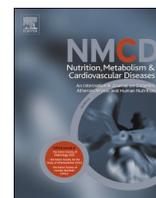




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Association of planetary health diet indices with diet composition, nutritional quality and environmental impacts in Italian adults

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ABSTRACT

Background and aims: Sustainable diets are increasingly recognized as a key strategy to promote human health while reducing environmental impacts. The Planetary Health Diet (PHD) provides a global framework for sustainable and healthy eating patterns, but evidence on its adherence and implications in specific populations is still limited. The aim of this study was to test the level of adherence, the environmental impact, and the nutritional quality of several scores assessing the level of adherence to the PHD in a cohort of Italian individuals. **Methods and results:** Dietary habits were assessed through validated food frequency questionnaires while various scores have been applied to evaluate the level of adherence to PHD (ELD-I, EAT, PHDI-Cacau, NB-EAT, PHDI-Bui) in 1936 Italian adults, using the Mediterranean diet (MEDI-LITE) as reference. The environmental impact was quantified as carbon and water footprints (CF and WF) using the SU-EATABLE LIFE database. Higher adherence to PHD-related indices generally corresponded to healthier nutrient profiles, higher fiber intake, and better concordance with Italian dietary recommendations, although some indices predicted lower intake of certain nutrients (e.g., vitamin B12, calcium). The MEDI-LITE index consistently predicted higher adequacy across dietary and nutrient recommendations. Absolute CF and WF showed mixed trends across indices, while energy-standardized values (per 1000 kcal) indicated lower impacts for all PHD-related scores, apart from the ELD-I. Adherence to the Mediterranean diet was also associated with favorable energy-adjusted environmental outcomes.

Conclusion: These findings reinforce the existing alignment between the intrinsic characteristics of the Mediterranean diet with both nutrition and sustainability objectives.

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1. Introduction

In recent years, sustainability has been considered of growing importance when investigating diet quality and food security [1,2]. Nutrition is an essential component for the international policy framework of the Sustainable Development Goals aiming, among other goals, to “end hunger, achieve food security and improved nutrition and promote sustainable agriculture” [3]. Public health efforts are now projected toward achieving food availability for all while preserving the environment for food production notwithstanding maintaining high nutritional standards [3]. Recent reports emphasize the role of animal products in the food chain at expense of environmental impact on greenhouse gas emissions, land and water use, and a number of other factors [4]. In contrast, diets rich in plant-based foods have a minor environmental impact, while potentially providing a healthier nutrient profile and positive health effects [5]. Despite there is no univocal identification of a “sustainable” diet, several dietary patterns characterized by preference of plant-derived over animal-derived foods have been considered as potentially eco-friendly in modeling studies [6]. Other reports providing data derived from cohort studies showed a substantial agreement between adherence to healthy dietary patterns and a lower environmental impact [7].

In early 2019, the EAT-Lancet Commission on “Healthy Diets from Sustainable Food Systems” (EAT-Lancet) published a pivotal report advocating for a Planetary Health Diet (PHD), designed to promote both human and planetary health [8]. This diet emphasizes the consumption of vegetables, fruits, whole grains, legumes, nuts, and unsaturated oils, with a moderate intake of seafood and poultry, and minimal consumption of red meat, processed meats, added sugars, refined grains, and starchy vegetables [8]. The primary aim of the EAT-Lancet diet is to simultaneously improve population health and reduce environmental impact, with the report affirming its nutritional balance and environmental sustainability [8]. The EAT-Lancet report suggests that widespread adoption of this diet could prevent approximately 11 million deaths annually, thereby highlighting its potential public health impact [8]. The diet has sparked extensive debate and research within the scientific community and the public, serving as a model for healthy and sustainable eating across various cultural contexts [9].

Investigations into adherence to the EAT-Lancet guidelines in diverse settings are ongoing, with some dietary indices inspired by such a dietary pattern showing adequate nutritional quality and lower environmental impact of people more in line with it [6]. However, the culprit of such an approach is that dietary scores are referring to general diets (i.e., consumption of certain food groups), that are first tested in modeling studies and then applied to actual empirical data to be tested for validity. Individuals living in the Mediterranean area have historically consumed a predominantly plant-based dietary pattern, eventually healthy and sustainable [10]. However, the application of *a priori* dietary scores at global level is challenging because their validity should be tested in each context, meaning the ability to adequately predict both diet quality and environmental impact. Hence, the aim of this study was to test the level of adherence, the nutritional quality, and the environmental impact of dietary patterns inspired by the EAT-Lancet commission's PHD in Italian adults. The application of various indices developed to measure adherence to the PHD will also serve to test their validity in the Italian context both in terms of environmental impact and diet quality.

2. Methods

2.1. Study population

The sample included in this cross-sectional study is part of the Mediterranean Healthy Eating, Aging, and Lifestyles (MEAL) study, an observational investigation designed to examine the relation between dietary and lifestyle habits common to people in the Mediterranean area. The detailed study protocol, including the rationale, design, and

methodologies, has been extensively discussed elsewhere [11]. A random sample of men and women (age 18+) registered in the medical records of residential general practitioners in the urban region of Catania, one of the major cities on the east coast of Sicily, southern Italy, constituted the cohort in the years 2014–2015. The sampling method involved stratifying the sample by age and sex, then randomly partitioning the sample into subgroups. General practitioners served as the sampling units, and those who registered with them formed the final sample units. Pregnant women were not considered in this study. Participants randomly selected for recruitment were stratified by sex and 10-year age groups. The total sample size consisted of 2044 respondents (85 % response rate) out of the 2405 people originally addressed for this study. All the study procedures were carried out in accordance with the Declaration of Helsinki (1989) of the World Medical Association.

2.2. Dietary habits

Two food frequency questionnaires (FFQs), long and short version, which were designed and previously validated for the reference population [12,13], were used to assess dietary habits. The long version of the FFQ consisted of 110 food and beverage items representative of the diet during the preceding six months. Study participants were asked how frequently they had averagely consumed the foods and beverages listed in the FFQ, they were provided nine options ranging from “never” to “4–5 times per day.” Intake of seasonal food items referred to consumption during the period in which the food was available and then adjusted by its proportional annual intake. After excluding inconsistent intakes (<1000 or >6000 kcal/d, checked case by case and verified due to missing food items or imprecise answers), a total of 1936 individuals were included in the analysis for the current study.

2.3. Adherence to the PHD

In order to assess the level of adherence to the PHD, various scores have been applied to the study sample. An early index proposed by Knuppel and colleagues [14] was the EAT-Lancet Diet score (ELD-I) based on the 14 food items included in the dietary recommendations of the EAT-Lancet commission providing 1 point for agreement with the recommended consumption, allowing a possible total score of 14 points. Another index named new EAT-Lancet index proposed by Stubbendorff and colleagues [15] consisted of 14 food components with defined intake levels and reference intervals (ranges) for which emphasized and limited intake denotes a possible range of 0–3 points (for each component, 0 points indicating low adherence to the EAT-Lancet diet target and 3 points indicating high adherence) and a total possible score ranging from 0 to 42 points. The PHD Index from Cacau et al. (PHDI-Cacau) [16] considers the energy contribution of 16 different components categorized for adequacy, optimum, ratio, and moderation scored proportionally from 0 to 10 points (while the ratio components scored from 0 to 5 points based on cut-off points settled for their individual contribution to their total energy intake), with a total possible score ranging between 0 and 150. A diverse index named nutrient-based EAT index (NB-EAT) was constructed by Llanaj et al. [17] by considering the nutrient composition of the original EAT-Lancet reference diet providing 1 point for each of the 12 nutrient targets met, with a total with a score range from 0 to 12. Finally, an index proposed by Bui and colleagues [18] denoted as PHDI-Bui included 15 food items with a minimum score (which was 0) based on the consumption per day that reflects the least beneficial health effect of that food group and a maximum score (which was 10, except for nonsoy and legumes, for which was 5) based on the consumption per day that reflected the greatest beneficial health effect of that food group based on the reference levels considered in the EAT-Lancet diet. Individual scores for a food group were assigned proportionally for the range between minimum and maximum, with a total score ranging from 0 to 140. For all indices, higher scores indicated higher adherence. For a detailed description of the characteristics of

different indices see [Supplementary Table S1](#).

2.4. Adherence to the mediterranean diet

To facilitate comparison with well-established indices predicting diet quality, the MEDI-LITE score has been used to determine the level of adherence to such a dietary pattern [19]. This literature-based scoring system is composed by positive scoring according to the consumption of foods in line to the Mediterranean diet (i.e., fruit, vegetables, legumes, cereals, fish, and olive oil) and moderate intake of alcohol, and negative scoring according to the consumption of foods not characteristic of this dietary pattern (i.e., meat and dairy products); the final score ranged between 0 and 18 points, with the higher scores indicating higher adherence to the Mediterranean diet [20].

2.5. Adequacy to dietary recommendations

Adequacy to Italian dietary recommendations was assessed through testing criteria provided by the Italian Center for Food and Nutrition [21]. Based on data availability, the following food groups were considered to test adequacy to the recommendations: (i) fruit, more than 2.5 servings per day; (ii) vegetables, more than 2.5 servings per day; (iii) potatoes/tubers, less than 2 servings per week; (iv) cereals, 3–7 servings per day; (v) red meat, 1–2 servings per week; (vi) white meat, 1–3 servings per week; (vii) processed meat, less than one serving per week; (viii) fish, 2–3 servings per week; (ix) eggs, 2–4 servings per week; (x) legumes, 2–3 servings per week; (xi) milk and yogurt, 2–3 servings per day; (xii) cheese, 2–3 servings per week; (xiii) olive oil, 2–4 servings per day, (xiv) butter and other fats, occasionally.

2.6. Environmental data

For the calculation of the environmental impact, the SU-EATABLE LIFE (SEL) database was used. The SEL database provides Carbon and Water footprint (CF and WF) data at different levels of detail [22]. CF and WF data of food commodities extracted from published studies and harmonized to refer to the same system boundaries and functional units. This data was then aggregated at different levels, such as food item (e.g., “lemon”, “mandarin”, “orange”), food typology (e.g., “fruit openfield”), or sub-typology (e.g., “citrus fruit”, which subdivide the fruit typology). Each food item level data also includes an indication of the associated uncertainty, labeled as either high or low. Each of the 110 items in the FFQ was associated with environmental impact data according to the following criteria, according to the recommendations provided by the author of the SEL database: If the FFQ item was individual (e.g., “walnuts”) and the level of uncertainty in the SEL database was low, it was associated with the corresponding data from the SEL database at the food item level; If the level of uncertainty for the corresponding food item in the SEL database was high, or if there was no entry corresponding to the FFQ food item in the SEL database, or if the FFQ food item included more than one food (e.g., “chicken and other poultry”), then data from the food typology (or sub-typology, if available) was associated with the FFQ food item. Using this approach, environmental data for 85.3 % of the total FFQ food items were retrieved for CF and 81.7 % for WF.

2.7. Statistical analysis

Categorical variables are presented as frequency and percentage, continuous variables are presented as means and standard deviations (SDs). The sample was categorized by quartiles for each index used and differences in mean values were tested by ANOVA test. For the sake of reliability of tabulation, values for only the extreme quartiles were reported. All reported P values were compared at a 5 % significance level. SPSS 29 software (SPSS Inc., Chicago, IL, USA) was used for all statistical calculations.

3. Results

The mean scores registered in this sample of southern Italian individuals were the following: PHDI-Cacau = 68.3 (SD 12.4) out of a possible maximum total of 150, EAT 26.3 (SD 12.9) out of possible maximum total 42, ELD-I 10.8 (SD 1.3) out possible maximum total 14, NB-EAT 4.1 (SD 1.6) out possible maximum total 12, and PHDI-Bui 90.0 (SD 11.8) out of possible maximum total 140. There was a certain agreement in the distribution of the mean score values across categories of background characteristics, with a general consistency concerning higher scores among non-smokers, and more physically active participants (Table 1). A trend toward higher adherence to the PHD among older individuals was evident when applying the PHDI-Cacau index, while no clear trends were detected for all other indices and variables, albeit some differences were found by educational and occupation status (i.e., higher scores among the medium categories) (Table 1). Similar trends were also reported for adherence to the Mediterranean diet (Table 1).

The average consumption of major food groups by quartiles of various scores is presented in Table 2. All scores (including the Mediterranean diet one) properly measured the consumption of most food groups in line with the expected validity of content (meaning increasing quantities of plant-derived and decreasing quantities of animal-derived foods), with some exceptions (Table 2): specifically, individuals in the highest quartile of NB-EAT score reported higher consumption of meat (total, red, and processed) and dairy products while those in the highest quartile of ELD-I consumed less fruit, vegetables, and total cereals, refined grains, whole grains, and legumes. Among specific food groups, tubers were more consumed with higher scores of NB-EAT, PHDI-Bui, and Mediterranean diet; refined grains were less consumed also with higher scores of PHDI-Bui; fish was actually more consumed with higher scores of all indices except PHDI-Cacau while eggs more consumed with higher scores of NB-EAT and Mediterranean diet; nuts were less consumed also with higher scores of Mediterranean diet; finally, alcohol was less consumed with higher scores of ELD-I and Mediterranean diet (Table 2).

When looking at the nutrient distribution by quartiles of the various indices analyzed, both healthy and unhealthy trends emerged (Table 3). Regarding energy intake, only the PHDI-Cacau displayed comparable levels between the first and fourth quartiles, reflecting its energy-adjusted approach. In contrast, the ELD-I was associated with a marked reduction in energy intake at higher scores. All the other indices showed an increase, ranging from moderate (EAT) to large (NB-EAT and PHDI-Bui). Concerning macronutrients, the average protein intake increase with higher scores of the EAT, NB-EAT, PHDI-Bui, and the Mediterranean diet indices; intake of lipids, including cholesterol, saturated fats, MUFA and PUFA resulted significantly lower with higher scores of the ELD-I while higher with NB-EAT and PHDI-Bui; total PUFA and both seafood and plant n-3 PUFA were also higher in individuals with higher scores of the EAT index. Notably, the healthiest lipid profile was observed with higher scores of the Mediterranean diet. Higher fiber intake was predicted in all indices with exception of the ELD-I. Also, minerals were not equally distributed across indices quartiles: sodium resulted lower with higher scores of PHDI-Cacau and ELD-I, while increased when applying the other scores. Iron and calcium were higher scores of all indices except for ELD-I, and the latter also for PHDI-Cacau. Potassium, zinc, and selenium were also distributed in a more optimal profile across the EAT, NB-EAT, PHDI-Bui and the Mediterranean diet scores. Concerning vitamins, all indices adequately predicted higher intakes with exception of the ELD-I score and the PHDI-Cacau, showing lower intake of animal-derived vitamins, such as vitamin B12 and vitamin D, in individuals reporting higher scores (Table 3).

Concerning the ability to predict adequacy to food-based national dietary recommendations, Fig. 1 shows the percentage of adherence by quartiles of various scores analyzed. No relevant differences in prediction of consumption of milk and yogurt, cheese, “other” fats, and white

Table 1

Distribution and mean values of the EAT-Lancet planetary health diet and Mediterranean diet scores by background characteristics of the study sample.

	n (%)	PHDI-Cacau	EAT	ELD-I	NB-EAT	PHDI-Bui	Mediterranean diet (MEDI-LITE)
Age groups, mean (SD)							
<35 y	506 (26.1)	65.7 (12.9)	26.3 (3.5)	10.8 (1.3)	4.1 (1.6)	90.0 (11.8)	11.7 (2.5)
35-49 y	547 (28.3)	66.1 (12.4)	27.0 (3.3)	10.9 (1.3)	4.3 (1.6)	91.7 (10.6)	12.0 (2.4)
50-65 y	474 (24.5)	67.2 (12.5)	27.6 (3.5)	11.2 (1.3)	4.3 (1.6)	92.8 (10.6)	12.4 (2.3)
>65 y	409 (21.1)	68.9 (11.5)**	27.5 (3.2)	11.3 (1.2)	4.3 (1.5)	90.8 (9.2)*	12.3 (2.3)**
Sex, mean (SD)							
Male	804 (41.5)	67.0 (12.2)	26.9 (3.5)	11.0 (1.3)	4.2 (1.5)	90.7 (10.3)	12.0 (2.5)
Female	1132 (58.5)	66.7 (12.6)	27.1 (3.4)	11.0 (1.3)	4.3 (1.6)	91.8 (11.0)	12.1 (2.3)
Educational status, mean (SD)							
Low	697 (36.0)	66.1 (12.4)	27.1 (3.3)	11.1 (1.3)	4.3 (1.5)	91.2 (10.6)	12.1 (2.3)
Medium	720 (37.2)	67.9 (12.2)	27.2 (3.4)	11.0 (1.3)	4.2 (1.6)	91.9 (10.5)	12.3 (2.3)
High	519 (26.8)	66.4 (12.7)*	26.8 (3.6)	11.1 (1.3)	4.2 (1.5)	90.9 (11.1)	11.6 (2.5)**
Occupational level, mean (SD)							
Unemployed	461 (27.8)	67.0 (12.9)	27.1 (3.4)	11.1 (1.3)	4.3 (1.7)	91.7 (11.3)	12.2 (2.3)
Low	266 (16.0)	68.5 (12.4)	27.0 (3.5)	11.2 (1.1)	4.5 (1.5)	91.0 (11.2)	12.4 (2.6)
Medium	440 (26.5)	65.1 (13.4)	26.9 (3.5)	11.2 (1.2)	4.1 (1.5)	89.9 (10.1)	11.9 (2.6)
High	491 (29.6)	67.5 (12.2)*	27.0 (3.5)	11.2 (1.2)	4.2 (1.5)*	91.3 (10.5)	11.8 (2.5)*
Smoking status, mean (SD)							
Non-smoker	1195 (61.7)	67.6 (12.1)	27.1 (3.4)	11.1 (1.3)	4.3 (1.6)	92.1 (10.8)	12.1 (2.4)
Current smoker	465 (24.0)	66.3 (13.5)	27.0 (3.5)	10.9 (1.3)	4.2 (1.6)	90.7 (10.5)	12.2 (2.4)
Former smoker	276 (14.3)	64.6 (11.7)**	26.7 (3.4)	11.1 (1.2)	4.1 (1.5)	89.3 (10.1)**	11.9 (2.4)
Physical activity level, mean (SD)							
Low	329 (19.0)	66.9 (11.9)	27.1 (3.1)	11.0 (1.3)	4.3 (1.5)	92.0 (10.5)	11.9 (2.3)
Medium	856 (49.5)	65.6 (12.4)	26.7 (3.5)	10.9 (1.4)	4.1 (1.5)	90.7 (11.4)	11.8 (2.5)
High	543 (31.4)	69.8 (12.6)**	27.4 (3.2)**	11.2 (1.2)*	4.4 (1.6)*	92.9 (9.5)**	12.5 (2.3)**

Abbreviations: PHDI, planetary health diet index; ELD-I, EAT-Lancet dietary index; NB-EAT, nutrient-based EAT.

Table 2

Distribution (reported as mean intake and standard deviations) of major food groups by extreme quartiles of EAT-Lancet Planetary Health Diet and Mediterranean diet.

	PHDI-Cacau		EAT		ELD-I		NB-EAT		PHDI-Bui		Mediterranean diet (MEDI-LITE)	
	Q1 (n = 467)	Q4 (n = 488)	Q1 (n = 440)	Q4 (n = 707)	Q1 (n = 237)	Q4 (n = 804)	Q1 (n = 223)	Q4 (n = 776)	Q1 (n = 484)	Q4 (n = 562)	Q1 (n = 462)	Q4 (n = 275)
Fruit	319.9 (318.3)	506.6 (404.9)**	283.1 (361.6)	482.6 (362.4)**	452.4 (490.8)	433.8 (334.4)*	224.6 (137.4)	611.1 (453.1)**	251.6 (236.1)	537.4 (413.1)**	217.1 (195.5)	607.0 (377.3)**
Vegetables	226.8 (141.5)	325.5 (233)**	180.1 (134.1)	339.9 (220.0)**	306.3 (300.6)	298.8 (159.5)**	179.9 (88.3)	363.9 (238.6)**	179.9 (127.2)	384.3 (243.1)**	184.2 (130.4)	356.4 (224.9)**
Tubers	32.9 (29.6)	17.8 (16.0)**	29.7 (37.8)	23.7 (24.3)*	53.8 (63.6)	22.9 (19.6)**	25.3 (17.1)	32.5 (38.9)**	26.6 (26.4)	32.0 (39.7)**	23.7 (28.8)	31.4 (31.3)*
Total cereals	190.7 (136.7)	244.4 (140.5)**	190.4 (146.4)	245.3 (131.6)**	288.5 (200.9)	200.8 (105.7)**	138.2 (66.0)	296.7 (160.7)**	205.1 (143.1)	233.2 (146.4)*	170.9 (125.5)	322.2 (140.5)**
Refined grains	159.7 (127.5)	198 (139.3)**	158.8 (130.8)	202.1 (131.9)**	218.9 (178.8)	169.1 (108.2)**	125.4 (63.5)	237.4 (154.3)**	188.2 (137.5)	157.4 (126.4)**	145.8 (119.1)	257.3 (141.9)**
Whole grains	30.9 (50.5)	46.4 (65.5)**	31.6 (57.1)	43.3 (61.7)*	69.7 (88.9)	31.7 (43.0)**	12.8 (15.6)	59.3 (78.0)**	16.9 (32.5)	75.8 (74.3)**	25.2 (43.6)	64.9 (86.5)**
Legumes	22.5 (31.3)	54.5 (57.8)**	18.1 (26.5)	57.2 (68.4)**	66.6 (107.1)	32.6 (28.3)**	20.9 (18.9)	61.2 (72.3)**	19.2 (19.5)	63.8 (80.3)**	20.3 (30.1)	50.3 (46.3)**
Total meat	87.8 (41.1)	53.8 (37.0)**	86.2 (39.4)	53.5 (33.3)**	84.0 (40.4)	61.7 (43.6)**	74.0 (34.9)	77.1 (46.1)**	86.9 (48.2)	60.6 (38.2)**	80.0 (41.5)	57.6 (30.7)**
Red meat	41.0 (27.0)	27.5 (26.0)**	43.8 (26.9)	24.6 (21.0)**	44.6 (31.7)	27.8 (26.4)**	34.1 (22.1)	37.6 (31.2)**	42.9 (30.3)	27.8 (26.3)**	38.3 (24.9)	28 (20.9)**
Processed meat	24.2 (24.6)	10.1 (13.9)**	20.3 (20.7)	11.3 (13.9)**	33.5 (37.6)	11.6 (14.3)**	19.0 (14.0)	20.0 (27.8)**	19.5 (19.4)	19.0 (28.3)**	19.1 (20.4)	12.8 (13.4)**
Dairy	229.9 (195.3)	154.5 (152.9)**	240.1 (230.1)	170.9 (139.5)**	289 (278.4)	171.2 (130.3)**	139.3 (124.2)	250.3 (220.8)**	229.7 (204)	181.1 (168.4)**	246.5 (192.9)	106.0 (84.3)**
Fish	66.6 (65.0)	56.5 (61.3)**	50.9 (65.1)	78.9 (92.7)**	151.9 (182.5)	54.5 (41.7)**	56.4 (41.5)	94.6 (122.1)**	45.1 (47.4)	101.3 (128.7)**	47.7 (55.3)	88.8 (103.7)**
Eggs	3.0 (5.8)	2.3 (4.2)*	2.7 (5.4)	2.4 (4.5)	3.2 (5.6)	2.2 (4.4)	2.1 (3.6)	2.9 (5.3)*	3.1 (5.8)	1.9 (3.1)**	2.4 (4.9)	3.1 (5.6)
Sweets and dessert	77.7 (82.8)	51.3 (63.1)**	81.5 (93.3)	52.9 (55.5)**	115.2 (117.8)	48.2 (52.8)**	101.7 (70.8)	62.3 (72.2)**	83.5 (93.2)	53.2 (54.2)**	64.5 (72.4)	62.8 (65.1)
Sweet beverages	56.1 (129.5)	30.9 (105.9)*	65.7 (149.8)	24.2 (60.6)**	108.3 (198.6)	24.9 (82.8)**	54.7 (107.3)	51.5 (138.4)*	62.0 (136.6)	36.1 (101.2)**	50.1 (110.3)	19.8 (48.4)*
Olive oil	6.5 (3.4)	7.7 (2.8)**	6.5 (3.3)	7.6 (2.9)**	5.5 (3.9)	7.7 (2.9)**	6.7 (3.2)	7.4 (3.1)**	6.5 (3.3)	7.1 (3.1)**	5.9 (3.4)	8.9 (2.3)**
Nuts	17.3 (25.6)	26.2 (46.7)*	10.8 (17.0)	28.3 (42.5)**	36.0 (101.6)	26.4 (38.5)**	22.7 (27.2)	30.6 (65.6)**	10.5 (16.7)	39.9 (73.2)**	18.8 (43.6)	16.9 (24.1)*
Alcohol	7.3 (12.0)	9.7 (14.1)**	7.1 (11.6)	8.5 (12.9)*	9.1 (12.9)	8.9 (13.3)**	7.4 (11.0)	8.8 (12.5)**	6.4 (11.1)	9.3 (13.1)**	7.9 (12.7)	5.0 (8.5)*

Abbreviations: PHDI, planetary health diet index; ELD-I, EAT-Lancet dietary index; NB-EAT, nutrient-based EAT.

Table 3
Distribution (reported as mean intake and standard deviations) of selected macro- and micronutrients by quartiles of EAT-Lancet Planetary Health Diet scores.

	PHDI-Cacau		EAT		ELD-I		NB-EAT		PHDI-Bui		Mediterranean diet (MEDI-LITE)		
Nutrients	Q1 (n = 467)	Q4 (n = 488)	Q1 (n = 437)	Q4 (n = 704)	Q1 (n = 236)	Q4 (n = 803)	Q1 (n = 223)	Q4 (n = 775)	Q1 (n = 480)	Q4 (n = 561)	Q1 (n = 462)	Q4 (n = 265)	
Energy (kcal)	2056.7 (791.9)	2121.7 (794.6)	1913.0 (1045.5)	2350.4 (1209.1)**	3363.2 (2046.3)	1893.0 (591.6)**	1822.5 (308.1)	2843.7 (1303.1)**	1858.2 (758.6)	2601.9 (1490.2)**	1796.9 (697.1)	2450.9 (627.7)**	
Energy (kJ)	8262.1 (3259.0)	8678.1 (3312.4)	7690.3 (4275.3)	9610.2 (5013.3)**	13759.9 (8458.4)	7664.2 (2445.7)**	7356.1 (1291.0)	11596.1 (5402.6)**	7450.5 (3083.6)	10639.0 (6194.2)**	7199.0 (2858.8)	10037.0 (2619.2)**	
Proteins (g/d)	87 (34.1)	85.5 (35.2)	80.6 (55.8)	98.8 (60.4)**	152.6 (111.2)	76.2 (22.8)**	72.2 (11.2)	122.4 (70.4)**	75.8 (29.6)	114.0 (74.9)**	75.1 (29.2)	100.8 (32.4)**	
Lipids (g/d)	66.8 (29.1)	56.2 (24.3)	61.6 (38.6)	64.9 (37.4)	105.1 (71.5)	55.2 (19.9)**	64.3 (12.0)	79.7 (47.5)**	57.9 (25.0)	76.7 (49.3)**	57.6 (26.8)	63.9 (20.7)**	
Cholesterol (mg/d)	225.9 (97.3)	155.7 (82.4)	213.7 (179.3)	193.4 (135.4)	376.0 (292.1)	160.7 (65.6)**	208.8 (44.3)	254.8 (199.2)**	197.8 (229.4)	229.4 (187.9)**	192.5 (94.9)	195.9 (114.9)*	
Saturated fatty acids (%)	27.7 (12.1)	20.4 (9.3)	25.7 (16.2)	24.2 (13.5)	41.4 (25.8)	21.1 (8.4)**	26.7 (5.4)	30.6 (17.8)**	24.7 (11.8)	27.7 (18.3)**	23.7 (11.8)	24.4 (8.1)	
MUFA (%)	27.6 (11.7)	24.2 (9.6)	25.5 (14.9)	27.7 (15.2)	42.0 (28.5)	24.0 (8.1)**	26.2 (5.2)	33.3 (18.6)**	24.7 (11.8)	27.7 (18.3)**	23.9 (10.6)	28.4 (8.2)**	
PUFA (%)	11.2 (6.2)	11.6 (5.3)	10.1 (7.4)	13.1 (8.5)**	19.9 (16.1)	10.3 (4.3)**	10.3 (2.8)	15.8 (10.2)**	9.5 (4.0)	15.5 (11.0)**	9.5 (4.8)	12.9 (4.5)**	
Total n-3 PUFA (%)	1.7 (0.9)	1.7 (0.8)	1.4 (0.7)	1.9 (0.8)**	2.2 (1.3)	1.6 (0.7)**	1.5 (0.5)	2.1 (1.0)**	1.4 (0.6)	2.1 (1.1)**	1.4 (0.8)	2.0 (1.0)**	
Seafood n-3 PUFA (%)	0.6 (0.6)	0.4 (0.4)	0.4 (0.5)	0.6 (0.6)**	0.9 (1.0)	0.4 (0.4)**	0.5 (0.4)	0.7 (0.8)**	0.4 (0.4)	0.6 (0.8)**	0.5 (0.6)	0.7 (0.8)**	
Plant n-3 PUFA (%)	1.1 (0.5)	1.3 (0.7)	0.9 (0.4)	1.3 (0.6)**	1.3 (0.6)	1.1 (0.6)**	1.0 (0.3)	1.5 (0.6)**	1.0 (0.4)	1.4 (0.7)**	1.0 (0.4)	1.3 (0.5)**	
Carbohydrates (g/d)	285.2 (121.2)	324.7 (130.9)	266.9 (146.9)	352.6 (187.2)**	467.8 (287.9)	278.1 (89.9)**	243.9 (56.4)	23.1 (184.8)**	268.1 (125.5)	372.7 (219.6)**	249.4 (106.4)	385.8 (108.2)	
Total fiber (g/d)	26.5 (14.0)	40 (21.9)	22.9 (15.9)	43.9 (32.9)**	50.9 (49.2)	32.0 (14.1)**	20.9 (6.5)	50.9 (32.1)**	21.8 (10.5)	48.4 (36.3)**	22.0 (10.9)	45.5 (17.6)**	
Sodium (mg/d)	3118.3 (1305.4)	2676.8 (1075.4)	2890.8 (1775.4)	3093.9 (1668.6)	4486.1 (3039.4)	2597.8 (884.9)**	2664.2 (789.9)	3740.0 (1964.1)**	2784.7 (1334.4)	3370.9 (2001.9)**	2736.3 (1195.2)	3376.3 (1125.2)**	
Iron (mg/d)	13.9 (5.8)	17.0 (5.9)**	12.3 (4.7)	17.5 (6.1)**	18.7 (9.0)	14.7 (4.7)**	12.0 (2.6)	20 (6.2)**	12.4 (4.3)	18.8 (7.1)**	12.1 (4.9)	19.1 (5.3)**	
Calcium (mg/d)	822.1 (358.8)	771.5 (317.9)*	749.4 (356.3)	827.1 (292.6)*	1011.9 (499.3)	763.3 (258.0)**	662.6 (198.8)	752.5 (355.4)**	1010.9 (325.4)	752.5 (325.4)	882.2 (337.9)**	738.1 (313.9)	822.8 (259.9)**
Magnesium (mg/d)	357.3 (137.1)	438.3 (143.5)**	319.4 (113.6)	445.9 (137.4)**	461.0 (205.2)	388.2 (115.3)**	303.7 (64.9)	510.0 (142.6)**	321.6 (103.2)	480.8 (163.1)**	313.3 (106.8)	492.0 (132.4)**	
Potassium (mg/d)	3420.9 (1586.3)	4229.7 (2058.7)	2984.2 (1873.3)	4646.8 (3037.7)**	5940.4 (4910.1)	3657.9 (1274.0)**	2784.7 (599.5)	5533.9 (3145.0)**	2787.9 (1105.0)	5391.7 (3482.3)**	2897.3 (1211.8)	4643 (1657.3)**	
Zinc (mg/d)	11.7 (4.6)	12.7 (4.7)*	10.5 (4.1)	13.3 (4.5)**	15.4 (6.5)	11.6 (3.9)**	10.1 (1.9)	15.6 (4.9)**	10.7 (3.9)	14.1 (5.4)**	10.1 (3.8)	14.7 (4.3)**	
Selenium (mg/d)	103.8 (49.4)	103.2 (45.8)	91.9 (46.6)	111.9 (46.2)**	141.9 (65.9)	94.0 (34.5)**	79.7 (20.5)	135.3 (52.5)**	95.2 (44.3)	113.5 (54.5)**	87.1 (43.5)	139.4 (49.7)**	
Vitamin A (retinol eq./d)	798.5 (444.4)	987.2 (528.9)	661.8 (369.0)	1038.0 (517.7)**	1027.2 (628.4)	927.7 (448.5)**	653.9 (232.4)	1186.0 (555.1)**	651.4 (339.6)	1169.9 (571.2)**	669.0 (363.5)	1138.3 (581.2)**	
Vitamin C (mg/d)	134.2 (95.8)	203.9 (136.5)	105.4 (94.4)	207.4 (150.7)**	202.8 (208.1)	173.7 (102.9)**	102.3 (50.9)	245.6 (162.3)**	97.8 (63.4)	239.2 (168.0)**	103.0 (67.1)	233.0 (134.6)**	
Vitamin E (mg/d)	8.1 (3.9)	9.9 (4.4)	7.2 (4.5)	10.5 (5.1)**	13.2 (9.2)	8.6 (3.2)**	7.6 (2.1)	12.2 (5.9)**	6.8 (2.9)	12.1 (6.3)**	7.0 (3.2)	11.0 (3.7)**	
Vitamin D (μ g/d)	6.0 (5.9)	4.4 (5.5)	5.4 (11.7)	6.3 (6.8)	13.7 (18.6)	4.5 (3.5)**	4.9 (3.6)	8.5 (12.3)**	4.1 (3.9)	8.2 (10.2)**	4.5 (4.8)	6.5 (7.3)**	
Vitamin B12 (μ g/d)	7.3 (4.5)	5.1 (3.5)	6.9 (8.2)	7.5 (12.5)	16.8 (22.9)	5.1 (2.3)**	6.0 (2.2)	10.1 (14.1)**	5.8 (3.3)	9.7 (15.1)**	6.2 (4.0)	7.0 (9.2)	
Vitamin B1 (μ g/d)	1.8 (0.9)	1.8 (0.8)	1.7 (0.9)	1.8 (0.8)	2.5 (1.2)	1.6 (0.7)**	1.8 (0.7)	2.2 (0.9)**	1.7 (0.9)	2.0 (0.8)**	1.5 (0.7)	2.0 (0.8)**	
Vitamin B2 (μ g/d)	2.3 (1.1)	2.2 (0.9)	2.2 (1.1)	2.3 (0.9)	3.1 (1.4)	2.0 (0.7)**	2.2 (0.7)	2.7 (1.0)**	2.2 (1.1)	2.4 (0.9)**	2.1 (0.9)	2.4 (0.9)**	
Vitamin B3 (μ g/d)	22.2 (9.2)	22.0 (7.0)	19.8 (7.7)	23.3 (7.7)**	28.7 (12.6)	20.6 (6.1)**	18.5 (4.1)	27.2 (9.8)**	19.2 (6.5)	25.7 (10.1)**	18.9 (7.7)	26.8 (8.8)**	
Vitamin B6 (μ g/d)	2.5 (0.9)	2.7 (0.9)*	2.2 (0.8)	2.8 (0.9)**	3.0 (1.3)	2.5 (0.8)**	2.0 (0.4)	3.3 (0.9)**	2.2 (0.8)	3.0 (1.0)**	2.1 (0.7)	3.0 (0.7)**	
Vitamin B9 (μ g/d)	292.3 (114.2)	448.9 (166.6)**	292.3 (114.2)	461.5 (171.3)**	292.3 (114.2)	394.3 (130.4)*	292.3 (114.2)	517.1 (180.1)**	292.3 (114.2)	500.5 (195.4)**	301.4 (134.3)	485.1 (147.1)**	

Abbreviations: PHDI, planetary health diet index; ELD-I, EAT-Lancet dietary index; NB-EAT, nutrient-based EAT.

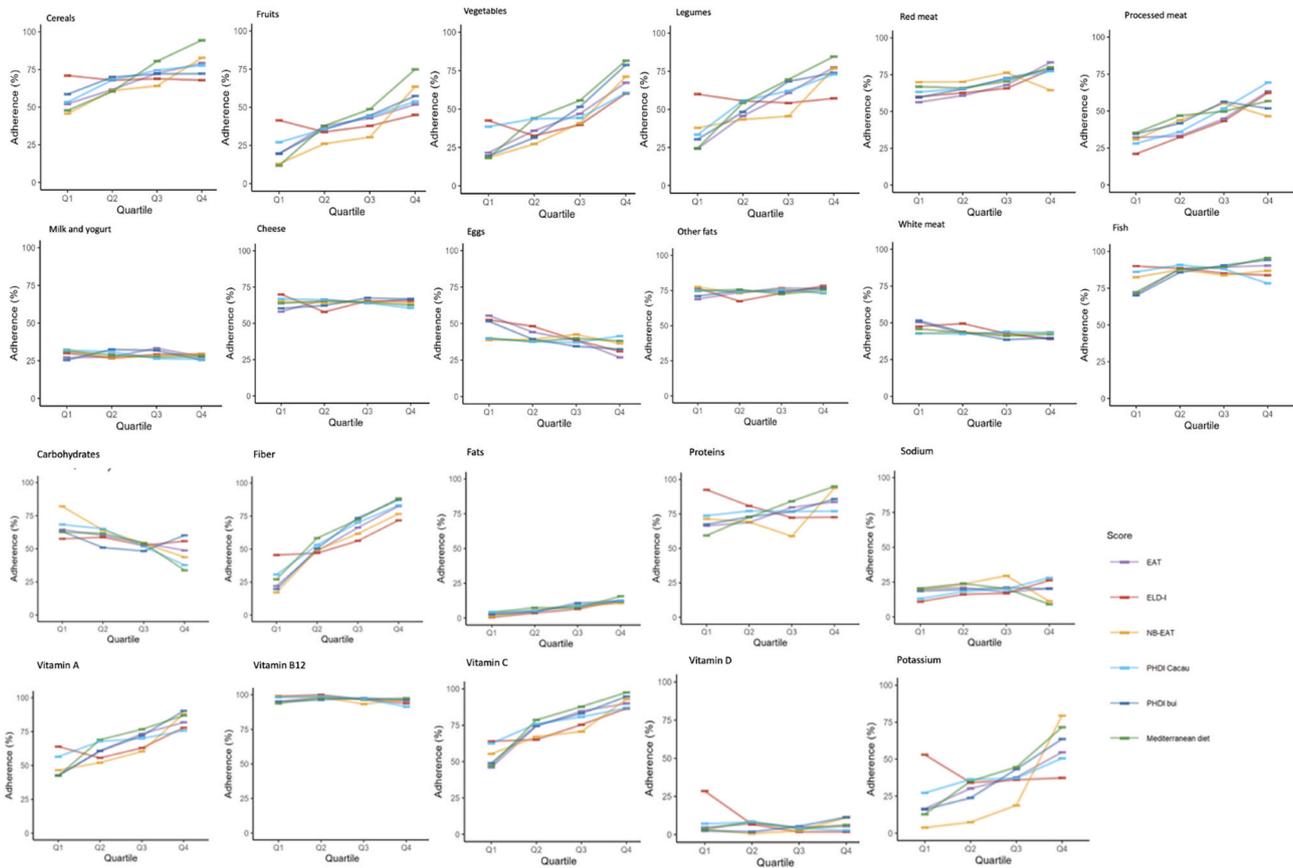


Fig. 1. Prevalence of adequacy to food-based Italian Dietary Guidelines and nutritional Italian recommendations by quartile of dietary scores assessing the adherence to the Planetary Health Diet and the Mediterranean diet.

meat across scores were found. However, the indices adopted to measure the adherence to the PHD all performed differently depending on the recommendations, with the NB-EAT predicting the higher proportion of adequacy to recommendations on fruit and vegetables, the EAT on red meat, and the PHDI-Cacau on processed meat, while the ELD-I resulting in worse prediction of adequacy to recommendations on cereals, fruit, vegetables, and legumes, the NB-EAT on red and processed meat recommendations, and the PHDI-Cacau on vegetables and fish recommendations (Fig. 1). However, a higher percentage of individuals in the highest quartile of adherence to the Mediterranean diet met recommendations for cereals, fruits, vegetables, legumes, and fish over all

the other indices applied (Fig. 1).

Frequency of adequacy to nutritional recommendations according to the Italian Dietary Reference Values (LARN) by category of indices is also presented in Fig. 1. All indices predicted a similar proportion of individuals meeting the recommendations on fats, vitamin B12, vitamin D, and marginally acceptable prediction of vitamin C and A. However, some differences occurred across indices, such as a highest adequacy to protein and potassium recommendations and lowest adequacy to vitamin A and vitamin C for the NB-EAT index, highest adequacy to sodium recommendations for the PHDI-Cacau, highest adequacy to carbohydrates recommendations for the PHDI-Bui, and lowest adequacy

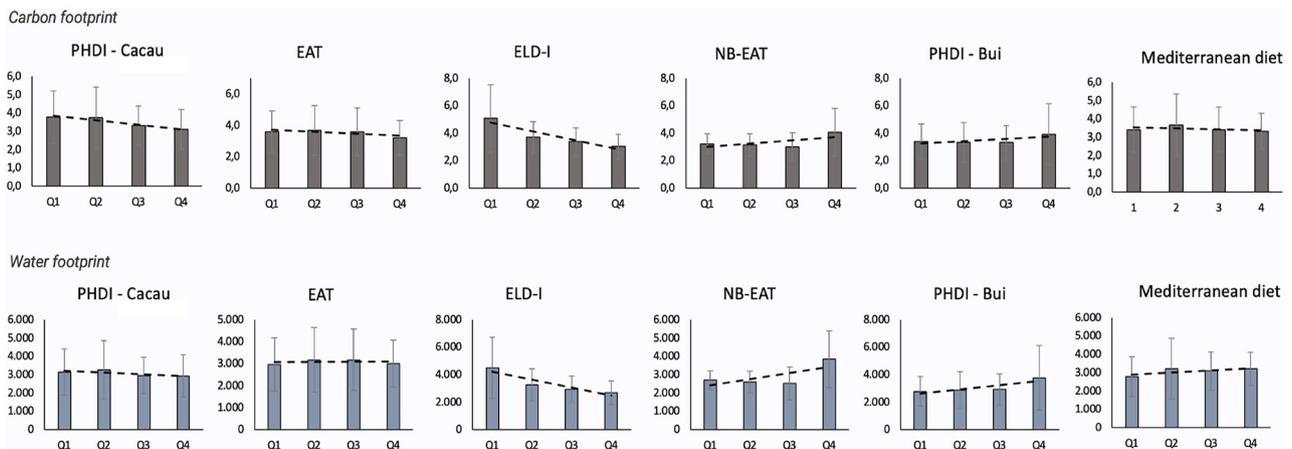


Fig. 2. Distribution of carbon and water footprint impacts by quartiles of various indices assessing the adherence to the Planetary Health Diet and the Mediterranean diet.

to fiber, protein, vitamin C, and potassium for the ELD-I. Notably, the Mediterranean diet still resulted in better prediction of adequacy to recommendations on fiber, sodium, potassium, and protein, but lowest for carbohydrates.

The distribution of mean CF and WF by quartiles of the various indices are presented in Fig. 2. The increase in PHDI-Cacau and ELD-I was significantly associated with reduction of both environmental measures, with the lowest absolute impact of 3.0 Kg CO₂ eq./day and 2708.1 L/day with only marginal differences between indices. The largest difference between the extreme categories was about 2.0 Kg CO₂ eq./day and 1000 L/day of GhG emission and water use, respectively, observed for the ELD-I indices. In contrast, higher scores in the NB-EAT and PHDI-Bui indices were actually related to higher environmental impacts. No large differences in the environmental impacts by quartiles of the Mediterranean diet were observed. Considering the variation in energy intake across adherence quartiles, CF and WF were also calculated per 1000 kcal (Table 4). When standardized for energy intake, both indicators generally decreased with higher adherence to most PHD-related indices, confirming a lower environmental impact per unit of energy consumed. The strongest reductions were observed for the PHDI-Cacau and EAT scores, while more moderate decreases were found for the NB-EAT and PHDI-Bui indices. In contrast, the ELD-I showed a slight increase in both CF and WF across adherence quartiles, indicating a less favorable environmental pattern. Higher adherence to the Mediterranean diet was also associated with a clear reduction in both CF and WF after energy adjustment, comparable to the most favorable PHD-related indices.

4. Discussion

The aim of this study was to test the food consumption, nutritional quality and environmental impacts of a diet in line with the principles of the PHD assessed through a variety of indices in a sample of Italian adults. The inclusion of a Mediterranean diet index was also considered for comparison to a traditional dietary pattern. In general, higher adherence to the PHD was associated with both healthier nutrient profile and lower CF and WF irrespectively of the index used. However, some differences emerged leading to further considerations when applying such scores in the Italian context. Overall, not a single score performed better than another. Specifically, a major concern arising when investigating dietary patterns with low consumption of animal products is the possibility of certain nutritional deficiencies (i.e., vitamin B12 and protein) if not adequately substituted. This limitation has been already suggested in modeling studies applying the PHD on dietary micronutrients adequacy showing a criticism concerning 4 key elements, namely vitamin B12, calcium, iron, and zinc [23]. When testing various scores inspired by the EAT-Lancet recommendations to actual dietary consumption, we observed only in part such a potential issue and found out that ideal nutrient intake was adequately predicted by most indices, although not unequivocally. For instance, protein intake was in fact inversely associated with some scores but directly with the PHDI-Bui one; iron and zinc were also directly associated with all the indices, while calcium and vitamin D were inversely associated with

PHDI-Cacau and ELD-I, respectively. Interestingly, vitamin B12 decreased with higher scores of PHDI-Cacau and ELD-I, although minimum intake of all the aforementioned critical nutrients was above the recommendations and did not differ substantially between indices. Notably, when comprehensively looking at the nutritional profile of the higher scores of the various indices, the Mediterranean diet resulted the best at predicting higher adequacy to both dietary and nutritional recommendations, as previously reported for the Italian population [24, 25].

Up to date, only a few studies have investigated the relation between adherence to indices inspired by the PHD and the dietary nutrient content so far. The early study used for validation of the PHDI-Cacau index [16] conducted on a sample of 14,779 participants of the Longitudinal Study on Adult Health (a multicenter cohort study in Brazil) reported a mean PHDI-Cacau of 60.4 (95 % CI: 60.2–60.5), hence slightly lower than in the present study, although remarking a similar distribution across the background characteristics reflecting an overall healthier lifestyle. Also, the associations with major nutrients of interest reflected an inverse relation with total fats except for PUFA, protein, vitamin B group, but in contrast a direct association with other vitamins and all minerals (no mention to vitamin D, though). Another study conducted in Brazil involving 46,164 participants aged over 10 years old from the National Dietary Survey conducted through the Household Budget Survey in 2017–2018 reported lower scores of PHDI-Cacau (45.9 points, 95 % CI: 45.6–46.1) [26]. Finally, a study investigating the average scores of PHDI-Cacau in over 33,000 US adults aged >20 y from 8 cycles (2003–2018) of the National Health and Nutrition Examination Survey (NHANES) reported an increase of the median PHDI values over the study period from 62.7 (95 % CI: 62.0–63.4) points in 2003–2004 to 66.9 (95 % CI: 66.2, 67.7) points in 2017–2018; only a higher rate of calcium deficiency, but not iron or potassium, in the highest quintile of adherence to the score was registered in the population investigated [27]. However, a study conducted on a subgroup of the NHANES (2017–2018) proposing an alternative version of the PHDI specific for the US population reported an average score of 46.7 out of 150 points, hence much lower than scores reported in other studies, and no mention of other nutrients was reported [28]. Lower mean scores (i.e., 29.4) were also found in 398 Brazilian non-institutionalized adults and elderly people [29]. Some additional studies also investigated the application of the PHDI-Cacau in the younger population. Analyses conducted on 1112 adults (mean age = 28.7 years) reported an average PHDI total score of 41.5 points, meaning a substantially lower score than reported in other investigations, probably due to the slightly younger age of participants [30]. The study also reported an inverse association between the PHDI-Cacau and pyridoxine and calcium, with no other negative outputs. However, a newer study conducted on 945 young adults with a mean age of 20.1 years old reported a mean PHDI-Cacau of 59.9 ± 14.16 and only showed an inverse association with MUFA/PUFA ratio [31]. In Europe, a study was conducted in the framework of the Healthy Lifestyle in Europe by Nutrition in Adolescence (HELENA) study on 1804 adolescents (12.5–17.5 years) reporting an average score was 44.3 (95 % CI 43.7–44.9) points and an inverse association with total protein, PUFA, niacin, and heme iron among beneficial nutrients [32]. Finally, a recent

Table 4

Comparison of energy-normalized daily mean carbon and water footprints between the first and fourth quartiles of the different indices.

	PHDI-Cacau		EAT		ELD-I		NB-EAT		PHDI-Bui		Mediterranean diet (MEDI-LITE)	
	Q1	Q4	Q1	Q4	Q1	Q4	Q1	Q4	Q1	Q4	Q1	Q4
Energy (kcal)	2057	2122	1913	2350	3363	1893	1823	2844	1858	2602	1797	2451
CF (kg CO ₂ eq.)	3.8	3.1	3.6	3.2	5.1	3.0	3.2	4.1	3.4	3.9	3.4	3.3
Energy normalized CF (kg CO ₂ eq./1000 kcal)	1.8	1.5	1.9	1.4	1.5	1.6	1.8	1.4	1.8	1.5	1.9	1.4
WF (L)	3151	2940	2976	3008	4515	2708	2707	3848	2783	3769	2788	3207
Energy normalized WF (L/1000 kcal)	1532	1386	1555	1280	1343	1431	1485	1353	1498	1448	1551	1309

Abbreviations: PHDI, planetary health diet index; ELD-I, EAT-Lancet dietary index; NB-EAT, nutrient-based EAT.

study conducted on 961 children aged 3–6 years old from the Food Environment Chilean Cohort (FECHIC) revealed a median PHDI-Cacau score of 50 points, although no data on relation with nutritional quality was provided [33]. Besides the PHDI-Cacau indices, other scores were used to investigate association with nutrient intakes. Higher scores were also found for the ELD-I, for instance with a score of 8.03 found in 190,893 participants from UK-Biobank [34], for the EAT as observed in over 22,000 adults from the Malmö Diet and Cancer cohort (mean score 17.9) [15] and for NB-EAT when compared to what found in over 700 Hungarians showing a median score of 2.0 [17]. Finally, lower scores for the PHDI-Bui ranging from 80.8 to 90.7 in the Nurses' Health Study (NHS) and from 59.9 to 94.5 in the Health Professionals Follow-up Study (HPFS), in the first and fifth quintiles, respectively, were found compared to the present study [18]. Concerning nutrient intake, in a study using a modified version of ELD-I, a decrease in the nutrient inadequacy prevalence when the adherence to the EAT-Lancet reference diet increased, particularly for vitamin B9 and vitamin C, despite inadequacy prevalence for fiber, vitamin B1, iodine and magnesium remained high in all the quintiles was observed [35]. Regarding the EAT index, the validation study reported that those with the higher score had a diet containing less fat and more dietary fiber, while in another an increased unsaturated fat:saturated fat ratio and a lower intake of added sugar in over 180,000 participants from the UK Biobank was found [36].

Also the estimation of environmental measures related to the indices used showed mixed findings, with higher scores of the PHDI-Cacau and ELD-I leading to lower impacts, the NB-EAT and PHDI-Bui to higher impacts, and the Mediterranean diet to relatively neutral differences across quartiles of adherence score. However, when normalizing CF and WF per 1000 kcal, a more nuanced picture emerged. The PHDI-Cacau showed consistent reductions in both absolute and normalized metrics, suggesting robustness of the index. The EAT also showed decreases in both measures, despite higher energy intake in the upper quartile. In contrast, the ELD-I was associated with lower absolute CF and WF, but with higher values when normalized per 1000 kcal. This suggests that the apparent reduction in absolute impacts mainly reflects lower overall energy intake, rather than a true shift toward less impact-dense diets. Indeed, the scoring system tends to assign higher values to individuals consuming less food, thereby biasing the association toward lower absolute footprints (see Table S1). Conversely, NB-EAT and PHDI-Bui were linked to higher absolute impacts but lower normalized ones, suggesting the ability to capture healthier and more sustainable food choices, while at the same time favoring diets with higher energy intake. Notably, when considering energy-adjusted values, adherence to the Mediterranean diet was also associated with a substantial reduction in both CF and WF, comparable to the most robust PHD-related indices. This result suggests that the intrinsic characteristics of the Mediterranean diet, together with the features of the adherence tool used (MEDI-LITE), are already aligned with achieving both a favorable nutritional profile and a lower environmental impact. The presented findings are in only partially in line with other studies applying the PHDI to the American population, showing lower environmental impacts and lower prevalence of obesity [37]. Among others, the highest adherence to the EAT-Lancet reference diet, measured by the ELD-I, was associated with the lowest gas emissions and land use, as well as higher water use in 525 Israelis [38], despite Kesse-Guyot showed that using the same index also unhealthy diets with a low ELD-I score may have low environmental impact [39]. More recently, a study showed that the highest adherence to the PHDI-Bui had a lower environmental impact than those with the lowest adherence, in terms of 29 % lower greenhouse gas emissions, fertilizer needs, and cropland use 29 % lower, 21 % lower fertilizer needs, 51 % lower cropland use, and 13 % lower irrigation water needs [18]. Further, previous reports showed substantially lower environmental impacts of higher adherence to the Mediterranean diet [40,41], demonstrating nearly comparable sustainability than other plant-based dietary patterns [42,43]. However, in the present study there were no trends with lower carbon and water footprints with higher adherence to this dietary

pattern. Although the Mediterranean diet is a dietary pattern characterized by a preference of plant-based foods over animal products with a strong interaction between nutrition, people, environment, and culture [44], its current composition may not necessarily be as low impacting as in the past, and studies with updated data such the present one are warrant to actually confirm whether a modern Mediterranean diet is still sustainable. Overall, a decline in adherence to the Mediterranean diet has been registered [45], leading to no large differences between low and high adherent (hence, a possible reason for lack of differences in terms of environmental footprint). Also, high intake of fish (which could have an important carbon footprint) and the inclusion of olive oil and nuts, which are water-consumptive crops, may further affect the environmental burden.

A higher adherence to the PHD reflecting a healthier diet was also consistently related with older age and a healthier lifestyle (meaning non-smoking and higher physical activity levels) in the present. This is in line with previous systematic assessment of lifestyle behaviors associated with meat *versus* fruit and vegetable in cohort studies [46]. Besides, we also found that average scores did not linearly increased with educational and occupational level; this finding may depend on the fact that, ecologically, older individuals had lower educational level and that unemployed participants, such as housewives, would on average have more time to dedicate on cooking and eventually be more in line with traditional dietary patterns [47,48]. The Mediterranean diet is a well-known traditional dietary pattern reported to be poorly appreciated among the younger generations probably due to a higher engagement in the modern lifestyle characterized by lack of free time in favor of more working hours, scarce access to fresh food in favor to processed, ready-to-eat alternatives, and a substantial abandonment of cultural heritage and family ethical values (such as conviviality) [10].

The present study has some limitations that should be acknowledged and considered when interpreting the findings. First, dietary data collection relied on self-reported information, which is inherently subject to recall bias and social desirability bias. Participants may have unintentionally underreported or overreported their food intake, particularly with regard to socially desirable or undesirable foods, potentially affecting the accuracy of dietary assessments. Second, although the tools used for dietary assessment (such as FFQs) were validated and widely adopted in nutritional epidemiology, they may not provide precise estimates of portion sizes or nutrient intakes. Measurement errors or limitations in the food composition databases used could also have influenced the estimation of specific nutrients. Then, the study sample was recruited exclusively from southern Italy, which may not be representative of the broader Italian population. Regional dietary habits, cultural practices, socioeconomic status, and access to certain foods can vary considerably across the country. Therefore, caution is warranted when generalizing these findings to populations in other geographic areas or with different demographic characteristics.

In conclusion, the application of a diet in line with the EAT-Lancet recommendations to the southern Italian population may reflect a lower environmental impact and a good nutritional quality diet. Depending on the index used, some caveats concerning the optimal intake of a certain food/nutrient or another do not allow to identify an index superior in predicting adequacy to dietary and nutritional recommendations. Overall, higher adherence to the Mediterranean diet seems to best capture the optimal dietary and nutritional profiles, although with no substantial benefits on environmental impacts. Future studies should consider applying various indices to test their potential predictivity of health outcomes taking into account they may not entirely reflect all features of a healthy diet nor an actual lower environmental impact. Adaptation of current indices to specific populations might improve their validity and strengthen the evidence for future country-specific food policy.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.numecd.2025.104537>.

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