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Environmental and nutritional analysis of the EAT-Lancet diet at the individual level: insights from the NutriNet-Santé study

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Running Head: planetary health diet and environmental impacts

ELD-I;

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Abbreviations:

ANCOVA: covariance analysis

BMI: body mass index

Cumulative energy demand: CED

CU: consumption units

EAT-Lancet Diet Index: ELD-I

FBDGs: food-based dietary guidelines

Food frequency questionnaire: FFQ

Greenhouse gas emissions: GHGe

HR : hazard ratio

Land occupation: LO

PNNS-GS, Programme National Nutrition Santé-Guideline Score

PNNS-GS2: Programme National Nutrition Santé-Guideline Score 2

Q: quintile

Abstract

The EAT-Lancet Commission has recently proposed a "universal" healthy reference diet. However, no study has specifically investigated its possible environmental benefits at the individual level based on observed data. Our objective was therefore to characterize the environmental pressures and impacts related to the level of adherence to the EAT-Lancet diet among French adults. Dietary data from a 264-item FFQ in 29,210 NutriNet-Santé participants (75% women, mean age=53.5y (SD=14.0)), were used to estimate (i) the level of adherence to the EAT-Lancet diet through the EAT-Lancet diet index (ELD-I), (ii) the food production-related environmental impacts using 3 individual environmental indicators (greenhouse gas emissions, cumulative energy demand and land occupation) and (iii) the overall environmental impact using a validated aggregated partial score (*p*ReCiPe). For clarity purpose, results are presented by quintile (Q) of ELD-I. High ELD-I (Q_5), compared to low (Q_1), was associated with lower greenhouse gas emissions (-56%), cumulative energy demand (-31%) and land occupation, (-54%). The *p*RECIPE was 62% lower in high ELD-I than in low ELD-I but the range of pReCiPe in Q1 was large. In this large scale-study of French adults, adherence to the EAT-Lancet recommendations led to lower environmental impacts. Nonetheless, some low-EAT diets (reflecting unhealthy diets), may exhibit low environmental impacts.

Keywords: environmental impacts; dietary patterns; cohort study; EAT-Lancet diet

Highlights

- the EAT-Lancet diet index was developed to assess the EAT-Lancet diet adherence while accounting for farming practices (organic or conventional).
- The diets highly correlated with the EAT-Lancet diet (compared to low adherence) led to lower impacts: -56% greenhouse gas emissions, -31% cumulative energy demand and -54% land occupation.
- A high variability in environmental impacts was observed among individuals with low adherence to the EAT-Lancet diet, reflecting a discrepancy between human and planetary health.

1. Introduction

It is now well established that modern eating habits, rich in fat, salt and sugar, largely contribute to the development of chronic diseases (GBD 2017 Diet Collaborators, 2019). In 2017, the Global Burden of Diseases estimated that 11 million (95% uncertainty interval 10–12) deaths were attributable to diet-related risk factors (GBD 2017 Diet Collaborators, 2019). Besides, diet production cause serious damages and long-term adverse effects on the environment. Indeed, the climate crisis, the depletion of natural resources and the pollution of water and soil require a radical and urgent change at multiple levels of the global food system, from field to plate (Clark et al., 2018). In case of no drastic change in the food system by 2050, greenhouse gas emissions (GHGe), land use, water use, as well as nitrogen and phosphorus application would drive natural processes beyond planetary limits (Springmann et al., 2018).

A growing body of evidence documents that diets largely based on plant foods with limited amount of animal products could bring benefits to the environment (Lukasz Aleksandrowicz et al., 2016; Auestad and Fulgoni, 2015; Chai et al., 2019). Specifically, vegetarian and vegan diets have been consistently associated with lower environmental impacts compared to meat-based diets (Chai et al., 2019). This is in line with findings from modeling studies aiming at determining environmental-friendly diets (Gazan et al., 2018; van Dooren, 2018). Besides, other studies have evaluated different types of diet such as the Mediterranean diet, the Nordic diet or adherence to several dietary guidelines (Lukasz Aleksandrowicz et al., 2016; Auestad and Fulgoni, 2015; Chai et al., 2019; Ridoutt et al., 2017). All these findings consistently documented environmental impacts of cropland and livestock (Clark et al., 2019). Livestock, in particular beef, is responsible for a large part of the dietary-related GHGe and also leads to deforestation and loss of biodiversity (Gerber et al., 2013). With regard to health aspects, other protein sources need to be favored, while meat - in particular red and processed meat - consumption should be reduced, given the positive link between meat consumption and numerous chronic diseases (cancer, cardiovascular diseases, type 2 diabetes as well as overall mortality) (GBD 2017 Diet Collaborators, 2019; Mariotti, 2019).

In that context, in 2019, the EAT-Lancet commission proposed a universal healthy diet. The evidence-based EAT–Lancet diet, aligning nutrition with planet preservation, is the first global reference diet that could allow a sustainable trajectory within the planetary boundaries. It provides an anchor point for future national food policies across culturally diverse countries by enabling them to incorporate environmental preservation into their national food-based dietary guidelines (FBDGs). It is also designed to serve as a reference for "estimating health and environmental effects of adopting an alternative diet to standard current diets (Willett et al., 2019). This diet is based on the available scientific literature on the relationships between food intake and health. The EAT Lancet Commission concluded that "a dietary change towards increased adoption of plant-based diets has high mitigation potential, which is probably needed to limit global warming to a less than 2°C increase" (Willett et al., 2019). The EAT-Lancet diet is a 2500 kcal daily diet which promotes plant food consumption such as whole grains, fruit and vegetables, legumes and drastically limits the intake of added fat and sugars as well as animal food such as beef, lamb, pork - and to a lesser extent fish, eggs and chicken. A recent study documented nutritional comparison between the EAT-Lancet diet and Dietary Guidelines for American and identified some discrepancies for some plant-based food groups that were more encouraged in the EAT-Lancet such as soy-based food, nuts and seeds and whole grain starch (Blackstone and Conrad, 2020). Besides, the EAT-Lancet report has generated controversies with studies documenting null (Zagmutt et al., 2020) or protective association as regards the risk of ischemic heart diseases, diabetes and mortality (Knuppel et al., 2019), while another study put into question its affordability for the world's poor (Hirvonen et al., 2020). A recent modelling study however indicates that the EAT-Lancet recommendations were more in line with the World agenda on health and sustainability than most national FBDG (Springmann et al., 2020). However, no study has explored environmental impact of adherence to the EAT-Lancet diet. Thus, the translation of the EAT-Lancet recommendations at the individual level and in various cultural settings is necessary to thoroughly characterize the sustainability of the EAT-Lancet diet and in particular environmental dimension.

Most studies exploring the associations between environmental pressures and dietary patterns have used a small range of indicators, mainly GHGe and land use (Jones et al., 2016). Besides, few studies have considered overall impact indicators whereas this would allow to include several pressure indicators, and thus to address trade-offs between the different environmental footprints (Kramer et al., 2017). In addition, studies have mainly considered the dominant intensive system in their assessment while agroecological systems might differ on some indicators (Gomiero et al., 2011). The use of the organic farming system as an alternative model is therefore of interest, especially since it has been shown that occidental individuals who eat a lot of plant foods also eat more organically-grown products (Lacour et al., 2018).

In the present work, we therefore aimed to explore the link between adherence to the EAT-Lancet diet and associated environmental impacts considering 3 indicator of pressure and 1 impact while considering farming practices for food production. A first dietary index based on binary components has been developed to reflect the adherence to the EAT-Lancet diet in the EPIC-Oxford study (Knuppel et al., 2019). However, this index does not account for variability in consumption, we thus, chose to develop a new continuous index to better apprehend variability in consumption.

2. Material and methods

2.1 Population

These analyses were based on the NutriNet-Santé study (registered at clinicaltrials.gov as NCT03335644). NutriNet-Santé is a prospective cohort study implemented in 2009 to investigate the links between food, its determinants and health (Hercberg et al., 2010). Participants are volunteers recruited through a media campaign and who complete regular online questionnaires. At inclusion and each year thereafter, they provided data on their health, their practices (diet, lifestyles) and their socio-demographic characteristics.

This study was conducted in accordance with the Declaration of Helsinki, and all procedures were approved by the Institutional Review Board of the French Institute for Health and Medical Research (IRB Inserm 0000388FWA00005831) and the National Commission on Informatics and Liberty (Commission Nationale de l'Informatique et des Libertés, CNIL 908450 and 909216). Electronic informed consent was obtained from all participants.

Data used in this work have been described elsewhere (Kesse-Guyot et al., 2020).

2.2 Dietary data

In 2014, a web-based semi-quantitative food frequency questionnaire (FFQ) (Kesse-Guyot et al., 2010) was proposed to the volunteers. They were asked to report their frequency of consumption of 264 food items, as well as the portion consumed with photographs helping for the identification of portion size. In addition in this modified version of the FFQ (Baudry et al., 2015), for each food item, participants declared the frequency with which the item was organic through the following modalities never, rarely, half of the time, most of the time, always. Weights (0, 0.25, 0.5, 0.75, 1) were allocated to the consumption to split the total consumption of each item into organic and conventional sources. Further details and sensitivity analyses related to computation have been published elsewhere (Baudry et al., 2015). Nutrient intakes were computed using a published composition table and under/over-reporters were excluded as previously described using percentiles of the ratio between energy intake and energy requirement (Baudry et al., 2015). Bioavailable zinc and iron were computed using published equation (Armah et al., 2013; Miller et al., 2007).

2.3 EAT-Lancet diet index (ELD-I)

Based on the definition of the universal healthy diet (Willett et al., 2019), component and cut-off of the EAT-Lancet diet have been already proposed in a previous work (Knuppel et al., 2019), regarding the following 14 food groups: whole grains, tubers and starchy vegetables, vegetables, fruits, dairy foods, beef/lamb/pork, chicken and other poultry, eggs, fish, legumes, nuts, saturated oil, unsaturated oils and sweeteners. Cutoffs for each component are presented in **Table 1**. For sweeteners component, intake of added sugars was used. To improve the power of discrimination of the dietary index reflecting the adherence to the EAT-Lancet diet, compared to the previously developed score (Knuppel et al., 2019), we accounted for deviation from the cut-off value. The EAT-Lancet diet index (ELD-I) for an individual *j* with intake for each *i* was computed as follows, equation (1):

$$\text{ELD-I}_{\text{j}} = \frac{100 \times \left\{ \sum_{component\ i=1}^{14} \frac{a_i \times \left(cut{-}off_{\ i} - \frac{consumption_{ij} \times 2500}{Energy\ intake_{\ j}} \right)}{cut{-}off_{\ i}} \right\}}{14} \qquad (1)$$

Where *i* referred to on the 14 food groups and j is the individual. $a_i = 1$ for component to limit and $a_i = -1$ for component to promote.

2.4 Environmental data

Three environmental indicators were computed, namely greenhouse gas emissions (GHGe), cumulative energy demand (CED), and land occupation (LO) whose computation has been extensively described elsewhere (Baudry et al., 2019). These impacts were considered at the farm level, *i.e.* without considering post-harvest storage, conditioning and transport since these data were not available for organic farming. It should be however noted that most of the environmental impacts take place during the agricultural production phase (Clune et al., 2017). Data were derived from the DIALECTE tool (Pointereau et al., 2012) developed by Solagro (Toulouse, France) aiming to measure the environmental performance of conventional and organic farms. Data were completed using other data sources (Baudry et al., 2019). Environmental impacts of 92 conventional and organic raw products were assessed and converted into food items using economic, cooking and edibility coefficients (Baudry et al., 2019). Environmental data related to raw products for both organic and conventional farming have been previously disclosed (Baudry et al., 2019). Procedures for environmental estimation is summarized on **Figure 1**.

Intake and related environmental impacts were compiled for each food and then summed up considering organic and conventional systems to compute daily environmental indicator at the diet level.

To provide a synthetic index of available indicators in our study, we used the partial ReCiPe index, based on the ReCiPe method, a synthetic environmental impact indicator (Kramer et al., 2017).

The *p*ReCiPe was calculated for each individual as follows, equation (2):

$$pReCiPe = 0.0459 \times GHGe + 0.0025 \times CED + 0.0439 \times LO \tag{2}$$

with GHGe, in kg of CO_2eq/d, CED, in MJ/d and LO, in m^2/d. The highest the pReCiPe, the highest the environmental impact.

2.5 Other data

As complementary approaches to the planetary health diet, we computed two scores: the PANDiet and the health gain score.

The PANDiet aims at estimating the probability of adequacy of nutrient intakes (Gavelle et al., 2018). This score includes an adequacy sub-score (averaging the probabilities of adequacy for 27 nutrients) and a moderation sub-score including 6 nutrients and 12 penalty values referring to the probabilities of exceeding upper limits of intakes as showed **on the Figure 2**.

The health gain score (HS) proposed by Van Dooren *et al.* (van Dooren et al., 2014) is a synthetic score designed to measure health benefits of diets. It includes 10 components, as trans fatty acids were not available in our database, we therefore adapted it as follows, equation (3):

$$\mathrm{HS} = \left[\left(\frac{\mathrm{vegetables}}{200}\right) + \left(\frac{\mathrm{fruits}}{200}\right) + \left(\frac{\mathrm{fiber}}{40}\right) + \left(\frac{\mathrm{fish}}{37}\right) + \left(\frac{6}{\mathrm{salt}}\right) + \left(\frac{30}{\%\ \mathrm{EI\ total\ fat}}\right) + \left(\frac{10}{\%\ \mathrm{EI\ SFA}}\right) + \left(\frac{10}{\%\ \mathrm{EI\ free\ sugars}}\right) + \left(\frac{2500}{\mathrm{EI}}\right)\right] \times \frac{100}{9} \tag{3}$$

where consumptions are in grams, EI denotes energy intake in kcal, and SFA denotes saturated fatty acids.

Sociodemographics (gender, age, education, professional categories, monthly incomes, household composition), lifestyle data (smoking status, physical activity), anthropometrics (height and weight) were collected using follow-up questionnaires (Kesse-Guyot et al., 2016). Monthly household income was calculated per consumption unit using the following weighting ("Définition - Unité de consommation | Insee," n.d.): 1 consumption unit (CU) is attributed for the first adult in the household, 0.5 CU for other persons aged ≥14 y, and 0.3 CU for children aged <14 y. Physical activity was assessed using a short form of the French version of the International Physical Activity Questionnaire (Hagstromer et al., 2006) and classified as low physical activity (<30 min of physical activity equivalent to brisk walking/d), moderate physical activity (≥30 and <60 min), or high physical activity (≥60 min), according to the French guidelines. BMI was calculated as the ratio of weight to squared height (kg/m^2). The data closest to the FFQ were retained.

Place of food purchase and prices were combined with consumption to estimate the daily cost of the diet. Briefly, a database of prices by place of purchase was developed using the Kantar database (Kantar Worldpanel, n.d.), involving 20,000 French households, and further completed with collected prices for short supply chains which are not available in Kantar. This procedure has been extensively described elsewhere (Baudry et al., 2019; Seconda et al., 2018).

2.6 Statistical analysis

For the present study, we selected the NutriNet-Santé participants who had completed the Org-FFQ in 2014 (N=37,685), with no missing covariates for weight and height (N=37,305), not detected as under- or over-energy reporter (N=35,196). Next, we selected participants with available data for computation of the cost of the diet (N=29,210).

Participants were ranked and categorized into quintiles (Q) of ELD-I reflecting the level of adherence. Associations between sociodemographics, cost of the diet, food group consumption, nutritional and environmental indicators and quintiles of the ELD-I were assessed with ANCOVA using observed margins. Differences across quintiles were estimated providing the means and the confidence intervals of the mean. For environmental indicators, additional models adjusted on energy intake were performed. For statistical tests, the type I error was set at 5%. Data management and statistical analyses were conducted using SAS® 9.4 (SAS Institute Inc.) and graphics were performed using R® (version 3.4.2).

3. Results

3.1. Relationship between adherence to the EAT-Lancet diet and socio-economic characteristics of participants

The characteristics of the sample according to the quintiles of the ELD-I are presented in **Table 2**. Compared to participants with lower ELD-I, participants with higher ELD-I were less frequently men (Q_5 vs. Q_1, 34.51% vs. 62.20%), older (mean age about +6y), less often postgraduate (Q_5 vs. Q_1, 19.14% vs. 25.26%), less often employee or manual worker (Q_5 vs. Q_1, 26.36% vs. 41.03%), and more often physically active (Q_5 vs. Q_1, 44.10% vs. 27.15%) or with high income and had lower BMI (mean BMI about –2kg/m²). In addition, Participants with high adherence to the EAT-Lancet had the highest diet cost. However, the association appeared to be J-shaped.

3.2. Relationship between adherence to the EAT-Lancet diet and the nutritional characteristics of the diet

Nutritional characteristics according to ELD-I quintiles are presented in **Table 3**. High ELD-I was negatively associated with energy intake (Q_5 vs. Q_1, 1935 kcal/d vs. 2099 kcal/d), and positively with the health gain score as well as the PANDiet score (mean PANDiet about +11), proportion of organic food in the diet (Q_5 vs. Q_1, 0.45 vs. 0.17), of polyunsaturated fatty acids, plant proteins, and intake of fibers, vitamin C, vitamin B9, vitamin E, total iron and bioavailable zinc. Participants with higher ELD-I also exhibited lower % of energy intake from saturated fatty acids and total proteins and lower intakes of sodium, zinc and heme-iron.

3.3. Relationship between adherence to the EAT-Lancet diet and environmental impact indicators

The three studied environmental indicators (CED, GHGe and LO) as well as the aggregated score (*p*ReCiPe) across quintiles of ELD-I are presented in **Table 4**. Negative associations were observed between the ELD-I (modeled as quintiles) and each environmental indicator, which were stronger for GHGe and LO than for CED but showed in each occasion a dropout in the 5th quintile. High EAT-LS (Q_5) compared to low (Q_1) was associated with lower greenhouse gas emissions (-56%), cumulative energy demand (-31%) and land occupation (-54%). As regards the *p*ReCiPe index, a reduction of 63% was observed when comparing Q_5 vs Q_1. All associations were linear ($p<0.0001$).

Further adjustment for energy intake did not strongly modify the association (for *p*ReCiPe index: -62%). The distributions of the pReCiPe across ELD-I quintiles are shown in **Figure 3.** Figure 4 showed that despite a statistically significant lowering values across quintiles, a great variability occurs, especially in the 1st quintile. Similar findings were showed for individual environmental indicators constituting the pReCiPe (data not shown). Pearson correlation coefficient between the ELD-I and the *p*ReCiPe was -0.59.

Food consumption (standardized for 2500 Kcal) by quintiles are presented in **Figure 4**. As consumption were almost zero, unsaturated oil consumption was not represented. Gradients across quintiles were expected by construction. However, the most stringent differences between quintiles were for fruits and vegetables and legumes. We can note that fish consumption appeared to be relatively similar across quintiles but a little weaker in the 5th quintile.

4. Discussion

In the present analysis, conducted in a large cohort of French adults, we explored, using detailed environmental and food data, the potential environmental benefits associated with adherence to the

"Universal" healthy plant-based diet as defined by the EAT-Lancet Commission (Willett et al., 2019). We showed that a higher adherence to the EAT-Lancet diet, using an individual dietary score accounting for distance to cut-offs value for each component, was markedly related to a better nutritional diet quality (higher PANDiet score). It is noteworthy that a high ELD-I was associated with a slightly lower bioavailable iron intake. However, the mean value for individuals in the 5th quintile remained higher than the estimated average losses (Hunt et al., 2009). In addition, micronutrients found in meat (such as zinc and vitamin B12) were not particularly low. As expected, fiber intake, which has been associated with lower risk of cancer, cardiovascular diseases, type 2 diabetes and mortality (Veronese et al., 2018), was high among participants with high ELD-I. Besides, plant proteins were high but ratio between plant to total protein reached 48% only. This may be directly due to the developed methodology as the score was based on probability rather than a threshold to be reached. The overall health gain score (related to nutrient intakes) was 55% higher in participants with high ELD-I compared to those with low ELD-I, arguing for a latent alignment between environmental and nutritional dimensions of the "*planetary health diet*".

Dietary patterns of participants in Q_5 were close to vegetarian dietary patterns, though animal products, especially meat, were not totally excluded from Q_5 participants' diets. This was illustrated by an increase in the PANDiet score across quintiles despite a reduced animal-food consumption. Dietary pattern in Q_5 of the ELD-I directly compared to the Q_5 of PNNS-GS2 reflecting French food-based dietary guidelines (FBDG), which conceptually considered sustainability, after standardization for a 2500 kcal diet, exhibited lower consumption in all food groups specifically, drastic lower consumption of meat (-36%), eggs (-34%), dairy product (-33%), fat and sweet products (-33%), as well as whole-grain (-34%) (data not shown). This stemmed from the fact that participants with high adherence to French FBDG exhibited low energy intake. In turn, translation for 2500 kcal led to higher levels of consumption (Kesse-Guyot et al., 2020). Another study, conducted in the US compared dietary guidelines for American (DAG) to EAT-Lancet diet (Blackstone and Conrad, 2020). The authors reported some consistencies between both diets but also divergences in particular concerning whole-grain starch, beans and peas and nuts, seeds and soy-based food leading to high increase in total proteins. This is in line with a global study reporting that most of national FBDG were not compatible with environmental objectives (Springmann et al., 2020).

Adherence to the EAT-Lancet diet was strongly and negatively related to the three studied environmental impacts, namely GHGe, CED and LO, as well as to the synthetic environmental index (*p*ReCiPe), allowing to consider potential trade-offs. A reduction of 62% of the pReCiPe index between participants with high vs low adherence to this diet was observed. This is consistent with the findings of the recent modelling study by Springmann et al. documenting a reduction in the demand for environmental resources associated with compliance with the EAT-Lancet diet (Springmann et al., 2020). We also showed that participants with high adherence to the EAT-Lancet diet had a significantly higher consumption of organic food in their diet. As previously shown, organic food consumption is positively associated with plant-based diet (Baudry et al., 2019; Lacour et al., 2018). Organic farming is an acknowledged agroecological production method that has been shown to be a good proxy of diet-related biodiversity due to non-use of chemical pesticides (Tuomisto et al., 2012) and is associated with reduced pesticides exposure from diet in our population (Baudry et al., 2018) and others (Mie et al., 2016).

Our results cannot be directly compared to scientific literature since, to the best of our knowledge, no study has reported environmental values related to the EAT-Lancet diet at the individual level. Nevertheless, our findings can be interpreted in light of findings about observed diets and dietary guidelines.

In France, diet is rather rich in animal products as it has been showed that comparing 4 other European countries, French diet, based on the representative national study INCA-2 Study (2006-2007), exhibited the highest values for land occupation and GHGe (Mertens et al., 2019). Besides, our findings are consistent with the scientific literature which have consistently documented that plant-based diets are associated with lower pressures on resources and environment in several observational or modelling studies (Springmann et al., 2018; Chai et al., 2019; L. Aleksandrowicz et al., 2016; Clark et al., 2019; Hallström et al., 2015), in line with the EAT Lancet Commission objectives. For instance, Hallström reported that changes in dietary patterns (with more or less exclusion of animal products) may lead to an up to 50% reduction in GHG emissions and land use demand (Hallström et al., 2015). A recent study estimating the impacts of six US consumer diets considered the EAT-Lancet diet among various dietary patterns (Laroche et al., 2020). In this work, the EAT-Lancet diet showed an intermediate land use, between the lacto-ovo-vegetarian and the low-meat diets. Apart from an expected lower demand for land occupation, this study revealed that low-meat diets rely more heavily on the abundance and diversity of pollinators and may increase impacts on water resources at least in some countries. In addition, the Mediterranean Diet, permitting some animal food (such as diary) consumption is often advanced as a sustainable diet (41). Indeed, one study documented a higher GHGe (+15%) and water use (+9%) for a diet based on the Spanish dietary guidelines compared to the Mediterranean diet (González-García et al., 2020). However, it has also been reported that Mediterranean Diet had a global warming potential about twice that of the vegan diet (Castañé and Antón, 2017).

Also, a recent study was conducted to evaluate sustainability (using a synthetic score summarizing 4 environmental indicators) and to compare environmental performances of different dietary guidelines. The authors showed that environmental values differed according to the diet, Nordic Diet being the most efficient (Grosso et al., 2020). Within the same large cohort as herein, we compared various dietary patterns and their relationships with various sustainable indicators. Using a validated dietary index reflecting adherence to the new French food-based guidelines (Chaltiel et al., 2019), we recently showed that high adherence was associated with markedly lower environmental impacts compared to low-adherence (Kesse-Guyot et al., 2020), with a 50% reduction in pReCiPe and a 46% reduction in GHGE. A lower overall environmental performance for the studied indicators than the EAT-Lancet diet was, though, observed (for a 2500kcal/d diet, data not shown). This seems somehow in accordance with a recent work by Springmann et al, indicating a greater reduction in GHGEs with the global FBGDs than the national FBGDs (Springmann et al., 2020).

In contrast, a recent review focusing on analysis of sustainability of dietary guidelines for Americans reported that healthy US dietary patterns may be responsible for similar or higher GHGe, energy and water use compared to current US diets (Reinhardt et al., 2020). The review study also underlined, as expected, that plant-based dietary guidelines may only contribute to limit environmental pressures related to food systems. Consistently, the modelling study of Springmann et al., evaluating environmental and health values of food-based dietary guidelines, compared to WHO and Eat-Lancet diet, showed that most of the national food-based dietary guidelines do not allow achieving health and environmental goals (Springmann et al., 2020).

It is noteworthy that the pReCiPe distribution across ELD-I quintiles revealed that low environmental impact was not systematically associated with healthy dietary patterns. Thus, while nutritionally healthy diet and environment preservation are overall in alignment, these dimensions however may not always go hand in hand. This observation seems in line with previous works showing that unhealthy foods, such as sweet and fat food, may exhibit low environmental impacts (Clark et al., 2019; Perignon et al., 2017) and observational studies showing that the lowest emitting diets are not systematically the most sustainable as regards their nutritional values (Vieux et al., 2020). This is of great importance from a public health point of view as it highlights the need of fostering both environment-friendly and healthy diets. It is also notable that unsustainable diets (low ELD-I) were those the least expensive, raising the issue related to affordability of sustainable and healthy diets for vulnerable population.

A global score such as the ELD-I score allows to consider recommendations as a whole as it integrates interrelations between food groups, (Burggraf et al., 2018). Based on predefined cut-off values (Knuppel et al., 2019),we developed a continuous index based on the overall consumption distributions to improve power of discrimination of the score and smooth distribution. It has indeed been shown that dietary scores based on binary scoring such as some Mediterranean diet scores led to little consideration of the variability in food consumption (Burggraf et al., 2018).

Some limitations of the present work should be noted. First, our sample was not representative of the general population as the NutriNet-Santé study included voluntary participants, limiting the external validation of the results. Second, our life cycle assessment did not cover the stages posterior to food production. However, production is one of the major drivers of environmental pressures within the food system, although food loss and waste along the supply chain are substantial (Morone et al., 2019). Few accurate information covering all the food chain exists especially for alternative production systems. Finally, we did not compute indicators related to water use, biodiversity, excess nitrogen or soil quality as data were not available.

Our study also presents major strengths that include the consideration of two different farming practices (organic and conventional systems) allowing a more accurate environmental analysis. In addition, the three computed environmental impacts reflect major environmental issues (Kramer et al., 2017). Furthermore, the large sample size permitted the access to a large variety of dietary patterns.

This study documented that the planetary health diet as defined by the EAT-Lancet Commission (i.e. based on a comprehensive review of the scientific literature) was associated with a higher nutritional quality and lower environmental impacts in accordance with the objectives of the EAT-Lancet report. This definition of a universal diet is crucial for aligning the health and environmental dimensions and allows comparable assessments in different contexts. It should however be noted that in some cases, unhealthy diets may also be linked to low environmental impacts arguing for dissemination of guidelines integrating both dimensions. However, further work is needed to better test for the validation of the EAT-Lancet diet. Future optimization models works to formulate adequate nutritional intakes with reduced environmental footprints and cultural adaptation of the EAT-Lancet diet, as conducted only in Denmark, is also warranted (Lassen et al., 2020). Relationships between the EAT-Lancet reference diet and various health outcomes should be evaluated in different settings. In addition, as regards environmental pressures, the consideration of a larger number of indicators (e.g. water use) while differentiating the type of farming system may be valuable. Finally, prospective scenarios to assess feasibility would be informative.

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Data sharing statement

Data of the study are protected under the protection of health data regulation set by the French National Commission for Information Technology and Liberties (Commission Nationale de l'Informatique et des Libertés, CNIL). The data are available upon request to the study's operational manager, Nathalie Pecollo (n.pecollo@eren.smbh.univ-paris13.fr), for review by the steering committee of the NutriNet-Santé study.

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Tables

Table 1: Cut-off for each component of the EAT-Lancet Diet Index [1]

Food component	Subcomponent	Cut-off
Whole grains		≤464 g/d
Potatoes and tuber		≤100 g/d
Vegetables		≥200 g/d
Fruits		≥100 g/d
Dairy foods		≤500 g/d
Proteins sources		
	Beef, lamb, pork	≤28 g/d
	Chicken and poultry	≤58 g/d
	Eggs	≤25 g/d
	Fish	≤100 g/d
	Legumes	≤100 g/d
	Nuts	≥25 g/d
Added fats		
	Saturated oil	≤11.8 g/d
	Unsaturated oils	≤80 g/d
Added sugars	All sweet	Added sugar≤31 g/d

[1] Cut-offs for a 2500 kcal diet based on Knuppel *et. al* (Knuppel et al., 2019).

Table 2: Characteristics of the sample across ELD-I quintiles, n= 29,210, NutriNet-Santé [1]

	Q_1	Q_2	Q_3	Q_4	Q_5	p^2
Cut-off	≤4.35	]4.35-21.46]	]21.46-37.67]	]37.67-59.74]	>59.74	
%men	62.2	50.91	42.03	38.13	34.51	<.0001
Age, y	50.54 (14.08)	52.12 (14.15)	53.93 (13.82)	55.16 (13.63)	56.03 (13.54)	<.0001
Education (%)						<.0001
< High-school diploma	58.14	54.15	58.13	60.27	68.76	
High school diploma	16.6	18.35	13.74	15.91	12.1	
Postgraduate	25.26	27.5	28.13	23.82	19.14	
Occupation (%)						<.0001
Unemployed	6.44	2.34	3.04	4.02	3.84	
Retired	15.31	27.89	30.56	35.25	36.32	
Employee, manual worker	41.03	28.06	28.06	26.19	26.36	
Intermediate profession	16.19	15.94	12.86	12.07	13.98	
Managerial staff and intellectual profession	8.55	9.85	11.42	8.93	7.04	
Never employed	7.97	10.25	10.43	10.47	7.44	
Self-employed, farmer	4.52	5.67	3.65	3.07	5.01	
Monthly income (%)						<.0001
Unwilling to answer	6.23	4.98	7.25	8.24	9.96	
< 1,200€	28.64	23.2	19.41	26.86	24.88	
1,200-1,800€	30.99	29.13	29.46	26.22	25.24	
1,800-2,700€	23.07	23.94	26.44	22.63	26.04	
> 2,700€	11.07	18.75	17.44	16.06	13.88	
Physical activity level (%)						<.0001
Missing data	19.76	12.3	12.23	10.46	16.49	
Low	26.74	24.15	19.94	20.44	10.41	
Moderate	26.34	30.88	33.2	33.83	29	
High	27.15	32.66	34.63	35.26	44.1	
Tobacco status (%)						<.0001
Never smoker	43.39	45.42	48.94	48.06	55.1	
Former smoker	42.72	39.1	38.92	43.68	38.09	
Current smoker	13.88	15.49	12.14	8.26	6.81	
Cost of the diet (€/d)	7.72 (2.92)	7.38 (2.65)	7.43 (2.73)	7.48 (2.73)	8.53 (3.66)	<.0001
Body mass index (kg/m²)	25.12 (4.95)	24.62 (4.62)	24.32 (4.65)	23.82 (4.44)	23.13 (4.21)	<.0001

Abbreviations: Q: quintiles;

[1] Values are means (SD) or %.

[2] P referred to ANOVA or Chi² test.

Table 3: Nutritional characteristics of the sample across EAT-Lancet Diet Index quintiles, n= 29,210, NutriNet-Santé [1]

	Q_1	Q_2	Q_3	Q_4	Q_5	P [2]
Energy intake (kcal/d)	2099 (694)	2030 (624)	1994 (606)	1947 (589)	1935 (612)	<.0001
PANDiet (/100)	59.47 (6.20)	62.54 (6.39)	64.81 (7.01)	67.50 (7.51)	70.55 (7.15)	<.0001
Health score (/9)	0.91 (0.22)	0.98 (0.21)	1.06 (0.22)	1.14 (0.22)	1.41 (0.38)	<.0001
Alcohol (g/d)	9.06 (13.23)	9.55 (13.06)	9.47 (13.44)	8.27 (11.45)	6.23 (10.90)	<.0001
Proportion of organic food [3]	0.17 (0.19)	0.23 (0.22)	0.28 (0.25)	0.35 (0.28)	0.45 (0.32)	<.0001
% Carbohydrates	35.37 (6.98)	38.39 (6.46)	39.65 (6.54)	40.80 (6.83)	43.89 (8.00)	<.0001
% Lipids [4]	42.96 (6.19)	41.89 (6.25)	41.30 (6.63)	40.91 (7.18)	39.05 (8.50)	<.0001
% SFA [4]	17.15 (3.13)	16.16 (3.12)	15.31 (3.15)	14.13 (3.09)	11.87 (3.22)	<.0001
% MUFA [4]	16.48 (3.31)	16.30 (3.52)	16.29 (3.84)	16.59 (4.31)	16.32 (5.17)	<.0001
% PUFA [4]	6.10 (1.80)	6.33 (1.99)	6.64 (2.23)	7.19 (2.61)	7.94 (3.28)	<.0001
% Proteins [4]	21.35 (3.72)	19.37 (3.02)	18.67 (3.09)	17.88 (3.23)	16.57 (3.53)	<.0001
Proportion of plant proteins	0.22 (0.07)	0.28 (0.07)	0.32 (0.09)	0.37 (0.12)	0.48 (0.19)	<.0001
Fibers (g/d)	16.03 (5.17)	19.38 (4.47)	22.25 (4.84)	25.74 (5.36)	33.36 (9.40)	<.0001
Sodium (mg/d)	2717 (574)	2621(473)	2563 (483)	2430 (478)	2181 (558)	<.0001
Vitamin B12 (µg/d)	8.17 (9.28)	6.84 (3.36)	6.40 (3.02)	5.97 (3.04)	5.15 (3.07)	<.0001
Vitamin C (mg/d)	108.00 (58.10)	127.08 (58.28)	142.37 (62.11)	161.19 (63.51)	223.82 (105.87)	<.0001
Vitamin B9 (µg/d)	333.10 (108.71)	366.88 (86.55)	400.76 (92.15)	443.67 (99.22)	552.95 (180.94)	<.0001
Vitamin E (mg/d)	11.80 (4.58)	13.06 (4.54)	14.15 (4.62)	15.53 (4.86)	18.34 (5.67)	<.0001
Calcium (mg/d)	1069 (323)	1119 (316)	1142 (319)	1138 (327)	1107 (331)	<.0001
Iron	14.33 (3.79)	14.52 (3.15)	15.26 (3.47)	16.05 (3.68)	17.26 (4.10)	<.0001
Heme-iron	2.17 (1.70)	1.49 (0.66)	1.23 (0.59)	1.02 (0.60)	0.74 (0.60)	<.0001
Zinc	14.25 (3.25)	12.89 (2.24)	12.58 (2.21)	12.30 (2.26)	11.78 (2.32)	<.0001

Abbreviations: MUFA: monounsaturated fatty acids, PUFA; polyunsaturated fatty acids, Q: quintiles; SFA: saturated fatty acidsx

[1] Values are means (standard deviations)

[2] P for trend across quintiles of PNNS-GS2 assessed by linear contrast

[3] Proportion of weight excluding water

[4] As percent of alcohol-free energy intake

Table 4: Environmental indicators across EAT-Lancet Diet Index quintiles, n= 29,210, NutriNet-Santé [1]

	Q_1	Q_2	Q_3	Q_4	Q_5	P[2]
CED (MJ/d)						
Model 1[2]	21.98 (21.79-22.16)	18.31 (18.13-18.50)	16.98 (16.80-17.16)	15.72 (15.53-15.90)	15.16 (14.97-15.34)	<.0001
Model 2[3]	21.18 (21.05-21.30)	18.13 (18.00-18.25)	17.10 (16.97-17.23)	16.16 (16.04-16.29)	15.58 (15.45-15.71)	<.0001
GHGE (CO_2eq/d)						
Model 1[2]	6.03 (5.98-6.09)	4.49 (4.43-4.54)	3.85 (3.80-3.91)	3.27 (3.21-3.32)	2.63 (2.57-2.68)	<.0001
Model 2[3]	5.83 (5.79-5.88)	4.44 (4.40-4.49)	3.88 (3.84-3.93)	3.38 (3.33-3.42)	2.73 (2.69-2.78)	<.0001
LO (m^2/d)						
Model 1[2]	15.53 (15.37-15.68)	11.61 (11.45-11.77)	10.06 (9.91-10.22)	8.66 (8.50-8.82)	7.17 (7.01-7.33)	<.0001
Model 2[3]	14.99 (14.86-15.12)	11.48 (11.35-11.61)	10.14 (10.01-10.27)	8.96 (8.83-9.09)	7.45 (7.32-7.58)	<.0001
*p*ReCiPe						
Model 1[2]	0.449 (0.445-0.452)	0.326 (0.323-0.329)	0.271 (0.268-0.275)	0.227 (0.223-0.230)	0.168 (0.165-0.172)	<.0001
Model 2[3]	0.444 (0.441-0.448)	0.325 (0.322-0.328)	0.272 (0.269-0.275)	0.229 (0.226-0.232)	0.170 (0.167-0.174)	<.0001

Abbreviations: CED, Cumulative energy demand; GHGE, Greenhouse gas emissions; LO, Land occupation; Q: quintiles

[1] Values are means and 95% confidence interval

[2] Model 1 is crude

[3] Model 2 is adjusted for daily energy intake

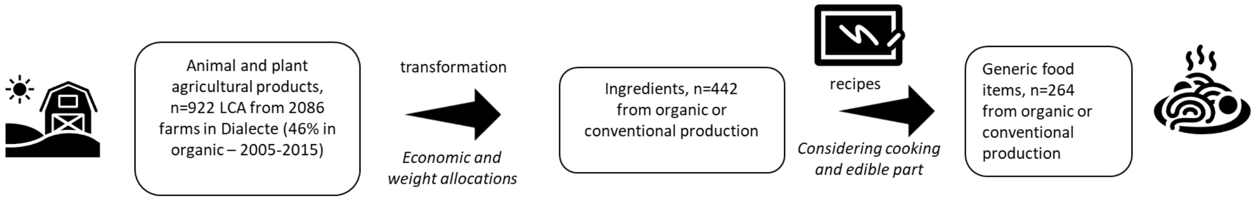

Figure 1: Steps for calculating the environmental indicators

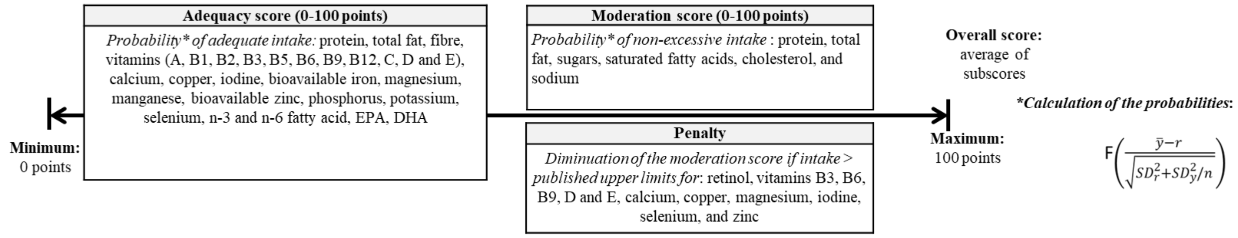

Figure 2: Computation of the PANDiet score

Abbreviations: DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid.

F (ranged from 0 to 1, where 1 represents a 100% probability that the usual intake was adequate): ‘Probnorm’ function in SAS, y is the mean intake, SD_y the day-to-day variability of intake, n the number of dietary record days, r the nutrient reference value, SD_r the interindividual variability.

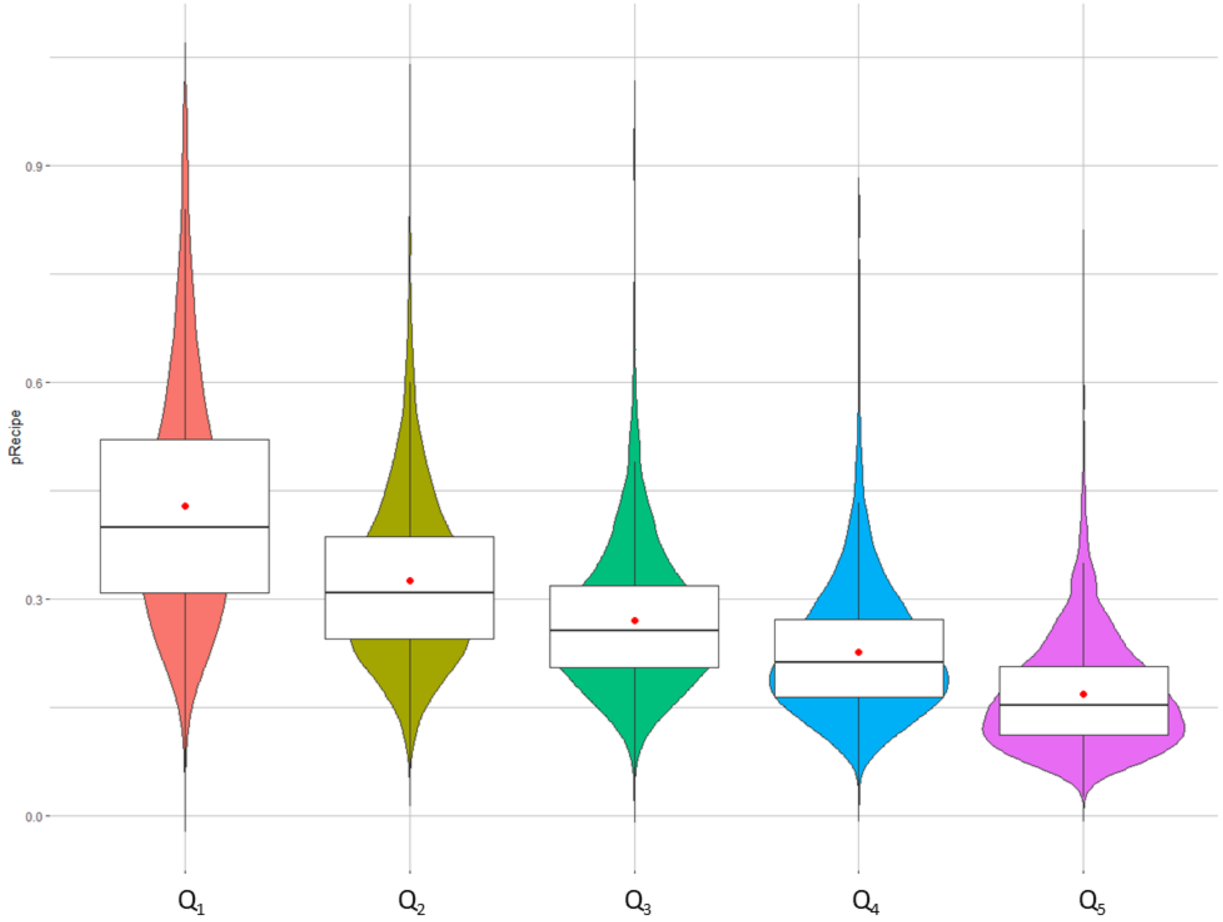

Figure 3: *p*Recipe distribution across ELD-I quintiles [1]

[1] Unadjusted distribution is presented.

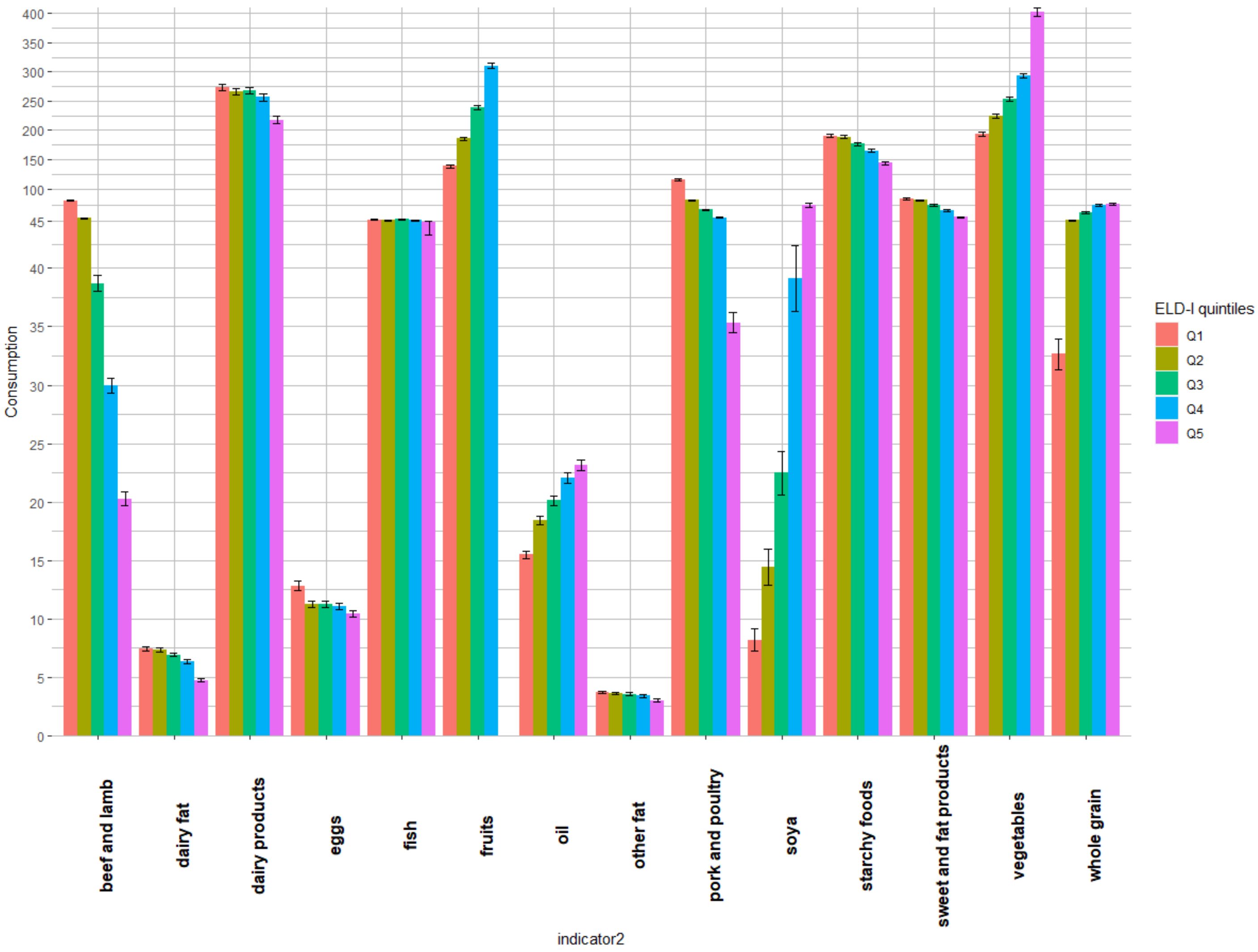

Figure 4: Food consumption (intake in g/d) across ELD-I quintiles [1]

Abbreviations: Q, quintile

[1] Values are unadjusted means and 95% confidence interval, all P-values for trend were <0.0001.