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Expansion of Plant-Based Meat and Its Impacts on Climate and Food Security

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Highlights

- To meet climate targets, a shift to low-emission diets that also support health and sustainability is necessary.
- A high-impact target is to reduce red meat consumption by 50 percent by 2030 in high- and middle-income countries based on the 2019 EAT-Lancet diet.
- Actions to reduce animal-based meat consumption (Table 9.1) could reduce dietary emissions by 3–8 billion tonnes of carbon dioxide equivalent per year.
- Scaling up plant-based meat (PBM) will require viable products, low costs, effective public policy to catalyse change, and strong markets.
- The priority actions are to facilitate consumer behavioural change for large segments of populations, promote policy targets and actions for reduced-meat diets in high- and middle-income countries, use public–private finance to improve alternative meat product nutrition and sustainability, and enhance affordable technology and business options.

9.1 Introduction

Scenario analysis shows that shifting diets to foods with lower emissions is necessary to meet climate-change mitigation goals, while also improving food systems' health, nutrition, and sustainability (Clark et al., 2020). Reducing demand for animal-sourced foods has received particular attention, as livestock contribute the majority of global food emissions and animal products have the highest greenhouse gas (GHG) emissions per kilogram among food products (Poore & Nemecek, 2018). Consumer interest in meat alternatives is also on the rise (He et al., 2020).

The rapid growth of innovations to reduce animal-based meat emissions has drawn attention to the potential for large-scale transformation of food systems. In

Table 9.1. *Dietary choices that reduce meat-related emissions*

Practice	Reduced frequency or amount of meat consumption	Lower-emission meat	Meat analogues	Plant-based, meat-free diets
What is it?	Regularly forgoing meat. Reduced meat waste.	Lower-emission meats, e.g., eating poultry, molluscs, or forage fish instead of beef; beef produced with lower emissions. Reduced meat loss in the supply chain.	Plant, mycoprotein, and cell-based foods that mimic meat, usually targeting meat consumers.	A vegan diet, i.e., no animal products; a vegetarian diet, i.e., no meat but includes animal products such as milk or eggs.
Status	Around 40 percent of the global population identify as flexitarian; 54 percent of these are under 30 years old, 34 percent are over 60. ¹	From 1990 to 2013, global poultry production increased by 165 percent, while global beef production increased by 23 percent. ²	The worldwide PBM market was worth US\$5.6 billion in 2020; it is forecast to reach US\$14.9 billion by 2027. ³	2–6 percent of the global population is vegetarian or vegan; India has the highest percentage of vegetarians, around 40 percent. ⁴
Examples of efforts to scale up	Meatless day movements, e.g., Meatless Monday, and sustainable city policies, e.g., Ghent En Garde.	Public health campaigns. Adoption of cattle-feed inhibitors, e.g., JBS, the world’s largest meat processor, will use Bovaer to reduce beef emissions.	Beyond Burger, Impossible Burger, Quorn, Mosa Meat, Memphis Meats, and Avant Meats.	Grassroots advocacy, e.g., People for the Ethical Treatment of Animals.

Challenges to wider adoption	Current dietary habits and identity, nutritional concerns, and a lack of awareness.	Current dietary habits and identity, motivation to reduce emissions, availability or cost of technical options, incentives for the adoption of mitigation practices, and nascent technology.	High production costs, particularly in cell-based meat, and retail price; nutritional value, taste, and sensory experience; market availability; the intensity of water and energy use in production; and nascent technology.	Current dietary habits and identity, nutritional concerns, and a lack of awareness.
Low emissions development implications	3–6 GT CO ₂ e avoided per year. ⁵	Reduction of around 3.5 GT CO ₂ e. Substituting chicken for beef reduces emissions by 89 percent.	89–90 percent reduction of GHG emissions for Impossible Burger and Beyond Burger. Also depends on the substitution level.	4–8 GT CO ₂ e avoided per year. ⁵

¹ Ho (2021).

² Ritchie & Roser (2017).

³ GlobeNewswire (2021).

⁴ Hargreaves et al. (2021).

⁵ Schiermeier (2019).

this chapter, we review the state of the shift to decrease animal-based meat consumption and what is needed to achieve large-scale impacts. We give special attention to plant-based meat (PBM), a market attracting significant investment along with other plant-based proteins like dairy. In high-income countries, PBM can provide a substitute for animal-based meat, and in low- and middle-income countries (LMICs), it can help shift diet trajectories to avoid unhealthy US- or European-style meat consumption levels (Good Food Institute, 2021). We conclude with recommended actions.

9.2 Options for Reducing Meat Consumption and Climate Impacts

New technology has enabled the development of PBM analogues that more accurately mimic animal products compared to traditional substitutes like tofu. The main ingredients of PBM are plant proteins, such as soy, pea, potato, rice, mung bean, wheat, or fungus; fats, such as canola, coconut, soybean, cocoa, or sunflower oil; and small quantities of vitamins, such as B1, B2, B6, B12, zinc, and iron, alongside ingredients with binding, nutritional, sensory, or food-safety qualities. The technologies underlying PBM convert already edible protein into meat-like textures.

In terms of nutrition, PBM is designed to be nominally similar to meat. A comparison of PBM with other meat and mycoprotein products showed PBM was comparable to beef and pork across most nutritional elements, although lower in total fat and vitamins (Rubio et al., 2020). A more in-depth study, however, indicated that 90 percent of 190 metabolites differed in grass-fed beef and high-quality PBM (Van Vliet et al., 2021). Additionally, PBM is a highly processed food.

Dietary change can significantly reduce emissions, with a technical mitigation potential of 2.7–6.4 billion tonnes of carbon dioxide equivalent (GT CO₂e) per year and economic potential of 1.8–3.4 GT CO₂e per year at US\$20–100 per tonne of carbon dioxide (Schiermeier, 2019). Transitioning to dietary standards such as the EAT-Lancet diet, which relies on more plant-based food, will reduce food system emissions by 70 percent by 2050 (Springman et al., 2016). Four behaviours cut emissions from animal-sourced foods (Table 9.1):

- Meat consumption remains, though the frequency or amount of meat consumed decreases.
- Consumption is shifted to lower-emission meats, such as from beef to chicken, or value chain food loss is diminished.
- Meat substitutes that mimic the nutritional and sensory aspects of meat are used.
- Meat-free, plant-based diets are adopted.

9.3 Impacts of Plant-Based Meat on Emissions and Sustainability Co-Benefits

Meat consistently has a larger environmental impact than other food items per kilogram of product or protein, with beef having the highest overall impact. In a review of 40 food products representing 90 percent of global protein and calorie consumption, GHG emissions from beef were 15 times higher than rice, the highest-emission crop, and 20 times higher than tofu (Poore & Nemececk, 2018) (Figure 9.1). Producing beef used 20 times more land than nuts or pulses, risking higher levels of land degradation, biodiversity loss, and land-use change. Substituting other meats, dairy, or plant-based proteins for beef offers the highest reduction in emissions per kilogram of food and per 100 grams of protein (Poore & Nemececk, 2018).

By contrast, PBMs use 47–99 percent less land and 72–99 percent less water, emit 30–90 percent fewer GHGs, and cause 51–91 percent less aquatic nutrient pollution than conventional meat (GFI, 2019, cited in Sha et al., 2021). Life-cycle analyses of meat and meat alternatives (Figure 9.2) show all products had significantly lower impacts than beef, with the exception of cell-based meat, which requires high energy inputs. The emissions and energy used for PBM were higher than for chicken (Rubio et al., 2020). Seafood was not examined in this analysis

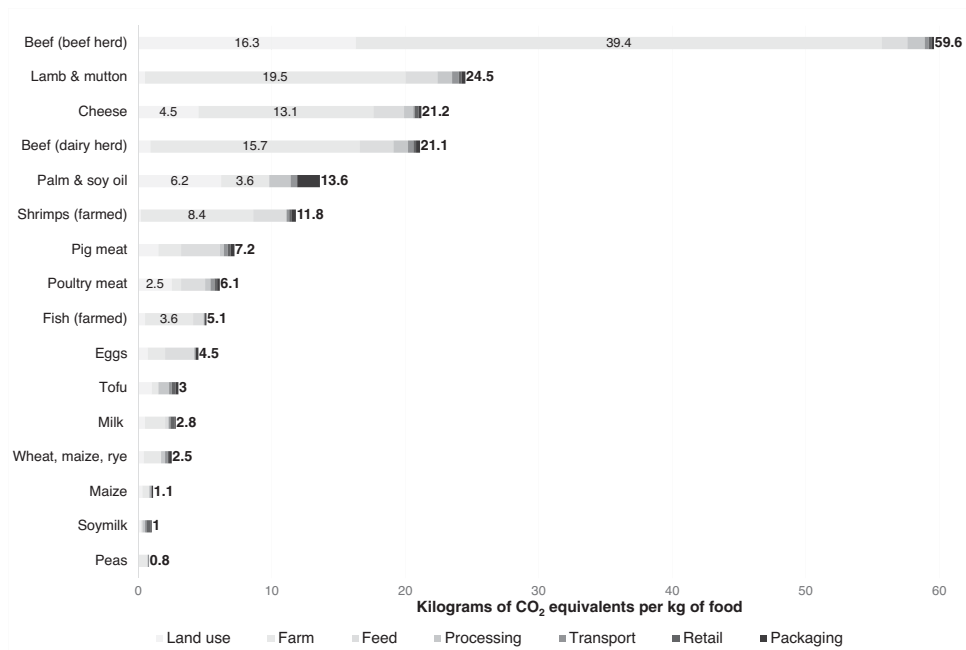


Figure 9.1 Kilograms of carbon dioxide equivalent per kilogram of food, including non-carbon dioxide greenhouse gases. Total emissions are indicated at the end of each row (Poore & Nemececk, 2018).

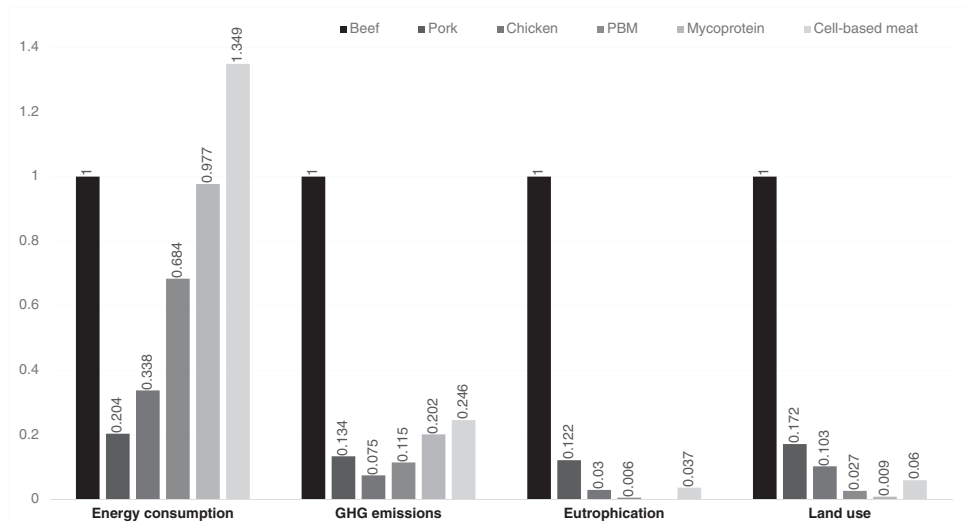


Figure 9.2 Comparison of the environmental impact of animal-based meat and meat analogues. Data are normalised to the impact of beef production (beef = 1). Eutrophication does not include mycoprotein. Adapted from Rubio et al. (2020).

but is expected to have high impacts where deforestation occurs, for example, shrimp farming in mangrove regions, and similar or lower impacts than pork and chicken, depending on the level of inputs.

The primary protein ingredient, packaging, and energy used for processing are the largest contributors of life-cycle emissions of PBM, and choices about these inputs strongly affect PBM's GHG footprint (Heller & Keoleian, 2018). For example, PBM's emissions are lower where primary protein ingredients are deforestation-free, processing technology is energy-efficient, energy is renewable, and by-products and waste are used (Sha et al., 2021).

Projections of PBM's global impacts indicate the possibility of substantial mitigation outcomes (Kozicka et al., forthcoming). A 25 percent substitution rate of PBM for its respective meat will lead to an emission reduction of 1 GT CO₂e per year by 2050. Predictably, substituting PBM for beef will have the highest impact. If the land released through the shift away from beef production is used as forest, the mitigation impact of PBM is doubled. The potential for biodiversity co-benefits is significant due to the reduced area of cultivated land and a lower pressure for expansion into forests.

With respect to social impacts, PBM will likely negatively affect livestock farmers, as will any intervention to reduce meat consumption. High-quality PBM is also best suited to large-scale production to achieve economies of scale; business

feasibility is discussed below. Industrial-scale PBM may lead to equity trade-offs if it displaces small-scale producers and farmers.

9.4 Priorities for Driving Change at Scale

The success of PBM's mitigation impacts will depend on how much PBM lessens animal-meat consumption (Wilkes, 2021). Reductions can occur via substitutions for current meat consumption or avoiding future higher levels of animal-meat consumption, for example in LMICs. Rising consumption of PBM is being driven by increased awareness of meat's impacts on health, the environment, and animal welfare, alongside the rising popularity of vegetarian and flexitarian diets, particularly among urban people under 30. Yet scaling production and consumption of PBM is challenging due to the current high cost of meat alternatives, a lack of easy and appealing choices, the social norms around animal-based meat, and political sensitivity about promoting meat alternatives (Kiff et al., 2016; Park, 2018).

To meet future climate goals, EAT-Lancet's 2030 recommendation to halve red meat consumption is a useful target (Willett et al., 2019). The target can be applied to reducing consumption where the future per-capita consumption of meat exceeds 80 kilograms per year, the current average in industrialised countries, and in cities. In 2050, 80 percent of global food consumption is expected to occur in cities.

The benefits of reducing meat consumption are clearest in high-income countries and urban areas of middle-income countries, where high meat consumption has led to negative nutritional and environmental consequences. Among rural populations in low-income countries, PBM may play a more important role as an additional protein source and business option but not as a substitute for meat, as livestock often play essential economic, social, and nutritional roles and meat consumption remains far below that of high-income-countries.

Below we look at the enabling conditions for reducing large-scale animal-meat consumption, namely influencing consumer behaviour, policy, industry and investment trends, markets, and business feasibility. We conclude with priorities for sustainable pathways towards low-emission diets.

9.5 Consumer Behaviour

Consumers will be more likely to reduce animal-based meat consumption when innovations for PBM address people's enjoyment of eating meat, their worries about the nutritional value of a vegetarian diet, the inconvenience of preparing

vegetarian food, the lack of restaurant options, the attitudes of their family and friends, and the perceived higher costs of vegetarianism (He et al., 2020). Attitudes towards meat and meat alternatives can also differ by gender, age, identity, culture, and other factors. For example, plant-based consumers are less willing than omnivores to try cell-based meats (Rubio et al., 2020).

Appealing to consumers' need for low-cost, easy, and appealing choices that align with social norms is a priority for enabling diet shifts (Park, 2019). Measures include making products more visible in shops or menus; creating affordable portion sizes; enabling substitution of a product, for example, blending plant-based ingredients into burgers; avoiding segregating or labelling plant-based foods as niche or restrictive; and integrating them into social norms (Park, 2019). Targeting mass markets – as the brands Impossible Foods and Beyond Meat have done through fast-food chains and retail stores – seems to be effective, as do celebrity endorsements. Future technologies may alleviate some constraints, like sensory appeal and cost.

9.6 Policy

Policy measures include funding for novel meat research and development, subsidies, restricting advertising for red or processed meat, carbon footprint labelling and certification, taxing high-carbon products, economic development plans, and health and sustainable food campaigns; however, all of these measures vary in efficacy (Kiff et al., 2016). Better information about the relative climate impacts of food products, for example, can inform consumers' choices, while policies for PBM nutritional standards may allay concerns about nutritional value. A number of policies are already emerging, with some countries having proposed or piloted meat taxes or conducted public health campaigns to eat less meat. Taxes on food, however, are politically sensitive and can be socially regressive, while health campaign results have been mixed (Kiff et al., 2016; Wilkes, 2021). In 2021, Denmark committed €168 million to implement a national action plan for plant-based foods with production and sale targets (GFI, 2021).

9.7 Industry and Investment Trends

Investment in PBMs and other alternatives to meat and dairy products has skyrocketed since the late 2010s, making 2020 a record year for alternative-protein investment. Plant-based protein has seen the biggest investment in the decade to 2020 (Gaan et al., 2021). Considerable investment is flowing to PBM research and development. In 2020, Beyond Burger spent over US\$30 million to improve their

Table 9.2. Comparison of investment and market status for different types of meat analogues

Technology	Invested capital 2010–2020 and market status
Plant-based	US\$4.4 billion Plant-based meat and dairy products are available to consumers around the world in supermarkets and restaurants. Start-ups can be found globally.
Cultivated	US\$0.49 billion Products are not on the shelf, but the first consumer testing has begun. The technology is rapidly advancing and beginning to gain investment.
Fermented mycoproteins	US\$1 billion Fermented products are mainly marketed as additives for plant-based products. Impossible Foods uses a fermentation process to create heme proteins.

product line, while Impossible Foods raised over US\$700 million for product development research. Table 9.2 summarises the total investment and state of the PBM industry compared to cultivated meat and mycoprotein additives such as heme – a molecule containing iron that is found in plants and the blood of animals. These investments reflect a level of consumer interest in PBM that few thought possible a decade ago.

9.8 Markets

Global sales of PBM grew by 24 percent, or US\$4.2 billion, in 2020, while plant-based milk sales rose by 4 percent or US\$16.9 billion (Gaan et al., 2021). While the largest markets for PBM and dairy are in higher-income countries, markets in LMICs have expanded since 2020, catalysed in part by COVID-19-related meat shortages. Youths are helping to drive the shift towards plant-based diets as the biggest consumers of PBM. Asia has one of the fastest-growing PBM markets, while in China the PBM market increased by 190 percent in 2014–19 to around US\$1 billion (Zhiyan Consulting Group, 2020).

9.9 Business Feasibility

Analysis of the business feasibility of expanding PBM in LMICs, using Brazil, China, Nigeria, and Vietnam as case studies (Box 9.1), found that despite similar

Box 9.1

Plant-Based Meat and Dairy Company Case Studies***VeggieVictory, Nigeria***

Global investors from the United States and Europe backed Nigeria's first PBM start-up, VeggieVictory. Africa is increasingly seen as a new frontier for plant-based protein investment, with a rapidly growing economy and a population seeking more dairy and meat. As well as expanding into US and European markets, VeggieVictory is growing in neighbouring West African countries and aims to focus on Africa through its restaurant in Lagos.

NotCo

The plant-based dairy product sector is growing rapidly, and innovation is driving investment. NotCo, a food-technology company producing plant-based milk and meat replacements, has seen huge investment since 2019, when the Craftory and Bezos Expeditions invested US\$30 million in the company. In 2021, NotCo received US\$235 million from thirteen investors. NotCo's attraction to investors is its patented artificial intelligence software that analyses an animal-based product at a molecular level and then generates recipes for NotCo chefs to try. NotCo sells plant-based burgers, ice cream, and mayonnaise throughout Latin America. In early 2021, the company started selling milk in several West Coast stores in the United States and is expanding distribution through Whole Foods. NotCo plans to grow its market in the United States, Canada, Europe, and Asia.

The New, Brazil

The New is one of Latin America's fastest-growing PBM brands and is attracting big-name investors. With over 700 retail locations after less than two years, The New's PBM products are gluten- and soy-free, making The New one of the few large-scale PBM brands to avoid these common allergens.

Oatly, Singapore

Oatly, a Swedish-based oat milk company, entered the Asian market by partnering with Singapore-based Yeo Hiap Seng, or Yeo's, and Starbucks. In late 2020, Starbucks launched a promotion for plant-based drinks and foods on its menus in Asia. Starbucks' promotion aimed to expand the Asian market using locally relevant recipes. In early 2021, Oatly and Yeo's jointly invested US\$30 million in a production facility to service the wider Asian market, initiating the first plant-based dairy outside the United States or Europe.

production processes among countries, costs and revenues differed significantly (Kashi et al., 2021). Upfront capital was not a major constraint, as investment costs were small relative to operating costs. The cost of retrofitting a meat processing facility to produce PBM is nevertheless significant – around

US\$63 million – indicating that only entities with access to significant capital are likely to produce high-quality meat analogues in the near future. Market price and sales volume were the main sources of risk, particularly where there was no current PBM market, for example in Nigeria. Off-take contracts and joint public investment could mitigate this risk. There is a need for better market research on revenue and integrated cost-benefit analysis of PBM that includes social and environmental impacts. Currently, PBM remains more expensive than animal-based meat, although PBM costs will likely decrease with future technology. In Brazil, China, Vietnam, and Nigeria, PBM was two to six times more expensive than conventional meat.

Based on these behavioural, policy, market, and business conditions, a number of priority actions would support consumers' shift to lower-emission PBM in high-income countries and middle-income cities. These include the following (Park, 2019; Steiner et al., 2020):

- Support labelling and certification of animal-based meat and other protein sources for GHG emissions, health, and other environmental factors, to raise consumer awareness.
- Develop incentives, enterprise support, and public–private investment for innovation and production of alternative meat and protein sources that are true, nutritional substitutes for meat, with smaller environmental footprints. Provide technical information and examples of investment to investors.
- Develop diverse, open-source technological options and business models that enable cost reduction for large- and small-scale producers.
- Promote awareness campaigns and social movements via science-informed celebrities, champions, and the media, driving alternative discourses, e.g., Greta Thunberg's 'School Strike for the Climate' movement, the C40 campaign, and the Meatless Monday movement.
- Increase the number of plant-based meat and dairy options on menus and in canteens and supermarkets. Display products prominently, and avoid segregating products or using branding or labelling that may alienate meat eaters. Address assumptions that meat is necessary for health and nutrition.
- Tax high-emission products, e.g., ruminant meat and dairy, or tax producers of these products to incentivise reformulation, such as by amending practices to reduce the carbon footprint per portion; subsidise innovation.
- Highlight social trends that normalise PBM consumption.
- Prioritise the production of PBM that can offer simple substitutions of high-volume, high-emission food items such as ground beef.
- Incentivise afforestation of lands released from feed production.

- In low-income countries, the priorities are to support investment in local industry development and research and to develop affordable, nutritious, sustainable forms of meat and protein alternatives.

9.10 Way Forward

Expected growth in meat and dairy consumption in the coming decades will exacerbate climate change, even if farm-level measures lessen GHG emissions. A transition to low-emission diets based on decreasing consumption of livestock products now in high-income countries or in LMICs in the future can accelerate progress towards global climate targets. Reducing beef consumption is a priority due to its high emissions impact. Alternative meat products are one strategy to help this transition, with PBM as the most prominent, quickly growing commercial option available. However, animal-based meat will continue to be important in some areas for its nutritional and economic roles.

Assessing emissions drivers and other environmental and social impacts of meat alternatives can inform future decision-making about sustainable PBM and its climate impact. In the next ten years, reducing land-use change and fossil fuels in alternative meat production will be a priority for minimising climate impacts. Monitoring PBM in diets can verify whether meat substitution is occurring. A more comprehensive analysis of the sustainability impacts of PBM is needed to assess trade-offs, including social dimensions. Comparisons must take better account of the different nutritional values and roles of PBM in diets to understand health impacts.

To achieve the impacts of PBM implemented at large scales will require viable products, effective public policy to catalyse change, and strong markets to expand transitions. Priority actions are to (1) improve the cost, ease, and appeal of alternative meat products for large population segments in all countries; (2) promote policy targets and actions for reduced-meat diets in high- and middle-income countries with excessive meat consumption; (3) use public–private finance to drive more rapid improvements in alternative meat products and their sustainability; and (4) enhance the availability of open-source technologies and the development of business opportunities for alternative meat production in LMICs, including large-scale and small-scale production (Figure 9.3). Research and development can enable the production of meat alternatives that are affordable, nutritious, safe, and appealing to the senses; that are easy to substitute for animal-based meat; that have low environmental impacts; and that are socially just. Improved nutrition and health impacts are foundational to ensure that PBM does not exacerbate existing dietary trends, such as excessive sodium and fat consumption. A vision for achieving low-emission diets is summarised in Figure 9.4.

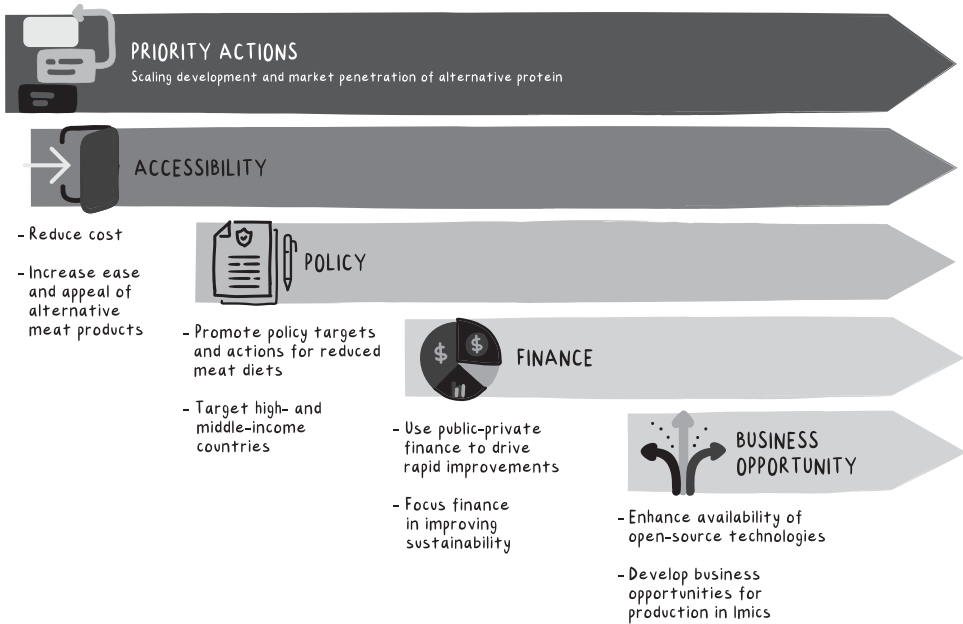


Figure 9.3 Priority actions to scale viable alternative meat products in all countries

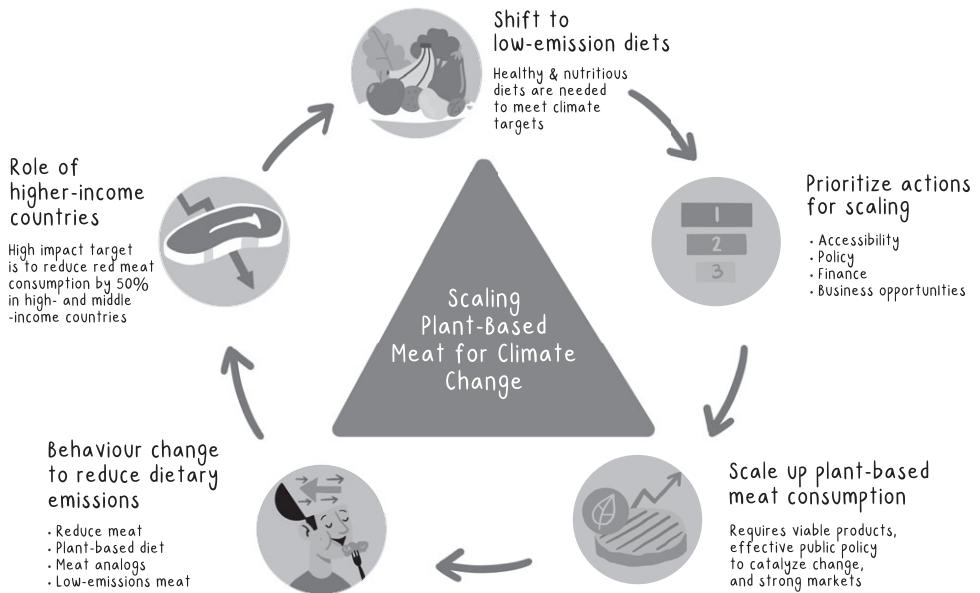


Figure 9.4 A vision for shifting to low-emission diets

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