Quantifying the Environmental and Food Biodiversity Impacts of Ultra-Processed Foods - Evidence from the EPIC Study

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Ethical Standards Disclosure: The present study is relevant to guide local agrifood systems transformation and nutrition research. Local research teams were invited to contribute to the manuscript and were included as co-authors in accordance with ICJME criteria.

This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by local ethics committees and by the Internal Review Board of the International Agency for Research on Cancer. Written informed consent was obtained from all subjects. For participants who were illiterate or otherwise unable to provide written consent, informed consent was obtained from a legal guardian or an appropriate representative on their behalf.

Data availability: EPIC data and biospecimens are available to investigators in the context of research projects that are consistent with the legal and ethical standard practices of IARC/WHO and the EPIC Centres. The use of a random sample of anonymized data from the EPIC study can be requested by contacting epic@iarc.fr. For information on the EPIC data access policy and on how to submit an application for gaining access to EPIC data and/or biospecimens, please follow the instructions at iarc.who.int

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Abstract

Objective: While associations of ultra-processed food (UPF) consumption with adverse health outcomes are accruing, its environmental and food biodiversity impacts remain underexplored. This study examines associations between UPF consumption and dietary greenhouse gas emissions (GHGe), land use, and food biodiversity.

Design: Prospective cohort study. Linear mixed models estimated associations between UPF intake (grams/day and kcal/day) and GHGe (kg CO_2-equivalents/day), land use (m^2/day), and dietary species richness (DSR). Substitution analyses assessed the impact of replacing UPFs with unprocessed or minimally processed foods.

Participants: 368,733 participants in the European Prospective Investigation into Cancer and Nutrition (EPIC) study.

Setting: Europe

Results: Stronger associations were found for UPF consumption in relation with GHGe and land use compared to unprocessed or minimally processed food consumption. Substituting UPFs with unprocessed or minimally processed foods was associated with lower GHGe (8.9%; 95%CI: -9.0; -8.9) and land use (9.3%; -9.5; -9.2) when considering consumption by gram per day and higher GHGe (2.6%; 95% CI: 2.5: 2.6) and land use (1.2%; 1.0; 1.3) when considering consumption in kilocalories per day. Substituting UPF by unprocessed or minimally processed foods led to negligible differences in DSR, both for consumption in grams (-0.1%; -0.2; -0.1) and kilocalories (1.0%; 1.0; 1.1).

Conclusion: UPF consumption was strongly associated with GHGe and land use as compared to unprocessed or minimally processed food consumption, while associations with food biodiversity were marginal. Substituting UPFs with unprocessed or minimally processed foods resulted in differing directions of associations with environmental impacts, depending on whether substitutions were weight- or calorie-based.

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1. Introduction

The food system's environment impact has become a pressing concern due to its contributions to greenhouse gas emissions (GHGe), land use, and biodiversity loss[1]. Intensive agricultural practices, especially monocultures like maize, wheat, and soy, degrade ecosystems and narrow crop diversity. Ultra-processed foods (UPFs), composed largely of ingredients produced from these high yield crops and livestock, have been indicated to have a negative impact on the environment due to their contribution to limited crop diversity and increased vulnerability to environmental pressures[2]. In addition, many UPFs are characterized by hyperpalatability, low satiety potential, and heavy marketing that can encourage overconsumption, leading to excessive food production and associated environmental pressures, while also contributing to significant public health challenges[3,4].

UPFs have been linked to negative health outcomes such as obesity, cardiovascular diseases, depressive symptoms, and certain cancers[5]. Consequently, countries like Mexico have incorporated recommendations to limit UPF consumption in dietary guidelines[6]. However, the environmental impacts of UPFs have received less attention, and the potential implications of substituting UPFs with unprocessed or minimally processed foods remain underexplored. With diets shifting toward greater UPF consumption globally, understanding their impact on the environment is critical, particularly in terms of GHGe, land use, and preservation of food biodiversity[7–9]. This convergence suggests that UPF-driven overconsumption represents a shared pathophysiological mechanism underlying both human and environmental health. The same hyperpalatable formulations, low satiety signals, and marketing strategies that promote excessive energy intake, could simultaneously drive increased food demand and production, amplifying environmental pressures. This dual pathway through overconsumption represents a novel framework for understanding how food processing impacts both human and planetary health through a common mechanism.

This study examined the relationship between dietary intake across food processing levels and environmental outcomes—specifically GHGe, land use, and food biodiversity—and evaluates the potential impact of substituting minimally processed foods for UPFs among adults in the European Prospective Investigation into Cancer and Nutrition (EPIC) cohort.

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2. Methods

2.1. The EPIC cohort

The EPIC cohort is a large multicentre cohort examining the links between metabolic, lifestyle, and environmental factors of cancer and chronic diseases. Between 1991 and 2000, over 500,000 participants aged 25–70 were recruited across 23 centres in 10 European countries: Denmark, France, Germany, Greece, Italy, the Netherlands, Norway, Spain, Sweden, and the United Kingdom. Dietary intake at enrolment was assessed using validated, country-specific questionnaires capturing habitual consumption over the past 12 months[10]. In order to study associations in a disease-free population participants with missing dietary data, extreme energy intake-to-requirement ratios, lack of follow-up, or prevalent diseases at baseline were excluded. Due to administrative constraints, cohorts from Greece, Norway, and Sweden were excluded, resulting in 368,733 participants (Supplemental Figure 1).

2.2. Dietary Assessment

In the 1990s, participants' usual food intake over the previous 12 months was assessed at baseline with country-specific dietary questionnaires. Depending on the study centre, quantitative dietary questionnaires, semi-quantitative food-frequency questionnaires, or a combination of semi-quantitative food-frequency questionnaires and 7-day food records were used. Data on frequencies, portion sizes, or intakes in grams per day were stored in a central IARC database[10]. Post-harmonization of dietary data was conducted, following standardized procedures (e.g., disaggregating recipes into ingredients), to obtain a standardized food list for which the level of detail is comparable between countries. The EPIC food composition database comprises more than 11,000 food and beverage items reflecting the specificities of each country.

2.3. Exposure - Nova classification

Standardized EPIC food items were categorized by processing level using the Nova classification: Nova 1 (unprocessed or minimally processed foods, e.g., fruits, vegetables), Nova 2 (processed culinary ingredients, e.g., oils, sugar), Nova 3 (processed foods, e.g., cheese, bread), and Nova 4 (UPFs, e.g., soft drinks, flavoured yoghurts). Since the Nova classification system was developed after the EPIC dietary data collection, there was some uncertainty in classifying certain food items according to their level of food processing. Therefore, three classification

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scenarios were developed to address this uncertainty, a lower, middle, and upper-bound scenario. This study used the most probable, middle-bound scenario[11]. Dietary contribution from each Nova class was expressed in both grams and kcal per day, as grams reflect absolute consumption, while kcal accounts for energy density, providing complementary insights into environmental impacts.

2.4. Outcomes - Environmental impacts and food biodiversity

Environmental outcomes were assessed using the SHARP indicators database, which estimates GHGe and land use from life cycle assessment data encompassing production, packaging, transport, and preparation[12]. Food items were matched between the EPIC and SHARP databases using EFSA's FoodEx2 base-term codes[13]. Diet-related GHGe and land use were computed for each individual by summing the amounts for all foods consumed; GHGe was expressed as kg CO_2-equivalents per day and land use as m^2 per day[12,13]. Food biodiversity was quantified using dietary species richness (DSR), defined as the count of unique biological species consumed across foods, beverages, and mixed dishes[14]. Composite foods were decomposed into ingredients using standard recipes and foods consumed "never or less than once per month" were not considered in the DSR computation.[14]

2.5. Study covariates

Sociodemographic and anthropometric covariates included in the models were: age at recruitment, body mass index height, sex, educational level, smoking status at baseline, physical activity using the Cambridge index, and alcohol intake.

2.6. Statistical analysis

Consumption of the Nova classes (gram/day or kcal/day) was modelled as continuous variables. Multivariable mixed linear models with random intercepts for study centres and adjustment for sociodemographic and anthropometric variables were fitted to assess associations between Nova class consumption, GHGe, land use, and DSR. Additive models assessed associations of the additional consumption of a Nova class. For this, weight- and energy-based all-component models were constructed, mutually adjusting for each Nova class, to account for the total weight or energy intake[15]. Additionally, substitution analyses were performed, using the 'leave-one-out' method estimated associations of replacing a specific amount of Nova 4 with Nova 1, by keeping

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total intake constant[16]. For instance, the substitution of Nova 4 by Nova 1 in GHGe can be parameterised as:

$$\text{GHGe} = \alpha + \gamma_1 \text{Nova 1} + \gamma_2 \text{Nova 2} + \gamma_3 \text{Nova 3} + \gamma_4 \text{total intake} + \text{covariates} + (1 \mid \text{Study Centre}) + \varepsilon$$

Here, γ_1 represents the relative estimate for replacing a quantity of Nova 4 with an equivalent amount of Nova 1, keeping the total intake constant.

Estimates were expressed as: 1) a 1-standard deviation (SD) increment in consumption of a Nova class, or 2) a 10% increase from the mean absolute total dietary intake. To interpret the results as percentage differences, these estimates were divided by the mean value of the respective outcome measure.

Sensitivity analyses included baseline models only mutually adjusted for each Nova class and main models further adjusted for the Mediterranean diet score (0–18 points)[17]. Statistical analyses were performed in RStudio (v4.0.4.1) with two-sided testing, and P-values <0.05 were considered statistically significant.

3. Results

3.1. Sample characteristics

This study included 368,733 participants from the EPIC cohort, of whom 259,268 (70.3%) were females. The mean (SD) age at recruitment was 51.3 (9.9) years, and the average BMI was 25.4 (4.3) kg/m² at baseline. On average, participants consumed 364 gram (278) or 672.9 kcal (412.0) of UPFs daily, representing 12.9% (8.5) of total intake by weight and 30.5% (15.3) by energy. Mean dietary GHGe and land use were 5.3 (1.82) kg CO_2-equivalents per day and 6.9 (2.6) m² per day, respectively. Average DSR was 68.2 (15.2) species per year (**Table 1**).

3.2. Associations between Nova class consumptions and GHGe, land use and food biodiversity

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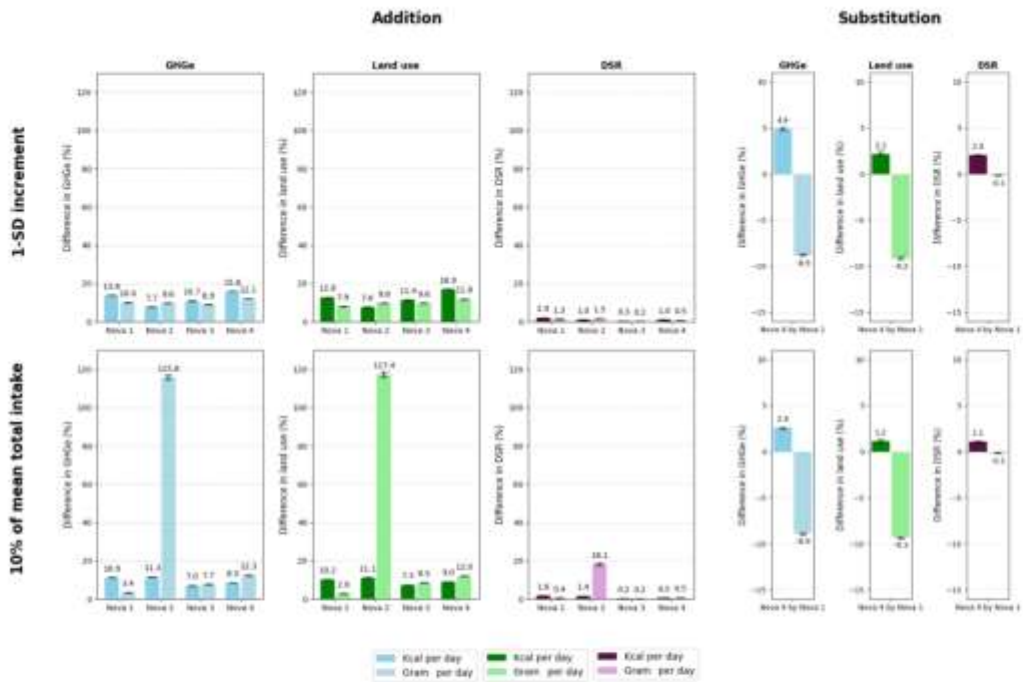

Figure 1 illustrates the percentage difference relative to the mean of GHGe, land use, and DSR associated with higher consumption of each Nova class. A 1-SD increment in consumption of each Nova class, either in gram or kcal per day, was associated with significantly higher GHGe, land use, and DSR, with Nova 4 consumption being more strongly associated with GHGe and land use compared to Nova 1. To illustrate, a 1-SD increment of Nova 4 consumption in kcal per day was related to 15.8% (95%CI: 15.8; 16.0) higher GHGe, 16.9% (16.9; 17.1) higher land use, and 1.0% (0.9;1.1) higher DSR, while for Nova 1 this was 13.8% (13.8; 14.0) for GHGe, 12.8% (12.7; 14.0) for land use. Similar findings were reported for consumption of the different Nova classes in grams/day. Strengths of associations differed within Nova 4 subgroups, with animal-based products showing the strongest positive associations with GHGe and land use, while plant-based alternatives and savoury snacks showed the weakest associations (**Supplemental table 1**).

3.3. Substitution of ultra-processed with unprocessed or minimally processed foods

10% of the mean total intake in grams per day substitution of Nova 4 substitution with Nova 1 was associated with 8.9% (95%CI: -9.0; -8.9) lower GHGe and 9.3% (-9.5; -9.2) lower land use (**Figure 1**). However, such a substitution was related to marginally lower DSR (-0.1%; -0.2; -0.1). Conversely, a Nova 4 substitution with Nova 1, 10% of the mean total intake in kcal per day, was associated with higher GHGe (2.6%; 2.5: 2.6), land use (1.2%; 1.0; 1.3), and DSR (1.0%; 1.0; 1.1) (**Figure 1**).

Sensitivity analysis confirmed our main findings (data not shown).

4. Discussion

This study found that higher UPF consumption was more strongly associated with increased dietary GHGe and land use compared to unprocessed or minimally processed foods. For DSR, associations were shown to be marginal. Energy-based substitution of UPFs with unprocessed or minimally processed foods were associated with higher environmental impacts, whereas weight-based substitutions were associated with lower environmental impacts.

These discrepancies likely stem from the higher energy density of UPFs. Energy-based substitutions require larger quantities of unprocessed or minimally processed foods to achieve isocaloric substitutions, potentially increasing environmental impacts[18]. Research suggests that individuals consuming diets high in unprocessed or minimally processed foods tend to have lower energy intake compared to those with UPF-rich diets, meaning isocaloric substitution may not fully capture these differences[19]. In contrast, weight-based substitutions, which emphasize food weight rather than caloric equivalence, show environmental benefits that align with UPFs' well-documented tendency to promote overconsumption through their hyper palatability, low satiety, softer textures requiring less chewing, widespread availability, and lower cost per calorie, which could lead to excessive energy intake, contributing to rising obesity rates[3,4,19]. Such overconsumption drives higher demand for foods, amplifying environmental impacts further. Additionally, while low-impact plant-based UPFs have lower environmental footprints, animal-based UPFs remain highly impactful, underlining the importance of considering UPF subgroups[20,21]. These findings support the hypothesis that overconsumption serves as a critical link between UPF consumption and environmental harm, paralleling established mechanisms for UPF-associated health risks.

Additionally, negligible DSR differences were observed when substituting UPFs with unprocessed or minimal foods, diverging from findings in Brazilian diets where UPFs involved fewer species[8]. This discrepancy may reflect methodological differences: the Brazilian study examined species diversity within UPF products at the food system level, while our analysis assessed how individual dietary patterns relate to overall species consumption.

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Our findings suggest that food biodiversity operates independently from processing level in individual diets. Substituting UPFs with unprocessed foods may not increase species diversity if individuals simply as individuals might simply consume larger quantities of the same limited set of species they already consume. Therefore, reducing UPF consumption alone may be insufficient to improve dietary biodiversity without concurrent efforts to promote species diversification. Alternatively, UPF-driven overconsumption may increase total food intake, maintaining dietary species richness through higher consumption volumes rather than dietary diversification.

Limited observational evidence on UPFs' environmental impacts exists, with most insights coming from life cycle assessments[22]. In a French cohort study, it was found that UPFs accounted for 19% of energy intake in the diet and contributed to 24% of greenhouse gas emissions (GHGe), 23% of land use, and 26% of energy demand. These highlight the significant environmental burden associated with diets rich in UPFs, with higher contributions from post-farm stages, in particular processing regarding energy demand[23]. A longitudinal study showed reducing UPF consumption lowered GHGe and energy demand, but increased water use[24]. Our study is unique in its large, diverse European cohort, allowing a comprehensive assessment of food processing levels and substitution effects.

Several limitations must be acknowledged. The EPIC cohort may differ substantially from current European populations. UPF intake has risen dramatically—from approximately one-third of energy intake in our cohort to over half in recent studies, due to changes in food environments and consumption patterns[25]. Although educational attainment has increased across EU member states, this has not corresponded with expected reductions in UPF consumption, suggesting altered socioeconomic determinants of dietary choices[26]. The shift toward sedentary lifestyles correlates with increased convenience food reliance, while younger populations exhibit greater price sensitivity toward UPF products[27,28]. These transitions suggest our cohort likely underestimates the environmental impacts of contemporary European diets. Misclassification within the Nova system and reliance on SHARP database estimates, which lack country specificity and farming method variations, may introduce error. Additionally, many UPF-specific ingredients (e.g., additives) lack environmental impact assessments, and UPFs typically rely on more intensively produced commodity ingredients than non-UPFs, differences our analysis cannot fully capture. These errors might attenuate the true associations due to non-differential measurement error. Variations in dietary assessment methods and the number of items included between centres could also affect DSR, and taxonomic limitations hinder further analysis of food biodiversity. The questionnaires did not distinguish between homemade and industrially processed foods, which could overlook ingredient differences leading to varying environmental impacts. Lastly, this study compared individuals rather than actual substitutions, and context-specific factors such as preparation time, cost, and food safety may influence dietary shifts and willingness to make substitutions[29,30]. For instance, while unprocessed or minimally processed foods are often more nutrient-dense, UPFs offer greater accessibility and food safety[31].

In conclusion, UPF consumption was more strongly associated with GHGe and land use as compared to unprocessed or minimally processed food consumption, while associations with food biodiversity were marginal. Substituting UPFs with unprocessed or minimally processed foods resulted in differing directions of associations with environmental impacts, depending on whether substitutions were weight- or calorie-based.

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Table 1. Baseline characteristics of 368,733 middle-aged adults enrolled in the European Prospective Investigation into Cancer and Nutrition (EPIC) study.

	Mean (SD) / N (%)
Nova 4 (% gram per day)	12.93 (8.52)
Nova 3 (% gram per day)	14.28 (10.56)
Nova 2 (% gram per day)	1.23 (1.06)
Nova 1 (% gram per day)	71.56 (12.50)
Nova 4 (% kcal per day)	30.55 (15.3)
Nova 3 (% kcal per day)	25.81 (12.04)
Nova 2 (% kcal per day)	7.95 (6.23)
Nova 1 (% kcal per day)	35.70 (10.62)
Dietary greenhouse gas emissions (kg CO_2 equivalents per day)	5.30 (1.82)
Dietary land use (m^2 per day)	6.86 (2.62)
DSR (count of unique species consumed per year)	68.22 (15.22)
Age at recruitment (years)	51.29 (9.90)
Body mass index (kg per m^2)	25.35 (4.25)
Height (cm)	165.67 (8.92)
Sex	
Male	109,465 (29.7%)
Female	259,268 (70.3%)
Country	
Denmark	55,014 (14.9%)
France	67,920 (18.4%)
Germany	49,352 (13.4%)
Italy	44,547 (12.1%)
Spain	39,990 (10.8%)
The Netherlands	36,538 (9.9%)
United Kingdom	75,372 (20.4%)
Education level	

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None or primary school completed	102,198 (27.7%)
Technical/professional school	80,266 (21.8%)
Secondary school	75,288 (20.4%)
Longer education (including university degree)	94,312 (25.6%)
Unknown	16,669 (4.5%)
Smoking status	
Never	184,435 (50.0%)
Current	99,923 (27.1%)
Former	78,175 (21.2%)
Unknown	6,200 (1.7%)
Cambridge physical activity index	
Inactive	76,776 (20.8%)
Moderately inactive	125,817 (34.1%)
Moderately active	88,476 (24.0%)
Active	70,923 (19.2%)
Unknown	6,741 (1.8%)
Alcohol intake	
Non-drinker	44,761 (12.1%)
> 0 to 6 gram per day	96,866 (26.3%)
> 6 to 12 gram per day	96,048 (26.0%)
> 12 to 24 gram per day	64,086 (17.4%)
> 24 gram per day	66,972 (18.2%)

DSR, dietary species richness. Nova 1, unprocessed or minimally processed foods. Nova 2, processed culinary ingredients. Nova 3, processed foods. Nova 4, ultra-processed foods

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