Dietary environmental impacts of French adults are poorly related to their income levels or food insecurity status

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Highlights

- Environmental impacts (15 indicators) of French adult diets were highly variable
- Higher water use in high income groups was related to higher fruit & vegetable intakes
- Higher eutrophication in high income groups was related to types of fish consumed
- For other indicators, variability was not linked to income or food insecurity status

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Abstract

Purpose: Recent global-scale analysis showed the extent of inequality in terms of carbon emissions related to overall consumption, with richer households emitting significantly more greenhouse gases than poorer ones. While socio-economic status is a known determinant of food consumption, and despite the urgent need to move towards more sustainable diets, very few studies have explored socio-economic differences regarding the environmental impacts of diets. The objective of the present study was to compare the environmental impacts of French adults' diets according to food insecurity (FI) status and income level.

Methods: The environmental impacts of diets of a representative sample of adults living in France (n=1964) were assessed using data from the last National Individual Food Consumption Survey (INCA3) and the Agribalyse® v3.0.1 environmental database. Fifteen impact indicators were estimated, including climate change, eutrophication (freshwater, marine, terrestrial), resource depletion (energy, minerals, water), and the single EF score. First, the mean diet-related impact (per day per person) was estimated for each environmental indicator by decile of environmental impact. Second, the environmental impacts of diets of individuals living in food insecure households (severe and moderate FI, as measured by the Household Food Security Survey Module) were compared with those of individuals living in food-secure households, the latter being divided by income decile. Differences in environmental impacts of diets (total and by food group) between these 12 sub-populations were tested by ANOVA after adjustment for age, gender, energy intake and household size.

Results: The 10% of the population with the highest environmental impact has a mean impact approximately 3 to 6 times higher than the 10th with the lowest environmental impact, depending on the indicator. Individuals living in households with severe and moderate FI represented 3.7% and 6.7% of the studied population, respectively. Results showed a high variability in impacts within each of the 12 sub-population and no difference in environmental impacts of diets between sub-populations, except for water use ($p<0.001$) and freshwater eutrophication ($p=0.02$). The lowest water use and freshwater eutrophication were observed for individuals living in households with severe FI and the highest for high income sub-populations, with differences mainly explained by the level of fruit and vegetable intakes and the type of fish consumed, respectively. Low-income populations, in particular individuals living in households with severe FI, had relatively high intakes of ruminant meat but for most indicators, the high environmental impact of this food group was offset by low consumption of other high impacting food groups (e.g. fruits and vegetables), and/or by high consumption of low impacting food groups (e.g. starches), resulting in no difference in the impact at the diet level.

Conclusion: While there is a high inter-individual variability in the environmental impacts of diets, this variability was not related to income level or FI status for most indicators, except higher water use and freshwater eutrophication in higher income populations. Overall, our results underline the importance of considering individual dietary patterns and thinking at the whole diet level, and not only considering specific food or food groups impacts, when designing educational tools or public policies to promote more sustainable diets.

Keywords: diet, environment, nutrition, sustainability, climate change, water use

1 Introduction

The sixth assessment report of the Intergovernmental Panel on Climate Change warned on the scale of recent changes across the climate system and the urgent need to limit human-induced climate change [1]. A recent global scale analysis of the distribution of consumption emissions among households in different income classes between 1990 and 2015 highlighted the extent of global carbon inequality, showing that the high-income groups continue to generate by far a disproportionate share of global emissions [2]. In 2015, the consumption of the richest 10% were linked to nearly half of global carbon emissions, and the average per capita consumption emissions linked to the top 1% were over 100 times greater than those of the poorest half of the world's population.

Among consumption sectors, food is a substantial driver of climate change and resources depletion. Current food system representing 34% of global greenhouse gas emissions (GHGE) [3] and ~70% of global freshwater use [4], dietary changes are identified as a lever to mitigate the environmental impact of food system, in combination with change in food production and transformation, and reduction of food loss and waste [5]. While it is well known that dietary intakes vary by income and socio-economic groups [6], most studies exploring food consumption changes towards more sustainable diet are based on a population-level analysis rather than exploring the differences within the population. Previous studies carried out in Europe, Brazil, the US and China have assessed the association between the environmental impact of diet and socio-economic status, but findings differ: some studies reported that diets of higher income populations have greater environmental impacts [7–9], some observed similar impacts across income quintiles [10, 11], and some authors highlighted that impact can be higher for low and medium income classes [12, 13].

Inequalities in food consumption, linked to income [14] and to food security status [15], have been documented in France, but no study explored the implications of these inequalities in terms of diet-related environmental impacts in a representative sample of the general population. The latest French Individual and National Food Consumption survey (named INCA3) did not describe dietary intakes across income levels, but documented differences across level of education [16], showing in particular higher intakes of meat (excluding poultry) for lower education level. Those results raise the question of whether or not such differences in intakes might be reflected in the environmental impact of diets, given the disproportionally high impact of ruminant meat [17].

Furthermore, income alone is probably not sufficient to explain the socio-economic differences in food consumption. Previous research showed that within low or intermediate income groups, dietary intakes differ according to food insecurity (FI) status [15]. Food insecurity refers to the situation where “the availability of nutritionally adequate and safe foods or the ability to acquire acceptable food in socially acceptable ways is limited or uncertain”[18]. In France, according to the INCA3 survey, 11% of adults lived in households experiencing food insecurity [16].

Hence, there is a gap in knowledge regarding socio-economic differences in the environmental impacts of food consumption, especially in France. Studies are needed to document inequalities, and better understand if dietary intakes of specific sub-populations require dedicated transition strategies towards more sustainable diets. The present study aimed to assess the environmental impacts associated to the dietary intakes of a representative sample of French adults in relation to their income level and food security status

2 Methods

2.1 Population sample and dietary data

Food consumption data of French adults (≥18 years old), household food insecurity status and socio-economic characteristics were derived from the Third French Individual and National Food Consumption (INCA3) Survey 2014-2015, a cross-sectional survey carried out between February 2014 and September 2015 among a representative sample of individuals living in mainland France [16].

The dietary intake of the individuals was collected over 3 non-consecutive days (2 weekdays and 1 weekend day) spread over around 3 weeks, using the 24h-recall method. A total of 2,121 adults validated their participation by responding at least to two dietary interviews.

Foods declared as consumed by participants were categorized into 12 groups (Fruit & vegetables, Starch, Dairy, Ruminant meat, Eggs & poultry, Other meat & processed meat, Fish, Mixed dishes, Foods high in fat sugar and salt (HFSS), Drinks, Fats, Others) and 25 subgroups (see details in **Supplemental Table 1**).

2.2 Food insecurity

Food insecurity status was estimated using the six-item short form of the U.S. Household Food Security Scale [19] which ask participants whether the following statements were often, sometimes, or never true for them or their household in the last 12 months: ‘The food that (I/we) bought just didn’t last, and (I/we) didn’t have money to get more’; ‘(I/we) couldn’t afford to eat balanced meals’. Respondents who reported ‘sometimes’ or ‘often’ to at least one of the latter statements were asked additional questions: ‘In the last 12 months, did (you/you or other adults in your household) ever cut the size of your meals or skip meals because there wasn't enough money for food’; ‘How often did this happen’; ‘In the last 12 months, did you ever eat less than you felt you should because there wasn't enough money for food?’; ‘In the last 12 months, were you every hungry but didn't eat because there wasn't enough money for food?'. Responses of 'often', 'sometimes', 'almost every month' and 'some months but not every month' were coded as affirmative. It is considered that an individual live in a food secure (FS) household for a score (sum of affirmative responses) of 0 or 1, in a moderately food insecure (MFI) household for a score between 2 and 4, and in a severely food insecure (SFI) household for a score of 5 or 6.

2.3 Income level

In order to assess the standard of living of individuals and allow comparison between individuals from households of different sizes or compositions, income level was normalized using an equivalence scale, i.e. a weighting system assigning a coefficient to each member of the household, normalized to 1 for the first adult corresponding to 1 consumption unit (CU), and less than 1 for the other members of the household in order to take into account the existence of economies of scale. Income per consumption unit was calculated as self-reported household total net income divided by the number of consumption units in the household. As the age of children in the household was not available, calculation of the number of consumption units was adapted from the methodology of the French National Institute of Statistics and Economic Studies (originally 1·consumption unit for the householder, 0.5 for other household members aged 14 or over, and 0.3 for each child aged less than 14 years old) and computed as follow: 1·consumption unit for the first adult, 0.5 for other household adults (aged 18 or over), and 0.3 for each child (< 18 years old).

Knowing that both income and food insecurity status influence food consumption, the population was first split into food secure vs. food insecure sub-populations, and then according to income within the FS sub-population. Adults living in households experiencing food security were divided into ten categories according to decile of the household income per consumption unit: FS1 (FS individuals in the lowest decile of income per consumption unit) to FS10 (FS individuals in the highest decile). Due to the expected small sample size and low income level of the food insecure sub-population, it was not divided according to income.

2.4 Environmental impacts of diets

The environmental impacts of diets were assessed using estimates from the Agribalyse v3.0 database [20] which provides life cycle inventory for 2500 food items registered in CIQUAL, the French national nutritional database. The environmental impact of diet was estimated for 15 different indicators: 14 midpoint impact categories calculated using the Environmental Footprint (EF3) method (climate change, ozone depletion, acidification, photochemical ozone formation, fine particulate matter, freshwater eutrophication, marine eutrophication, terrestrial eutrophication, energy use, water use, use of mineral resources, land use, ionizing radiation and freshwater toxicity), and the EF3 single score recommended by the European Commission, which is an aggregate score that refers to the overall environmental impact after normalization and weighting of 16 LCA impact categories; it is expressed in milli-point (mPt), 1 Pt being representative of the annual environmental impact of a European resident. The weighting takes into account both the relative robustness of each of the 16 impact categories and the environmental challenges. Further explanations of the 14 midpoint impact categories can be found in the Supplementary material. The environmental impacts of diets were assessed for the whole sample and for the 12 sub-populations: SFI, MFI and FS1 to FS10.

2.5 Statistical analyses

In order to ensure the national representativeness of the results presented, weighting factors - accounting for geographic and socio-economic variables - provided with the INCA3 survey were taken into account for analyses. For each environmental indicator, the mean impact (per day per person) was estimated for the final sample, and by decile of environmental impact. The interdecile ratio was computed by dividing the mean impact in the 10th decile to that of the 1st

decile; it allows capturing the extent of disparities, that is, how different the highest and lowest deciles are, in ratio format. Socio-demographic characteristics and diet-related environmental impacts (total and by food groups) were compared between the sub-populations using the $\chi 2$ test for categorical variables and ANOVA for continuous variables. Comparisons of daily environmental impacts were adjusted for age, gender, total energy intake, and number of household members. Then, for indicators with significant differences among the 12 sub-populations, multiple comparisons were conducted using Bonferroni post hoc tests. Statistical analyses were computed using SURVEYFREQ and SURVEYREG of SAS Statistical Software (version 9.4) and the threshold for statistical significance was $p < 0.05$.

3 Results

3.1 Prevalence of food insecurity

The prevalence of severe and moderate food insecurity in the total sample (n=2,121) were 3.5% and 6.2%, respectively. Household income was not reported for 157 FS participants, who were removed from sample for analyses, leading to a final sample of 1,964 individuals. In the final sample of adults, 3.7% and 6.7% were considered as living in a household experiencing severe and moderate food insecurity, respectively.

3.2 Socio-economic characteristics

Socio-economic characteristics of participants are presented in Table 1. Approximately 46% of the participants were aged under 45 years, and 51.6 % were women. The mean income per consumption unit was 1,543 € (SE 32) per month. The mean income levels of the severe (706€/month) and moderate (935€/month) food insecure households were higher than in the 1st decile of food secure households (425€/month). All socio-demographic characteristics differed significantly among the 12 sub-populations, except for gender.

3.3 Dietary intakes

Mean food group intakes in the 12 sub-populations, after adjustment for age, gender, total energy intake, and number of household members, are shown in **Figure 1** and **Supplemental Figure 1**. There was a significant difference in quantities consumed between sub-populations for the Fruit & vegetables, Ruminant meat, and Fats groups. The lowest intake of Fruit & vegetables was observed in SFI individuals (231 g/day); the other sub-populations had intakes ranging between 341 g/day (MFI individuals) and 492 g/day (FS4 individuals). The lowest intake of Ruminant meat was observed for FS5 individuals (20 g/day), and the highest for FS1 individuals (49 g/day). SFI individuals also had relatively high mean intakes of ruminant meat (40 g/day). For fats, the highest intake was observed for SFI individuals (26 g/day), and the lowest for MFI individuals (13 g/day). At the food subgroup level (**Supplemental table 1)**, significant differences of intakes were observed among sub-populations for Fruits, Vegetables, Animal fats and Water.

3.4 Daily diet-related environmental impacts

The mean daily diet-related environmental impacts (EF single score and the 14 midpoint impact categories) estimated on the final sample are presented in **Table 2**.

Estimations by decile of each environmental impact and computation of the interdecile ratio showed that the first decile, i.e. the 10% of the population with the lowest impact per day per person, has a mean impact approximately 3 to 6 times lower (depending on the environmental indicator considered) than the 10^{th} decile, i.e. the 10% with the highest impact (**Table 2**). This shows a high inter-individual variability of the environmental impacts of diets.

The daily diet-related environmental impacts (mean and IC95) by sub-populations are presented for the 15 indicators in **Figure 2**. After adjustment, there was no significant differences in the environmental impacts between the 12 sub-populations, except for water use ($p<0.001$) and freshwater eutrophication (p=0.02). For these 2 indicators, the lowest environmental impact was observed for the SFI sub-population.

Pairwise comparisons between sub-populations using post hoc tests showed that water use was significantly lower for SFI in comparison to FS1 and FS4 to FS10 sub-populations (**Figure 3A**). For freshwater eutrophication, the impact was significantly lower for the SFI sub-population in comparison to the FS10 one (**Figure 3B**).

3.5 Diet-related environmental impacts by food group

The environmental impacts by food group were more specifically explored for the 2 indicators that showed significant differences between sub-populations at the total diet level, namely water use and freshwater eutrophication (**Figure 4**). Results for the other 13 indicators are shown in Supplemental Material. The significant differences observed between sub-populations for water use and freshwater eutrophication were related to the consumption of three food groups: Fruit & vegetables, Fish products and Fats between sub-populations (**Figure 4 and Supplemental Figure 2**). For water use (**Figure 4A**), the difference between sub-populations was mainly explained by the impact related to the consumption of Fruit & vegetables: the lowest impact related to Fruit & vegetables intakes was observed for SFI (1.35 m3 deprivation/day) and the other sub-populations had impacts ranging between 2.16 to 3.04 m3 deprivation/day. For freshwater eutrophication (**Figure 4B**), the difference between sub-populations was mainly explained by the impact related to the consumption of Fish: the lowest impact related to Fish was observed for SFI (0.059 E-03 kg P eq/day) and the highest impact for FS10 (0.258 E-03 kg P eq/day). It should be noted that there was no significant difference in the amount of Fish consumed between sub-populations (see "Dietary intakes" and **Figure 1**). Supplemental Figure 2 details the quantities consumed (panel A), water use (panel B) and freshwater eutrophication (panel C) impacts for the three food groups, showing significant differences in impacts between sub-populations: for Fruit and vegetables, differences in impacts were clearly related to differences in amounts consumed, but for Fish, intakes were similar, showing that impacts differences were related to the types of fish consumed. Further analyses (data not shown) indicate that higher income groups had higher intakes of salmon (which is among the highest impacting food within the fish group), whereas lower income groups had higher consumption of pollock and breaded fish (data not shown).

For each of the other 13 environmental indicators (those with no significant difference between sub-populations at the total diet level), the impacts associated with the consumption of the different food groups by the 12 sub-populations (SFI, MFI, FS1 to FS10) are presented in **Supplemental Figure 3**, and the statistical significance of the differences between the 12 sub-populations s by food group are summarized in **Supplemental Table 2**. Results showed that the environmental impact related to Fruit & vegetables consumption was significantly different among the 12 sub-populations for all indicators (**Supplemental table 2**), with the lowest impact observed for the SFI sub-population (**Supplemental Figure 3**). The environmental impact related to Fats consumption was significantly different among sub-populations for most indicators, however the contribution of this food group to daily environmental impact remained very low (≤2%) whatever the indicator. The environmental impact related to Ruminant meat consumption was significantly different among the 12 sub-populations for 9 indicators (EF single score, climate change, fine particulate matter, acidification, terrestrial eutrophication, ionizing radiations, photochemical ozone formation, land use, and use of mineral resources), with the highest impact observed for the FS1 sub-population. Impact of Starch consumption was significantly different between sub-populations for 6 indicators: ozone depletion, acidification, terrestrial eutrophication, ionizing radiations, energy use, and use of mineral resources. Overall, results of the analysis by food group suggest that for the 13 indicators, differences in impacts related to specific food groups offset each other and result in no significant difference in daily diet impact. In particular, individuals living in households experiencing severe FI had relatively high intakes of ruminant meat but for most indicators, the high environmental impact of this food group was offset by low consumption of other high impacting food groups (e.g. fruits and vegetables), and/or by high consumption of low impacting food groups (e.g. starches), resulting in no difference in the impact at the diet level.

4 Discussion

Based on the latest nationally representative study on individual food consumption in French adults and 15 environmental impact indicators estimated using Life Cycle Assessment method, results from the present study indicate that, after adjusting for confounders, there was no significant difference in diet-related environmental impacts according to income and food insecurity status, except for 2 indicators: water use and freshwater eutrophication. For both indicators, higher impacts were observed for high income sub-populations and was mainly explained by greater fruit and vegetable intakes, and by differences in the type of fish consumed.

In France, previous studies described socioeconomic differences in dietary intakes across levels of income [14] and education [16], raising the question of whether such differences in intakes are reflected in the environmental impact of diets. An originality of the present study is to not limit the analysis of diet-related environmental impacts across income levels but to also consider food insecurity status. Indeed, previous research in French adults showed that within low or intermediate income groups, dietary intakes differed according to food insecurity status [15], in particular regarding the consumption of fruit and vegetables and fish. Low income is actually one of the most important determinant of food insecurity, however food insecurity is not just about income poverty: the determinants of food insecurity are multidimensional and associated with several other demographic and socio-economic factors such as housing and other material conditions or single-parenting [21]. Accordingly, in the present study, mean income of the households experiencing severe and moderate food insecurity was higher than in the 1st decile of income of food secure households.

After adjusting for confounders, differences in food group intakes between the sub-populations were significant only for three food groups, i.e. Fruit & vegetables, Ruminant meat, and Fats. As ruminant meat, in particular, is the food with the highest climate change impact per gram [17], one may have expected that differences in ruminant meat intakes would drive differences in the environmental impact of diets. Interestingly, while our results showed that, for most environmental indicators, the impact of ruminant meat consumption did differ across sub-populations, when estimated at the whole diet level the environmental impacts were not significantly different across levels of income and FI status. Such an apparent discrepancy could be explained by the fact that in self-selected diets, high consumption of high impacting food groups (e.g. ruminant meat) can be offset by low consumption of other high impacting food groups (e.g. fruits and vegetables), and/or by high consumption of low impacting food groups (e.g. starches), as observed for the SFI sub-population. This underlies the high inter-individual variability of the environmental impacts within each sub-population, resulting in no significant differences between sub-populations. These results underline the importance of thinking in terms of total diet when exploring diet sustainability, and not only considering the environmental impacts of specific food and food groups. In that connection, the fact that the ranking of the environmental impact of food items differs depending on the functional unit used to express the impact (e.g. per kg or per kcal) suggests that LCA data on food items are not sufficiently informative to guide food choices and need to be integrated at the diet level [22, 23]. Moreover, results suggest that the higher consumption of meat among low-income populations should not be an argument to design guilt-inducing messages since for most indicators there was no difference in the environmental impacts of their diets compared to high-income populations.

It is only for water resources depletion and freshwater eutrophication that differences in total daily impacts were found, with higher impacts observed for higher incomes categories. For both indicators, the lower environmental impact associated with the diet of adults living in households experiencing SFI was mainly due to a lower intake of fruits and vegetables (231g/day for SFI, vs. 341-492 g/day for other sub-populations). Interestingly, whereas total amounts of fish consumed were similar across sub-populations (differences were not statistically significant), the impacts related to this group were 4 times (freshwater eutrophication) to 6 times (water use) higher for FS10 than for SFI sub-population. This suggests that differences in impact were not related to the total quantity but to the types of fish consumed. Indeed, results indicated a higher consumption of salmon for high income populations and, conversely, a higher consumption of pollock and breaded fish for low income populations (data not shown), with salmon having a 40-fold greater impact per kg (vs. pollock) for indicators of freshwater eutrophication and water use. In addition, water use and freshwater eutrophication impacts were greater for high-income sub-populations in comparison with the SFI sub-population, but not in comparison with the lowest income food-secure sub-population (i.e., FS1). In accordance with a previous study in French adults [15], this suggests the importance of considering other indicators than the level of income when characterizing diet inequalities, and to distinguish between the diets of low-income individuals, depending on whether they are living in a household experiencing food insecurity or not.

In the literature, the relation between income and the environmental impact of diets is poorly studied, and conclusions differ. Regarding climate change, our results are consistent with two previous studies conducted in the UK and the Netherlands that similarly found no income-related differences in diet-related GHGE [10, 11]. On the opposite, a recent study in a large cohort of French adult volunteers showed that low-income individuals had lower environmental impacts than those in the highest income category [24]. This study used a synthetic environmental score including GHGE, cumulative energy demand, land occupation, and organic food consumption (the latter indicator was used as a proxy for biodiversity). However, study participants are adult volunteers enrolled in a cohort focusing on nutrition and health and therefore more likely overall to exhibit dietary habits different from the general population. A recent study of He et al. on the environmental impacts of US diets also reported that individuals with higher income are responsible for larger environmental impacts in terms of GHGE, blue water footprint, land use and energy consumption [25]. However, the authors did not show statistical analysis testing the difference between environmental impacts of diet according to income levels (only analysis by food groups were provided). Hence, while figures of mean impacts suggest increased environmental impacts with higher socio-economic status, results provided by He et al. do not allow knowing whether differences are significant or not when considering inter individual variability and confounding factors. In addition, similarly to our study, the authors reported that extents in differences between income level vary by the types of environmental impacts, with the largest difference observed for water footprint. Two other studies conducted in Australia [8] and Hungary [7] reported that the environmental impacts of food consumption increased as income did, both for ecological footprint in the case of Hungarian households, and for energy, GHGE, water and waste indicators in the case of Australian ones. However, although authors refer to “food consumption”, data used in those studies are not dietary intakes but food household spending sourced from a Household Expenditure Survey. Estimation of environmental impacts are thus based on quantities including food waste. Since the study precisely showed that waste increased with income, and that food waste can also be related to diet composition or quality [26], the socioeconomic differences in daily environmental impact observed in this study might rather be explained by difference in food waste than by diet composition. Finally, two studies in Brazil reported higher diet-related GHGE for middle-income groups, compared to low and high-income [12, 13]. One of those Brazilian studies was based on a consumer expenditure survey [13], and the authors suggested that the lower GHGE impact they observed for higher income classes might be due to the lack of data on out-of-home food consumption, which is greater for wealthier individuals.

Regarding water resources, our results are consistent with previous studies conducted in the US [25], China [9] and Australia [8] that showed that water use impacts of food consumption increased with an increase in income level. On the opposite, one of the previously mentioned studies conducted in Brazil explored water and ecological footprints and found that impacts were higher for adults from medium and low-income classes, respectively [12]. Authors underlined the higher daily consumption of legumes (mainly beans), rice and red meat by lower income classes, and attributed the higher diet-related impact of medium income adults to their higher consumption of red meat.

Some noteworthy strengths of our study are to base the analysis on food consumption data from a representative sample of the French adult population, and to assess the environmental impact at the individual level, hence allowing to account for variability within sub-populations. Regarding environmental data, we used estimates from the most recent French database on environmental impact of foods which provides a set of midpoint indicators calculated using Life Cycle Assessment based EF3 method as recommended by the European Commission to quantify the environmental impacts of products [20, 27]. In contrast with other studies exploring diet sustainability based on LCAs data aggregated from the literature with diverse methods and assumptions, our study relies on the Agribalyse database which provides LCA indicators for more than 2500 food products using a single consistent methodology, thus reducing uncertainty. Our results underline the importance of assessing multiple indicators covering various environmental issues in relation to different types of damages (water, land, mineral resources, etc…) and not to focus only on climate change assessment, in order to catch the complexity and possible transfers between diet-related environmental impacts. Indeed, hierarchies of impacts by food group are different according to environmental indicators. For instance, fruits and vegetables ranged among food groups with the lowest impact when expressed as GHGE per 100 g edible food [28], whereas they are among high impact food groups in terms of use of water resources. That said, it is important to bear in mind that beyond the impact per 100g of food, the environmental impact of diet directly depends on the quantities of food consumed, and on the shares of the different food groups in the diet. Hence, the most relevant approach to explore diet sustainability is to adopt a whole diet approach and not only consider the environmental impacts of specific food and food groups. A strength of the present study is precisely to have used such whole diet approach to assess the environmental impact of dietary consumption.

The present study also has limitations. First, it should be noted that our analysis does not include the environmental impact related to food waste, which might differ across levels of income and diet quality, as suggested in other studies [8, 26]. With this regard, it could be expected that populations with budget constraints pay more attention to food waste, suggesting that socioeconomic differences in daily environmental impact could be heightened if impact of food waste was included. Secondly, data available on the environmental impacts and on food consumption did not allow to differentiate impact of foods from conventional vs. organic production : on the one hand, the French Agribalyse database provides some LCA data for organic agricultural products at the farm gate, but they are not sufficient to estimate an environmental impact at diet scale; and, on the other hand, the food consumption data used in our study do not allow to distinguish intakes of foods with different production methods. It should also be noted that there are some limitations on the relevance of Agribalyse database to assess the environmental impact of organic products since it does not consider effects on biodiversity or on toxicity for humans, animals, soils, and air. [29]. These limits underline the need to develop environmental databases that include different estimates depending on the food production method – but also source and processing methods – to better account for the variability of diet-related environmental impacts in future research on diet sustainability. Such assessment also requires that food consumption surveys collect and provide data that differentiate foods according to these criteria. Thirdly, we did not consider possible differences in environmental impact of foods according to their place of consumption (in- or out-of-home), although it could influence the impact through different type of processing. Some studies actually showed that in the case of complex dishes, higher-scale systems, with proper energy and environmental practices, can have lower environmental burdens than small-scale systems [30]. Moreover, waste generation might be higher for out of home consumption.

5 Conclusion

Based on a representative sample of the adult population, the present study assessed for the first time the environmental impacts of individual food consumptions across sub-populations sorted by levels of income and food insecurity status in France. Results showed a high variability in impacts within each sub-population and no difference in daily environmental impacts between sub-populations, except for water use and freshwater eutrophication for which the lowest impacts were observed for adults living in households experiencing severe food insecurity.

Overall, our results suggest that individual food patterns and a whole diet approach are important to consider when designing educational tools or public policies for promoting more sustainable diets.

6 Declarations

Ethical standards: Dietary data used in the present study were derived from the Third French Individual and National Food Consumption (INCA3) study. The INCA3 study was conducted according to the guidelines laid down in the Declaration of Helsinki. The study protocol was approved by the French Data Protection Authority (Commission Nationale Informatique et Libertés) on May 2, 2013 (Decision DR 2013-228), after a favourable opinion from the Advisory Committee on Information Processing in Health Research (Comité consultatif sur le traitement de l'information en matière de recherche dans le domaine de la santé) on January 30, 2013 (Opinion 13.055). All participants gave their informed consent prior to their inclusion in the study.

Competing Interests: The authors declare that they have no conflict of interest.

Authors' contributions: Conceptualization and methodology, M.P., F.V, E.V, N.B., N.D.; Formal Analysis, F.V.; Writing – Original Draft Preparation, M.P.; Writing – Review & Editing, M.P., F.V, E.V, N.B., N.D.; Visualization, M.P.; Supervision, M.P. and N.D. All authors read and approved the final manuscript.

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Abbreviations: FI: food insecurity; FS: food secure; GHGE: Greenhouse gas emissions; HFSS: Foods high in fat sugar and salt; MFI: moderately food insecure; SFI: severely food insecure; FV: Fruit and Vegetables.

Data availability: Food consumption data from the Third French Individual and National Food Consumption (INCA3) Survey are available on the data.gouv.fr plateform. Data on the environmental impacts of foods consumed in France are available on the agribalyse.ademe.fr plateform.

7 Figures and Tables

Table 1: Socio-economic characteristics of the adult participants with no missing data on income (n=1964)[1] living in severe food-insecure (SFI), moderate food-insecure (MFI), or food-secure households, by level of income (FS1 to FS10), Étude Individuelle Nationale des Consommations Alimentaires (INCA3), 2014-2015, France.

	SFI	MFI	FS1	FS2	FS3	FS4	FS5	FS6	FS7	FS8	FS9	FS10	All	p*
Age (n=1964)														<.001
18-44 y	61.8	49.3	61.9	36.5	51.1	28.1	48.9	45.3	73.3	35.4	31.7	46.7	45.6	
45-64 y	36.0	43.9	29.1	49.6	32.3	37.6	31.2	31.9	19.5	44.6	42.3	42.8	37.5	
65-79 y	2.2	6.8	9.0	13.9	16.5	34.4	19.9	22.8	7.2	19.9	26.1	10.4	17.0	
Participant gender (n=1964)														
Women	62.1	66.7	55.4	50.8	55.1	60.1	54.0	48.0	56.2	45.9	41.7	38.7	51.6	0.053
Income per consumption unit (€/month) (n=1958)														
Mean	706	935	425	752	1011	1166	1362	1542	1811	1980	2519	3396	1543	<0.001
SE	59	73	21	12	9	3	4	5	4	10	8	54	32	
Number of household members (n=1964)														
Mean	2.5	2.7	3.7	3.1	3.0	2.3	3.0	2.4	3.4	2.3	2.3	2.5	2.7	<0.001
SE	0.2	0.3	0.3	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
Education level of the head of household (n=1963)														<.001
Primary and middle school	46.5	66.9	62.0	64.6	54.6	71.0	52.0	46.5	15.1	42.4	30.5	22.6	47.9	
High school	46.1	18.6	23.1	15.9	14.6	12.5	19.1	17.6	15.0	21.5	12.8	15.3	18.0	
1-3 y of post-secondary education	3.2	9.9	12.2	10.9	18.4	11.5	19.5	19.3	30.0	18.7	28.5	18.3	17.3	
≥4 y of post-secondary education	4.3	4.6	2.7	8.6	12.5	5.0	9.3	16.6	40.0	17.4	28.2	43.8	16.8	
Total energy intake (kcal/day) (n=1964)														
Mean	1893	1937	2037	2166	2214	1897	2189	2217	2068	2151	2194	2145	2110	0.004
Total intake (g/day) (n=1964)														
Mean	2467	2864	2653	3030	3158	2879	2973	3041	2838	2942	3066	3124	2953	0.007

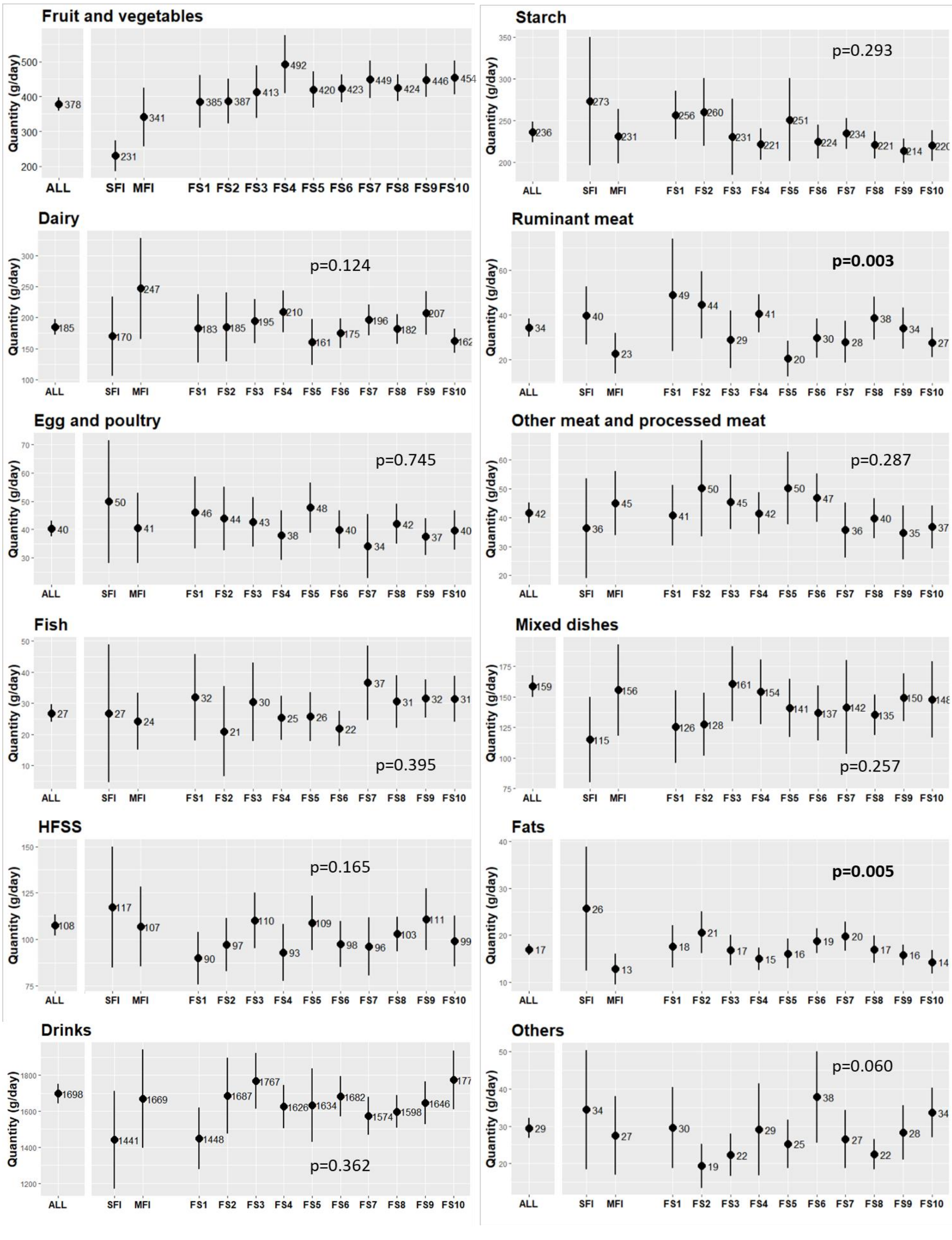
[1] Data weighted for geographic and socio-economic variables using weighting factors provided with the INCA3 survey. Data presented are percentages unless otherwise indicated. *Statistical significance of the differences among the 12 categories of individuals (SFI, MFI, FS1 to FS10): $\chi 2$ tests for categorical variables and ANOVA for continuous variables. BMI: Body Mass Index

Table 2: Diet-related environmental impacts[1] (expressed per day per person) for the whole sample (ALL, n=1964 adults) and in the 1st and 10th decile of each impact indicator, Étude Individuelle Nationale des Consommations Alimentaires (INCA3), 2014-2015, France

	Daily impact per person						
	ALL		**1st decile**		**10th decile**		**interdecile ratio (D10/D1)**
	Mean	SE	Mean	SE	Mean	SE	
EF single score (mPt)	0,72	0,01	0,35	0,01	1,32	0,03	3,8
Climate change (kg CO2 eq)	5,80	0,13	2,51	0,04	11,91	0,45	4,7
Ozone depletion (E-06 kg CVC11 eq)	0,51	0,01	0,25	0,00	0,90	0,02	3,7
Ionizing radiation (kBq U-235 eq)	1,49	0,02	0,76	0,01	2,50	0,04	3,3
Photochemical ozone formation (E-03 kg NMVOC eq)	17,88	0,42	7,12	0,11	41,70	1,46	5,9
Fine particulate matter (E-06 disease incidence)	0,53	0,01	0,23	0,00	1,07	0,03	4,7
Acidification (mol H+ eq)	0,07	0,00	0,03	0,00	0,15	0,00	4,9
Terrestrial eutrophication (mol N eq)	0,30	0,01	0,12	0,00	0,62	0,02	5,1
Freshwater eutrophication (E-03 kg P eq)	0,99	0,02	0,45	0,01	2,12	0,05	4,7
Marine eutrophication (E-03 kg N eq)	23,79	0,47	10,92	0,22	46,08	1,45	4,2
Land use (Pt)	286,30	6,88	110,20	2,08	645,51	22,28	5,9
Freshwater toxicity (CTUe)	155,88	2,22	68,98	1,13	285,38	5,10	4,1
Water use (m3 deprivation)	7,12	0,11	3,03	0,08	13,84	0,35	4,6
Energy use (MJ)	61,63	0,81	32,47	0,52	102,49	1,63	3,2
Use of mineral resources (E-06 kg Sb eq)	9,43	0,13	4,62	0,06	16,83	0,36	3,6

[1] Data weighted for geographic and socio-economic variables using weighting factors provided with the INCA3 survey.

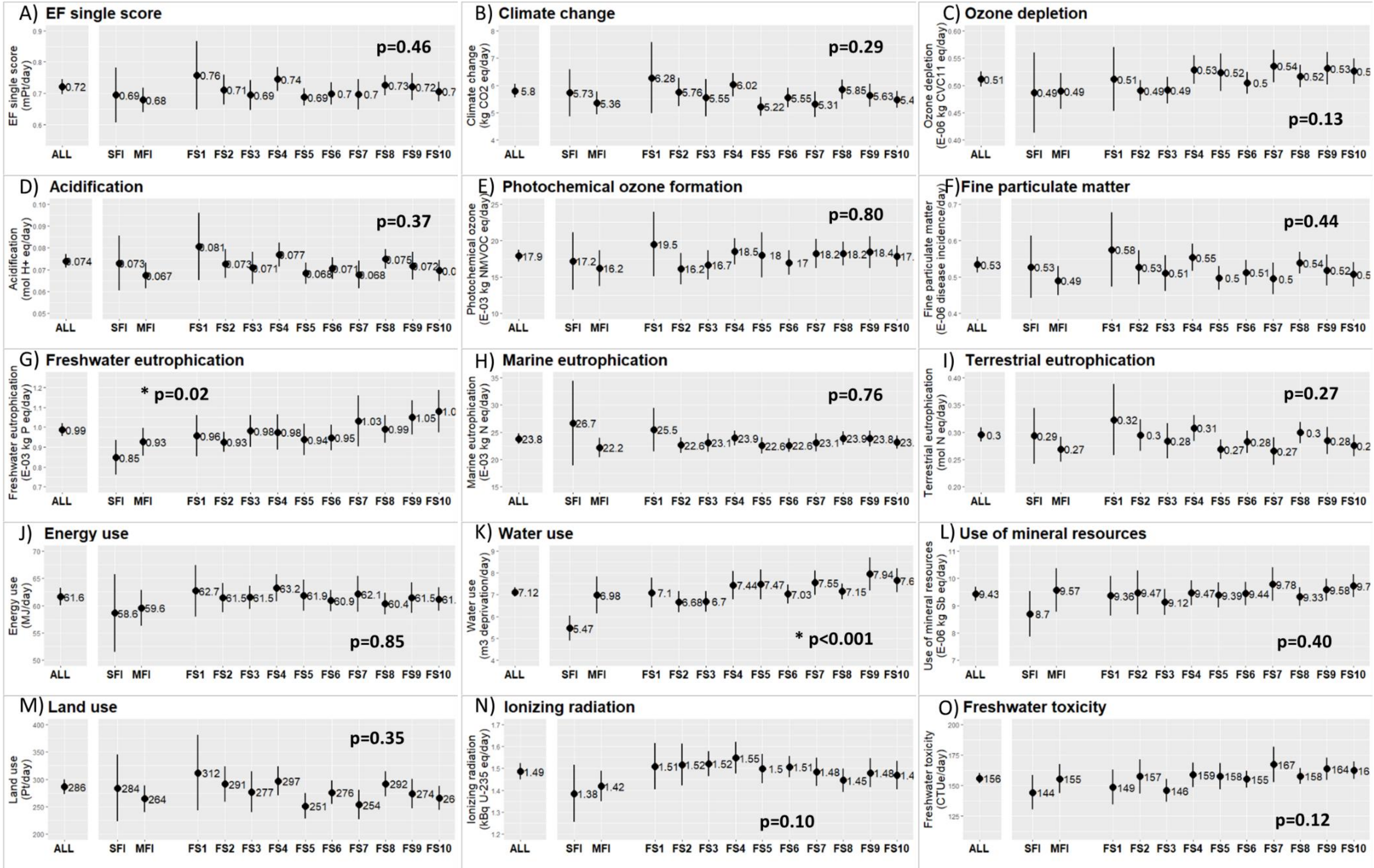
Figure 1: Mean food group intakes[1] in g/day [IC95] for the whole sample (ALL, n=1964) and the 12 sub-populations (SFI: adults living in severe food insecure households, MFI: adults living in moderate food insecure households, FS1 to FS10: adults living in food secure households by decile of income)



[1] Data weighted for geographic and socio-economic variables using weighting factors provided with the INCA3 survey. For the subpopulations, means were adjusted for age, gender, total energy intake, and number of household members and p-values show statistical significance for differences among

the 12 sub-populations (SFI, MFI, FS1 to FS10) with the same adjustment. HFSS: Foods high in fat sugar and salt.

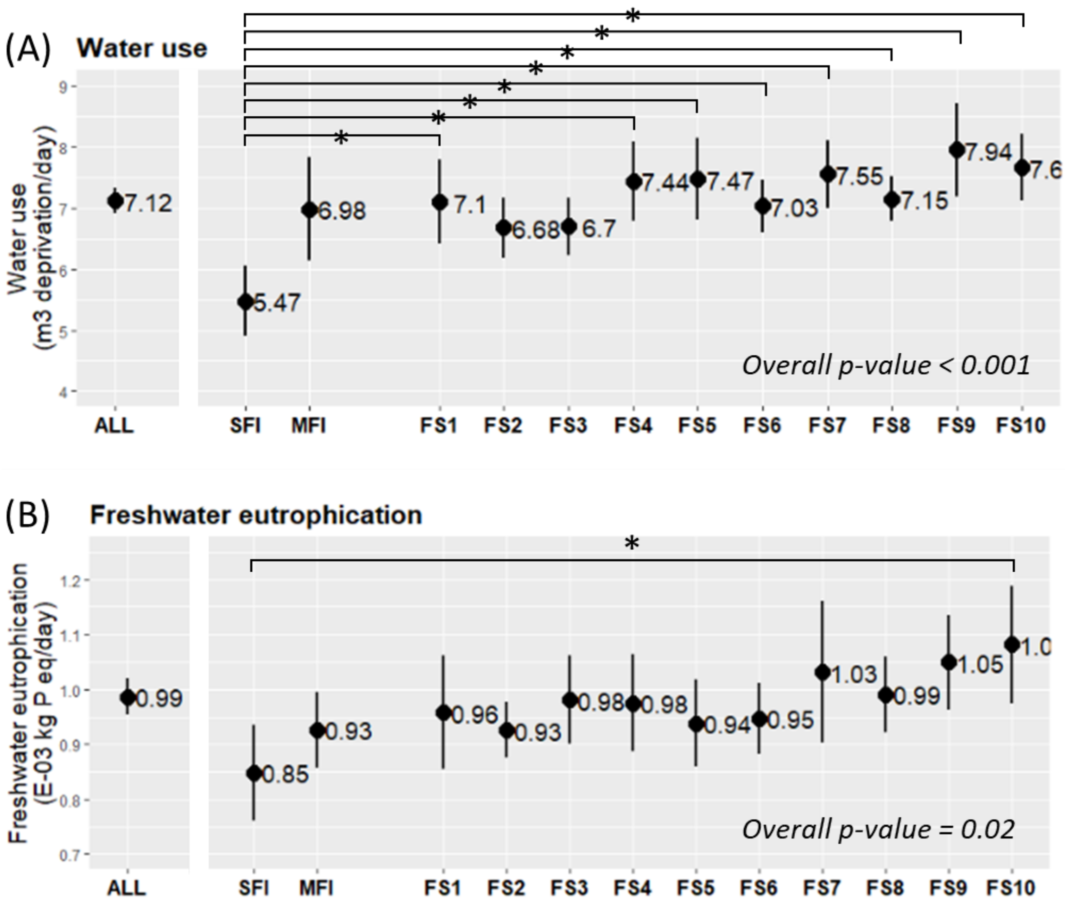
Figure 2: Mean environmental impacts[1] (IC95) for the whole sample (ALL) and by sub-populations (SFI: adults living in severe food insecure households, MFI: adults living in moderate food insecure households, FS1 to FS10: adults living in food secure households, by decile of income) for the EF single score (panel A), and the 14 midpoint indicators : Climate change (panel B), Ozone depletion (panel C), Acidification (panel D), Photochemical ozone formation (panel E), Fine particulate matter (panel F), Freshwater eutrophication (panel G), Marine eutrophication (panel H), Terrestrial eutrophication (panel I), Energy use (panel J), Water use (panel K), Use of mineral resources (panel L), Land use (panel M), Ionizing radiation (panel N) and Freshwater toxicity (panel O).



A) EF single score
p=0.46
EF single score (mPt/day)
ALL SFI MFI FS1 FS2 FS3 FS4 FS5 FS6 FS7 FS8 FS9 FS10
B) Climate change
p=0.29
Climate change (kg CO2 eq/day)
C) Ozone depletion
p=0.13
Ozone depletion (E-06 kg CVC11 eq/day)
D) Acidification
p=0.37
Acidification (mol H+ eq/day)
E) Photochemical ozone formation
p=0.80
Photochemical ozone (E-03 kg NMVOC eq/day)
F) Fine particulate matter
p=0.44
Fine particulate matter (E-06 disease incidence/day)
G) Freshwater eutrophication
* p=0.02
Freshwater eutrophication (E-03 kg P eq/day)
H) Marine eutrophication
p=0.76
Marine eutrophication (E-03 kg N eq/day)
I) Terrestrial eutrophication
p=0.27
Terrestrial eutrophication (mol N eq/day)
J) Energy use
p=0.85
Energy use (MJ/day)
K) Water use
* p<0.001
Water use (m3 deprivation/day)
L) Use of mineral resources
p=0.40
Use of mineral resources (E-06 kg Sb eq/day)
M) Land use
p=0.35
Land use (Pt/day)
N) Ionizing radiation
p=0.10
Ionizing radiation (kBq U-235 eq/day)
O) Freshwater toxicity
p=0.12
Freshwater toxicity (CTUe/day)

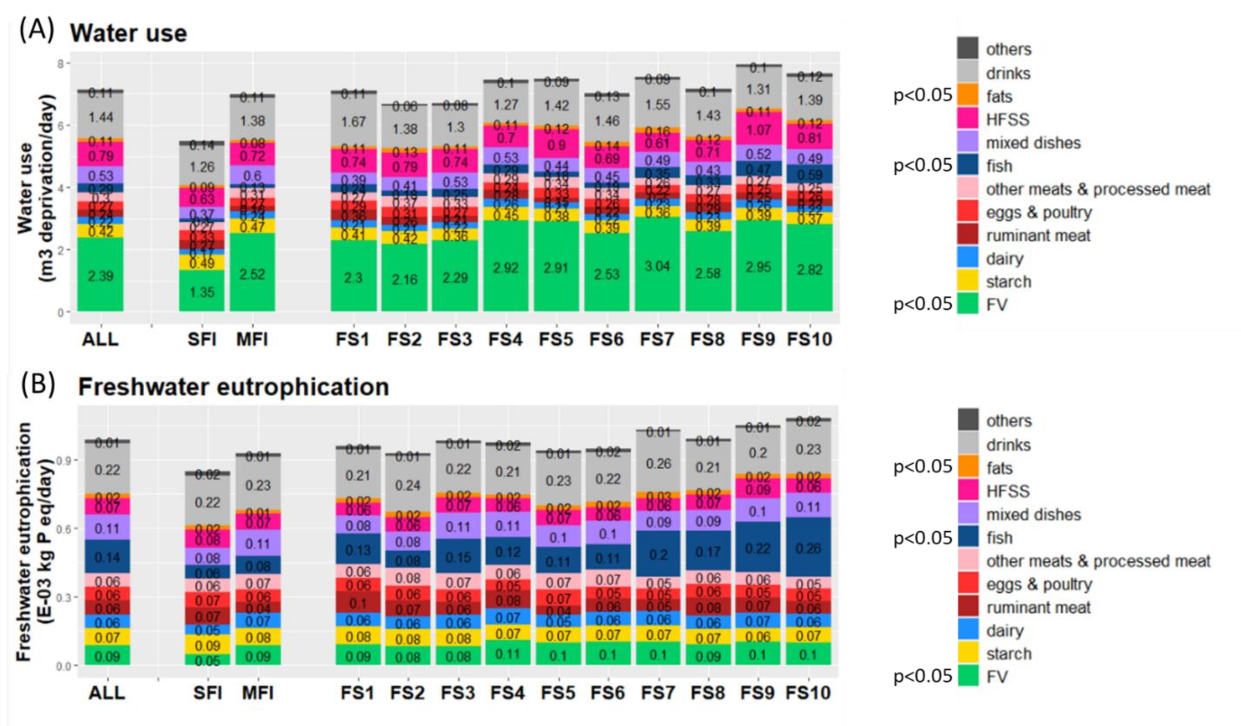
[1] Data weighted for geographic and socio-economic variables using weighting factors provided with the INCA3 survey. For the subpopulations, means were adjusted for age, gender, total energy intake, and number of household members and p-values show statistical significance for differences among the 12 sub-populations (SFI, MFI, FS1 to FS10) with the same adjustment.

Figure 3: Mean diet-related environmental impacts[1] for the whole sample (ALL) and pairwise comparisons between sub-populations (SFI: adults living in severe food insecure households, MFI: adults living in moderate food insecure households, FS1 to FS10: adults living in food secure households by decile of income) for indicators of water use (panel A) and freshwater eutrophication (panel B).



Data presented are adjusted means ± IC95. * p<0.05: pairwise comparisons using Bonferroni adjustment. [1] Data weighted for geographic and socio-economic variables using weighting factors provided with the INCA3 survey. For the subpopulations, means were adjusted for age, gender, total energy intake, and number of household members and p-values show statistical significance for differences among the 12 sub-populations (SFI, MFI, FS1 to FS10) with the same adjustment

Figure 4: Environmental impacts[1] by food group for the whole sample (ALL, n=1964) and the 12 sub-populations (SFI: adults living in severe food insecure households, MFI: adults living in moderate food insecure households, FS1 to FS10: adults living in food secure households by decile of income) for indicators of water use (panel A) and freshwater eutrophication (panel B).



[1] Data weighted for geographic and socio-economic variables using weighting factors provided with the INCA3 survey. For the subpopulations, means were adjusted for age, gender, total energy intake, and number of household members and p-values show statistical significance for differences among the 12 sub-populations (SFI, MFI, FS1 to FS10) with the same adjustment. Not significant if not specified. HFSS: Foods high in fat sugar and salt; FV: Fruits & vegetables.

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