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Associations of Adherence to a Dietary Index Based on the EAT–*Lancet* Reference Diet with Nutritional, Anthropometric, and Ecological Sustainability Parameters: Results from the German DONALD Cohort Study

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ABSTRACT

Background: Validation of the EAT–*Lancet* reference diet (ELR-diet), recently proposed by the EAT–*Lancet* Commission, within the context of real-life studies is necessary to elucidate its feasibility, nutritional value, sustainability, and health effects.

Objectives: We aimed to develop a dietary index (DI) score to measure adherence to the ELR-diet. We further aimed to study the association between the DI score and *1*) nutritional characteristics, *2*) indicators of ecological sustainability, and *3*) anthropometric markers and biomarkers for cardiometabolic health.

Methods: A DI score was constructed by comparing the categories defined by the ELR-diet with the dietary data of 2–5 sets of 3-d weighed dietary records from DONALD (Dortmund Nutritional and Anthropometric Longitudinal Designed) study participants ($n = 298$; $\geq$15 y of age). Prospective associations between the DI score and risk markers (anthropometric and cardiometabolic) in young adulthood ($\geq$18 y old) were investigated using multivariate linear regression.

Results: Adherence to the DI score components was considerable (majority > 50%), but varied within the population (2%–100%). The highest tertile of the DI score was inversely associated with the intake of protein (tertile 3 compared with tertile 1: 13.5 compared with 14.5 energy %), added sugars (10.5 compared with 12.4 energy %), and cholesterol (100 compared with 116 mg/1000 kcal), but positively associated with fiber intake (10.0 compared with 8.82 g/1000 kcal) (all $P < 0.05$). The DI score was inversely associated with greenhouse-gas emissions (tertile 1 compared with tertile 3: 6.48 compared with 5.85 kg of carbon dioxide equivalents/2500 kcal; $P < 0.001$) and land use (8.24 compared with 7.16 $m^2 \times y$/2500 kcal; $P < 0.001$). Inverse associations between the DI score and anthropometric markers during young adulthood were observed (e.g., BMI: tertile 1 compared with tertile 3: 22.9 compared with 21.9 kg/m^2; $P = 0.03$) (all $P < 0.05$). No associations between the DI score and cardiometabolic risk markers were found (all $P \geq 0.05$).

Conclusions: Adherence to the ELR-diet was associated with favorable nutritional characteristics and reduced environmental impact. Adherence to the DI score in adolescence was also beneficial with respect to anthropometric markers in early adulthood, although not for further cardiometabolic risk markers. *J Nutr* 2022;152:1763–1772.

Keywords: sustainability, EAT–*Lancet*, dietary index, anthropometry, cardiovascular disease risk markers

Introduction

Food systems are one of the most important underlying drivers in the global syndemic of malnutrition and climate change (1). According to the Global Burden of Disease study, the number of deaths attributable to dietary risks increased from 8 to 11 million worldwide between 1990 and 2017, with cardiovascular diseases (CVDs) being the leading causes of diet-related deaths (2). Equally important, the transition toward westernized diets has contributed to environmental degradation (3), with food systems now responsible for ∼11% of global greenhouse-gas emissions (GHGEs). This is predominantly through agricultural activities, which are conducted on 40% of all arable land (4). Hence, shifts toward healthy and sustainable diets are needed.

Existing food-based dietary guidelines (FBDGs) are typically based on scientific studies focused on diet–disease relations.

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Yet few countries have incorporated aspects of environmental sustainability into the derivation of these guidelines (5). However, although most FBDGs emphasize the consumption of plant-based foods, and aim to establish dietary patterns which align human health goals with environmental sustainability, clear scientific targets must be established (6). Therefore, in 2019 the EAT–*Lancet* Commission proposed global scientific targets for healthy diets and sustainable food systems. These targets defined a safe operating space for dietary intake while simultaneously considering overall human and planetary health. In the end, a reference diet was proposed, including recommended food intake ranges for 8 food groups. This was the EAT–*Lancet* reference diet (ELR-diet) (6).

This framework was not designed or intended to provide a plan for translating the proposed global targets to a national or subnational level (6). Therefore, the next milestone required was to investigate how definitions of a set of global targets translated to smaller scales (6). As a result, the evaluation of the ELR-diet in the context of real-life studies has shed light on its feasibility, nutritional value, and effect on human health (7). In this process, important steps are the calculation of the adherence to the ELR-diet across populations, evaluation of its nutritional value, investigation of its associations with specific health outcomes, and identifying indications of its environmental sustainability and impact. Comparisons of the ELR-diet with dietary guidelines from the USA (8), Italy (7), India (9), and Denmark (10) have been reported. Moreover, adherence to the ELR-diet has been investigated in relation to environmental indicators (including GHGEs) in French adults (11). Ultimately, the diet was found to be associated with lower risks of ischemic heart disease and diabetes, yet no clear associations with mortality and stroke were found in the English European Prospective Investigation into Cancer and Nutrition (EPIC)-Oxford cohort (12). In addition, in a Swedish population, the ELR-diet was found to be associated with a lower risk of mortality (including all-cause, cancer, and cardiovascular mortality) (13).

To our knowledge, no study has evaluated adherence to the ELR-diet using individual-level data from Germany, or its associations with specific health outcomes. The German Nutrition Society has reported that the current FBDGs are mostly correspondent with the ELR-diet (14). However, according to the EAT–*Lancet* Commission, regional and local adaptation must be carefully considered in order to successfully transition to healthier diets and sustainable food systems (6). Therefore, the aim of this study was to develop a dietary index (DI) score to measure the adherence to the ELR-diet, using data from the DONALD (Dortmund Nutritional and Anthropometric Longitudinal Designed) study. In addition, our aim was to analyze the cross-sectional association of this DI score with nutritional characteristics, GHGEs, and land use (LU), and the longitudinal association of the DI score with anthropometric markers and risk biomarkers for cardiometabolic health, specifically including concentrations of plasma lipids and plasma glucose, and blood pressure.

Methods

Study design

The DONALD study is based on an ongoing cohort in Dortmund, Germany. Since 1985, every year 35–40 infants aged 3 mo have been newly recruited to the cohort. The overall aim of the DONALD study is to examine the complex relations between nutritional intake, metabolism, and growth, from infancy into adulthood (15). Annual examinations take place during childhood and adolescence. These include 3-d weighted dietary records (WDRs), anthropometric measurements, lifestyle interviews, and medical examinations. From the age of 18 y onward, participants are in addition invited to provide fasting blood samples for analyses. A detailed description of the DONALD study can be found elsewhere (16). Written informed consent was obtained from all parents and adult participants. This study has been performed in accordance with the Declaration of Helsinki, and was approved by the Ethics Committee of the University of Bonn, Germany (ethics applications: 098/06 and 185/20).

Study participants

As of January 2021, a total of 1761 participants were enrolled in the ongoing DONALD cohort. For this study, participants with the following characteristics were included: *1*) ≥15 y old at dietary intake assessment, *2*) ≥2 WDRs available (to take into account habitual intake), *3*) 1 adult fasting blood sample available, *4*) born full-term (36–42 weeks of gestation), *5*) singleton birth, and *6*) a birth weight ≥ 2500 g. Participants who potentially underreported their energy intake by providing more than half of the available WDR with a reported energy intake not matching the basal metabolic rate were excluded. The basal metabolic rate was calculated based on Schofield's sex- and age-specific equations (17) and Goldberg's cutoff limits for energy intake (18). A final sample of $n = 298$ was included in the analysis, with 2–5 WDRs per participant (**Figure 1**).

Dietary assessment and construction of the DI score

In the WDR, detailed information on food and drink intake was recorded. This included recipes and convenience food products. All composite food items were deconstructed to their individual ingredients (16). Foods were grouped according to the 18 food components included in the ELR-diet (**Supplemental Table 1**). Modifications were made for whole grains, peanuts, and tree nuts; and intake of all grains was considered with a minimum intake of whole grain, in a manner similar to methods used in previous investigations (12). Because the intake of peanuts and all nuts was low in the DONALD study, they were combined into all nuts.

The mean of all WDRs available was used (≥2 WDRs; range: 2–5) for each participant, in order to calculate their individual habitual DI score. In detail, the mean of each component for each individual WDR was calculated and standardized to 2500 kcal (by multiplying the mean of the food component by 2500 kcal and dividing the product by the individual energy intake), with an energy intake of 2500 kcal/d used as the basis for the ELR-diet (6). Next, the mean intake for each food component was determined for each participant by calculating the arithmetic mean from each of their total WDRs. Then, 1 point was assigned when the average food component intake was in line with

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Supplemental Tables 1 and 2 and Supplemental Figures 1 and 2 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/jn/.

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Abbreviations used: AP, animal to plant protein; BW, body weight; CVD, cardiovascular disease; DBP, diastolic blood pressure; DI, dietary index; DONALD, Dortmund Nutritional and Anthropometric Longitudinal Designed; ELR-diet, EAT–*Lancet* reference diet; EPIC, European Prospective Investigation into Cancer and Nutrition; FBDG, food-based dietary guideline; FFMI, fat-free mass index; FPG, fasting plasma glucose; GHGE, greenhouse-gas emission; kgCO$_2$eq, kilogram of carbon dioxide equivalents; LU, land use; SHARP, Sustainable, Healthy, Affordable, Reliable, and Preferred diets; TG, triglyceride; WC, waist circumference; WDR, 3-d weighted dietary record; %BF, percentage body fat.

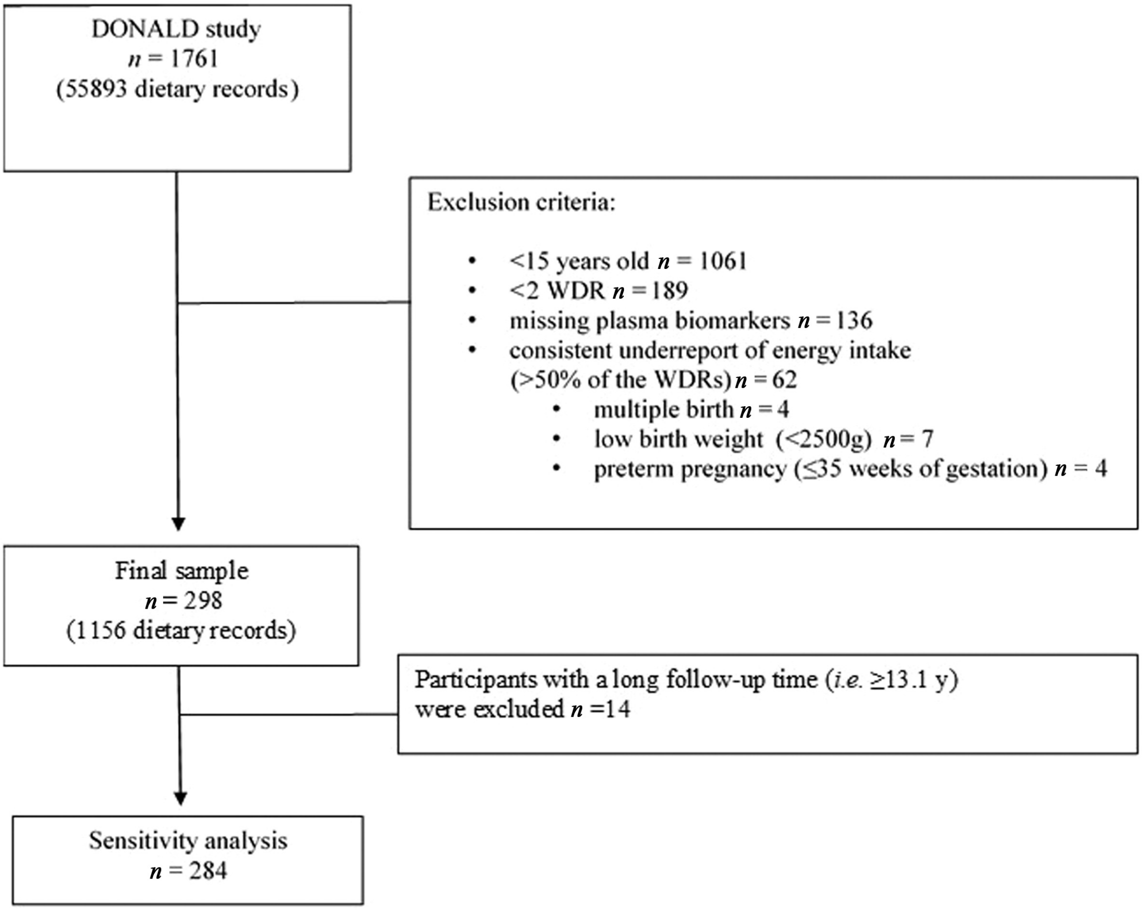

FIGURE 1 Flowchart of the study population. DONALD, Dortmund Nutritional and Anthropometric Longitudinal Designed; WDR, 3-d weighted dietary record.

the proposed recommendations (6) (Supplemental Table 1); otherwise, 0 points were assigned. Finally, the overall score was computed by summing the individual points of each food component for each person. Thus, the DI score ranged from 0 (low adherence) to 18 (high adherence) points.

Indicators of environmental sustainability

All reported food items were linked to the environmentally Sustainable, Healthy, Affordable, Reliable, and Preferred diets (SHARP) indicators database (19). The European SHARP indicators database includes information on GHGEs and LU for food items from life-cycle analyses. The SHARP indicators database was used to assess the environmental impacts of individual-level diets (20), with GHGEs expressed as kg of carbon dioxide equivalents (kgCO$_2$eq) per kg of food item, and LU expressed as m^2 × y/kg food item (20). The individual daily GHGEs (kgCO$_2$eq/d) and daily LU [m^2 × y/(kg food item × d)] for each participant's habitual diet were calculated as described earlier.

Anthropometric measures and biomarkers for cardiometabolic health

The young adult anthropometric markers used in the study included body weight (BW), BMI (in kg/m^2), waist circumference (WC), body fat percentage (%BF), and fat-free mass index (FFMI). Anthropometric measurements were conducted by trained nurses utilizing standard procedures, which have been described elsewhere (16). Cardiometabolic risk markers included plasma concentrations of total cholesterol, LDL and HDL cholesterol, triglycerides (TGs), fasting plasma glucose (FPG), systolic blood pressure, and diastolic blood pressure (DBP). Fasting blood samples were retrieved, centrifuged at 4°C for 15 min, stored at −18°C, and analyzed as previously described (21). For a small number of participants, some anthropometric and cardiometabolic risk markers were unavailable (i.e., FFMI and %BF, $n = 17$; FPG, $n = 2$; LDL cholesterol, $n = 6$; HDL cholesterol, $n = 4$; TGs, $n = 10$; and blood pressure, $n = 4$).

Assessment of covariates

Low birth weight (22), preterm birth (23), and educational attainment (24) have been previously associated with cardiometabolic disorders later in life. Therefore, this study considered early-life factors, including birth weight (g) and pregnancy duration (wk), which were obtained from standardized German pregnancy documents. In addition, educational attainment data related to school and higher education histories of participants and their parents were acquired through questionnaires.

Statistical analysis

A significantly higher DI score was observed among females. Therefore, sex-specific tertiles were used for analyses. Thus, participants within the first tertile ($n = 99$) had a median score of 9 points (range: 7–9 for males; 6–10 for females). Participants within the second tertile ($n = 98$) had a median score of 10 points (males) or 11 points (females). Participants classified in the highest tertile ($n = 101$) had a median score of 11 points (males) or 12 points (females) (range: 11–14 for males; 12–15 for females). Energy intake, dietary fiber, added sugar, micronutrients, plant protein and animal to plant protein (AP) ratio, PUFAs, alcohol, and cardiometabolic risk markers were log-transformed before analysis. Missing data for 5 covariates ($n = 5$, 1.68% of all data) were imputed using a multiple imputation process, which resulted in the creation of 10 imputed databases. The duration (i.e., follow-up time) between the assessment of the mean habitual DI score and assessment of the outcome in young adulthood was calculated as the difference in age between the 2 assessments.

Differences across the DI score tertiles were tested using linear regression for continuous variables and the chi-square test for categoric variables. Age-adjusted linear regression was used to investigate the cross-sectional association between the DI score and the nutritional characteristics. The cross-sectional association between the DI score and GHGEs or LU was examined using linear regression. The prospective associations between the DI score and anthropometric and cardiometabolic risk markers in adulthood were investigated using multivariable linear regression models. In addition to a crude model (model 1), adjusted models were constructed to include potential confounders. Model 2 was adjusted for age and sex; whereas, model 3 was adjusted for age, sex, birth weight, gestational age, socioeconomic factors (i.e., participant and parental school and higher education attainment), follow-up time, and total energy intake [i.e., mean of all dietary records (kcal/d)], using the standard multivariate method.

Post hoc sensitivity analyses were conducted to analyze whether a long follow-up time might have had an effect on the results. Therefore, participants with follow-up times between the latest WDR provided and the outcome assessments >90th percentile (≥13.1 y) were excluded. In addition, an alternative version of the DI score was compiled, which was standardized to 2500 kcal/d for males and 2200 kcal/d for females. This accounted for the fact that females generally have lower energy requirements.

All analyses were conducted using SAS software (version 9.4; SAS Institute). A P value ≤ 0.05 was considered statistically significant. In addition, we considered multiple testing by holding the false discovery rate at 5%.

Results

Fifty-two percent of the study population was male, and the averaged median age at the time of assessment of the habitual diet was 16.7 y. Participants were 18.1 y old at outcome assessment and the median follow-up time between the first dietary assessment and the outcome assessment was 3.01 y (range: 1.58–32.2 y). On average, 3 WDRs were used for the calculation of the DI score. Male participants had a slightly lower mean DI score (10.15 points; range: 7–14 points) than young females (10.76 points; range: 6–15 points), but there was no statistically significant difference between the sexes ($P = 0.12$). Furthermore, baseline characteristics were similar across DI score tertiles (Table 1).

The majority of the population adhered well (>50%) to 11 of the 18 components, with the intakes of fish; dry beans, lentils, and peas; and soy foods being almost fully in line (>98% adherence) with the recommendations proposed by the EAT–*Lancet* Commission. However, <10% of the population consumed pork (8.72%), added sugar (1.68%), all nuts (1.01%), and butter (0.34%), varying from the recommendations (Table 2). The average total energy intake of the 298 participants was 2261 kcal/d (range: 1365–3872 kcal/d). The intakes of energy, as well as the intakes of carbohydrates, fat, and saturated fats, were similar across the DI score tertiles (all $P > 0.05$). However, participants within the highest DI score tertile consumed significantly less total protein (13.5 compared with 14.5 EN%; $P < 0.001$), less animal protein (19.2 compared with 23.0 g/1000 kcal; $P < 0.001$), and higher amounts of plant protein (14.2 compared with 12.8 g/1000 kcal; $P < 0.001$), than did participants classified as in the lowest DI score tertile. Likewise, the AP ratio was found to be lower in the third tertile than in the first tertile (tertile 1: 1.75; 95% CI: 1.56, 1.95 compared with tertile 3: 1.25; 95% CI: 1.12, 1.39; $P < 0.001$). In addition, the DI score was inversely associated with added sugars (10.5 compared with 12.4 EN%; $P = 0.005$) and cholesterol (100 compared with 116 mg/1000 kcal; $P < 0.001$), as well as positively associated with total intake of fiber (10.0 compared with 8.82 g/1000 kcal; $P < 0.001$), fiber from grains (4.55 compared with 3.97 g/1000 kcal; $P = 0.004$), insoluble- (6.89 compared with 6.08 g/1000 kcal; $P < 0.001$), and soluble fiber (3.41 compared with 2.97 g/1000 kcal; $P < 0.001$) (Table 3). Moreover, significant differences were observed across the DI score tertiles in the intake of some fatty acids including linoleic acid (18:2n–6; $P = 0.007$), arachidonic acid (20:4n–6; $P < 0.001$), α-linolenic acid (18:3n–3; $P = 0.001$), and ω-6 to ω-3 fatty acid ratio ($P < 0.001$), but not all, e.g., EPA (20:5n–3; $P = 0.95$) and DHA (22:6n–3; $P = 0.39$). Intakes of micronutrients, including magnesium ($P = 0.012$), vitamin E ($P = 0.001$), total folic acid ($P = 0.018$), and vitamin K ($P = 0.018$), were significantly higher in the third tertile than in the first tertile (Table 3).

In this population, the mean ± SD GHGEs associated with dietary intake were 6.14 ± 1.03 kg CO_2eq/2500 kcal and the mean ± SD LU was 7.66 ± 1.53 $m^2 \times$ y/2500 kcal. An inverse association between the DI score and GHGEs and LU (both $P < 0.0001$) was observed (Table 4).

The average BMI of the participants was 22.6 kg/m^2. Inverse associations between the DI score during adolescence and BW ($P = 0.002$), BMI ($P = 0.004$), FFMI ($P = 0.034$), WC ($P = 0.022$), and BF% ($P = 0.049$) during young adulthood were observed. Participants within the lowest DI score tertile had a statistically significantly higher BMI (22.9; 95% CI: 22.0, 23.9) than participants classified within the highest DI score tertile (21.9; 95% CI: 20.9, 22.8; P-trend = 0.030) (Table 5). After correction for multiple testing, the inverse associations for BW ($P = 0.009$) and BMI ($P = 0.015$) remained statistically significant (data not shown). No additional cardiometabolic risk markers were associated with the DI score. Sex-stratified analyses revealed that inverse associations of the DI score with continuous BW ($P = 0.036$) and continuous BMI ($P = 0.020$) were found for males. Differences in DBP across DI score tertiles were observed only in female participants ($P = 0.039$) (**Supplemental Figures 1** and **2**). Similar results were observed in sensitivity analyses which excluded participants with longer follow-up times (**Supplemental Table 2**). When an alternate DI score was used which had been standardized to 2500 kcal/d for males and 2200 kcal/d for females, the findings remained similar and led to the same conclusions (data not shown).

Discussion

The participants of this study included adolescents and young adults, and it was observed in the prospective analysis that a higher DI score was inversely associated with anthropometric markers (BW, BMI, FFMI, WC, and %BF). Moreover, the observed associations with a more favorable dietary intake and lower environmental impact confirm the validity of the ELR-diet concept.

To our knowledge, few studies have investigated the ELR-diet with respect to nutritional or health associations (7, 9–12). Knuppel et al. (12) and Stubbendorff et al. (13) evaluated the associations with major health outcomes and mortality, respectively, in middle-aged populations, and other studies have evaluated the ELR-diet in relation to existing FBDGs in Italy (7), the USA (8), and Denmark (10). Thus, this is not only the first study to have investigated the ELR-diet in a German cohort including adolescents (median age: 16.7 y), but also the first to have investigated the DI score and its

TABLE 1 General characteristics of the 298 study participants across tertiles of the DI score[1]

Characteristics	Tertiles of the DI score Tertile 1 ($n = 99$)	 Tertile 2 ($n = 98$)	 Tertile 3 ($n = 101$)	P value[2]
DI score, male	9 (7–9)	10 (10–10)	11 (11–14)	<0.001
DI score, female	9 (6–10)	11 (11–11)	12 (12–15)	<0.001
Sex, male	47 (30.3)	47 (30.3)	61 (39.4)	0.116
Age at first dietary assessment, y	15.1 (15.0–16.9)	15.1 (15.0–17.1)	15.1 (15.0–16.3)	0.383
Mean age at DI assessment, y	16.7 (15.6–26.1)	16.8 (15.5–21.8)	16.7 (16.0–21.4)	0.819
Age at outcome assessment, y	18.2 (18.0–47.3)	18.2 (17.9–36.8)	18.1 (17.9–35.4)	0.276
Follow-up time,[3] y	3.01 (1.90–32.2)	2.99 (1.60–20.7)	3.01 (1.70–19.9)	0.247
Education status				
School education	94 (33.5)	92 (32.7)	95 (33.8)	0.941
Higher education	35 (38.5)	30 (32.9)	26 (28.6)	0.337
Parental school education	55 (30.7)	58 (32.4)	66 (36.9)	0.359
Parental higher education	33 (28.5)	39 (33.6)	44 (37.9)	0.325
Early-life factors				
Birth weight, g	3440 (2570–4660)	3575 (2680–4670)	3490 (2550–4600)	0.361
Pregnancy duration, wk	40 (37–42)	40 (36–42)	40 (37–42)	0.464

[1] Values are median (range) for continuous variables and n (%) for categoric variables, unless otherwise indicated. DI, dietary index.
[2] P values for trend were calculated using a linear model for continuous variables and the chi-square test for categoric variables.
[3] Time between the first dietary assessment and the outcome assessment.

associations with nutritional characteristics, indicators of environmental sustainability, and risk markers for cardiometabolic health.

These results regarding the nutritional characteristics of the DONALD study are in agreement with previous findings. The observed associations of a higher DI score with lower added sugar and higher fiber intakes are consistent with key dietary priorities for cardiometabolic health (25). However, in this study, a higher DI score was not found to be associated with energy intake, or with fat and carbohydrate intake. This likely reflected the relatively low adherence by study cohort members to certain individual components, in particular intake of vegetables, pork, butter, and unsaturated oils. Regardless, a higher DI score was found to be associated with lower intake of total and animal proteins, which may be the result of the relatively high adherence (≥44.9%) with respect to sources of protein from meat (e.g., chicken and other poultry, and beef and lamb), and eggs. Interestingly, the amount of animal protein consumed was higher in the first tertile than in the third tertile (23 compared with 19 g/1000 kcal; $P < 0.001$). Likewise, the AP ratio was found to be higher in the first than in the third tertile (1.75; 95% CI: 1.56, 1.95 compared with 1.25; 95% CI: 1.12, 1.39; $P < 0.001$), and it has been shown that a better AP ratio may have beneficial effects on cardiometabolic risk factors (26).

TABLE 2 Adherence to the individual food components included in the DI score among 298 participants from the DONALD (Dortmund Nutritional and Anthropometric Longitudinal Designed) study[1]

Food component	All ($n = 298$)	Male ($n = 155$)	Female ($n = 143$)
Whole grains and all grains[2]	289 (96.9)	149 (96.1)	140 (97.9)
Tubers or starchy vegetables	243 (81.5)	127 (81.9)	116 (81.1)
Vegetables	81 (27.2)	29 (18.7)	52 (36.4)
Fruits	163 (54.7)	75 (48.4)	88 (61.5)
Dairy foods	219 (73.5)	107 (69.0)	112 (78.3)
Beef and lamb	134 (44.9)	58 (37.4)	76 (53.2)
Pork	26 (8.7)	8 (5.2)	18 (12.6)
Chicken and other poultry	266 (89.3)	138 (89.0)	128 (89.5)
Eggs	195 (65.4)	105 (67.7)	90 (62.9)
Fish[3]	295 (98.9)	154 (99.4)	141 (98.6)
Dry beans, lentils, and peas[2]	298 (100.0)	155 (100.0)	143 (100.0)
Soy foods	298 (100.0)	155 (100.0)	143 (100.0)
All nuts[4]	3 (1.01)	1 (0.7)	2 (1.4)
Palm oil	265 (88.9)	135 (87.1)	130 (90.9)
Unsaturated oils	76 (25.5)	40 (25.8)	36 (25.2)
Butter	1 (0.3)	1 (0.7)	0 (0.0)
Lard or tallow	256 (85.9)	133 (85.8)	123 (86.0)
All sweeteners	5 (1.7)	4 (2.6)	1 (0.7)

[1] Values are n (%).
[2] Whole grain and beans, lentils, and peas as dry, raw weight.
[3] Includes fish and shellfish.
[4] Includes tree nuts and peanuts.

Moreover, diets lower in GHGEs have been shown to be higher in plant-based protein-rich foods, and as such might prove beneficial for the environment (27).

In addition, this study's results are similar to those from the NutriNet-Santé study, which showed that adherence to the ELR-diet may lead to reduced negative environmental impacts (11). Moreover, a pooled analysis including 443,991 participants from the EPIC-cohort suggested that cobenefits for human health and the environment could be achieved synergistically by adhering to diets that are based on the ELR-diet (28).

Although no association was observed between the DI score and cardiometabolic risk markers, these results are of primary interest because being overweight and being obese are well-known risk factors for CVD (29). Hence, considering that BMI is an intermediate risk marker, adherence to the DI score may be beneficial for the prevention of CVD and other chronic diseases in later life. Consistent with this study, an inverse association was observed between the "EAT-Lancet score" and BMI in cross-sectional analyses conducted in a subsample of the EPIC-Oxford study (12).

It is possible that the ELR-diet has limitations in its ability to fully capture how diets potentially lower the risk of disease in specific, regional scenarios, such as seen here. One possible

TABLE 3 Nutritional characteristics across tertiles of the DI score among 298 participants from the DONALD (Dortmund Nutritional and Anthropometric Longitudinal Designed) study[1]

	Tertiles of the DI score[2]			
Nutritional characteristics	Tertile 1 ($n = 99$)	Tertile 2 ($n = 98$)	Tertile 3 ($n = 101$)	*P*-trend[2,3]
Energy, kcal/d	2165 (2078, 2256)	2195 (2107, 2288)	2275 (2184, 2369)	0.226
Carbohydrate, EN%	50.3 (49.3, 51.3)	51.0 (50.0, 52.0)	51.1 (50.2, 52.1)	0.435
Protein, EN%	14.5 (14.1, 14.8)	13.5 (13.1, 13.8)	13.5 (13.2, 13.9)	<0.001
Fat, EN%	33.7 (32.8, 34.6)	33.8 (32.9, 34.8)	33.5 (32.6, 34.5)	0.906
Added sugar, EN%	12.4 (11.4, 13.4)	12.4 (11.4, 13.4)	10.5 (9.80, 11.4)	0.005
Total fiber,[4] g/1000 kcal	8.82 (8.40, 9.26)	8.89 (8.47, 9.34)	10.0 (9.57, 10.5)	<0.001
Fiber from grains,[5] g/1000 kcal	3.97 (3.74, 4.21)	4.08 (3.85, 4.34)	4.55 (4.29, 4.82)	0.004
Animal protein, g/1000 kcal	23.0 (22.1, 23.9)	20.3 (19.4, 21.2)	19.2 (18.3, 20.1)	<0.001
Saturated fats, g/1000 kcal	16.7 (16.2, 17.2)	16.7 (16.2, 17.2)	16.2 (15.6, 16.7)	0.268
Cholesterol, mg/1000 kcal	116 (111, 122)	108 (102, 113)	100 (95, 106)	<0.001
Plant protein, g/1000 kcal	12.8 (12.4, 13.2)	13.0 (12.6, 13.5)	14.2 (13.7, 14.6)	<0.001
AP ratio	1.75 (1.56, 1.95)	1.53 (1.37, 1.71)	1.25 (1.12, 1.39)	<0.001
Polyunsaturated fats, g/1000 kcal	5.11 (4.89, 5.33)	5.18 (4.96, 5.40)	5.58 (5.36, 5.80)	0.007
Linoleic acid (18:2n–6), g/d	9.06 (8.57, 9.58)	9.35 (8.84, 9.89)	10.3 (9.70, 10.8)	0.007
Arachidonic acid (20:4n–6), mg/d	119 (107, 132)	101 (90.8, 112)	86.6 (78.1, 96.1)	<0.001
α-Linolenic acid (18:3n–3), g/d	1.37 (1.29, 1.45)	1.46 (1.38, 1.55)	1.60 (1.51, 1.69)	0.001
EPA (20:5n–3), mg/d	47.9 (38.4, 59.9)	47.1 (37.7, 58.8)	49.6 (39.8, 61.7)	0.946
DHA (22:6n–3), mg/d	83.6 (70.4, 99.4)	79.8 (67.1, 94.9)	94.2 (79.4, 112)	0.386
n–6:n–3 PUFA ratio	0.08 (0.08, 0.09)	0.07 (0.06, 0.07)	0.05 (0.05, 0.06)	<0.001
Sodium, g/d	2.78 (2.63, 2.94)	2.76 (2.62, 2.91)	2.76 (2.62, 2.91)	0.978
Potassium, g/d	2.89 (2.77, 3.03)	2.86 (2.73, 2.99)	3.04 (2.91, 3.18)	0.138
Calcium, g/d	0.96 (0.90, 1.03)	0.96 (0.90, 1.02)	1.03 (0.97, 1.10)	0.179
Magnesium, mg/d	316 (300, 332)	320 (304, 337)	350 (332, 368)	0.012
Phosphorus, g/d	1.30 (1.24, 1.37)	1.28 (1.22, 1.34)	1.36 (1.29, 1.43)	0.183
Iron, mg/d	12.2 (11.6, 12.8)	11.6 (11.0, 12.2)	12.7 (12.1, 13.4)	0.058
Zinc, mg/d	10.8 (10.2, 11.4)	10.6 (9.98, 11.2)	11.3 (10.7, 11.9)	0.256
Iodine, μg/d	97.0 (90.5, 104)	88.7 (82.8, 95.1)	95.6 (89.3, 102)	0.159
Vitamin A,[6] mg/d	1.23 (1.13, 1.33)	1.22 (1.13, 1.32)	1.28 (1.19, 1.39)	0.639
Vitamin E,[7] mg/d	12.2 (11.5, 12.9)	12.9 (12.2, 13.8)	14.4 (13.6, 15.3)	0.001
Thiamin, mg/d	1.15 (1.07, 1.23)	1.14 (1.07, 1.23)	1.19 (1.11, 1.28)	0.647
Riboflavin, mg/d	1.52 (1.42, 1.63)	1.48 (1.38, 1.59)	1.54 (1.43, 1.64)	0.742
Vitamin B-6, mg/d	1.74 (1.62, 1.87)	1.77 (1.65, 1.89)	1.84 (1.71, 1.97)	0.549
Total folic acid, μg/d	371 (349, 395)	375 (352, 398)	423 (398, 450)	0.004
Vitamin D, μg/d	1.54 (1.39, 1.70)	1.70 (1.53, 1.88)	1.82 (1.64, 2.01)	0.071
Vitamin K, μg/d	82.2 (72.8, 92.7)	88.6 (78.5, 99.9)	105 (92.9, 118)	0.018
Vitamin B-12, μg/d	4.64 (4.22, 5.10)	4.40 (4.00, 4.83)	4.44 (4.04, 4.87)	0.705
Alcohol, g/d	0.45 (0.27, 0.72)	0.69 (0.42, 1.12)	0.93 (0.58, 1.50)	0.105

[1] Values are adjusted mean estimates (95% CIs) obtained from linear regression. AP ratio, animal to plant protein ratio; DI, dietary index; EN%, percentage of total energy intake.
[2] Adjusted for age.
[3] *P* value for trend across tertiles of the dietary index.
[4] Total fiber intake.
[5] Intake of fiber attributed to intake of grains.
[6] Vitamin A equivalents.
[7] Vitamin E activity including tocotrienols.

explanation for this may be the low observed variance of the DI score (range: 6–15 points). This is supported by previous results from the DONALD study, which indicated that dietary factors were associated with various health outcomes (30, 31) in younger adulthood. One potential pitfall to this explanation may be that the ELR-diet allows 0 consumption of some food components for which meta-analyses have demonstrated positive health effects (i.e., fish, legumes, soy, and nuts) (32). Indeed, Hanley-Cook et al. (33) have already argued that positive scoring of nonconsumption (i.e., 0 g/d) for all nutrient-dense food components, in a dietary score based on the ELR-diet, should be avoided. In the present study, the methodological implication of this was evident for fish; dry beans, lentils, and peas; and soy foods—where these were consumed very rarely, but were scored with >98.9% adherence. This was the result of a considerable number (27.9%, 21.1%, and 40.9%, respectively) of nonconsumers. Local investigations are highly warranted, because this German investigation and others (8, 10) have identified peculiarities specific to the populations under investigation. For instance, excess consumption of animal protein may not be a problem in India (9) as it may be in other regions. Finally, it was noticed that some food components may be unrepresented in the ELR-diet, such as beverages and processed foods. In fact, Sharma et al. (9) have already included an additional component in their diet score to consider the intake of processed foods. Interestingly, some food items such as tea, coffee, chocolate, and alcohol were not considered in the ELR-diet, yet coffee and tea have been found to be

TABLE 4 Associations between indicators of environmental sustainability and the DI score measuring the adherence to the EAT–*Lancet* reference diet in 298 participants from the DONALD (Dortmund Nutritional and Anthropometric Longitudinal Designed) study[1]

			Tertiles of the DI score			
Indicators of environmental sustainability	β (95% CI)[2]	*P* value[2]	Tertile 1 ($n = 99$)	Tertile 2 ($n = 98$)	Tertile 3 ($n = 101$)	*P*-trend[3]
Greenhouse gas emissions (kgCO$_2$eq/2500 kcal)	− 0.22 (−0.30, −0.14)	<0.001	6.48 (6.28, 6.67)	6.08 (5.88, 6.28)	5.85 (5.66, 6.05)	<0.001
Land use (m^2 × y/2500 kcal)	− 0.40 (−0.52, −0.29)	<0.001	8.24 (7.95, 8.52)	7.61 (7.32, 7.90)	7.16 (6.87, 7.44)	<0.001

[1] Values are crude mean estimates (95% CIs) obtained from linear regression. DI, dietary index; kgCO$_2$eq, kilogram of carbon dioxide equivalents.
[2] Linear model including the DI score as a continuous variable.
[3] *P* value for trend across tertiles of the DI score.

associated with lower risk of stroke and dementia (34), and an inverse association between CVD risk and moderate coffee consumption has been reported in a meta-analysis of 36 studies (35). However, it has been shown that ∼20% of daily GHGEs can be attributed to beverages. For adults, coffee, tea, and alcoholic beverages are the major contributors to daily GHGEs (36), and it has been suggested that tea, coffee, and alcohol should be replaced with more sustainable alternatives (37). Therefore, it would be worthwhile to consider these beverages in a reference diet which considers both human and planetary health.

Similar to the limited number of studies (7, 10) which have investigated the ELR-diet, some methodological issues were encountered when developing and applying the DI score in the DONALD study. Two modifications were necessary to construct the DI score within this German cohort. First, whole grain intake is 1 of the 8 food groups included in the ELR-diet (6); whereas, for the DI score, intake of all grains was taken into account. This is because the German FBDG refers to intake of all grains and a recommended fiber intake of 30 g/d, and considers intake from various fiber sources. To emphasize intake of fiber and whole grain, a conditional minimum intake of fiber from both grains and whole grains was applied (Supplemental Table 1), which was similar to a previous approach (12). Second, in contrast to previous studies calculating indexes based on the ELR-diet using an FFQ (12) or a 24-h recall (33), dietary data in the DONALD study were derived by multiple WDRs. This resulted in very detailed dietary data which allowed distinctions

TABLE 5 Prospective associations between adherence to the EAT–*Lancet* reference diet during adolescence measured by a DI score and anthropometric and cardiometabolic risk markers during young adulthood in 298 participants from the DONALD (Dortmund Nutritional and Anthropometric Longitudinal Designed) study[1]

				Tertiles of the DI score[2]			
Risk markers[3]	*n*[4]	β (95% CI)[5]	*P* value[3,5]	Tertile 1	Tertile 2	Tertile 3	*P*-trend[3]
BW, kg	298						
Model 1		0.97 (0.95, 0.98)	<0.001	70.9 (68.3, 73.6)	70.4 (67.8, 73.1)	68.7 (66.2, 71.3)	0.480
Model 2		0.98 (0.97, 0.99)	0.004	70.5 (67.9, 73.1)	70.5 (68.0, 73.1)	69.1 (66.6, 71.6)	0.659
Model 3		0.98 (0.97, 0.99)	0.002	70.5 (67.3, 73.8)	69.4 (66.4, 72.7)	67.6 (64.6, 70.7)	0.117
BMI, kg/m^2	298						
Model 1		0.98 (0.97, 0.99)	<0.001	22.8 (22.2, 23.5)	22.4 (21.8, 23.0)	21.7 (21.1, 22.3)	0.045
Model 2		0.98 (0.97, 0.99)	0.004	22.7 (22.1, 23.3)	22.4 (21.9, 23.0)	21.8 (21.3, 22.4)	0.104
Model 3		0.99 (0.97, 0.99)	0.004	22.9 (22.0, 23.9)	22.5 (21.6, 23.5)	21.9 (20.9, 22.8)	0.030
FFMI, kg/m^2	281						
Model 1		0.98 (0.97, 0.99)	<0.001	17.1 (16.7, 17.6)	17.0 (16.5, 17.5)	17.0 (16.6, 17.5)	0.925
Model 2		0.99 (0.99, 0.99)	0.039	17.1 (16.6, 17.6)	17.0 (16.6, 17.5)	17.1 (16.6, 17.5)	0.980
Model 3		0.99 (0.99, 0.99)	0.034	16.9 (16.3, 17.5)	16.8 (16.2, 17.4)	16.6 (16.1, 17.2)	0.514
WC, cm	298						
Model 1		0.98 (0.97, 0.99)	<0.001	77.1 (75.4, 78.8)	76.5 (74.8, 78.2)	75.1 (73.5, 76.8)	0.265
Model 2		0.99 (0.98, 0.99)	0.025	76.7 (75.1, 78.4)	76.6 (74.9, 78.2)	75.4 (73.8, 76.9)	0.451
Model 3		0.99 (0.98, 0.99)	0.022	77.1 (74.8, 79.4)	76.3 (74.1, 78.6)	74.9 (72.7, 77.1)	0.089
Body fat, %	281						
Model 1		1.01 (0.98, 1.04)	0.423	23.2 (21.5, 24.9)	22.1 (20.4, 23.9)	20.1 (18.6, 21.8)	0.040
Model 2		0.98 (0.96, 0.99)	0.038	22.9 (21.3, 24.7)	22.2 (20.5, 23.9)	20.3 (18.8, 21.9)	0.071
Model 3		0.98 (0.96, 0.99)	0.049	25.1 (22.6, 27.9)	24.2 (21.8, 26.8)	22.9 (20.6, 25.5)	0.149
FPG, mg/dL	296						
Model 1		0.99 (0.98, 1.00)	0.158	90.3 (88.3, 92.4)	92.9 (90.8, 95.0)	90.7 (88.7, 92.8)	0.176
Model 2		0.99 (0.99, 1.00)	0.667	90.3 (88.3, 92.3)	92.9 (90.9, 95.1)	90.8 (88.8, 92.8)	0.166
Model 3		0.99 (0.99, 1.01)	0.647	92.1 (88.9, 95.4)	94.7 (91.5, 98.1)	92.2 (89.0, 95.5)	0.138
Plasma total cholesterol, mg/dL	298						
Model 1		1.01 (0.99, 1.03)	0.197	162 (156, 169)	164 (158, 171)	158 (152, 164)	0.379
Model 2		1.00 (0.99, 1.02)	0.70	161 (155, 167)	165 (158, 171)	159 (153, 165)	0.428
Model 3		1.00 (0.99, 1.02)	0.747	161 (151, 171)	165 (155, 175)	160 (150, 170)	0.467

(*Continued*)

TABLE 5 (*Continued*)

Risk markers[3]	n[4]	β (95% CI)[5]	P value[3,5]	Tertiles of the DI score[2]			P-trend[3]
				Tertile 1	Tertile 2	Tertile 3	
Plasma LDL cholesterol, mg/dL	292						
Model 1		1.01 (0.99, 1.04)	0.365	87.8 (82.6, 93.5)	88.1 (82.7, 93.8)	87.3 (82.1, 92.8)	0.979
Model 2		1.01 (0.98, 1.03)	0.565	87.2 (82.0, 92.7)	88.2 (82.9, 93.9)	87.8 (82.7, 93.3)	0.967
Model 3		1.01 (0.98, 1.03)	0.616	86.6 (78.6, 95.4)	87.6 (79.6, 96.5)	87.4 (79.4, 96.2)	0.981
Plasma HDL cholesterol, mg/dL	294						
Model 1		1.02 (1.00, 1.04)	0.029	55.6 (52.9, 58.4)	57.3 (54.6, 60.3)	54.5 (51.9, 57.2)	0.357
Model 2		1.01 (0.99, 1.02)	0.561	55.5 (52.8, 58.2)	57.4 (54.6, 60.3)	54.6 (52.1, 57.4)	0.371
Model 3		1.00 (0.99, 1.02)	0.676	56.4 (52.5, 60.6)	58.7 (54.7, 63.0)	56.5 (52.7, 60.7)	0.394
Plasma TGs, mg/dL	288						
Model 1		1.00 (0.97, 1.03)	0.899	82.6 (75.2, 90.8)	79.6 (72.5, 87.4)	80.4 (73.4, 88.1)	0.848
Model 2		0.99 (0.96, 1.04)	0.954	82.4 (75.0, 90.6)	79.7 (72.5, 87.5)	80.6 (73.5, 88.3)	0.876
Model 3		1.00 (0.96, 1.04)	0.999	76.5 (65.8, 89.0)	74.4 (64.2, 86.3)	74.9 (64.5, 86.8)	0.911
SBP, mm Hg	294						
Model 1		0.99 (0.99, 1.00)	0.204	114 (112, 116)	114 (112, 116)	115 (113, 117)	0.573
Model 2		1.00 (0.99, 1.01)	0.877	114 (112, 116)	114 (112, 116)	115 (113, 117)	0.547
Model 3		1.00 (0.99, 1.01)	0.925	114 (111, 117)	114 (111, 117)	115 (112, 118)	0.739
DBP, mm Hg	294						
Model 1		0.99 (0.99, 1.01)	0.467	73.1 (71.3, 74.9)	71.9 (70.2, 73.7)	73.8 (72.0, 75.6)	0.336
Model 2		1.00 (0.99, 1.00)	0.962	72.9 (71.2, 74.7)	71.9 (70.2, 73.7)	73.9 (72.2, 75.7)	0.292
Model 3		0.99 (0.98, 1.01)	0.873	73.2 (70.4, 75.9)	71.9 (69.2, 74.7)	73.7 (70.9, 76.6)	0.330

[1] Values are adjusted mean estimates (95% CIs) obtained from linear regression unless otherwise indicated. BW, body weight; DBP, diastolic blood pressure; DI, dietary index; FFMI, fat-free mass index; FPG, fasting plasma glucose; SBP, systolic blood pressure; TG, triglyceride; WC, waist circumference.

[2] Numbers of participants within each tertile of the DI score with available respective anthropometric and cardiometabolic risk markers are as follows: BW, BMI, WC, and plasma total cholesterol: $n = 99$, 98, and 101; FFMI and body fat: $n = 96$, 92, and 93; FPG: $n = 98$, 97, and 101; plasma LDL cholesterol: $n = 98$, 94, and 100; plasma HDL cholesterol: $n = 99$, 95, and 100; plasma TGs: $n = 94$, 95, and 99; SBP and DBP: $n = 98$, 96, and 100, for tertiles 1, 2, and 3, respectively.

[3] Model 1 = crude; model 2 = adjusted for age and sex (continuous DI score only); model 3 = adjusted for age, sex (continuous DI score only), total energy intake, follow-up time, birth weight, pregnancy duration, parental school and higher education, and participant school and higher education.

[4] Total number of participants with available anthropometric and cardiometabolic risk markers.

[5] β estimates (95% CIs) from a linear model including the DI score as a continuous variable.

to be made between the meat components beef and lamb, and pork; and between 4 subgroups of added fats.

The strength of this study lies in the prospective design with a mean follow-up time of 5.64 y. In addition, the ELR-diet recommendation was adopted precisely in association with a dietary assessment consisting of multiple WDRs and recipe deconstruction, as well as the incorporation of 4 subgroups addressing added fats in the DI score. Furthermore, a variety of data related to socioeconomic factors were prospectively collected as well, and this allowed for adjustments to be made to address potential confounders. Lastly, the DI score was related to indicators of environmental sustainability.

The present study has several limitations which should be noted. First, there is the relatively young age of the population; the majority of study participants might have been too young to present characteristics of CVDs. However, this was the first study examining a younger population. Nonetheless, participants from the DONALD study that were ≥15 y of age were included, because their recommended energy intake is ∼2500 kcal (38), which is the basis for different isocaloric dietary scenarios that were used by the EAT–*Lancet* Commission (6). In addition, the ELR-diet is focused at generally healthy individuals 2 y of age and older. Second, the sample size was modest ($n = 298$) in comparison with the EPIC-Oxford study ($n = 46{,}069$) (12). Finally, participants in the DONALD study were quite homogeneous in terms of their educational and socioeconomic status (16), which might limit the generalizability. This may have minimized residual confounding, yet it cannot be excluded. Moreover, because of the homogeneous population, it was not possible to fully investigate diversity, yet the population was stratified by sex to gain some indication of that factor. Lastly, GHGEs and LU were investigated, but no additional environmental indicators were examined.

Outlook

The full range of benefits and potential issues faced when adopting global targets and adapting them to a national or subnational level which are specific to a population under investigation may only manifest when diverse populations are examined. Hence, further studies are warranted from various locations, examining different age groups and using various dietary assessment tools. These future studies will likely improve the understanding of the peculiarities of the ELR-diet and its corresponding implications for environment and health.

In conclusion, few studies have evaluated a proposed planetary health diet within the context of real-life studies. This study used data from a German cohort study, then constructed a DI score based on the ELR-diet for sustainable food systems (6), and then found that the adherence to the DI score varied across food components and was associated with lower environmental impacts. Moreover, the observed inverse association with BMI and BW established modifiable intermediate risk markers for CVD and other chronic diseases. This indicated that adherence to the DI score may be beneficial for disease prevention in later life.

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Data Availability

Data described in the article, code book, and analytic code of this study will be made available upon request. DONALD study data are available upon reasonable request for research questions within the scope of the DONALD study and which are consistent with the legal and ethical standard practices of the DONALD study. Requests should be addressed to epi@uni-bonn.de.

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