

Original Research Article

Different Levels of Ultraprocessed Food and Beverage Consumption and Associations with Environmental Sustainability and All-cause Mortality in EPIC-NL



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ABSTRACT

Background: The adverse health effects of high ultraprocessed food and drink (UPFD) consumption are well documented. However, the environmental impact remains unclear, and the separate effects of ultraprocessed foods (UPFs) and drinks (UPDs) on all-cause mortality have not been studied previously.

Objectives: To assess the association between levels of UPFD, UPF, and UPD consumption and diet-related environmental impacts and all-cause mortality in Dutch adults.

Methods: Habitual diets were assessed by a Food Frequency Questionnaire (FFQ) from 1993–1997 in 38,261 participants of the Dutch European Prospective Investigation into Cancer and Nutrition cohort. The mean follow-up time was 18.2 y (SD = 4.1); 4,697 deaths occurred. FFQ items were categorized according to the NOVA classification. Associations between quartiles of UPFD, UPF, and UPD consumption and environmental impact indicators were analyzed using general linear models and all-cause mortality by Cox proportional hazard models. The lowest UPFD, UPF, and UPD consumption quartiles were used as comparator.

Results: The average UPFD consumption was 181 (SD = 88) g/1000 kcal. High UPF consumption was statistically significantly inversely associated with all environmental impact indicators (Q4vsQ1: −13.6% to −3.0%), whereas high UPD consumption was, except for land use, statistically significant positively associated with all environmental impact indicators (Q4vsQ1: 1.2% to 5.9%). High UPFD consumption was heterogeneously associated with environmental impacts (Q4vsQ1: −4.0% to 2.6%). After multivariable adjustment, the highest quartiles of UPFD and UPD consumption were significantly associated with all-cause mortality (HR_{Q4vsQ1}: 1.17, 95%CI: 1.08, 1.28 and HR_{Q4vsQ1}: 1.16, 95%CI: 1.07, 1.26, respectively). UPF consumption of Q2 and Q3 were associated with a borderline significant lower risk of all-cause mortality (HR_{Q2vsQ1}: 0.93, 95% CI: 0.85, 1.00; HR_{Q3vsQ1}: 0.91, 95% CI: 0.84, 0.99) whereas Q4 was not statistically significant (HR_{Q4vsQ1}: 1.06, 95% CI: 0.97, 1.15).

Conclusions: Reducing UPD consumption may lower environmental impact and all-cause mortality risk; however, this is not shown for UPFs. When categorizing food consumption by their degree of processing, trade-offs are observed for human and planetary health aspects.

Keywords: ultraprocessed foods, ultraprocessed drinks, NOVA classification, all-cause mortality, environmental impact, planetary health, EPIC-NL

Abbreviations: CPAI, Cambridge Physical Activity Index; En%, energy percentage; EPIC-NL, Dutch European Prospective Investigation into Cancer and Nutrition; eq, equivalent; GHG, greenhouse gas; GLM, general linear models; LCA, life cycle assessments; UPD, ultraprocessed drink; UPF, ultraprocessed food; UPFD, ultraprocessed food and drink.

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<https://doi.org/10.1016/j.ajcnut.2023.05.021>

Received 17 August 2022; Received in revised form 11 April 2023; Accepted 15 May 2023

Available online 18 May 2023

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Introduction

Industrial processing of foods has increased the shelf life and availability of foods and beverages, resulting in a worldwide decrease of hunger and undernutrition [1]. However, industrial processing has also led to the exhaustion of natural resources and an increase in the production and consumption of ultraprocessed foods and drinks (UPFDs) [1,2]. UPFDs are mostly or entirely created from substances extracted from foods or derived from food constituents and are often transformed into unrecognizable, ready-to-eat foods that contain cosmetic additives and high amounts of energy, sugar, fat, and salt [3]. UPFDs are generally energy dense and have rapidly replaced unprocessed or minimally processed foods and beverages [4].

In the Netherlands, the consumption of UPFDs has increased in recent decades and now accounts for more than half of the energy intake [5] and in high income countries in general ranges from 24% to 60% of energy intake [6–8]. High consumption of UPFDs is associated with an increased risk of overweight, obesity, cardiovascular diseases, cancer, and all-cause mortality [2,9,10]. Furthermore, it is widely acknowledged that food consumption does not only affect human health [11]. Production and consumption of foods determines 26% of total greenhouse gas (GHG) emissions, 70% of freshwater withdrawals, and 78% of marine and freshwater eutrophication. Additionally, agriculture leads to soil and surface water acidification, loss of biodiversity, and air pollution [11].

Although limited research has been conducted to quantify the environmental impact of UPFDs [5,12–17], studies have found that the environmental impact of UPFDs varies depending on the food type, food group, and environmental impact indicators [5,15]. One study found that, per kg, ultraprocessed foods (UPFs) emit similar or higher GHG emissions, whereas ultraprocessed drinks (UPDs) emit lower GHG emissions compared with unprocessed or minimally processed foods [5]. Generally, UPFDs require more packaging, transportation, and processing, which contribute significantly to environmental impacts [18]. To illustrate, UPFDs are typically packaged in single-use plastics, transported over long distances, and require refrigeration. The production of UPFDs also requires large amounts of energy, water, chemicals, and additives that have negative environmental impacts.

In Brazil, France, and the Netherlands, purchasing or consuming UPFDs accounted for 20%, 24%, and 43% of diet-related GHG emissions and 22%, 23%, and 23% of diet-related water use, respectively [5,14,16]. Furthermore, in Brazil and France, UPFD consumption was positively associated with environmental impacts due to higher caloric intake. However, the association disappeared or became negative after energy adjustments [16,17].

As a previous study suggested that the association between UPF and UPD production and consumption and environmental impact indicators differs, this has raised the question whether this also applies to UPF and UPD consumption in relation to all-cause mortality. Although previous studies have explored the relationship between UPFDs and all-cause mortality [6,7,19–22], no study has assessed the separate effects of UPF and UPD consumption on all-cause mortality. Therefore, the aim of this study was to explore the joint and separate association between UPF and UPD consumption and diet-related GHG emissions, blue water, land use, acidification, fresh- and marine water eutrophication, and all-cause mortality.

Methods

Study population

Participants were selected from the population-based Dutch European Prospective Investigation into Cancer and Nutrition (EPIC-NL) cohort [23]. EPIC-NL consists of 2 cohorts, which are Prospect and the Monitoring Project on Risk Factors for Chronic Diseases (MORGEN). Both cohorts started between 1993 and 1997. At baseline, EPIC-NL consisted of 40,011 participants between the ages of 20 and 70 y, of which 17,357 were females aged 50 to 70 y from Prospect and 22,654 were females and males aged 20 to 59 y from MORGEN. Details are available in the cohort profile [23]. After progressive exclusion of those who withdrew informed consent during follow-up ($n = 1$), with missing data on dietary intake ($n = 218$), BMI ($n = 21$), educational level ($n = 264$), or smoking status ($n = 39$), and those with implausible energy intake (<500 or >3500 kcal) ($n = 1207$), 38,261 participants were included in the analysis (Supplementary Figure 1).

At baseline, general information on age, sex, educational level, physical activity, and smoking status was obtained using a self-reported questionnaire. Height and weight were measured by trained staff according to standardized procedures. BMI was calculated as $\text{weight}/\text{height}^2$. For BMI, the following categories were used: $<18.5 \text{ kg/m}^2$ (underweight), 18.5 to 24.9 kg/m^2 (normal weight), 25 to 29.9 kg/m^2 (overweight), and $\geq 30 \text{ kg/m}^2$ (obesity). Educational level was defined as the highest attained educational level and was categorized as low (lower vocational education or less), moderate (advanced elementary education until higher general secondary education), and high (at least higher vocational education). Physical activity was assessed with the validated Cambridge Physical Activity Index (CPAI) and categorized into inactive, moderately inactive, moderately active, or active [24]. Smoking status was categorized as never smoked, past smoker, or current smoker.

Dietary assessment

A self-administered validated 178-item FFQ, of which 30 items were beverage-specific, was completed by the participants at baseline (1993–1997) [25]. The FFQ was validated against 12 24-h recalls and biomarkers in 24-h urine and blood [25,26]. Spearman rank correlation coefficients based on estimates of the FFQ and 24-h recalls were 0.58 for potatoes, 0.38 for vegetables, 0.68 for fruits, 0.47 for meat, 0.32 for fish, 0.64 for cheese, 0.71 for dairy, 0.78 for sweet products, 0.56 for biscuits and pastry, 0.65 for nuts and seeds, 0.67 for nonalcoholic beverages, and 0.74 for alcoholic beverages. The FFQ covered questions on the habitual consumption frequency and portion sizes of food items in the year preceding enrollment. Energy and sodium intake and macronutrients were estimated using the 1996 Dutch Food Composition Table [27].

Classification of dietary intake according to the degree of processing

The NOVA classification was applied to define the degree of processing of foods and beverages [3]. The classification contains 4 categories: unprocessed or minimally processed foods, processed culinary ingredients, processed foods, and UPFs. Unprocessed or minimally processed foods and drinks are foods or drinks that are unaltered or only slightly altered by industrial processes such as removal of inedible or unwanted parts, drying, crushing, grinding, fractioning, roasting, boiling, pasteurization, refrigeration, freezing, placing in containers, vacuum packaging, or nonalcoholic fermentation. Examples are vegetables, plain

yogurt, and muscle meat. Processed culinary ingredients are substances obtained from unprocessed foods or from nature and created by industrial processes such as pressing, centrifuging, refining, extracting, or mining, for example, salt, sugar, and oils. Processed foods are industrial products made by adding ingredients such as salt, sugar, oils, or fats to unprocessed or minimally processed foods, resulting in canned fruits and vegetables, cheeses, and smoked or salted meat. UPFDs are formulations of ingredients mostly of exclusive industrial use that result from a series of industrial processes like hydrogenation, hydrolysis, chemical modifications, extrusion, molding, and pre-frying, which often contain cosmetic additives (such as colors, flavors, emulsifiers) to make them palatable, for example, sausages, cookies, and sugar-sweetened beverages. Prior to analysis, FFQ items were classified according to corresponding NOVA categories, which is described elsewhere [28]. Briefly, since dietary assessment was conducted in the nineties, the food items were classified into 3 scenarios (lower, middle, and upper bound), which reflected how strictly the food items were classified based on NOVA. The 3 scenarios were designed to capture the potential variation in the degree of food processing. The lower bound scenario included food items that could have been less processed compared to the middle-bound scenario, whereas the upper bound scenario encompassed food items that could have been more processed than the middle-bound scenario. The middle-bound scenario, which represented the most likely scenario, was used for the primary analysis [28]. FFQ items were additionally classified as either foods or drinks, resulting in UPFs and UPDs, respectively. The classification of all FFQ items can be found in [Supplementary Table 1](#).

Environmental impact assessment

The environmental impacts of FFQ items were derived from the Dutch Life Cycle Assessments (LCAs) food database [29]. A detailed description of the LCAs can be found elsewhere [5,30]. Briefly, the LCAs quantify all inputs and materials used through the entire product life cycle, from the primary mining of raw materials, processing, transport (except between supermarket and consumer), distribution, preparation by the consumer, and the waste of products. The LCAs have an attributional approach and hierarchical perspective and were performed following the ISO 14040 and 14044 guidelines. Economic allocation was applied when production processes led to more than one food product, except for milk, for which biophysical allocation was used. The LCA food database provided primary data for 265 foods and drinks, which cover 75% of the total amount of food intake in the Netherlands [5]. Six environmental impact indicators were linked to the FFQ items. Indicators included were: GHG emissions, (kg CO₂-equivalent [eq]), land use (m²/year), blue water consumption (m³), acidification (kg SO₂-eq), freshwater eutrophication (kg P-eq), and marine eutrophication (kg N-eq).

All-cause mortality assessment

The vital status of participants was obtained from the municipal population registries. Participants were followed over time until date of death, emigration, loss to follow-up or were censored (survived), with censoring date 31 December, 2014.

Statistical analysis

Both food and beverage consumption and environmental impacts were standardized to 1000 kcal in order to assess the relative contributions toward the total dietary intake and environmental impacts. Participants were divided into quartiles based on UPFD, UPF, and UPD consumption in g/1000 kcal. Baseline characteristics were summarized

for the total population and by quartiles with descriptive statistics in means and SDs or median (25th percentile, 75th percentile) for continuous variables and percentages for categorical variables.

In order to investigate associations between quartiles of UPFD consumption and the environmental impact indicators, general linear models were applied to estimate the mean differences in environmental impact with 95% CIs. The first quartile, representing lowest UPFD consumption, was used as a reference in the analyses. Analyses were adjusted for sex, age at baseline, and total energy intake based on the literature [30,31]. The variables sex, age, and total energy intake were added as covariates to the model. Means and 95% CIs are expressed in percentage difference compared to the reference.

Cox proportional hazard models were used to estimate crude and adjusted HRs with 95% CIs for the strength of associations between quartiles of UPFD consumption and all-cause mortality. The first quartile, representing lowest UPFD consumption, was used as reference in the analyses. The proportionality of hazard assumptions was assessed using log minus log plots. The Cox proportional hazard models were all Cox-stratified for age because the covariate age failed to meet the proportional hazard assumption. Models were adjusted for potential confounders, which were identified in advance based on the literature rather than statistics [32]. Three successive models were built. Model 1 was Cox stratified for age and adjusted for sex. Model 2 was additionally adjusted for educational level (low, moderate, high), smoking status (never, former, current), physical activity level (inactive, moderately inactive, moderately active, active), and total energy intake (continuous, kcal/d). Model 3 consisted of model 2 with adjustments for BMI (continuous, kg/m²). All models were repeated for UPFs and UPDs separately. The statistical analysis was performed using SAS software, version 9.4 (SAS Institute Inc).

Results

Of the participants, 76% were female, with a mean age of 50 (SD = 12) y ([Table 1](#)). The average UPFD consumption was 181 (SD = 88) g/1000 kcal of which 91 (SD = 29) g were UPFs and 90 (SD = 86) g were UPDs. Cookies/biscuits, salty snacks, and chocolate bars/candy bars contributed the most to daily energy intake from UPFs ([Table 2](#)). Chocolate milk, liquors, sweetened soft drinks, and specifically cola, contributed most to daily energy intake from UPDs.

Participants in the highest quartile of UPFD consumption (Q4) consumed approximately 3 times as much UPFD per day (297 g/1000 kcal) compared to participants in the lowest quartile (Q1) (97 g/1000 kcal) ([Table 1](#)). Participants with a higher UPFD consumption were more likely to be male, younger, current smokers with higher BMIs and a lower educational level than those with a lower UPFD consumption. Population characteristics according to quartiles of UPFs and UPDs can be found in [Table 3](#) and [4](#).

Higher UPFD consumption (Q4vsQ1) was significantly associated with slightly higher eutrophication of fresh water (2.6%; 95% CI: 2.1, 3.0%) and GHG emissions (1.9%; 95% CI: 1.3, 2.4%) compared to low UPFD consumption. On the contrary, blue water consumption (−4.0%; 95% CI: −4.9, −3.0%), eutrophication of marine water (−1.5%; 95% CI: −2.2, −0.8), land use (−0.9%; 95% CI: −1.4, −0.5%), and terrestrial acidification (−0.9%; 95% CI: −1.6, −0.1%) were lower for those with higher UPFD consumption compared with those with lower UPFD consumption (Q4vsQ1) ([Table 5](#)). Except for GHG emissions, the estimates for the second and third quartiles compared with the lowest quartile were generally in the same direction as estimates for the highest quartile, but with a lower magnitude.

TABLE 1

Characteristics of the total population and according to quartiles of ultraprocessed food and drink consumption.

UPFD (g/1000 kcal)	Total		Q1 (low) [<124]		Q2 [124–162]		Q3 [162–217]		Q4 (high) [>217]	
n	38261		9565		9565		9566		9565	
Age at enrollment (y)	50	(12)	53	(10)	51	(11)	49	(12)	46	(13)
BMI (kg/m ²)	25.7	(4.1)	25.5	(4.0)	25.5	(3.9)	25.7	(3.9)	26.2	(4.3)
Sex										
Male	24	%	21	%	22	%	24	%	27	%
Female	76	%	79	%	78	%	76	%	73	%
BMI (kg/m ²)										
<18.5	1	%	1	%	1	%	1	%	1	%
18.5–24.9	48	%	49	%	49	%	48	%	43	%
25–29.9	38	%	37	%	38	%	39	%	39	%
≥30	13	%	12	%	12	%	12	%	16	%
Educational level										
Low	17	%	21	%	16	%	14	%	15	%
Moderate	63	%	56	%	61	%	65	%	70	%
High	20	%	23	%	23	%	21	%	16	%
Level of physical activity										
Inactive	8	%	9	%	7	%	7	%	9	%
Moderately inactive	25	%	26	%	25	%	25	%	25	%
Moderately active	26	%	25	%	27	%	27	%	25	%
Active	41	%	40	%	41	%	41	%	41	%
Smoking status										
Never	38	%	38	%	40	%	39	%	37	%
Former	32	%	32	%	33	%	32	%	29	%
Current	30	%	30	%	27	%	29	%	34	%
Food and energy intake										
Quantity (g/1000kcal)	1547	(436)	1592	(447)	1510	(395)	1493	(397)	1593	(490)
Total energy intake (kcal)	1991	(535)	1898	(525)	2006	(510)	2044	(525)	2018	(567)
Unprocessed and minimally processed foods (g/1000kcal)	1215	(451)	1314	(477)	1216	(414)	1166	(410)	1166	(481)
Energy intake from unprocessed and minimally processed foods (En%)	35	(9)	37	(10)	35	(8)	34	(8)	33	(9)
Processed culinary ingredients (g/1000kcal)	11	(10)	13	(11)	11	(9)	11	(9)	10	(9)
Energy intake from processed culinary ingredients (En%)	6	(5)	7	(5)	6	(4)	6	(4)	6	(4)
Processed foods (g/1000kcal)	139	(95)	169	(121)	140	(88)	129	(80)	120	(77)
Energy intake from processed foods (En%)	27	(9)	31	(10)	28	(8)	26	(8)	24	(8)
UPFD (g/1000kcal)	181	(88)	97	(20)	143	(11)	187	(15)	297	(92)
Energy intake from UPFD (En%)	32	(9)	25	(7)	31	(7)	34	(7)	37	(8)
UPF (g/1000kcal)	91	(29)	72	(21)	93	(24)	99	(28)	100	(33)
UPD (g/1000kcal)	90	(86)	25	(18)	50	(25)	88	(32)	198	(100)
Energy intake from UPF (En%)	28	(8)	23	(7)	28	(7)	30	(8)	30	(9)
Energy intake from UPD (En%)	4	(4)	2	(2)	3	(2)	4	(3)	7	(5)
Carbohydrates (En%)	45	(6)	44	(7)	45	(6)	45	(6)	47	(6)
Total fat (En%)	36	(5)	36	(6)	36	(5)	36	(5)	35	(5)
Protein (En%)	16	(2)	16	(3)	16	(2)	15	(2)	15	(2)
Alcohol (En%)	2	(0,5)	2	(0,6)	2	(0,5)	2	(0,5)	2	(0,5)
Fiber (g/1000 kcal)	12	(3)	13	(3)	12	(3)	12	(3)	11	(3)
Sodium (mg/1000 kcal)	1174	(235)	1184	(250)	1179	(225)	1174	(224)	1159	(238)
Potatoes (g/1000 kcal)	45	(29,67)	47	(28,71)	45	(29,66)	45	(30,65)	45	(29,65)
Cereals (g/1000 kcal)	89	(71,110)	93	(74,117)	91	(73,110)	88	(71,108)	83	(66,104)
Vegetables and legumes (g/1000 kcal)	67	(49,91)	76	(55,102)	68	(51,90)	64	(48,85)	63	(45,86)
Fruit, nuts, and seeds (g/1000 kcal)	91	(52,149)	108	(59,175)	97	(56,154)	86	(52,138)	76	(42,130)
Dairy and cheese (g/1000 kcal)	200	(117,296)	203	(112,309)	208	(130,299)	202	(124,290)	184	(103,285)
Meat (g/1000 kcal)	50	(33,65)	49	(31,66)	49	(33,65)	50	(34,65)	51	(35,67)
Fish (g/1000 kcal)	4	(1,8)	4	(1,8)	4	(2,7)	4	(2,7)	4	(1,7)
Eggs (g/1000 kcal)	7	(4,11)	7	(4,11)	7	(4,11)	7	(4,11)	7	(4,11)
Sugar and confectionery (g/1000 kcal)	14	(7,23)	13	(6,22)	15	(8,24)	15	(8,24)	14	(7,24)
Cake and biscuits (g/1000 kcal)	12	(6,21)	11	(5,19)	14	(8,23)	14	(7,22)	11	(5,19)
Fats and oils (g/1000 kcal)	13	(9,17)	13	(9,18)	13	(9,18)	13	(9,17)	12	(8,17)
Savory sauces, snacks, and bread toppings (g/1000 kcal)	12	(7,18)	10	(5,16)	11	(6,17)	13	(7,19)	14	(8,21)
Composite dishes and soups (g/1000 kcal)	30	(16,53)	27	(14,53)	30	(16,53)	31	(17,54)	31	(17,53)
Miscellaneous (g/1000 kcal)	0	(0,0)	0	(0,0)	0	(0,0)	0	(0,0)	0	(0,0)
Nonalcoholic beverages(g/1000 kcal)	693	(521,932)	701	(518,946)	667	(509,880)	667	(508,884)	753	(559,1019)
Alcoholic beverages (g/1000 kcal)	28	(4,90)	25	(2,101)	29	(5,82)	31	(5,86)	28	(4,92)

Abbreviations: En%, energy percentage; UPD, ultraprocessed drink; UPF, ultraprocessed food; UPFD, ultraprocessed food and drink.

Numbers are mean (SD), median (25th percentile, 75th percentile), or percentage (%).

TABLE 2

Top 5 foods and beverages according to the degree of food processing that contribute the most to daily energy intake.

Foods	Unprocessed or minimally processed	Processed culinary ingredients	Processed	Ultraprocessed
1	Potatoes	Sugar	Bread, whole grain	Cookies, biscuits
2	Soups	Butter, unsalted	Bread, brown/wheat	Salty snacks
3	Pasta without filling	Oil, soy	Cheese, cream cheese	Chocolate bars, candy bars
4	Apple, pear	Oil, sunflower	Bread, white	Sweet bread toppings
5	Pork meat	Whipping cream	Nuts, ground nuts	Cakes, large cookies
Drinks	Unprocessed or minimally processed	Processed culinary ingredients	Processed	Ultraprocessed
1	Milk, semi-skimmed		Beer	Milk, chocolate
2	Buttermilk		Wine, red, rosé	Liquor
3	Orange, grapefruit juice		Wine, white	Sugar-sweetened soft drinks
4	Yogurt drink			Cola
5	Milk, full-fat			Port, sherry, etc.

More pronounced differences in environmental impact were observed between the highest and lowest quartiles of UPF and UPD consumption when analyzed separately. Compared to low UPF consumption, higher UPF consumption (Q4vsQ1) was statistically significantly inversely associated with blue water (−13.6%; 95% CI: −14.4, −12.7%), GHG emissions (−7.7%; 95% CI: −8.2, −7.2%), acidification (−7.2%; 95% CI: −7.9, −6.4%), marine water eutrophication (−5.4%; 95% CI: −6.1, −4.7%), freshwater eutrophication (−5.3%; 95% CI: −5.8, −4.9%), and land use (−3.0%; 95% CI: −3.5, −2.6%). Contrarily, higher UPD consumption (Q4vsQ1) was statistically significantly associated with higher GHG emissions (5.9%; 95% CI: 5.4, 6.5%), fresh water eutrophication (5.0%; 95% CI: 4.5, 5.5%), blue water (3.2%; 95% CI: 2.2, 4.1%), acidification (2.9%; 95% CI: 2.1, 3.7%), marine water eutrophication (1.2%; 95% CI: 0.5, 2.0%), and similar land use (0.4%; 95% CI: −0.1, 0.9%) when compared with low UPD consumption.

For both UPF and UPD, estimates for the second and third quartile compared with the lowest quartile were in the same direction as estimates for the highest quartile, but with a lower magnitude.

After a mean follow-up of 18.2 y (SD = 4.1), 4,697 deaths occurred. Higher UPFD consumption was significantly positively associated with all-cause mortality risk (HR_{Q4vsQ1}: 1.18, 95% CI: 1.09, 1.28) in model 1 (Table 6) compared to lower UPFD consumption. In the fully adjusted model 3, including adjustments for educational level, smoking status, physical activity, BMI, and total energy intake, the HR was essentially similar (HR_{Q4vsQ1}: 1.17, 95% CI: 1.08, 1.28). Compared to the lowest UPFD quartile, no associations between UPFD consumption and all-cause mortality were observed for the second and third UPFD quartiles.

The association between UPF and UPD consumption with all-cause mortality was separately assessed. Compared with a lower UPF consumption, higher UPF consumption across all quartiles was significantly associated with a lower mortality risk (HR_{Q2vsQ1}: 0.83, 95% CI: 0.76, 0.89; HR_{Q3vsQ1}: 0.78, 95% CI: 0.72, 0.84; and HR_{Q4vsQ1}: 0.87, 95% CI: 0.80, 0.94) in model 1 (Table 6). In the fully adjusted model, UPF consumption was associated with a borderline significant lower risk of all-cause mortality (HR_{Q2vsQ1}: 0.93, 95% CI: 0.85, 1.00; HR_{Q3vsQ1}: 0.91, 95% CI: 0.84, 0.99). Additionally, the association reversed for the highest UPF quartile (HR_{Q4vsQ1}: 1.06, 95% CI: 0.97, 1.15). In the fully adjusted model, higher UPD consumption was significantly associated with a higher risk of all-cause mortality (HR_{Q4vsQ1}: 1.16, 95% CI: 1.07, 1.26) compared with lower UPD consumption. No associations between UPD consumption with all-cause mortality in the second and third quartile, compared with the lowest quartile, were observed.

Discussion

In this prospective study among 38,261 Dutch adults aged 20 to 70 y, the joint and separate association of UPFD consumption with diet-related GHG emissions, blue water, land use, acidification, fresh- and marine water eutrophication, and all-cause mortality was investigated.

One of the primary aims of this study was to investigate the joint and separate effect of UPFs and UPDs on the environment. The limited number of previous studies showed heterogeneous results for UPF and UPD separately [5], and no or inverse associations for UPFD, after energy adjustments [16,17]. The differences in environmental impact indicators for diets low versus high in UPFs or UPDs in this study were statistically significant (except for the null association between UPD and land use) but relatively small. Our results showed that, compared with lower consumption, higher UPF consumption was associated with lower diet-related environmental impacts (Q4vsQ1: −13.6% to −3.0%), whereas higher UPD consumption was associated with higher diet-related environmental impacts (Q4vsQ1: 1.2% to 5.9%), except for land use. Subsequently, the net diet effect on the environment of higher UPFD consumption compared to lower intakes was more neutral. The amounts consumed according to degree of processing and their associated environmental impact varied across the quartiles. Participants with diets high in UPF consumed less from unprocessed and minimally processed foods and vice versa. Therefore, the amount of unprocessed and minimally processed foods consumed is likely to be a more significant factor in determining the dietary environmental impacts and might determine the total daily dietary environmental impacts to a larger extent than UPFD, as has been shown elsewhere [5, 12,14]. For UPD, our outcome is mainly attributable to a higher consumption of UPD itself; the consumption of other foods and drinks was approximately similar across the quartiles.

Previous studies showed increased all-cause mortality risks for high versus low UPFD consumption and reported HRs between 1.14 and 1.62 [6,7,19–22] and did not focus on the separate effects of UPFs and UPDs. The different settings and applied methods, such as exposure expressed in frequency, grams, or En%, indicate a robust association. Our findings suggest that the obtained association between UPFD consumption and all-cause mortality might be predominantly driven by UPD consumption. In accordance with previous studies, we observed a positive association between UPDs, such as sugar- and artificially sweetened beverages, and all-cause mortality. A meta-analysis demonstrated that a high consumption of sugar- and artificially sweetened beverages are associated with a higher risk of all-cause mortality, with HRs of 1.12 (95% CI: 1.06, 1.19) and 1.12 (95% CI: 1.04, 1.21), respectively [33]. The absence of a significant association

TABLE 3

Characteristics of the population according to quartiles of ultraprocessed food consumption.

UPF (g/1000 kcal)	Q1 (low) [<72]		Q2 [72–90]		Q3 [90–109]		Q4 (high) [>109]	
n	9565		9565		9566		9565	
Age at enrollment (y)	51	(11)	50	(12)	49	(12)	48	(12)
BMI (kg/m ²)	25.9	(4.2)	25.7	(34.1)	25.6	(3.9)	25.7	(4.1)
Sex								
Male	24	%	24	%	23	%	23	%
Female	76	%	76	%	77	%	77	%
BMI (kg/m ²)								
<18.5	1	%	1	%	1	%	1	%
18.5–24.9	47	%	47	%	48	%	48	%
25–29.9	38	%	39	%	39	%	38	%
≥30	15	%	13	%	12	%	13	%
Educational level								
Low	19	%	16	%	15	%	16	%
Moderate	59	%	63	%	64	%	67	%
High	22	%	21	%	21	%	17	%
Level of physical activity								
Inactive	11	%	7	%	7	%	7	%
Moderately inactive	26	%	25	%	25	%	26	%
Moderately active	25	%	25	%	27	%	27	%
Active	39	%	43	%	41	%	41	%
Smoking status								
Never	31	%	37	%	41	%	45	%
Former	31	%	32	%	32	%	31	%
Current	38	%	31	%	27	%	25	%
Food and energy intake								
Quantity (g/1000 kcal)	1683	(485)	1564	(418)	1500	(405)	1441	(394)
Total energy intake (kcal)	1862	(530)	2000	(530)	2047	(524)	2057	(535)
Unprocessed and minimally processed foods (g/1000 kcal)	1340	(502)	1236	(434)	1177	(421)	1109	(408)
Energy intake from unprocessed and minimally processed foods (En%)	38	(10)	36	(8)	34	(8)	31	(7)
Processed culinary ingredients (g/1000 kcal)	13	(12)	12	(9)	11	(8)	10	(8)
Energy intake from processed culinary ingredients (En%)	8	(5)	6	(4)	6	(4)	5	(4)
Processed foods (g/1000 kcal)	174	(129)	145	(88)	128	(73)	110	(63)
Energy intake from processed foods (En%)	31	(10)	28	(8)	26	(7)	23	(7)
UPFD (g/1000 kcal)	156	(98)	172	(88)	185	(77)	212	(79)
Energy intake from UPFD (En%)	23	(7)	30	(5)	34	(5)	40	(7)
UPF (g/1000 kcal)	56	(13)	81	(5)	99	(5)	128	(19)
UPD (g/1000 kcal)	100	(98)	91	(88)	86	(76)	83	(78)
Energy intake from UPF (En%)	18	(5)	26	(4)	30	(4)	37	(6)
Energy intake from UPD (En%)	5	(5)	4	(4)	4	(3)	3	(3)
Carbohydrates (En%)	44	(7)	45	(6)	46	(6)	47	(6)
Total fat (En%)	34	(6)	36	(5)	36	(5)	36	(5)
Protein (En%)	16	(3)	16	(2)	15	(2)	15	(2)
Alcohol (En%)	4	(0,9)	2	(0,6)	3	(0,4)	2	(0,3)
Fiber (g/1000 kcal)	12	(3)	12	(3)	12	(3)	12	(3)
Sodium (mg/1000 kcal)	1137	(256)	1171	(222)	1181	(217)	1207	(237)
Potatoes (g/1000 kcal)	43	(26,68)	46	(30,68)	46	(31,67)	45	(30,65)
Cereals (g/1000 kcal)	88	(68,112)	89	(72,110)	89	(72,108)	89	(71,109)
Vegetables and legumes (g/1000 kcal)	76	(54,104)	69	(51,92)	65	(48,87)	61	(45,82)
Fruit, nuts, and seeds (g/1000 kcal)	99	(52,169)	95	(54,157)	90	(53,143)	81	(48,131)
Dairy and cheese (g/1000 kcal)	207	(111,328)	209	(121,307)	206	(126,292)	181	(108,262)
Meat (g/1000 kcal)	50	(31,67)	50	(34,65)	50	(34,64)	49	(33,66)
Fish (g/1000 kcal)	4	(2,8)	4	(2,8)	4	(1,7)	3	(1,7)
Eggs (g/1000 kcal)	7	(4,12)	7	(4,11)	7	(4,10)	6	(4,10)
Sugar and confectionery (g/1000 kcal)	10	(4,19)	13	(7,22)	16	(9,24)	18	(11,27)
Cake and biscuits (g/1000 kcal)	7	(3,12)	12	(6,19)	15	(9,23)	18	(11,28)
Fats and oils (g/1000 kcal)	12	(8,16)	13	(9,17)	13	(9,18)	14	(9,18)
Savory sauces, snacks, and bread toppings (g/1000 kcal)	10	(5,16)	12	(7,18)	13	(7,19)	13	(8,20)
Composite dishes and soups (g/1000 kcal)	26	(13,53)	29	(16,52)	31	(17,52)	33	(18,56)
Miscellaneous (g/1000 kcal)	0	(0,0)	0	(0,0)	0	(0,0)	0	(0,0)
Nonalcoholic beverages (g/1000 kcal)	756	(559,1026)	704	(531,936)	669	(510,895)	656	(497,870)
Alcoholic beverages (g/1000 kcal)	54	(6,142)	35	(6,97)	24	(4,72)	15	(2,52)

Abbreviations: En%, energy percentage; UPD, ultraprocessed drink; UPF, ultraprocessed food; UPFD, ultraprocessed food and drink.

Numbers are mean (SD), median (25th percentile, 75th percentile), or percentage (%).

TABLE 4

Characteristics of the population according to quartiles of ultraprocessed drink consumption.

UPD (g/1000 kcal)	Q1 (low) [<32]		Q2 [32–67]		Q3 [67–121]		Q4 (high) [>121]	
n	9565		9565		9566		9565	
Age at enrollment (y)	53	(10)	50	(11)	49	(12)	46	(13)
BMI (kg/m ²)	25.5	(4.0)	25.5	(3.9)	25.6	(3.9)	26.2	(4.3)
Sex								
Male	19	%	24	%	25	%	27	%
Female	81	%	76	%	75	%	73	%
BMI (kg/m ²)								
<18.5	1	%	1	%	1	%	1	%
18.5–24.9	49	%	49	%	49	%	43	%
25–29.9	38	%	37	%	38	%	40	%
≥30	12	%	12	%	12	%	17	%
Educational level								
Low	21	%	15	%	15	%	15	%
Moderate	58	%	61	%	64	%	68	%
High	21	%	24	%	21	%	16	%
Level of physical activity								
Inactive	8	%	7	%	7	%	9	%
Moderately inactive	27	%	24	%	25	%	25	%
Moderately active	26	%	26	%	27	%	25	%
Active	39	%	43	%	41	%	41	%
Smoking status								
Never	41	%	40	%	38	%	35	%
Former	32	%	33	%	32	%	29	%
Current	27	%	27	%	31	%	36	%
Food and energy intake								
Quantity (g/1000 kcal)	1552	(442)	1494	(390)	1508	(391)	1635	(499)
Total energy intake (kcal)	1912	(516)	2032	(526)	2035	(526)	1987	(563)
Unprocessed and minimally processed foods (g/1000 kcal)	1282	(468)	1198	(413)	1177	(410)	1206	(498)
Energy intake from unprocessed and minimally processed foods (En%)	35	(9)	35	(9)	34	(8)	34	(9)
Processed culinary ingredients (g/1000 kcal)	12	(10)	11	(10)	11	(9)	11	(9)
Energy intake from processed culinary ingredients (En%)	7	(5)	6	(5)	6	(4)	6	(4)
Processed foods (g/1000 kcal)	149	(108)	144	(94)	137	(89)	127	(86)
Energy intake from processed foods (En%)	29	(10)	28	(9)	27	(8)	25	(8)
UPFD (g/1000 kcal)	109	(32)	142	(30)	183	(32)	292	(96)
Energy intake from UPFD (En%)	29	(9)	31	(8)	32	(8)	34	(9)
UPF (g/1000 kcal)	92	(30)	93	(28)	91	(29)	88	(29)
UPD (g/1000 kcal)	17	(9)	49	(10)	91	(15)	204	(94)
Energy intake from UPF (En%)	28	(9)	28	(8)	28	(8)	27	(8)
Energy intake from UPD (En%)	1	(1)	3	(2)	4	(3)	8	(5)
Carbohydrates (En%)	45	(6)	45	(6)	45	(6)	46	(7)
Total fat (En%)	36	(6)	36	(5)	36	(5)	34	(5)
Protein (En%)	16	(2)	16	(2)	15	(2)	15	(2)
Alcohol (En%)	1	(0,4)	2	(0,5)	2	(0,6)	2	(0,6)
Fiber (g/1000kcal)	13	(3)	12	(3)	12	(3)	11	(3)
Sodium (mg/1000 kcal)	1202	(248)	1182	(225)	1168	(226)	1143	(235)
Potatoes (g/1000 kcal)	48	(30,71)	44	(29,66)	45	(29,65)	45	(29,66)
Cereals (g/1000 kcal)	93	(75,115)	91	(74,111)	88	(71,109)	83	(65,103)
Vegetables and legumes (g/1000 kcal)	73	(54,98)	67	(49,88)	65	(48,88)	65	(46,88)
Fruit, nuts, and seeds (g/1000 kcal)	105	(59,168)	93	(54,150)	87	(52,141)	79	(43,135)
Dairy and cheese (g/1000 kcal)	196	(111,291)	205	(126,297)	204	(123,300)	192	(107,296)
Meat (g/1000 kcal)	49	(31,66)	49	(33,64)	50	(34,64)	51	(35,67)
Fish (g/1000 kcal)	4	(1,8)	4	(2,7)	4	(2,7)	4	(1,8)
Eggs (g/1000 kcal)	7	(4,11)	7	(4,11)	7	(4,11)	7	(4,11)
Sugar and confectionery (g/1000 kcal)	15	(8,24)	15	(8,24)	15	(8,24)	13	(6,22)
Cake and biscuits (g/1000 kcal)	15	(7,24)	14	(7,22)	12	(6,20)	10	(5,17)
Fats and oils (g/1000 kcal)	14	(9,18)	13	(9,18)	13	(9,17)	12	(8,16)
Savory sauces, snacks, and bread toppings (g/1000 kcal)	10	(5,16)	12	(7,18)	13	(7,19)	13	(8,20)
Composite dishes and soups (g/1000 kcal)	28	(14,53)	30	(16,54)	31	(17,54)	30	(16,52)
Miscellaneous (g/1000 kcal)	0	(0,0)	0	(0,0)	0	(0,0)	0	(0,0)
Nonalcoholic beverages(g/1000 kcal)	686	(511,928)	656	(497,865)	672	(514,885)	772	(573,1048)
Alcoholic beverages (g/1000 kcal)	15	(1,69)	32	(6,83)	34	(6,94)	34	(4,108)

Abbreviations: En%, energy percentage; UPD, ultraprocessed drink; UPF, ultraprocessed food; UPFD, ultraprocessed food and drink.

Numbers are mean (SD), median (25th percentile, 75th percentile), or percentage (%).

TABLE 5

Adjusted mean difference (absolute and percentage) in environmental impact standardized to 1000 kcal for quartiles of ultraprocessed food and drink, ultraprocessed food, and ultraprocessed drink consumption.

UPFD (g/1000 kcal)	Q1(low) [<124]			Q2 [124–162]			Q3 [162–217]			Q4 (high) [>217]		
	Mean			Mean ^a	95% CI		Mean ^a	95% CI		Mean ^a	95% CI	
GHG emission (kg CO ₂ -eq)	2.856			-0.027	(-0.042, -0.013)		-0.009	(-0.024, 0.005)		0.053	(0.038, 0.068)	
%				-1.0%	(-1.5%, -0.4%)		-0.3%	(-0.8%, 0.2%)		1.9%	(1.3%, 2.4%)	
Blue water consumption (m ³)	0.083			-0.002	(-0.003, -0.002)		-0.003	(-0.004, -0.002)		-0.003	(-0.004, -0.003)	
%				-2.8%	(-3.7%, -1.9%)		-3.5%	(-4.4%, -2.6%)		-4.0%	(-4.9%, -3.0%)	
Land use (m ² /y)	1.625			-0.015	(-0.022, -0.007)		-0.015	(-0.023, -0.007)		-0.015	(-0.023, -0.007)	
%				-0.9%	(-1.4%, -0.4%)		-0.9%	(-1.4%, -0.4%)		-0.9%	(-1.4%, -0.5%)	
Terrestrial acidification (kg SO ₂ -eq)	0.030			0.000	(-0.001, 0.000)		0.000	(-0.001, 0.000)		0.000	(0.000, 0.000)	
%				-1.3%	(-2.1%, -0.6%)		-1.2%	(-1.9%, -0.4%)		-0.9%	(-1.6%, -0.1%)	
Fresh water eutrophication (kg P-eq×10000)	1.968			-0.007	(-0.016, 0.002)		0.009	(0.001, 0.018)		0.051	(0.042, 0.060)	
%				-0.4%	(-0.8%, 0.1%)		0.5%	(0.0%, 0.9%)		2.6%	(2.1%, 3.0%)	
Marine water eutrophication (kg N-eq×10000)	49.973			-0.645	(-0.999, -0.291)		-0.709	(-1.065, -0.353)		-0.757	(-1.118, -0.396)	
%				-1.3%	(-2.0%, -0.6%)		-1.4%	(-2.1%, -0.7%)		-1.5%	(-2.2%, -0.8%)	
UPF (g/1000 kcal)	Q1 (low) [<72]			Q2 [72–90]			Q3 [90–109]			Q4 (high) [>109]		
	Mean			Mean ¹	95% CI		Mean ¹	95% CI		Mean ¹	95% CI	
GHG emission (kg CO ₂ -eq)	2.981			-0.097	(-0.111, -0.082)		-0.157	(-0.172, -0.143)		-0.229	(-0.244, -0.215)	
%				-3.2%	(-3.7%, -2.8%)		-5.3%	(-5.8%, -4.8%)		-7.7%	(-8.2%, -7.2%)	
Blue water consumption (m ³)	0.087			-0.005	(-0.006, -0.004)		-0.008	(-0.009, -0.007)		-0.012	(-0.013, -0.011)	
%				-5.8%	(-6.7%, -5.0%)		-9.3%	(-10.1%, -8.4%)		-13.6%	(-14.4%, -12.7%)	
Land use (m ² /y)	1.641			-0.022	(-0.029, -0.014)		-0.036	(-0.044, -0.028)		-0.050	(-0.058, -0.042)	
%				-1.3%	(-1.8%, -0.8%)		-2.2%	(-2.7%, -1.7%)		-3.0%	(-3.5%, -2.6%)	
Terrestrial acidification (kg SO ₂ -eq)	0.031			-0.001	(-0.001, -0.001)		-0.001	(-0.002, -0.001)		-0.002	(-0.002, -0.002)	
%				-2.8%	(-3.5%, -2.1%)		-4.6%	(-5.3%, -3.9%)		-7.2%	(-7.9%, -6.4%)	
Fresh water eutrophication (kg P-eq×10000)	2.044			-0.058	(-0.066, -0.049)		-0.085	(-0.093, -0.076)		-0.109	(-0.118, -0.100)	
%				-2.8%	(-3.2%, -2.4%)		-4.1%	(-4.6%, -3.7%)		-5.3%	(-5.8%, -4.9%)	
Marine water eutrophication (kg N-eq×10000)	50.826			-1.023	(-1.377, -0.670)		-1.737	(-2.093, -1.382)		-2.765	(-3.121, -2.408)	
%				-2.0%	(-2.7%, -1.3%)		-3.4%	(-4.1%, -2.7%)		-5.4%	(-6.1%, -4.7%)	
UPD (g/1000 kcal)	Q1(low) [<32]			Q2 [32–67]			Q3 [67–121]			Q4 (high) [>121]		
	Mean			Mean ¹	95% CI		Mean ¹	95% CI		Mean ¹	95% CI	
GHG emission (kg CO ₂ -eq)	2.7850			0.0486	(0.0341, 0.0631)		0.0877	(0.0731, 0.1022)		0.1654	(0.1507, 0.1801)	
%				1.7%	(1.2%, 2.3%)		3.1%	(2.6%, 3.7%)		5.9%	(5.4%, 6.5%)	
Blue water consumption (m ³)	0.0794			0.0020	(0.0013, 0.0028)		0.0020	(0.0013, 0.0028)		0.0025	(0.0018, 0.0033)	
%				2.6%	(1.6%, 3.5%)		2.6%	(1.6%, 3.5%)		3.2%	(2.2%, 4.1%)	
Land use (m ² /y)	1.6112			0.0016	(-0.0061, 0.0093)		0.0030	(-0.0048, 0.0107)		0.0067	(-0.0012, 0.0145)	
%				0.1%	(-0.4%, 0.6%)		0.2%	(-0.3%, 0.7%)		0.4%	(-0.1%, 0.9%)	
Terrestrial acidification (kg SO ₂ -eq)	0.0294			0.0003	(0.0001, 0.0005)		0.0005	(0.0003, 0.0007)		0.0009	(0.0006, 0.0011)	
%				1.0%	(0.2%, 1.7%)		1.7%	(1.0%, 2.5%)		2.9%	(2.1%, 3.7%)	
Fresh water eutrophication (kg P-eq×10000)	1.941			0.018	(0.010, 0.027)		0.045	(0.036, 0.054)		0.097	(0.088, 0.106)	
%				0.9%	(0.5%, 1.4%)		2.3%	(1.9%, 2.8%)		5.0%	(4.5%, 5.5%)	
Marine water eutrophication (kg N-eq×10000)	49.173			0.131	(-0.224, 0.485)		0.343	(-0.013, 0.699)		0.613	(0.252, 0.973)	
%				0.3%	(-0.5%, 1.0%)		0.7%	(0.0%, 1.4%)		1.2%	(0.5%, 2.0%)	

Abbreviations: GHG, greenhouse gas; UPD, ultraprocessed drink; UPF, ultraprocessed food; UPFD, ultraprocessed food and drink.

Estimates are adjusted for age, sex, and total energy intake.

¹ Represents the mean difference with the first quartile used as the reference category.

TABLE 6

Hazard ratios for ultraprocessed food and drink, ultraprocessed food, and ultraprocessed drink consumption and all-cause mortality.

	Quartiles according to UPFD consumption in g/1000 kcal			
	Q1(low) [<124]	Q2 [124–162]	Q3 [162–217]	Q4 (high) [>217]
N/ Events	9565/1387	9565/1160	9566/1058	9565/1092
Model 1	Ref	0.91 (0.84, 0.99)	0.93 (0.86, 1.01)	1.18 (1.09, 1.28)
Model 2	Ref	0.95 (0.87, 1.02)	0.96 (0.88, 1.04)	1.15 (1.06, 1.24)
Model 3	Ref	0.97 (0.89, 1.05)	0.99 (0.91, 1.07)	1.17 (1.08, 1.28)
	Quartiles according to UPF consumption in g/1000 kcal			
	Q1(low) [<72]	Q2 [72–90]	Q3 [90–109]	Q4 (high) [>109]
N/ Events	9565/1388	9565/1152	9566/1042	9565/1115
Model 1	Ref	0.83 (0.76, 0.89)	0.78 (0.72, 0.84)	0.87 (0.80, 0.94)
Model 2	Ref	0.89 (0.82, 0.97)	0.86 (0.79, 0.94)	0.98 (0.90, 1.06)
Model 3	Ref	0.93 (0.85, 1.00)	0.91 (0.84, 0.99)	1.06 (0.97, 1.15)
	Quartiles according to UPD consumption in g/1000 kcal			
	Q1(low) [<32]	Q2 [32–67]	Q3 [67–121]	Q4 (high) [>121]
N/ Events	9565/1396	9565/1102	9566/1064	9565/1135
Model 1	Ref	0.94 (0.87, 1.02)	0.99 (0.91, 1.07)	1.24 (1.14, 1.34)
Model 2	Ref	0.97 (0.89, 1.05)	0.99 (0.99, 1.07)	1.15 (1.06, 1.25)
Model 3	Ref	0.98 (0.90, 1.06)	1.00 (0.92, 1.08)	1.16 (1.07, 1.26)

Abbreviations: UPD, ultraprocessed drink; UPF, ultraprocessed food; UPFD, ultraprocessed food and drink.

Model 1 = age stratified and adjusted for sex.

Model 2 = Model 1 and adjusted for educational level, smoking status, physical activity, and total energy intake.

Model 3 = Model 2 and adjusted for BMI.

between UPF consumption and all-cause mortality observed in our study may be attributed to the comparatively less pronounced contrast between high and low UPF consumption as opposed to the contrast in UPD consumption. This might be explained by the relatively advanced age of the cohort and of the population within this cohort.

To facilitate the transition toward a healthier and more environmentally sustainable diet, recommended foods and beverages are ideally both the healthy and sustainable choice. Our findings underpin the adverse health effects of UPFD, and especially UPD, consumption. From a public and planetary health perspective, a lower consumption of UPDs results in win-wins. However, this is not directly applicable to UPFs, based on our study. Diets with higher shares of UPFs had lower environmental impacts; therefore, even the opposite might occur: by replacing UPFs with less processed alternatives with higher environmental pressure, the burden on the environment might increase while consumption is generally healthier. This is, for instance, the case when processed meat is replaced by unprocessed meat [29]. Further research is needed to quantify the impact on the environment of UPF and UPD consumption and to obtain a deeper understanding of their relationship.

Strengths and limitations

To our knowledge, this is the first study that examined the associations between UPFD, UPF and UPD consumption, environmental impacts, and all-cause mortality. Strengths of our study were its prospective design, relatively large sample size, and long follow-up time, which broadens the generalization of our results. Moreover, the inclusion of 6 environmental impact indicators enabled us to study the environmental effects of UPFD consumption on more than climate change only. Previous studies mainly focused on GHG emission and water use; however, as processing steps add up to, for instance, acidification, it is important to include other indicators, besides GHG emission and water use, for a comprehensive assessment.

This study also has limitations. Dietary data was collected using a FFQ that was not designed to collect data on the degree of food processing. For instance, misclassification could occur because, according

to the FFQ, it was not clear if tomato sauce was homemade (unprocessed or minimally processed food) or ready-to-eat (processed food). This complicates the classification of foods according to the degree of processing. In order to account for the variation in the level of strictness and the potential transition of food processing over time we applied a middle-bound scenario, which was developed previously by Cordova et al. [28] for the international EPIC study and most likely reflects the scenario in the nineties. Although the NOVA classification is most used to classify foods according to their degree of processing, insufficient standardization of the application of the methodology makes food classification with NOVA difficult [34] and can lead to confusion and subjective coding of foods and drinks [35]. The classification was cross-checked through the process of triangulation to minimize misclassification. Dietary data was collected between 1993 and 1997 and may not reflect current dietary patterns in the Netherlands. We used a single measurement of dietary intake data. In a comparison study with a second FFQ measurement of the EPIC-NL cohort in 2015, it was concluded that the consumption by food groups has not changed significantly [36]. A previous study has examined the consumption of UPFDs using the second FFQ from 2015 with slightly different application of the NOVA classification method and measured 37% energy intake derived from UPFD [37]. A Dutch food consumption survey (2012–2016), based on a repeated 24-h recall, estimated a share of UPFDs of 62% of energy intake [5]. The influence of differences in dietary assessment method, application of food processing application methods such as NOVA, and time period might have influenced the results and cannot be disentangled. Finally, it is important to note that although our dietary data is from the nineties, our environmental impact data is from 2019. Technological improvements in production over time may mean we are underestimating the absolute environmental impact of the diet in the nineties.

To conclude, reducing UPD consumption could lower environmental impact and all-cause mortality risk; however, this was not shown for UPFs. When categorizing food consumption by their degree of processing, trade-offs are observed for human and planetary health aspects.

Acknowledgments

The authors' responsibilities were as follows – REV, IvdB, EHMT, SB: conceptualization; REV, IvdB: investigation, methodology, formal analysis, visualization; REV, IvdB: writing – original draft; REV, IvdB, JMAB, YTvdS, MCH, WMMV, PvtV, EHMT, SB: writing – review and editing; EHMT, SB: supervision; and all authors: read and approved the final manuscript. The authors report no conflicts of interest.

Funding

The authors reported no funding received for this study.

Data availability

Data are available upon request.

Author disclosures

The authors report no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ajcnut.2023.05.021>.

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