* For example, feed reformulation and feed additives can increase efficiencies and reduce environmental impacts, but these were not picked up in the analysis above. Because alternative production systems only comprise part of what companies and consumers associate with "better meat," below we further examine changes within dominant production systems that can reduce environmental impacts associated with meat production. We focus on beef, given its large absolute climate impact and its prominence in food companies' scope 3 GHG emissions.

REDUCING GHG EMISSIONS FROM BEEF PRODUCTION

Of all the animal proteins, beef has the largest absolute climate impact. For example, Gerber and FAO (2013) found that beef production contributed 41 percent of global GHG emissions from the livestock sector, and that its average emissions intensity (per gram of protein produced) was also the highest among animal proteins at the global level. Expansion of cattle pasture is a leading driver of tropical deforestation since 2000 (Goldman et al. 2020). Beef often registers as a high contributor to diet-related land use and GHG emissions in country-level studies in North America and Europe, such as in the United States (Eshel et al. 2014) and Denmark (Mogensen et al. 2020). In these regions, beef often is a prominent contributor to food companies' scope 3 GHG emissions (Cho and Waite 2023). Because of beef's outsized climate and land impacts, and its connection to recent deforestation, dietary strategies to reduce emissions often focus on shifting from beef toward lower-carbon foods (Ranganathan et al. 2016).

While beef has a large climate impact, beef production systems show a wide range in performance across countries (Herrero et al. 2013; Poore and Nemecek 2018) and within countries, including across different production systems (Figures 2a–2d). Because of this, the growing interest in identifying and sourcing beef with below-average GHG emissions is not surprising.

A number of strategies, summarized below, can reduce GHG emissions from beef production. While many of these do not constitute major shifts to "alternative production systems"—and therefore did not appear in the above analysis of LCA data—they are important options for companies to be aware of as they work to reduce their scope 3 GHG emissions.

- *Improve efficiency and productivity.* Globally, this is an important strategy, as many beef production systems—especially in the tropics—could benefit from the use of improved feeding practices, more digestible feeds, improved pasture grasses, cattle bred for higher growth rates, and better veterinary care. More intensive grazing management can also reduce the amount of pastureland needed per unit of beef produced, reducing "carbon opportunity costs" of beef production and pressure on forests. These types of improvements do not require a shift to feedlots. That said, efficiency and productivity are already relatively high in North America and Europe, so this strategy is most relevant when sourcing beef from areas where productivity is currently lower, such as in Latin America. As with other commodities, because efficiency and productivity gains can increase profit, this strategy may trigger agricultural expansion and additional land clearing (called the "rebound effect" or "Jevons paradox"). One important way to avoid the rebound effect is to accompany productivity gains with local ecosystem protection.
- *Reduce enteric methane emissions.* Methane from enteric fermentation ("cow burps") is a large source of beef-related emissions. Important research is advancing on feed additives that prevent formation of methane in cattle digestive processes, including the chemical 3-nitrooxypropanol (3-NOP, marketed as "Bovaer" in the European Union) and *Asparagopsis* seaweeds. Studies have found reductions in enteric methane emissions of between 20 percent and 98 percent without affecting productivity or cattle health (Roque et al. 2019; Kinley et al. 2020; Melgar et al. 2020). While these results are promising, such feed additives are not yet being used in the mainstream, and some hurdles remain (e.g., it is feasible to use the additives in concentrated feeds but

> A major challenge for companies in reducing their scope 3 GHG emissions is that complex beef supply chains hinder traceability back to the farms and ranches where the meat is produced.

more difficult to do so when the cattle are grazing on pasture). Researchers are also aiming to breed cattle with lower enteric methane intensity.

- *Improve manure management.* Manure releases both methane and nitrous oxide, and better management of it can reduce emissions of both of these potent greenhouse gases. When animals live in confined settings, separating liquids from solids can reduce the quantity of gases emitted. While there is currently much focus on the use of anaerobic digesters to collect manure to produce biogas for electricity, digesters are a relatively costly form of GHG emissions mitigation.
- *Stabilize and sequester carbon in vegetation and soils.* Increasing soil carbon improves soil health (Bradford et al. 2019), and practices aimed at improving soil health are commonly called "regenerative." In places with low pasture productivity and poor soil quality—such as in the tropics—practices such as silvopasture (integrating trees and shrubs on pasturelands) and rotational grazing can increase the amount of beef produced per hectare while also sequestering additional carbon in both soils and vegetation. In North America and Europe, however, where pasture productivity is relatively high, practices that aim to increase on-farm soil carbon may not have a climate benefit if the amount of beef produced per hectare declines. This is because the local benefits of soil carbon sequestration would need to be compared to the potential off-farm carbon losses to clear new lands to replace the lost beef production. Box 3 goes further into the complexities around the impacts of "regenerative grazing" on soil carbon sequestration, land use, and the climate. Because the impacts of management practices on soil carbon sequestration can be complex and hard to predict, we recommend that net carbon sequestration from increases in soil carbon stocks be explored as a potential climate mitigation strategy, but not be seen as a "silver bullet."

A major challenge for companies in reducing their scope 3 GHG emissions is that complex beef supply chains hinder traceability back to the farms and ranches where the meat is produced. Further complicating the challenge is that even in cases where there is traceability, there are usually no GHG emissions data linked to the farm, ranch, or supply chain. In an ideal world, a company would have supplier-specific GHG emissions data, for each beef product purchased, that it could use to assign emissions estimates to its beef purchases. Today, however, companies often rely on "industry average" GHG emissions factors (e.g., regional- or national-level estimates for emissions associated with 1 kg of conventional beef production) when estimating scope 3 emissions. Over time, companies should work to refine the emissions data with their suppliers, using a hybrid approach if necessary (Figure 4), to more accurately match the characteristics of the products they are purchasing. Because of the many challenges with scope 3 emissions accounting, the GHG Protocol (WRI and WBCSD 2023) is gathering perspectives from a variety of stakeholders related to market-based accounting approaches ("credits" for specific projects that reduce GHG emissions or increase carbon removals at the level of a farm or sourcing region, use of certifications linked to practices that reduce net emissions, etc.).

Companies can use three main strategies to reduce scope 3 emissions from beef purchasing:

- *Engage beef suppliers.* In general, engagement of current suppliers is the best practice (SBTi 2018). A variety of approaches can encourage suppliers to adopt the changes to production practices described above, including setting standards and/or scoring systems for suppliers, helping suppliers set their own GHG reduction targets, investing directly in on-farm projects or sourcing region-level projects that reduce emissions, and partnering with other major beef purchasers that buy from those suppliers.
- *Purchase certified lower-emissions beef.* This opportunity is still in its infancy, but with interest in climate action continuing to grow, it is likely that certified lower-emissions food products, including beef, will be more available on the market in coming years. For example, companies in Sweden have trialed selling "methane-reduced beef" (from cattle fed *Asparagopsis* seaweed) in supermarkets (Byrne 2023), and companies in the United States are aiming to sell certified beef with 10 percent fewer GHG emissions than average (Marks 2023).
- *Shift toward lower-emissions foods.* As noted elsewhere in this report, because beef is an emissions-intensive food, shifting purchases and sales toward lower-emissions foods can help companies reduce scope 3 emissions.

BOX 3 | Beef, soil carbon, regenerative grazing, and land use

There is growing interest in improving grazing management to increase the amount of carbon sequestered in pasturelands, a practice often called "regenerative grazing." Some proponents of regenerative grazing even suggest that by removing carbon from the atmosphere, soil carbon sequestration could fully offset GHG emissions from beef production, suggesting potentially "carbon neutral" or "carbon negative" beef. And while traditional life cycle assessments assumed that soil carbon stocks on agricultural lands were in equilibrium and did not include soil carbon stock changes in studies on agriculture's environmental impacts, more recent studies have begun to incorporate soil carbon measurements, including several beef studies included in our review (Buratti et al. 2017; Eldesouky et al. 2018; Stanley et al. 2018).

Following the draft "Greenhouse Gas Protocol Land Sector and Removals Guidance" (WRI and WBCSD 2022), we separated out the soil-related carbon removals from the emissions reported in each of the studies, rather than presenting them as combined net emissions amounts. Therefore, only changes to GHG emissions are shown in Figure 2a. Across the three studies, soil-related carbon removals equated to between 2 and 54 percent of total GHG emissions across the full beef life cycle (that is to say, the soil carbon sequestration offset 2–54 percent of the beef production–related emissions).[8] At the high end, the annual soil carbon sequestration rate (3.6 tons of carbon per hectare per year [tC/ha/yr] reported in Stanley et al. 2018) was far higher than that commonly reported in the literature on soil carbon sequestration in grazing lands (e.g., 0.1 to 1.45 tC/ha/yr on grasslands, reported in Minasny et al. 2017). Moreover, this 3.6 tC/ha/yr rate for soil carbon sequestration alone is substantially higher than the typically reported sequestration rates for forests, which include not only soil carbon sequestration but also the much larger amount of carbon sequestered in aboveground vegetation (Cook-Patton et al. 2020). Stanley et al. (2018) also caution that because soils eventually reach a saturation point, it is not appropriate to extrapolate these sequestration results over an extended period.

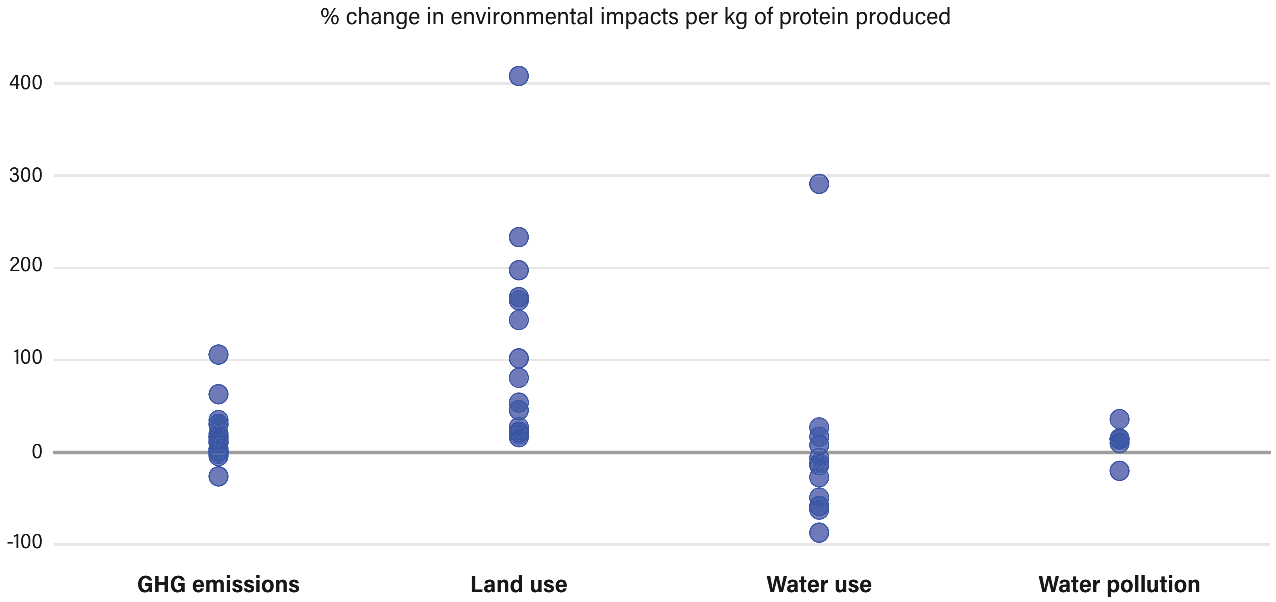
As one other indicator of mitigation potential, a global modeling study by Henderson et al. (2015) estimated the total net soil carbon sequestration potential at about 300 million tons of CO_2e per year across the world's pasturelands, when also accounting for potential nitrous oxide emissions increases linked to legume sowing. If fully realized, this would offset only 10 percent of annual global beef-related emissions (Gerber and FAO 2013).

Carbon removal accounting is relatively new and subject to significant uncertainty. The latest draft of the "Land Sector and Removals Guidance" (September 2022) requires companies reporting carbon removals in their supply chains to also have a plan to monitor the carbon stocks over time to ensure permanence of the removals. Because of these various nuances around carbon removal accounting, we recommend that companies explore net soil carbon sequestration from increased soil carbon stocks as one of a suite of potential mitigation options for beef production, rather than expect it to be a "silver bullet" to achieve carbon neutrality in beef production.

Finally, it is important to note that management practices that increase soil carbon sequestration on pastures can lead to carbon losses elsewhere. One example is the conversion of annual cropland to pastureland: although this will sequester additional carbon for a number of years, that parcel of land (under grazing instead of cropping) will also produce much less food than before. Global crop demand continues to rise, so converting cropland to pastureland will likely require other lands to be converted to cropland elsewhere, releasing carbon. Similarly, practices to increase soil carbon sequestration on existing pasturelands can also result in less meat production per hectare than under conventional production systems. The study in our LCA review with the most impressive soil carbon sequestration result (Stanley et al. 2018) also saw a 22 percent increase in land use per kilogram (kg) of beef compared to conventional beef, when considering the animals' full life cycle. Figure B3-1 shows that across all of the alternative beef production systems assessed, GHG emissions and land use per kg of beef protein tended to be higher than under conventional production. As noted elsewhere in this report, if companies shift to sourcing beef with higher land requirements, they would need to further reduce beef purchasing so as not to increase land pressures (and risks of driving further land-clearing) associated with their supply chains.

BOX 3 | Beef, soil carbon, regenerative grazing, and land use (cont.)

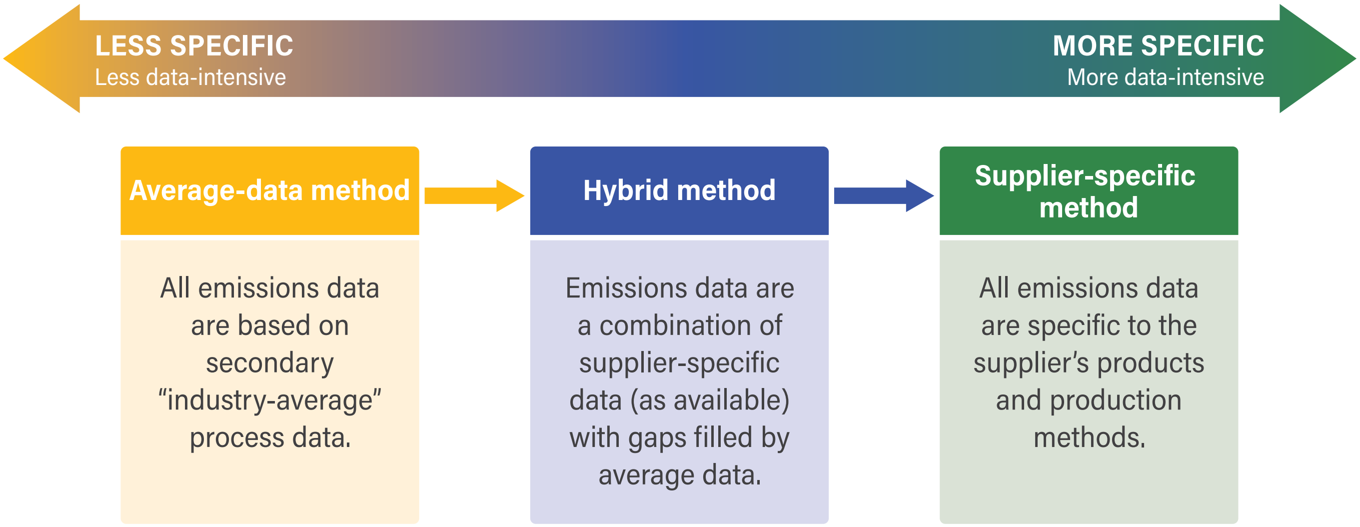
FIGURE B3-1 | Estimated effects of shifting from conventional to alternative production systems in comparative beef LCAs



Notes: GHG = greenhouse gas; kg = kilogram; LCA = life cycle assessment. GHG emissions only are shown (not carbon removals).

Source: Authors' analysis based on paired data points from Poore and Nemecek (2018), supplemented by WRI literature review.

FIGURE 4 | Methods to estimate supply chain (scope 3) GHG emissions



All emissions data are based on secondary "industry-average" process data.

Emissions data are a combination of supplier-specific data (as available) with gaps filled by average data.

All emissions data are specific to the supplier's products and production methods.

Source: Adapted from WRI and WBCSD (2013).

This subsection has focused on beef (given its high environmental impacts across the board) and climate (given its high relevance to companies). That said, the main approaches companies can use—including engaging suppliers to improve production practices, purchasing certified lower-impact products, and shifting toward lower-impact foods (e.g., plant-based foods)—are broadly relevant for other animal proteins and other environmental and social or ethical impacts as well.

One particular social or ethical impact—animal welfare—stood out in our stakeholder interviews as especially relevant to "better meat." But how does animal welfare interact with the various meat production systems and their environmental impacts? The next subsection takes a closer look at animal welfare and how companies can weigh various sustainability goals when designing meat sourcing strategies.

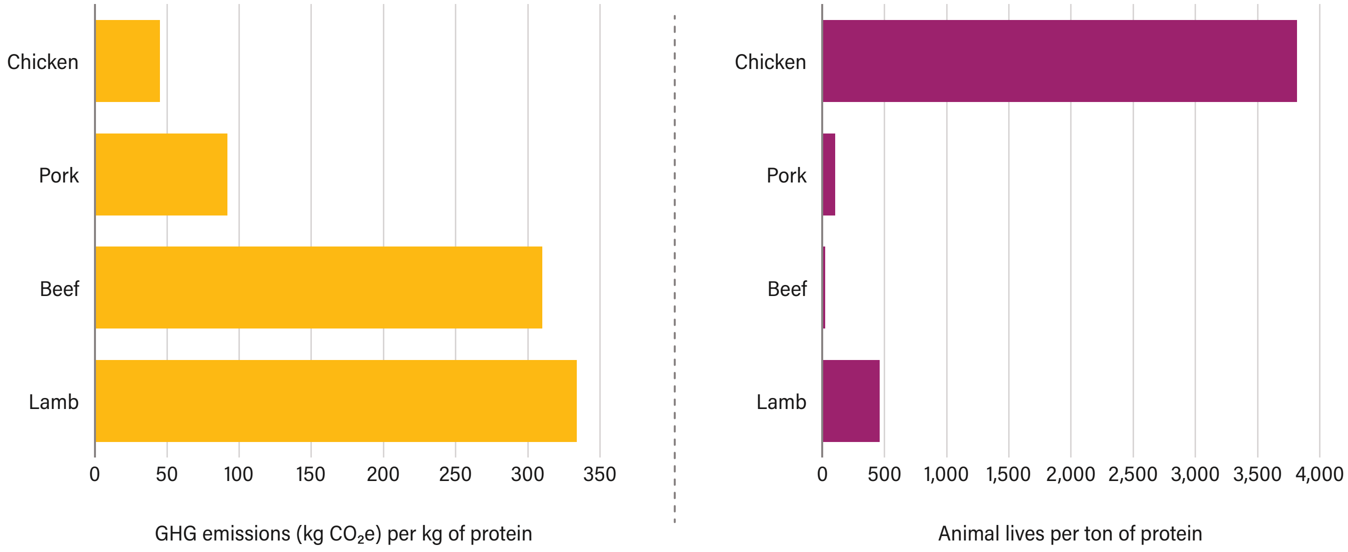
LINKING ANIMAL WELFARE WITH THE ENVIRONMENTAL IMPACTS OF MEAT PRODUCTION

Thus far, this report has focused on the environmental attributes of "better meat" and how various production systems and practices are likely to affect these attributes. Here, we add in data and guidance about animal welfare to show how companies can balance welfare and environmental goals when purchasing animal proteins.

It is true that poultry has a lower climate impact per kilogram of protein than beef and lamb, and climate strategies may consider a shift in purchasing from beef toward chicken to continue to provide the same amount of meat to consumers while reducing GHG emissions. However, an important trade-off to consider from an animal welfare perspective is the number of animal lives per unit of protein produced. While alternative systems thought of as "better" might improve the quality of life of the animals to some degree, animal welfare experts also recognize the inherent value of all animals, and companies might choose to factor the number of animals slaughtered into their decision-making as a simple and easily understood indicator of animal welfare.

Figure 5 shows the trade-off between climate and animal welfare indicators when shifting between animal-based foods, showing that the foods with the highest climate impact per kg of protein also require the fewest animals to be killed, and vice versa. For example, to produce a kg of protein, more than 100 times as many chickens need to be slaughtered compared to cows.

FIGURE 5 | Trade-off between climate and animal welfare indicators



Notes: GHG = greenhouse gas; kg CO_2e = kilograms of carbon dioxide equivalent.

Sources: Average North America and Europe GHG emissions data from Poore and Nemecek (2018); data for animals slaughtered, meat produced, and protein content for North America and Europe from FAO (2023).

Beyond animal lives, there are several other characteristics of animal welfare that organizations sourcing meat might choose to prioritize, and these can be connected to environmental impacts. Through our stakeholder interviews and our review of various authorities on animal welfare, we identified a set of animal welfare attributes of interest.

The five animal welfare characteristics that we focused on were the use of antibiotics, the use of growth hormones, outdoor access, breeding for slower growth, and the use of cages. Through our interviews, we found that, while some companies can sufficiently monitor their supply chains to provide specific information on the welfare of animals on the farms from which they source, many rely on welfare certifications. Certifications link certain qualities with a given product, and ensure that that quality follows the product throughout the supply chain. This makes it easier for companies to source products with a specific characteristic, such as organic or free-range. For companies that are unable to assess the detailed state of animal welfare on their supplying farms, certifications can serve as a proxy, and allow companies to set priorities and make claims regarding the social and ethical attributes of "better meat."

Because our analysis focuses on North America and Europe, we considered welfare certifications that are applicable in both regions. We discussed the key attributes of animal welfare with experts in the United States and United Kingdom, and determined which certifications are most broadly applicable in North America and Europe and address most welfare targets. We consulted various animal welfare resources to ensure that the definitions of the certifications are comparable in both regions (European Commission 2023; *Consumer Reports* 2023; Fanatico and Born 2011). We then conducted a mapping exercise in which we determined which alternative production systems guarantee the inclusion of certain welfare characteristics. For example, an organic production system in Europe guarantees that the product is antibiotic- and hormone-free, and is bred for slower growth. However, perhaps counterintuitively, an organic system does not guarantee that the animals are raised in a cage-free environment (European Commission 2023). Table 6 shows how we mapped the alternative production systems from our environmental analysis to the different animal welfare characteristics, using the example of eggs. The cells show the connection between the environmental attributes and animal welfare characteristics: light orange cells mean that the production system *might* include that

TABLE 6 | Qualitative mapping of alternative animal production systems to animal welfare characteristics (example for eggs)

	ANIMAL WELFARE CHARACTERISTICS				
Production system	**Antibiotic-free**	**Growth-hormone-free**	**Outdoor access**	**Breeding for slow growth**	**Cage-free and/or reduced confinement**
Barn	🟨	⬜	🟨	🟨	🟧
Free-range	🟨	⬜	🟧	🟨	🟧
Organic	🟧	⬜	🟨	🟧	🟨
Outdoor access	🟨	⬜	🟧	🟨	🟧

APPLICABILITY OF ANIMAL WELFARE CHARACTERISTICS	
⬜	Not applicable
🟨	Maybe applicable
🟧	Applicable

Note: The alternative production systems at left are only those that we also examined for environmental outcomes; some conventional systems may also incorporate some animal welfare characteristics (e.g., responsible antibiotic use, cage-free).

Source: Authors' analysis based on European Commission (2023); *Consumer Reports* (2023); and Fanatico and Born (2011).

animal welfare category, and dark orange means that it is guaranteed. We recognize that there are production system differences between North America and Europe but found that these welfare characteristics remained broadly applicable across the production systems. Note that the European Union has voted to phase out the use of cages for animal agriculture by 2027, at which point conventional production systems in the European Union will be more like cage-free systems, whose environmental impacts theirs will also resemble (Axworthy 2021).

Table 7 connects the animal welfare and environmental analyses. The rows include the various types of alternative production systems from our environmental analysis across the different product types (listed in Table 3). As an example of how Table 7 could be used, a company could choose to shift from conventional to cage-free eggs, and the table shows that this would be guaranteed by outdoor access or free-range certification labels. The environmental data in Table 7, in turn, show that the company could generally expect an increase in GHG emissions, land occupation, and water use related to the production of eggs with these labels—relative to conventional egg production.

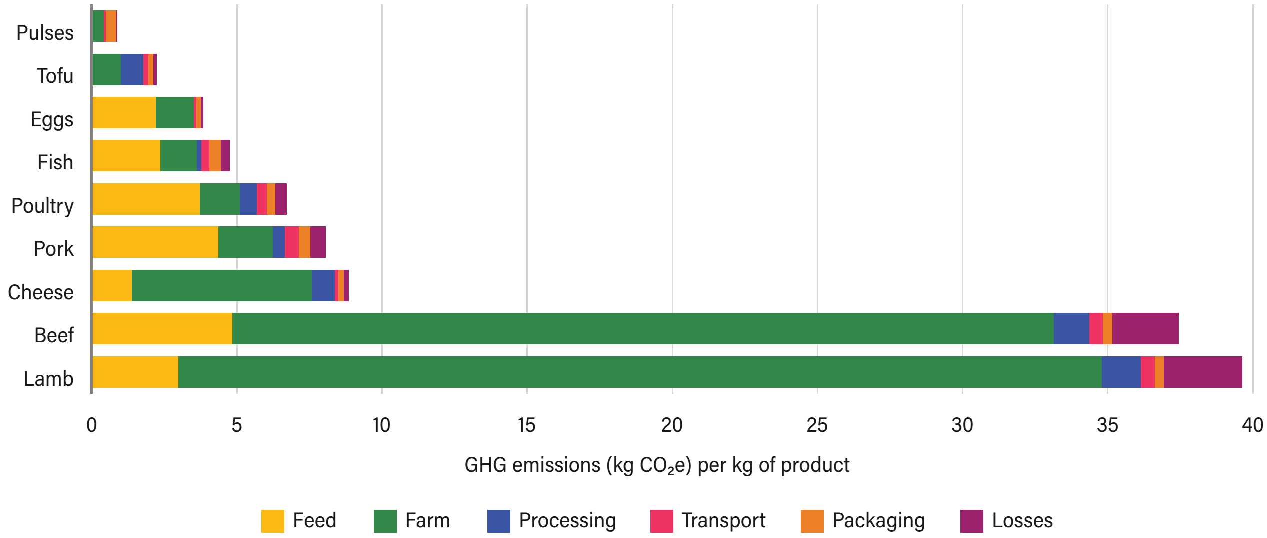
To be clear, the analysis shown in Table 7 does not imply that cage-free eggs are inherently environmentally "bad." Figures 2a–2d showed that even the highest-impact eggs have a significantly lower impact than even the lowest-impact beef and lamb. Companies, therefore, should consider the broader context when designing their protein sourcing strategy: if cage-free eggs form part of a company's animal welfare strategy, but the climate impact of those eggs is higher than conventional eggs, then the company should think about sourcing *even less meat* (or other animal-based foods) than it otherwise would have in order to meet its climate targets. That is to say, reducing the purchasing of animal-based foods—especially beef and lamb—creates the climate "space" for organizations to source animal proteins produced in these alternative ways, and makes it possible to achieve multiple sustainability goals at once.

Finally, locally sourced meat may have more transparent animal welfare standards, as it increases the likelihood a food company could interact directly with a certain producer and visit its operations. Even then, however, "local" and "higher animal welfare" may not be synonymous (e.g., local farms can fall short on animal welfare; welfare-certified products may come from farther away). Although locally sourced meat is

BOX 4 | What are the links between local meat sourcing and the climate?

Local food sourcing is often perceived as a strategy that has significant climate benefits, and it also garners a lot of consumer interest. However, transport only accounts for 3–6 percent of food-related emissions globally, representing a small fraction of the total emissions related to a product (Poore and Nemecek 2018; Tubiello et al. 2021; Ritchie 2023) (Figure B4-1). For animal-based products with high greenhouse gas (GHG) emissions, an adjustment to transportation (e.g., shifting from a national supplier to a local one, or from an international supplier to a domestic one) does not bring a significant reduction in emissions. While local sourcing is not a major climate strategy, it has other benefits. Local sourcing can help to support local producers and businesses, boosting the regional economy and preserving well-managed farmland, and it can also help provide more transparency around animal welfare practices, which can be challenging to achieve with national suppliers who lack any animal welfare certification.

FIGURE B4-1 | GHG emissions per kg of product by supply chain stage



Notes: GHG = greenhouse gas; kg CO_2e = kilogram of carbon dioxide equivalent.

Source: Poore and Nemecek (2018) (Europe averages).

commonly thought to have lower emissions due to reduced transportation distance, Box 4 explains why local meat sourcing is not a major climate strategy.

Table 8 and Figure 6 show how a company might analyze potential effects of different meat sourcing strategies to link environmental and animal welfare goals. It takes the example of a fictitious North American food service company that serves roughly 6 million meals per year in the typical dietary pattern. The company uses the Coolfood calculator (www.coolfood.org) and finds that in the base year, terrestrial animal proteins make up more than 70 percent of its scope 3 emissions associated with agricultural supply chains, and more than 80 percent of its carbon opportunity costs. It then examines several scenarios:

- The company first simulates a pure "less meat" strategy to reduce scope 3 emissions and carbon opportunity costs by a combined 25 percent. To do so, it finds that sourcing 50 percent less beef, 20 percent less of other meats, and 15 percent less dairy—and shifting the purchases toward pulses, soy, and vegetables—achieves this 25 percent reduction in climate impacts.

- The company then explores a plausible scenario of shifting all chicken and egg purchases toward higher-welfare products. It uses Table 7 and selects points within the impact ranges to assume that free-range chicken and eggs could lead to 15 percent higher GHG emissions and 25 percent higher land use (carbon opportunity costs) than conventional chicken. The company estimates that this would increase total climate impacts, but only slightly, since chicken and eggs represent a small amount of the company's total climate impact. Under this scenario, total climate impacts are reduced versus the base year by "only" 24 percent instead of 25 percent.
- The company then slightly adjusts beef sourcing downward—from 50 percent less to 53 percent less—to reattain the 25 percent climate impact target.
- The company then explores the effects of also shifting its beef purchases to grass-fed. Using Table 7, it estimates that sourcing grass-fed beef could lead to 25 percent higher GHG emissions and 100 percent higher land use (carbon opportunity costs) than conventional beef. Under this scenario, many of the climate benefits from "less meat" would be offset by the higher environmental impacts of the grass-fed beef, and climate impacts only go down by 5 percent relative to the base year.
- Finally, the company adjusts beef sourcing downward—from 53 percent less to 75 percent less than the base year—to reattain the 25 percent climate impact target.

TABLE 7 | Connecting environmental impacts of alternative production systems to animal welfare characteristics by protein type

		ENVIRONMENTAL IMPACTS PER KG PROTEIN				ANIMAL WELFARE CHARACTERISTICS				
Food type and alternative system	**Number of comparisons to conventional**	**GHG emissions (kg CO_2e)**	**Land occupation (m^2*yr)**	**Water use - freshwater withdrawal (l)**	**Water pollution - eutrophication potential (kg PO_4^{3-}-e)**	**Antibiotic-free**	**Growth-hormone-free**	**Outdoor access**	**Breeding for slow growth**	**Cage-free and/or reduced confinement**
Lamb		**334**	**1,110**	**No data**	**1.02**					
Organic	2	-6% to -42%	+30% to +136%	No data	+205%	🟧	🟧	🟨		🟨
Pasture-based/grass-fed/extensive	3	+9% to +33%	No data	No data	-70%	🟨	🟨	🟧		🟨
Beef		**310**	**663**	**11,672**	**1.84**					
No growth-enhancing technologies	1	+16%	+22%	+17%	No data	🟨	🟧	🟨		🟨
Organic	6	-26% to +35%	+19% to +102%	-87% to -14%	-20% to +15%	🟧	🟧	🟨		🟨
Pasture-based/grass-fed/extensive	11	+1% to +106%	+16% to +408%	-62% to +291%	+10% to +36%	🟨	🟨	🟧		🟨
Pork		**92**	**177**	**16,227**	**0.54**					
Free-range	4	-14% to +13%	-19% to +7%	0%	0% to +39%	🟨	🟨	🟧	🟨	🟨
Outdoor access	1	+1%	+2%	0%	+5%	🟨	🟨	🟧	🟨	🟨
Organic	8	-6% to +36%	+44% to +143%	-5% to +103%	+7% to +112%	🟧	🟧	🟨	🟧	🟨
Red Label [*Label Rouge*]	1	+24%	+1%	-15%	-19%	🟨	🟧	🟧	🟧	🟨

TABLE 7 | Connecting environmental impacts of alternative production systems to animal welfare characteristics by protein type (cont.)

		ENVIRONMENTAL IMPACTS PER KG PROTEIN				ANIMAL WELFARE CHARACTERISTICS				
Food type and alternative system	Number of comparisons to conventional	GHG emissions (kg CO_2e)	Land occupation (m^2*yr)	Water use - freshwater withdrawal (l)	Water pollution - eutrophication potential (kg PO_4^{3-}-e)	Antibiotic-free	Growth-hormone-free	Outdoor access	Breeding for slow growth	Cage-free and/or reduced confinement
Dairy		**56**	**50**	**No data**	**0.12**					
Local breed	1	+32%	No data	No data	No data	🟨	🟨	🟨	⬜	🟨
Organic	15	-12% to +16%	+6% to +172%	-40%	-39% to +33%	🟧	🟧	🟨	⬜	🟨
Pasture-based/ grass-fed/ extensive	9	-38% to +66%	-34% to +312%	-93% to +101%	-35% to +44%	🟨	🟨	🟧	⬜	🟨
Poultry		**45**	**84**	**10,254**	**0.30**					
Free-range	1	+14%	+29%	+15%	+18%	🟨	⬜	🟧	🟨	🟧
Organic	3	-23% to +53%	+127% to +346%	-85% to +242%	0% to +131%	🟧	⬜	🟨	🟧	🟨
Outdoor access	1	+30%	+41%	+27%	+2%	🟨	⬜	🟧	🟨	🟧
Red Label	3	+23% to +38%	+36% to +51%	+5% to +68%	+42% to +52%	🟨	⬜	🟧	🟧	🟧
Eggs		**35**	**59**	**5,263**	**0.19**					
Barn	5	+9% to +26%	+5% to +20%	+9% to +20%	+10% to +24%	🟨	⬜	🟨	🟨	🟧
Free-range	3	+16% to +22%	+25% to +28%	+15%	+19%	🟨	⬜	🟧	🟨	🟧
Organic	4	-45% to +52%	+108% to +323%	+190% to +208%	+25% to +102%	🟧	⬜	🟨	🟧	🟨
Outdoor access	3	+8% to +26%	+12% to +25%	+53%	+14% to +63%	🟨	⬜	🟧	🟨	🟧
Soy		**13**	**20**	**990**	**0.09**					
Pulses		**6**	**35**	**4,786**	**0.02**					

APPLICABILITY OF ANIMAL WELFARE CHARACTERISTICS	
⬜	Not applicable
🟨	Maybe applicable
🟧	Applicable

Notes: GHG = greenhouse gas; kg CO_2e = kilograms of carbon dioxide equivalent; l = liters; m^2*yr = square meter-years; kg PO_4^{3-}-e = kilograms of phosphate equivalent. The alternative production systems at left are only those that were also examined in this report for environmental outcomes; some conventional systems may also incorporate some animal welfare characteristics (e.g., responsible antibiotic use, cage-free).

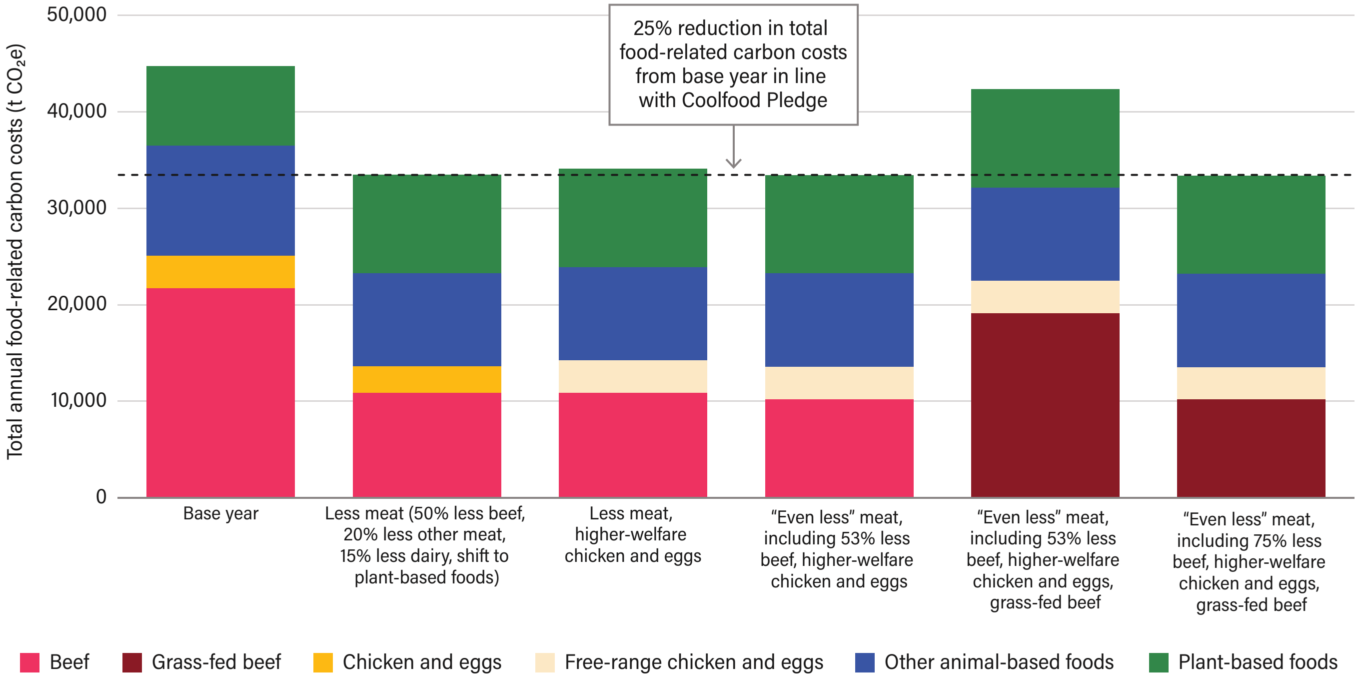
Sources: For environmental impacts, authors' analysis based on paired data points from Poore and Nemecek (2018), supplemented by WRI literature review. For animal welfare characteristics, authors' analysis based on European Commission (2023); *Consumer Reports* (2023); and Fanatico and Born (2011).

TABLE 8 | Descriptions of “less meat” and “better meat” scenarios

SCENARIO	DESCRIPTION
Base year	Average consumption pattern in the United States and Canada from FAO (2023)
Less meat	50% less beef, 20% less other meat, 15% less dairy, replaced with roughly equal increases of soy, pulses, vegetables
Less meat, higher-welfare chicken and eggs	Same as above, but free-range chicken and eggs emit 15% more greenhouse gases (GHGs) and require 25% more land
“Even less” meat, higher-welfare chicken and eggs	Same as above, but 53% less beef
“Even less” meat, higher-welfare chicken and eggs, grass-fed beef	Same as above, but grass-fed beef leads to 25% higher GHG emissions and 100% higher land use
“Even less” meat including 75% less beef, higher-welfare chicken and eggs, grass-fed beef	Same as above, but 75% less beef

Source: Authors.

FIGURE 6 | Illustrative effects of “less meat” and “better meat” scenarios on a company’s food-related GHG emissions



Notes: t CO_2e = tons of carbon dioxide equivalent. Calculations assume a company serving roughly 6 million meals per year in the average consumption pattern for the U.S. and Canada for 2015 as given in FAO (2023). “Total annual food-related carbon costs” given as sum of scope 3 agricultural supply chain emissions and carbon opportunity costs.

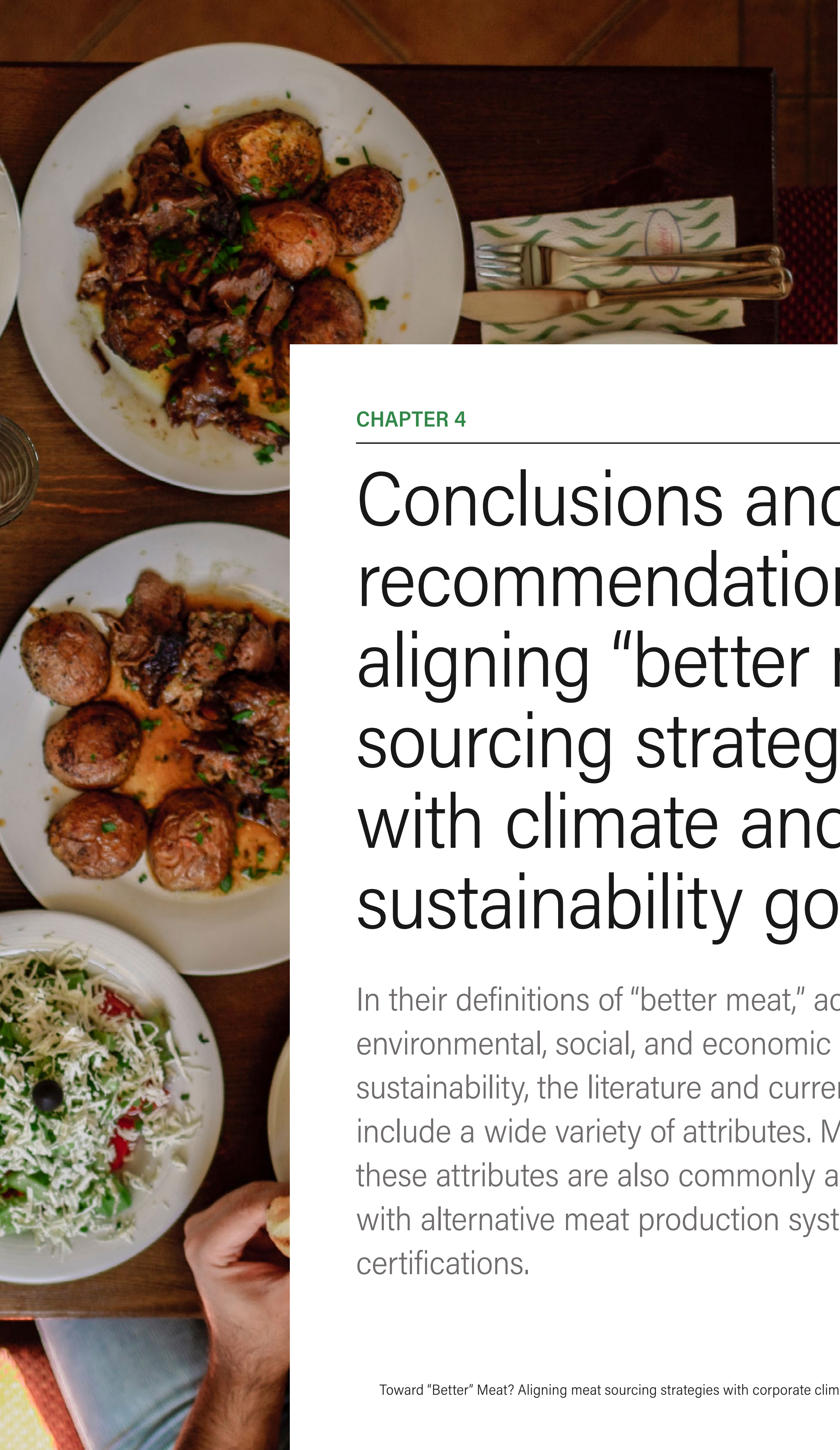
Sources: Author calculations using Coolfood calculator (Waite et al. 2019); emission factors from Poore and Nemecek (2018) (agricultural supply chain) and Searchinger et al. (2018) (carbon opportunity costs).

Several takeaways follow from this analysis linking animal welfare with environmental impacts:

- *The impacts of animal welfare improvements on environmental performance are mixed, and there are trade-offs.* Production systems that result in animal welfare improvements do not always have a positive impact on environmental performance; often they increase the environmental impact of the system. Many systems that improve animal welfare also require a larger land footprint (e.g., for grass-fed, pasture-raised, or free-range animals), resulting in higher land use, which can increase pressure on natural ecosystems. In addition, slow-growth or grass-fed animals have a slower growth rate, resulting in higher resource use over their lifetime, and—for ruminant animals like cows—more time spent emitting methane.
- *Reducing beef and lamb purchasing opens up climate "space" for sourcing from higher-welfare systems.* Since beef and lamb are the most GHG-intensive animal products, reducing the purchase of them has an outsized impact in reducing a company's food-related emissions. These significant reductions create more climate "space" for companies to then turn their attention to sourcing from higher-welfare systems for lower-emitting animal proteins (e.g., eggs, chicken, pork). The higher emissions of these animal welfare systems are then more than offset by the significant GHG emissions reductions from the reduced purchase of beef and lamb, as shown in Figure 6. This strategy potentially enables a company to both reduce its emissions and improve its performance on animal welfare. This strategy is also relevant if a company wishes to switch to other alternative systems (e.g., organic) to appeal to consumers.
- *If purchasing "better meat" causes higher resource use or environmental impacts per kg of protein, "less meat" must become "even less meat."* As noted in Table 2 and Figures 2a–2d, food companies with climate and nature targets can shift the mix of what they purchase and serve away from animal-based foods ("less meat") and toward

plant-based foods and alternative proteins to broadly reduce environmental impacts (Ranganathan et al. 2016). If "better meat" strategies lead to higher environmental impacts from the remaining meat in their supply chains, this counteracts the environmental gains under the "less meat" strategy. In such cases, to hit environmental targets, companies would need to reduce the amount of animal-based foods by even more than under a pure "less meat" strategy. In other words, "less meat" would need to become "even less meat." Table 8 and Figure 6 show a few examples of how a company might balance "less meat" and "better meat" while meeting a GHG emissions target.

- *A shift toward plant-based foods and (in most cases) alternative proteins is a multiple win for climate, nature, and animal welfare.* Shifts between or within animal products often lead to trade-offs. Beyond the basic trade-off in a shift from beef to chicken (lower emissions and other environmental impacts, yet higher number of animals slaughtered and greater animal suffering), the data also indicate that improvements in animal welfare within an animal product (e.g., slow-growth chicken) tend to lead to higher climate and other environmental impacts, although not in all cases. However, these trade-offs can be reduced or avoided with shifts toward plant-based foods. The carbon footprints of plant proteins are lower than those of all animal products examined here, the other environmental impacts of plant proteins are almost always lower than animal proteins, and plant-based foods mostly avoid adverse impacts on animal welfare.[7] This allows companies to both lower their climate and nature impacts, and avoid making difficult decisions on animal welfare that consumers may oppose or that may run contrary to corporate goals.



CHAPTER 4

Conclusions and recommendations for aligning “better meat” sourcing strategies with climate and sustainability goals

In their definitions of “better meat,” across the environmental, social, and economic pillars of sustainability, the literature and current practices include a wide variety of attributes. Many of these attributes are also commonly associated with alternative meat production systems and certifications.

The trade-offs noted in our analysis can make it seem challenging for food companies to design a strategy that sources "better meat" while contributing to climate and nature goals. Our analysis indicates that many alternative systems have higher GHG emissions per kg of protein produced, and that most require more land per kg of protein, a concern in a world that needs to end deforestation.

A number of promising strategies exist to reduce GHG emissions and other environmental impacts from meat production. Our analysis also shows that it is possible for companies to source higher-welfare meat products while meeting climate and other sustainability goals.

Figure 7 shows six steps that can help companies adjust their meat sourcing strategy in a way that maximizes co-benefits for climate, nature, and animal welfare, and minimizes trade-offs:

1. *Calculate the scope 3 GHG emissions baseline of food purchases, including meat.* Establishing a scope 3 GHG emissions baseline for food purchases will allow companies to understand how much of an impact meat has on their food-related carbon footprint and enable them to pinpoint emission hot spots. Companies that work with Coolfood already use our calculator (available at www.coolfood.org) to track the emissions associated with their meat (and other food) purchases each year.
2. *Shift from high-emissions products like beef and lamb toward lower-emissions products like plant-based foods and alternative proteins.* Coolfood members are already pursuing this strategy, which has allowed early adopters of the Coolfood Pledge to reduce their emissions per plate by 10 percent through 2022—with some sectors reducing per-plate emissions by up to 24 percent—(Cho and Waite 2023), and they should continue to do so. WRI's *Playbook for Guiding Diners toward Plant-Rich Dishes in Food Service* includes a number of options for the food service sector, including modifying popular meals to make them more plant-rich and offering a wider variety of plant-based dishes, modifying menus and displays to make plant-rich meals more prominent, using more appealing language to describe plant-rich dishes and marketing them more creatively, and training chefs on how to cook plant-rich dishes (Attwood et al. 2020).
3. *Define priorities around improved meat sourcing by product type.* Companies could use Figure 1 and Table 1 to think through each of the "better meat" attributes by product type. For example, around beef, the goal might be to reduce climate and land impacts—both through sourcing less of it, and through encouraging lower-emissions production methods. For chicken and eggs, the goal might be to improve animal welfare. By pursuing these strategies in tandem, a company's overall performance could improve in the areas of climate, land use, and animal welfare simultaneously. Given the many possible definitions of "better meat," companies should also communicate clearly about their sourcing plans and progress.
4. *Assess the potential impacts of sourcing changes on climate and other "better meat" priority goals.* The analysis should include both co-benefits and trade-offs. It could be quantitative (e.g., through analysis of potential scenarios' effects on indicators, as in Figure 6, or scoring that relates to current or envisioned sustainability/marketing goals) and/or qualitative (e.g., "likely direction of travel") in nature.
5. *If a "better meat" sourcing strategy increases environmental impacts, shift to sourcing "even less meat."* If a company's analysis suggests that shifting sourcing to "better meat" will lead to higher environmental impacts from their supply chains, as in Figure 6, they should move beyond a "less meat" strategy to an "even less meat" strategy to

> We recommend six steps that can help companies adjust their meat sourcing strategy in a way that maximizes co-benefits for climate, nature, and animal welfare, and minimizes trade-offs.

stay on track for their environmental targets. And as companies look to shift their meat sourcing strategies, alternative proteins present new options to fill the gap, enabling companies to offer more varied meat alternatives (Box 5).

6. *Engage with suppliers to improve their production practices and develop more transparent emissions quantification and ways to verify other "better meat" attributes.* This step entails the most work, and it could unfold over many years. For example, companies can define standards and scoring systems for their suppliers, buy certified products connected to attributes of interest, encourage suppliers to make voluntary commitments, and invest in on-farm projects.

We hope to work more closely with food companies and their suppliers in the future to improve the availability and quality of emissions data—and other data associated with "better meat" attributes—along food supply chains. Guidance could include how to choose metrics to account for the various attributes of "better" meat, considerations around data quality and supply chain traceability, and strategies for supplier and producer engagement. Guidance could also help companies navigate the various certifications

FIGURE 7 | Six steps that companies can take to design a meat sourcing strategy

1. Calculate the scope 3 GHG emissions baseline of food purchases.

2. Shift from high-emissions products toward lower-emissions products.

3. Define priorities around improved meat sourcing by product type.

4. Assess the potential impacts of sourcing changes on climate and other "better meat" priority goals.

5. If a "better meat" sourcing strategy increases environmental impacts, shift to sourcing "even less meat."

6. Engage with suppliers to improve production practices and develop more transparent emissions quantification.

Source: Authors.

and other labeling schemes that can identify products that have somehow "improved" an attribute of interest (high animal welfare, responsible antibiotic use, deforestation-free, lower-than-average emissions, etc.).

Further work is necessary to gather publicly available data on other environmental, social, and economic attributes of "better meat," such as for soil health, on-farm biodiversity, and agricultural livelihoods. Similarly, better data are needed on alternative fish and seafood production systems and practices, where data are even scarcer than with terrestrial animal agriculture.

Our analysis shows that companies with sustainability goals need to consider both co-benefits and trade-offs across all goals when designing meat sourcing strategies, and that balancing these goals is possible. Finally, this analysis confirms the critical importance of shifting diets high in animal-based foods toward plant-based foods to improve both environmental and animal welfare outcomes.

BOX 5 | The potential role of alternative proteins in sustainable diets

Alternative proteins encompass a wide range of products that are specifically designed to mimic the flavor and texture of conventional meat and dairy products, while producing fewer environmental and animal welfare harms. They fall into four broad categories:

- *Plant-based proteins.* The most common in terms of current sales volume, these products are made from soy protein, pea protein, wheat gluten, or other plant-based sources. Examples include the Impossible Burger and Beyond Meat. This category also includes dairy alternatives such as almond, oat, pea, and soy milks.
- *Fermentation-enabled proteins.* These include products in which microorganisms such as fungi and microalgae are used to convert glucose into protein (e.g., mycoprotein) via a biomass fermentation process. The microbial biomass is typically consumed, such as in products from the companies Quorn and Meati. This category also includes foods containing functional ingredients (e.g., egg proteins, enzymes) produced by microorganisms through a precision fermentation process. The ingredients that are created are typically used to improve the flavor and texture of other foods, such as dairy products containing animal-free whey protein produced by Perfect Day.
- *Cultivated meat.* This novel technology produces meat from animal cells and is also known as "cell-based," "cultured," or "lab-grown" meat. Animal cells are grown in a bioreactor in a growth medium, producing actual animal meat. Examples include Eat Just's chicken nuggets currently available for sale in Singapore, and cultivated chicken from Upside Foods and Good Meat for sale in the United States (Lucas 2023).
- *Blends/hybrids.* These products combine conventional animal proteins with one of the alternatives listed above. For example, Perdue's Chicken Plus 50/50 blend combines chicken and Better Meat Co. mycoprotein.

Because the production of alternative proteins generally results in fewer GHG emissions than conventional animal proteins, there is a significant opportunity for emissions reduction—and other improvements across other environmental and ethical indicators—if diets shift toward them. Plant-based and fermentation-enabled meat substitutes were found to emit 43–93 percent fewer greenhouse gases than their conventional terrestrial meat counterparts per 100 grams of protein, along with using 76–89 percent less water, and requiring 77–98 percent less land (Santo et al. 2020). Furthermore, an ex-ante life cycle assessment conducted for cultivated meat, projected to 2030 with three different scenarios for scaling technology, found that cultivated meat products would also have a lower GHG footprint than beef in most cases, while the relative impacts compared to chicken and pork depend on the extent of renewable energy used (Sinke et al. 2023). There are numerous other environmental and public health challenges that alternative proteins could help address compared to conventional animal proteins, including water pollution, pesticide use, biodiversity loss, antimicrobial resistance, and pandemic risk (McNamara and Bomkamp 2022; Rzymski et al. 2021; Santo et al. 2020).

Consumption of alternative proteins is still low; in 2020, 13 million tons of alternative proteins were consumed globally, accounting for just 2 percent of the animal protein market (Morach et al. 2021). One recent estimate, however, projected that this share may increase to 10 percent or more by 2035 (Morach et al. 2021). In order to grow their market share, alternative proteins need to overcome three barriers: taste and texture, cost parity, and consumer acceptance. Once alternative proteins offer consumers the same taste and texture experience as animal proteins, and cost the same or less, consumers will not have to "sacrifice" while choosing more sustainable options. Consumer acceptance may also be increased through interventions to increase familiarity with alternative proteins and to influence social norms and encourage positive feelings about them (Onwezen et al. 2021). The ability of alternative proteins to overcome these barriers will also depend on levels of investment and technological advances in the coming years.

Appendices

APPENDIX A. STAKEHOLDER INTERVIEWS

The literature shows that "better meat" can mean many different things in different contexts. Companies that source and produce meat are ultimately responsible for setting priorities and pursuing strategies to improve the sustainability of their supply chains. To gain a deeper understanding of stakeholder perspectives, we interviewed 17 stakeholders from North America and Europe between January and May 2022, including a range of food companies and civil society organizations, to understand what "better meat" means to them. We interviewed five food service providers, two retailers, four food manufacturers, and six nonprofit and academic organizations.

The interview structure varied slightly based on the role of each interviewee, but in general, the conversations focused on the following three questions:

1. What does "better meat" mean to you?
2. What priorities or goals does your company (or organization) have in place around more responsibly or sustainably produced meat?
3. What obstacles do you face in improving meat sourcing or production?

APPENDIX B. UPDATED LITERATURE REVIEW

The goal of our literature review was to expand upon our environmental analysis that used the life cycle assessments found in Poore and Nemecek (2018) to incorporate the latest published studies. These were comparative life cycle assessments, performed in North America or Europe, looking at conventional and alternative production systems for beef, lamb, pork, poultry, dairy, eggs, and fish. By updating the search through to the publication year 2022, we sought to find more recent studies that differentiate between the environmental impacts of different animal production systems.

We then narrowed our search in scope to focus on beef, lamb, and dairy because these were generally the animal-based products with the highest aggregate environmental impacts (Cho and Waite 2023) and large variation in impacts across studies (Figures 2a–2d). We conducted a literature review through EBSCOhost using the following terms: "life cycle assessment OR life cycle analysis OR greenhouse gas emissions" AND "product name," for "beef," "dairy," and "lamb AND sheep AND mutton." We then narrowed down the articles using the inclusion criteria, outlined in Table B1. Our search returned an initial n=8,610 potentially relevant articles, which we then narrowed down manually to a final n=15, as detailed in Tables B2 and B3. These 15 additional studies complement the 30 studies retained from Poore and Nemecek (2018), for a total set of 45 unique studies used in this report.

In order to make appropriate comparisons between studies we calculated all studies to the same system boundary of cradle to gate, ensuring that we were looking at the full life cycle for each study. In two cases (Stanley et al. 2018; Klopatek et al. 2022), this required an additional calculation to make a study equivalent to a full life cycle. For the studies that only looked at a part of the life cycle, we used average country-level life cycle data from Rotz et al. (2019) to add in the missing stages in order to approximate a full cradle-to-gate life cycle that could be compared to other full life cycle assessments.

In addition, some more recent studies (e.g., Buratti et al. 2017; Eldesouky et al. 2018) included measurements of not only GHG emissions but also carbon removals from agricultural soil carbon sequestration. In these cases, to make all studies comparable, and given uncertainty around carbon removals accounting (Box 4), we separated out the emissions from the removals. Finally, several studies included enough data to allow us to estimate the land use of the various systems. These adjustments are noted in Table B3.

TABLE B1 | Study inclusion criteria

Published between 2000 and 2022
Life cycle assessment, or similar methodology
Comparative study, looking at two or more production methods, where one is "conventional"
Study location in Europe or North America
Based on real farm data, not simulated
Available in print or online, peer-reviewed, full text
In English

Source: Authors.

TABLE B2 | Total articles found

ANIMAL-BASED FOOD	TOTAL POTENTIALLY RELEVANT ARTICLES	ARTICLES DOWNLOADED FOR FURTHER READING BASED ON ABSTRACT	ARTICLES WITH OBSERVATIONS ADDED TO ANALYSIS
Beef	2,660	63	6
Lamb	88	8	3
Dairy	5,849	66	6
Total	**8,610**	**137**	**15**

Source: Authors.

TABLE B3 | Articles with paired conventional-alternative systems analyzed in this report

AUTHORS	YEAR	LOCATION	PRODUCT	SYSTEMS COMPARED	ADJUSTMENTS MADE FOR THIS REPORT
Alig et al.	2012	Switzerland	Beef	▪ Conventional ▪ Organic	N/A
Alig et al.	2012	Switzerland	Pork	▪ Conventional ▪ Animal welfare ▪ Organic	N/A
Alig et al.	2012	Switzerland	Poultry	▪ Indoor ▪ Outdoor access ▪ Organic	N/A
Arsenault et al.	2009	Canada	Dairy	▪ Confinement ▪ Pasture-based	N/A
Basset-Mens and van der Werf	2005	France	Pork	▪ Conventional ▪ Red Label [*Label Rouge*] ▪ Organic	N/A
Batalla et al.	2015	Spain	Dairy (sheep milk)	▪ Semi-intensive, foreign breed ▪ Semi-intensive, local breed ▪ Semi-extensive, local breed	None
Bragaglio et al.	2018	Italy	Beef	▪ Intensive (confinement systems, high grain fattening) ▪ Extensive (native breeds, specialized breeds)	Unit for water pollution (eutrophication potential) is g NO_3-e; % changes between production systems assumed to be same as our eutrophication potential unit.
Buratti et al.	2017	Italy	Beef	▪ Conventional ▪ Organic	Carbon removals separated from GHG emissions.
Bystricky et al.	2014	Switzerland	Dairy	▪ Concentrate-based feed ▪ Grass-based feed ▪ Pasture-based feed	N/A
Capper	2012	United States	Beef	▪ Conventional ▪ Natural system, without hormones ▪ Grass-finished	N/A
Casey and Holden; Blonk et al.	2006; 2008	Ireland	Beef	▪ Conventional, suckler ▪ Pasture-based/extensive ▪ Organic	N/A
Cederberg and Flysjö	2004	Sweden	Dairy	▪ Conventional ▪ Extensive ▪ Organic	N/A
Cederberg and Mattsson	2000	Sweden	Dairy	▪ Conventional ▪ Organic	N/A
Cederberg et al.	2007	Sweden	Dairy	▪ Conventional ▪ Organic	N/A

TABLE B3 | Articles with paired conventional-alternative systems analyzed in this report (cont.)

AUTHORS	YEAR	LOCATION	PRODUCT	SYSTEMS COMPARED	ADJUSTMENTS MADE FOR THIS REPORT
Dakpo et al.	2013	France	Lamb	▪ Conventional ▪ Organic	N/A
Dekker et al.	2011	Netherlands	Eggs	▪ Battery cage ▪ Barn (single-tiered) ▪ Barn (multitiered) ▪ Free-range, single-tiered ▪ Free-range, multitiered ▪ Organic, single-tiered ▪ Organic, multitiered	N/A
Eldesouky et al.	2018	Spain	Beef	▪ Extensive cattle, feedlot-finished ▪ Extensive cattle, grass-finished	Carbon removals separated from GHG emissions.
Frank et al.	2019	Germany	Dairy	▪ Conventional ▪ Organic	Carbon removals separated from GHG emissions.
Gess et al.	2020	Italy	Lamb	▪ Semi-intensive ▪ Semi-extensive	None
Gross et al.	2022	Germany	Dairy	▪ Conventional ▪ One year into organic conversion	Land use derived by authors.
Guerci et al.	2013	Denmark Germany	Dairy	▪ Average conventional (Denmark) ▪ Confinement (Germany) ▪ Organic (Denmark) ▪ Summer grazing (Germany)	N/A
Halberg et al.	2010	Denmark	Pork	▪ Tent system ▪ Free-range sows, indoor fattening ▪ Free-range	N/A
Hörtenhuber et al.	2010	Austria	Dairy	▪ Alpine, conventional ▪ Upland, conventional ▪ Lowland, conventional ▪ Alpine, organic ▪ Upland, organic ▪ Lowland, organic	N/A
Jakobsen et al.	2015	Denmark	Pork	▪ Indoor finishing ▪ Free-range, grass clover ▪ Free-range, alternative crops	N/A
Klopatek et al.	2022	United States	Beef	▪ Conventional, feedlot-finished ▪ Grassfed for 20 months ▪ Grassfed for 20 months, dry grain-finished ▪ Grassfed for 25 months	Study for backgrounding and finishing phases only, cow-calf phase added using data for U.S. Southwest from Rotz et al. (2019), Table S8.
Koch and Salou	2015	France	Poultry	▪ Conventional ▪ Red Label ▪ Organic	N/A

TABLE B3 | Articles with paired conventional-alternative systems analyzed in this report (cont.)

AUTHORS	YEAR	LOCATION	PRODUCT	SYSTEMS COMPARED	ADJUSTMENTS MADE FOR THIS REPORT
Koch and Salou	2015	France	Eggs	▪ Indoor system, cage ▪ Indoor system, noncage ▪ Outdoor system ▪ Organic	N/A
Kool et al.	2009	Denmark Germany Netherlands United Kingdom	Pork	▪ Conventional (Denmark) ▪ Conventional (Germany) ▪ Conventional, indoor (Netherlands) ▪ Indoor (UK) ▪ Organic (Denmark) ▪ Organic (Germany) ▪ Organic, part outdoor (Netherlands) ▪ Organic (UK)	N/A
Kristensen et al.	2011	Denmark	Dairy	▪ Conventional ▪ Organic	N/A
Laca et al.	2020	Spain	Dairy	▪ Semi-confinement ▪ Pasture-based	Land use derived by authors.
Leinonen et al.	2012a	United Kingdom	Poultry	▪ Conventional ▪ Free-range ▪ Organic	N/A
Leinonen et al.	2012b	United Kingdom	Poultry	▪ Cage ▪ Barn ▪ Free-range ▪ Organic	N/A
Mogensen et al.	2015	Denmark	Beef	▪ Intensive ▪ Extensive	N/A
Mollenhorst et al.	2006	Netherlands	Eggs	▪ Battery cage ▪ Barn, deep litter ▪ Deep litter, outdoor access ▪ Aviary with outdoor run	N/A
O'Brien et al.	2012	Ireland	Dairy	▪ Intensive confinement ▪ Extensive	N/A
O'Brien et al.	2014	Ireland	Dairy	▪ High-performance confinement ▪ Grass-based	N/A
Pelletier et al.	2010	United States	Beef	▪ Conventional, weaned directly to feedlot ▪ Backgrounded on pasture, finished in feedlot ▪ Pasture- and hay-finished	N/A
Perez	2009	United Kingdom	Pork	▪ Indoor ▪ Organic, outdoor	N/A

TABLE B3 | Articles with paired conventional-alternative systems analyzed in this report (cont.)

AUTHORS	YEAR	LOCATION	PRODUCT	SYSTEMS COMPARED	ADJUSTMENTS MADE FOR THIS REPORT
Pirlo and Lolli	2019	Italy	Dairy	▪ Conventional ▪ Organic	Land use derived by authors.
Presumido et al.	2018	Portugal	Beef	▪ Semi-intensive, grain-finished ▪ Extensive organic, pasture-based, grass-finished	Unit for water pollution (eutrophication potential) is g PO_4-e; % changes between production systems assumed to be same as our eutrophication potential unit.
Prudêncio de Silva et al.	2014	France	Poultry	▪ Conventional ▪ Red Label	N/A
Ripoll-Bosch et al.	2013	Spain	Lamb	▪ Zero-grazing, industrial indoors ▪ Pasture-based ▪ Mixed cereal, daily grazing	None
Salvador et al.	2016	Italy	Dairy	▪ Conventional ▪ Organic	Land use derived by authors.
Stanley et al.	2018	United States	Beef	▪ Feedlot-finished ▪ Adaptive multipaddock grazing—finished / regenerative	Study for finishing phase only, prefinishing phases (cow-calf, backgrounding) added using data for U.S. Midwest from Rotz et al. (2019), Table S8. Carbon removals separated from GHG emissions.
Thomassen et al.	2008	Netherlands	Dairy	▪ Conventional ▪ Organic	N/A
van der Werf et al.	2009	France	Dairy	▪ Conventional ▪ Organic	N/A
Veysset et al.	2011	France	Beef	▪ Conventional, beef steers production ▪ Conventional, intensive baby beef production ▪ Organic, beef steers production ▪ Organic, intensive baby beef production	N/A
Williams et al.	2006	United Kingdom	Lamb	▪ Conventional ▪ Organic	None
Williams et al.	2006	United Kingdom	Pork	▪ Indoor breeding ▪ Organic	N/A

Notes: GHG = greenhouse gas; g NO_3-e = grams of nitrate equivalent; g PO_4-e = grams of phosphate equivalent. "N/A" in rightmost column indicates that the study was included in Poore and Nemecek (2018). All other entries were added by the authors during analysis conducted for this report.

Source: Authors.

GLOSSARY

“Better meat” attributes

ATTRIBUTE	DESCRIPTION
Environmental	
Climate (reduced GHG emissions)	Reduced emissions from agricultural supply chains (e.g., on-farm, feed production, post-farmgate emissions like transport and processing).
Land use and land-use change (and land-related GHG emissions)	Reduced net emissions from land use and land-use change (e.g., reduced deforestation, soil carbon sequestration); reduction in land occupied by agriculture; improvement in land management.
Water use	Includes all irrigation water used on the farm for livestock and production of feed. In this report, it does not include rainwater. Water use can vary by production system and environment.
Water quality and pollution	Indicators include eutrophication and acidification, and water pollution takes into account the impacts of runoff from farms that can impact nearby open water sources. Groundwater sources can also be impacted by farm operations.
Biodiversity	Accounts for diversity of both flora and fauna in a given location. This can be measured by the number of different species growing in a field, or the number of different animals that are observed in an area.
Soil health	Can be measured by a variety of indicators, including levels of soil carbon and other nutrients, in addition to erosion and topsoil measurements. Improvements to soil health can include carbon sequestration, improved nutrient content, and restored topsoil.
Social	
Animal welfare	Considers animals’ quality of life and includes metrics such as access to the outdoors, use of growth hormones or antibiotics, and the types of enclosures livestock are kept in. See below for additional terms related to animal welfare.
Local sourcing	Food produced in the same area as where it is sold as the final product. Some definitions are more specific (e.g., produced within a certain distance from the final destination, or produced within the same jurisdiction).
Antimicrobial resistance	A condition that “occurs when bacteria, viruses, fungi and parasites change over time and no longer respond to medicines making infections harder to treat and increasing the risk of disease spread, severe illness and death” (WHO 2021).
Nutrition and public health	Takes into account the nutrient availability of animal products, and considers their implications for public health, along with other links between food production and public health (e.g., antibiotic resistance).
Farmer and farmworker livelihoods	Farmer and farmworker livelihoods often depend on the price of the products they sell. They also depend on whether a living wage is offered. Farmworkers, in particular, can be vulnerable to exploitation and poor working conditions.
Equity and social justice	Equity refers to fairness, impartiality, and justice. In the context of food production and consumption, and effects on people across supply chains, it is equivalent to food justice: “universal access to nutritious, affordable, and culturally appropriate food for all, while advocating for the well-being and safety of those involved in the food production process” (Boston University 2023).
Economic and financial	
Perceived quality	How a consumer perceives the quality of the meat; includes flavor and food safety among other factors.
Cost, profitability, and consumer affordability	Three linked economic concerns: how much a given product costs a company to purchase, how much profit a company makes from selling a given product, and consumers’ ability to afford a given product (i.e., the price paid by the consumer for the product, relative to the consumer’s income).

Production systems

SYSTEM TYPE	DESCRIPTION
Adaptive multipaddock grazing	A system of grazing for livestock that depends on rotation through multiple enclosures (paddocks) to ensure that the land is not overly degraded by grazing.
Barn	An egg production system with loose (i.e., not caged) housing without outdoor access.
Conventional	A general term that describes the dominant methods or systems of terrestrial animal agriculture in North America and Europe. Relative to the other "alternative" systems in this table, "conventional" could refer to systems such as feedlot-finished beef, dairy cows raised in confinement systems, intensive indoor poultry systems, egg production systems where chickens are raised in cages, and use of nonorganic feeds.
Extensive	A production system that uses small inputs relative to the amount of land being farmed.
Free-range	A production system that allows livestock to roam around.
Grass-finished	A finishing system, primarily for beef, where the animals are raised on grass for their final period of growth.
Mixed cereal and grazing	A production system that provides grazing and a variety of cereal crops for animal feed.
Organic	A specific type of production system that adheres to organic guidelines as laid out by the authoritative body, and is certified organic by the authority (e.g., U.S. Department of Agriculture).
Outdoor	Animals have access to the outdoors as part of their confinement.
Pasture-based	A production system that is based on pasture grazing for the bulk of the animal's feed.
"Red Label"	Also known as *Label Rouge*, this is a sign of quality assurance in France. For poultry and eggs, the label focuses on promoting animal welfare and has specific requirements for certification.
Regenerative	A system that is focused on soil health and conservation with practices like no-till and adaptive multipaddock grazing.

Animal welfare categories

ANIMAL WELFARE CATEGORY	DESCRIPTION
Antibiotic-free	Animals are raised without the use of antibiotics.
Growth-hormone-free	Animals are raised without the use of growth hormones, which are often used to promote speedier growth, leading to animals growing faster than they should and resulting in complications.
Breeding for slow growth	Animals are bred for slower growth at more natural rates, as opposed to being bred for speedier growth, which can cause complications.
Outdoor access	Animals have access to the outdoors as part of their confinement.
Cage-free and/or reduced confinement	Animals (e.g., egg-laying hens, veal calves, breeding pigs) are raised without the use of cages, giving them greater free rein and space. The animals' living conditions may also adhere to a minimum standard for how they are confined (e.g., minimum floor space, freedom of movement).

Notes: GHG = greenhouse gas. The above animal welfare category terms were selected for the purpose of brevity but do not substitute for labels with official claims.

ENDNOTES

1. Following the convention of the world regions in Poore and Nemecek (2018)'s global analysis, whose LCA data are heavily used in this report, "North America" refers to the United States and Canada, and "Europe" refers to the European Union, Norway, Switzerland, and the United Kingdom.

2. Because more than 90 percent of the meat and dairy products produced in North America and Europe are also consumed in these regions (FAO 2023), it is valid to assume that data from production systems in these regions are relevant to consumption of these products. We also weighted all indicator values for beef by the size of the beef herd and dairy herd in each region using data from Poore and Nemecek (2018) (North America: 76 percent beef herd and 24 percent dairy herd; Europe: 21 percent beef herd and 79 percent dairy herd). A weighted average approach makes sense because purchasers usually do not know if they are sourcing beef from a beef herd or from a dairy herd. Also of note: we use the word "lamb" throughout this report as a shorthand to refer to all types of sheep meat.

3. There is no one perfect way to compare the relative impacts of different foods. The numerator, which measures environmental impacts in these calculations, can be measured using different metrics. For example, for greenhouse gas emissions, this report uses global warming potentials over a 100-year timescale, which aligns with the draft "Greenhouse Gas Protocol Land Sector and Removals Guidance" (WRI and WBCSD 2022) and the Coolfood Pledge (Waite et al. 2019). However, other timescales can be used to measure global warming potential, such as a 20-year timescale, in which shorter-lived greenhouse gases like methane have even greater impacts on temperature rise relative to carbon dioxide. For example, the IPCC's Sixth Assessment Report estimates the 100-year global warming potential of methane at 27–30 times greater than carbon dioxide, while methane's 20-year global warming potential is 81–83 times greater than carbon dioxide (EPA 2023). If we used the 20-year warming potential, the GHG emissions estimates in Table 2 and Figure 2a for lamb, beef, and dairy would be significantly higher. Similarly, different denominators can be used to compare foods' impacts. Three often-used denominators are "per kg of food," "per kilocalorie of food," and "per kg of protein in food," since all of these are available to calculate via conversion factors in FAO (2023). "Per kg of food" is often used because this is the "functional unit" often used in LCAs and is also the unit in which food is often sold and purchased. However, "per kg" can be misleading because foods with high water content, such as cow's milk, appear resource-efficient just because a high amount of water (with no nutritional value) is in the denominator. "Per kilocalorie of food" deals with the water content issue and is a better indicator of food energy delivered per amount of resources used, but this also makes certain energy-dense but unhealthy foods like sugars appear the most beneficial. "Per kg of protein in food" is used here because this report is focused on terrestrial animal-based foods, which are foods highly valued for their protein content. One additional consideration for the use of "per kg of protein in food" comparisons is that animal-based proteins are more bioavailable than plant-based proteins. Comparing the environmental impacts of foods per unit of digestible lysine, the most common first-limiting amino acid in human diets, has been proposed as a more nutritionally sound alternative (Moughan 2021). That said, even when factoring in how lysine digestibility is lower for pulses (87 percent) and soy (83 percent) than meats and dairy (97 percent), the plant-based foods in Table 2 and Figure 2a remain less GHG emissions-intensive than all of the animal-based foods per unit of digestible lysine. Finally, there are more complex nutrient quality indices that could be used as denominators (FAO 2021; Katz-Rosene et al. 2023), but, since no consensus exists about which one is "best," we have used the simpler denominator of protein. In sum, use of any of these alternative numerators and denominators would not change the main findings and recommendations of this report.

4. For GHG emissions, we removed land-use-change emissions from the estimates in Poore and Nemecek (2018), so as not to double-count with the "carbon opportunity costs" of agricultural land use.

5. We used the values from Poore and Nemecek's (2018) database, available at https://ora.ox.ac.uk/objects/uuid:a63fb28c-98f8-4313-add6-e9eca99320a5, to determine percent changes in indicators between production systems. Poore and Nemecek (2018) made some adjustments to the numbers in the original studies to increase comparability across all studies. Because of this, the percent changes quoted in our report do not always exactly match the percent changes in the original studies. In our own literature review, we also made several adjustments to the studies we found for comparability's sake, and these adjustments are described in Appendix B, Table B3.

6. In this report, we use the term "conventional" to describe the dominant methods or systems of terrestrial animal agriculture in North America and Europe. Relative to the other "alternative" systems in Table 3, "conventional" could refer to systems such as feedlot-finished beef, dairy cows raised in confinement systems, intensive indoor poultry systems, egg production systems where chickens are raised in cages, and use of nonorganic feeds. See the Appendix B, Table B3, for more details on the various "conventional" systems assessed in the included LCA studies.

7. In some situations, production of plant-based foods can indirectly have adverse impacts on animal welfare, such as when soy is produced in recently deforested areas that have displaced animal habitat. However, even in these cases, if increased consumption of soy products by people leads to a reduction in meat consumption, overall agricultural land demand will be reduced, which reduces pressure globally to convert natural ecosystems (and habitats) to agriculture.

8. Stanley et al. (2018) note that both feedlot-finishing and grass-finishing beef production systems follow similar management in the earlier stages of beef production, namely the cow-calf and backgrounding stages. To make this "paired study"—which only focused on the finishing stage of beef production—comparable to other studies on our list, we added GHG emissions from the cow-calf stage (18.4 kg CO_2e per kg beef produced) and backgrounding stage (2.2 kg CO_2e per kg beef) for the U.S. Midwest from Rotz et al. (2019), Table S8. This adjustment raises the emissions of the grass-finishing system from 9.62 kg CO_2e per kg beef, as reported in Stanley et al. (2018) for the finishing stage, to 30.22 kg CO_2e per kg beef for the full life cycle. It thus suggests that neither of the beef production systems in Stanley et al. (2018) were "carbon-negative" when accounting for the full life cycle; instead, the high level of soil carbon sequestration in the finishing stage (which led to removals of –16.27 kg CO_2e per kg beef) appear to offset 54 percent of the emissions of 30.22 kg CO_2e per kg beef in the full life cycle.

REFERENCES

Alig, M., F. Grandl, J. Mieleitner, T. Nemecek, and G. Gaillard. 2012. *Life Cycle Assessment of Beef, Pork and Poultry*. Report. Zurich: Agroscope ART. https://ira.agroscope.ch/en-US/publication/30130.

Arsenault, N., P. Tyedmers, and A. Fredeen. 2009. "Comparing the Environmental Impacts of Pasture-Based and Confinement-Based Dairy Systems in Nova Scotia (Canada) Using Life Cycle Assessment." *International Journal of Agricultural Sustainability* 7 (1): 19–41.

Attwood, S., P. Voorheis, C. Mercer, K. Davies, and D. Vennard. 2020. *Playbook for Guiding Diners toward Plant-Rich Dishes in Food Service*. Washington, DC: World Resources Institute.

Axworthy, N. 2021. "EU's Historic Ban: Factory Farm Cages to Be Phased Out for 300 Million Animals by 2027." *VegNews*, July 9. https://vegnews.com/2021/7/eu-ban-factory-farm-cages.

Basset-Mens, C., and H.M. van der Werf. 2005. "Scenario-Based Environmental Assessment of Farming Systems: The Case of Pig Production in France." *Agriculture, Ecosystems & Environment* 105 (1): 127–44.

Batalla, I., M.T. Knudsen, L. Mogensen, Ó. del Hierro, M. Pinto, and J.E. Hermansen. 2015. "Carbon Footprint of Milk from Sheep Farming Systems in Northern Spain Including Soil Carbon Sequestration in Grasslands." *Journal of Cleaner Production* 104 (October): 121–29. doi:10.1016/j.jclepro.2015.05.043.

Beal, T., C.D. Gardner, M. Herrero, L.L. Iannotti, L. Merbold, S. Nordhagen, and A. Mottet. 2023. "Friend or Foe? The Role of Animal-Source Foods in Healthy and Environmentally Sustainable Diets." *Journal of Nutrition* 153 (2): 409–25. doi:10.1016/j.tjnut.2022.10.016.

Blonk, H., A. Kool, B. Luske, S. de Waart, and E. ten Pierick. 2008. "Milieueffecten van Nederlandse consumptie van eiwitrijke producten: Gevolgen van vervanging van dierlijke eiwitten anno 2008." https://research.wur.nl/en/publications/milieueffecten-van-nederlandse-consumptie-van-eiwitrijke-producte.

Boston University. 2023. "What Is Food Justice?" https://www.bu.edu/csc/edref-2/what-is-food-justice/. Accessed June 22, 2023.

Bradford, M.A., C.J. Carey, L. Atwood, D. Bossio, E.P. Fenichel, S. Gennet, J. Fargione, et al. 2019. "Soil Carbon Science for Policy and Practice." *Nature Sustainability* 2 (12): 1070–72. doi:10.1038/s41893-019-0431-y.

Bragaglio, A., F. Napolitano, C. Pacelli, G. Pirlo, E. Sabia, F. Serrapica, M. Serrapica, and A. Braghieri. 2018. "Environmental Impacts of Italian Beef Production: A Comparison between Different Systems." *Journal of Cleaner Production* 172 (January): 4033–43.

Buratti, C., F. Fantozzi, M. Barbanera, E. Lascaro, M. Chiorri, and L. Cecchini. 2017. "Carbon Footprint of Conventional and Organic Beef Production Systems: An Italian Case Study." *Science of the Total Environment* 576 (January): 129–37.

Byrne, J. 2023. "Volta Greentech and Protos Launch Next Phase of Climate-Friendly Beef Project in Switzerland." *Feed Navigator*, June 7. https://www.feednavigator.com/Article/2023/06/07/Volta-Greentech-and-Protos-launch-next-phase-of-climate-friendly-beef-project-in-Sweden?mc_cid=def7e68bd3&mc_eid=f3d0a91d99.

Bystricky, M., M. Alig, T. Nemecek, and G. Gaillard. 2014. "Life Cycle Assessment of Selected Swiss Agricultural Products Compared to Imports." Zurich: Agroscope.

Capper, J.L. 2012. "Is the Grass Always Greener? Comparing the Environmental Impact of Conventional, Natural and Grass-Fed Beef Production Systems." *Animals: An Open Access Journal from MDPI* 2 (2): 127–43. doi:10.3390/ani2020127.

Casey, J.W., and N.M. Holden. 2006. "Greenhouse Gas Emissions from Conventional, Agri-environmental Scheme, and Organic Irish Suckler-Beef Units." *Journal of Environmental Quality* 35 (1): 231–39. doi:10.2134/jeq2005.0121.

Casey, J.A., B.F. Kim, J. Larsen, L.B. Price, and K.E. Nachman. 2015. "Industrial Food Animal Production and Community Health." *Current Environmental Health Reports* 2 (3): 259–71. doi:10.1007/s40572-015-0061-0.

CCAC (Climate and Clean Air Coalition) and UNEP (UN Environment Programme). 2021. *Global Methane Assessment*. Full report. https://www.ccacoalition.org/en/resources/global-methane-assessment-full-report.

Cederberg, C., and A. Flysjö. 2004. "Life Cycle Inventory of 23 Dairy Farms in South-western Sweden." Gothenburg: Swedish Institute for Food and Biotechnology.

Cederberg, C., and B. Mattsson. 2000. "Life Cycle Assessment of Milk Production: A Comparison of Conventional and Organic Farming." *Journal of Cleaner Production* 8 (1): 49–60. doi:10.1016/S0959-6526(99)00311-X.

Cederberg, C., A. Flysjö, and L. Ericson. 2007. *Lifecycle Assessment of Milk Production in Northern Sweden*. SIK report no. 761. Gothenburg: Swedish Institute for Food and Biotechnology.

Cho, C., and R. Waite. 2023. "Coolfood Pledge: Collective Member Progress through 2022." https://coolfood.org/news-and-updates/pledgeupdate2022/. Accessed October 16, 2023.

Consumer Reports. 2023. "Consumer Reports Guide to Food Labels." Accessed February 8, 2023. https://www.consumerreports.org/food-labels/seals-and-claims.

Cook-Patton, S.C., S.M. Leavitt, D. Gibbs, N.L. Harris, K. Lister, K.J. Anderson-Teixeira, R.D. Briggs, et al. 2020. "Mapping Carbon Accumulation Potential from Global Natural Forest Regrowth." *Nature* 585 (7826): 545–50. doi:10.1038/s41586-020-2686-x.

Dakpo, H., G. Laignel, M. Roulenc, and M. Benoit. 2013. "L'élevage biologique consomme-t-il moins d'énergie et émet-il moins de gaz à effet de serre que l'élevage conventionnel? Analyse en production ovine allaitante." *Innovations Agronomiques* 32: 95–107.

Dekker, S.E.M., I.J.M. de Boer, I. Vermeij, A.J.A. Aarnink, and P.W.G.G. Koerkamp. 2011. "Ecological and Economic Evaluation of Dutch Egg Production Systems." In "Assessment for Sustainable Development of Animal Production Systems," special issue of *Livestock Science* 139 (1): 109–21. doi:10.1016/j.livsci.2011.03.011.

Eating Better. 2021. "Sourcing Better: A Pathway to Less and Better Meat and Dairy." https://www.eating-better.org/uploads/Documents/Sourcing_Better_Framework.pdf.

Eldesouky, A., F.J. Mesias, A. Elghannam, and M. Escribano. 2018. "Can Extensification Compensate Livestock Greenhouse Gas Emissions? A Study of the Carbon Footprint in Spanish Agroforestry Systems." *Journal of Cleaner Production* 200 (November): 28–38.

EPA (U.S. Environmental Protection Agency). 2023. "Understanding Global Warming Potentials." https://www.epa.gov/ghgemissions/understanding-global-warming-potentials. Accessed November 4, 2023.

Eshel, G., A. Shepon, T. Makov, and R. Milo. 2014. "Land, Irrigation Water, Greenhouse Gas, and Reactive Nitrogen Burdens of Meat, Eggs, and Dairy Production in the United States." *Proceedings of the National Academy of Sciences* 111 (33): 11996–12001. doi:10.1073/pnas.1402183111.

European Commission. 2021. "Food-Based Dietary Guidelines in Europe—Table 9." https://knowledge4policy.ec.europa.eu/health-promotion-knowledge-gateway/food-based-dietary-guidelines-europe-table-9_en.

European Commission. 2023. "Organic Production and Products." January 18. https://agriculture.ec.europa.eu/farming/organic-farming/organic-production-and-products_en.

Fanatico, A., and H. Born. 2011. "Label Rouge: Pasture-Based Poultry Production in France." *Poultry Site*, February 23. https://www.thepoultrysite.com/articles/label-rouge-pasturebased-poultry-production-in-france.

FAO (Food and Agriculture Organization of the United Nations). 2021. "Integration of Environment and Nutrition in Life Cycle Assessment of Food Items: Opportunities and Challenges." https://www.fao.org/3/cb8054en/cb8054en.pdf.

FAO. 2022a. "Global Emissions from Livestock in 2015." GLEAM v3.0. foodandagricultureorganization.shinyapps.io/GLEAMV3_Public/.

FAO. 2022b. *The State of the World's Land and Water Resources for Food and Agriculture: Systems at Breaking Point*. Main report. Rome: FAO. https://doi.org/10.4060/cb9910en.

FAO. 2022c. *The State of World Fisheries and Aquaculture 2022: Towards Blue Transformation*. Rome: FAO. https://doi.org/10.4060/cc0461en.

FAO. 2023. FAOSTAT. https://www.fao.org/faostat/en/#data.

FOLU (Food and Land Use Coalition). 2023. "Aligning Regenerative Agricultural Practices with Outcomes to Deliver for People, Nature and Climate." https://www.foodandlandusecoalition.org/knowledge-hub/regenag-people-nature-climate/. Accessed February 8, 2023.

Frank, H., H. Schmid, and K.-J. Hülsbergen. 2019. "Modelling Greenhouse Gas Emissions from Organic and Conventional Dairy Farms." *Landbauforschung* 69 (1): 37–46. doi:10.3220/LBF1584375588000.

Franks, B., C. Ewell, and J. Jacquet. 2021. "Animal Welfare Risks of Global Aquaculture." *Science Advances* 7 (14): eabg0677. doi:10.1126/sciadv.abg0677.

Gephart, J.A., P.J.G. Henriksson, R.W.R. Parker, A. Shepon, K.D. Gorospe, K. Bergman, G. Eshel, et al. 2021. "Environmental Performance of Blue Foods." *Nature* 597 (7876): 360–65. doi:10.1038/s41586-021-03889-2.

Gerber, P.J., and FAO (Food and Agriculture Organization of the United Nations), eds. 2013. *Tackling Climate Change through Livestock: A Global Assessment of Emissions and Mitigation Opportunities*. Rome: FAO.

Gess, A., I. Viola, S. Miretti, E. Macchi, G. Perona, L. Battaglini, and M. Baratta. 2020. "A New Approach to LCA Evaluation of Lamb Meat Production in Two Different Breeding Systems in Northern Italy." *Frontiers in Veterinary Science* 7 (September). doi:10.3389/fvets.2020.00651.

Goldman, E., M. Weisse, N. Harris, and M. Schneider. 2020. "Estimating the Role of Seven Commodities in Agriculture-Linked Deforestation: Oil Palm, Soy, Cattle, Wood Fiber, Cocoa, Coffee, and Rubber." World Resources Institute. doi:10.46830/writn.na.00001.

Gross, A., T. Bromm, S. Polifka, and F. Schierhorn. 2022. "The Carbon Footprint of Milk during the Conversion from Conventional to Organic Production on a Dairy Farm in Central Germany." *Agronomy for Sustainable Development* 42 (3): 1–17.

Guerci, M., M.T. Knudsen, L. Bava, M. Zucali, P. Schönbach, and T. Kristensen. 2013. "Parameters Affecting the Environmental Impact of a Range of Dairy Farming Systems in Denmark, Germany and Italy." *Journal of Cleaner Production* 54 (September): 133–41. doi:10.1016/j.jclepro.2013.04.035.

Halberg, N., J.E. Hermansen, I.S. Kristensen, J. Eriksen, N. Tvedegaard, and B.M. Petersen. 2010. "Impact of Organic Pig Production Systems on CO_2 Emission, C Sequestration and Nitrate Pollution." *Agronomy for Sustainable Development* 30 (4): 721–31. doi:10.1051/agro/2010006.

Hall, S.J., A. Delaporte, M.J. Phillips, M. Beveridge, and M. O'Keefe. 2011. "Blue Frontiers: Managing the Environmental Costs of Aquaculture." Penang, Malaysia: WorldFish Center. https://digitalarchive.worldfishcenter.org/bitstream/handle/20.500.12348/1148/WF_2821.pdf?sequence1=.

Hayek, M. 2022. "Intensive, Lower-Carbon Animal Farming Could Raise Pandemic Risks." Guest post. *Carbon Brief*, November 30. https://www.carbonbrief.org/guest-post-intensive-lower-carbon-animal-farming-could-raise-pandemic-risks/.

Hayek, M.N., and R.D. Garrett. 2018. "Nationwide Shift to Grass-Fed Beef Requires Larger Cattle Population." *Environmental Research Letters* 13 (8): 084005. doi:10.1088/1748-9326/aad401.

Hayek, M.N., H. Harwatt, W.J. Ripple, and N.D. Mueller. 2021. "The Carbon Opportunity Cost of Animal-Sourced Food Production on Land." *Nature Sustainability* 4 (1): 21–24. doi:10.1038/s41893-020-00603-4.

Hélias, A., H.M.G. van der Werf, L.-G. Soler, F. Aggeri, J.-Y. Dourmad, C. Julia, L. Nabec, S. Pellerin, B. Ruffieux, and G. Trystram. 2022. "Implementing Environmental Labelling of Food Products in France." *International Journal of Life Cycle Assessment* 27 (7): 926–31. doi:10.1007/s11367-022-02071-8.

Henchion, M.M. 2022. "The Many Meanings of 'Less but Better' Meat." *Nature Food* 3 (408). https://doi.org/10.1038/s43016-022-00535-6.

Henderson, B.B., P.J. Gerber, T.E. Hilinski, A. Falcucci, D.S. Ojima, M. Salvatore, and R.T. Conant. 2015. "Greenhouse Gas Mitigation Potential of the World's Grazing Lands: Modeling Soil Carbon and Nitrogen Fluxes of Mitigation Practices." *Agriculture, Ecosystems & Environment* 207 (September): 91–100. doi:10.1016/j.agee.2015.03.029.

Herrero, M., P. Havlík, H. Valin, A. Notenbaert, M.C. Rufino, P.K. Thornton, M. Blümmel, et al. 2013. "Biomass Use, Production, Feed Efficiencies, and Greenhouse Gas Emissions from Global Livestock Systems." *Proceedings of the National Academy of Sciences* 110 (52): 20888–93. doi:10.1073/pnas.1308149110.

Hörtenhuber, S., T. Lindenthal, B. Amon, T. Markut, L. Kirner, and W. Zollitsch. 2010. "Greenhouse Gas Emissions from Selected Austrian Dairy Production Systems: Model Calculations Considering the Effects of Land Use Change." *Renewable Agriculture and Food Systems* 25 (4): 316–29. doi:10.1017/S1742170510000025.

IPCC (Intergovernmental Panel on Climate Change). 2019. *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. Geneva: IPCC.

Jakobsen, M., T. Preda, A.G. Kongsted, and J.E. Hermansen. 2015. "Increased Foraging in Outdoor Organic Pig Production-Modeling Environmental Consequences." *Foods* 4 (4): 622–44. doi:10.3390/foods4040622.

Katz-Rosene, R., F. Ortenzi, G.A. McAuliffe, and T. Beal. 2023. "Levelling Foods for Priority Micronutrient Value Can Provide More Meaningful Environmental Footprint Comparisons." *Communications Earth & Environment* 4 (1): 1–9. doi:10.1038/s43247-023-00945-9.

Kinley, R.D., G. Martinez-Fernandez, M.K. Matthews, R. de Nys, M. Magnusson, and N.W. Tomkins. 2020. "Mitigating the Carbon Footprint and Improving Productivity of Ruminant Livestock Agriculture Using a Red Seaweed." *Journal of Cleaner Production* 259 (June): 120836. doi:10.1016/j.jclepro.2020.120836.

Klopatek, S.C., E. Marvinney, T. Duarte, A. Kendall, X. (C.) Yang, and J.W. Oltjen. 2022. "Grass-Fed vs. Grain-Fed Beef Systems: Performance, Economic, and Environmental Trade-Offs." *Journal of Animal Science* 100 (2): skab374. doi:10.1093/jas/skab374.

Koch, P., and T. Salou. 2015. AGRIBALYSE®: METHODOLOGY, version 1.2. Angers, France: ADEME.

Kool, A., H. Blonk, T. Ponsioen, W. Sukkel, H. Vermeer, J. De Vries, and R. Hoste. 2009. "Carbon Footprints of Conventional and Organic Pork: Assessment of Typical Production Systems in the Netherlands, Denmark, England and Germany." Gouda, the Netherlands: Blonk Consultants.

Kristensen, T., L. Mogensen, M.T. Knudsen, and J.E. Hermansen. 2011. "Effect of Production System and Farming Strategy on Greenhouse Gas Emissions from Commercial Dairy Farms in a Life Cycle Approach." *Livestock Science* 140 (1): 136–48.

Laca, A., N. Gómez, A. Laca, and M. Díaz. 2020. "Overview on GHG Emissions of Raw Milk Production and a Comparison of Milk and Cheese Carbon Footprints of Two Different Systems from Northern Spain." *Environmental Science & Pollution Research* 27 (2): 1650–66.

Laestadius, L.I., R.A. Neff, C.L. Barry, and S. Frattaroli. 2014. "'We Don't Tell People What to Do': An Examination of the Factors Influencing NGO Decisions to Campaign for Reduced Meat Consumption in Light of Climate Change." *Global Environmental Change* 29 (November): 32–40. doi:10.1016/j.gloenvcha.2014.08.001.

Leinonen, I., A.G. Williams, J. Wiseman, J. Guy, and I. Kyriazakis. 2012a. "Predicting the Environmental Impacts of Chicken Systems in the United Kingdom through a Life Cycle Assessment: Broiler Production Systems." *Poultry Science* 91 (1): 8–25. doi:10.3382/ps.2011-01634.

Leinonen, I., A.G. Williams, J. Wiseman, J. Guy, and I. Kyriazakis. 2012b. "Predicting the Environmental Impacts of Chicken Systems in the United Kingdom through a Life Cycle Assessment: Egg Production Systems." *Poultry Science* 91 (1): 26–40. doi:10.3382/ps.2011-01635.

Lucas, A. 2023. "U.S. Regulators Approve Sale of Cell-Cultured Chicken by Two Startups." CNBC, June 21. https://www.cnbc.com/2023/06/21/us-approves-sale-of-cell-cultured-chicken-to-two-start-ups.html.

Marks, M. 2023. "Is "Climate-Friendly" Beef All Sizzle?" KUT, *Texas Standard*, June 5. https://www.kut.org/texasstandard/2023-06-05/climate-friendly-brazen-beef-tyson-foods-details-unclear.

McNamara, E., and C. Bomkamp. 2022. "Cultivated Meat as a Tool for Fighting Antimicrobial Resistance." *Nature Food* 3 (10): 791–94. doi:10.1038/s43016-022-00602-y.

Melgar, A., K.C. Welter, K. Nedelkov, C.M.M.R. Martins, M.T. Harper, J. Oh, S.E. Räisänen, et al. 2020. "Dose-Response Effect of 3-Nitrooxypropanol on Enteric Methane Emissions in Dairy Cows." *Journal of Dairy Science* 103 (7): 6145–56. doi:10.3168/jds.2019-17840.

Minasny, B., B.P. Malone, A.B. McBratney, D.A. Angers, D. Arrouays, A. Chambers, V. Chaplot, et al. 2017. "Soil Carbon 4 per Mille." *Geoderma* 292 (April): 59–86. doi:10.1016/j.geoderma.2017.01.002.

Mogensen, L., T. Kristensen, N.I. Nielsen, P. Spleth, M. Henriksson, C. Swensson, A. Hessle, and M. Vestergaard. 2015. "Greenhouse Gas Emissions from Beef Production Systems in Denmark and Sweden." *Livestock Science* 174 (April): 126–43. doi:10.1016/j.livsci.2015.01.021.

Mogensen, L., J.E. Hermansen, and E. Trolle. 2020. "The Climate and Nutritional Impact of Beef in Different Dietary Patterns in Denmark." *Foods* 9 (9): 1176. doi:10.3390/foods9091176.

Mollenhorst, H., P.B.M. Berentsen, and I.J.M. De Boer. 2006. "On-Farm Quantification of Sustainability Indicators: An Application to Egg Production Systems." *British Poultry Science* 47 (4): 405–17. doi:10.1080/00071660600829282.

Morach, B., B. Witte, D. Walker, E. von Koeller, F. Grosse-Holz, J. Rogg, M. Brigl, et al. 2021. "Food for Thought: The Protein Transformation." Boston Consulting Group. https://www.bcg.com/publications/2021/the-benefits-of-plant-based-meats.

Moughan, P.J. 2021. "Population Protein Intakes and Food Sustainability Indices: The Metrics Matter." *Global Food Security* 29: 100548.

Nguyen, T.L.T., J.E. Hermansen, and L. Mogensen. 2010. "Environmental Consequences of Different Beef Production Systems in the EU." *Journal of Cleaner Production* 18 (8): 756–66.

O'Brien, D., L. Shalloo, J. Patton, F. Buckley, C. Grainger, and M. Wallace. 2012. "A Life Cycle Assessment of Seasonal Grass-Based and Confinement Dairy Farms." *Agricultural Systems* 107 (March): 33–46. doi:10.1016/j.agsy.2011.11.004.

O'Brien, D., J.L. Capper, P.C. Garnsworthy, C. Grainger, and L. Shalloo. 2014. "A Case Study of the Carbon Footprint of Milk from High-Performing Confinement and Grass-Based Dairy Farms." *Journal of Dairy Science* 97 (3): 1835–51. doi:10.3168/jds.2013-7174.

Onwezen, M.C., E.P. Bouwman, M.J. Reinders, and H. Dagevos. 2021. "A Systematic Review on Consumer Acceptance of Alternative Proteins: Pulses, Algae, Insects, Plant-Based Meat Alternatives, and Cultured Meat." *Appetite* 159 (April): 105058. doi:10.1016/j.appet.2020.105058.

Pelletier, N., R. Pirog, and R. Rasmussen. 2010. "Comparative Life Cycle Environmental Impacts of Three Beef Production Strategies in the Upper Midwestern United States." *Agricultural Systems* 103 (6): 380–89. doi:10.1016/j.agsy.2010.03.009.

Perez, R.O. 2009. "Analysis of Sustainability in the Pig Production Chain: Life Cycle Assessment of Contrasting Scenarios." PhD diss., Newcastle University.

Pirlo, G., and S. Lolli. 2019. "Environmental Impact of Milk Production from Samples of Organic and Conventional Farms in Lombardy (Italy)." *Journal of Cleaner Production* 211 (February): 962–71.

Poore, J., and T. Nemecek. 2018. "Reducing Food's Environmental Impacts through Producers and Consumers." *Science* 360 (6392): 987–92. doi:10.1126/science.aaq0216.

Presumido, P.H., F. Sousa, A. Gonçalves, T.C. dal Bosco, and M. Feliciano. 2018. "Environmental Impacts of the Beef Production Chain in the Northeast of Portugal Using Life Cycle Assessment." *Agriculture*, no. 10: 1.

Prudêncio da Silva, V., H.M.G. van der Werf, S.R. Soares, and M.S. Corson. 2014. "Environmental Impacts of French and Brazilian Broiler Chicken Production Scenarios: An LCA Approach." *Journal of Environmental Management* 133 (January): 222–31. doi:10.1016/j.jenvman.2013.12.011.

Ranganathan, J., D. Vennard, R. Waite, P. Dumas, B. Lipinski, and T. Searchinger. 2016. "Shifting Diets for a Sustainable Food Future: Creating a Sustainable Food Future, Installment Eleven." World Resources Institute. https://www.wri.org/research/shifting-diets-sustainable-food-future.

Resare Sahlin, K., and J. Trewern. 2022. "A Systematic Review of the Definitions and Interpretations in Scientific Literature of 'Less but Better' Meat in High-Income Settings." *Nature Food* 3 (6): 454–60. doi:10.1038/s43016-022-00536-5.

Resare Sahlin, K., E. Röös, and L.J. Gordon. 2020. "'Less but Better' Meat Is a Sustainability Message in Need of Clarity." *Nature Food* 1 (9): 520–22. doi:10.1038/s43016-020-00140-5.

Ripoll-Bosch, R., I.J.M. de Boer, A. Bernués, and T.V. Vellinga. 2013. "Accounting for Multi-functionality of Sheep Farming in the Carbon Footprint of Lamb: A Comparison of Three Contrasting Mediterranean Systems." *Agricultural Systems* 116 (March): 60–68. doi:10.1016/j.agsy.2012.11.002.

Ritchie, H. 2023. "Eating Local Is Still Not a Good Way to Reduce the Carbon Footprint of Your Diet." January 5, 2023. https://www.sustainabilitybynumbers.com/p/food-miles.

Roque, B.M., J.K. Salwen, R. Kinley, and E. Kebreab. 2019. "Inclusion of Asparagopsis Armata in Lactating Dairy Cows' Diet Reduces Enteric Methane Emission by over 50 Percent." *Journal of Cleaner Production* 234 (October): 132–38. doi:10.1016/j.jclepro.2019.06.193.

Rotz, C.A., S. Asem-Hiablie, S. Place, and G. Thoma. 2019. "Environmental Footprints of Beef Cattle Production in the United States." *Agricultural Systems* 169 (February): 1–13. doi:10.1016/j.agsy.2018.11.005.

Rzymski, P., M. Kulus, M. Jankowski, C. Dompe, R. Bryl, J.N. Petitte, B. Kempisty, and P. Mozdziak. 2021. "COVID-19 Pandemic Is a Call to Search for Alternative Protein Sources as Food and Feed: A Review of Possibilities." *Nutrients* 13 (1): 150. doi:10.3390/nu13010150.

Salvador, S., M. Corazzin, E. Piasentier, and S. Bovolenta. 2016. "Environmental Assessment of Small-Scale Dairy Farms with Multifunctionality in Mountain Areas." *Journal of Cleaner Production* 124 (June): 94–102.

Santo, R.E., B.F. Kim, S.E. Goldman, J. Dutkiewicz, E.M.B. Biehl, M.W. Bloem, R.A. Neff, and K.E. Nachman. 2020. "Considering Plant-Based Meat Substitutes and Cell-Based Meats: A Public Health and Food Systems Perspective." *Frontiers in Sustainable Food Systems* 4. https://www.frontiersin.org/articles/10.3389/fsufs.2020.00134.

SBTi (Science Based Targets initiative). 2018. "Value Change in the Value Chain: Best Practices in Scope 3 Greenhouse Gas Management." https://sciencebasedtargets.org/resources/legacy/2018/12/SBT_Value_Chain_Report-1.pdf. SBTi. 2022. "Forests, Land and Agriculture Science Based Target Setting Guidance." https://sciencebasedtargets.org/sectors/forest-land-and-agriculture.

Schmidinger, K., and E. Stehfest. 2012. "Including CO_2 Implications of Land Occupation in LCAs—Method and Example for Livestock Products." *International Journal of Life Cycle Assessment* 17 (8): 962–72. doi:10.1007/s11367-012-0434-7.

Searchinger, T.D., S. Wirsenius, T. Beringer, and P. Dumas. 2018. "Assessing the Efficiency of Changes in Land Use for Mitigating Climate Change." *Nature* 564 (7735): 249–53. doi:10.1038/s41586-018-0757-z.

Searchinger, T., R. Waite, C. Hanson, J. Ranganathan, and E. Matthews. 2019. *Creating a Sustainable Food Future: A Menu of Solutions to Feed Nearly 10 Billion People by 2050*. Washington, DC: World Resources Institute. https://research.wri.org/wrr-food.

Seufert, V., and N. Ramankutty. 2017. "Many Shades of Gray: The Context-Dependent Performance of Organic Agriculture." *Science Advances* 3 (3): e1602638. doi:10.1126/sciadv.1602638.

Seufert, V., N. Ramankutty, and J.A. Foley. 2012. "Comparing the Yields of Organic and Conventional Agriculture." *Nature* 485 (7397): 229–32. doi:10.1038/nature11069.

Sinke, P., E. Swartz, H. Sanctorum, C. van der Giesen, and I. Odegard. 2023. "Ex-Ante Life Cycle Assessment of Commercial-Scale Cultivated Meat Production in 2030." *International Journal of Life Cycle Assessment* 28 (3): 234–54. doi:10.1007/s11367-022-02128-8.

Stanley, P.L., J.E. Rowntree, D.K. Beede, M.S. DeLonge, and M.W. Hamm. 2018. "Impacts of Soil Carbon Sequestration on Life Cycle Greenhouse Gas Emissions in Midwestern USA Beef Finishing Systems." *Agricultural Systems* 162 (May): 249–58.

Thomassen, M.A., K.J. van Calker, M.C.J. Smits, G. Iepema, and I.J.M. de Boer. 2008. "Life Cycle Assessment of Conventional and Organic Milk Production in the Netherlands." *Agricultural Systems* 96 (1–3): 95–107. doi:10.1016/j.agsy.2007.06.001.

Tigchelaar, M., J. Leape, F. Micheli, E.H. Allison, X. Basurto, A. Bennett, S.R. Bush, et al. 2022. "The Vital Roles of Blue Foods in the Global Food System." *Global Food Security* 33 (June): 100637. doi:10.1016/j.gfs.2022.100637.

Tubiello, F.N., C. Rosenzweig, G. Conchedda, K. Karl, J. Gütschow, P. Xueyao, G. Obli-Laryea, et al. 2021. "Greenhouse Gas Emissions from Food Systems: Building the Evidence Base." *Environmental Research Letters* 16 (6): 065007. doi:10.1088/1748-9326/ac018e.

Twine, R. 2021. "Emissions from Animal Agriculture—16.5% Is the New Minimum Figure." *Sustainability* 13 (11): 6276. doi:10.3390/su13116276.

USDA (U.S. Department of Agriculture) and USDHHS (U.S. Department of Health and Human Services). 2020. "Dietary Guidelines for Americans, 2020–2025." 9th ed. https://www.dietaryguidelines.gov/sites/default/files/2020-12/Dietary_Guidelines_for_Americans_2020-2025.pdf. Accessed February 24, 2020.

van der Werf, H.M.G., C. Kanyarushoki, and M.S. Corson. 2009. "An Operational Method for the Evaluation of Resource Use and Environmental Impacts of Dairy Farms by Life Cycle Assessment." *Journal of Environmental Management* 90 (11): 3643–52. doi:10.1016/j.jenvman.2009.07.003.

Veysset, P., M. Lherm, and D. Bébin. 2011. "Productive, Environmental and Economic Performances Assessments of Organic and Conventional Suckler Cattle Farming Systems." *Organic Agriculture* 1 (1): 1–16. doi:10.1007/s13165-010-0001-0.

Waite, R., M. Beveridge, R. Brummett, S. Castine, N. Chaiyawannakarn, S. Kaushik, R. Mungkung, et al. 2014. "Improving Productivity and Environmental Performance of Aquaculture." Working paper, Installment 5 of *Creating a Sustainable Food Future*. World Resources Institute, June 4. https://www.wri.org/research/improving-productivity-and-environmental-performance-aquaculture.

Waite, R., D. Vennard, and G. Pozzi. 2019. "Tracking Progress toward the Cool Food Pledge: Setting Climate Targets, Tracking Metrics, Using the Cool Food Calculator, and Related Guidance for Pledge Signatories." World Resources Institute, September 24. https://www.wri.org/research/tracking-progress-toward-cool-food-pledge.

WHO (World Health Organization). 2021. "Antimicrobial Resistance." https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance.

Williams, A., E. Audsley, and D. Sandars. 2006. "Determining the Environmental Burdens and Resource Use in the Production of Agricultural and Horticultural Commodities: Defra Project Report IS0205." http://randd.defra.gov.uk/Default.aspx.

WRI (World Resources Institute) and WBCSD (World Business Council for Sustainable Development. 2011. "Corporate Value Chain (Scope 3) Standard." https://ghgprotocol.org/corporate-value-chain-scope-3-standard.

WRI and WBCSD. 2013. "Technical Guidance for Calculating Scope 3 Emissions (GHG Protocol)." https://ghgprotocol.org/scope-3-calculation-guidance-2.

WRI and WBCSD. 2022. "Greenhouse Gas Protocol Land Sector and Removals Guidance: Draft for Pilot Testing and Review." https://ghgprotocol.org/land-sector-and-removals-guidance.

WRI and WBCSD. 2023. "Survey on Need for GHG Protocol Corporate Standards and Guidance Updates." https://ghgprotocol.org/survey-need-ghg-protocol-corporate-standards-and-guidance-updates. Accessed August 16, 2023.

Xu, X., P. Sharma, S. Shu, T.-S. Lin, P. Ciais, F.N. Tubiello, P. Smith, et al. 2021. "Global Greenhouse Gas Emissions from Animal-Based Foods Are Twice Those of Plant-Based Foods." *Nature Food* 2 (9): 724–32. doi:10.1038/s43016-021-00358-x.

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