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# Development of a methodology to compare and evaluate health and sustainability aspects of dietary intake across countries

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To solve the rising issue of how to feed our planet in the future, we need to enhance our knowledge of peoples' current eating patterns and analyze those in terms of their health and environmental impacts. Current studies about adherence to existing national and global dietary recommendations often lack the ability to cross-compare the results among countries. Therefore, this study aims to develop a methodology to evaluate adherence to food-based dietary guidelines (FBDGs) and the Planetary Health Diet (PHD) on a national level, which can be replicable in different countries. First, national dietary intake data was collected from surveys published by the respective responsible public institutions from five countries (Italy, Denmark, Germany, Morocco, and Poland). Second, food groups represented in the intake data and the FBDGs were mapped to establish a proposal for a new common grouping (i.e., comprehensive food groups) that enables cross-country comparison. Third, dietary intake was compared to the recommendations according to national FBDG and the PHD. The adherence to the recommended diets was assessed using an adapted version of the German Food Pyramid Index. Our results show that different ways of grouping foods may change adherence levels; when measuring adherence to the FBDGs with the food groups suggested in the FBDGs, average scores ( $45.5 \pm 5.4$ ) were lower than by using comprehensive food groups ( $46.9 \pm 3.7$ ). Higher adherence to the PHD ( $52.4 \pm 6.1$ ) was found also using the comprehensive food groups. Particularly the foods meats, eggs, and legumes in one group (i.e., protein equivalents) appear to influence the outcome of scores using the comprehensive food groups. This study developed a methodology to evaluate national dietary intake against national FBDGs and the PHD. Our study points out the fact that it is difficult to overcome the challenge that countries have different food grouping clusters. Yet, the combination of the methods developed enables cross-country comparisons and has the potential to be applied to different national settings globally.

## KEYWORDS

SysOrg, food-based dietary guidelines, planetary healthy diet, sustainable diets, adherence to diets, diet quality

## Introduction

Food-based dietary guidelines (FBDGs) are key tools to promote sustainable healthy diets (Tuomisto, 2018; FAO and WHO, 2019). However, most populations are not fully complying with their recommendations (Leme et al., 2021). Prevailing dietary patterns are unhealthy and unsustainable, requiring a Great Food Transformation to be able to properly nourish people in the future without causing excessive harm to the environment (Willett et al., 2019). This transformation calls for a better understanding of current dietary patterns and analyzing them regarding health and environmental outcomes.

Research has shown that adherence to FBDGs is a good indicator of diet quality regarding both health and environmental impact. Observational studies showed that populations with lower adherence to their FBDGs presented a higher risk for cardiovascular diseases (Ewers et al., 2020) and all-cause mortality (Biesbroek et al., 2017; Ewers et al., 2020). Moreover, previous research has shown that eating accordingly to the FBDGs decreases the dietary environmental impact when compared to current Western dietary patterns (Biesbroek et al., 2017; Arrieta and González, 2018).

In this context, several studies have measured adherence to FBDGs in cohorts using different methods (von Ruesten et al., 2010; Knudsen et al., 2012; Struijk et al., 2014; Biesbroek et al., 2017; Looman et al., 2017; Gómez-Donoso et al., 2019; Ewers et al., 2020). These studies, however, are not easily comparable as most adherence indexes are designed to fit either the dietary assessment tools used, or they evaluate specific aspects of diet (e.g., energy contribution of fats).

Alternatively, dietary patterns can be evaluated against a globally applicable reference diet, such as the Planetary Health Diet (PHD). The PHD comprehends global dietary recommendations proposed by the EAT-Lancet Commission and is designed to have a lower environmental impact and be healthier than current dietary patterns (EAT-Lancet Commission, 2019; Willett et al., 2019). Despite some criticism regarding affordability (Hirvonen et al., 2020), the PHD has been used to evaluate diet quality and sustainability of dietary patterns and guidelines (Sharma et al., 2020; Hendrie et al., 2022). The PHD is also applied as a scientific base for developing dietary guidelines, such as the Danish Dietary Guidelines (Lassen et al., 2020). Moreover, different indexes based on the PHD have been proposed, such as WISH (Trijsburg et al., 2021), and PHDI (Cacau et al., 2021). Despite their strengths, they have not been used to evaluate other populations besides the ones in the original studies. Both FBDGs and the PHD can be important tools to promote sustainable diets, which are diets that “[...] have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable” (FAO and WHO, 2019).

Considering the potentiality of the FBDGs and the PHD in promoting sustainable healthy diets, it is important to understand to which degree current dietary patterns comply with these references. Therefore, the present study seeks to develop a methodology that evaluates dietary patterns across five nations based on the recommendations of their FBDGs and the PHD on a national level. To our knowledge, this is the first study that elaborates comprehensive food groups to enable a cross-comparison of diet quality across nations.

## Materials

The current study is part of the project “Organic agro-food systems as models for sustainable food systems in Europe and Northern Africa” (SysOrg) ([www.uni-kassel.de/go/sysorg](http://www.uni-kassel.de/go/sysorg), last accessed 13 January 2023) that investigates five case study territories (CSTs) in five countries: Italy, Denmark, Germany, Poland, and Morocco. Therefore, these countries were considered the geographical boundaries of this study.

### Dietary guidelines

For this study, the national FBDGs and complementary materials were used (Table 1). Unlike the European countries, Morocco has no FBDG but a Nutrition Guide (Ministère de la Santé, 2016) intended to be used by healthcare professionals, which for this study was used equivalently as a substitute. The recommendations from Italy, Morocco, and Poland were available only in the local languages and were translated using Google Translator (Italian: Sep/2021; French and Polish: Jan/2022). The complementary materials were used to assess the portion sizes established for each population and are listed in Table 1.

Recommended daily dietary intakes were established by applying upper values as reference (e.g., the Moroccan Nutrition Guide recommends two servings a day of vegetables ranging from 150 to 300 g each, so 300 g was established as the portion size). Moreover, the recommendations were adjusted for daily intake. Therefore, weekly recommendations were divided by seven (e.g., Italian FBDG recommends an upper intake of 100 g of red meats a week, so daily recommendations are  $100/7 = 14.28$  g/day).

### Dietary intake

Average intake information was extracted from national dietary intake surveys and reports (Table 2). Only mean values were considered for this step, and data were converted to daily intake in grams or milliliters when needed. When possible, dietary intake collected was from adults, since FBDGs are calculated for adults with a 2,000 kcal or 10 MJ energy requirement (Oberritter et al., 2013; Danish Veterinarian and Food Administration, 2021). Data on alcohol intake was not available in all countries. Considering the impact of alcoholic beverages on diet and health (Johnson et al., 2022), data on alcohol intake was extracted from the Global Health Observatory (WHO, 2019) for the five countries. Values considered for calculating adherence scores are available in the Supplementary material.

### The Planetary Health Diet

Reference values from the PHD were extracted from Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems (Willett et al., 2019) considering the midpoint values proposed in the reference diet. Reference values for legumes were given for dry pulses, but for this study, we used 175 g

TABLE 1 List of materials used for recommended intake of food groups.

Country	FBDG*	Complementary material**
Denmark	The official dietary guidelines-good for health and climate <sup>a</sup>	Development of a Danish adapted healthy plant-based diet based on the EAT-lancet reference diet <sup>b</sup>
Germany	Ten guidelines of the German Nutrition Society for a wholesome diet <sup>c</sup>	The DGE Nutrition Circle–Presentation and Basis of the Food-Related Recommendations from the German Nutrition Society (DGE) <sup>d</sup>
Italy	Dietary guidelines for healthy eating– revision 2018 <sup>e</sup>	-
Morocco	Moroccan Nutrition Guide for use by healthcare professionals <sup>f</sup>	Dietary and health guidelines for the preparation of menus at the level of university residences and boarding schools in higher education establishments <sup>g</sup>
Poland	Healthy eating recommendations: plate of healthy eating <sup>h</sup>	Check how many servings of different products you can eat during the day <sup>i</sup>

\* Assessed in September 2021. \*\* Assessed in January and February 2022. <sup>a</sup>Danish Veterinarian and Food Administration (2021). <sup>b</sup>Lassen et al. (2020). <sup>c</sup>The German Nutrition Society (DGE) (2017). <sup>d</sup>Oberriitter et al. (2013). <sup>e</sup>CREA (2019). <sup>f</sup>Ministère de la Santé (2016). <sup>g</sup>Ministère de la Santé (2013). <sup>h</sup>Narodowe Centrum Edukacji Zywieniowej (NCEZ) (2020b). <sup>i</sup>Narodowe Centrum Edukacji Zywieniowej (NCEZ) (2020a). Adapted with permission from Diet quality and sustainability in different countries and territories (Philippi Rosane, 2022).

TABLE 2 Dietary intake surveys and their methodology, time frame and data extracted.

Country	Survey	Methodology	Population and data extracted
Denmark	Dietary Habits in Denmark 2011–2013 <sup>a</sup> For a healthier and more sustainable diet <sup>b</sup>	7 consecutive days pre-coded food record questionnaire	3,016 adults (18 to 75 years), 1,552 females Mean individual daily intake, in total and per sex
Germany	Results of the National Nutrition Monitoring, survey year 2014 <sup>c</sup>	Food consumption and dietary patterns were assessed by dietary history interviews and 24-h recalls	1,508 adults (22 to 80 years), 868 females Mean individual daily intake, per sex and age groups (22–50 and 51–80 years)
Italy	The Italian National Food Consumption Survey INRAN-SCAI 2005–06 <sup>d</sup>	A cross-sectional study performed with randomly selected households; food consumption was assessed on three consecutive days through individual estimated dietary records	2,312 adults (18 to 64.9 years), 1,244 females Mean of individual daily consumption (3 days average), in total and per sex
Morocco	The National Survey on Household Consumption and Expenditure 2013/2014 <sup>e</sup>	Food consumption per household was assessed by frequency of food purchase	15,970 households Average annual intake per capita
Poland	Household budget survey in 2019 <sup>f</sup>	Food consumption was measured by assessing food purchased, received for free and taken activity	35,923 households; 93759.03 participants (average number of people living in a household: 2.61) Average monthly consumption per capita

<sup>a</sup>Pedersen et al. (2015). <sup>b</sup>Trolle et al. (2019). <sup>c</sup>Bundesministerium für Ernährung und Landwirtschaft Max Rubner Institute (2014). <sup>d</sup>Leclercq et al. (2009). <sup>e</sup>Haut Commissariat au Plan (2016). <sup>f</sup>GUS (2019). Adapted with permission from Diet quality and sustainability in different countries and territories (Philippi Rosane, 2022).

of cooked legumes for the score, considering a 2.5 weight change factor, as proposed in the work of Lassen et al. (2020).

## Methods

In this study, three adherence scores were developed for different purposes (Table 3). The first score (ADH1) measures adherence to FBDGs using the corresponding food groups established by each country, resulting in a tailored score for each population. For comparison purposes, a second score (ADH2) was designed to compare adherence levels to the FBDGs across different populations. The third score, (APHD) was designed to assess adherence to the PHD, allowing a comparison of the different populations using a common diet as a reference.

## Methods development steps

### Step 1-identifying the food groups

Step 1 consisted of identifying the food groups represented in the materials and assuring that all food groups were represented in the recommendations and intake sources (Tables 1, 2). For

better visualization, a color scheme was created for the food group mapping, as seen in Table 4.

The FBDGs of the five CSTs show different food groups (Table 4). For the ADH2 and APHD, this difference required the creation of a new common food group distribution to allow cross-comparison between different populations. The new classification generated seven comprehensive food groups, following groupings suggested by the FBDGs as displayed in Table 5.

All food groups and comprehensive food groups were classified into “positive,” “neutral,” and “negative” for health, as seen in Table 5. The classifications are based on scientific evidence, following assortments proposed by other authors (von Ruesten et al., 2010; Gómez-Donoso et al., 2019).

### Step 2-upper intake of alcohol and sweets

Table 4 displays that none of the FBDGs have recommended intake for the groups in the “negative” class. Therefore, following similar studies (Gómez-Donoso et al., 2019), a value of upper-limit consumption was determined for the negative food groups. The determined values were:

- Sugar and sweets (Ygil, 2013):

**TABLE 3** Adherence scores developed for food-based dietary guidelines and the Planetary Health Diet.

	ADH1	ADH2	APHD
Name	Adherence to FBDG	Adherence to FBDG using comprehensive food groups	Adherence to the PHD
Index dimensions	Health impact		Health and environmental impact
References	FBDG recommendations and national dietary intake	FBDG recommendations and national dietary intake, in comprehensive food groups	PHD recommendations and national dietary intakes, in comprehensive food groups
Scores per food group	Class 1 (positive): 0 to 10; up to 10 extra points could be given for extra intake Class 2 (neutral): 0 to 10; extra intake caused proportional deduction of points Class 3 (negative): 0 to 10; calculated inversely (10 is no intake)		
Maximum total score	IT: 190 (150 + 40 extra points) DK: 180 (150 + 30 extra points) DE: 130 (110 + 20 extra points) MA: 140 (110 + 30 extra points) PL: 110 (90 + 20 extra points)	For the five countries: 80 (70 for the seven food groups + 10 extra points from the positive class)	
<b>Methods development steps</b>			
Step 1	Identification and color coding the identified food groups present (Table 4)		
	Establishment of comprehensive food groups for comparing countries (Table 5)		
Step 2	Establishment of upper limit intake for alcohol and sweets [Ygil, 2013; Gómez-Donoso et al., 2019; National Institute on Alcohol Abuse and Alcoholism (NIAAA), n.d.]		
Step 3	Assessment of health impacts of the food groups and classification of them accordingly		
Step 4	Calculation of score for each food group using Eq1 and Eq2 according to groups classifications (von Ruesten et al., 2010)		

FBDG, Food-Based Dietary Guidelines; PHD, The Planetary Health Diet (Willett et al., 2019); IT, Italy; DK, Denmark; DE, Germany; MA, Morocco; PL, Poland. Adapted with permission from Diet quality and sustainability in different countries and territories (Philippi Rosane, 2022).

- o One serving of 25 g/d
- Alcohol [Gómez-Donoso et al., 2019; National Institute on Alcohol Abuse and Alcoholism (NIAAA), n.d.]:
  - o For females: 1 dose/d or 14 g in pure alcohol/d
  - o For males: 2 doses/d or 28 g in pure alcohol/d
  - o For the general population (males and females): 1.5 doses/d or 21 g in pure alcohol/d

### Step 3-health impacts of the food group

The first class, “positive,” has food groups with protective effects for diet-related diseases and is composed of fruits, vegetables, potatoes, and water or unsweetened drinks (for Italy only). The “neutral” class consisted of food groups whose intake should be within recommendations, as their excessive intake could be harmful to health, consisting of cereals, dairy, protein equivalents, and fats. The third class, “negative,” consists of food groups that the FBDGs recommend limiting the consumption or eating in moderation, which in this study were sugar and sweets, and alcohol. These classifications were later (i.e., step 4) used as a reference for scoring the intake of each food group.

### Step 4-calculation of score for each food group

The three adherence scores (ADH1, ADH2, and APHD) were developed inspired by the German Food Pyramid Index (GFPI) (von Ruesten et al., 2010) but adapted from servings/day to gram/day. Each class of food groups was scored differently. The score for food groups within the “positive” class was calculated

using the following equation:

$$\text{food group score} = \frac{\text{average consumption/d}}{\text{recommended intake/d}} \times 10 \quad (1)$$

Considering the potential health benefits of higher consumption than recommended, up to 10 extra points could be given for extra intakes, following Eq1.

The scores for “neutral” food groups were also obtained with Eq1. However, intake of foods surpassing the recommendations in this class was deduced. The deduction of points was done by calculating their score using Eq2, as follows:

$$\text{food group score} = \frac{\text{recommended intake/d}}{\text{average consumption/d}} \times 10 \quad (2)$$

The “negative” food groups’ scores were calculated by using Eq2, which means 10 points were given for consumption below the upper limit. In case of no intake, 10 points were given.

Scores were calculated using Microsoft® Excel version 16.59. Adherence to FBDGs (ADH1) was measured differently in each country, as it considers each country’s particularities. Italian national adherence was done for adult males and females separately, and they could be scored from 0 to 200 (160 points from the 16 food groups + 40 possible extra points in the four positive groups). The Danish population was assessed using the intake of the general adult population, and separately for adult males and females, being scored from 0 to 170 (140 points from the 14 food groups + 30 possible extra points). Adherence to the German FBDG was assessed for adult men and women separately and scored from 0 to 130 (110 points for 11 food groups + 20 possible extra points).

TABLE 4 Identification of food groups represented in the recommendations and in the dietary intake surveys per country for Italy, Denmark, Germany, Morocco, and Poland.

Italy		Denmark		Germany		Morocco		Poland	
Recommendation	Intake	Recommendation	Intake	Recommendation	Intake	Recommendation	Intake	Recommendation	Intake
Vegetables	Vegetables	Vegetables	Vegetables	Vegetables	Vegetables	Vegetables	Vegetables	Vegetables	Vegetables
Fruits	Fruits	Fruits	Fruits	Fruits	Fruits	Fruits	Fruits	Fruits	Fruits
Red meats	Red	Red meat	Red meat	Meats	Meats	Red meats	Meats	Meats	Red meat
White meat	White	Poultry	Poultry			White meat			Poultry
Fish	Fish	Fish	Fish	Fish	Fish	Fish	Fish		Fish
Eggs	Egg	Eggs	Eggs	Eggs		Eggs	Eggs		Eggs
Legumes	Legumes	Legumes	Legumes			Legumes	Legumes		Legumes
Dairy	Dairy	Dairy	Dairy	Dairy	Dairy	Dairy	Dairy	Dairy	Milk
Cheese	Cheese	Cheese	Cheese	Cheese	Cheese				Cheese
Oils and fats	Oils and fats	Oils and fats	Oils and fats	Oils and fats	Oils and fats	Oils and fats	Oils and fats	Oils and fats	Oils and fats
Cereals	Cereals	Cereals	Cereals	Cereals	Cereals	Cereals	Cereals	Cereals	Cereals
Potatoes	Potatoes	Potatoes	Potatoes	Potatoes	Potatoes	Potatoes		Potatoes	Potatoes
	Alcohol		Alcohol						
	Sugar and sweets		Sugar and sweets		Sugar and sweets		Sugar and sweets		Sugar and sweets
Nuts and oily seeds	Nuts								
Water	Water								

Foods in the same colors are in the same food group. Reprint with permission from Diet quality and sustainability in different countries and territories (Philippi Rosane, 2022).

**TABLE 5** Comprehensive food groups, their respective classification and food groups they contain.

Food group class	Comprehensive food group	Food groups present
Positive	FVP	Fruits Vegetables Potatoes
Neutral	Cereals	Cereals Grains
Neutral	Dairy	Dairy Milk and yogurt Cheese
Neutral	Protein equivalents	Red meat White meat Meats Eggs Fish Legumes
Neutral	Fats	Fats
Negative	Sweets	Sweets
Negative	Alcohol	Alcohol

Reprint from Diet quality and sustainability in different countries and territories (Philippi Rosane, 2022). Food group classification are based on the work of von Ruesten et al. (2010) and Gómez-Donoso et al. (2019).

In Morocco and Poland, dietary intake data sources were household surveys with an estimated average intake per capita (Table 2), therefore the analysis is based on the general populations (males and females of all ages) of those countries. The Moroccan population intake was scored from 0 to 140 (120 points for 12 food groups + 20 possible extra points), while the Polish population could be scored from 0 to 110 (90 for 9 food groups + 20 possible extra points).

## Results

The results present the scores calculated for the three different adherence scores (ADH1, ADH2, and APHD), followed by an overview of the scores' results observed, unraveled by the food groups. Lastly, we present the data from the dietary intake surveys collected for comparison. This study focuses on the description of the methodology developed.

### The comprehensive food groups

Cross-comparison of diet quality between the populations in Denmark, Germany, Italy, Morocco, and Poland was only possible due to the proposal of a common food grouping, the comprehensive food groups (Table 5). Compared to the food groups proposed by most of the FBDGs (Table 4), the main differences in the comprehensive food groups were "FVP" and "protein equivalents." Fruits and vegetables were grouped mainly because in Morocco their recommendations are given together without specifying how to divide the recommendation between both groups. Similarly, in Poland, potatoes are included in the

recommendations for vegetables as interchangeable, while in other countries potatoes intake has been presented separately.

As for "protein equivalents," Denmark and Italy were the only two countries to have all meats, eggs, and legumes separately. For Morocco and Germany, data was presented with fish separated from other meats and eggs. Due to the Polish recommendations, all protein sources besides dairy were grouped together, without specifying a frequency intake for specific foods, that is, all foods in the "protein equivalents" are presented as interchangeable.

### The three different scores

The three different scores applied to the studied populations showed different scores as seen in Figure 1, using a maximum total score of 80 for the comparison. Regarding adherence to FBDG, all countries had higher scores when evaluated with the comprehensive food groups (ADH2). For all countries except Poland, adherence scores were higher for the APHD than for the methods comparing adherence to national recommendations (ADH1 and ADH2). For Poland, similar scores for different methodologies were observed for ADH2 and APHD. The average total scores for the indexes were 45.5 ( $\pm 5.4$ ) for ADH1, 46.9 ( $\pm 3.7$ ) for ADH2, and 52.4 ( $\pm 6.1$ ) for APHD.

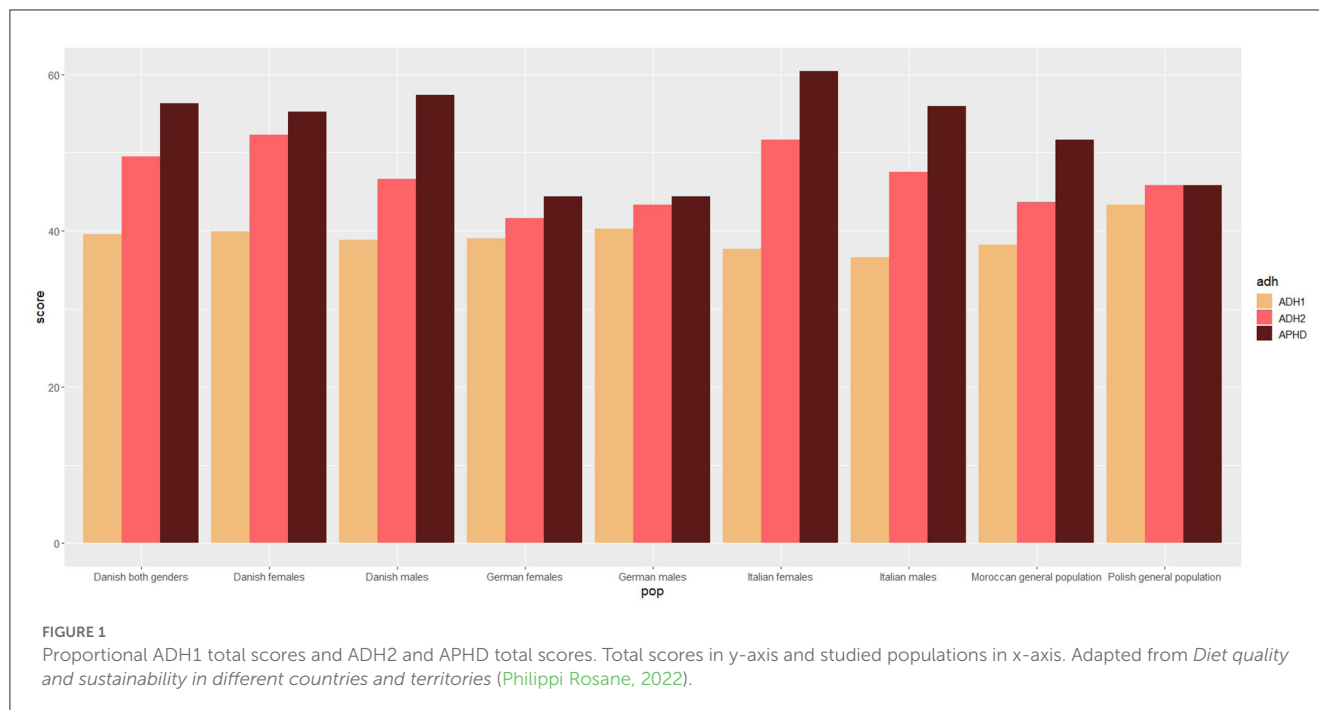
### Adherence to food-based dietary guidelines (ADH1 and ADH2)

The ADH1 score assesses the degree to which the actual consumption of the population, according to national intake data, complies with the national FBDGs. Table 6 presents an overview of the scores given to each population per food group and the overall score. In the countries where red meats were evaluated separately from other meats (i.e., Denmark and Italy) the populations showed an intake of red meats that surpassed the recommendations. In Italy and Denmark, the intake of other animal proteins (i.e., dairy and eggs) was also higher than suggested by their FBDGs.

For cross-comparison purposes, the ADH2 used the same food groups (i.e., the comprehensive food groups), for which the results are displayed in Table 7. For ADH2, Danish females had the highest score, which means they adhere the best to the recommendations while the lowest adherence was observed in German females. In this scoring system, Danes and Italians were scored inversely for protein equivalents for having intakes surpassing the recommendations. For dairy, higher intakes than recommendations were observed in Danish adults.

### Adherence to the Planetary Health Diet

Italian females had the closest diet to the PHD recommendations, as indicated by the highest APHD score (Table 8). Contrasting, both German females and German males had diets that differ the most from the PHD. In the APHD, the cereals food group was often scored inversely, with most populations surpassing the recommended intake.



## Discussion

This study proposed a methodology with three different indexes for evaluating diet quality considering health and environmental impacts. Additionally, it displays how some of the difficulties to compare diet quality across nations can be met but still includes limitations due to eating cultures and that food groups differ significantly across nations and intake surveys differ in methods.

The starting point was the development of dietary quality indexes that considered the particularities of five different populations in Italy, Denmark, Germany, Morocco, and Poland. Considering the environmental burden of current food systems, it is imperative that sustainability is considered when evaluating diets (FAO and WHO, 2019). Moreover, comparing diet quality between different populations (i.e., cross-country comparison) can construct a better understanding of the challenges people face to adhere to sustainable healthy diets.

Several diet quality indexes have been developed and validated in previous studies (Waijers et al., 2007), but they cannot be tailored to different populations, and most do not consider the environmental impacts of diets. For this study, the FBDGs were chosen as references since they are tailored to the nutritional needs and dietary habits of the country where they were developed (FAO, 2007). Other studies have investigated adherence to FBDGs but lacked the environmental impact perspective (von Ruesten et al., 2010; Knudsen et al., 2012; Struijk et al., 2014; Biesbroek et al., 2017; Looman et al., 2017; Gómez-Donoso et al., 2019; Ewers et al., 2020). In this study, we proposed as a solution the adherence to the PHD as a complementary measurement of diet quality, being a reference of a sustainable healthy diet.

Recent quality indexes based on the PHD tried to assess the sustainability of dietary patterns in cohort studies, such as PHDI (Cacau et al., 2021), and WISH (Trijsburg et al., 2021).

These indexes can be globally applicable but lack to consider the nutritional particularities of each country. Another index that considers health and environmental outcomes is SHED (Tepper et al., 2021), however, it requires that subjects answer a questionnaire about their dietary habits, which is not always possible. In this study, dietary intake surveys were used, which are often publicly available.

## Use of comprehensive food groups

The use of comprehensive food groups was proposed as a way of enabling a cross-country comparison of adherence to reference diets per food group. The results show that the use of comprehensive food groups increased the total scores of all populations. However, the discrepancies in the total scores (Figure 1) for ADH1 and ADH2 suggest that adherence scores with comprehensive food groups should not be used by themselves as they might dilute excessive and very low intakes of certain food groups. In ADH1, the intake of red meats was assessed separately from other meats for countries where there were specific recommendations for red meats (i.e., Denmark, Germany, and Italy). In these three countries, the intake of red meats was higher than national recommendations, having their adherence score calculated inversely to deduce points from excessive intake (Table 6). In ADH2, excessive intake is no longer observed as these populations eat less fish and legumes than recommended. Therefore, we see a dilution of the low scores that would occur for excessive intake and for not meeting the recommendations, which benefitted the total scores of Danes, Germans, and Italians.

Similarly, the higher scores observed for APHD can properly be explained by the use of comprehensive food groups due

TABLE 6 Populations' scores for adherence to the FBDGs, using the ADH1 method, by food group and total score.

Population	FVP	Cereals	Dairy	Protein equivalents	Fats	Sweets	Alcohol	Total score/maximum score
Danish both genders	Fruits: 6.3 Vegetables: 6.6 Potatoes: 9.1	5.6	Milk and yogurt: 8.2* Cheese: 4.5*	Red meats: 1.1* White meats: 8.7 Fish: 7.4 Eggs: 6.3* Legumes: 0.2	7.1*	6.8	6.1	83.9/170
Danish females	Fruits: 5.5 Vegetables: 6.9 Potatoes: 6.5	4.8	Milk and yogurt: 9.2* Cheese: 4.9*	Red meats: 1.5* White meats: 8.0 Fish: 6.8 Eggs: 6.5* Legumes: 0.2	8.3*	7.1	8.5	84.8/170
Danish males	Fruits: 7.1 Vegetables: 6.4 Potatoes: 8.5*	6.4	Milk and yogurt: 7.4* Cheese: 4.3*	Red meats: 0.9* White meats: 9.7 Fish: 8.0 Eggs: 5.8* Legumes: 0.2	6.8*	6.6	5.2	82.5/170
German females	Fruits: 6.3 Vegetables: 3.5 Potatoes: 2.5	8.0	Milk: 5.4 Cheese: 8.2	Meats: 8.3 Fish: 5.1	4.7	4.8	6.6	63.4/130
German males	Fruits: 5.3 Vegetables: 3.4 Potatoes: 3.0	9.9	Milk: 6.2 Cheese: 8.2	Meats: 7.0 Fish: 7.3	6.7	4.3	4.1	65.6/130
Italian females	Fruits: 4.8 Vegetables: 4.3 Potatoes: 8.1	7.6	Milk and yogurt: 3.7 Cheese: 7.9*	Red meats: 1.8* White meats: 4.3 Fish: 8.9 Eggs: 8.7 Legumes: 1.7	7.7*	8.1	10**	94.1/200
Italian males	Fruits: 4.4 Vegetables: 4.6 Potatoes: 9.5	9.7	Milk and yogurt: 2.9 Cheese: 6.5*	Red meats: 1.3* White meats: 5.3 Fish: 9.7 Eggs: 8.8* Legumes: 1.8	6.5*	6.8	6.4	91.5/200
Moroccan general population	Fruits: 3.1 Vegetables: 5.7	7.3	2.4	Meats: 5.2 Fish: 4.3 Legumes: 11.1	9.8*	Sugar: 3.7	10.0**	66.8/140
Polish general population	Fruits: 7.9 Vegetables: 5.1 Potatoes: 7.6*	8.9	2.6	Meats and protein equivalents: 9.8	8.9	Sugar and sweets: 4.6	5.2	59.5/110

\*Score by equation 2, because intake surpasses the recommendations.

\*\*Score of 10 was given for intakes of negative food groups that were lower than the upper levels. FVP, fruits, vegetables, and potatoes. Reprint with permission from Diet quality and sustainability in different countries and territories (Philippi Rosane, 2022).

to the grouping of all meats and legumes in the group of “protein equivalents.” The PHD advocates a plant-based diet, with low or no intake of meats (Willett et al., 2019). Legumes are proposed as healthy and sustainable protein sources and as alternatives to meats (Fabricius et al., 2021). The PHD suggests a daily intake of 178 g of pulses in a 10 MJ diet (Lassen et al., 2020), which is a goal far from the consumption of the studied populations; European countries in our study have a habitual intake below 12 g/d (Supplementary material). In contrast, in Morocco, the consumption of legumes is substantially higher than in Europe (Supplementary material). At the same time, the Moroccan Nutrition Guide is the only guideline, among the five analyzed in this study, recommending the daily consumption of meat (Supplementary material; Ministère de la Santé, 2016), which could implicate in an increased intake of meats.

As previously mentioned, the “protein equivalents” group was created because in Poland the dietary recommendations suggest one daily portion of either meat (beef, chicken, fish, other), eggs, or legumes [Narodowe Centrum Edukacji Żywnościowej (NCEZ), 2020a], without specifying a minimum or maximum for each food. The Polish FBDG [Narodowe Centrum Edukacji Żywnościowej (NCEZ), 2020a], however, advocates increasing the intake of legumes and fish and decreasing the intake of red and processed meats. Additionally, the Polish FBDG recommends replacing meat with plant-based protein, fish, and eggs. Despite grouping animal and plant-based proteins together, the consumption of those foods is not balanced. According to the Household Budget Survey from 2019 (GUS, 2019), monthly per capita intake of meats is on average 5.08 kg, while consumption of fish is 0.27 kg/month and consumption of legumes is not reported, which might indicate that intake of legumes is low.



TABLE 7 Adherence scores to FBDG according to comprehensive food groups (ADH2).

Population	FVP	Cereals	Dairy	Protein equivalents	Fats	Sweets	Alcohol	Total score
Danish both genders	6.9	5.6	7.8*	9.4*	7.1*	6.8	6.1	49.5
Danish females	6.2	4.8	8.6*	8.7	8.3*	7.1	8.5	52.3
Danish males	7.4	6.4	7.0*	7.8*	6.2*	6.6	5.2	46.7
German females	4.0	8.0	5.9	7.6	4.7	4.8	6.6	41.6
German males	3.8	9.9	6.6	7.9*	6.7	4.3	4.1	43.3
Italian females	4.7	7.7	4.6	8.9	7.7*	8.0	10.0**	51.6
Italian males	4.8	9.7	4.2	8.9*	6.5*	6.9	6.4	47.6
Moroccan general population	4.4	7.3	2.4	6.1	9.8*	3.7	10.0**	43.6
Polish general population	6.9	8.9	2.6	9.8	7.8	4.6	5.2	45.8

\*Scored by equation 2, because intake surpasses the recommendations. \*\*Score of 10 was given for intakes of negative food groups that were lower than the upper levels. FVP, fruits, vegetables, and potatoes. Reprint with permission from Diet quality and sustainability in different countries and territories (Philippi Rosane, 2022).

TABLE 8 Adherence scores to the PHD (APHD).

Population	FVP	Cereals	Dairy	Protein equivalents	Fats	Sweets	Alcohol	Total score
Danish both genders	8.7	9.4	7.2*	8.6	7.9	8.4	6.1	56.3
Danish females	7.9	8.1	8.0*	7.0	6.8	8.9	8.5	55.2
Danish males	9.5	9.3*	6.5*	9.6*	9.1	8.2	5.2	57.4
German females	6.6	9.7*	7.4	4.1	4.1	6.0	6.6	44.4
German males	6.3	7.8*	8.2	6.8	5.8	5.3	4.1	44.4
Italian females	9.7	10.0*	7.7	6.6	7.5	9.9	10.0**	60.4
Italian males	8.9	7.8*	7.0	8.3	8.9	8.5	6.4	55.9
Moroccan general population	9.5	4.6*	6.5	8.1	8.4*	4.6	10.0**	51.7
Polish general population	6.9	7.7	6.2	7.6	6.7	5.7	5.2	46.0

\*Scored by equation 2, because intake surpasses the recommendations. \*\*Score of 10 was given for intakes of negative food groups that were lower than the upper levels. FVP, fruits, vegetables, and potatoes. Reprint with permission from Diet quality and sustainability in different countries and territories (Philippi Rosane, 2022).

## Sustainability of dietary patterns

The PHD is a global reference for a sustainable healthy diet that can be adapted to the local context and considers different populations, their food culture, nutritional status, and food availability (Willett et al., 2019). These characteristics made the PHD a reference diet for the five countries studied in the present study. Considering that the PHD is formulated to have lower environmental impacts, we can presume that populations with dietary patterns closer to the PHD, would have diets of a lower environmental burden than dietary patterns that differ considerably from the PHD. Therefore, we estimate that the populations with a higher APHD score would have a more sustainable diet (i.e., Italian females). Italians and Danes presented the highest scores for the APHD, mainly due to the highest scores for adequate intake of fruits, vegetables, and potatoes (FVP).

The “protein equivalents” group contains food groups with divergent environmental and health impacts. Red meats, especially beef, are the foods with the highest environmental burden in their production chain, due to land and water use, and greenhouse gasses emissions (Pradhan et al., 2013; Ritchie et al., 2018; Chai et al., 2019). Additionally, red meats and processed meats have been correlated to non-communicable diseases (NCDs) in different observational studies and reviews (Clark et al., 2019; Libera et al.,

2021). Contrastingly, recent work with risk-benefit assessment on the substitution of red meats for pulses in Danish diets concluded that this substitution would improve public health due to a reduction of the burden of cardiovascular diseases and diabetes (Fabricius et al., 2021).

Ahead of the evaluation of adherence to FBDGs, sustainability aspects of the FBDGs were assessed for the countries studied in SysOrg; Denmark, Germany, Italy, Morocco, and Poland. In this previous study (Philippi Rosane, 2021), we focused on amounts of different food groups recommended as other pieces of advice related to sustainability, such as purchasing seasonal and local produce. The study concluded that the Moroccan Nutrition Guide (Ministère de la Santé, 2016) has the highest environmental impact among the five countries because it recommends the highest intake of meats. On the other hand, the Danish Dietary Guidelines (Danish Veterinarian and Food Administration, 2021) had the lowest environmental impact, with guidelines focusing on a plant-based diet with very low meat intake. In this context, Danish females presented the healthiest and more sustainable diets (Figure 1). Danes, however, eat more red meats and less legumes than recommended, while in Morocco they eat less meats than recommended and considerably more legumes than the European populations (Tables 5, 8; Supplementary material). These food groups differ significantly in their environmental impact.

Therefore, it is important to look not only at overall scores but at the intake and recommendations of the different food considering their impact on the environment and health. An assessment of the sustainability aspects of the FBDGs has also been seen as needed to complement the analysis of diet quality based on the FBDGs. Additionally, the use of APHD has been shown important as a complement to the FBDGs in the assessment of health and sustainability of dietary patterns.

## Strengths and limitations

Several strengths and limitations unfolded in the development of this dietary evaluation methodology. First, this methodology permits the application of tailored recommendations for the evaluation of each population, that is, their own FBDG. Second, this study also used a globally applicable reference diet (i.e., the PHD) to complement the cross-comparison. Third, another strength of the methods here proposed is the adaptability to different populations and recommendations. The comprehensive food groups as adherence scores to FBDGs can and should be adapted to the studied populations in future studies.

The following aspects were identified as limiting factors of the methodology. First, the merging of certain food groups, especially all meats and legumes. Second, the quality of foods within each group was not considered. Third, although most FBDGs recommend the intake of whole-grain cereals over refined grains (Philippi Rosane, 2021), this evaluation was not possible as their intake was not distinguished on any of the dietary intake surveys. Lastly, no statistical test to determine significant differences between adherence scores was applied, because each population was treated as one observation, and no variance in intake was collected.

The limitations caused by the use of comprehensive food groups can be minimized in the future if dietary intake and recommendations consider that certain foods cannot be grouped together, despite having somewhat similar roles in diets, as they differ in environmental and health impacts (e.g., meats and legumes, vegetables and potatoes). However, it should be noted that the comprehensive food groups method is flexible to assemble differences presented by the diet materials being analyzed. Therefore, in future studies, they should be adapted to the FBDGs and dietary intake under investigation.

Additionally, dietary intake data varied in methods used in the assessment of diets, as seen in Table 2. In Denmark, Germany, and Italy, intake was calculated based on individual assessment but using different tools (i.e., food frequency questionnaires (FFQs), interviews, 24 h recall, and food records). In contrast, in Morocco and Poland, consumption per capita was estimated based on household consumption. In Morocco, respondents to the national survey were asked to inform their total annual purchase of foods from the previous year (Haut Commissariat au Plan, 2016); in Poland, estimated consumption per household was calculated by monthly purchases and divided by the national average of residents per household (GUS, 2019). These differences are a limitation of our methodology since FFQ, 24 h food recall, and food records are more precise and trustworthy than household estimations and

relying on memory-based information (Henríquez-Sánchez et al., 2009; Archer et al., 2018).

## Conclusion

The present study proposes a diversified methodology to evaluate diet quality based on criteria of health and sustainability. To our knowledge, this study is a pioneer in evaluating dietary patterns according to FBDGs across different countries based on food groups. Our results show that using a combination of methods to compare dietary intake with national and global recommendations allows for cross-country comparisons. Due to the variability of data in the different countries, especially the use of different food groups, this study calls attention to the challenge of comparing different recommendations and dietary patterns. Therefore, the combination of the three methods developed can deliver an improved evaluation methodology of diets across different populations. Our cross-comparison methods for diet quality assessment (i.e., ADH2 and APHD) should not be used by themselves as the common food grouping (i.e., comprehensive food groups) impacted the adherence scores positively. This methodology can be useful for future evaluation of dietary patterns having health and environmental impact as quality aspects. Moreover, adherence to the FBDGs should be frequently assessed to guide nutrition campaigns and health policies.

Additionally, this study evidenced the need for assessing dietary intake aligned with the recommendations given in combination with separating foods according to their environmental and health impacts. To avoid wrong grouping and misleading scoring results, dietary intake surveys and recommendations should consider that certain foods cannot be grouped together. The reason is that food groups that currently are grouped together differ in environmental and health impacts (e.g., meats and legumes, vegetables and potatoes).

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

## Author contributions

Conceptualization, methodology, and writing—original draft preparation: BP, LM, and SB. Data collection: BP, LM, RG-W, KK, DŚ-T, RK, LR, and YA. Data curation, formal analysis, and visualization: BP. Critical review and editing: LM, RG-W, KK, DŚ-T, RK, LR, YA, and SB. All authors have read and agreed to the published version of the manuscript.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships

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that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fsufs.2023.1147874/full#supplementary-material>

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