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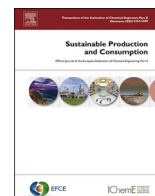
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Review Article

Climate Change Mitigation Potential in Dietary Guidelines: A Global Review

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ABSTRACT

To achieve global and country-level climate goals, changes in food production and population diets are essential. There is a growing attention to environmental sustainability aspects in national Food-based dietary guidelines (FBDG), but less is known about the extent to which different countries communicate food advice with climate change mitigation potential.

A systematic review and quantitative content analysis of food-based dietary guidelines for the adult population were conducted. A score was developed to assess and rank the climate change mitigation potential of FBDG at three levels: food life cycle, dietary patterns, and food groups.

Selection criteria were met by 93 FBDG from 92 countries. Overall, most countries include little low-emissions food advice in their dietary guidelines (Dietary Climate Mitigation score median 31.14, IQR 19.71–39.14, score range 0–100). Scores were significantly higher for high-income countries, guidelines published after 2010, and the 38 countries that explicitly mention environmental sustainability. Recommendations with high climate mitigation potential, such as limiting red meat consumption, are less frequent than those with relatively lower mitigation potential, such as reducing the transport impact of food. Positioning meat within a broader food group, so not as default, and recommending legume intake is already prevalent in most guidelines. Explicit meat replacements, legumes within the protein-rich food group, and maximum intake limits for dairy, meat, and red meat, are included in a growing minority. Future food-based dietary guidelines can be better aligned with human and planetary health by clearly communicating what dietary shifts have limited or substantial climate change mitigation potential.

1. Introduction

Food systems generate a third (range 25 % to 42 %) of the total human-induced greenhouse gas (GHG) emissions that accelerate global warming (Crippa et al., 2021). It is estimated that even in scenarios where all fossil fuel or non-food emissions were net zero, food system emissions alone, if unchanged, would still contribute to exceeding the 1.5 °C target of The Paris Agreement (Clark et al., 2020). To limit the global temperature rise to 1.5 °C or maximum 2 °C above preindustrial levels, countries must also adopt rapid changes in food production and consumption patterns.

Different stages of the production consumption continuum

contribute to the climate impact of food and its potential mitigation. Demand side climate mitigation measures, such as dietary shifts, hold a promising potential compared to supply side interventions, especially in high- and middle-income countries (Costa et al., 2022). While improvements in food production can reduce agricultural GHG emissions by 10 %, dietary shifts offer a reduction potential of up to 80 % (Willett et al., 2019). So far, five countries already include dietary measures in their nationally determined contributions to the Paris Agreement (WWF, 2022).

Food-based dietary guidelines (FBDG) were originally conceived as an evidence-based communication tool to create demand for healthy diets, in an easy to understand way and adapted to the local

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socioeconomic and cultural contexts (FAO/WHO, 1998). Food-based, instead of nutrient-based, advice is meant to help consumer adherence, and to make the most of the epidemiological evidence that links dietary patterns and foods to specific health outcomes and prevention of diseases. The double burden of malnutrition and overnutrition that originally inspired food-based dietary guidelines is still relevant today (Afshin et al., 2019). In addition, climate change is now recognized as one of the biggest threats to global public health and the human health gains of the past 70 years (Horton and Lo, 2015; Romanello et al., 2022).

FBDGs inform a wide range of interventions and policies, including nutrition education, standards for public food procurement, and laws and regulations for health and agriculture. Wijesinha-Bettoni and colleagues found that FBDG influence national school curricula and in the training of health professionals and agricultural extension workers. FBDGs also set standards for public food procurement in school canteens, hospitals, residential centers, and social assistance programs, and are the basis of national laws on food labelling, leading to food industry reformulation, and regulation of junk food marketing (Wijesinha-Bettoni et al., 2021).

Early advocates of considering sustainability in dietary guidelines underlined the inefficient link between the low nutritional value of some foods and their required inputs (natural resources and energy), calling for less energy-intensive diets around local, seasonal, and less processed plant-based foods (Dye Gussow, 1999; Gussow and Clancy, 1986). Other arguments were grounded on the indirect health effects of food system-driven environmental degradation (Tuomisto, 2018), the health co-benefits of environmentally sustainable diets (Willett et al., 2021), and the impact of widespread unsustainable diets on long-term food security (Rose et al., 2019). Despite cases of resistance and unsuccessful attempts (Lang and Mason, 2018), the number of countries reportedly including environmental sustainability in their official dietary guidelines has grown from 4 countries, in 2016, (Gonzalez Fischer and Garnett, 2016) to 37 in 2020 (James-Martin et al., 2022).

Past reviews of environmental sustainability in FBDG included a limited selection of countries (Ahmed et al., 2019; Gonzalez Fischer and Garnett, 2016; James-Martin et al., 2022; Martini et al., 2021b), while reviews of a large number of countries focused on human health (Herforth et al., 2019), or had a narrower scope such as legumes, dairy, or plant-based diets advice (Comerford et al., 2021; Herforth et al., 2019; Hughes et al., 2022; Klapp et al., 2022). Two reviews assessed sustainability of FBDG against the guiding principles for healthy sustainable diets from the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) (James-Martin et al., 2022; Martini et al., 2021b). The WHO/FAO principles combine recommendations traditionally aimed to improve human health, such as breastfeeding or nutrition adequacy, with sociocultural, and environmental sustainability principles, such as biodiversity preservation (FAO and WHO, 2019). This set of principles represent consensus and provide flexible benchmarks applicable to different country contexts, but they still need to be operationalized (Harrison et al., 2022). Also, the environmental impacts of adopting different principles vary widely, from minimizing the use of plastic, or reducing food waste to keeping GHG emissions from agriculture within set targets (Crippa et al., 2021). This underlines the opportunity for considering both operationalization and environmental impact of adoption when assessing dietary recommendations.

This review aimed to assess and rank the environmental sustainability of national dietary guidelines, based on their inclusion of recommended eating behaviors with climate change mitigation potential. A secondary aim was to identify how eating behaviors with climate mitigation potential are operationalized in dietary recommendations for consumers. Finally, it aimed to expand the geographic reach of previous reviews so to provide a comprehensive assessment of the climate mitigation potential of food-based dietary guidelines for adults around the world.

2. A Framework to Assess the Climate Change Mitigation in Dietary Advice

Food-based dietary guidelines were assessed using a set of measures based on the literature on the climate impact of food at three levels: 1) food life cycle (Crippa et al., 2021; Poore and Nemecek, 2018), 2) dietary patterns (Springmann et al., 2020a), and 3) food groups (Clark et al., 2019). Behaviors linked to each level, build on sustainable food consumption behavioral outcomes identified in a previous systematic review of observational studies (Aguirre Sánchez et al., 2021), and expert feedback.

2.1. Food Life Cycle

Life cycle assessment literature provides evidence on how the environmental impacts of food are distributed along each stage of the supply chain (production, processing, packaging, transport, and food waste). While consumers do not have direct control over the supply chain, demand and food consumption have a footprint connected to each of the stages of the production to waste continuum. The assessment of the distribution of anthropogenic emissions along the food supply chain, is based on the EDGAR-FOOD emission database. EDGAR-FOOD was built combining the widely used databases EDGAR and FAOSTAT, which have served as key resources for climate policy and form the basis of the Intergovernmental Panel on Climate Change (IPCC) assessment reports (Crippa et al., 2021). Following the IPCC guidelines for national greenhouse inventories (IPCC, 2006), this emission assessment incorporates human activity data on land use and management practices and country-specific emission factors for specific gases and source categories, which results in sectorial food-systems emission estimates for each country in the world for each individual year, from 1990 to 2015. These results constitute the best available knowledge on food emissions, confirming and advancing the results of a prior comprehensive food emission assessment. Based on 570 life cycle analysis studies, Poore and Nemecek (2018) estimate supply chain global emissions attributable to 40 food products representing ~90 % of global protein and calorie consumption, from ~38,700 farms in 119 countries. Both food emission assessments are referred to throughout this article.

2.1.1. Production

Emissions from land use, and land use change in agriculture contribute to 32 % of total food emissions, and emissions from production (related to fishing, agriculture, and aquaculture) contribute to 39 %, so production is the most climate intensive food stage (Crippa et al., 2021). Consumer behaviors connected with production include choosing organic or otherwise sustainably produced food, such as food certified with sustainable farming or fishing labels. Those behaviors have limited mitigation potential due to the highly heterogeneous efficacy of sustainable production solutions at the regional and farm level (Poore and Nemecek, 2018), e.g., organic farming has lower emissions, but production is less efficient, so the gains in emission reduction would be cancelled by additional land-use change (Smith et al., 2019).

2.1.2. Processing

The share of GHG emissions from food processing is 0.6 Gt CO₂e of the 17.9 Gt CO₂e. If emissions from cooking are included (0.5 Gt CO₂e), emissions reach 6 % of total food emissions on average (Crippa et al., 2021). Consumer behaviors related to this stage can include limiting consumption of ultra-processed foods and using energy-efficient cooking methods. Based on their emissions, the mitigation potential of these behaviors is relatively low compared to other stages of the food life cycle (Arrieta and González, 2019).

2.1.3. Packaging

On average, emissions from packaging are responsible for 6 % of total food emissions (Crippa et al., 2021). A more nuanced analysis

confirms that the footprint of packaging varies considerably across materials (Gallego-Schmid et al., 2019; Korbelyiova et al., 2021), and that plastic emissions do not exceed 10 % GHG emissions for most foods, but liquids, especially carbonated drinks are the exception (Kan and Miller, 2022). Consumer behaviors aimed at reducing the impact of packaging include avoiding bottled drinks, and disposable packaging.

2.1.4. Transport

Transport accounts for 4.8 % of total food emissions (Crippa et al., 2021). Consumer behaviors aimed at decreasing the environmental impact of food transport include eating local and seasonal food to reduce the distance that food travels from the place of production to the consumer. Estimates of food transport emissions increase if they include the transport of agricultural inputs, which are often attributed to the production stage (Li et al., 2022). This analysis focuses on post-farm emissions as they are more relevant for consumer advice. On a fully domestic food consumption scenario, emissions would be reduced by 0.27 Gt CO₂e, or less than 2 % of total food emissions (Li et al., 2022). This underlines the comparatively low climate mitigation potential of favoring seasonal and local foods.

2.1.5. Food Waste

Food waste occurs along all stages of the supply chain, but mainly at the production and distribution stages in low- and middle-income countries and at the retail and consumption stage in high-income countries (Jeswani et al., 2021; Read et al., 2020). Emissions associated with food waste are estimated in 1.6 Gt CO₂e so 9 % of the total (Crippa et al., 2021). Recommendations to reduce food waste at the consumer level include planning food shopping and eating leftovers, provided they are stored safely.

2.2. Dietary Patterns

Dietary shifts are key to reduce food environmental impacts of food consumption. The term dietary pattern refers to the combination and variety of foods in a diet and the quantity or frequency of habitual consumption, which can be assessed a priori, based on modelled combinations of foods, or a posteriori, based on empirically observed population eating patterns (Cespedes and Hu, 2015). Dietary patterns are used to assess human and planetary health, as these different combinations of foods that build diets (e.g., western, Mediterranean, or vegetarian) have been linked to significantly different health and environmental outcomes (Tilman and Clark, 2014). Vegan and vegetarian diets have the lowest climate footprint, compared to other diets (Burke et al., 2023; Görkem ÜÇTUĞ et al., 2021; Scarborough et al., 2014), and to the dietary patterns recommended in FBDG (Springmann et al., 2020a). They are also associated with positive health outcomes compared to prevalent western dietary patterns (Oussalah et al., 2020; Selinger et al., 2022). Therefore, this framework category includes advice related to plant-based diets, as eating behaviors related to meal planning and choice of meat and dairy substitutes are essential for vegan and vegetarian patterns that mitigate climate impacts without compromising nutritional quality (Melina et al., 2016; Mertens et al., 2021; Saget et al., 2020).

2.3. Food Groups

Selection and intake quantities of critical food groups are efficient parameters to mitigate climate dietary impacts because different foods, even within the same food group, produce substantially different amounts of GHG emissions. This means that even under sustainable production practices, foods with high climate footprint, such as ruminant meat, largely exceed the footprint of low emission foods under conventional production, e.g., beef produces 10 times the GHG emissions of poultry, and 35 times the emissions of legumes, per kilogram (Poore and Nemecek, 2018). Food groups with the highest GHG

emissions per serving are, in this order, processed red meat, unprocessed red meat, dairy, fish and chicken, while unprocessed vegetables, fruits, nuts, whole grains, and legumes have a comparably lower climate impact (Clark et al., 2019). Legumes, along with nuts, have the lowest climate impact among protein-rich foods and are associated with positive health outcomes (Martini et al., 2021a; Reynolds et al., 2023; Svanes et al., 2022). Legumes also produce climate mitigation benefits, such as soil carbon sequestration, and biological nitrogen fixation, which lowers the need for synthetic fertilizers (Stagnari et al., 2017). Based on their relevance for human-planetary health synergies, this framework assesses dietary recommendations for meat, red meat, dairy and legumes. Key eating behaviors related to this category include the choice of protein sources with lower climate impact, and moderate consumption of dairy and meat, especially ruminant meat, without exceeding the upper-level intake limits recommended by the planetary health reference diet (Willett et al., 2019).

3. Methods

We conducted a systematic review and quantitative content analysis of food-based dietary guidelines for the adult population. A score was developed to assess and rank the climate mitigation potential of FBDG at three levels: food life cycle, dietary patterns, and food groups. Applicable PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for reporting were followed (Page et al., 2021).

3.1. Search Strategy and Selection Criteria

All countries that have published food-based dietary guidelines (FBDG) were eligible for inclusion. Available FBDG were first identified on 27 July 2021 from the database of the Food and Agriculture Organization of the United Nations (FAO) and the study by Springmann et al. (2020b). After the data extraction tool was piloted with a subset of 28 countries and refined, the FAO source database was searched on 11 April 2022 for updates. Documents were accessed and downloaded from the FAO website, from 11 to 19 April 2022, and those not available were searched in Google using the terms “Food-based dietary guidelines” AND “[country name]”, between 20 and 26 April 2022.

Dietary guidelines were selected when the following criteria were met: The guidelines targeted the adult population; were publicly available online or by request; were available in a file format that allowed keyword search and automated translation to English; and were the latest release. The guidelines were excluded if they were addressed to a population sub-group such as infants, children, adolescents, pregnant or breastfeeding women, or elderly adults. If a document was not publicly available online, the relevant country institution was contacted to request the document, allowing a 4-week waiting time before the end of the data extraction phase. Document files that did not allow keyword search, particularly those that consisted of scanned images, went through an image-to-text conversion tool. The available PDF documents of guidelines not published in English were translated using Google Translate. The FAO database was constantly consulted for updates during data extraction. This resulted in the inclusion of the 2022 FBDG from Ethiopia, retrieved on 4 June 2022.

3.2. Data Extraction

Based on the proposed framework (Section 2, above) a data extraction tool was developed to collect dietary recommendations at the three levels of climate impact: food life cycle, dietary patterns, and food groups. The data extraction tool was programed in the web-based survey tool Qualtrics to facilitate a uniform extraction of textual contents, numeric data entry and multiple selection for categorical variables. Unique survey links were created for all countries and divided among the review team. The extraction of each variable was aided by written

instructions and specific keyword search terms. Data extraction was conducted using the original English and English translated documents. In cases of uncertainty about the translation, reviewers verified it with a second translation tool or referred to the original language documents. Language proficiency of the review team included Arabic, English, French, German, Indonesian, Italian, Portuguese, and Spanish. Each FBDG document was extracted by one researcher and verified by a second researcher. Discrepancies were documented, discussed, and solved by agreement or a third researcher. Data extraction took place from 15 April to 6 June 2022. Data for each FBDG included country, year of publication, and mentions to food security, food safety, animal welfare, and environmental sustainability. The food life cycle section of the tool included variables such as the presence of explicit mentions to each sub-category from production to waste, and if information (facts) and/or actionable recommendations were included. The dietary patterns section investigated whether FBDG included any explicit guidance for sustainable diets, recommendations for people following plan-based dietary patterns (vegan or vegetarian), as well as recommended meat and dairy substitutes, and whether they were framed as encouraged, explicit, implicit, or discouraged. The food groups section examined the presence of advice for meat, red meat, dairy and legumes, type of recommendation (reduce, limit, neutral, ensure or increase), and mentions of intake ranges in grams, and/or number of servings. Upper food intake limits for dairy, meat, and red meat were coded, and whether those intakes exceeded the planetary health reference diet recommended limits (Willett et al., 2019). How foods were positioned within food groups, and whether they were considered as a default or optional part of a healthy diet was also coded.

3.3. Data Analysis

Content analysis was performed in a subset of 28 countries to identify dietary recommendations with climate mitigation potential within each framework category presented in Section 2 above. After data reduction, the resulting unique recommendations were converted into the values of categorical variables, which allowed the subsequent quantification of relevant recommendations in the complete sample.

An overall score of Dietary Climate Mitigation (DCM) was developed to assess the extent to which different countries incorporate climate mitigation in their food advice. The score is composed of three independent sub-scores based on the assessment framework categories: Food Life Cycle Mitigation (FLCM), Dietary Patterns Mitigation (DPM), and Food Groups Mitigation (FGM).

The DCM score was developed in a two-stage process. In the first stage, points were assigned based on the presence or absence of specific contents in the data extraction tool, according to the defined framework categories. For each binary (yes/no) variable (e.g., presence of sustainable food production information, or presence of upper-level intake limits for meat and dairy) one point was allocated. The scoring system, including a comprehensive list of variables, possible values, and the corresponding allocated points, can be found in the supplementary information (Supplementary information – SI. Table 1).

The three independent sub-scores were calculated and scaled on a range of 0 to 100. At this stage, no weighting was considered. In the second stage, the overall score was determined by combining the three sub-scores. To prevent an underestimation of dietary recommendations with high climate mitigation potential, weights were incorporated into the score formula. The overall DMC score assigns a lower weight to the FLCM sub-scores and higher weights to DPM and FGM sub-scores (See Tables 1 and 2).

A ranking was created to synthesize the weighted score results and map visualizations were used to illustrate the differences between the three unweighted sub-scores. Descriptive statistics summarized numeric variables and Wilcoxon signed-rank tests determined significant score differences based on explicit mention of environmental sustainability, publication year and country income, as per World Bank classification

Table 1

Weighted and unweighted formulas for Dietary Climate Mitigation (DCM) Score (scaled from 0 to 100).

Score	Formula
Unweighted	Dietary Climate Mitigation Score = (Sub-Score Food Life Cycle Mitigation*0.333) + (Sub-Score Dietary Patterns Mitigation*0.333) + (Sub-Score Food Groups Mitigation*0.333)
Weighted	Dietary Climate Mitigation Score = (Sub-Score Food Life Cycle Mitigation*0.2) + (Sub-Score Dietary Patterns Mitigation*0.4) + (Sub-Score Food Groups Mitigation*0.4)

Table 2

Sub-Score weighting (in %) for Unweighted Score and Weighted Score.

Sub-score	Unweighted (%)	Weighted (%)	Difference in sub-score weighting between Unweighted and weighted sub-scores (%)
Food Life Cycle Mitigation	33.33 %	20 %	-13.33 %
Dietary Patterns Mitigation	33.33 %	40 %	+6.67 %
Food Groups Mitigation	33.33 %	40 %	+6.67 %
Total	100 %	100 %	0 %

(The World Bank, 2022). Map visualizations were generated with the web-based tool Datawrapper. Statistical analyses were carried out using the STATA/MP version 16 (StataCorp, College Station, TX, USA).

4. Results and Discussion

This review assessed and scored most of the existing national food-based dietary guidelines, based on their inclusion of recommendations that mitigate the climate impact of food consumption across three categories: the food life cycle, dietary patterns, and food groups. These results advance the work of reviews that have assessed broad sustainability considerations in food advice (Gonzalez Fischer and Garnett, 2016; James-Martin et al., 2022; Martini et al., 2021b), as well as reviews that focused on specific aspects covered within our sub-scores categories (Comerford et al., 2021; Hughes et al., 2022; Klapp et al., 2022).

4.1. Sample Characteristics

The search for FBDG resulted in 100 eligible Guidelines from 99 countries, as Belgium provides separate guidelines for the Flemish population. After further screening, 93 FBDG from 92 countries met the inclusion criteria and were included in the review (See Fig. 1, for PRISMA flowchart). Publication dates or latest update year ranged between 1991 and 2022, with 76 % of the guidelines published after 2010 (See SI. Table 2 for a list of selected FBDG). Results reported for “countries” include the guidelines of a subnational region (e.g., Belgium-Flemish).

Food safety is mentioned in 59 guidelines (63 %), food security in 28 (30 %), and animal welfare in eight (9 %). The link between environmental sustainability and food consumption is explicitly acknowledged in the guidelines from 38 countries (41 %), with the earliest appearance in 2010 (Japan), and the most recent in 2022 (Ethiopia).

4.2. Contents and Frequency of Recommendations

We identified dietary recommendations with climate mitigation potential across the three main Dietary Climate Mitigation categories (See SI. Table 3). Recommendations ordered by frequency are shown in Fig. 2.

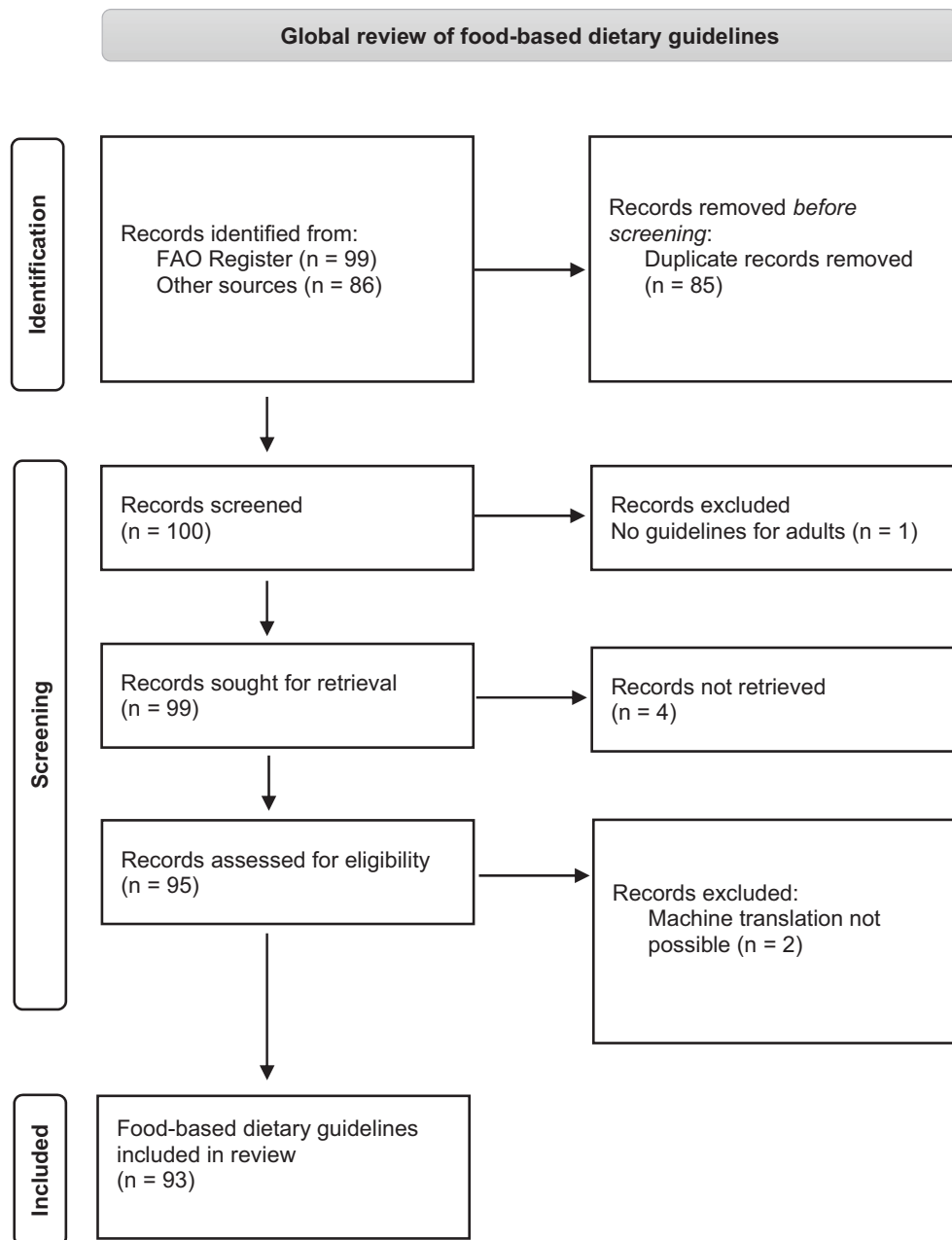


Fig. 1. Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flowchart for selected food-based dietary guidelines (Page et al., 2021).

4.2.1. Food Life Cycle Recommendations: From Production to Waste

In 74 of the reviewed FBDG (80 %) eating behaviors linked to at least one of the stages of the food life cycle were addressed, and 15 (16 %) covered all of them: production, food transport, processing, packaging, and waste. Guidelines that included at least one recommendation falling into the transport category, were the most frequent (59[63 %]), followed by processing (47[51 %]), food waste (34[37 %]), packaging (28 [30 %]), and finally production (14[15 %]) (See Fig. 2, part A). From a content perspective, the most frequent explicit sub-category of recommendations was related to the transport footprint (59[63 %]). This mainly refers to the advice of choosing local and seasonal foods, which has limited climate mitigation potential since transport contributes to 4.8 % of global food emissions (Crippa et al., 2021). Most transport emissions occur on local or regional transport by road (81 %) or rail (15 %), which can also occur for local and seasonal food products. Other transport emissions come from navigation (3.6 %) or aviation (0.4 %) (Crippa et al., 2021). Despite its relatively low climate mitigation

potential, eating seasonal and local foods has other economic, social and health benefits that can be still communicated in dietary guidelines.

Our results partially align and expand those of past reviews. Martini et al. and James-Martin et al., reviewed 43 and 37 FBDG guidelines respectively using the 16 WHO/FAO guiding principles of sustainable healthy diets (James-Martin et al., 2022; Martini et al., 2021b). The WHO/FAO principles cover health, environmental, and sociocultural impacts, partially overlapping with our review, which focused on environmental impact. Our review mapped the inclusion of consumer recommendations aimed at reducing impacts of food production and transport, which are not explicitly included in the WHO/FAO principles although are arguably covered within the ninth principle (“maintain greenhouse gas emissions, water and land use, nitrogen and phosphorus application and chemical pollution within set targets”). In our analysis, the most frequent recommendations are related to the environmental impact of transport ($n = 59$), however this aspect does not exactly match any of the principles evaluated in past reviews.

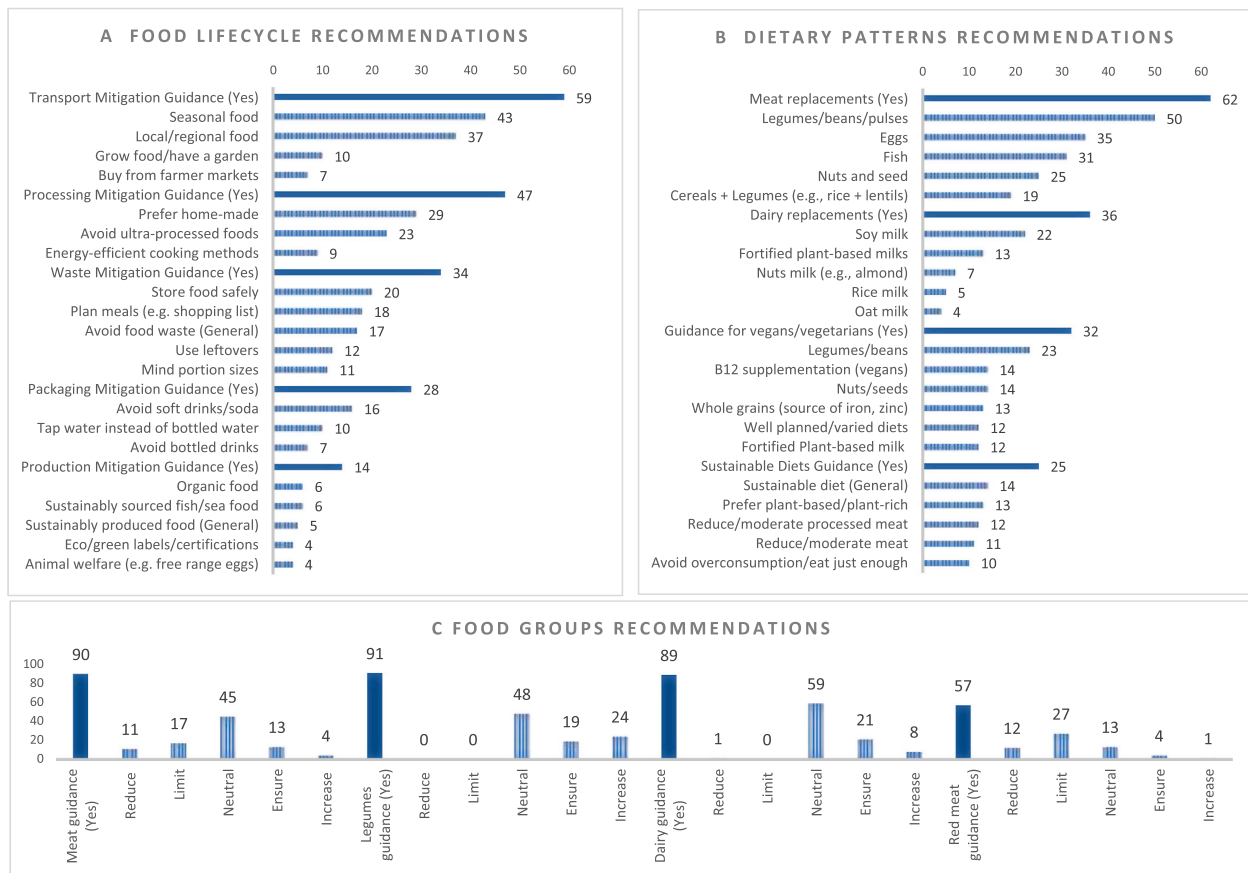


Fig. 2. Recommendations across the three main Dietary Climate Mitigation (DCM) categories. Solid lines quantify the presence of at least one recommendation within framework sub-categories, and dashed lines quantify the frequency of each recommendation within framework sub-categories, in descending order.

4.2.2. Dietary Patterns Recommendations: Plant-based Diets and Relevant Substitutes

More than half of the guidelines provide recommendations for meat replacements (62[67 %]), although only 38 (41 %) constitute explicit (24[26 %]) or encouraged advice (14[15 %]). Common meat replacements include legumes/beans/pulses (50[54 %]), eggs (35[38 %]), nuts and seed (25[27 %]), and a mix of cereals and legumes (19[20 %]). A third of the countries provide dairy replacements (36[39 %]), of which 23 (28 %) are explicit, and 10 (12 %) implicit. No guidelines encourage dairy replacements and 3 (4 %) discourage them. Common dairy replacements include soy milk (22[24 %]) and other fortified alternatives (13[14 %]). Explicit advice addressed to people following a vegetarian or vegan diet was provided in 32 (34 %) countries. The most common recommendations for vegans or vegetarians are consumption of legumes/beans (23[25 %]), B12 supplementation for vegans (14[15 %]), and the consumption of nuts/seeds (14[15 %]). (See Fig. 2, part B).

Our results align with those of Klapp et al. (2022), as we also found that most countries do not provide specific recommendations compatible with plant-based diets (vegan and vegetarian), and their mean score of plant-based diets and animal food substitutes (33.58) is close to our relevant mean sub-score (36.46). The difference in the number of FBDG that address vegetarian diets (n = 38 in their study, n = 32 in ours) is likely due to coding systems: Klapp et al. (2022) report the number of countries that contain a position on vegetarian diets while this study counts FBDG that provide actionable dietary recommendations compatible with vegan or vegetarian diets.

James-Martin et al. (2022) report that plant-based foods, and animal-based foods were the most addressed principles (n = 23 each), which could be comparable to the guidance for vegans and vegetarians (n = 39), or the advice of reducing or moderating meat in our analysis (n =

28). The differences may be due to differences in sample sizes, but the increase is not proportional, which confirms our result that plant-based related advice is more prevalent in guidelines that explicitly mention environmental sustainability.

4.2.3. Key Food Groups Recommendations: Meat, Dairy and Legumes

In 79 (85 %) guidelines, meat is positioned as part of a broader food group so it can be implicitly exchanged for other foods. Reducing or limiting red meat consumption is recommended in 39 (42 %) countries, and 28 (30 %) recommend reducing or limiting meat in general. In 32 (34 %) countries, dairy is positioned as part of a broader food group so it can be exchanged for other foods. Only one country recommends reducing dairy consumption, while 21 (23 %) countries recommend ensuring at least a certain amount and eight recommend increasing consumption. Out of the 91 guidelines that mention legumes, also called pulses or beans, 41 (44 %) classify legumes as part of a protein-rich food group, 11 (12 %) present it as a starchy food and 8 (9 %) as vegetables, 19 (20 %) recommend ensuring the consumption, and 24 (26 %) increasing consumption (See Fig. 2, part C).

Like our analysis, Comerford et al. (2021) found that in most FBDG, dairy foods are classified as a separate food group and as a default part of the diet. However, proportions vary between FBDG that classify dairy as a distinct food group (three quarters in their review versus two thirds in ours) and those that include dairy as part of a broader food group (one quarter in their review versus one third in ours). This difference is likely due to the period of data extraction, since 15 new dietary guidelines were released between 2020 and June 2022. This may indicate a trend towards positioning dairy as an exchangeable part of a broader food group. Our results align with Hughes et al. (2022), as legumes are most often categorized in the protein-rich food group, followed by a separate

food group, the starchy staples group and less often as a vegetable. Small differences in the distribution (e.g., $n = 33$ in their review, $n = 41$ in ours for the protein group, $n = 17$ versus $n = 23$ for the separate group, and $n = 13$ versus $n = 11$ for the starchy group) may be attributable to differences in the data extraction periods, which may indicate that more countries now frame legumes within the protein rich group. Presentation of legumes within the protein rich, instead of the starchy or vegetable food groups, would be more compatible with human-planetary health synergies, since the mix of cereals and legumes reach similar nutritional quality to meat protein (Marinangeli and House, 2017). Since food groups in dietary guidelines are by convention complementary, they should also reflect the dietary complementarity between plant-based protein sources (Ferrari et al., 2022).

Existing evidence of the health and environmental synergies of adherence to plant-based diets with moderate intake of meat and dairy (Melina et al., 2016; Willett et al., 2019), is not yet reflected in most dietary guidelines. While moderated amounts of meat and red meat are recommended in more than a third, few recommend reducing or moderating the intake of dairy products and recommended amounts vary so widely that they are unlikely to be based entirely on health evidence but other cultural or socioeconomic factors. For example, there is evidence that the presence of recommendations related to plant-based diets and meat and dairy substitutes in guidelines correlates negatively with the importance of animal-based products in their economies (Klapp et al., 2022). In low-income settings, dairy foods can improve nutrition, while increased dairy intake does not provide equal benefits in less constrained settings with access to higher diet quality (Willett and Ludwig, 2020). There is therefore a large margin of action to adapt meat and dairy recommendations to meet planetary health limits, especially in regions where current intakes of meat already exceed healthy recommended limits (Springmann et al., 2020b).

Our assessment of the key food group sub-category is based on the rationale that specific food choices and intake quantities are essential parameters for dietary climate mitigation. This is compatible with results that show that 39 (42 %) countries suggest reduced or moderate levels of red meat consumption and that most positioned meat and dairy as exchangeable parts of the diet and legumes as part of the protein-rich food group. There is however a large gap when it comes to food intake quantities, as few FBDG provide upper limit intake recommendations for meat, red meat, and dairy, and even fewer of those are below the planetary health reference diet limits (See SI. Table 4).

4.3. Upper-Level Intake Limits Compared to Planetary Health Limits

A minority of FBDG recommended maximum intake limits in grams for meat, red meat, or dairy, and some of them exceed EAT-Lancet planetary health reference diet limits (Willett et al., 2019) (See Table 3). In 22 (24 %) countries upper-level limits for dairy in number of servings are provided, ranging from a maximum of 2 to 4 servings per day (mean 3 [SD 0.69]), while 11 (12 %) countries provide upper-level limits in grams, ranging from 300 to 960 g per day (575-45 [SD 198.71]), of which five exceed planetary health recommended limit of 500 g per day of dairy in milk or equivalents.

Upper-level limits for meat in number of servings are provided in 13 (14 %) countries, ranging from maximum three to 28 servings per week (mean 7.23 [SD 7.03]), and upper-level limits in grams are present in 10 (11 %) countries, ranging from a maximum of 300 to 1120 g/week (558 [SD 216.75]), of which two exceed planetary health diet meat limit of 602 g/week. Ten (11 %) countries provide upper-level limits for red meat in number of servings, ranging from one to seven servings per week (mean 3.20 [SD 2.15]), while 22 (24 %) countries provide upper-level limits in grams, ranging from 150 to 560 g per week (423.33 [SD 129.40]), of which 18 (19 %) exceed planetary health diet limit of 196 g of red meat per week.

To sum up, dietary guidelines are within the planetary health reference diet limits for meat in eight of the ten countries that provide

Table 3

Alignment between National Dietary Guidelines and Planetary Health reference diet upper limit intake recommendations for selected food groups (Willett et al., 2019). Number of countries (n), percentage of countries (%).

	n	%
Dairy - Maximum intake in grams not provided	82	88.17
Dairy - Maximum intake in grams provided	11	11.83
Dairy - Maximum intake in grams provided is within Planetary Health recommended limit	6	6.45
Dairy - Maximum intake in grams provided exceeds Planetary Health recommended limit	5	5.38
Meat - Maximum intake in grams not provided	83	89.25
Meat - Maximum intake in grams provided	10	10.75
Meat - Maximum intake in grams provided is within Planetary Health recommended limit	8	8.60
Meat - Maximum intake in grams provided exceeds Planetary Health recommended limit	2	2.15
Red Meat - Maximum intake in grams not provided	72	77.42
Red Meat - Maximum intake in grams provided	21	22.58
Red Meat - Maximum intake in grams provided is within Planetary Health recommended limit	2	2.15
Red Meat - Maximum intake in grams provided exceeds Planetary Health recommended limit	19	20.43

relevant maximum intake limits in grams, for dairy in six countries of the 11 that provide relevant limits, and for red meat in two of the 21 countries that provide relevant limits. Guidelines that provide upper-level intake limits for red meat are compatible with the large body of evidence on the association between high red meat consumption and adverse health outcomes, especially cardiometabolic and cancer risk (Grosso et al., 2022), including evidence available before the publication year of most dietary guidelines (Norat et al., 2002).

4.4. Dietary Climate Mitigation Score

The overall score of Dietary Climate Mitigation (DCM) in FBDG ranged from four to 84, (mean 33.42, median 31.14, SD 18.29, IQR 19.71–39.14, range of variation 80, score range 0–100). A Wilcoxon Mann–Whitney test indicates that the DCM score was significantly higher in high-income countries ($Z = -3.252$, $p < 0.01$), guidelines published after 2010 ($Z = -3.509$, $p < 0.001$), and those that explicitly recognize an environment-diet link ($Z = -5.919$, $p < 0.001$). The year 2010 was considered as a relevant cut-off year as it is when FAO first published a consensus definition of “sustainable diets” (FAO, 2010). Low DMC scores from countries that published their official dietary guidelines before 2010, some of which are low-income countries, must be interpreted with caution. The highest ranked guidelines are from Belgium-Flemish, Australia, Zambia, Israel, and Spain (See full ranking on Table 4).

Only 20 (22 %) of the 93 guidelines included in this review reached 50 points or above in the Dietary Climate Mitigation (DCM) Score. The number decreases to 12 (13 %) FBDG for the Food Groups Mitigation (FGM) sub-score, the category of recommendations with the highest climate mitigation potential. The Food Life Cycle Mitigation (FLCM) sub-score ranged from 0 to 90 (mean 30 SD 24.49), the Dietary Patterns Mitigation (DPM) sub-score ranged from 0 to 100 (mean 36.46, SD 30.26), and the Food Groups Mitigation (FGM) sub-score ranged from 10 to 75 (mean 32.15 SD 12.81). (See SI. Table 5). This shows that while all FBDG attained at least 10 points in the FMG sub-score, related to recommendations that lower the climate impact of key foods such as meat, red meat, and dairy, most countries do not mention at least a half of the assessed recommendations. The Food Life Cycle Mitigation (FLCM) sub-score ranged from 0 to 90 (mean 30 SD 24.49), the Dietary Patterns Mitigation (DPM) sub-score ranged from 0 to 100 (mean 36.46, SD 30.26), and the Food Groups Mitigation (FGM) sub-score ranged from 10 to 75 (mean 32.15 SD 12.81). (See SI. Table 5). The geographic distribution of the three main sub-scores is represented in Fig. 3.

The FGM sub-score has the lowest degree of variation and tend to

Table 4
Country ranking. Weighted score of dietary climate mitigation (Range 0–100).

Country	Year	Dietary Climate Mitigation Score (weighted)
Belgium- Flemish	2021	84.00
Australia	2013	76.00
Zambia	2021	76.00
Israel	2020	74.00
Spain	2016	70.00
Netherlands	2020	66.57
Seychelles	2020	66.29
Denmark	2021	64.00
Sweden	2015	64.00
United Kingdom	2016	60.29
Switzerland	2011	60.00
Estonia	2015	56.86
Italy	2019	56.57
New Zealand	2020	56.57
Qatar	2015	56.57
Greece	2017	54.57
Malta	2016	52.86
Canada	2019	52.57
France	2019	51.14
Brazil	2015	50.86
Benin	2015	42.57
Belgium-French	2020	41.43
Iceland	2014	39.14
China	2016	39.14
Lebanon	2013	39.14
Cyprus	2007	38.86
El Salvador	2012	38.86
Romania	2006	38.57
Bulgaria	2006	37.43
Albania	2008	37.14
Malaysia	2020	37.14
Paraguay	2017	37.14
Chile	2013	37.14
Colombia	2020	37.14
Germany	2017	35.71
Mexico	2015	35.43
Norway	2014	35.14
Uruguay	2016	35.14
Thailand	1998	34.86
Latvia	2020	33.14
Argentina	2016	33.14
United States of America	2020	32.86
South Africa	2013	31.71
Slovenia	2015	31.43
Ecuador	2021	31.43
Indonesia	2014	31.14
Barbados	2017	31.14
Ethiopia	2022	29.71
Sri Lanka	2011	29.43
Oman	2009	29.43
India	2011	29.14
Finland	2014	27.71
Costa Rica	2010	27.71
Sierra Leone	2016	27.71
Cuba	2009	27.43
Grenada	2006	27.43
Turkey	2016	27.43
Afghanistan	2016	25.71
Bangladesh	2013	25.43
Poland	2020	25.43
Jamaica	2015	25.43
R. B. de Venezuela	1991	25.43
Honduras	2013	25.14
Saudi Arabia	2012	23.43
United Arab Emirates	2019	23.43
Ireland	2016	23.43
Kenya	2017	22.00
Portugal	2003	21.71
Guatemala	2012	21.43
Slovak Republic	2016	19.71
Guyana	2018	19.71
Bolivia	2014	19.43
Austria	2010	18.00

Table 4 (continued)

Country	Year	Dietary Climate Mitigation Score (weighted)
Georgia	2005	18.00
Peru	2019	18.00
Japan	2010	18.00
North Macedonia	2014	15.71
Belize	2012	14.00
Republic of Korea	2016	14.00
Philippines	2012	12.00
Saint Kitts and Nevis	2010	12.00
Dominican Republic	2015	12.00
Fiji	2013	12.00
Bosnia and Herzegovina	2004	12.00
The Bahamas	2002	10.00
Saint Lucia	2007	10.00
Antigua and Barbuda	2013	10.00
St. Vincent & The Grenadines	2006	10.00
Panama	2013	10.00
Hungary	2016	9.71
Dominica	2007	8.00
Namibia	2000	8.00
Nigeria	2006	4.00

converge on a low score range (median 30 IQR 20–40). In contrast, the FLCM sub-score (median 20 IQR 10–50), and the DPM sub-score (median 28.57 IQR 14.28–57.14) vary widely across countries. The lowest FGM sub-score is 10, attained in three (3 %) countries, 18 (19 %) countries score 0 for the FLCM sub-score, and 20 (21 %) countries score 0 for the DPM sub-score. At the same time, 25 (27 %) countries reach FLCM and DPM sub-scores ≥ 50 , versus 12 (13 %) countries reaching ≥ 50 for the FGM sub-score (See Fig. 4). This shows that a greater presence of guidance linked to the food life cycle stages, and guidance that support those following plant-based diets, improves the Dietary Climate Mitigation assessment for the specific group of countries that already consider those aspects. However, there is an overall low attainment of recommendations with the highest climate mitigation potential, such as those that lower the climate footprint of key food groups like meat and dairy, and increase the mitigation benefits of foods such as legumes. FBDG that considered sustainability according to Gonzalez Fischer & Garnett's analysis from 2016 (Germany, Brazil, Sweden, and Qatar) are still among the 38 that address environmental sustainability in this study. However, they rank just above the average for the food groups category, so although they address environmental sustainability, their food intake recommendations could be more aligned with planetary health. Based on the dietary patterns sub-score of 36.46, we interpret an overall low policy support of recommending plant-based diets. Only 32 (34 %) of the 93 guidelines included in this review provide actionable recommendations for vegans and vegetarians, such as ensuring legumes intake, or B12 supplementation for vegans (See Fig. 2). These recommendations can ensure the dietary quality for those already following or intending to adopt dietary patterns with low climate impact.

4.5. Opportunities to Align Consumer Food Advice With Climate Change Mitigation

We found that some recommendations aligned with climate change mitigation, and health co-benefits, are already the norm for the majority of the reviewed dietary guidelines: recommending legume (pulses) consumption, positioning meat as part of a broader food group so it can implicitly be exchanged for other foods, and recommending water as the fluid of choice. Future dietary guidelines can benefit from including advice, that is already offered by a growing minority of countries, such as providing explicit meat replacements, positioning legumes as part of the protein-rich food group, and providing maximum intake limits for dairy, meat and red meat, that ideally align with planetary health reference diet maximum intake limits (Willett et al., 2019).

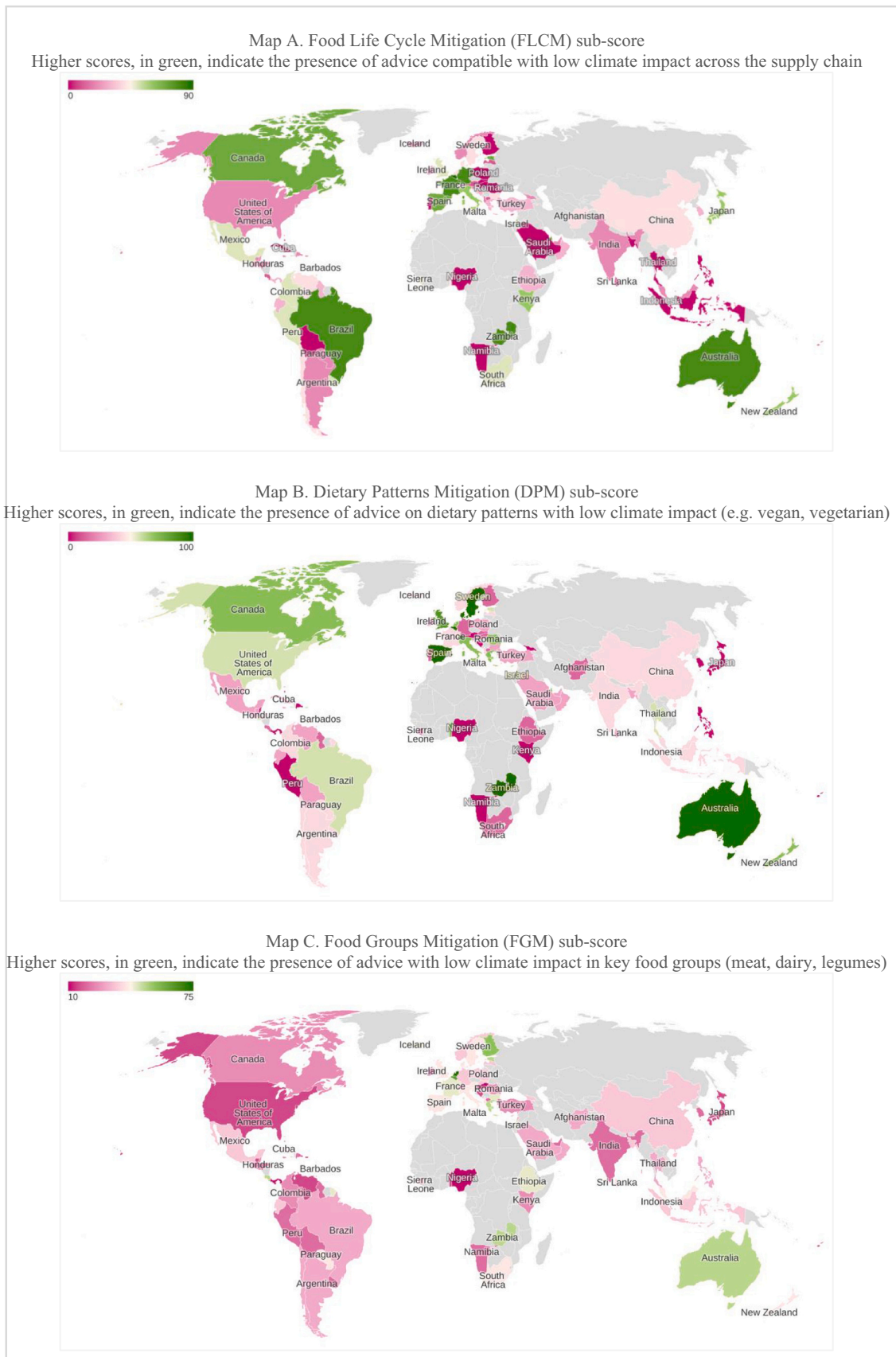


Fig. 3. Geographic distribution of Dietary Climate Mitigation sub-scores. Lowest sub-scores are in magenta and highest sub-scores are in green. Intense green represents a higher presence of recommendations with climate change mitigation potential for the relevant sub-score. Countries in grey were not included in the review, either because they do not release official dietary guidelines or did not meet the inclusion criteria.

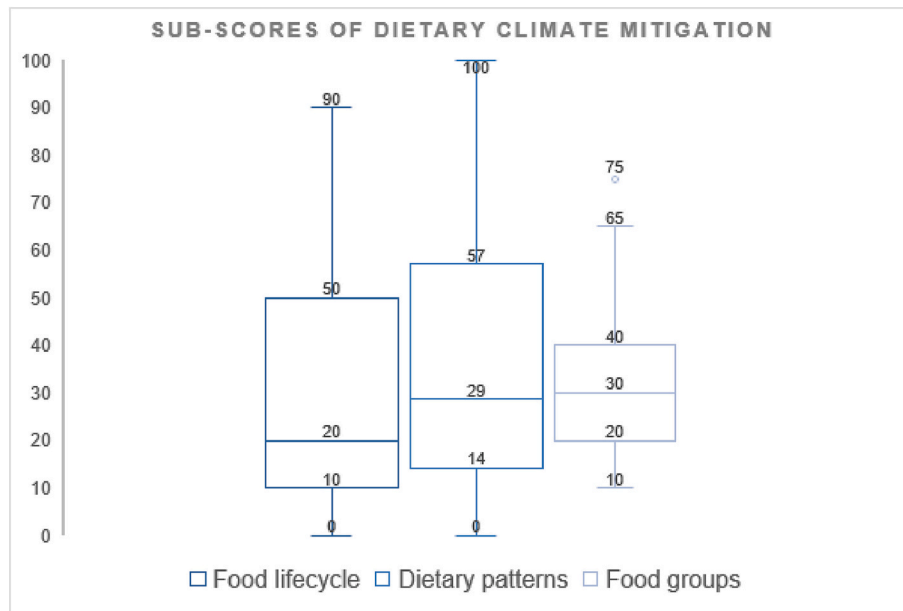


Fig. 4. Comparison of Dietary Climate Mitigation Sub-scores in food advice. From top to bottom: maximum value, upper quartile, median, lower quartile, minimum value.

From a consumer perspective, recommendations to adopt food products from more sustainable supply chains (e.g., organic, seasonal, local, less packaging) currently have a limited climate mitigation potential compared to dietary shifts. This is because carbon-intensive foods, such as meat or dairy, even when sustainably produced, largely exceed the impact of less carbon intensive foods, such as legumes or nuts (Poore and Nemecek, 2018). In the future, these food system constraints could be overcome by the widespread adoption of innovations such as circular agriculture (Frehner et al., 2022), which are not yet in place. Even as more sustainable food supply options become available, the effective consumer adoption, and the relevance of related advice in national dietary guidelines, would require additional measures. These can range from improved transparency for consumers about the climate impacts of the food life cycle, via information-based interventions such as food labels, to market-based interventions such as food carbon taxes (Ammann et al., 2023; Bunge et al., 2021; García-Muros et al., 2017). Communicating the climate impacts of different foods, would also align with available behavioral evidence showing that common pro-environmental behaviors are often weakly correlated with environmental impact (Bleys et al., 2018; Jagers et al., 2017; Kennedy et al., 2013; Moser and Kleinhüchelkotten, 2018; Wynes et al., 2018), and consumers tend to incorrectly estimate the environmental impact of their behaviors (MacCutcheon et al., 2020; Pasca, 2022; Sörqvist and Holmgren, 2022; Wynes et al., 2020).

4.6. Limitations

To our knowledge, this is the most comprehensive review of an environmentally relevant aspect of food-based dietary guidelines (climate mitigation) and with the largest geographical coverage. However, this review focuses on environmental sustainability impact and not on other social, cultural, and economic sustainability aspects of dietary advice. Also, other key food environmental impacts, or planetary boundaries beyond climate change, such as land use, water use, or biodiversity loss, are not included. Yet, greenhouse gas emissions is the most frequent indicator to measure the environmental footprint of food (Harrison et al., 2022), and there is a strong correlation between GHG and other adverse environmental impacts (van Dooren et al., 2018). Food groups that were not included for this analysis can also be key for environmental sustainability, especially since they can act as meat

replacements such as nuts, fish, or eggs. However, in depth analysis for other food groups are available elsewhere (Herforth et al., 2019). The list of recommendations resulting from the content analysis, can serve as an inventory of dietary advice with climate mitigation potential that can be feasibly adapted by different countries. However, this list is not exhaustive. Since the recommendations have been extracted from existing guidelines, recommendations linked to emerging sustainable food innovations, such as edible insects, or cultured meat, did not appear in our analysis.

Finally, an intrinsic limitation of food-based dietary guidelines is that foods are grouped in a way that can be relevant for health impacts but not for climate impact. The definition of “red meat” which includes lamb, beef, and pig meat is often grouped, arguably because recommendations are based on health factors (promotion and disease prevention). However, there are substantial differences in the environmental impacts of beef and pig meat that could not be included in the assessment because FBDG rarely differentiate them.

4.7. Future Research and Policy Implications

To advance the understanding of dietary climate mitigation potential of official food advice, regional or country-level studies are needed. Future studies may explore the Dietary Climate Mitigation assessment results provided in this review, in relation to the country-specific climate impact share of the food sector. This can help identify the specific food sectors and actions that represent the highest potential gains for climate change mitigation in local contexts. Regional and country-level studies are also needed in public health research to assess how the Dietary Climate Mitigation potential in food-based dietary guidelines relates to observed population diets and current nutritional needs. Prevalent dietary patterns may already adhere, exceed or be below human and planetary health dietary requirements in different countries. Dietary climate mitigation potential also needs to be evaluated against local burdens of overnutrition and undernutrition that can vary widely across countries and sub-national regions. Practitioners and institutions responsible for updating food-based dietary guidelines in countries that already have the intention to integrate environmental considerations into their dietary advice, can benefit from an impact-driven approach to increase the responsiveness of dietary advice to human and planetary health. This can include communicating the dissimilar environmental

footprints of different foods, providing specific quantitative intake limits compatible with human and planetary health, in addition to general principles, and providing guidance to ensure a healthy diet among consumers who choose to adopt dietary shifts for environmental reasons.

5. Conclusion

This review provided an assessment and ranking of the environmental sustainability in most of the existing national dietary guidelines for the adult population, focusing on the inclusion of dietary recommendations with climate change mitigation potential. Overall, based on the Dietary Climate Mitigation (DCM) score, the reviewed dietary guidelines show a low attainment of recommendations that can lower the climate impact of population diets (median 31.14 IQR 19.71–39.14, score range 0–100). From a content analysis perspective, we found that dietary guidelines address eating behaviors with low and high climate mitigation impact, but most can improve. Recommendations with high climate change mitigation potential and health co-benefits, such as limiting red meat intake quantities, are less frequent than those with relatively lower mitigation potential, such as the advice to reduce food transport impact (e.g., eating local and seasonal foods). Moving forward, an impact-based approach to the design and update of future dietary recommendations can result in food-based dietary guidelines that are better aligned to national health and environmental goals.

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Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the final preparation of this work the authors used OpenAI (2021) ChatGPT [Software] (Version May 24, 2023) to check selected sentences for grammar and readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Lucía Aguirre-Sánchez: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization, Project administration. **Ronja Teschner:** Conceptualization, Methodology, Validation, Investigation, Data curation, Writing – review & editing, Visualization. **Neha K. Lalchandani:** Methodology, Validation, Investigation, Writing – review & editing, Visualization. **Yassmeen El Maohub:** Methodology, Validation, Investigation, Writing – review & editing, Visualization. **L. Suzanne Suggs:** Methodology, Conceptualization, Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary Data

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