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Advantages and limitations of the methodological approaches used to study dietary shifts towards improved nutrition and sustainability

Marlène Perignon
and Nicole Darmon

Acting on diet is one of the changes required – in combination with actions on food production, transformation, and waste – to address the challenges of reducing the environmental impact of our food systems and eliminating all forms of malnutrition. The number of studies exploring how to move towards a more sustainable diet has exploded over the past decades, but there is a need to facilitate their understanding and use by policy makers and all other stakeholders possibly influencing diet sustainability. The aim of the present article is to propose a categorization of studies into 4 approaches, based on the type of methodology used to explore diet sustainability, and to highlight the principles, advantages, and limitations of each approach in order to help study users in their interpretation. The 4 approaches are: assessment of sustainability characteristics of hypothetical diets (approach 1) or existing diets (approach 2), identification of existing "positive deviants" (approach 3), and design of more sustainable diets with constrained optimization (approach 4). Specificities and key findings drawn from each approach are described, and challenges for future studies are discussed.

INTRODUCTION

Sustainable diets were defined by the Food and Agriculture Organization of the United Nations (FAO) for the first time in 2010 as diets that are nutritionally adequate, healthy, safe, culturally acceptable, economically fair, accessible and affordable, and protective and respectful of biodiversity and ecosystems.[1] According to this definition, all dimensions (health, environment, sociocultural, and economic) should be considered and fulfilled for a diet to be sustainable. Nevertheless, for many people, the term sustainable refers only to the environmental dimension. Therefore, in a recent report, FAO and the World Health Organization (WHO) decided to communicate on "sustainable healthy diets," in order to reaffirm that the health/nutrition dimension is at the core of this concept.[2]

Diet sustainability is influenced by the "demand" (ie, dietary choices) and also by the "supply" (ie, the features of the available food products).[3] A report by the World Resources Institute shows that to feed 10 billion human beings in 2050, while holding global warming

Affiliation: M. Perignon and N. Darmon are with the MoISA, Université de Montpellier, CIHEAM-IAMM, CIRAD, INRAE, Institut Agro, IRD, Montpellier, France.

Correspondence: *N. Darmon*, MoISA, Université de Montpellier, CIHEAM-IAMM, CIRAD, INRAE, Institut Agro, IRD, Campus INRAE-SupAgro de la Gaillarde, 2 place Pierre Viala, 34060 Montpellier Cedex 2, France. E-mail: nicole.darmon@inrae.fr.

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below 2°C, different actions must be combined: improving food production and transformation, reducing food loss and waste, and changing the diet composition. However, in their recent overview of 32 highly cited and influential international policy reports on food system transformation, Brouwer et al noted that the large majority of reports are focused on the food production, agri-food supply chains, and food environment components of the food system, while ignoring or underestimating the role of consumer choice motives as potential drivers for food systems change.[4] Brouwer et al also underline that, generally, less attention is given to nutrition and diets, stating that "most of these reports [. . .] devote little attention to the composition of the food basket and outcomes in terms of dietary diversity or nutrient adequacy." Hence, results from studies exploring the potential of change from the "demand" side, especially that related to the impact on nutritional quality of diets, seem to be underused in policy making.

The study of the links between the different dimensions of sustainable diets requires a food database that contains accurate information on each dimension. A preliminary step for such analysis is thus to collect data or identify existing databases on food consumption, and to match the foods declared to be consumed with foods in databases from different sources providing information on the nutritional composition, price, contaminant concentration, environmental impacts, or any other relevant information on foods.[5] It should be noted that some degree of genericity cannot be avoided, and that the subsequent analysis is thus dependent on the availability and accuracy of existing databases on food characteristics. In particular, the type of data available for characterizing food consumption will limit and orient the type of methodology that can be used to explore changes toward more sustainable diets.

In response to the urgent issue of mitigating the environmental impacts of food systems, the number of published studies exploring the sustainability of diet has exploded over the past decade (Figure 1). In the face of such a profusion of studies, there is a need to facilitate their understanding and use by policy makers and all other stakeholders possibly influencing diet sustainability. They should be provided with keys for reading and tools for classifying the numerous studies, to help them become aware of each study's scope and limitations, and ensure a well-informed interpretation of results.

In the present article, studies are addressed from a methodological point of view, and a categorization into 4 approaches is suggested, based on the type of methodology used to explore diet sustainability. The objective is to highlight the advantages and limitations of each approach, and the data required to apply them, in order to help study users in their interpretation and researchers in choosing the most relevant methodology for future studies. Key findings drawn from each approach are described, and challenges requiring future studies are discussed.

METHODS

Four categories of methodologies used in studies aimed at identifying more sustainable diets are proposed, based on the approaches that dominate the literature: (i) assessment of sustainability characteristics of hypothetical diets (approach 1), (ii) assessment of sustainability characteristics of existing diets (approach 2), (iii) identification of "positive deviants" within existing diets (approach 3), and (iv) design of more sustainable diets with constrained optimization (approach 4). The approaches, described in the following sections, are schematized in Figures 2–5 with a summary of their advantages and limitations.

Nonexhaustive examples of studies are described within each suggested category to illustrate the associated methodological approach and to clarify its advantages and limitations. The studies used as examples were identified from previous literature reviews of studies exploring the sustainability of diets,[6–10] and supplemented with studies published since then.

The relevance of the categorization (into 4 types of approaches) suggested in the present article has been assessed by testing the classifiability of more than 50 studies identified in 2 recent systematic reviews on sustainable diets.[11,12] A large majority of the studies could be classified within the 4 classes.

APPROACH 1: EVALUATION OF THE SUSTAINABILITY CHARACTERISTICS OF HYPOTHETICAL DIETS (A PRIORI SCENARIOS)

Many studies on sustainable diets have focused on a priori–designed hypothetical diets. Their sustainability characteristics are generally evaluated by comparing them with an average actual diet. Those theoretical diets are designed according to various scenarios,[6–8] such as the fulfillment of official dietary recommendations[13,14] or the adherence to traditional dietary patterns.[13,15,16] More radical scenarios simulate the exclusion of entire food categories (eg, pesco-vegetarian, vegetarian, and vegan diets).[17–22] Other scenarios involve food substitutions supposed to lead to more sustainable diets (eg, replacement of ruminant meat with poultry or dairy products; total or partial replacement of meat or animal products with plant-based food).[6,23–26]

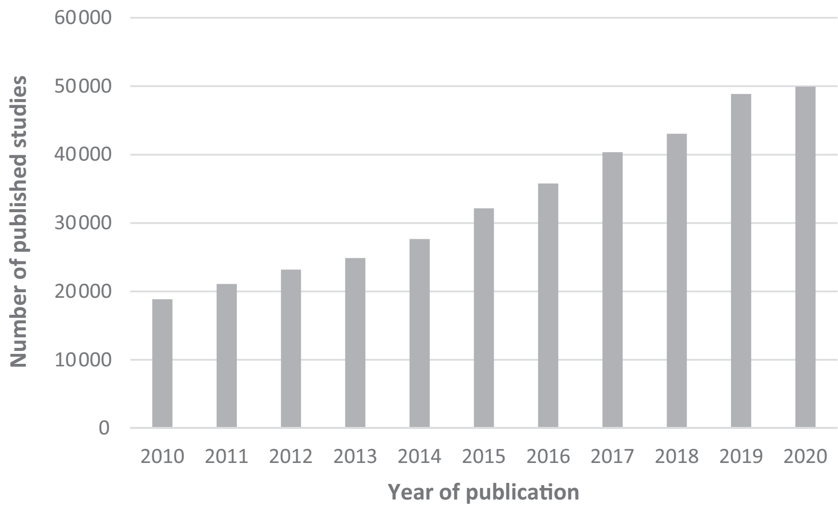


Figure 1 **Number of published studies on the topic of diet sustainability over the past decade**

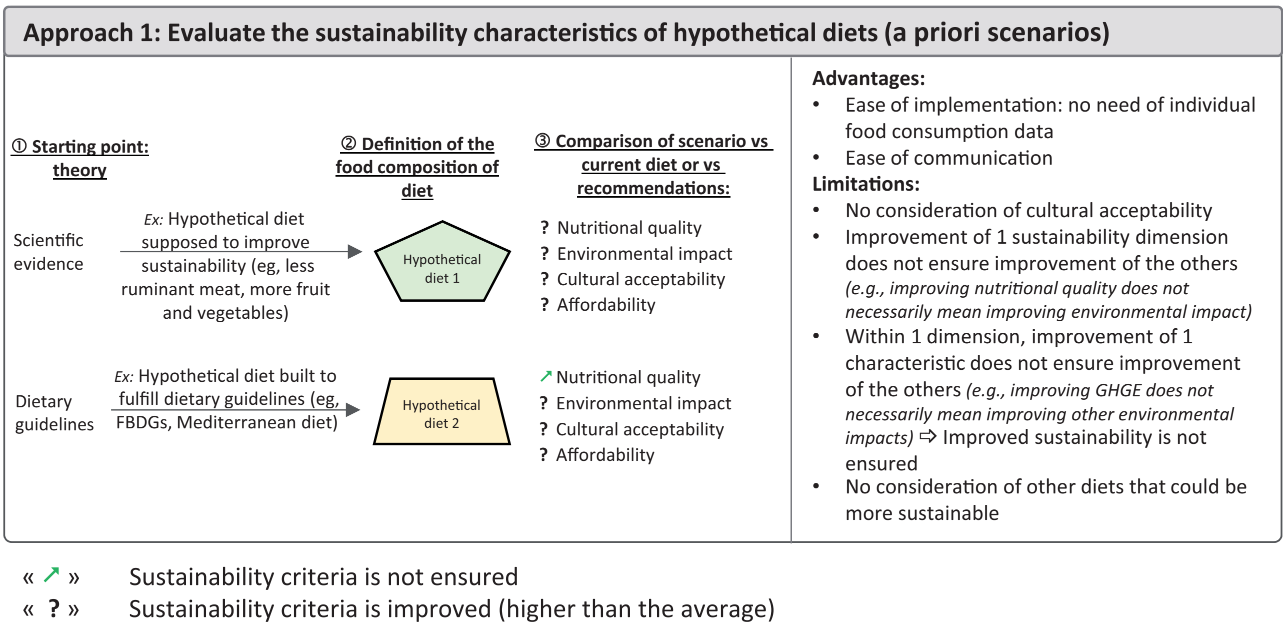


Figure 2 **Principles, advantages, and limitations of approach 1: evaluate the sustainability characteristics of hypothetical diets**.

FBDGs, food-based dietary guidelines; GHGE, greenhouse gas emissions.

Principles of approach 1 based on examples of studies

Diets based on traditional dietary patterns The rationale behind the studies in this section is that diets following traditional dietary patterns, such as the "Mediterranean diet"[13,15] or the "new Nordic diet,"[16] should be more sustainable because they are healthy and their "traditional" feature may suggest that they have a lower environmental impact than a post-industrial dietary pattern. Once they have been designed, the sustainability characteristics of these diets are estimated and compared with the characteristics of current diets.

One example is the theoretical "new Nordic diet" (NND) that was developed to be "healthy (. . .), palatable, environmentally friendly and based largely on foods originating from the Nordic region".[27] Sustainability was stated by NND designers as a crucial principle in its development. The NND was designed to contain 35% less meat than the average Danish diet; more whole-grain products, nuts, fruit, and vegetables; locally grown food in season; and >75% organic produce.[28] The differences between this theoretical diet and the average Danish diet in terms of cost and environmental impacts (based on 16 different environmental indicators) were estimated, taking into account import-related transport as well as the production method (organic/conventional).[28] The results showed that diet cost and the 16 environmental indicators improved due to diet changes (less meat, more plant-based products) and to the reduction of imported foods associated with the NND. However, when the recommendation of including organic products was taken into account, the cost reduction became negligible, and only 10 environmental indicators were improved while 6 worsened. Therefore, some but not all sustainability characteristics studied were actually improved in the pre-defined NND.

Another study focused on a "Mediterranean Dietary Pattern" derived from the "Mediterranean Diet pyramid" defined by a consortium of experts.[29] The greenhouse gas emissions (GHGEs) of that pre-defined "Mediterranean Dietary Pattern" were then assessed, and compared with those of the average Spanish diet.[15] Adherence to the Mediterranean pyramid was found to be associated with greatly reduced GHGEs (by 72%) compared with the "average" diet in Spain, leading to the conclusion that evidence was provided that the proposed Mediterranean Dietary Pattern was actually more sustainable than current diets. However, it should be noted that the caloric content of the Mediterranean Dietary Pattern actually contained 61% fewer calories than the average Spanish diet (calculation from data provided in supplementary files), probably explaining most of the dramatic GHGE reduction announced.

Simulation of the compliance with official dietary guidelines An assumption underlying many studies is that a healthy diet is necessarily environmentally friendly. In line with this premise, several studies have simulated the effect of compliance with dietary recommendations (ie, the official food-based dietary guidelines, FBDGs) on the environmental impact of diets.

A study showed that a theoretical diet complying with the German FBDGs would reduce the water footprint compared with that of the average European diet.[30] However, the authors stressed that the benefit was mainly explained by the fact that the theoretical diet contained fewer calories (−20%). They concluded that encouraging frugality should be the first strategy to move toward more sustainable diets in an industrial context, which is in agreement with the fight against the obesity epidemic.

In 2017, Behrens et al evaluated the carbon footprint, land use, and eutrophication associated with diets in 37 countries (representing in total 64% of the world population), and estimated the changes in these variables that would be induced by following the dietary guidelines of each country.[31] The study found large differences between the environmental impacts of the diets currently consumed in the different countries, with the highest levels of environmental impacts being observed in Australia, the USA, Canada, Norway, and Brazil (meat being the major contributor). In most countries, except poor countries where meat consumption is low (eg, India), adherence to the nutritional guidelines would reduce diet-associated environmental impacts. In rich countries, the decrease would range between 13% and 25% for carbon footprint, 10% and 21% for eutrophication, and 6% and 18% for land use. Again, the role of frugality was highlighted, because half of these reductions were attributed to a decrease in the diet calorie content, and the other half was mainly explained by a reduction in the consumption of animal-derived products.

However, some studies did not confirm the environmental gains associated with adherence to the dietary guidelines. For instance, following Dietary Guidelines for Americans would not change the average dietary-related carbon footprint.[32] A US study showed that following the USDA dietary guidelines (particularly increasing the intake of fruits and vegetables and other plant-derived products, while decreasing fat and sweet products) without concomitantly reducing caloric intake would in fact increase dietary GHGEs (+11%), and the use of blue water (+16%) and energy (+43%).[33]

In a recent study, Springmann et al evaluated the effects of adopting the dietary guidelines of 85 countries on the risk of mortality due to chronic diseases and on different environmental indicators (GHGEs, as well as use of freshwater, cultured land, and fertilizers), at the national level and worldwide.[34] This study showed that respecting national dietary guidelines would be associated with a mean reduction by 15% of premature mortality (from 4% to 30% depending on the country), compared with eating in accordance with the average national food consumption estimated using the food availability data from the FAO's food balance sheets. GHGEs would decrease, on average, by 13%, but with a strong regional variability (from −34% to +34%). The use of cultivated land would increase by 8%, and the use of freshwater, nitrogen, and phosphorus would not change. These impacts were then compared with the global health and environmental targets. Among the 85 national dietary guidelines, 1 out of 3 were incompatible with the objective of reducing by one third the premature mortality rate due to noncommunicable diseases, and most of them (67%–87%) were incompatible with the objective of the Paris Climate Agreement (surpassed on average by 140%) and other environmental targets.

Finally, a review of studies conducted since 2015 on the sustainability of food consumption in the United

States concluded that recent studies do not corroborate earlier conclusions that diets meeting the national dietary recommendations are necessarily more sustainable than current diets.[35] Most of the studies analyzed in the review by Reinhardt et al show a similar or higher level of GHGEs and of water and energy use associated with diets complying with national nutritional guidelines compared with the current average diet. Nevertheless, this review confirmed that, among the healthy diets, those richer in plant-based foods and poorer in animal-derived foods were associated with lower environmental impacts.

Simulation of food item substitution with other food items It is well known that animal-based products generally have higher environmental impacts than plant-based products. Bovine meat, in particular, is the food with the highest carbon footprint, even when this impact is expressed for 100 g of proteins.[36] Moreover, it is currently recommended to avoid excessive consumption of red meat (ie, more than 500 g per week) to preserve health.[37] Therefore, many studies are based on the assumption that replacing meat with plant products will increase the sustainability of diets.

For instance, the reduction of meat consumption was simulated based on dietary data from the French adult population.[38] In a scenario where, for each individual, red meat was reduced to 50 g/day and processed meat was eliminated, dietary GHGEs decreased, on average, by 12%, but dietary energy also decreased, on average, by 133 kcal. When the lost calories were compensated for by an increase of other food items, the magnitude of the GHGE reduction was lower. Interestingly, when meat and processed meats were isocalorically replaced with fruits and vegetables, dietary GHGEs unexpectedly increased (by +2.7%). This increase was explained by the large increase of fruits and vegetables (+426 g) needed to compensate for the loss of 133 kcal from meat and processed meat. This study confirmed that the reduction of meat consumption is a major strategy for decreasing dietary GHGEs, but it also showed that the choice of food items proposed as alternatives to meat is crucial in determining the actual sustainability of the substituted diet. The apparent paradox of an increase in the environmental impact when substituting meat with fruits and vegetables (explained by the difference in energy density between foods and the strong link between quantity consumed and carbon footprint of diets) was summed up a few years later in a sentence that caused controversy in the media: "Eating lettuce is over three times worse in greenhouse gas emissions than eating bacon," which was declared by an author of the previously described study of Tom et al.[33]

A systematic review of the literature concluded that switching from the observed diet to a hypothetical diet involving partial replacement of meat with dairy, mixed, or plant foods might result in a −5% to +5% change in diet-related GHGEs,[39] while total replacement of ruminant meat by monogastric meat would result in 20%–35% reduction. For example, replacing beef and lamb with pork or poultry would reduce by 18% the carbon footprint of the UK diet.[40] According to this systematic review, vegetarian diets would induce an even greater reduction of dietary GHGEs, by 20%–35%.[39] The authors indicated that the reduction potential depends mainly on the quantity and type of meat and animal-based products, with the quantity of ruminant meat being a key parameter. They concluded that it is possible to reduce the GHGEs by changing dietary choices, but that this effect would be relatively limited, less than 20%, unless consumers make a radical shift in their dietary patterns in the future.

Diets predefined by experts: The "EAT-Lancet reference diet" case The experts of the "EAT-*Lancet* Commission on Healthy Diets from Sustainable Food Systems" proposed a theoretical diet, called the "healthy reference diet," on the basis of their analysis of the scientific literature on the relationships between diet and health.[41] By using a model based on the known links between mortality, weight status, and intake of specific food categories (fruits, vegetables, grains and nuts, red meat, seafood), they calculated that the implementation of this diet might avoid 11.1 million deaths in 2030 and reduce premature mortality by 19%. In addition, the authors estimated the environmental impacts of food consumption in 2050 under "business as usual" and "adoption of the reference diet" scenarios, with or without changes in production methods or food waste. They compared the impacts with targets of planetary boundaries for sustainable food production defined by the EAT-*Lancet* Commission, including cropland use, biodiversity loss, water use, GHGEs, and nitrogen and phosphorus pollution that can be due to food production. Results indicated that adopting the reference diet, ie, without changes in food production practices and reduction of food waste, would induce environmental impacts exceeding the boundaries for most indicators (only GHGEs would remain within the limits, and biodiversity under the most ambitious scenario). Compared with the "business as usual" scenario, impacts in 2050 would be reduced only for GHGEs and nitrogen and phosphorus application. In fact, the authors mentioned that to stay within planetary boundaries a combination of dietary changes and production- and management-related measures are required. Yet, the "healthy reference diet" is often promoted and considered as a sustainable diet, good for both health and the environment.

One problem is that the communication of the findings of this study is always focused on the single "healthy reference diet," although in reality the experts of the EAT-*Lancet* Commission promoted an infinite number of diets. Thus, for each food category, the article indicates not only the quantity "of reference," but also a range around this target. In particular, for all animal products categories, this range includes also the value of 0. For instance, the recommended intake of "Fish" is 28 g/day, with possible ranges from 0 to 100 g/day. Consequently, a vegan diet, composed only of plant-based products, is considered sustainable and recommendable by these experts, and it is therefore promoted under the umbrella of "the EAT-*Lancet* diet." Yet, no evidence is presented to justify the inclusion of a vegan diet as one of the "healthy diet" alternatives. A recent study questioned the inclusion of zero consumption recommendations for various nutrient-dense dietary components for populations more vulnerable to malnutrition and food insecurity, such as women of reproductive age, especially in low- and middle-income countries.[42] The results showed that without minimum intake values for food categories, the EAT-*Lancet* diet score (constructed based on the 14 key recommendations of the EAT-*Lancet* diet) was consistently negatively associated with the mean probability of micronutrient adequacy (MPA) of diets in rural women of reproductive age in the Democratic Republic of Congo, Ecuador, Kenya, Sri Lanka, and Vietnam. In contrast, when the mean value of the proposed intake ranges was used as minimum intake value, the EAT-*Lancet* diet score was positively associated with MPA. These findings suggest that the EAT-*Lancet* diet score should include minimum intake values (>0 g/d) for all nutrient-dense food groups, to avoid being associated with low predicted micronutrient intake adequacy in vulnerable populations.

The EAT-*Lancet* Commission report was also questioned regarding the estimation of the number of deaths that could be prevented by adopting the reference diet.[43] The criticism from Zagmutt *et al.* was very severe: "The report did not meet standards for transparency and reproducibility, nor did it fully account for statistical uncertainty. Our attempt to replicate the mortality calculations for the United States revealed flaws in the assumptions and methods used to estimate the avoided mortalities. After correcting some calculation errors and fully accounting for uncertainty in the avoided mortalities, the mortality reduction effect of the EAT-*Lancet* proposed diet in the USA is no greater than the impact of energy consumption changes that would prevent underweight, overweight and obesity alone".

Advantages and limitations of the analysis of hypothetical diets based on predetermined assumptions

A main advantage of the approach exploring sustainable diets based on the analysis of hypothetical diets (ie, approach 1) is that it does not require data on individual food consumption, or on food characteristics of detailed food items. This type of approach can for instance be analyzed from food availability data from the FAO's food balance sheets, providing average food supply per capita per year at an aggregated food group level, by country or world regions. Moreover, results from this approach are generally straightforward and easy to understand, hence more suitable for dissemination.

This approach is thus still very widespread (see, eg, Kim et al 2020[22]), although it has many limitations. An obvious drawback of these studies is that they are based on predetermined assumptions concerning the food content of a sustainable diet. Therefore, they do not allow the investigation of other possible (not envisaged a priori) diets that could be similarly, or even more, sustainable. A main limitation of this approach based on theoretical scenarios is that the sustainability of the proposed diets cannot be completely ensured, because the sustainability criteria are verified a posteriori, the composition of the diets having been defined prior to the sustainability assessment. Hence, the nutrient content and the environmental impacts of such hypothetical diets are not necessarily improved and may even deteriorate for some indicators. For example, a study that simulated the total replacement of meat and dairy products by plant-based products in a representative sample of the adult Dutch population showed that this scenario would reduce the carbon footprint by 40%, but that the coverage of the requirements in vitamin A, thiamine, vitamin B12, zinc, calcium, and bioavailable iron would be inadequate.[23] However, there is a more important issue: many of these studies did not analyze the nutritional quality of the theoretical diets, because a basic assumption of the theoretical diet approach is that these diets are "healthy," or healthier than the average observed diet, which is not always true. For instance, some diets presented as sustainable by the EAT-*Lancet* Commission are assumed to be healthy, notably the vegan version. However, the authors acknowledged that riboflavin remained low, and that calcium and vitamin B12 fell below the recommended values in the vegetarian or vegan diets, or both, stating that if these diets were to be adopted, supplements or fortified food items would be required.[20] Yet, these diets are presented as sustainable options, which is in contradiction with the definition of sustainable diet, ie, a diet that must be nutritionally adequate.

In addition, theoretical diets might be designed with respect to one aspect of the environmental dimension, eg, climate change, while their impact on other indicators is not necessarily improved. For example, one study showed that the water footprint (blue water stress) would be worsened if the EAT-*Lancet* diet was widely adopted.[44]

Moreover, the economic accessibility of hypothetical diets is not ensured. For example, a recent study demonstrated that even by considering the lowest prices for the food items in each country, the EAT-*Lancet* reference diet would be unattainable for 1.6 billion people worldwide.[45] In the 26 countries considered as "low-income" by the World Bank, following the EAT-*Lancet* reference diet would cost 89% of the mean income per head, and in the 47 "lower-middle income" countries, this diet would cost 52% of the mean income per head. In the same study, the researchers estimated that the EAT-*Lancet* reference diet cost was 1.6 times higher than that of an optimal diet fulfilling all nutritional recommendations at a minimized cost, although the nutritional adequacy of the EAT-*Lancet* reference diet was not ensured.

Finally, a major weakness of a priori scenarios for hypothetical diets is the limited consideration of the sociocultural acceptability dimension. The unexplored but underlying assumption is that promoting this eating mode should result in its adoption by people. For example, the promoters of the EAT-*Lancet* diet acknowledge that the reference diet deviates considerably from the usual diets: drastic reduction in consumption of meat, eggs and tubers, and elimination of refined grains, whereas all other food families (with the exception of fish) are increased, including dairy products (which could be considered surprising in relation to the drastic reduction of bovine meat), and particularly vegetable oils, legumes, and whole grains, the quantities of which in this diet are extremely high compared with mean consumption worldwide. Quantitatively, the differences in the actual consumption patterns are such that it is obvious that the target of cultural acceptability is not met by these scenarios.

Nevertheless, a recent study took into account the issue of the acceptability of dietary guidelines in an interesting manner. In a representative sample of the US population, the authors identified the individuals receptive to a diet change (ie, the participants who declared that they wanted to follow the recommendations of the national food guidelines and agreed that humans contribute to global warming): these individuals represented 16% of the whole sample.[46] Then, they simulated in the diets of only these "receptive" participants some theoretical substitutions, in which bovine meat was replaced by poultry or plant-based protein foods. The results showed that these substitutions led to significant benefits (particularly when bovine meat was replaced by plant-based protein foods than by poultry) in terms of carbon footprint, cost, and nutritional balance (measured with the "Healthy Eating Index"). However, as these diets would be followed only by a minority (the 16% of "potential changers"), the benefit would be modest: the carbon footprint would be reduced approximately by 5% if bovine meat were replaced by poultry or plant-based protein foods. Another study concluded that following the Dutch dietary guidelines, while trying to respect the diet habits of the population, would reduce the GHGEs only minimally.[25] Similarly, a French study showed that step-by-step substitutions of animal protein sources by plant protein sources in order to improve nutritional quality without upsetting the habits of each participant would decrease the carbon footprint only of their diets by 5%.[47]

Main conclusions from studies using approach 1

Several studies exploring the sustainability of hypothetical diets showed that complying with FBDGs was associated with a decrease in environmental impact when compared with the average actual diet. Several authors highlighted the role of frugality, because reductions were partly attributed to a decrease in the diet calorie content. However, some studies did not confirm these environmental gains, and some authors underlined the finding that without concomitantly reducing caloric intake, adherence to dietary guidelines would in fact increase the diet-related environmental impact.

The dietary reduction of meat, particularly ruminant meat, is the most frequently studied scenario when investigating more sustainable diets. Reduction of meat consumption appears as a major strategy for decreasing dietary GHGEs; however, several studies indicated that the reduction potential depends on the quantity and type of meat (the quantity of ruminant meat being a key parameter) and that the choice of foods with which to replace meat is crucial, since some isocaloric substitutions could in fact increase the environmental impacts.

APPROACH 2: EVALUATION OF THE SUSTAINABILITY CHARACTERISTICS OF EXISTING DIETS (UNIVARIATE EPIDEMIOLOGICAL APPROACH)

Principles of approach 2 based on examples of studies

In this second type of methodology, the studies use an epidemiological approach by analyzing diets self-

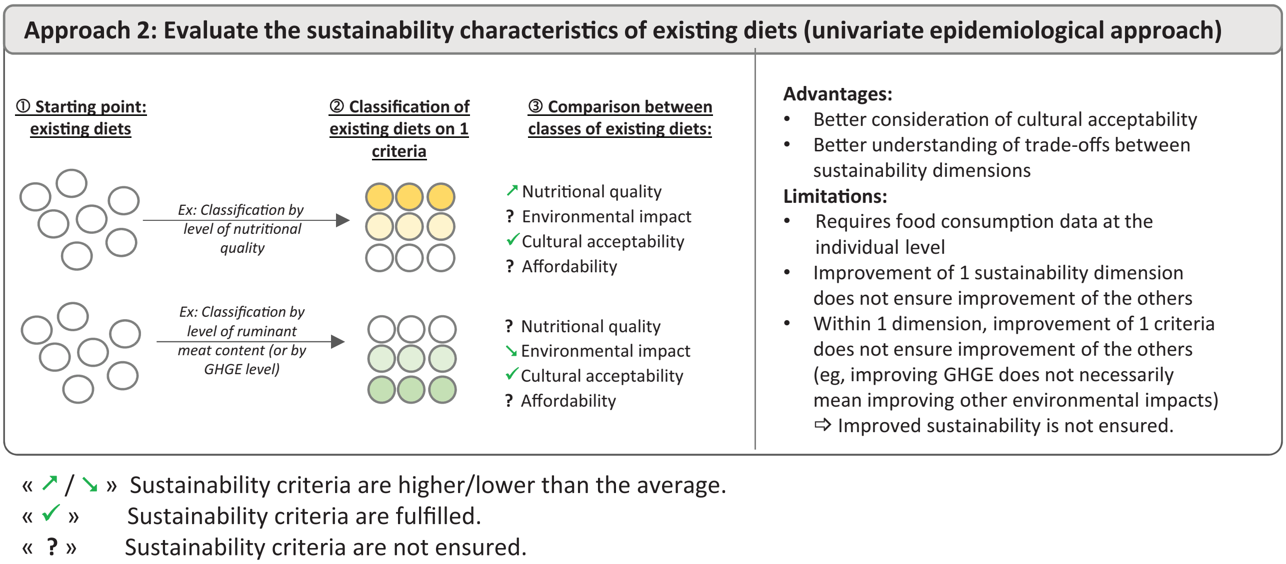


Figure 3 **Principles, advantages, and limitations of approach 2: evaluate the sustainability characteristics of existing diets (univariate epidemiological approach).**

GHGE, greenhouse gas emissions.

selected by individuals, based on daily food intake declared at the individual level in food consumption surveys or cohorts.

One of the important contributions of the first epidemiological studies that have looked at the environmental impact of self-selected diets has been the highlighting of the huge interindividual variability of these impacts. In a pioneering study, Coley et al revealed an extensive intervariability of the embodied energies among typical UK diets.[48] Large interindividual differences were also found for the total daily carbon impact of French self-selected diets, and this variability was mainly explained by a quantity effect.[38] A positive correlation was found between dietary GHGEs and the ingested quantities, and the correlation was even stronger between dietary GHGEs and total energy intakes. Notably, the environmental impact of women's diets is generally lower than that of men's diets, mostly because women eat less than men (eg, in France: 1.24 kg vs 1.45 kg of solid foods per day for women and men, respectively, according to Masset et al[49]). Therefore, the first lever for reducing the environmental impact of food consumption is certainly to buy less, to waste less, and to eat just what is needed – not more, which is fully consistent with the public health messages about being overweight and obesity.

Given the large environmental impact differential between animal and plant foods, the amount of meat consumed is another important determinant of the large interindividual variability of the environmental impact of diets. Thus, in a study performed in the United Kingdom (55 000 volunteers from the EPIC-Oxford cohort), the authors compared the GHGEs of self-selected diets according to the level and type of animal-based products consumed.[50] Mean dietary GHGEs, expressed in $kgCO_2e$/day per 2000 kcal, were 7.19 for high meat-eaters ($\geq$100 g/d), 5.63 for medium meat-eaters (50–99 g/d), 4.67 for low meat-eaters (<50 g/d), 3.91 for fish-eaters, 3.81 for vegetarians, and 2.89 for vegans. This progressive reduction of the place of meat and animal-based products was also accompanied by favorable trends in terms of macronutrients intakes and fiber and fruits and vegetables consumption. However, one limitation of this study was that micronutrients and essential fatty acid intakes were not calculated (it is well known that fish is an irreplaceable source of long-chain omega 3 fatty acids, dairy products are major sources of calcium, and vegan diets lack several micronutrients).

In a French study based on the second national study on individual food consumption, the authors classified the individuals' diets into 4 groups with different levels of nutritional quality.[51] The study showed that, despite the presence of a large proportion of plant-derived food items in the diets with the best nutritional quality, those diets had higher GHGEs (+9% for men and +22% for women) than diets with lower nutritional quality. The authors also studied the correlations between diet-related GHGEs and nutritional quality indicators and showed that, for the same energy intake, the higher the nutritional quality of individual diets, the higher their dietary GHGEs, and the relationship was weak but statistically significant. Thus, indicators of poor nutritional quality, such as high energy density (in kcal/100 g) and high mean excess ratio (percentage of maximum recommended values for nutrients for which intake should be limited), were associated with lower dietary GHGEs. Conversely, higher nutritional quality of a diet, measured by the mean adequacy ratio (mean daily percentage of recommended intakes for 20 essential nutrients) was associated with higher dietary GHGEs. Moreover, at a given energy intake, dietary GHGEs were lower for higher consumption of sweet products and savory snacks, and were much higher for elevated intakes of fruits and vegetables.

In a study carried out on more than 24 000 volunteers in the United Kingdom (the EPIC-Norfolk cohort),[52] the authors stratified the population according to the Dietary Approaches to Stop Hypertension (DASH) score, a dietary quality indicator based on the consumption (adjusted for energy intake) of 7 food groups and sodium (5 positive components: fruits, vegetables, nuts and legumes, whole grains, and low-fat dairy products; and 3 negative components: red and processed meats, foods high in added sugars, and foods high in sodium). They found that a better DASH score was associated with lower dietary GHGEs (16% difference between extreme quintiles), but with higher dietary cost (18% difference between extreme quintiles).

In a recent study based on data from the Nutrinet-Santé survey, the population was stratified according to a score of adherence to the French FBDGs. The authors showed that the environmental impact (estimated by the synthetic partial ReCiPe (p-ReCiPe) score comprising GHGEs, energy use and land occupation) of the diet of participants whose diets most agreed with the new French dietary recommendations was reduced by 50% compared with that of the diet of people who deviated most from these guidelines.[53] Following the FBDGs would also prevent 35 000 premature deaths per year. Nevertheless, by following French FBDGs, diet cost would increase by approximately 1 € per person per day (compared with the diet cost for those who deviated the most from the FBDGs).

In a recent study in the United States, Conrad et al linked data on daily food intake at the individual level from the National Health and Nutrition Examination Survey (NHANES) with nationally representative data on food loss and waste to explore the relationship between observed diet quality and the amount of agricultural land, fertilizer nutrients, pesticides, and irrigation water used to produce food.[54] They showed that higher diet quality was linked with greater food loss and waste, and linked with trade-offs for agricultural resource use (lower land use but potentially greater use of pesticides and irrigation water), thus pointing out that healthier diets are not necessarily more environmentally sustainable. They noted, however, that the relationship between diet quality and agricultural resource use depended on how diet quality was measured.

Advantages and limitations of the analysis of existing diets based on a univariate epidemiological approach

A strength of epidemiological studies based on diets actually observed in the population is their better ability, in comparison with studies based on theoretical scenarios, to take into account the cultural acceptability dimension of sustainability. Considering that such studies are based on diets self-selected by individuals in their everyday life, it is reasonable to assume that these choices are culturally acceptable for the majority of the surveyed participants.

Another main advantage of the epidemiology approach is that it allows the compatibility and trade-offs between the different sustainability dimensions to be studied. This approach has made it possible to show that, in existing self-selected diets, the various sustainability dimensions are not necessarily compatible with one another.[9] For example, the fact that it is more difficult to have a balanced diet on a small budget reveals a contradiction between nutritional adequacy and affordability of diets.[55] Similarly, nutritional adequacy does not systematically imply lower environmental impact. For example, in France, self-selected adult diets with the highest nutritional quality were not those with the lowest GHGEs.[51]

Following the description of a positive correlation between nutritional quality and GHGEs of self-selected French diets,[51] a literature review confirmed that existing dietary patterns with low GHGEs are generally associated with lower nutritional quality, particularly with higher sugar levels and/or less favorable health indicators.[56] Yet, these conclusions are rarely relayed by the media, because they go against the general belief that a diet good for health is necessarily good for the environment and vice versa. This idea is so embedded that it is still conveyed in the scientific literature despite some evidence against it. For example, in a study on a representative sample of Dutch adults, the abstract of the article states: "As expected, a significant negative correlation was found between Dutch Healthy Diet index and the GHGEs, indicating that health and sustainability can, to some extent, be improved in synergy with one another"; however, the correlation mentioned in the main text was almost null ($R^2 = 0.07$, $P < 0.001$).[57] Similarly, in France, for a study comparing the nutritional quality of the diets of healthy participants stratified by quintiles of dietary GHGEs, the report abstract states that "diets with low GHGEs were characterized by a high nutritional quality." However, the results did not necessarily support this, since the high nutritional quality score of participants in the lowest GHGEs quintile was mostly explained by a higher moderation subscore (ie, a score based on nutrients to limit, such as sugar, sodium, and saturated fatty acids), while the lowest adequacy subscore (reflecting the content of "positive" nutrients such as fiber, vitamins, and minerals) was in the lowest GHGEs quintile.[58] Moreover, participants in the lowest GHGEs quintile consumed on average 1000 kcal less per day than participants in the highest GHGEs quintile. As explained above, it is logical that lower caloric intakes are associated with lower environmental impacts.[22,31,38] However, it is not always explicitly mentioned in the studies what part of the reduction in environmental impact is attributable to the reduction in caloric intake.

Studies that used the epidemiological approach to study diet sustainability also highlighted trade-offs regarding the economic dimension, and they allow quantification of the magnitude of those trade-offs. For instance, the average additional cost of 1 €/day for the more sustainable diets reported in the Nutrinet study presented above[53] is not negligible for socially and economically disadvantaged people, particularly for the 8 million food-insecure individuals in France, whose daily food budget does not reach 4 €/d.[59]

Beyond the analysis of correlation, the epidemiological approach allows the exploration of how food groups – or any other determinants – contribute to variability in a sustainability dimension. Animal products, especially meat, have thus been identified as strong determinants of the environmental impact of diet.[50,51] For instance, the authors who studied compliance with the DASH diet showed that the 8 components of the DASH score did not always converge in terms of GHGEs and costs.[52] Specifically, consuming less red and processed meats contributed to concomitantly reducing GHGEs and cost. Conversely, consuming more vegetables and less sweet products increased both GHGEs and cost.

The main limitation of the univariate epidemiological approach is related to the data required for the analysis: assessing self-selected diets requires food consumption data at the individual level. Data from national individual food consumption surveys or cohorts are not always available, and tedious work is required in terms of data management and analysis.

Main conclusions from studies using approach 2

The epidemiological approach, based on the analysis of existing diets, has allowed the large interindividual variability of diet-related environmental impacts to be shown. The results suggest, in accordance with the approach based on hypothetical diets (ie, approach 1), that reductions in meat consumption and energy intake are the main factors for reducing diet-related GHGEs.

Most importantly, this approach allows the highlighting of trade-offs and antagonisms between the sustainability characteristics of particular diets. Several studies thus observed that in self-selected diets, higher nutritional quality is often associated with higher cost, and may be associated with greater environmental impact.

A literature review combining studies based on hypothetical scenarios and actual diets (approaches 1 and 2) concluded that, across all measures of "healthiness," reduced dietary GHGEs were generally (for 64% of studied diets) associated with worse health indicators.[56] The authors reported that "while lower-GHGE patterns show no consistent relationship with reduced nutrients to limit or positive health outcomes, many do show a correlation with reductions in micronutrient intake and with elevated sugar levels".

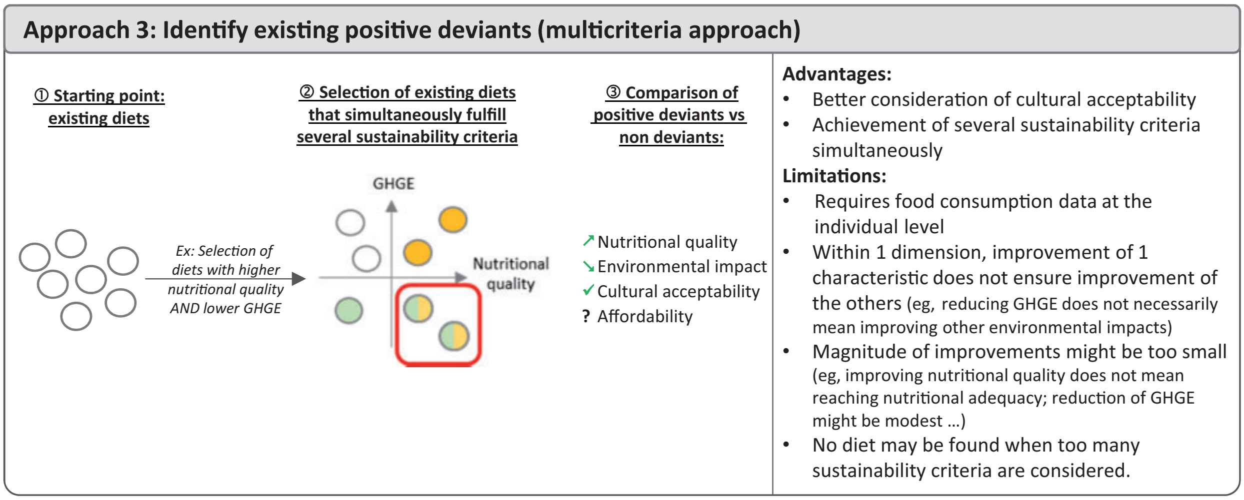
These results highlight the crucial importance of assessing several dimensions when exploring dietary changes that will increase sustainability, and emphasize micronutrients adequacy as a key concern in advocating for a reduced GHGEs diet.

As discussed in the previous paragraphs, describing observed diets often leads to the highlighting of trade-offs between the targets associated with the various sustainability dimensions (environmental impact, economic accessibility, nutritional quality, and social and cultural acceptability). In order to properly study such a complex concept as sustainable diets, a multicriteria approach might be more suitable, ie, an approach investigating the simultaneous compliance with several sustainability targets. In the present article, 2 types of multicriteria approaches are presented: the positive deviance approach and the diet optimization approach, both of which are used for identifying more sustainable diets.

APPROACH 3: IDENTIFICATION OF DIETS MORE SUSTAINABLE THAN OTHERS AMONG EXISTING DIETS: THE POSITIVE DEVIANCE APPROACH

Principles of approach 3 based on examples of studies

This approach is based on the principle of positive deviance, according to which some individuals adopt "positive" (or beneficial) behaviors, although the constraints to which they are submitted and/or the context in which they live should lead them to adopt a "negative" behavior, like the majority of individuals in



« ↗ / ↘ » Sustainability criteria is improved (higher or lower than the average)
« ✓ » Sustainability criteria is fulfilled
« ? » Sustainability criteria is not ensured : it needs to be assessed a posteriori, or included in the selection criteria

Figure 4 **Principles, advantages, and limitations of approach 3: identify existing "positive deviants" (multicriteria approach).**

GHGE, greenhouse gas emissions.

the same population.[60] The term "positive deviance" reflects the fact that the method aims at identifying "deviant" behaviors (ie, practices that are different from the ordinary behaviors), but positively deviant, as they lead to a better outcome – increased sustainability in the present case. The first time the positive deviance approach was used to identify more sustainable diets was in a study based on the second national study on individual food consumption (INCA2) in France.[49] The objective of the study was to identify, among the existing diets, the one combining lower environmental impact (GHGEs below the median value) and better nutritional quality (PanDiet indicator higher than the median value).[49] These "more sustainable" diets identifed using the positive deviance approach represented approximately 20% of all diets observed in France. Their dietary GHGEs were reduced by 19% for men and 17% for women, compared with the respective national averages, and this without any additional cost (the energy cost, in €/kcal, was the same, and the daily cost, in €/day, was even lower). These "more sustainable" diets differed from the others mainly by both lower total energy content (−200 kcal/day) and lower energy density (141 kcal/100 g instead of 156 kcal/100 g, on average). Conversely, their food composition was not radically different from that of the observed average current diet. Notably, all food groups and subgroups were included. However, the more sustainable existing diets were characterized by higher caloric contributions from starchy foods, fruits, vegetables, and nuts, and lower caloric contributions from meat, composite dishes containing meat, and alcoholic drinks.

The positive deviance approach was also applied to identify more sustainable diets in Europe, using data from dietary surveys of 5 European countries (France, Finland, Italy, Sweden, and the United Kingdom).[61] The results confirmed the findings previously obtained for France. One individual in 5 already had a more sustainable diet, characterized by better nutritional quality coupled with lower GHGEs (−20%). On average, the daily diet of individuals with a positive deviant behavior in Europe contained 1 kg of plant products (400 g of fruits and vegetables, 100 g of juices, 500 g of grain products, potatoes, legumes, and other plant-based products) and 400 g of animal-derived products (100 g of meat, fish, and eggs, 30 g of cheese, 220 g of other dairy products, and 50 g of composite dishes). The more sustainable diet also contained bovine meat (134 g/week on average), despite its high GHGEs level. The main differences between the average diet of the positive deviants and the observed average diet of the general populations of these 5 European countries were the higher amount (+200 g) of plant-based products (notably, 400 g/day of fruit and vegetables instead of only 250 g/day), and the lower content of sweet products and alcoholic drinks. On the other hand, both diets contained the same total quantity of animal-derived products (400 g/day), but distributed slightly differently: less ruminant meat for the positive deviants compared with the general population (19 g/day vs 33 g/day), less processed meat and offal (25 g/day vs 32 g/day), and a smaller quantity of composite dishes containing animal products (43 g/day vs 68 g/day), but more dairy products (251 g/day vs 217 g/day) and slightly more fish (29 g/day vs 26 g/day); the quantities of eggs and poultry (27 g/day vs 29 g/day) were very similar. Therefore, these results showed that it is possible to reduce dietary GHGEs while increasing the nutritional quality, and without eliminating whole food categories.

The Food4Me study, another European study, in this case including participants from 7 different countries, also used a "positive deviance" approach and involved selecting individuals whose diet combined several positive characteristics in terms of nutritional quality and environmental impact.[62] The chosen criteria were numerous (3 nutritional indicators and 3 environmental targets) and quite strict (eg, the expected GHGEs level needed to be lower than the value of the first tertile), so that only 0.5% of the whole population sample met all these requirements. The authors called the average diet of these positive deviants the "best practice diet." The "best practice diet" provided 1949 kcal/day and included smaller quantities of sweet products, meat, and drinks, and more vegetables and grain products than the average diet of each country, with some additional specificities according to country and gender. The study also observed a high interindividual variability in the food choices allowing good nutritional quality and low environmental impact to be combined.

Recently, the positive deviance approach was used on dietary data for more than 96 000 Swedish adults from a population-based prospective cohort.[63] Participants were categorized into 4 groups based on the nutrient density and the GHGEs of their diet. This study showed that diets benefiting both nutrition and climate do exist and are associated with lower mortality among women, but also that diets with low climate impact may have either a positive or a negative impact on health, depending on the diet quality.

Advantages and limitations of the positive deviance approach

The main advantage of the positive deviance approach is its greater consideration of cultural acceptability. Thus, the diets of positive deviants are culturally acceptable because they are actually consumed (at least by the fraction of the population already consuming them). Moreover, this approach allows diets that simultaneously improve several sustainability dimensions to be identified. However, the magnitude of the improvements might be small (eg, the reduction in GHGEs might be modest) and, despite their good nutritional quality, the diets of positive deviants are not perfectly adequate (because none of the observed diets actually fulfill all nutritional recommendations). In addition, within one dimension of sustainability, improvement in one characteristic does not ensure improvement in others (eg, reducing GHGEs does not necessarily mean that there will be improvement in other environmental impacts). It should be noted, however, that very few diets might be found when too many dimensions or criteria are considered.[62]

Finally, as for approach 2, also based on existing diets, a limitation of the positive deviance approach is that it requires food consumption data at the individual level, which are not always available, and it involves tedious work in terms of data management and analysis.

Main conclusions from studies using the positive deviance approach (ie, approach 3)

Overall, the results of the still rare studies based on the principle of positive deviance are in agreement with the fundamentals of nutrition, according to which a diversified diet is the best way to avoid nutritional deficits. They also show that, just as there are a thousand ways of having a balanced diet,[64] there might also be multiple ways of having a more sustainable diet. The differences between the more sustainable diets of the positive deviants and the average observed diet are minor, but they are enough to ensure better nutritional quality and a reduced environmental impact. The dietary changes identified in these realistic diets (termed realistic because they are actually consumed) are less drastic than those in the hypothetical diets described in a previous section. In particular, the results obtained from this approach showed that it is possible to reduce dietary GHGEs while increasing nutritional quality, without eliminating whole food categories.

APPROACH 4: DESIGN OF MORE SUSTAINABLE DIETS WITH CONSTRAINED OPTIMIZATION

Principles of approach 4 based on examples of studies

Diet optimization aims to find the optimal combination of foods for a population, a subpopulation, or an individual that fulfills a set of constraints (eg, in terms of food items, nutrients, cost, GHGEs, and other environmental impacts), while optimizing (minimizing or maximizing) an objective function (eg, cost, calories, GHGEs, deviation from an existing diet).[10]

Constrained optimization was used in the United Kingdom to develop a diet that met the dietary requirements of an adult woman, while minimizing GHGEs.[65] This study demonstrated that it is possible to create a

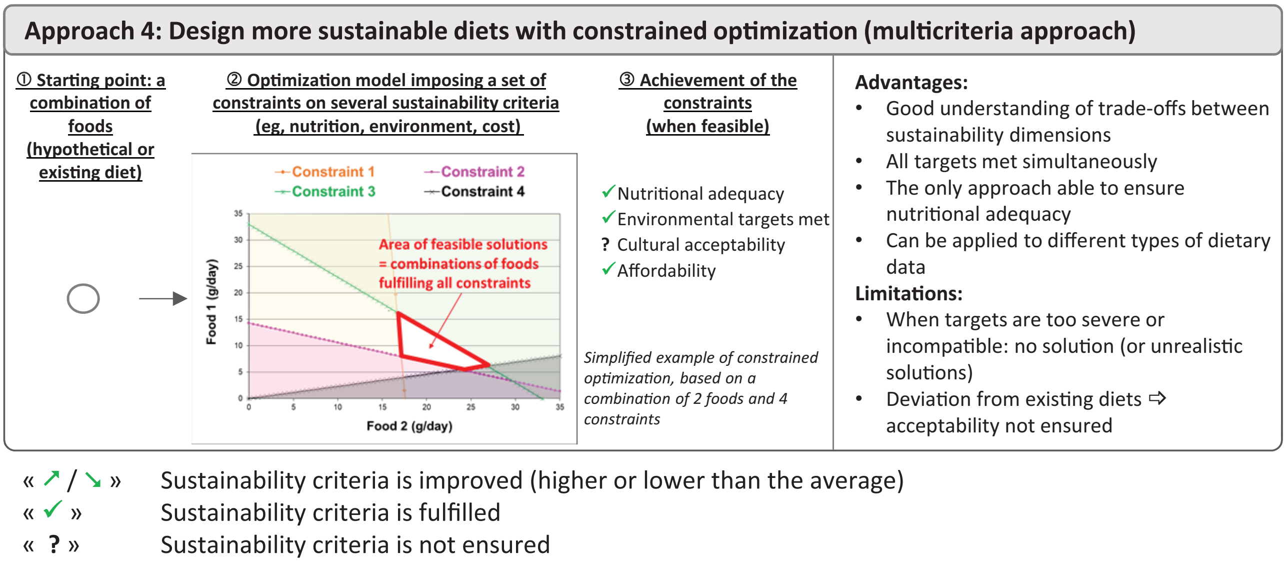


Figure 5 **Principles, advantages, and limitations of approach 4: design more sustainable diets with constrained optimization (multicriteria approach)**

healthy diet with lower GHGEs, without the elimination of meat and dairy and at no additional cost to consumers.

The constrained optimization approach was used to identify the dietary changes that would be required to respect all of the nutrient-based recommendations (not only for the balance of macronutrients, but also for the minimum intakes of vitamins, minerals, trace elements, fiber, and essential fatty acids, and the maximum intakes of sodium, saturated fatty acids, and free sugars, without changing the energy intake), while progressively reducing dietary GHGEs, and minimizing the deviation (in terms of food types and quantities) from the average French diet.[66] The results showed that it is possible to reduce dietary GHGEs by 30%–40% while attaining perfect nutritional adequacy (and without cost increase). This was achieved without drastically changing the food choices, with the exception of an important increase in intake of fruit and vegetables and the almost complete elimination of ruminant meat and alcoholic drinks, while intake of dairy products remained stable. These changes are more drastic than those described in the study on the positive deviants in France,[49] because the constraints of the diet are more demanding in terms of nutritional quality improvement (all recommendations are respected) and GHGEs decrease (a 30% reduction, rather than the 20% reduction obtained with the positive deviants approach). By directly minimizing GHGEs (instead of just noting the deviation between the observed and the optimized diet), GHGEs can even be reduced by 70%–74%, depending on gender. However, such a reduction would imply an almost total removal of dietary meat and a huge increase in consumption of starchy foods. Social acceptability, a key feature of sustainable diets, risks being seriously undermined, as the gap between the constrained optimization diet and usual consumption might be too large.

Similar optimization models have been applied to the data from dietary surveys of 5 European countries (France, Finland, Italy, Sweden, and the United Kingdom).[67] The greatest theoretically achievable GHGEs reduction ranged from 62% to 78%, depending on the country and gender considered, but was in all cases associated with dramatic dietary changes. For a 30% reduction in GHGEs, the changes proposed by the models were less important and consisted mainly of substitutions: replacing some of the calories from fat, sweet products, and alcoholic drinks with calories from starchy foods, fruits, and vegetables, and substitutions between animal-derived products. Specifically, the energy contributions from meats, particularly from ruminants (beef and lamb), and processed meat were generally reduced. It has been estimated that the adoption of these nutritionally adequate optimized diets throughout adulthood would increase life expectancy by between 2.3 and 6.8 months, depending on the country.[68] These estimated health benefits were not influenced by the level of GHGEs reduction (which for the optimized diets varied from no reduction to the highest reduction).

A recent study used mathematical optimization to design diets for 152 countries that simultaneously met environmental (carbon emissions, and water, land, nitrogen, and phosphorus use), nutritional (daily recommended levels for 29 nutrients), and cultural acceptability constraints.[69] The required dietary changes were highly country-specific, but overall the intake of meat, dairy, rice, and sugar had to be decreased and that of fruits, vegetables, legumes, nuts, and other grains had to be increased. Moreover, the constraints for fiber, vitamin B12, vitamin E, and saturated fats, and the planetary boundaries for carbon emissions and nitrogen use were found to be the most difficult to meet.

As shown by Barré et al,[70] this powerful method also allows integration of exigencies regarding the bioavailability (ie, efficiency of nutrient absorption and utilization or retention by the body) of key nutrients (proteins, iron, zinc, vitamin A), as well as coproduction links between different foods (eg, the links between meat and milk, or offal and meat from the same animal). Sophisticated models were therefore developed to include nutrient bioavailability and coproduction links, in addition to the reduction of several environmental impacts (GHGEs, eutrophication, and acidification; each reduced by at least 30%) and the respect of nutritional recommendations. As in the simpler models without constraint on bioavailability, the quantities of fruits and vegetables and of starchy foods increased, and the animal/plant ratio and the cost per day of the diets decreased. The quantity of meat, notably ruminant meat, also had to be reduced, but the reduction was much less drastic than with the model without consideration of nutrient bioavailability and coproduction links. It is interesting to note that the reductions in red and processed meat identified in this optimization study were similar to those of the study on the positive deviants in France[49] and in Europe.[61] Therefore, it seems that a total of 40 g/day of meat (ruminant + processed meat), which corresponds to 280 g/week (not including the meat contained in composite dishes), is compatible with a more sustainable diet. This is lower than the international guidelines that recommend limiting consumption of red meat to no more than about 3 portions per week, equivalent to approximately 350–500 g/week.[37] However, it is higher than the quantity recommended by the EAT-*Lancet* reference diet (100 g/week of ruminant meat, no processed meat), the nutritional adequacy of which is not guaranteed.

Advantages and limitations of the constrained optimization approach

The main strength of diet optimization is the ability to simultaneously apply constraints to the various characteristics of diet sustainability (food and nutrients content, diet cost, environmental impacts, etc.). This approach thus allows diets to be designed that concurrently fulfill different sustainability goals and avoid impairing some dimensions in favor of others. In particular, this is the only approach able to ensure nutritional adequacy. It should be noted that when targets are too severe or incompatible, this approach can lead to no solution (or unrealistic solutions). Yet, infeasibility or unrealism are also interesting outcomes, because they reveal trade-offs between sustainability dimensions, or within a dimension. In particular, this approach can be used to identify the nutrients for which the recommended intake is the most difficult to fulfill (or is unattainable), indicating an insufficient amount of nutrients in the food supply or incompatibility with another constraint applied in the model.

Another strength of optimization under constraints is that it can be applied to different types of dietary data. When available, individual food consumption data can be used to design optimized diets at the individual level, but such a level of detail is not required. For instance, an optimized diet can be designed based on a list of dietary food items without precise information about consumption levels — although fulfilling the acceptability dimension will be challenging — or using an average diet estimated from food availability or food consumption data at a country or regional level.

The weakness of mathematical optimization, like all theoretical approaches, is the difficulty of properly including the cultural acceptability dimension. However, some models do this better than others. In particular, minimizing only one variable (eg, environmental impact, cost, or calories) in a mathematical optimization model is strongly discouraged to, due to the risk of obtaining totally unrealistic diets.[10] On the other hand, minimizing the deviation from the observed diet attempts to better account for current dietary patterns (although there is no consensus on how to define such "deviation"). Some researchers have been able to more finely integrate diet accessibility and acceptability by using price elasticities in the models,[71] or by declining them for subpopulations with different income levels.[72]

More effort should be focused on optimization approaches with the aim of developing relevant models that comprehensively integrate the coproduction links among food items and also more specific data on the environmental impacts, prices, and nutritional composition of food items, taking into account the kinds of food production methods, particularly for animal-derived foods.

Like the previously described theoretical approaches, constrained mathematical optimization leads to theoretical diets. Nevertheless, when the models are relevant and well designed and the data are robust, diets optimized to be more sustainable do not have the limitations of hypothetical diets based on preconceived views (that the diets may prove to be of insufficient nutritional quality, and/or too expensive, and/or sometimes disappointing in terms of environmental gain).

Main conclusions from studies using approach 4

Several research teams have developed constrained optimization models to design more sustainable diets that simultaneously integrate environmental impact, nutritional adequacy, and affordability, while also considering cultural acceptability. In a literature review of studies that used mathematical optimization to explore diet sustainability, Gazan et al concluded that, regardless of the diet optimization model applied and local-country specificities (ie, food habits and nutritional recommendations), a more sustainable diet required an increase in fruit and vegetables and legumes and a decrease in meat products, and noted that a sustainable diet is not exclusively plant-based.[10]

Moreover, this approach was used to estimate the maximal reduction in GHGEs theoretically achievable while meeting nutritional constraints: eg, up to 90% in the United Kingdom,[65] 70%–74% in France,[66] or 62%–78% in Europe, depending on country and gender.[67] However, such reductions were in all cases associated with dramatic dietary changes that would most probably compromise the cultural acceptability of these optimized diets.

The diet optimization approach was also used to test incremental reductions in diet-related environmental impact and thus to identify the level of reduction above which deviation from current diet became major and potentially unacceptable. Studies in the Netherlands,[73] France,[66] and the United Kingdom[71] identified similar thresholds of 30%–40% reduction in the environmental impact of diets (mostly assessed by GHGEs) while satisfying nutritional constraints and without a major departure from the average observed diet. Gazan et al highlight in their literature review that with the current food production system (ie, assuming no changes in the environmental impact and price of foods), nutritional, cultural, economic, and environmental dimensions seem compatible with up to a 30%–40% reduction in the environmental impact of diets.[10]

CHALLENGES

CHOICE OF RELEVANT CULTURAL ACCEPTABILITY CRITERIA

One of the major challenges of studies aimed at improving the sustainability of diets is taking into account all the characteristics of diets, because of possible incompatibilities among the nutritional, environmental, and economic dimensions. The cultural acceptability dimension, included in the 2010 FAO definition of sustainable diets,[1] has been approached by using data from individual dietary surveys, and by considering price elasticities, to better guarantee that the beneficial dietary changes identified may be compatible with current eating habits. However, the choice of indicators for representing the sociocultural dimension remains subjective and still too often depends on the available data and the interest of the research teams. For instance, in an index called the "sustainable diet index",[74] the variables representing the sociocultural dimension in this index were the frequency of purchases in shops other than supermarkets (eg, markets, grocery stores, local producers) and the frequency of consumption of ready-to-eat products (canned food, prepared dishes, frozen products), the relevance of which for assessing cultural acceptability is disputable; many other variables could have been considered instead, such as the deviation from the national average diet as a measure of acceptable dietary changes.

Additional studies are needed to improve the incorporation of the sociocultural dimension in the evaluation of sustainability. The biggest challenge remains in identifying relevant metrics for assessing cultural acceptability, and in some cases the obtaining of reliable data for estimating it. For instance, when food consumption surveys are not available, the mean observed diet cannot even be used as a proxy for the acceptable diet.

It is also important to remember that the approaches described in this review do not take into account other more qualitative features of the diets, such as palatability, the hedonic dimension, and commensality.

CONSIDERATION OF DIFFERENT AGE GROUPS

Most of the studies in the field of diet sustainability are based on the diets and nutritional requirements of adult populations. As the requirements in key nutrients (eg, iron and zinc) are higher in children and adolescents, the conclusions drawn by studies on adults are potentially not suitable for young populations. Hence, in a study investigating the impact of diets with less or no meat and dairy products on nutrient intakes in children 2–6 years of age, the authors showed that partial replacement of meat and dairy by plant-derived foods was beneficial, but with full replacements the proportion of girls aged 4–6 years with intakes below recommendations increased.[75] Only a few recent studies have looked at developing nutritionally adequate, GHGEs-reduced, and affordable school menus using mathematical optimization.[76,77] Similarly, very few studies have considered the specific nutritional requirements of older adults, especially their relatively high protein needs (which could increase GHGEs when fulfilled), except when a multicriteria approach has been applied, as in the study of Grasso et al[78]

More studies that take into account the dietary habits and nutritional requirements of children, adolescents, and older adults are needed to assess more finely the health dimension and to produce recommendations for more sustainable diets that are adapted for the various age groups.

CONSIDERATION OF FOOD PRODUCTION AND PROCESSING METHODS

Differential food production methods have rarely been taken into account in studies on sustainable diets. The French Bio-Nutrinet survey that included approximately 30 000 participants of the Nutrinet-Santé cohort is the only data set that allows differentiation between the consumption of organic and conventional food in the evaluation of the sustainability of self-selected individual diets.[79] The differences between organic and conventional food – in terms of environmental impact, price, and pesticide contamination level – were considered, as well as the dietary choices of participants with respect to the amount of organic products they consumed. Higher consumption of organic food was associated with greater intake of plant-based foods, lower intake of animal-derived products, better nutritional quality, and lower body mass index. Moreover, exposure to pesticides was lower, and the environmental impacts were reduced (by 37% for GHGEs, by 25% for energy use, and by 23% for land use) in the diets of participants in the highest quintile of organic product consumption (ie, the highest consumers) compared with participants in the lowest quintile. The low intake of food of animal origin in the high consumers of organic products explained the environmental benefits of their diet, but their high consumption of organic products was associated with a high diet cost (plus 2€/d compared with participants in the lowest quintile of organic food consumption). The Bio-Nutrinet study interestingly showed that, since organic consumers generally consume less meat, their diet was ultimately less impacting than that of small organic consumers, although the environmental impacts of organic products can be higher than those of conventional products for some indicators (such as land use, or GHGEs) for animal products.[28,80] These conclusions are in agreement with those of a previous Danish study[28] showing that the benefits on several environmental impact indicators of the "new Nordic diet," with reduced meat consumption, were attenuated (or reversed for some impacts) in a scenario in which almost all food items were of organic origin.

It should be noted that life cycle assessment (LCA), the most widely used method for assessing environmental impacts of agricultural products, focus on emissions. LCA has in particular highlighted the GHGEs of the livestock sector. However, soil properties and functions remain little represented in LCA, and the ecosystemic services provided by such a sector are not considered.[81] This narrow perspective on functions of agricultural systems has led to an unbalanced view of reality, and tends to misrepresent some agroecological systems, such as extensive grassland systems. Further improvements are needed in the methodological aspects of LCA to ensure adequate consideration of the complexity of food systems.[82]

Beyond food production methods, processing stages can also influence diet-related environmental impact. Some studies suggested that the impacts of a home-made meal are lower than those of the equivalent ready-made meal.[83] In contrast, some studies have shown that ready-to-eat school lunches cause less potential impact than the equivalent home-made lunches,[84] and that in the case of complex dishes, higher-scale systems, with proper energy and environmental practices, can have lower environmental burdens than small-scale systems.[85] Hence, the potential lowering of GHGEs through food processing methods should be further explored.

CONSIDERATION OF COUNTRY OR WORLD REGION SPECIFICITIES

A large majority of the studies exploring dietary changes toward more sustainability have been conducted in high-income countries. However, it can be expected that the direction and extent of changes needed may differ according to local contexts, in particular according to the environmental issues, the level of meat consumption, and the stage of nutrition transition experienced in a region. Hence, current findings in high-income countries may not be scalable out to other regions of the world where undernutrition and micronutrient deficiencies are bigger issues than obesity (though all forms of malnutrition can coexist), where water resources are the most critical factor, or where diets are low in meat or animal-based products. Considering the approximately 10-fold variation in meat consumption between high-consuming and low-consuming populations, McMickael et al suggested convergence toward a global target of 90 g per person per day, not more than 50 g of which should come from red meat from ruminant animals, to stabilize GHGEs from the livestock sector.[86] This would mean a substantial reduction in meat consumption in industrialized countries and constrained growth in demand in developing countries.

Some modeling studies have indicated that dietary changes toward respecting of FBDGs[31,34] or nutritional recommendations[87] would imply an increase in resource demand in the Near East region,[34] in Tunisia,[87] and in India and Indonesia,[31] due to an increased intake in animal products. Using diet optimization, Rao et al showed that healthy, affordable, and climate-friendly diets could be attained in India by diversifying diets, particularly toward coarse cereals, pulses, and leafy vegetables, and away from rice.[88] Perignon et al underlined that, in Tunisia, moving toward healthy diets with lower environmental impact relied more on redistributing the sources of animal-based products rather than on reducing their total contribution.

The diversity of dietary habits, food cultures, and environmental issues requires context-specific solutions. There is a need for better knowledge about the dietary shifts with the greatest potential for generating health and environmental benefits in low- and middle-income countries.

SUSTAINABILITY AT THE FOOD SYSTEM SCALE

Sustainable diets are part of the larger framework of food systems, defined by the High Level Panel of Experts of Food Security and Nutrition (HLPE) as "all the elements (environment, people, inputs, processes, infrastructure, institutions, markets and trade) and activities that relate to the production, processing, distribution and marketing, preparation and consumption of food and the outputs of these activities, including socio-economic and environmental outcomes."[89] By analyzing how dietary changes can improve diet sustainability, the studies described in this review addressed only one aspect of the food system. Actions aimed at changing consumption patterns need to be combined with strategies focused on the other components of the food system (eg, production, transformation, waste management) to achieve sustainable development goals. Changing both consumption and production patterns is necessary to avoid improving some dimensions of sustainability at the expense of the others.

The case of organic food is a prime example highlighting this need: eating organic products without changing consumption patterns, regarding meat consumption in particular, would be beneficial in terms of impact on biodiversity, or exposure to pesticides, eg, but might induce a deterioration for other indicators, since organic products can have higher environmental impacts than conventional products for some indicators, such as land use.[28,80] The benefit for both health and environment seems possible for all the indicators only if production methods and consumption are changed simultaneously.

Beyond sustainable diets, the challenge is thus to take a more holistic view of sustainability by broadening the assessment to the entire food system. The HLPE defines a sustainable food system as "a food system that ensures food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition of future generations are not compromised."[89] According to the methodology proposed by the FAO,[90] a food system–wide sustainability assessment thus requires integrating the dimensions of environmental integrity, economic resilience, governance, and social well-being.

CONCLUSION

Figures. 2–5 present the principles, advantages, and limits of the 4 main methodological approaches used in studies aimed at identifying or designing more sustainable diets. Approach 1 (a priori scenarios), used in numerous studies, consists of assessing the sustainability characteristics of hypothetical diets. The main advantage of this approach lies in the ease of its implementation — in particular, since it does not require data on individual food consumption — and the ease of communication of the results. However, it encompasses important drawbacks: in particular, improvement in the sustainability characteristics of such predefined diets is not ensured, and they may even be impaired, and cultural acceptability is poorly considered. Approach 2 (the univariate epidemiological approach) consists of assessing the sustainability of existing diets; in this way, it better considers cultural acceptability. A main strength of this epidemiological approach is the way it enables the study of compatibility of the various targets, highlights trade-offs between the various sustainability dimensions, and explores how food groups – or any other determinants – contribute to the variability of a sustainability dimension. However, it relies on the availability of individual food consumption data, and allows the improvement of only one dimension of sustainability to be studied, without ensuring improvement in the others. With approach 3 (identification of "positive deviants"), the aim is to select, from among the existing diets, the ones that simultaneously fulfill several sustainability criteria; with this approach, the magnitude of the achievements can be too small. Approach 4 (using constrained optimization to design more sustainable diets) allows different sustainability goals to be fulfilled concurrently, and avoids impairing some dimensions in favor of others. Notably, this is the only approach able to ensure nutritional adequacy. However, though such methodology can minimize the deviation from current diets, cultural acceptability is not ensured.

A better knowledge and understanding of the specificities of the different methodological approaches used to explore diet sustainability is crucial for a good interpretation and a relevant use of study outcomes. The categorization of the approaches proposed in the present article, in particular the descriptions of their limitations and advantages, will therefore be helpful and provide robust support for decision making by public and private stakeholders who rely on such studies to build recommendations, interventions, and public policies.

Overall, the results of the studies confirm that it is possible to reduce the environmental impact of diets while improving their nutritional quality through informed food choices. They also show that entire food categories do not need to be eliminated to have a more sustainable diet. In conclusion, more than ever, "diversity and moderation" remain relevant. The question is not to what extent meat consumption should be reduced, or how much the consumption of plant products should be increased, but how to convince as many people as possible to take a step toward a better balance, each from their own starting point. From a methodological point of view, studies have progressed from the analysis of sustainability at the food item scale to that of diets. Now, they need to move toward an analysis at the food system scale.

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