Association between dietary environmental pressures and major chronic diseases: assessment from the prospective NutriNet-Santé cohort

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Summary

Background Plant-based diets offer co-benefits for human health and the environment, but assessments often consider only specific aspects. This study comprehensively examines the links between diet-related environmental pressures and risk of chronic diseases as well as mortality.

Methods Data from a population study of 34,077 participants to the NutriNet-Santé French cohort were used. Dietary data were collected using a food frequency questionnaire, distinguishing between organic and conventional foods, and were merged with food production environmental indicators. The associations between greenhouse gas emissions (GHGe), energy demand, land occupation (LO), ecological infrastructures (EI), water use, and pesticide treatment frequency and a synthetic environmental pressures index (EPI) and incidence of cancer, cardiovascular diseases (overall, coronary and cerebrovascular diseases), type 2 diabetes and mortality were estimated using weighted multivariable cox proportional risk model.

Findings Over a mean median follow-up of 8.39 years (IQR = 5.62, 256,891 person-year), the diet's overall environmental pressures (EPI) was positively associated with the risk of all tested chronic diseases except stroke. The HR for 1 SD increment ranging from 1.15 (95% CI = 1.03–1.28) for cancer (all locations) to 1.50 (95% CI = 1.29–1.73) for coronary heart disease and type 2 diabetes, but no association with stroke or death was detected.

Interpretation Diets with low overall environmental pressures are associated with important health benefits, suggesting that food systems with lower environmental impacts could be key drivers of both environmental and health sustainability.

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Keywords: Chronic diseases; Diet; Environmental indicators; Climate; Epidemiology; Cohort

Introduction

Diet plays a significant role in the burden of disease,[1,2] with 2.1 billion people suffering from overweight or obesity.[3] In 2021, dietary risk factors were the second leading cause of attributable deaths among women (3.48 million deaths, uncertainty intervals: 2.78–4.37) and the third among men (4.47 million deaths, 3.65–5.45) globally, highlighting regional disparities.[2]

Abbreviations: BMI, Body mass index; CED, Cumulative energy demand; CHD, Coronary heart diseases; CVD, Cardiovascular diseases; EI, Ecological infrastructures; EPI, Environmental pressures index; GHGe, Greenhouse gas emissions; LO, Land occupation; Org-FFQ, Organic food frequency questionnaire; T2D, Type 2 diabetes

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Trial registration: The NutriNet-Santé cohort is registered at clinicaltrials.gov (NCT03335644).

Translation: For the French translation of the abstract see the Supplementary Materials section.

Research in context

Evidence before this study

A recent systematic review has gathered existing evidence on sustainable diets, indicating that certain dietary patterns may benefit both human health and the environment. The review included studies published in English until December 2024 that examined the associations between environmental indicators and the risk of cardiovascular diseases, cancer, diabetes, and mortality. These studies were identified through a PubMed search using the terms (diet-related OR from diet OR dietary) AND (greenhouse gases OR GHG OR greenhouse gas emissions) AND (mortality OR cancer OR diabetes OR death OR cardiovascular OR chronic) AND prospective. Three studies modelled environmental indicators as exposure to health risk in prospective studies. The first, conducted in EPIC-NL, examined the prospective link between diet-related greenhouse gas emissions (GHGe) and land use and mortality. The second study, involving the entire European EPIC cohort, looked at the association between GHGe and land occupation and risk of mortality (overall and cause-specific). The third study, conducted in EPIC-Spain, examined the relationship between diet-related GHGe and the risk of cancer, cardiovascular diseases, and type 2 diabetes.

Added value of this study

This study is, to our knowledge, the first to explore the links between a wide range of environmental indicators distinguishing more or less sustainable diets and the risk of morbidity and mortality based on prospective cohort data with a median follow-up of 8.39 years (interquartile range = 5.62). Using data from a large (N = 34,077) population study from the NutriNet-Santé French cohort who completed a food frequency questionnaire distinguishing organic and conventional foods, we computed a synthetic environmental pressures index (EPI) of the specific environmental pressures associated with the production of diets, based on the following standardised indicators: GHGe, cumulative energy demand, LO, ecological infrastructures (EI), water use and frequency of pesticide use. The risk of death, type 2 diabetes, cardiovascular diseases (CVD) and cancer, based on validated multi-source data, was estimated for different levels of environmental pressures associated with individual diet. We found that diets with high environmental pressures, less adherent to the French dietary guidelines and EAT-Lancet diet, were positively associated with the risk of chronic diseases except for stroke that was not associated. Findings were robust in sensitivity analyses, particularly in causal inference models that simulate intervention changes in EPI.

Implications of all the available evidence

Our research indicates that a diet with lower environmental pressures is linked to a reduced risk of type 2 diabetes, CVD, and cancer. The co-benefits of a diet that is less detrimental to the environment vary depending on environmental indicators, as evidenced by inverse associations with water use and ecological infrastructure. However, the overall trend supports the hypothesis that such a diet also benefits human health. Emphasising these health co-benefits may appeal to individuals less concerned about environmental issues.

The main dietary contributors to these attributable deaths are insufficient consumption of whole grains, fruits and vegetables, excessive intake of red and processed meats, and high sodium intake. These dietary patterns are closely linked to the onset of cancer, cardiovascular diseases, and diabetes.[1]

At the same time, activities within agri-food systems, particularly at the food production stage, significantly impact land use and the environment,[4,5] and contribute to exceeding several planetary boundaries.[6,7]

Livestock production, including beef and dairy as well as, to a lesser extent, monogastric breeding, shows the most significant environmental impacts across many indicators: acidification, eutrophication, greenhouse gas emissions (GHGe), soil and water use, etc.[8,9] Observational studies have shown that, in a population, diets rich or exclusively based on plant products have GHGe and land use levels well below those of meat consumers.[10,11] Other types of scenario modelling studies confirm that diets including low quantities of or no food products of animal origin present lower environmental pressures than those of meat eaters, particularly GHGe.[10,12,13]

The recent scientific literature, based on cohort data, has documented that healthy dietary patterns may offer co-benefits for both environmental and human health.[14–17]

These findings generally support the EAT-Lancet Commission's guidelines, which recommend a high intake of plant-based foods, including wholegrain cereals, vegetables, fruits, pulses, nuts, and seeds. They also advise reducing the consumption of animal products such as red meat, dairy, eggs, and fish, while limiting processed foods and added sugars.[5] Research shows that following the EAT-Lancet guidelines while respecting planetary boundaries could worldwide prevent up to 11 million premature deaths annually, accounting for about 19%.[5] In this context, many studies have assessed the links between environmental pressures or health indicators and adherence to the EAT-Lancet diet.[18] It is also worth noting that numerous adherence indicators have been developed, and they display different properties.[19]

However, some authors emphasised that most of the evaluated co-benefits centre on air pollution and that public health researchers, epidemiologists, and health economists should aim to collaborate more actively to advance research into health co-benefits.

Furthermore, Reganold et al. conducted a literature review examining the performance of organic farming.[20] They concluded that, although average yields are lower, organic farming significantly reduces environmental impact and offers social and ecological benefits. For instance, it is widely recognised that organic production requires less energy than conventional systems.[20] Concerning GHGe, the disparities between organic and conventional systems are less clear and depend on the products. In addition, because organic farming yields are lower, land use tends to be higher. Diets mainly based on organic food have also been linked to a reduced risk of some chronic diseases.[21]

In this context, we examined the relationship between food-related environmental pressures and various indicators, including greenhouse gas emissions (GHGe), land occupation (LO), energy use, pesticide application, water use, and ecological infrastructures—considering the production method (organic and conventional). Additionally, we employed a composite indicator designed to reflect the overall environmental impact and potential disparities among different indicators and health risks across a broad cohort, utilising both observational and counterfactual methodologies. Importantly, the individual environmental indicators were estimated by considering the farming method of the food.

Methods

Study population

This study was conducted on a sample of adults from the web-based prospective NutriNet-Santé cohort, which aims to investigate the complex relationships between dietary habits and health and disease.22 Participants are volunteers aged over 15 years recruited from the general French population. In the present study, data collected between 2014 and 2024 were used.

Ethical approval

The study is registered at https://clinicaltrials.gov/ct2/show/NCT03335644, conducted according to the Declaration of Helsinki guidelines and approved by the Institutional Review Board of the French Institute for Health and Medical Research (IRB-Inserm) and by the French National Commission for Information Technology and Liberties (Commission Nationale de l'Informatique et des Libertés) (CNIL n°908450/n°909216). Each participant provides an electronic informed consent form in the NutriNet-Santé cohort before enrolment.

Data collection

Data on age, sex, highest educational attainment, occupation, income per household unit per month, marital status, smoking habits, and physical activity were collected at cohort enrolment and annually thereafter using validated questionnaires.[22,23] Physical activity was measured using the International Physical Activity Questionnaire (IPAQ).[24] Tobacco consumption, expressed in pack-years, was also calculated. Validated anthropometric questionnaires provided information on height and weight.[23] Family history, including the history of cancer, stroke, myocardial infarction, and type 2 diabetes (T2D) among parents and siblings, was collected.

Dietary data (baseline point) were collected between June and December 2014 using a 264-item self-administered semi-quantitative food frequency questionnaire (Org-FFQ). This enables the specification of whether the food was organic (as defined by the official European standards and label) or conventionally produced.[25] This dietary measurement tool is based on a previously validated FFQ,[26] improved by a five-point scale to assess the proportion of organic food consumption in the diet.[25] For each food item, participants reported the frequency with which it was consumed as organic by selecting one of the following options: "never", "rarely", "half-of-the-time", "often" or "always" in response to the question '*How often was the product of organic origin*?'. Each modality was assigned a weight, i.e., 0, 25, 50, 75, and 100%, respectively. Nutrient and total energy intakes were calculated using a published food composition table.[27] To identify underreporting or overreporting participants, we estimated basal metabolic rate by Schofield equations according to sex, age, weight, and height collected at enrolment in the study.[28] Energy requirement, accounting for physical activity level and basic metabolic rate, was compared with energy intake. The ratio of energy intake to energy requirement was calculated, and individuals with ratios below or above cut-offs (0.35 and 1.93) were excluded.[25]

Two dietary scores, sPNNS-GS2, reflecting the adherence to the French dietary guidelines[29] and the Planetary Health Dietary Index (PHDI)[30] were computed. Details are provided in Supplemental Method 1.

All covariates were collected as close in time to the completion of the FFQ.

Environmental pressures were estimated by combining food consumption (except for drinking water) with six indicators: GHG emissions, LO, cumulative energy demand (CED), ecological infrastructures (EI) reflecting biodiversity, pesticide use (using treatment frequency index (TFI)) and water use (related to irrigation). Life cycle assessments from the DIALECTE database were used to calculate food-related GHGe, CED, and LO. The computation procedures for these three indicators have been extensively described elsewhere.[31] Various databases (French annual agricultural statistics, FAOSTAT,[32] Surveys on farming practices in France, Agribalyse,[33] Graphic parcel register, BD Haie, BD Forêt®, effectives wetlands, Agreste[34]) were used to calculate EI (Ecological Infrastructures constitute a network of elements incorporated into the agricultural environment to harmonise production with biodiversity preservation), pesticide use, and water use for both organic and conventional food. Economic and biophysical allocations, along with cooking and edibility coefficients, were applied to agricultural raw materials. Details and references are provided in Supplemental Method 2.

For each indicator, a higher value reflects greater pressure, except for EI. Based on the 6 environmental normalised indicators (reversed for EI), a summarised environmental pressures index (EPI) was computed, with a higher value reflecting greater pressure. The procedure is explained in Supplemental Method 3.

Health events were identified using a multisource approach. Participants were asked to report significant health events by completing a yearly health questionnaire, a specific biannual questionnaire, or using a specific interface on the study website at any time. After reporting a major health event such as cardiovascular diseases or cancer, participants were asked to provide all medical records and anatomopathological reports to confirm the diagnosis. If necessary, the study physicians contacted the participants' general practitioners or relevant medical institutions to collect further information and to validate the reported cases. In addition, the data collected within the NutriNet-Santé study were linked to medico-administrative databases of the Caisse Nationale de l'Assurance Maladie (social health insurance system), thereby limiting potential bias for participants who may not report their disease to the study investigators. Finally, additional and exhaustive information on mortality (date and cause of death) was obtained from the countrywide Centre d'épidémiologie sur les causes médicales de Décès (CépiDc) database. All cases were defined as the first occurrence of cancer (except basal cell carcinoma, not considered as cancer), cardiovascular diseases (CVD), considering all CVD, stroke and coronary heart diseases (CHD) specifically, T2D and death, occurring between the completion of FFQ and August 2024.

Details are provided in Supplemental Method 4.

Statistical analysis

To be included in the present study, participants had to have completed the Org-FFQ and reside in France to ensure their eligibility for the French census weighting process. To conduct a disease-specific analysis, the prevalent cases (type 1 and 2 diabetes in the case of the T2D analysis) of the respective disease were excluded. The participants' flowchart is shown in Supplemental Figure S1.

For each sex, a weighting was determined by on the 2009 national census considering age, occupational categories, area of residence and whether or not the household included at least one child (<18 y), marital status, and educational attainment, using the iterative proportional fitting procedure, to adjust the percentage of individuals in each stratum to the actual percentage in the French population. Weights were calculated using the "CALage sur MARges" procedure (SAS CALMAR macro).[35]

To illustrate the profiles of the participants in the cohort, compared with the French population, the weights according to characteristics are presented in Supplemental Table S1. Then all analyses are weighted.

For descriptive purposes, the mean (SD) or percentage of baseline characteristics - including sociodemographic, lifestyle, and environmental and dietary indicators - are presented for the overall weighted sample and the weighted quintile of EPI. Tests for differences were calculated using the Mantel-Haenszel χ^2 test for dichotomous or ordinal variables, or linear contrasts from ANOVA for numeric variables.

In addition, dietary consumptions (standardised to 2000 kcal) are presented per weighted quintile of EPI.

Cox proportional hazard models, with age as the primary time scale, were used to evaluate the association between each environmental indicator or the EPI and the incidence of cancer, CVD, T2D, and all causes of mortality (except suicides, fatal accidents, and unknown causes). Participants contributed person-time from the Org-FFQ completion until the date of the studied health event, the date at which the last questionnaire was completed, the date of death, or August 2024, whichever occurred first. Hazard ratios (HR) and 95% confidence intervals (CI) were computed for each model. Exposure variables were environmental indicators considered as continuous variables (per one SD) and weighted sex-specific quintiles. Cox proportional hazard assumption was verified using the rescaled Schoenfeld-type residual method,[36] as shown in Supplemental Figure S2. The log-linearity and dose–response of the relationships between environmental indicators and hazard ratios for chronic diseases were appraised using restricted cubic splines,[37] as shown in Supplemental Figure S3. The selection of confounding factors is based on the literature of the major determinants of dietary behaviours and the health events studied.

In the main analyses (model M1), models were adjusted for age (time-scale), sex (male/female), physical activity level (low, moderate, high), smoking status (current smoker, former smoker, non-smoker), cumulative number of pack-years of cigarette smoking, energy intake (continuous, kcal/d), educational attainment (< High school diploma, High school, ≤3 years after high school, >3 years after high school), living status (cohabiting or not), occupational status (retired, unemployed, farmer/merchant/craftworker/company director, manual worker, employee/manual worker, intermediate profession, managerial staff/intellectual profession), monthly household income per consumption unit (non-disclosed, <1200 €, 1200–1800 €, 1800–3700 €, ≥3700 €), body mass index (BMI) (continuous, kg/m^2), and family history of cancer, diabetes or cardiovascular diseases depending on the analysis. For the cancer analysis, height (continuous, cm) and, for women, the number of children, hormone replacement, age at menarche and contraceptive use at enrolment were included in the model.

We derived marginal survival curves, which can be interpreted as the counterfactual survival function that would have been observed if the entire population had been exposed to food with high environmental pressures. Finally, marginal structural models (MSM) were constructed to estimate the "causal" effect of environmental pressures on several health events while considering confounding factors.[38,39] The MSM approach mimics the design of a randomised controlled trial (RCT) by creating pseudo-randomisation through statistical reweighting, thereby reducing confounding bias that would otherwise preclude causal inference in observational data. In short, the MSM approach involved three key stages: the estimation of propensity scores, i.e. the inverse probability of treatment weights (IPTW), using logistic regression models that included the major covariates. The weights are composed of two propensity scores, which estimate either the probability of 'receiving' an exposure as a function of the covariates or the probability of censoring. More details on the method and assumptions are provided in Supplemental Material 5.

Several sensitivity analyses are described in Supplemental Method 5. SAS 9.4 (SAS Institute) and R® version 4.0.4 (R 197 Foundation) were used for the analyses; tests were two-sided and considered statistically significant when the *P*-value was <0.05.

Role of funding source

The funders had no role in study design, data collection and analysis, manuscript preparation, or the decision to submit for publication.

Results

Characteristics of the sample and diets

The weighted mean of baseline age of the study population (n = 34,077) was 48.4 years (SD = 16.3). After weighted adjustment, women composed approximately 52% of the sample.

The characteristics of the EPI by weighted sex-specific quintile and in the overall sample are shown in Table 1. The EPI was positively associated with age and negatively associated with educational attainment. Executive or higher intellectual professions had lower EPI, while retired people had higher EPI. The Environmental Pressures Index was also inversely associated with income level. The environmental and dietary characteristics by weighted sex-specific quintile and in the overall sample are shown in Table 2. The weighted mean of the EPI for 2000 Kcal is 13.90/100 (SD = 3.77) (Table 2).

By construction, EPI was positively associated with each of its constituent contributors from pressure indicators. Higher ecological infrastructure was observed despite the inversion of the indicator in the Environmental Pressures Index computation (Supplemental Method 5).

The diet of the participants in the 5th weighted quintile of EPI (compared to the 1st) exhibited +286% higher food-related GHGe, +219% higher CED, +264% higher LO, +272% higher EI, +240% higher pesticide use and +129% water use (Table 2).

Participants in the 5th weighted quintile of EPI (compared to the 1st) had higher energy intake (+99%) and lower nutritional quality of the diet, they also had higher consumption of total and animal protein intakes (Table 2).

The average food consumptions per 2000 kcal across EPI quintiles are presented in Fig. 1, and crude values are presented in Supplemental Table S2. When considering consumption per 2000 kcal, diets with a high level of EPI were characterised by high consumption of meat (pork, ruminants, poultry, offal and processed meat). Conversely, the consumption of wholegrain foods and pulses was significantly lower in diets with the highest EPI than in diets with the lowest one.

Environmental pressure and health risk

The weighted median (IQR) of follow-up times were 8.04 (5.74), 8.15 (5.72), 8.21 (5.71) and 8.39 (5.62) for cancer (n cases = 1706), CVD (n cases = 739), T2D (n cases = 596) and death (n cases = 881), analyses, respectively. The associations between EPI and health risk are presented in Fig. 2 and Table 3. A higher value of the Environmental Pressures Index was positively associated with the risk of chronic diseases, i.e. cancer, CVD (all), CHD and T2D, but no association was detected for stroke and death (see Fig. 2 and Table 3). The HR for 1 SD ranged from 1.15 (95% CI = 1.03–-1.28) for the risk of cancer (all locations) to 1.50 (95% IC = 1.29–1.73) for the risk of coronary heart disease and 1.50 (95% IC = 1.29–1.74) for the risk of T2D.

Results of the sensitivity analyses for the EPI are shown in Supplemental Table S3. Most findings yielded results similar (magnitude of the hazard ratio and statistical significance) to the main model (M1), notably those without energy adjustment and early cases exclusion (sensitivity analyses 1 and 2, respectively), except that the association with cancer risk was attenuated. Findings were also similar to the main findings in the models with capping weight (sensitivity analyses 3).

In models employing a marginal structural model (sensitivity analysis 4), which simulate a randomised trial, and in models without weighting (sensitivity analysis 5) for Census data, the findings were similar to the main models but achieved statistical significance only for T2D risk.

	All	Q1	Q2	Q3	Q4	Q5
N (weighted)						
Cut-off						
Men		<10.42	10.42-<13.12	13.12-<15.79	15.79-<20.49	≥20.49
Women		<9.07	9.07-<11.47	11.47–13.99	13.99-<17.89	≥17.89
EPI, median [IQR]						
Men	14.44 (98.44)	21.33 (70.12)	8.24 (8.41)	11.67 (2.69)	14.28 (2.67)	17.67 (4.69)
Women	12.18 (85.21)	7.45 (9.07)	10.27 (2.4)	12.61 (2.52)	15.71 (3.91)	21.33 (70.12)
Sex, %Women	52.30	52.39	52.98	51.77	52.09	52.29
Age (y), mean (SD)	48.39 (16.23)	45.91 (16.52)	47.12 (16.66)	47.78 (16.12)	50.46 (15.11)	50.66 (16.28)
Education, (%)						
<High school diploma	59.63	50.18	58.84	61.74	58.46	68.88
High school	15.51	19.45	15.09	13.30	15.78	13.93
≤3 years after high school	11.85	13.65	11.72	12.29	13.26	13.65
>3 years after high school	13.01	16.73	14.35	12.66	12.50	8.86
Occupation, (%)						
Retired	27.48	22.82	26.31	27.21	31.43	29.62
Executive or higher intellectual profession	9.11	11.65	9.44	7.88	9.61	6.96
Craftsman, trader, business manager, farmer	4.46	6.95	4.87	3.59	3.94	2.97
Intermediate occupation	14.49	17.40	16.02	12.68	14.62	11.78
Employee/manual worker	31.14	27.76	29.92	34.56	28.77	34.64
Unemployed	4.25	4.36	5.76	5.25	2.55	3.34
Never Unemployed	9.07	9.06	7.69	8.83	9.09	10.68
Monthly income per household unit, (%)						
<1200€	14.16	13.73	16.84	15.23	10.57	14.47
1200–1800€	28.64	26.24	28.05	30.26	31.21	27.43
1800–3700€	24.23	25.56	25.60	19.86	26.52	23.64
>3700€	14.98	15.56	13.75	15.41	16.27	13.90
Missing data	17.98	18.90	15.76	19.23	15.43	20.57
Marital status, % cohabiting	80.22	77.53	79.05	78.82	82.12	83.55
Tobacco use, %						
Never-smokers	47.37	54.11	50.08	47.75	42.25	42.73
Former smokers	39.95	32.27	40.19	36.53	46.19	44.57
Current smokers	12.68	13.62	9.73	15.72	11.57	12.70
Physical activity, %						
High	33.99	31.87	32.32	34.19	36.10	35.44
Moderate	30.59	31.96	31.76	30.88	31.94	26.45
Low	21.10	24.43	21.98	21.23	18.90	18.97
Missing data	14.32	11.74	13.95	13.70	13.06	19.14
BMI (kg/m^2)	24.94 (5.91)	23.75 (4.56)	24.85 (8.66)	24.78 (4.93)	25.14 (4.63)	26.16 (5.65)

Abbreviations: BMI, body mass index; EPI, environmental pressures index; IQR, interquartile range. All P-value <0.001 except for sex. [a]Value are weighted means (SD) or % as appropriate, except otherwise is specified.

Table 1: **Baseline sociodemographic and lifestyle data across weighted quintiles of Environmental Pressures Index (NutriNet-Santé cohort, 2014, n = 34,077).[a]**

The adjusted survival curves for a fixed covariate profile are presented for each health event in Supplemental Figure S4. The differential risk across EPI quintiles is quite distinct for the risk of diabetes, CVD, CHD and mortality, especially from age 65 onwards. For the risk of cancer and stroke, the confidence intervals are wide.

The associations for each environmental indicator are presented in Supplemental Figure S5. GHGe, CED, LO, and pesticide use were all positively associated with cancer, CVD (in particular CHD), and T2D risks, while GHGe was additionally inversely associated with stroke. The last two indicators, Water use and EI, exhibited completely different profiles. Water use was found to have a negative association with cancer risk. In addition, EI, which indicates biodiversity levels, where higher values are preferable, was positively linked to risks for cancer, CVD, CHD, and T2D, with no association observed regarding mortality.

Discussion

This study employed data from a large adult cohort to assess the relationship between various environmental

	All	Q1	Q2	Q3	Q4	Q5
EPI Cut-off						
Men		<10.42	10.42–<13.12	13.12–<15.79	15.79–<20.49	≥20.49
Women		<9.07	9.07–<11.47	11.47–13.99	13.99–<17.89	≥17.89
EPI standardised to 2000 kcal	13.90 (3.77)	10.64 (2.86)	12.88 (2.82)	14.16 (3.47)	14.93 (2.67)	16.85 (3.91)
Individual environmental indicators						
GHGe (kgCO_2eq/d)	4.44 (2.79)	2.04 (0.84)	3.14 (1.17)	4.07 (1.37)	5.06 (1.44)	7.88 (3.87)
Energy demand (MJ/d)	18.59 (8.49)	9.71 (2.50)	13.73 (2.39)	17.31 (2.67)	21.16 (3.11)	30.98 (8.88)
Land occupation (m^2/d)	11.49 (7.47)	5.51 (2.24)	8.23 (3.14)	10.61 (4.08)	13.01 (4.20)	20.05 (11.11)
Pesticides use (FTI/d)	23.09 (12.35)	11.51 (5.22)	17.02 (6.42)	20.87 (5.87)	26.80 (6.98)	39.16 (13.62)
Water use (m^3/d)	0.25 (0.12)	0.16 (0.06)	0.21 (0.09)	0.24 (0.08)	0.28 (0.08)	0.37 (0.15)
Ecological infrastructures (m^2/d)	0.80 (0.57)	0.38 (0.20)	0.56 (0.26)	0.74 (0.36)	0.90 (0.36)	1.40 (0.87)
Dietary indicators						
Energy Intake (kcal/d)	2112.22 (709.09)	1492.13 (400.56)	1775.82 (399.44)	2002.45 (472.80)	2314.00 (429.01)	2971.39 (746.08)
Alcohol (g/d)	8.01 (12.63)	5.92 (10.15)	7.06 (10.62)	6.86 (12.35)	9.84 (13.01)	10.33 (16.12)
% of organic food in the diet	0.26 (0.27)	0.36 (0.32)	0.29 (0.30)	0.24 (0.24)	0.22 (0.22)	0.17 (0.21)
sPNNS-GS2	2.03 (3.70)	4.23 (2.62)	3.39 (3.06)	2.51 (3.35)	0.99 (3.17)	−0.96 (3.84)
PHDI	90.78 (13.16)	94.38 (14.53)	91.67 (14.41)	90.40 (12.79)	89.37 (10.94)	88.08 (11.86)
Total proteins (g/d)	97.20 (39.83)	60.36 (16.38)	77.04 (16.91)	92.28 (20.37)	107.36 (21.39)	148.65 (47.45)
Animal proteins (g/d)	67.05 (37.18)	33.50 (16.16)	49.14 (18.48)	63.43 (19.12)	76.88 (21.05)	112.02 (46.91)

Abbreviations: EPI, summarized Environmental Pressures Index; FTI, frequency treatment index; GHGe, greenhouse gas emissions; PHDI, planetary health dietary index; sPNNS-GS2, simplified *Programme National Nutrition-Santé* Guidelines-score 2. All P-values for linear contrast across quintiles are <0.05. Data are weighted for the Census. [a]Values are unadjusted weighted mean (SD) except otherwise is specified.

Table 2: **Environmental and dietary indicators across weighted quintiles of Environmental Pressures Index (NutriNet-Santé cohort, 2014, n = 34,077).**[a]

pressures related to dietary production and associated morbidity and mortality. While most previous studies focused on GHGe and LO, this research examined multiple environmental indicators and distinguished between organic and conventional production methods. A higher diet-related Environmental Pressures Index (EPI) was associated with increased risks of cancer, CVD, and T2D. Additionally, the marginal survival curves and marginal structural models, which simulate a randomised trial, assessed how changes in dietary EPI exposure impact health risks among similar individuals, reinforcing findings from the traditional approach.

The dietary profiles of participants with a lower EPI closely aligned with the recommendations of the EAT-Lancet Commission,[5] characterised by low meat intake (including poultry and red meat), moderate dairy intake and high consumption of fruits, vegetables and whole grains. However, processed meat consumption was relatively high, and pulses consumption was relatively low, likely influenced by Westernised eating patterns.

Studies quantifying the co-benefits of dietary changes for human and planetary health mainly rely on modelling approaches that estimate averted deaths associated with more sustainable diets through simulation or identify healthier and more sustainable diets using optimisation.[12,17,40–42] For instance, Springmann et al. conducted a modelling analysis on delayed deaths resulting from changes in food consumption and their subsequent environmental pressures.[40] Additionally, a review by Wilson et al. listed the optimisation studies used to identify healthy and sustainable diets and described those aimed at distinguishing them. However, all these studies help identify the best dietary profiles and their potential benefits, but do not assess observable effects in real-world settings.[12]

Furthermore, our findings are consistent with the scientific literature, which connects less environmentally impactful diets with improved health outcomes. Diets that follow the EAT-Lancet recommendations, i.e., within planetary boundaries, have been associated with a lower risk of diabetes, CVD, stroke, cancer, and death.[18,43–54] Caution is advised when interpreting our stroke findings, as limited statistical power due to a low number of cases affects this outcome. However, a study investigating the link between an adherence index for the EAT-Lancet diet and stroke observed similar results, indicating a trend towards increased stroke risk with greater adherence to the diet.[43]

In fact, limited research has measured co-benefits using individual-level data to comprehensively outline the underlying related diets.[14,55] A previous study with a large sample from the European EPIC cohort, followed for 14 years, revealed that diet-related GHGe and LO were positively associated with overall and cause-specific mortality, notably by cancer and CVD.[56] Another study in Spain reported higher risks of cancer, CHD and T2D among participants with higher diet-related GHGe but did not investigate stroke risk.[57] Our data generally align with these studies.

Our study presents an added value, by highlighting additional key factors not previously considered in the

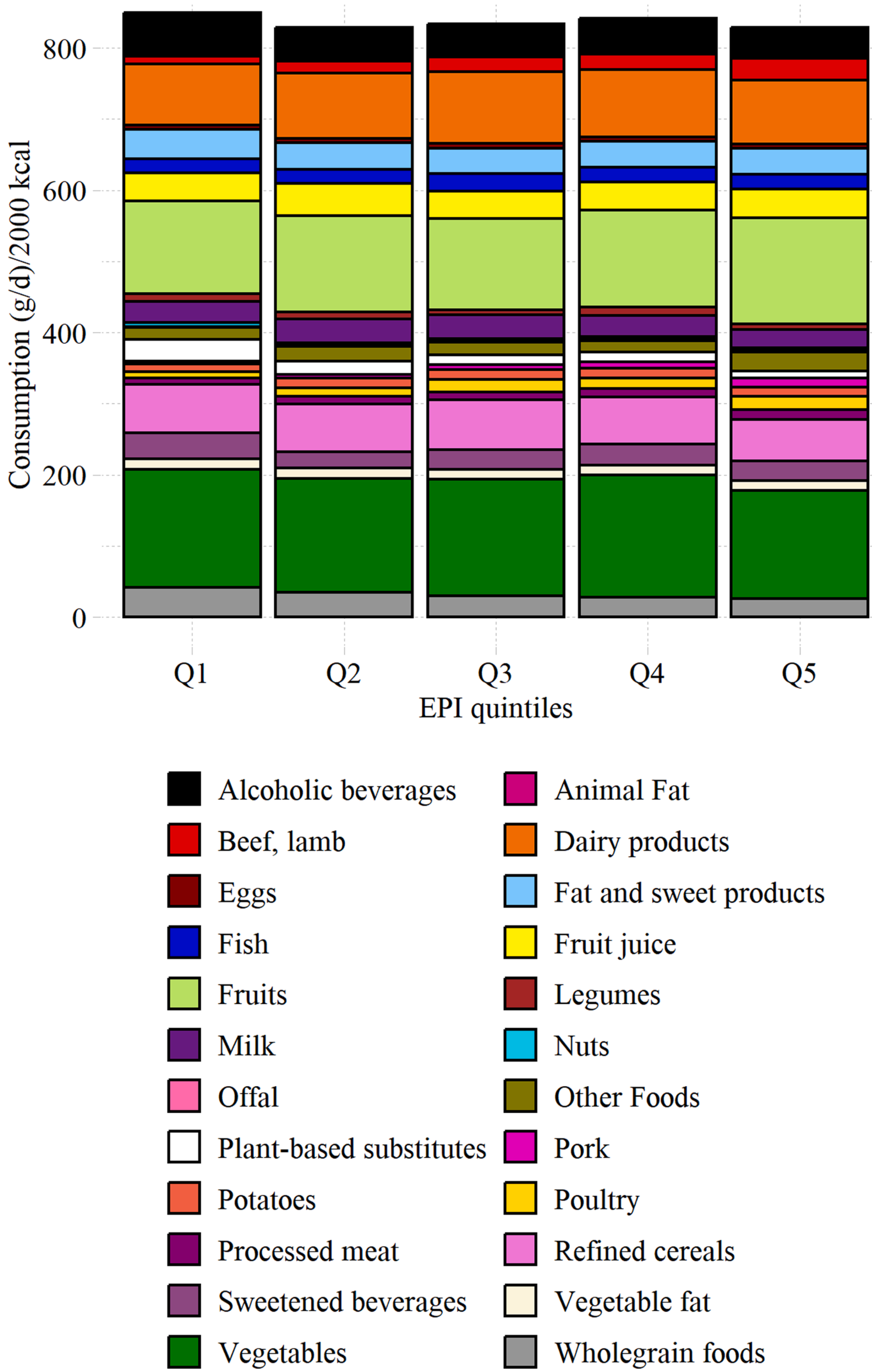

***Fig. 1:* Food consumption (g/d) per 2000 kcal across weighted quintile of summarized Environmental Pressures Index (NutriNet-Santé study FFQ, 2014, n = 34,077).** Values are per 2000 kcal/d weighted on the French National Census.

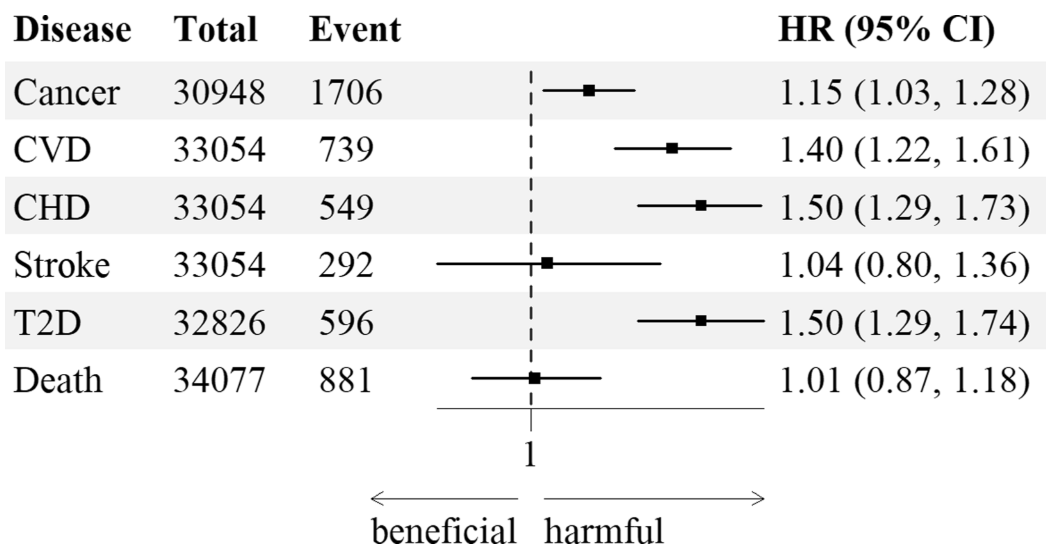

Fig. 2: **Prospective Association between the summarized Environmental Pressure Index and risk of chronic diseases and mortality (NutriNet-Santé study, 2014–2024)**. Abbreviations: CHD, Coronary heart disease; Cardiovascular diseases, CVD; EPI, Environmental pressures Index; T2D, type 2 diabetes. The stroke and coronary heart disease sub-analyses also included non-validated events, which explains why the sum is greater than the CVD total, which includes validated events only. Values are number (total and disease cases), HR (95% CI). HR (95% CI) are extracted from a multivariable Cox proportional hazards model weighted on national Census and adjusted for age (time-scale), sex (male/female), physical activity level (low, moderate, high), smoking status (status as smoker, former smoker and non-smoker, and number of pack-year), number of 24-h dietary records (continuous), educational attainment (<high-school degree, ≤3 years of higher education, >3 years of higher education), living status (cohabiting or not), occupational status (retired, unemployed, farmer/merchant/craftworker/company director, employee/manual worker, intermediate profession, managerial staff/intellectual profession, never employed), monthly income per unit consumption of the household (non-communicated, <1200 €, 1200–1800 €, 1800–3700 €, ≥3700 €), energy intake (continuous, in kcal/d), body mass index (BMI) (continuous, in kg./m^2), and family history of cancer, diabetes or cardiovascular diseases depending on the analysis. For the cancer analysis, height (continuous, in m) and, for women, number of children, hormone replacement and contraceptive use were included in the model.

literature. While agriculture uses about 70% of global water withdrawals and is a major driver of biodiversity loss and degradation,[8] biodiversity conservation and water resource use have received insufficient attention within the co-benefits approach for human and planetary health.

Here, we found that, unlike most other environmental footprints, water resource preservation conflicted with health, as diets higher in water demand were associated with a lower cancer risk. This is probably because water use mainly results from fruit consumption,[5,58,59] which is protective against cancer of the upper aerodigestive tract and allows high fibre intake associated with reduced risk of colorectal cancer.[60] This finding aligns with previous research showing that environmental co-benefits are not ubiquitous in relation to water use and sustainable diets.[14,61,62] Likewise, the preservation of biodiversity, measured by a proxy such as the ecological infrastructures (where higher values are preferable), is considered more crucial in meat-rich diets; however, connecting it to land use (as highlighted in our summary indicator) is essential.

Interestingly, our findings suggest that the frequency of pesticide treatment is positively linked with the risk of cancer, cardiovascular diseases (CVD), and T2D. To the best of our knowledge, this particular indicator, which mostly reflects the pressure on the environment from pesticide use and, at least partly, participants' exposure, has not been extensively studied. However, it can be somewhat interpreted in light of existing research that shows a connection between exposure to pesticide residues and the risk of non-communicable diseases.[63,64] It should be noted that the TFI measures a very different aspect from exposure to pesticide residues through food. For example, in our data, TFI values of animal products are high due to pesticides used in feed, yet pesticide residues in these products tend to be low.[65] Conversely, for plant-based foods rich in pesticide residues, the TFI indicates dietary exposure. While the associations between pesticide pollution or biodiversity loss and health outcomes have not been thoroughly explored, a recent review compiling scientific knowledge on soil and water pollution related to CVD risk concluded that deforestation, excessive fertiliser use, plastics, and pesticides, alongside their environmental release, lead to soil and water contamination pollution.[66] These factors significantly contribute to biodiversity loss, reduce ecosystem

	Continuous variable[b]	P-value	Sex-specific		Quintile			P-trend[c]
			Q1	Q2	Q3	Q4	Q5	
Cancer								
n cases (unweighted)	1706		282	301	379	411	333	
Person-year	226,017		41,939	44,040	42,964	44,192	44,547	
Model 1 (main)	1.15 (1.03–1.28)	0.01		0.71 (0.58–0.87)	1.46 (1.22–1.75)	0.97 (0.79–1.19)	1.21 (0.95–1.55)	0.02
Cardiovascular diseases								
n cases (unweighted)	739		115	136	156	180	152	
Person-year	244,734		43,708	45,442	45,313	46,507	46,666	
Model 1 (main)	1.40 (1.22–1.61)	<0.0001		1.29 (0.99–1.68)	1.38 (1.05–1.81)	1.67 (1.26–2.20)	1.94 (1.38–2.72)	0.0001
Coronary heart diseases								
n cases (unweighted)	549		86	103	106	133	121	
Person-year	244,734		43,708	45,442	45,313	46,507	46,666	
Model 1 (main)	1.50 (1.29–1.73)	<0.0001		1.25 (0.94–1.66)	0.94 (0.69–1.29)	1.55 (1.15–2.10)	2.19 (1.53–3.14)	0.0001
Stroke								
n cases (unweighted)	292		54	53	65	64	56	
Person-year	244,734		43,708	45,442	45,313	46,507	46,666	
Model 1 (main)	1.04 (0.80–1.36)	0.76		1.75 (1.08–2.82)	2.34 (1.45–3.77)	1.37 (0.80–2.34)	1.26 (0.65–2.41)	0.76
Type 2 diabetes								
n cases (unweighted)	596	71	90	125	141	169	596	
Person-year	244,248		42,709	46,162	44,326	46,054	46,554	
Model 1 (main)	1.50 (1.29–1.74)	<0.0001		0.37 (0.26–0.52)	0.95 (0.71–1.28)	1.13 (0.85–1.52)	1.41 (0.99–2.02)	0.0001
Death								
n cases (unweighted)	881	146	160	187	190	198	881	
Person-year	256,891		45,850	48,355	47,737	49,366	49,337	
Model 1 (main)	1.01 (0.87–1.18)	0.85		0.95 (0.74–1.21)	1.20 (0.94–1.54)	0.93 (0.71–1.21)	0.95 (0.68–1.33)	0.79

[a]The main model (M1) is a weighted multivariable Cox proportional hazard model adjusted for age (time-scale), sex (male/female), physical activity level (low, moderate, high), smoking status (status as current smoker, former smoker and non-smokers, and number of pack-year), energy intake (continuous, in kcal/d), number of 24-h dietary records (continuous), educational attainment (<high-school degree, ≤3 years of higher education, >3 years of higher education), living status (cohabiting or not), occupational status (retired, unemployed, farmer/merchant/craftworker/company director, employee/manual worker, intermediate profession, managerial staff/intellectual profession, never employed), monthly income per unit consumption of the household (non-communicated, <1200 €, 1200–1800 €, 1800–3700 €, ≥3700 €), body mass index (BMI) (continuous, in kg/m^2), and family history of cancer, diabetes or cardiovascular diseases depending on the analysis. For the cancer analysis, height (continuous, in m) and, for women, number of children, hormone replacement and contraceptive use were included in the model. HR (Hazard Ratio) and 95% CI (95% confidence interval) are derived from multivariable Cox proportional hazard, Q: Quintile. [b]By increment of 1SD. [c]P-value of Wald test for quintile as an ordinal variable.

Table 3: **Association between Environmental Pressures Index and risk of chronic diseases and death, main analyses (NutriNet-Santé cohort, France, 2014–2024 n = 34,077).[a]**

sustainability and food crop yields, and jeopardise human health.[67]

Public health serves as a crucial leverage point to promote the adoption of sustainable lifestyles, particularly by emphasising the links between dietary choices, environmental impact, and individual health.[68,69] In fact, framing the climate debate from the perspective of human health proves to be a strong motivator for personal engagement, especially in high-income countries[68] or among demographic segments that might remain passive when faced with climate-only arguments.[70] Furthermore, delivering messages from a health-focused perspective elicits more positive emotional responses and gains greater support than discussions that focus solely on environmental or climate threats.[71] A public health communication strategy that clearly emphasises the health benefits of sustainable lifestyles enhances both individual and collective motivation, thus supporting the shift towards more environmentally sustainable eating habits.[68] This approach generates momentum that encourages commitment and long-term behavioural change. Health professionals and policymakers can play a key role by leading targeted initiatives to facilitate this vital transformation.[70]

This study presents several limitations. First, the study sample consisted of volunteers with particular traits, notably a predominance of women and educated individuals and is not representative of the general population. Similarly, the dietary patterns within the NutriNet-Santé cohort are often healthier than those observed in representative French national surveys. While a diverse range of dietary profiles can be captured with this large sample, census data weighting was employed to address this concern. Second, the sample size was quite limited, which restricted the statistical power for examining cancer sites broadly, and the number of strokes was low compared to other health outcomes. Another limitation is that the environmental indicators were evaluated solely at the production level; however, it is known that most pressures occur during this phase.[8] Then, as with any observational study, residual confounding bias may still exist despite attempts to account for various confounding variables; therefore, caution is necessary when interpreting the results. More critically, the MSM assumes that this type of bias is absent, which is a key requirement considered. Also, caution must be exercised when interpreting the results, as the decisions taken when allocating indicator values (as mentioned in the Supplementary Material) can directly have a significant impact on the results, and residual confounding may have occurred. Finally, it is possible that risk alpha was inflated with multiple comparisons. However, our analyses were hypothesis-driven, and the number of analyses for each exposure-outcome pair was limited.

Furthermore, the large sample size, long follow-up period, and detailed characterisation of the sample enabled high-quality analyses. It is also noteworthy that using causal inference models, such as survival marginal models, produced robust results. Lastly, regarding environmental pressures, the matching of consumption data with environmental indicators considered whether foods were produced through conventional or organic farming methods, allowing for accurate estimates. In addition to common factors like GHGe and LO, we also explored associations with ecological infrastructure and pesticide use.

Conclusion

In our study, using a composite index of six environmental indicators that accounted for two farming methods, we found that diets with higher environmental pressures were linked to increased risks of cancer, cardiovascular diseases, and type 2 diabetes. These findings emphasise that while certain environmental necessities, such as water resources and biodiversity preservation, may conflict with reducing some health risks, the overall relationship between environmental footprint and morbidity supports a win–win scenario, i.e. strong alignment of benefits. The health benefit could be an additional lever to promote more environmentally friendly practices. Promoting a shift towards sustainable diets for human health could also help engage segments of the population that are less responsive to environmental concerns.

Contributors

EK-G designed the study, AC, SB, AR, and CC developed the database related to environmental indicators. EK-G, MT, and SH designed and conducted the NutriNet-Santé study; EK-G conducted the statistical analyses and wrote the manuscript. All authors provided critical comments on the manuscript. EK-G, JBau, JBer, MT, AC, SB, AR, and CC have an access to the raw data and verified the data. EK-G takes the responsibility for integrity of the data and the accuracy of the data analysis, she is the guarantor. She had primary responsibility for the final content, and all authors read and approved the final manuscript.

Data sharing statement

Researchers from public institutions can submit a request to have access to the data for strict reproducibility analysis (systematically accepted) or for a new collaboration, including information on the institution and a brief description of the project to collaboration@etude-nutrinet-sante.fr. All requests will be reviewed by the steering committee of the NutriNet-Santé study. If the collaboration is accepted, a data access agreement will be necessary and appropriate authorisations from the competent administrative authorities may be needed. In accordance with existing regulations, no personal data will be accessible. R/SAS code is available without restrictions upon request at collaboration@etude-nutrinet-sante.fr.

Declaration of interests

No conflict of interest is declared for any of the authors.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lanepe.2025.101481.

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Supplemental Material
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Supplemental Method 1: Dietary indexes computation

sPNNS-GS2

In March 2017, as part as the development of the fourth *Programme National Nutrition Santé* (PNNS, 2017-2021), the *Haut Conseil de Santé Publique* (HCSP) published a report updating the 2001 PNNS recommendations [1] based on scientific literature about the relationships between diet and long-term health and a model created by the *Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail* (Anses). [2] These new recommendations provide dietary guidelines, with 6 food groups to favor ("fruits and vegetables", "nuts", "legumes", "wholegrain", "milk and dairy products", and "fish and seafood") and 6 items to moderate ("meat", "processed meat", "added fats", "sugary products", "beverages", and "salt"). The nutrition experts who were involved in developing the guidelines defined the thresholds and corresponding scores. These thresholds and related scores are defined so as that following the guidelines is associated with one point, whereas not following them is scored zero points. To increase the power of discrimination, half-points are allocated in a linear fashion above the guideline thresholds. However, an exception was made for milk and dairy products, and fish. As, the relationship between these foods and health is non-linear, allocated points form a parabolic relationship. [3]

The sPNNS-GS2 emphasizes on the distinction between bonus components (healthy foods considered beneficial, which have a positive adequacy score, e.g. legumes) and malus components (unhealthy food thought to be avoided, which have a negative moderation score, e.g. salt).

The Planetary Health Diet Score

The Planetary Health Diet Score[4] (PDHI) evaluates compliance with a dietary framework established by the EAT-Lancet Commission.[5] It comprises 15 components, with each rated on a scale of 0 to 10 points. Notably, legumes and soy-based products contribute with a weight of 0·5, bringing the maximum score to 140. Scores are assigned on a scale from 0 to 10, depending on whether the consumption aligns with the established ranges; if it does not, the score defaults to either 0 or 10, depending on the component scoring with the consumption (ascending or descending).

	Target of EAT-Lancet diet reference[1]		**Criteria for scoring (g/d)**		
Component	g/d (for 2500 kcal/d)	% total energy intake	**0 (min)**	**10 (max)**	**Weight in the PDHI**
Whole grain	232 (0%–60%[2])	811	0	≥75 or ≥90 g/d[3]	1
Tubers	50 (0–100)	39	≥200	≤50	1
Vegetable	300 (200–600)	78	0	≥300	1
Whole fruit	200 (100–300)	126	0	≥200	1
Dairy foods	250 (0–500)	153	≥1000	≤250	1
Red/processed meat[4]	14 (0–28)	30	≥100	≤14	1
Chicken and other poultry	29 (0–58)	62	≥100	≤29	1
Eggs	13 (0–25)	19	≥120	≤13	1
Fish and shellfish	28 (0–100)	40	0	≥28	1
Nuts	50 (0–75)	291	0	≥50	1
Non-soy legumes	50 (0–100)	172	0	≥100	0·5
Soybean/soy foods	25 (0–50)	112	0	≥50	0·5
Unsaturated added fat	40 (20–80)	354 (14·2%)	≤3·5%[2]	≥21%[2]	1
Saturated added fat	11·8 (0–11·8)	96 (3·8%)	≥10%[2]	0%[2]	1
Added sugar	31 (0–31)	120 (4·8%)	≥25%[2]	≤5%[2]	1

Abbreviations: TEI, total energy intake

[1] As defined by the Lancet Commissions [5]

[2] of total energy intake

[3] ≥75 g/d for female, ≥90 g/d for males

[4] Including beef, lamb, pork

Supplemental Method 2: Environmental impact indicators by agricultural product relating to pesticides, water and ecological infrastructures

Methodological choices and assumptions:
The newly developed environmental indicators have been calculated for 84 agricultural products, including 73 plant products and 11 animal products. Indicators for fishery and aquaculture products have not been calculated.

Two farming systems were considered: "conventional" (i.e., non-organic) and "organic" agricultural methods as defined in European Commission (EU) 2018/848. [6]
For products produced in France, French references are used, while foreign references are used for imported products. The term "organic agriculture" refers to production methods that meet the standards set out in the European Union's regulations. [6] All other production methods that do not meet these standards are classified as "conventional".
We ensured that the sources correspond to the geographical areas where the food consumed in France was produced. The FAO trade matrices [7] are used to identify the main countries producing and exporting to the European Union and France. The supply balances were compiled using the MOSUT [8] tool designed by SOLAGRO, based on data from the supply balances [9] between 2017 and 2020. These assessments were then used to categorize products into two groups: those that are "mainly imported" (imports/resources > 50%) and those that are "mainly produced" in France (imports/resources < 50%). In total, references for 12 products produced outside France were sought: Coffee, Cocoa, Tea, Orange, Grapefruit, Lemon, Rice, Olive, Walnut, Green Bean, Soy, and Tomato.
For each product defined as "mainly imported", the main producing countries were identified based on production and trade data available in FAOSTAT. [10] In the case where data on production yields, pesticide use, and water consumption (mostly irrigation) were available for only one of the main producing countries, that data were used for calculation. For example, soy flour used in animal feed is mainly imported from Brazil in conventional farming and from Togo, India, or Ukraine in organic farming. [7] For certain products such as rice, walnuts, and green beans, no references were available for the main producing and exporting countries to France, so French references were used by default.

In 2021, organic farming, accounting for 10·5% of French agricultural land, was included in the statistical data without distinction between conventional and organic methods. Therefore, the average production from the annual statistics was assumed to represent conventional production. Thus, the average yield in "conventional" agriculture was calculated by dividing the total quantity produced by the total cultivated area. Average organic yields were calculated using yield loss coefficients from Dialecte, [11] Agribalyse or scientific publications. For imported products and buckwheat, the FAO average yield was used as yield for conventional farming.
To quantify the environmental indicators for animal products, the land used to produce their feed was considered. The Agribalyse ® database 3·1 [12] provides information on animal food products consumed in France. It uses livestock feed data and regional yields to calculate indicators for products like milk, eggs, and meat. A biophysical allocation method was applied to allocate resources to co-products. [13] Although organic systems for turkey, duck, rabbit, goat's milk, and sheep's milk were not considered in this study, case studies have been adapted for these types of farms.

Computation of the indicators:

Pesticide footprint
The plant health treatment frequency index (TFI) is a standardized indicator that measures the frequency of pesticide use for a given crop. The TFI, derived from farmers' reported practices, was adapted from the Danish indicator. [14] It is defined as the number of reference doses applied per spatial unit over a specified period. In most cases, the spatial unit is the plot, with the period being the crop year. This indicator can then be aggregated at different spatial and temporal scales. Furthermore, the index can be segmented by family or type of plant protection product, by type of treatment, or by type of crop. It can also be broken down into different segments, according to the type of product used: herbicide, insecticide, fungicide, seed treatment, biological control, or other. By aggregating substances with different modes of action, the TFI provides a comprehensive measure of overall pesticide use.

For further details on the French standardized calculation of the TFI, see to the Ministry of Agriculture and Food's methodological guide. [15] In this study, we assessed three TFI: total TFI (excluding biological control products), herbicide TFI and non-herbicide TFI (excluding biological control products).
Biological control products were excluded from the analysis, as our primary focus is on the environmental impact of synthetic pesticides, which generally pose a greater environmental risk compared to biological alternatives. [16,17]
The pesticide footprint quantifies the land area treated with pesticides to produce 1 kg of a given commodity. The calculation method differs for plant and animal products:

- For crops, the footprint is obtained by multiplying the average Total TFI by the inverse of the crop yield.
- For animal products, we first determined the average area of land required to produce 1 kg of product per crop type. This area was then multiplied by the corresponding TFI and multiplied by the inverse of their yield.

The result is expressed as pesticide-impacted area equivalents, referred to as pesticide use. The area impacted by pesticide use is referred to as the pesticide footprint. This includes the herbicide footprint use and the non-herbicide use.

The data used for the computation of pesticides footprint are summarized below (Table 1).

Table 1 Data sources for the computation of the pesticide's footprint

	Data sources
TFI herbicides, excluding herbicides et total (excluding biological control), conventional	- French surveys on plant protection practices (2017 for field crops, 2018 for fruit growing and vegetables, 2019 for vine growing) -Technical documents and scientific literature -Agribalyse ® -Surveys on the use of plant protection products in Spain
TFI herbicides, excluding herbicides et total (excluding biological control) organic	- French surveys on phytosanitary practices (for fruit growing, 2019 for vine growing) -Technical documents from the DEPHY networks
Average conventional yield	-Average yield between 2017 and 2021 from annual agricultural statistics (assimilated to average conventional yield)

Water use

The Water indicator groups two indicators to characterize agricultural production:

- **Water requirements for crop production** (irrigation);
- **Water requirements for livestock production** (watering, and cleaning of facilities).

Several methods have been developed to assess water footprint in recent years: [18–20]

- Pfister et al.[21]("Withdrawal to Availability" method). It considers both **water consumed (EC)** and **water returned (ER)** to the environment, treating returned water as part of the overall water footprint.
- Hoekstra et al. ("Consumption to Availability" methods). [20,22] This method excludes water withdrawals and returns from the calculation, focusing only on water consumption. means that the quantities of water withdrawn and returned to the system (ER) are excluded from the calculation.
- AWaRe method [23] (Available Water Remaining). This method developed as part of the latest generation of water footprint assessments, calculates water consumed (EC) relative to the water available in the region studied.

Our objective was to quantify the total water withdrawn for food production, rather than just the water consumed by plants. Although some of the withdrawn water returns to the system, water withdrawal represents the volume of water temporarily unavailable for other uses, creating potential competition with other sectors. Therefore, irrigation water used was estimated using the "withdrawal to availability" calculation method developed by Pfister et.al. [18]

Irrigation water use is significant: in France, representing nearly 3 billion m^3 per year, including 1 billion m^3 for maize irrigation and 306 million m^3 for soft wheat irrigation. [24] The irrigation water indicator highlights the pressure on a product's water resources as a function of its production method (organic and conventional) and practice (m^3/ha).

The indicator is calculated using the total amount of irrigation water used in mainland France for the crop under study, divided by its total production.

$$\text{water for irrigation}\left(\frac{\text{m}^3}{\text{kg}}\,\text{of product}\right) = \frac{\text{total quantity of water withdrawn}}{\text{total production per crop}}$$

Total quantity of water used for irrigation is determined by multiplying the irrigated area of the crop in question by the quantity of irrigation applied per hectare:

$$\text{total quantity of water withdrawn}_{region} = \text{irrigated area}_{region} \times \text{quantity of irrigation per ha}_{\,region}$$

The irrigated area data are sourced from the Agricultural Census (AC) available on the Agreste website. [25] The most recent available data (2020) were used, as they best reflect current irrigation practices and average climatic conditions. The data were analyzed by region and by crop.

Due to lack of data, to calculate irrigation water usage, it was assumed that the percentage of irrigated area and the amount of water per hectare is the same for both organic and conventional farming. This assumption was necessary because comparative data on organic vs. conventional irrigation practices are scarce. Moreover, irrigation water management depends on various factors as: irrigation technologies (sprinklers, drippers, etc.), soil textures (sandy, loamy, etc.), organic matter percentage, soil preparation, etc. [26] While irrigation needs may differ between organic and conventional systems, the available data did not allow for a precise differentiation. The only factor we were able to account for was climate, using regional irrigation data. [27] The water use per kg of product is influenced by both yield variation and geographical distribution of production. For example:

- 39% of conventional and 34% of organic maize is cultivated in "Nouvelle Aquitaine" region where the water amount is 199 mm/ha whereas,

- 10% of conventional and 21% of organic maize is cultivated in “Pays de la Loire” region where the water amount is 111 mm/ha.

Although total water use per ha for maize in France is greater for conventional than organic, the yield difference (-30% lower for organic maize) results in higher water use per kg of organic maize.
To estimate the organic irrigated areas, the total irrigated area per region has been multiplied by the proportion of organic farmland in that region.
Irrigation water data (mm/ha) are not systematically available for all crop types in all region. Then data were available from cropping surveys, [27] They were used directly. For the missing data, additional sources were used and validated by experts.

Water indicator for livestock farming (excluding irrigation) was calculated using data from Agribalyse 3.1®, which provides estimates of water used for watering and facility cleaning per liter of milk or kg of meat. The calculation follows the ReCiPe 2016 Midpoint (H) method: Water consumption - market for tap water. [28]

Ecological infrastructure (EI)

EI refers to landscape features that support biodiversity and ecosystem services. These features can be classified into several types:
- Linear or surface tree formations (hedges, copses, trees, agroforestry, etc.),
- Grassed areas (extensive grassland, areas under environmental cover, etc.),
- Cultivated areas (environmental set-aside, extensive arable strips, etc.),
- Ruderal areas (low walls, terraces, grassed paths),
- Wetlands (ponds, springs, wet ditches).

To develop the EI indicator, we standardized all features using a common characteristic variable that could be linked to food or fodder production areas. To ensure robustness and comprehensive coverage, the following features were included:
- Surface area of hedges and linear tree elements
- Surface area of grassed strips (buffer strips along watercourses)
- Surface area of forest edges resulting from an intersection between the BD Forêt® and the GPR (Graphic parcel register)
- Surface area of copses
- Surface area of wet meadows (share of wetlands in permanent pasture by livestock production area)
- Surface of grazed woodland (share of grazed woodland in permanent pasture by livestock production area)
- Surface of fallow land (> 5 years old) (code J6S in GPR 2021)
- Surface of dry-stone walls
- Surface of ponds

Each of these EI was identified using spatial data and quantified in terms of surface area, either by characterizing the surface area directly (wet grasslands, for example) or by multiplying it by an effect coefficient applied to the linear length of the EI.

Priority was given to applying coefficients derived from the CAP11 Ecological Interest Areas. [29]
Grassed strips and fallow lands were assigned to crops in proportion to the length of intersection with the adjacent plots.
Wet meadows and grazed woodland were only assigned to livestock production.
We did not assign any ecological infrastructure to the imported products.

Table 2 Ecological infrastructures data source and unit

Type	unit	Data source	Used coefficient
Hedges	Linear meter	Intersection between the plots of the 2021 GPR (Graphic Parcel Register) and the "hedges" layer of the BD TOPO (IGN).	1 m = 20 m²
Grass strips	Square meter	Plots of the 2021 GPR coded BTA	Real surface area
Woodland edge (excluding poplar groves)	Linear meter	Intersection between the plots of the 2021 GPR and the linearized BD FORET (IGN) layer	1 m = 8 m²
Wet meadows	Square meter	Intersection between the plots of permanent pastures coded PPH, SPH, SPL, BOP, CAE, CEE in the 2021 GPR and the inventory of effective wetlands from the SIG Wetlands Network: https://sig.reseau-zones-humides.org/	Actual surface area m^2 inventoried as "wet" per m^2 of permanent pastureland
Fallow land over 5 years old	Square meter	Plots of the 2021 GPR coded J6S	Actual area m² fallow per m² adjacent crop
Grazed woods	Square meter	Plots of the 2021 GPR coded BOP	Actual surface area m² of woodland grazed per m² of permanent pasture
Groves	Square meter	Intersection between the plots of the 2021 GPR and the "Zone de vegetation" layer of the BD TOPO (IGN), where the "nature" field is equal to "Bois"	1 m^2 = 1,5 m²
Dry-stone walls	Linear meter	Intersection between the plots of the 2021 GPR and the "Construction linéaire" layer of the BD TOPO (IGN), where the "nature_detaillee" field is equal to "Mur de pierres sèches"	1 linear meter = 1 m²
Seas	Square meter	Intersection between the plots of the 2021 GPR and the "Plan d'eau" layer of the BD TOPO (IGN), where the "nature" field is equal to "Mare"	1 m^2 = 1·5 m²

Abbreviations: GPR, graphic parcel register ; BD TOPO IGN, Institut national de l'information géographique et forestière topographic database

Comparison with national figures

To validate the results obtained, the calculated indicators per kilo of raw product were multiplied by the quantities produced in mainland France or by the quantities imported (for soy) and compared to national data.
▶In 2024, the total pesticide footprint of the plant products considered in conventional agriculture is estimated at 57.7 million hectares in France. [30] As part of the ADONIS project, Solagro used the same calculation method (based on TFI) to assess the pesticide use frequency at the municipal level. The sum of the ADONIS TFIs for mainland France is 60.1 million hectares. The difference can be explained by the fact that the considered products do not cover all treated crops (e.g., seed production is excluded). Additionally, the 57·7 million hectares estimate does not include organic farming, or feed production for livestock. Despite these limitations, the results align closely with national estimates, validating the order of magnitude of the calculated pesticide indicators.

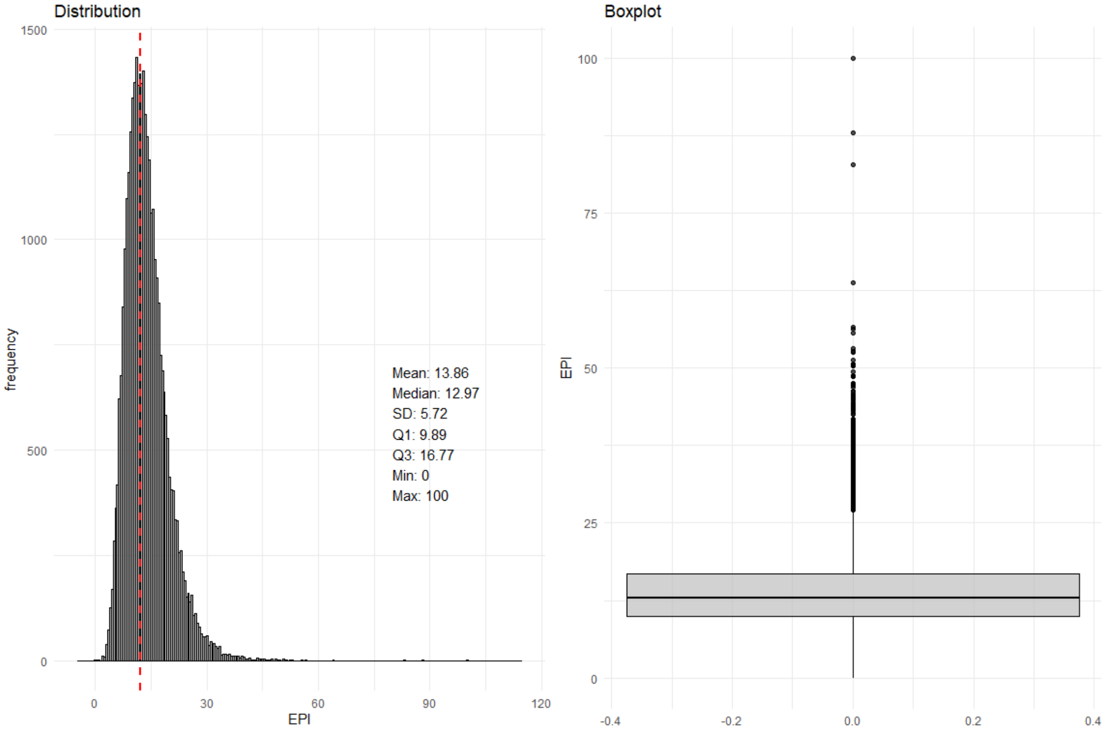
▶The total annual irrigation water use for the considered products is 2.7 billion m^3.
According to the "Banque nationale des prélèvements quantitatifs en eau", [24] the volume of water withdrawn for irrigation in France was 3.1 billion m^3/year between 2017 and 2020. Since the considered products account for 85% of irrigated land, this confirms the validity of calculated irrigation water indicator. Using the "Water consumption" indicator from the Agribalyse ReCiPe 2016 Midpoint (H) method, water use for livestock watering and cleaning buildings is estimated at 234 million m^3.
There are few recent references on overall water use. A 2001 study by the French Institute for the Environment estimated water consumption at ~400 million m³. [31]
However, since 2001, the number of cattle and pigs has fallen. IDELE (Institut de l'élevage, French livestock institute) now estimates that "*the water footprint of dairy and meat products is of the order of 1 to 3 liters of water per liter of milk and 30 to 50 liters of water per kilo of live meat (at the farm gate)*", which confirms the order of magnitude used in in

this project, but with a higher footprint for milk (6L for 1L of milk) and a lower footprint for meat (27L for 1kg of meat). [32] These estimates require further consolidation.
According to these figures, nearly 60% of the watering and washing water footprint is accounted for by dairy cattle, 15% by beef cattle and 11% by pigs.

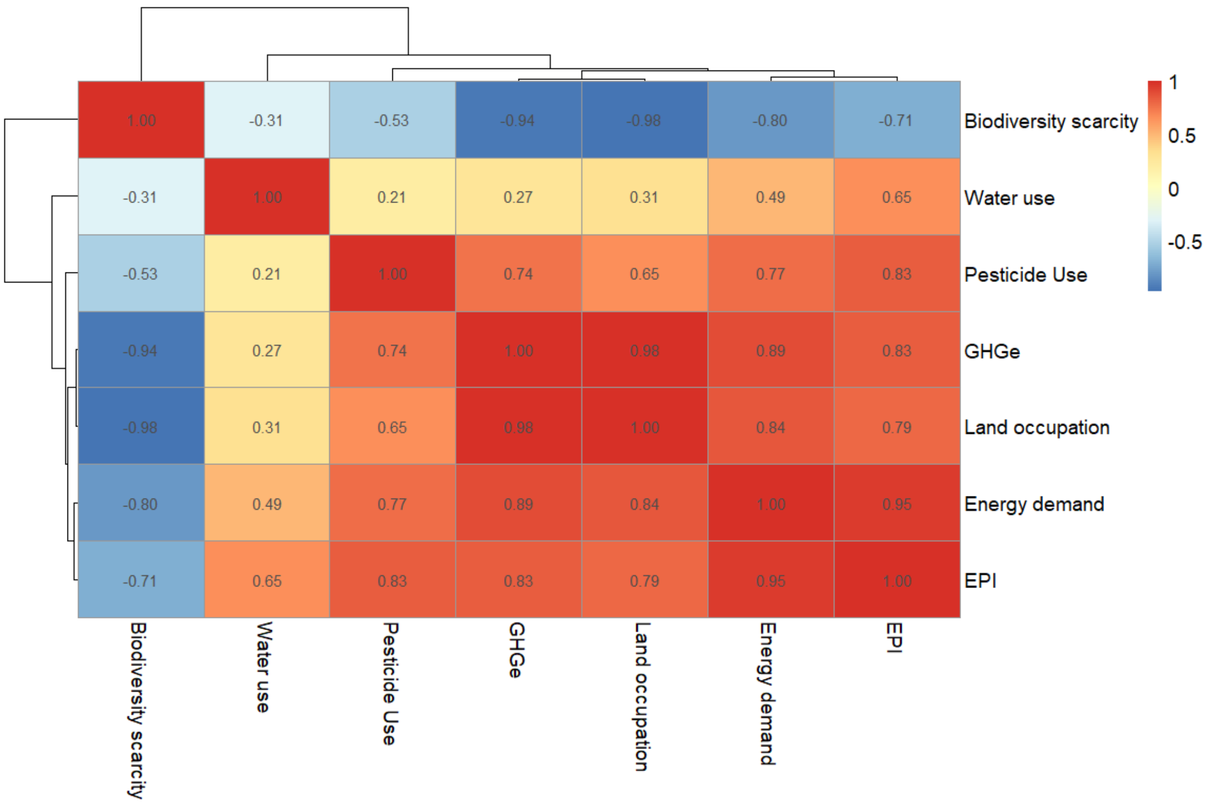
▶To validate the EI, we applied the coefficients calculated for each EI to national agricultural production in mainland France. The expected results should correspond to the length or surface area of the EI in France (excluding areas that are not considered int the perimeter, such as seed production, sorghum, etc.).
The obtained values are higher than those of the source data, which come from the intersection between the plots in the GPR and the EI layer. This discrepancy arises because the GPR covers only 80-85% of cultivated areas in France. Therefore, EI coverage is likely higher than those intersected by the GPR. Wet grassland extrapolated from animal products covers 302,638 ha, compared to an identified total of 328,574 ha, representing 92% agreement.
Grazed woodland extrapolated from animal products covers 229,537 ha, compared to an identified total of 290,048 ha, representing 79% agreement.

Supplemental Method 3: Description of the Environmental Pressures Index

A synthetic Indicator of Environmental Pressures (EPI) was calculated by normalizing each indicator to a scale of 0 to 1. For agroecological infrastructures, a high value is considered positive; therefore, the result was subtracted from one. These standardized values were then summed and rescaled to stay within the same range of 0 to 1. The final sum was then multiplied by 100 to produce an EPI that ranges from 0 to 100. A higher EPI indicates a greater environmental impact. The distribution of the EPI is showed below:



The correlation between EPI and individual environmental indicators are shown below:



Abbreviations: EI ecological infrastructures; EPI, environmental pressures index; GHG, greenhouse gas emissions. Biodiversity scarcity is (100 - Ecological infrastructures) to facilitate reading and ensure that all indicators point in the same direction

Supplemental Method 4: Case ascertainment.

Participants were asked to declare major health events through the yearly health questionnaire, a specific health check-up questionnaire every six months, or at any time through a specific interface on the study website. They were also asked to declare all currently taken medications and treatments via the check-up and yearly questionnaires. A search engine with an embedded exhaustive Vidal® drug database facilitates medication data entry for the participants. Besides, our research team was the first in France to obtain authorization by Decree in the Council of State (n°2013-175) to link data from our general population-based cohorts to medico-administrative databases of the National Health Insurance. Thus, data from the NutriNet-Santé cohort were linked yearly to these medico-administrative databases, providing detailed information about medication reimbursement and medical consultations.

CVD and cancer cases were classified according to the International Chronic Diseases Classification, 10th Revision, Clinical Modification.

Specifically, all cancers except basal cell carcinoma were included, and the CVD included acute coronary syndrome, angina pectoris, myocardial infarction, stroke, and transient ischemic attack including only validated events. For stroke and coronary heart disease sub-analyses, non-validated events were also included explaining why the sum is greater than the CVD total, which includes validated events only.

Cases of T2D were identified using a multi-source approach, in which participants were asked to self-report their T2D status during follow-up, and to report whether they were taking any T2D medication (or reimbursement of T2D medication detected from SNIIRAM) or had hyperglycemia in the biological data along with one T2D medication use. All T2D cases were primarily detected through the participants' declaration of a T2D diagnosis by a physician and/or diabetes medication use in follow-up questionnaires. The questions were: "Have you been diagnosed with T2D (if yes, indicate the date of diagnosis)" and "Are you treated for T2D ?". ATC codes considered for T2 diabetes medication were A10AB01, A10AB03, A10AB04, A10AB05, A10AB06, A10AC01, A10AC03, A10AC04, A10AD01, A10AD03, A10AD04, A10AD05, A10AE01, A10AE02, A10AE03, A10AE04, A10AE05, A10AE30, A10BA02, A10BB01, A10BB03, A10BB04, A10BB06, A10BB07, A10BB09, A10BB12, A10BD02, A10BD03, A10BD05, A10BD07, A10BD08, A10BD10, A10BD15, A10BD16, A10BF01, A10BF02, A10BG02, A10BG03, A10BH01, A10BH02, A10BH03, A10BX02, A10BX04, A10BX07, A10BX09, A10BX10, A10BX11, A10BX12.

In addition to the abovementioned questions about the diagnosis of T2 diabetes and/or a medication report, two additional sources of confirmation were considered. Initially, the connection with medico-administrative databases validated over 80% of the surveyed cases (ICD-10 codes E11). Furthermore, in the group providing blood samples during the clinical/biological examination, 85·3% of those exhibiting elevated fasting blood glucose levels (≥1·26 g/L) had reliably reported a diagnosis of T2 diabetes and/or were receiving medication. However, elevated blood glucose levels without any confirmation of a T2 diabetes diagnosis or treatment were deemed insufficiently specific to classify the participant as having T2 diabetes case.

Supplemental Method 5: Description of the sensitivity analyses

Several sensitivity analyses for testing robustness were conducted. 1) A model (M2) similar to M1 (main model) but without adjustment for energy intake was used. 2) We used the principal model (model M1) after removing early cases occurring during the first two years of follow-up to limit potential reverse causality. 3) The data were re-analyzed after capping weight > 95^{th} percentile to this value. [33] 4) We also conducted marginal structural modelling (MSM) to build counterfactual models. Detailed methodology is provided below. Causal inference techniques are designed to predict the effect of a potential intervention using randomized experiments or observational data. Marginal structural models are a form of causal inference technique involving a multi-stage estimation procedure designed to control for the effect of confounding variables, particularly when the exposure distribution is unbalanced. [34,35] Observations are weighted by individual weights to create a pseudo-population in which exposure is no longer associated with confounding variables, thus replicating a randomized study used to estimate a causal effect.

Such models considered two weights based on inverse probability weighting implying the probability of exposure and the probability of censoring. Two weights based on inverse probability weighting implying the probability of exposure and the probability of censoring are combined as follows:

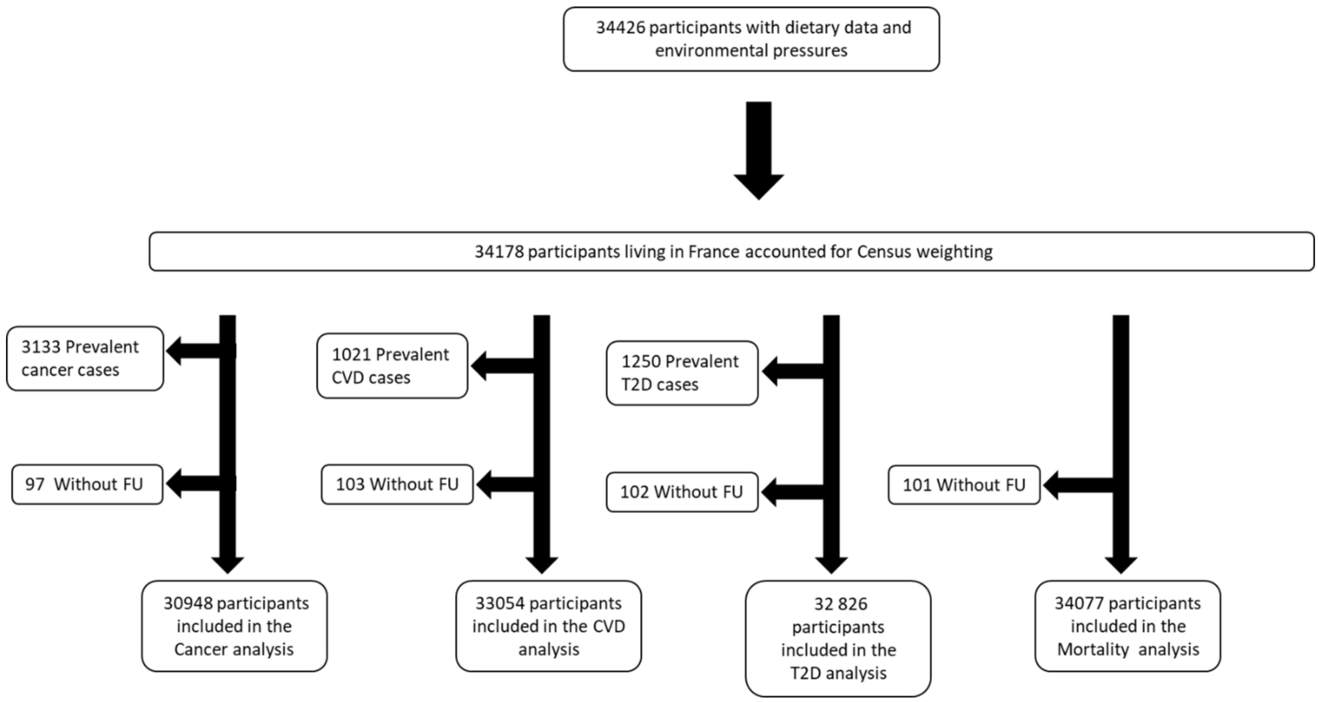
$$SW^{E,C} = SW^{E} \times SW^{C} = \frac{f(E_0)}{f(E_0|A_0)} \times \frac{Pr[C = 0|E_0]}{Pr[C = 0|E_0, A_0]}$$

The combined weights $SW^{E,C}$ are calculated by multiplying the stabilized inverse probability of exposure weight (SW^{E}) and the stabilized inverse probability of censoring weight (SW^{C}). These probabilities were obtained through linear and logistic regressions, with f(x) denoting a probability density function assuming Gaussian distribution. [36] The variables E, A and C were defined as follows: E represents exposure, A is a vector of covariates, and C is the indicator variable for censoring during the follow-up. Both the numerators were used for stabilization process and were derived from distinct models. The probability of exposure was estimated using the covariates of the model M1.

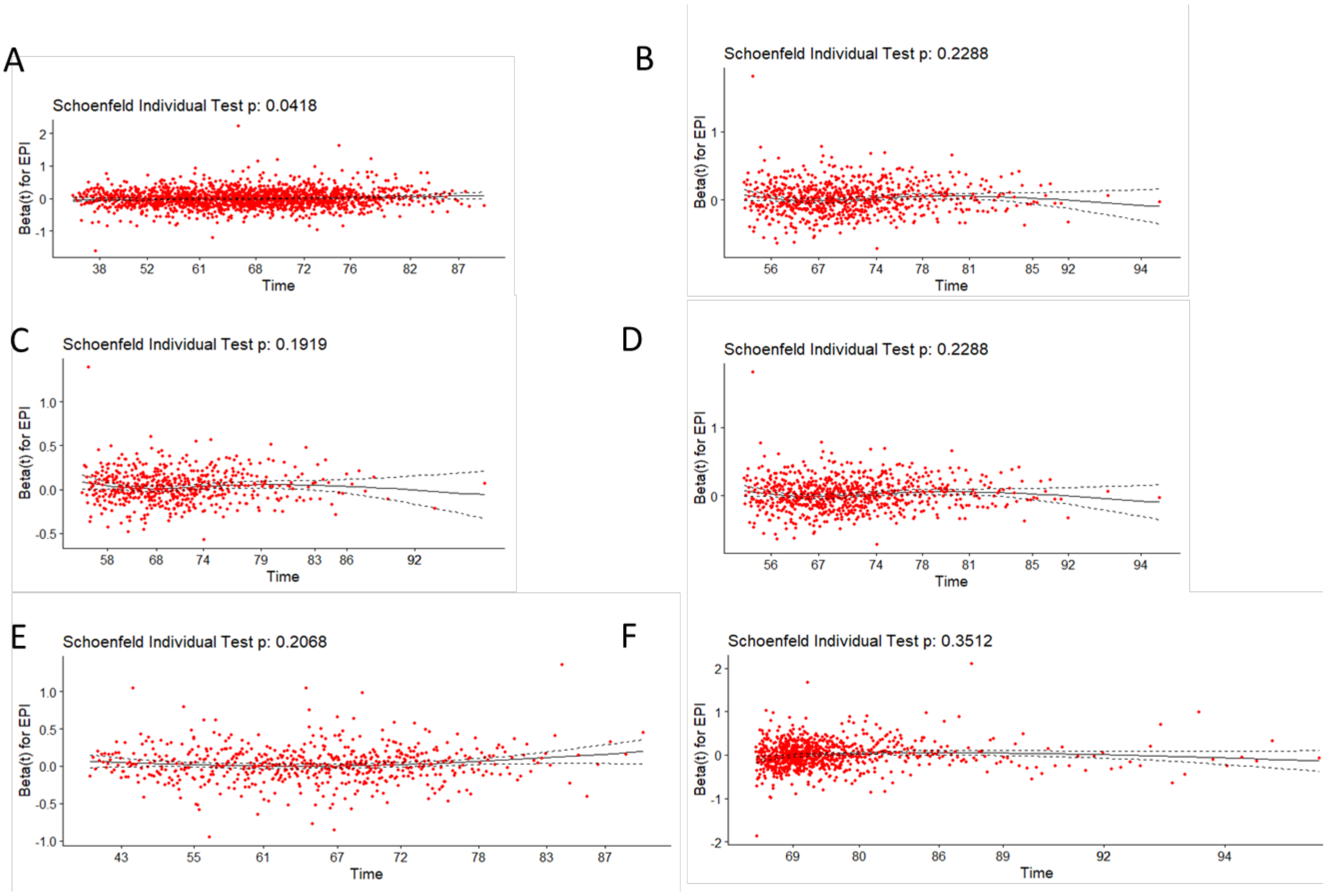
Untruncated weight may lead to doubtful findings. Thus, participants with a weight >10 were excluded.[33]

If we assume that there were no measurement errors during the study, no unmeasured confounders and that the models used for estimating weights are correctly specified, then the application of the combined weights to the study participants will result in the generation of a pseudo-population. This population ensures that the distribution of diet-related environmental pressures is free from any confounding factors.

Marginal Structural Model allows to provide adjusted survival curves to account for residual confounding and censoring. [34,35] Weight for census data and weight for MSM were then combined.



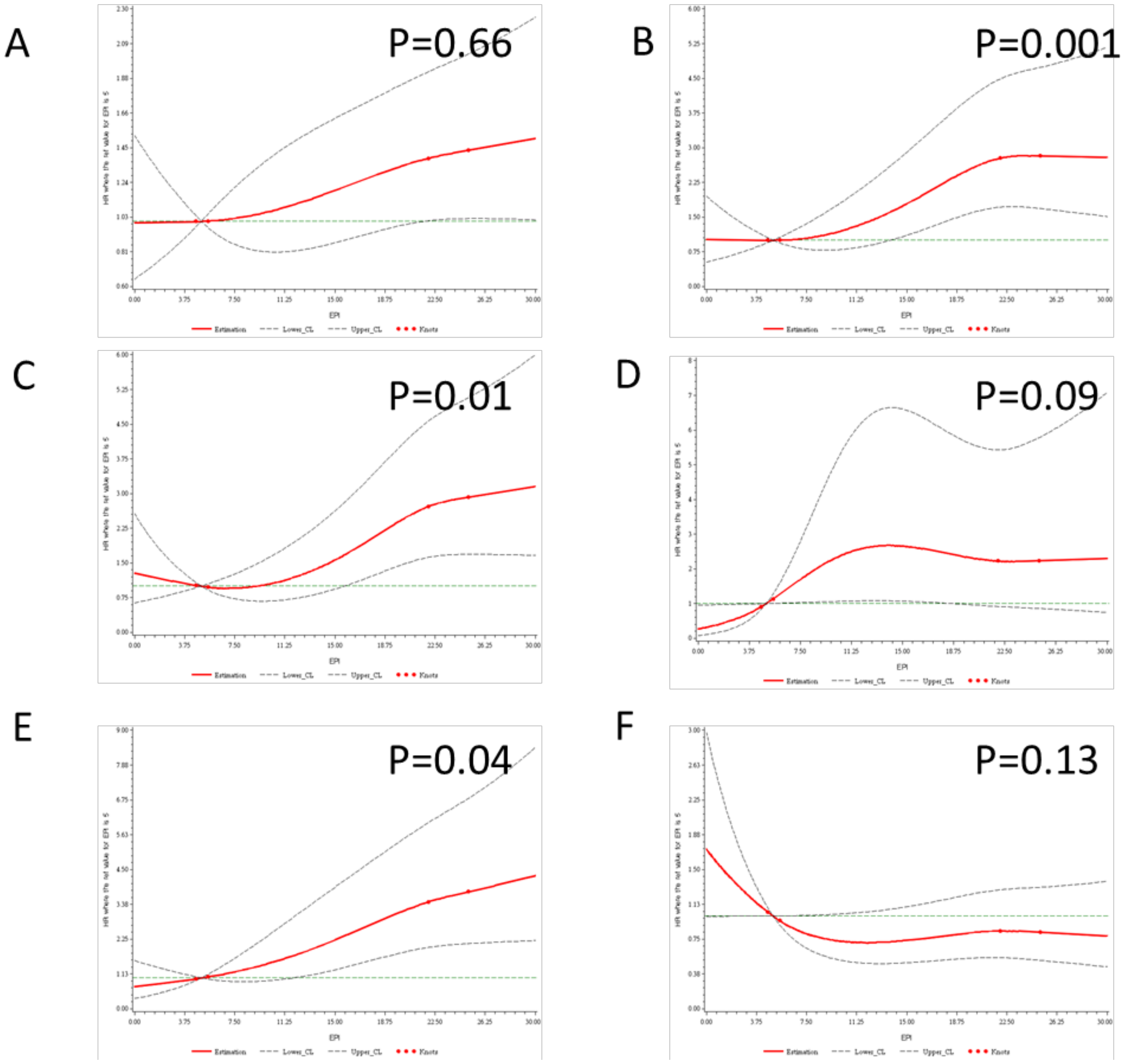
Supplemental Figure 1: Flowchart, NutriNet-Santé cohort, France, 2014-2024
FU: Follow-up; CVD: cardiovascular diseases; T2D: Type 2 diabetes



Supplemental Figure 2: Correlations between Schoenfeld residuals and timescale (age, y) from multivariable Cox models between EPI and risk of chronic diseases and mortality, NutriNet-Santé study, 2014-2024, (n = 34,077).

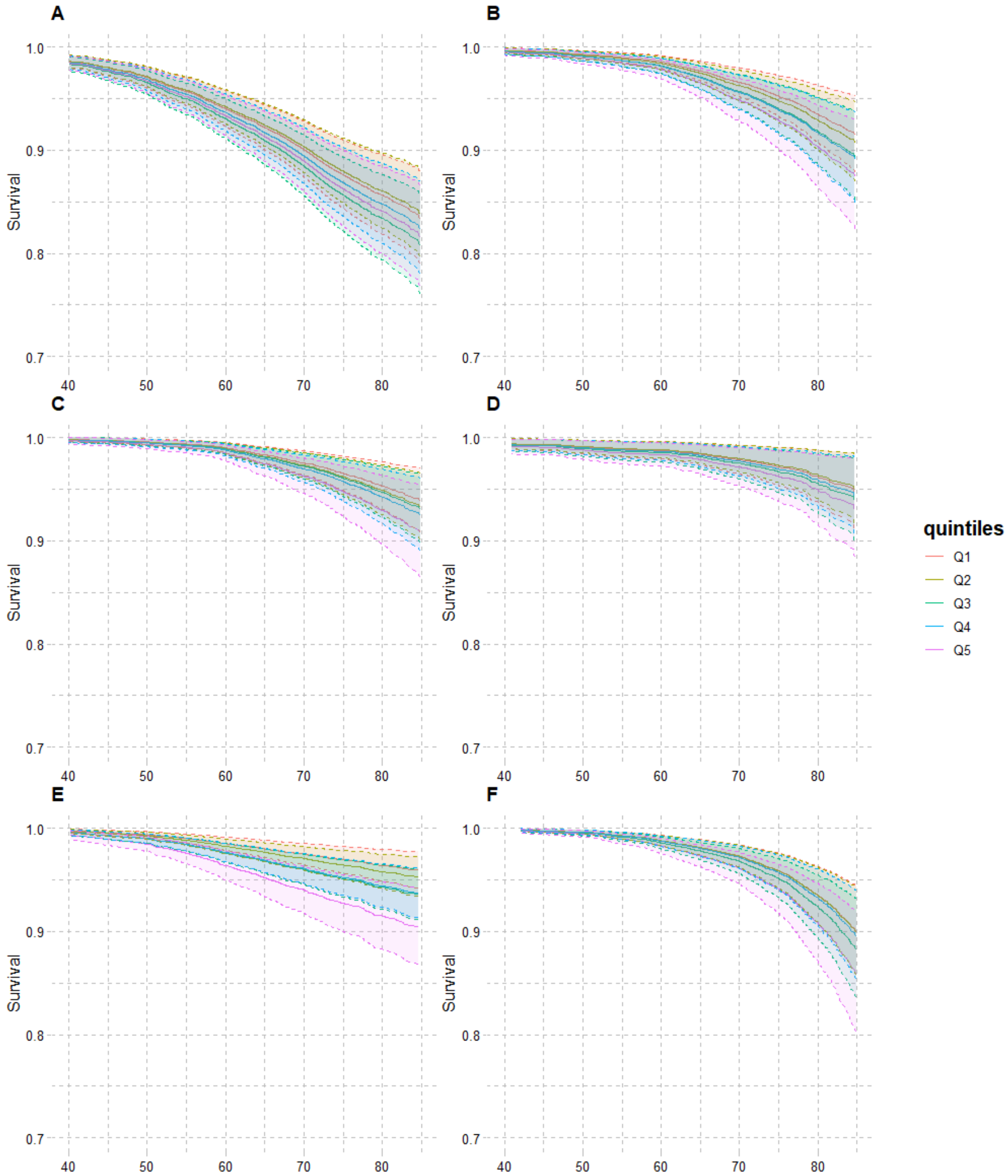
Abbreviations: EPI, Environmental Pressure Index. Time is age and data are weighted

Panel A is cancer, B is cardiovascular diseases, C is coronary heart disease, D is Stroke, E is type 2 Diabetes, and F is mortality. Schoenfeld residuals plots according to time allow to check for the proportional hazard assumption. Multivariable Cox models are adjusted for age (time-scale), sex (male/female), physical activity level (low, moderate, high), smoking status (status as smoker, former smoker and non-smokers, and number of pack-year), energy intake (continuous, in kcal/d), number of 24-hour dietary records (continuous), educational attainment (<high-school degree, ≤3 years of higher education, >3 years of higher education), living status (cohabiting or not), occupational status (retired, unemployed, farmer/merchant/craftworker/company director, employee/manual worker, intermediate profession, managerial staff/intellectual profession, never employed), monthly income per unit consumption of the household (non-communicated, <1,200 €, 1,200 – 1,800 €, 1,800 – 3,700 €, ≥ 3,700 €), body mass index (BMI) (continuous, in kg/m²), and family history of cancer, diabetes or cardiovascular diseases depending on the analysis. For the cancer analysis, height (continuous, in m) and, for women, number of children, hormone replacement, age at menarche and contraceptive use were included in the model.



Supplemental Figure 3: Restricted cubic spline plots of the association between EPI and risk of chronic diseases and mortality, NutriNet-Santé study, 2014–2024 (n = 34,077).

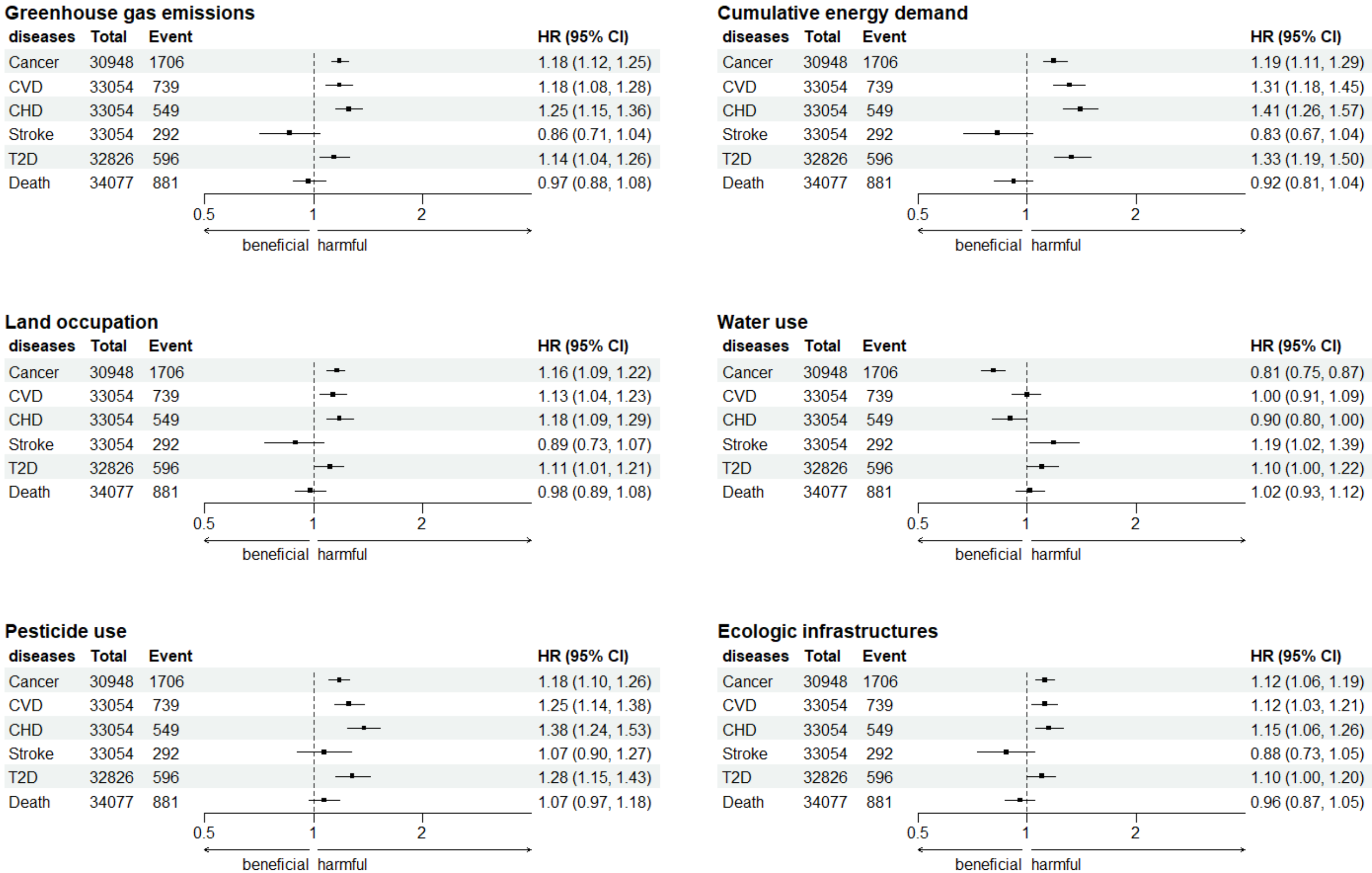
Panel A is cancer, B is cardiovascular diseases, C is coronary heart disease, D is Stroke, E is type 2 Diabetes, and F is mortality. Multivariable Cox models using Restricted Cubic Spline (RCS) SAS Macro®[37] and adjusted for age (time-scale), sex (male/female), physical activity level (low, moderate, high), smoking status (status as smoker, former smoker and non-smokers, and number of pack-year), energy intake (continuous, in kcal/d), number of 24-hour dietary records (continuous), educational attainment (<high-school degree, ≤3 years of higher education, >3 years of higher education), living status (cohabiting or not), occupational status (retired, unemployed, farmer/merchant/craftworker/company director, employee/manual worker, intermediate profession, managerial staff/intellectual profession, never employed), monthly income per unit consumption of the household (non-communicated, <1,200 €, 1,200 – 1,800 €, 1,800 – 3,700 €, ≥ 3,700 €), body mass index (BMI) (continuous, in kg/m²), and family history of cancer, diabetes or cardiovascular diseases depending on the analysis. For the cancer analysis, height (continuous, in m) and, for women, number of children, hormone replacement, age at menarche, and contraceptive use were included in the model. P referred to the test for non-linearity.



Supplemental Figure 4: Standardized survival curves by quintiles of EPI for chronic diseases or mortality, NutriNet-Santé cohort, France, 2014-2024

Abbreviations; CHD, coronary heart diseases; CVD, cardiovascular diseases; T2D, type 2 diabetes.

The x-axis is age (in y). Each curve depicts the age-standardized probability of survival (marginal survival curves) for chronic disease (cancers, cardiovascular diseases, type 2 diabetes) and total mortality. Standardized survival is based on the counterfactual model for the covariates and is interpreted as a change in risk associated with the changes in diet for a fixed covariate profile. The covariate profile is for women, employees, without cancer family history, living in couple, physically active, education attainment ≤3y after high school, former smokers, income between 1200 and 1800€/month/unit consumption, with cumulative tobacco consumption of 5.5 pack year, 2000 Kcal/d, body mass index of 24 kg/m², and for risk of cancer height of 1.66m, no contraceptive and hormonal replacement use, age at menarche <12y, and 2 children.



Supplemental Figure 5: Association between each individual environmental indicator and chronic diseases and mortality (NutriNet-Santé, 2014-2024)

Abbreviations; CHD, coronary heart diseases; CVD, cardiovascular diseases; T2D, type 2 diabetes.

Values are number (total and cases of disease), HR (95% CI). HR (95% CI) are extracted from multivariable Cox models are adjusted for age (time-scale), sex (male/female), physical activity level (low, moderate, high), smoking status (status as smoker, former smoker and non-smokers, and number of pack-year), energy intake (continuous, in kcal/d), number of 24-hour dietary records (continuous), educational attainment (<high-school degree, ≤3 years of higher education, >3 years of higher education), living status (cohabiting or not), occupational status (retired, unemployed, farmer/merchant/craftworker/company director, employee/manual worker, intermediate profession, managerial staff/intellectual profession, never employed), monthly income per unit consumption of the household (non-communicated, <1,200 €, 1,200 – 1,800 €, 1,800 – 3,700 €, ≥ 3,700 €), body mass index (BMI) (continuous, in kg/m^2), and family history of cancer, diabetes or cardiovascular diseases depending on the analysis. For the cancer analysis, height (continuous, in m) and, for women, number of children, hormone replacement, age at menarche, and contraceptive use were included in the model.

Supplemental Table 1: Description of weight according to characteristics categories (NutriNet-Santé cohort, France, 2014 (n = 34,077)

	N	Mean	SD
Sex			
Women	25,723	0·69	2·39
Men	8,354	1·94	7·92
Age (years)			
<30	2,453	2·26	9·33
30-45	7,030	1·27	5·97
45-60	11,202	0·85	3·97
>60	13,392	0·75	1·6
Education			
< High school diploma	7,157	2·84	8·39
High school	5,020	1·05	4·24
≤3 years after high school	10,458	0·39	1·94
>3 years after high school	11,442	0·39	1·12
Smoking status			
Never smoker	16,610	0·97	4·26
Former smoker	13,754	0·99	4·38
Smoker	3,713	1·16	5·57
Occupation			
Unemployed	14,06	1·03	5·64
Retired	12,375	0·76	1·61
Employee/manual worker	4,955	2·14	9
Craftsman, trader, business manager, farmer	631	2·41	7·81
Intermediate occupation	5,095	0·97	4·34
Executive or higher intellectual profession	7,186	0·43	1·45
Never employed	2,429	1·27	4·15
Income			
<1200€	2,387	2·02	7·62
1200–1800€	7,890	1·24	4·6
1800–3700€	9,313	0·89	3·9
>3700€	10,787	0·47	1·61
NA	3,700	1·65	7·31
Living status			
Cohabiting	28,626	0·95	4·24
Alone	5,451	1·24	5·53
Physical Activity			
Unknown	3,688	1·32	6·11
High	11,318	1·02	4·47
Medium	12,498	0·83	3·48
Low	6,573	1·09	5

Supplemental Table 2: Dietary Consumption according to EPI quintiles (NutriNet-Santé cohort, 2014, n=34,077)[1,2]

Food consumption (g/d)[2]	Q1	Q2	Q3	Q4	Q5
Offal	1·51 (2·97)	2·41 (4·08)	3·40 (5·41)	5·29 (7·17)	8·74 (42·34)
Animal fat	24·15 (20·90)	32·49 (28·95)	36·82 (33·78)	37·91 (28·47)	95·02 (341·00)
Sweetened beverages	3·26 (4·94)	4·47 (6·39)	5·51 (6·82)	5·84 (6·59)	7·75 (8·80)
Processed meat	79·54 (153·66)	82·83 (121·42)	83·94 (157·54)	117·71 (155·02)	124·12 (193·14)
Wholegrain	597·48 (410·54)	648·80 (441·57)	702·88 (498·37)	799·64 (506·52)	843·67 (586·88)
Refined cereals	54·70 (141·64)	40·81 (100·23)	58·23 (129·29)	69·30 (164·05)	87·02 (194·25)
Fruits	11·91 (12·19)	17·44 (17·36)	21·49 (18·09)	28·26 (20·36)	38·99 (36·41)
Fruit juice	77·27 (102·97)	61·50 (76·72)	70·76 (106·86)	59·09 (69·82)	59·93 (81·93)
Milk	105·40 (87·07)	125·38 (92·65)	142·35 (130·05)	149·74 (92·76)	168·39 (124·55)
Legumes	171·30 (135·91)	220·18 (185·57)	254·27 (204·06)	300·97 (222·27)	460·59 (502·51)
Vegetable fat	44·73 (66·72)	69·93 (100·64)	85·59 (109·99)	93·85 (110·18)	121·33 (160·12)
Nuts	42·93 (109·74)	60·38 (127·36)	62·66 (136·67)	73·98 (137·77)	81·81 (170·00)
Fat and sweet products	23·20 (50·62)	24·97 (63·35)	15·72 (29·37)	17·86 (39·41)	20·04 (32·27)
Fish	20·98 (13·77)	23·92 (17·52)	27·12 (16·77)	34·09 (21·18)	39·49 (28·88)
Pork	9·52 (18·06)	9·10 (19·61)	6·92 (15·17)	7·15 (14·47)	8·43 (19·04)
Potatoes	62·65 (50·29)	67·89 (52·08)	73·79 (56·92)	89·25 (58·30)	112·87 (90·23)
Dairy products	24·92 (30·69)	31·21 (29·75)	45·93 (45·42)	48·84 (44·03)	58·58 (64·39)
Ruminant meat	5·18 (6·86)	9·53 (10·61)	12·90 (14·27)	19·99 (16·34)	38·44 (111·00)
Plant-based substitutes	18·31 (17·55)	23·13 (19·67)	29·50 (36·09)	32·38 (25·39)	40·39 (55·34)
Vegetables	116·59 (103·69)	153·34 (115·31)	198·32 (140·96)	216·84 (145·19)	261·12 (192·97)
Poultry	14·54 (13·93)	25·86 (19·89)	37·90 (26·25)	49·80 (27·45)	87·78 (71·07)
Eggs	56·71 (119·88)	44·21 (138·52)	27·40 (95·31)	20·44 (70·31)	29·28 (128·02)

Abbreviations: EPI, environmental pressures index; Q, quintiles

[1]Values are unadjusted mean (SD), weighted on Census

[2]P-values for linear contrast across quintiles are <0·05

Supplemental Table 3: Association between EPI and risk of chronic diseases and death, main analyses (NutriNet-Santé cohort, France, 2014–2024 (n = 34,077)[1]

	Continuous variable[2]	P-value		Sex-specific	quintile			P-trend[3]
			Q1	Q2	Q3	Q4	Q5	
Cancer								
n cases (unweighted)	1,706		282	301	379	411	333	
person-year	226017							
			41,939	44,040	42,964	44,192	44,547	
Model 1 (main)	1·15 (1·03-1·28)	0·01		0·71 (0·58-0·87)	1·46 (1·22-1·75)	0·97 (0·79-1·19)	1·21 (0·95-1·55)	0·02
Cardiovascular diseases								
n cases (unweighted)	739		115	136	156	180	152	
person-year	244,734		43,708	45,442	45,313	46,507	46,666	
Model 1 (main)	1·40 (1·22-1·61)	<0·0001		1·29 (0·99-1·68)	1·38 (1·05-1·81)	1·67 (1·26-2·20)	1·94 (1·38-2·72)	0·0001
Coronary heart diseases								
n cases (unweighted)	549		86	103	106	133	121	
person-year	244,734		43,708	45,442	45,313	46,507	46,666	
Model 1 (main)	1·50 (1·29-1·73)	<0·0001		1·25 (0·94-1·66)	0·94 (0·69-1·29)	1·55 (1·15-2·10)	2·19 (1·53-3·14)	0·0001
Stroke								
n cases (unweighted)	292		54	53	65	64	56	
person-year	244,734		43,708	45,442	45,313	46,507	46,666	
Model 1 (main)	1·04 (0·80-1·36)	0·76		1·75 (1·08-2·82)	2·34 (1·45-3·77)	1·37 (0·80-2·34)	1·26 (0·65-2·41)	0·76
Type 2 diabetes								
n cases (unweighted)	596	71	90	125	141	169	596	
person-year	244,248		42,709	46,162	44,326	46,054	46,554	
Model 1 (main)	1·50 (1·29-1·74)	<0·0001		0·37 (0·26-0·52)	0·95 (0·71-1·28)	1·13 (0·85-1·52)	1·41 (0·99-2·02)	0·0001
Death								
n cases (unweighted)	881	146	160	187	190	198	881	
person-year	256,891		45,850	48,355	47,737	49,366	49,337	
Model 1 (main)	1·01 (0·87-1·18)	0·85		0·95 (0·74-1·21)	1·20 (0·94-1·54)	0·93 (0·71-1·21)	0·95 (0·68-1·33)	0·79

[1] HR (Hazard Ratio) and 95% CI (95% confidence interval) are derived from multivariable Cox proportional hazard, Q: Quintile.

[2] by increment of 1SD

[3] P-value of Wald test for quintile as an ordinal variable

[4] The main model (M1) is a weighted multivariable Cox proportional hazard model adjusted for age (time-scale), sex (male/female), physical activity level (low, moderate, high), smoking status (status as current smoker, former smoker and non-smokers, and number of pack-year), energy intake (continuous, in kcal/d), number of 24-hour dietary records (continuous), educational attainment (<high-school degree, ≤3 years of higher education, >3 years of higher education), living status (cohabiting or not), occupational status (retired, unemployed, farmer/merchant/craftworker/company director, employee/manual worker, intermediate profession, managerial staff/intellectual profession, never employed), monthly income per unit consumption of the household (non-communicated, <1,200 €, 1,200 – 1,800 €, 1,800 – 3,700 €, ≥ 3,700 €), body mass index (BMI)

(continuous, in kg/m^2), and family history of cancer, diabetes or cardiovascular diseases depending on the analysis. For the cancer analysis, height (continuous, in m) and, for women, number of children, hormone replacement and contraceptive use were included in the model.

Supplemental Table 4: Association between EPI and risk of chronic diseases and death, main and sensitivity analyses (NutriNet-Santé cohort, France, 2014–2024 (n = 34,077)[1]

	Continuous variable[2]	P-value	Q1	Q2	Q3	Q4	Q5	P-trend[3]
Sensitive analysis 1[4]								
Cancer	1·11 (1·04-1·19)	0·001		0·71 (0·58-0·87)	1·46 (1·23-1·73)	0·97 (0·81-1·16)	1·21 (1·02-1·44)	0·002
Cardiovascular diseases	1·05 (0·96-1·14)	0·27		1·18 (0·91-1·52)	1·16 (0·90-1·50)	1·27 (0·99-1·62)	1·18 (0·92-1·52)	0·19
Coronary heart diseases	1·10 (1·01-1·21)	0·04		1·13 (0·85-1·49)	0·78 (0·58-1·06)	1·14 (0·87-1·49)	1·26 (0·97-1·65)	0·06
Stroke	0·96 (0·82-1·13)	0·62		1·72 (1·07-2·76)	2·28 (1·46-3·58)	1·32 (0·81-2·13)	1·17 (0·71-1·93)	0·68
Type 2 diabetes	1·14 (1·04-1·25)	0·01		0·33 (0·24-0·47)	0·82 (0·62-1·08)	0·90 (0·70-1·16)	0·93 (0·72-1·20)	0·01
Death	0·95 (0·87-1·04)	0·28		0·93 (0·74-1·18)	1·17 (0·93-1·48)	0·89 (0·70-1·12)	0·88 (0·70-1·11)	0·20
Sensitive analysis 2[5]								
Cancer	1·15 (1·02-1·30)	0·02		0·75 (0·60-0·94)	1·60 (1·31-1·96)	0·95 (0·75-1·20)	1·23 (0·93-1·63)	0·06
Cardiovascular diseases	1·41 (1·21-1·64)	<0.0001		1·29 (0·96-1·73)	1·34 (0·99-1·82)	1·74 (1·28-2·37)	1·96 (1·34-2·87)	0·0001
Coronary heart diseases	1·50 (1·28-1·76)	<0.0001		1·37 (0·99-1·88)	0·90 (0·63-1·30)	1·74 (1·24-2·44)	2·57 (1·71-3·84)	0·0001
Stroke	1·03 (0·77-1·37)	0·86		1·60 (0·97-2·62)	2·01 (1·22-3·31)	1·19 (0·68-2·09)	0·92 (0·45-1·85)	0·67
Type 2 diabetes	1·59 (1·36-1·87)	<0.0001		0·34 (0·23-0·50)	0·97 (0·71-1·32)	1·14 (0·83-1·57)	1·60 (1·09-2·35)	0·0001
Death	1·03 (0·88-1·20)	0·72		0·99 (0·77-1·28)	1·30 (1·01-1·69)	0·97 (0·73-1·29)	0·89 (0·62-1·26)	0·66
Sensitive analysis 3[6]								
Cancer	1·08 (0·95-1·23)	0·22		0·80 (0·64-1·00)	1·01 (0·81-1·25)	0·97 (0·77-1·23)	1·08 (0·81-1·42)	0·28
Cardiovascular diseases	1·35 (1·14-1·59)	0·001		1·37 (1·00-1·87)	1·45 (1·05-2·02)	1·79 (1·27-2·52)	2·07 (1·38-3·12)	0·0003
Coronary heart diseases	1·42 (1·19-1·71)	0·0001		1·23 (0·87-1·75)	1·08 (0·74-1·59)	1·54 (1·05-2·26)	2·28 (1·46-3·57)	0·001
Stroke	1·06 (0·78-1·44)	0·69		1·47 (0·89-2·46)	1·96 (1·17-3·27)	1·73 (0·98-3·06)	1·38 (0·68-2·82)	0·22
Type 2 diabetes	1·39 (1·17-1·64)	0·0001		0·56 (0·37-0·85)	1·24 (0·86-1·78)	1·06 (0·72-1·56)	1·33 (0·85-2·07)	0·02
Death	1·00 (0·85-1·18)	0·96		0·78 (0·59-1·03)	1·20 (0·91-1·59)	0·94 (0·69-1·27)	0·98 (0·68-1·41)	0·69
Sensitive analysis 4[7]								
Cancer	1·08 (0·98-1·20)	0·13		0·87 (0·69-1·10)	1·11 (0·89-1·38)	0·79 (0·62-1·00)	1·17 (0·95-1·46)	0·23
Cardiovascular diseases	0·95 (0·84-1·08)	0·45		1·44 (1·08-1·91)	1·32 (0·99-1·76)	1·24 (0·93-1·66)	1·15 (0·86-1·54)	0·99
Coronary heart diseases	1·01 (0·87-1·17)	0·91		1·47 (1·05-2·05)	1·22 (0·87-1·72)	1·29 (0·92-1·80)	1·27 (0·91-1·78)	0·53
Stroke	0·79 (0·64-0·99)	0·04		1·27 (0·82-1·96)	1·28 (0·83-1·96)	0·94 (0·59-1·48)	0·85 (0·53-1·34)	0·15
Type 2 diabetes	1·44 (1·27-1·63)	<0.0001		1·40 (1·00-1·95)	1·44 (1·03-2·00)	1·26 (0·90-1·77)	2·40 (1·77-3·26)	0·0001
Death	0·93 (0·83-1·05)	0·254		0·88 (0·68-1·13)	1·03 (0·81-1·31)	0·97 (0·76-1·24)	0·85 (0·66-1·09)	0·41
Sensitive analysis 5[8]								
Cancer	1·04 (0·94-1·15)	0·43		1·00 (0·84-1·18)	1·12 (0·94-1·32)	1·08 (0·90-1·29)	1·08 (0·87-1·34)	0.31
Cardiovascular diseases	1·08 (0·93-1·26)	0·30		1·03 (0·80-1·33)	1·27 (0·98-1·64)	1·18 (0·89-1·56)	1·41 (1·01-1·96)	0.03
Coronary heart diseases	1·13 (0·89-1·45)	0·30		0·92 (0·62-1·36)	1·17 (0·79-1·74)	1·04 (0·67-1·61)	1·33 (0·80-2·24)	0.27
Stroke	1·07 (0·90-1·27)	0·43		1·04 (0·78-1·39)	1·18 (0·87-1·59)	1·07 (0·77-1·48)	1·42 (0·97-2·07)	0.12
Type 2 diabetes	1·31 (1·14-1·51)	0.0001		0·99 (0·72-1·36)	1·51 (1·10-2·06)	1·37 (0·98-1·90)	1·97 (1·37-2·84)	0.0001

Death	1·03 (0·90-1·18)	0·65	0·90 (0·71-1·14)	1·18 (0·93-1·48)	0·99 (0·76-1·27)	1·22 (0·91-1·64)	0.15

[1] HR (Hazard Ratio) and 95% CI (95% confidence interval) are derived from multivariable Cox proportional hazard, Q: Quintile.
[2] by increment of 1SD
[3] P-value of Wald test for quintile as an ordinal variable
[4] Sensitivity analysis 1 is model M1 (see Footnote of the supplemental table 3) without adjustment for total energy intake (kcal/d)
[5] Sensitivity analysis 2 is model M1 after removing early cases (in the first 1.5y of follow-up), 1,344 cancer, 609 cardiovascular diseases, 446 coronary heart diseases, 262 stroke, 506 type 2 diabetes, and 796 deaths
[6] Sensitivity analysis 4 is a model weighed for census data after capping weight for census >95th percentile at this value
[7] Sensitivity analysis 3 is Marginal Structural Model additionally weighted for census data after removing participants with weight >10, 1,683 cancer, 729 cardiovascular diseases, 541 coronary heart diseases, 290 stroke, 591 type 2 diabetes, and 970 death
[8] Sensitivity analysis 5 is a model without weighing for census data

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