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Modelled gradual changes in protein intake to increase nutrient adequacy lead to greater sustainability when systematically targeting an increase in the share of plant protein

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1 **Abstract**

2 In line with sustainability issues, we are currently seeing a transition towards a lower consumption of animal
3 protein. How ongoing gradual rearrangements in protein patterns impact sustainability and climatic change
4 remains unknown. We used data from a French representative survey and selected for each individual the dual
5 substitution of a serving of a protein food that most improved nutritional adequacy (using the probabilistic
6 PANDiet score), with an increase in the percentage of plant protein required (SP) or not (SN). This was iterated
7 20 times incrementally and we monitored the evolution of sustainability endpoints, including greenhouse gas
8 emissions (GHGE) and predicted premature deaths avoided. After 20 iterations, the plant protein intake (31.1%
9 total protein) decreased under SN (30.0%) and increased under SP (37.7%). The food groups whose contribution
10 to protein intake increased the most were legumes (+225%), fatty fish (+151%) and lean chicken (+82%) under
11 SN and legumes (+502%), pizzas and quiches (+190%) and fatty fish (+102%) under SP. The PANDiet score
12 rose slightly more under SN ($+7.5\pm 0.1$) than SP ($+6.2\pm 0.1$). GHGE levels increased from 5.4 ± 0.05 to 5.7 ± 0.04
13 kg eq.CO₂/d under SN and decreased to 5.1 ± 0.04 under SP. Diet costs increased from 7.4 ± 0.06 to 8.2 ± 0.05 €/d
14 under SN and 7.6 ± 0.05 under SP. Predicted avoided premature deaths annually in France were 2,200
15 [1700;2700] under SP and 1,700 [1400;2000] under SN. In those series of small realistic changes in the
16 individual diets, systematically increasing the plant share slightly limits the gain in nutritional adequacy but
17 result in diets that are far more sustainable.

18 **Keywords:** Plant protein, diet modeling, nutrient adequacy, simple changes, sustainability parameters, French
19 population.

20 1. Introduction

21 The Food and Agriculture Organization of the United Nations (FAO) defined sustainable diets as “*diets with*
22 *low environmental impacts which contribute to food and nutrition security and to healthy life for present and*
23 *future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally*
24 *acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while*
25 *optimizing natural and human resources*” (Burlingame and Dernini 2012). The consumption of animal-based
26 food, and particularly of meat, has been associated with negative effects on several sustainability parameters
27 when compared to plant sources of protein (Godfray et al. 2018). Indeed, a high consumption of red and
28 processed meats has been associated with a risk of colorectal cancer and cardiovascular diseases (Anses 2016b;
29 Norat et al. 2005; Rohrmann et al. 2013) which are central to the disease burden in western countries (Bauer et
30 al. 2014). Animal protein sources generate more greenhouse gas emissions (GHGE) than plant protein sources
31 (Gerber et al. 2013), in a context where GHGE are a crucial feature of climate change issues (Cleveland and Gee
32 2017). With regards to the cost of diets, meat and fish are among the principal contributors while cereals and
33 legumes contribute much less (Darmon and Drewnowski 2015). However, animal-based and plant-based food
34 have completely different nutrient profiles and so their substitutability needs to be studied in the context of the
35 complex dietary models that govern their intake. Indeed, because animal products are the main sources of
36 protein, iron, zinc and vitamin B-12 in western diets, a drastic reduction of their consumption could lead to an
37 inadequacy of these nutrients of importance to nutrition security (Phillips et al. 2015). Animal and plant protein
38 sources also differ in terms of the contaminants profiles, with fish containing higher concentrations of dioxin,
39 furans and methyl-mercury and vegetables or cereal-based foods containing more lead, nickel, cadmium,
40 mycotoxins and pesticide residues (Anses 2011b; Millour et al. 2011; Noël et al. 2012; Nougadère et al. 2012;
41 Sirot et al. 2013; Sirot et al. 2012).

42 Since the early 2000s, the trend towards reducing meat consumption in western countries because of the
43 concerns regarding sustainability issues mentioned above (FranceAgriMer 2015; Godfray et al. 2018) has caused
44 a general and gradual rearrangement in the consumption of protein sources (FAO 2018). More plant-based diets
45 such as semi-vegetarian and vegetarian are becoming increasingly popular and they are expected to favor long
46 term-health and be more sustainable when compared to standard western diets (Appleby and Key 2016; Orlich et
47 al. 2013). Dietary transitions operate mainly via a series of gradual changes to individual dietary choices rather
48 than an abrupt adherence to predefined diets such as those proposed in national guidelines (Anses 2016e; U.S.
49 Department of Health and Human Services and U.S. Department of Agriculture 2015) or consumed by a small

50 part of the population (e.g. vegetarians) (Niva et al. 2017). It nevertheless remains unclear how the general
51 population might make gradual, simple and appropriate changes to their diet in order to improve its quality while
52 reducing its content in animal foods. Recent studies have shown that the dietary patterns of individuals are key to
53 identifying the best modifications that can be made to protein intake in order to increase overall nutrient
54 adequacy (de Gavelle et al. 2019). As we showed in that recent study, the simple and gradual changes to protein
55 patterns in a population would be the first steps in rearranging protein intake and can be studied by modeling
56 unitary modifications to portion sizes with nutritional objectives such as improving nutrient adequacy. Studying
57 the effect of constraints to achieve a higher plant:animal protein ratio could be useful to understand how this
58 affects different sustainability endpoints.

59 The objective of the present study was therefore to identify pathways of gradual modifications to the
60 consumption of protein components in the diet that could lead to improved nutrient adequacy, with or without
61 the systematic targeting of an increase in plant protein. We thus assessed the effects of these change scenarios on
62 several parameters covered by the FAO definition of sustainable diets: diet costs, GHGE, exposure to food
63 contaminants and the number of premature deaths avoided.

64 2. Subjects and Methods

65 2.1. Population, food intake and dietary composition

66 The study sample was composed of adult participants of the Second Individual and National Study on
67 Food Consumption (INCA2) of the French population conducted in 2006-2007, as previously described (de
68 Gavelle et al. 2017; Dubuisson et al. 2010). In summary, we excluded adults over 65 years of age (because their
69 nutrient requirements differ from those of younger adults) and energy under- and over-reporters identified by
70 comparison of the reported energy intake and the basal metabolic rate, as estimated using Henry equations
71 (Henry 2005), and a cut-off value as defined by Black (Black 2000), resulting in a final sample of 1,678 adults
72 representative of the French population (717 males and 961 females aged 18 to 65 years old) (**Online Resource**
73 **1**). Food intakes were calculated from seven-day food records, and individual characteristics (e.g. sex, age, body
74 weight or physical activity) were extracted from self-reported questionnaires and in-person interviews. The
75 nutritional composition of the foods involved has already been described in detail (de Gavelle et al. 2018). In
76 brief, data on nutritional composition were extracted from the 2016 CIQUAL (*Centre d'Information sur la*
77 *Qualité des Aliments* – Centre for Information on Food Quality) food composition database (Anses 2016c), an
78 amino acid database as previously described (de Gavelle et al. 2017), and databases on phytate (Amirabdollahian
79 and Ash 2010), and heme and non-heme iron in animal foods (Centre d'Information des Viandes 2005; Centre
80 d'Information des Viandes & INRA 2009; Kongkachuichai et al. 2002). The digestibility of protein (de Gavelle
81 et al. 2017) and the bioavailability of iron (Armah et al. 2013; Hallberg and Hulthen 2000) and zinc (Miller et al.
82 2007) were taken into account. The percentages of animal and plant protein in each food item were obtained by
83 assigning food items to both categories and breaking down the mixed food into ingredients from the recipes, as
84 described in detail elsewhere (Camilleri et al. 2013). The food groups presented in this publication were adapted
85 from the INCA2 food groups, taking account of their fat content. Indeed, meat (excluding poultry) and poultry
86 were both split into two groups depending on whether or not fat contributed to more than 35% of energy; 71% of
87 meat foods were “fatty meat” and 61% of poultry foods were “fatty poultry”. Fish was considered as “fatty” if
88 the EPA+DHA content was >1g/100g (Anses 2016e); 34% of fish-based foods were considered to be “fatty”.

89 Protein foods were defined as INCA2 food items that met two criteria: 1) the percentage of energy from
90 protein was >10%, (referring to their intrinsic protein content), and 2) the level of intake at the 90th percentile
91 was >5g protein/portion, referring to their potential contribution to protein intake at a relatively high level of
92 consumption. The percentages of protein foods in each food group are detailed in **Online Resource 2**.

93 2.2. Nutrient adequacy

94 Nutrient adequacy was assessed using PANDiet probabilistic scoring (Verger et al. 2012), as previously
95 described (de Gavelle et al. 2019). Briefly, the PANDiet score is calculated as the mean of an Adequacy Sub-
96 score (AS), which is the average of the probabilities of adequacy (PAs) of nutrients for which an Estimated
97 Average Requirement is defined, and a Moderation Sub-score (MS), which is the average of the PAs of nutrients
98 with an existing upper bound reference value. The reference values applied were mainly the most recent values
99 published by the French Agency for Food, Environmental and Occupational Health & Safety (Anses) (Anses
100 2016a). For each individual, we therefore calculated the PANDiet score (from 0 to 100) where a higher score
101 reflected the higher overall nutrient adequacy of the diet. Details on the PANDiet score are given in **Online**
102 **Resource 3**.

103 2.3. Statistical analyses and models

104 Stepwise dietary models of changes were used to improve the initial PANDiet score calculated for each
105 individual. The models consisted of pairing an increase in the portion size of a protein food with a reduction in
106 the portion size of another protein food in the 7-day diets of the INCA2 individuals. Every possible paired
107 modification was simulated, and the PANDiet score was calculated for each of them. The algorithm then
108 selected the paired modification that most markedly increased the PANDiet score, and implemented the
109 modification in the 7-day diet of the individual. This process was iterated 20 times. We limited the models to 20
110 steps in order to avoid any drastic change to the diets, as performed in other studies (Verger et al. 2014). Two
111 different scenarios were implemented, as adapted from the scenarios previously described (de Gavelle et al.
112 2019).

113 Under the first scenario (SN, standing for scenario with no constraint), individuals could have paired
114 modifications between two protein foods that they were already consuming. Moreover, they could reduce the
115 portion size of a protein food consumed, while introducing a portion of food not consumed in the observed diet
116 but consumed by >10% of individuals with a similar pattern of protein food intake. The scenario SN was the
117 same as the one that we described in detail in a previous publication and referred to as S2 (de Gavelle et al.
118 2019). Under the second scenario (SP, for constrained by an increase in the plant:animal protein ratio), the same
119 modifications were permitted but the percentage of plant protein (among total protein) in the diet of each
120 individual had to increase at each iteration of the stepwise models, i.e. the modification was constrained by an

121 increase in plant:animal protein. Therefore, the percentage of animal protein among total protein also decreased
122 at each iteration. Details on the paired modifications of portion sizes are given in **Online Resources 4 and 5**.

123 The weighting schemes proposed in INCA2 (for unequal sampling probabilities and differential non-
124 responses by region, agglomeration size, age, sex, occupation of the household head, size of the household and
125 season) were used to ensure statistical representativeness. An overall level of significance of 5% was used for
126 statistical analyses. When ANOVA identified a significant effect of the type of scenario, we used pairwise post
127 hoc tests with Bonferroni correction to examine differences between the observed and each of the two final
128 simulated diets. All analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, NC, USA).

129 *2.4. Other sustainability parameters*

130 In addition to nutrient adequacy, other sustainability parameters covered by the FAO definition were
131 assessed in the present study: diet costs, GHGE, exposure to food contaminants and the number of premature
132 deaths avoided. The prices of food items were obtained from the 2006 Kantar WorldPanel household consumer
133 panel for France (Kantar WorldPanel 2006), which gives the annual expenditures on and quantities purchased of
134 each food item available on the market by a representative sample of 12,000 French households. A price was
135 assigned to each INCA2 food commodity and a mean price per individual and per day was calculated. Estimates
136 of the GHGE associated to the consumption of food commodities were obtained from the database published by
137 Hartikainen and Pulkkinen based on statistics and existing literature (Life Cycle Assessment (LCA)-based
138 studies). The LCAs accounted for agricultural production and processing steps. A GHGE estimate, expressed in
139 grams of CO₂ equivalents (g CO₂eq), was assigned to each of the food items in the INCA2 nomenclature using
140 the 151 food categories in the database (Hartikainen and Pulkkinen 2016).

141 The dietary exposure of INCA2 individuals was assessed by combining individual consumption data
142 and occurrence data from the French Second Total Diet study (TDS2). This study listed the concentrations of
143 440 substances (including trace elements, persistent organic pollutants, additives, pesticide residues, mycotoxins,
144 etc.) in 212 core foods sampled in 2007-2009. The food items analyzed during TDS2 were defined from the
145 INCA2 nomenclature and covered about 90% of the entire French diet (Sirot et al. 2009). Sampling took account
146 of seasonality and geographic variability. The management of left-censored data under different hypotheses
147 (lower-bound (LB) and upper-bound (UB)), the hypotheses of speciation drawn for some substances and how the
148 estimated daily intakes were calculated are detailed in **Online Resource 6**.

149 The Health-Based Guidance Values (HBGVs) considered were those defined in the TDS2 (Anses
150 2011b) or, when more recent, values determined in Anses opinions and in the HBGV database (Anses 2016d;

151 Anses 2016e; Anses 2018). The risks associated with dietary exposure to each chemical were evaluated by
152 calculating the percentage of individuals exceeding HBGVs and their 95% confidence intervals (CI_{95%}), or, in
153 the case of a benchmark dose lower limit (BMDL) by calculating the corresponding margin of exposure (MOE)
154 according to international recommendations (EFSA 2005). In the present study, the substances considered were
155 those for which a risk was identified in the population before or after 20 steps of the stepwise models. We chose
156 not to consider certain pesticides which have been banned since TDS2 as the occurrence data are no longer
157 appropriate. Moreover, those pesticides were not detected during more recent studies (Anses 2016d) using lower
158 limits of detection than those applied in TDS2.

159 The PRIME (Preventable Risk Integrated Model) (Scarborough et al. 2014b) is a scenario model that
160 links behavioral risk factors with mortality from noncommunicable diseases (NCD), either directly or mediated
161 by body mass index (BMI), blood cholesterol or blood pressure. This was used to assess the effects of the
162 modifications simulated under scenarios N and P on premature NCD mortality (mainly diet-related
163 cardiovascular diseases, cancers and diabetes). For the analyses reported in this paper, the following dietary risk
164 factors were included: fruit, vegetables, fiber, total fat, saturated fat, polyunsaturated fat, monounsaturated fat,
165 dietary cholesterol and salt. The method parameters, including relative risks estimates and CI, were the same as
166 originally reported (Scarborough et al. 2014b). The 25-65 years old French population in 2006 (63 million
167 inhabitants) was considered in order to fit with the population in the dietary survey. The situation in INCA2 was
168 considered as the baseline situation in France in 2006, and the scenarios SN and SP were considered as the
169 counterfactual scenarios. The input variables were adjusted for energy intake using the residual method (Willett
170 et al. 1997), as the PRIME model is highly sensitive to even small variations in energy intake (Cobiac et al.
171 2018), whereas dietary surveys involve considerable inaccuracy with respects to energy intake estimates. To
172 assess the difference between SN and SP regarding premature deaths avoided, we calculated, for each individual
173 at each step, the difference between SN and SP for each parameter, which we called δ_{SN-SP} . Then we added the
174 δ_{SN-SP} to the observed value, to assess the effect of the difference between the two scenarios, and used the
175 PRIME model to estimate the number of premature death avoided by the difference between SN and SP. A
176 Monte Carlo simulation was performed to estimate 95% uncertainty intervals around the results. Uncertainty
177 intervals (CI) were estimated, based on the 2.5th and 97.5th percentiles of results generated from 10^5 iterations
178 of the PRIME models, where the estimates of relative risks used to parameterize the model were allowed to vary
179 stochastically according to the distributions reported in the literature.

180 3. Results

181 3.1. Contribution of different food groups to total protein intake

182 After 20 steps in the SN, the mean (\pm SD) plant protein intake fell from 31.1% (\pm 8.0) to 30.0% (\pm 7.6) in
 183 the whole population ($P < 0.0001$). It remained constant among men, and fell from 31.5% (\pm 7.7) to 29.4% (\pm 7.2)
 184 ($P < 0.0001$) of total protein intake among women. In the SP, the mean plant protein intake rose ($P < 0.0001$)
 185 from 31.1% (\pm 8.0) to 37.7% (\pm 8.2) in the whole population, and from 30.8% (\pm 8.4) and 31.5% (\pm 7.7) to 36.7%
 186 (\pm 8.5) and 38.7% (\pm 7.9) in men and women, respectively. The mean contribution to protein intake of high-fat
 187 meat, high-fat poultry, deli meat, sandwiches and bread decreased in men and women under both scenarios. The
 188 mean contribution to protein intake of fatty fish, pizzas and quiches and legumes increased in both sexes and
 189 both scenarios. The mean contribution to protein intake of lean meat (women only), lean poultry, yogurts and
 190 prepared dishes (men only) increased in SN only, whereas the contribution of pasta and vegetables (women only)
 191 increased in SP only (**Fig. 1**).

192 The highest rates of increase were for legumes (+225%), fatty fish (+151%) and lean poultry (+82%) in
 193 SN and for legumes (+502%), pizzas and quiches (+190%) and fatty fish (+102%) in SP. Likewise, the highest
 194 rates of decrease were for deli meat (-52%), sandwiches (-31%) and cheese (-25%) in SN, and for deli meat (-
 195 49%), high-fat meat (-38%) and high-fat poultry (-37%) in SP.

196 3.2. Nutrient adequacy

197 The two scenarios significantly increased overall nutrient adequacy, as assessed using the PANDiet
 198 score. The mean (\pm SEM) increase in the PANDiet score was smaller ($P < 0.0001$) under SP (+6.2 \pm 0.1 points)
 199 than SN (+7.5 \pm 0.1) in the whole population. The increase was also smaller ($P < 0.0001$) under SP (5.9 \pm 0.1 and
 200 6.5 \pm 0.1 points) than SN (6.9 \pm 0.1 and 8.0 \pm 0.1) in men and women, respectively (**Table 1**). The AS increase was
 201 higher under SN than SP in both men and women, which was explained by higher increases in PAs for
 202 EPA+DHA, iron, iodine, potassium, zinc, riboflavin, vitamin B-6 and B-12 but lower PAs for fiber and folate.
 203 The rise in the MS was similar under both SN and SP, because of similar PAs for total fat, SFA and sodium.

204 3.3. Diet costs

205 When comparing observed diets with the rearranged diets resulting from SN, the mean (\pm SEM) diet cost
 206 increased ($P < 0.0001$) from €7.4 \pm 0.06/d to €8.2 \pm 0.05/d in the whole population, and from 8.4 \pm 0.07 and
 207 €6.5 \pm 0.04/d to €9.2 \pm 0.09 and €7.4 \pm 0.04/d among men and women, respectively. Under SP, the mean cost of the

208 rearranged diets slightly increased ($P<0.01$) in the whole population ($\text{€}7.6\pm0.05/\text{d}$), did not significantly change
 209 in men and slightly increased ($P<0.05$) in women ($\text{€}6.7\pm0.06/\text{d}$). Among both men and women, the mean diet
 210 cost was lower under SP than SN ($P<0.0001$). Under SN, the increase in the intake of fatty fish ($+\text{€}0.44$ and
 211 $+\text{€}0.35/\text{d}$ for men and women, respectively), prepared dishes ($+\text{€}0.28$ and $+\text{€}0.20/\text{d}$ for men and women,
 212 respectively), and lean poultry ($+\text{€}0.14$ and $+\text{€}0.30/\text{d}$ for men and women, respectively) contributed the most to
 213 the higher cost. Under SP, the increases in the intake of pizzas and quiches ($+\text{€}0.36$ and $+\text{€}0.14/\text{d}$ for men and
 214 women, respectively) and fatty fish ($+\text{€}0.28$ and $+\text{€}0.20/\text{d}$ for men and women, respectively) contributed the
 215 most to the higher diet cost.

216 3.4. GHGE

217 Under SN, mean (\pm SEM) GHGE levels increased ($P<0.0001$) from 5.4 ± 0.05 kg eq. CO_2/d to 5.7 ± 0.04
 218 kg eq. CO_2/d in the whole population, and 6.3 ± 0.08 and 4.5 ± 0.06 kg eq. CO_2/d to 6.5 ± 0.09 and 5.1 ± 0.06 kg eq.
 219 CO_2/d , for men and women, respectively. Conversely, under SP, mean GHGE levels decreased ($P<0.01$) to
 220 5.1 ± 0.04 kg eq. CO_2/d in the whole population, and to 5.9 ± 0.07 and 4.3 ± 0.04 kg eq. CO_2 for men and women,
 221 respectively (**Fig. 2**). Under SN, the increase in the intake of lean meat ($+0.10$ and $+0.32$ kg eq. CO_2/d for men
 222 and women, respectively) and prepared dishes ($+0.21$ and $+0.14$ kg eq. CO_2/d for men and women, respectively)
 223 contributed the most to the higher GHGE. Under SP, the reduction in the intake of high-fat meat (-0.38 and -0.35
 224 kg eq. CO_2/d for men and women, respectively) and deli meat (-0.10 and -0.07 kg eq. CO_2/d for men and
 225 women, respectively) contributed the most to the lower GHGE.

226 3.5. Risks related to exposure to food contaminants

227 A risk (as a percentage of the population $>$ HBGV significantly different from 0) was identified for 13
 228 substances in the observed diets or at least one of the scenarios and hypotheses for censored data (**Table 2**).
 229 However, under the LB hypothesis, the risks related to exposure to acrylamide, cadmium, chromium VI,
 230 methylmercury and sulfites did not differ between under SN and SP and the observed diets. In SP only, the risk
 231 related to mycotoxins increased (Deoxynivalenol (DON) in men in LB and UB and T2 + HT-2 in women, in UB
 232 only). The risks related to exposure to dioxins, furans and PCB-DL increased in SN only for both sexes and the
 233 risk related to PCB-NDL increased for men only in SN. Finally, the risks related to lindane exposure decreased
 234 in SP for women only, and the risk related to nickel exposure increased in SN and was higher in SP than in SN
 235 and the observed diet in women.

236 The risks related to acrylamide, chromium VI, inorganic arsenic and lead were characterized using the
237 calculation of MOEs based on BMDLs (**Table 3**). In the observed diet, the MOEs for acrylamide at the 95th
238 percentile were around 150 for men and women, and slightly decreased in SN and SP. The MOEs for chromium
239 VI at the 95th percentile were between 1,641 and 2,844 for men and women under LB and UB, and were the
240 same in the observed diet, SN and SP. Thus the MOEs were <10,000 and a risk could not be ruled out for
241 acrylamide and chromium VI. The MOEs for inorganic arsenic at the 95th percentile ranged from 0.45 to 16.22
242 for men and women under LB and UB, which was too low to rule out a health risk. The MOE fell in SN and SP,
243 leading to a higher risk related to inorganic arsenic exposure. The MOEs of lead at the 95th percentile were <10
244 in the observed diet which indicated a risk related to lead exposure, and decreased in the rearranged diets using
245 both scenarios for men and women.

246 The differences in risk related to contaminant exposure could be explained by the differences in intake
247 of a few food groups. Indeed, the contribution of fatty fish to exposure to dioxins, furans and PCB-DL increased
248 from 13% in the observed diet to 21% and 31% in the rearranged diets under SP and SN, respectively. The
249 contribution of fatty fish to methylmercury exposure also increased from 10% in the observed diet to 18% and
250 26% under SP and SN, respectively, while its contribution to PCB-NDL rose from 23% in the observed diet to
251 35% and 47% under SP and SN, respectively. The contribution of bread to cadmium exposure fell from 21% in
252 the observed diet to 17% and 16% under SN and SP, respectively, with concomitant increases in the
253 contributions of vegetables (from 10% to 14% and 16%), legumes (from 0% to 1% and 3%) and pizza (from 2%
254 to 4% and 7%). The contribution of pizza to DON exposure rose from 6% in the observed diet to 13% and 20%
255 under SN and SP, respectively. The contributions to nickel exposure of legumes (from 1% to 5% and 9%) and
256 pizza (from 1% to 3% and 5%) increased in the observed diet, SN and SP, respectively. The contribution of
257 pizza to inorganic arsenic increased from 2% in the observed diet to 5% and 8% under SN and SP, respectively.
258 Finally, the contribution of legumes to lead exposure increased from 1% in the observed diet to 4% and 6%
259 under SN and SP, respectively.

260 *3.6. Avoidance of premature deaths*

261 Using the PRIME model, we predicted that that the diet modifications after 20 steps of rearrangement
262 would avoid a total of 1,667 [CI 95% 1,354;1,984] premature deaths/year in France under SN (1,325
263 [1,076;1,576] men and 343 [277;410] women) and 2,173 [1,701;2,637]/year in France under SP (1,666
264 [1,311;2,016] men and 507 [385;627] women) when compared to the observed diets (**Fig. 3**). These premature

265 deaths were mainly linked to changes in serum cholesterol levels (44% of deaths avoided under SN and SP) and
266 fiber intake (35% under SN and 49% under SP), mainly leading to an avoidance of cardiovascular diseases (92%
267 of deaths avoided under SN and 89% under SP). When assessing the impact of the differences between SN and
268 SP, we predicted that the SP would avoid 511 [281;813] more premature deaths per year than the SN.

269 4. Discussion

270 This study identified that targeting the rearrangements that increased nutrient adequacy towards an increase
271 in the percentage of plant protein intake (i.e. in SP vs SN) led to a smaller increase in overall nutrient adequacy
272 but better values regarding all the other sustainability parameters studied in a French representative population.

273 The constraint of increasing the percentage of plant protein at each step resulted in certain differences
274 regarding the intakes of food groups: under SP, the intake of lean meat, lean poultry and yogurts did not
275 increase, that of fatty fish increased less than under SN and the intake of pizzas, pasta, vegetables and legumes
276 was much higher than under SN. These differences explained most of the differences between the two rearranged
277 diets in terms of the sustainability parameters studied. Indeed, a higher intake of lean meat and poultry under SN
278 explained the better PAs for iron, zinc and vitamin B-12, but a higher cost and higher GHGEs when compared to
279 SP. A higher fatty fish intake under SN led to higher PAs for EPA + DHA, a higher cost of the diet and a higher
280 risk related to dioxins, furans and PCBs when compared to SP. A higher intake of pizzas, bread, legumes and
281 vegetables explained the higher PAs for fiber and folates, the lower cost, lower GHGEs but some trends towards
282 higher risk regarding exposure to mycotoxins and nickel under SP when compared to SN. Under SP, the higher
283 intake of vegetables and fiber and lower intake of dietary cholesterol explained the smaller estimated number of
284 deaths avoided. The evolution of nutrient adequacy is particularly interesting when compared to the results of a
285 study assessing the nutritional status of adults in France (Castetbon et al. 2009). Indeed, in this study, 8.7% of
286 women had a mean serum ferritin $< 15.0 \mu\text{g/L}$, 6.7% of men and 5.8% of women had a deficiency in plasma
287 folate and 2.9% of men and 3.7% of women had a deficiency of plasma vitamin B-12. Both scenarios helped to
288 identify which dietary modifications could increase the nutrient adequacy of these 3 nutrients without decreasing
289 the adequacy of the other nutrients, depending on whether or not individuals aim at eating more plant protein.
290 These findings could be useful to address nutrient deficiencies in dietary transition.

291 How the intake of specific food groups changed in both scenarios were in line with French national dietary
292 guidelines, which recommend limiting red meat intake and markedly reducing deli meat intake while increasing
293 that of fatty fish, legumes and vegetables (Anses 2016e). However, as pizzas were consumed by a large part of
294 the population in the observed diets, the pizza intake rose markedly, particularly under SP. However, it appeared
295 that when the selected modifications consisted of an increase of a portion size of pizza (or the introduction of a
296 small portion of pizza), 53% of the foods which had their portion size reduced in parallel were deli meats, which
297 contained more salt and SFA and less calcium, zinc, fiber and vitamin B-9 than pizzas. As a result, our results

298 should not be interpreted as meaning that pizzas are a “healthy food”, but that they are simple substitute when
299 gradually reducing the consumption of deli meat in order to increase overall nutrient adequacy. Conversely, the
300 increases in portions of legumes were mostly limited to clusters that contained legumes in their cluster
301 repertoires. This underlines that account must be taken of both initial dietary patterns and the acceptability of the
302 change, as we discussed previously (de Gavelle et al. 2019). Furthermore, it has been argued elsewhere that the
303 consumption of plant protein from existing sources is more likely to increase in groups that are already
304 consuming them (Niva et al. 2017). The change model used here indeed reflected this reality of a barrier to
305 change by allowing increases among actual consumers or by introducing these foods into the apparent repertoire
306 of likely consumers only. It could seem surprising that fish intake increased in SP, as there was a constraint of
307 increasing the percentage of plant protein at each iteration. However, this was the case when a portion of animal
308 protein food (e.g. meat) was replaced by a portion of fish with a lower protein content, which led to an increase
309 in the share of plant protein among total protein at the end of the iteration.

310 The SN findings revealed that increasing overall nutrient adequacy, even by means of minor changes, led to
311 a higher diet cost (+11%) and higher GHGE levels (+7%) than in the observed diets, which was in line the fact
312 that the different sustainability parameters are not always compatible with each other (Perignon et al. 2017). For
313 example, observational studies (also conducted as part of the INCA2 study) showed that diets with high
314 nutritional quality were associated with significantly higher diet-related GHGEs than low nutritional quality diets
315 (Vieux et al. 2013), or that the higher quality diets were associated with higher costs and higher GHGEs (Masset
316 et al. 2014). However, Seconda et al. identified, on a large observational French cohort, that the diets with the
317 lowest GHGE were also diets with the lowest cost and high nutritional quality (Seconda et al. 2018). Our finding
318 that the SP diets generated lower GHGE than the SN and observed diets shows that favoring plant protein in
319 change scenarios is a pivotal factor even when only simple and moderate changes to protein patterns are
320 considered. This finding therefore well complements those of previous studies which demonstrated much lower
321 GHGE and higher nutrient adequacy with plant-based diets than with typical western diets, and reductions in
322 GHGE in the context of more radical change models involving plant-based diets (Biesbroek et al. 2018;
323 Macdiarmid et al. 2012; Scarborough et al. 2014a; Springmann et al. 2016; Tilman and Clark 2014). In our study
324 the parallel decrease in GHGE levels and the number of deaths avoided when systematically increasing the
325 percentage of plant proteins (SP vs SN) was in line with previous findings regarding an increase in plant protein
326 intake or a reduction in animal protein intake (Perignon et al. 2017). For example, under a scenario in the UK
327 where the proportions of vegetarians was doubled and the rest of the sample adopted a dietary pattern that was

328 low in red and processed meats, the health risk of colorectal cancer was significantly reduced (Aston et al. 2012).
329 Likewise, in the EPIC-NL cohort, replacing 35 g of meat/day with an equal amount of vegetables, fruits, fish, or
330 cereal/rice/couscous lowered GHGE levels and decreased the all-cause mortality risk (Biesbroek et al. 2014).
331 The contaminants identified as involving a significant risk were almost the same as in the French TDS2 (Anses
332 2011b; Nougadère et al. 2012), except for nickel, for which no risk was identified in TDS2, and dioxins and
333 dioxin-like PCBs, for which the risk was much lower in TDS2 (which was published before the HBGVs for
334 nickel and dioxins and dioxin-like PCBs were markedly revised downwards) (EFSA CONTAM Panel 2015;
335 EFSA CONTAM Panel 2018).

336 When comparing SP with SN in our study, there was a lower overall nutrient adequacy but a higher number
337 of deaths were avoided, which could be understood as a discordance between nutrition-related indicators.
338 However, these indicators fundamentally differ. The PRIME model is based on 7 nutrients and account for fruit
339 and vegetable intakes, whereas the PANDiet score takes account of 32 nutrients and no food group, at least
340 directly. The PANDiet also does not include cholesterol, as no reference value has been set by Anses (Anses
341 2011a), the EFSA (EFSA Panel on Dietetic Products 2010), or the Dietary Guidelines for Americans (U.S.
342 Department of Health and Human Services and U.S. Department of Agriculture 2015). The PANDiet was not
343 developed to predict mortality but rather nutritional status and security and it accounts for many nutrients that
344 have little known association with a risk of chronic disease. The PRIME model was a better indicator than the
345 PANDiet in terms of predicting the number of premature deaths avoided, but did not account for morbidity and
346 other health effects related to the intake of other important nutrients whose intakes were increased by the
347 PANDiet score. Nor did the PRIME model account for potential premature deaths linked to exposure to food
348 contaminants at levels higher than HBGVs.

349 The strengths of this study were that nutrient adequacy was assessed using the most precise estimates of the
350 probabilities of adequacy for each nutrient, using the most recently published nutrient reference values and
351 taking account of the bioavailability of iron and zinc and the digestibility of protein. The rearrangements were
352 realistic because changes to portion sizes have been acknowledged as being highly acceptable (Bianchi et al.
353 2018; Poquet et al. 2017; Vanhonacker et al. 2013), they remained within the food repertoires of clusters of
354 individuals sharing similar dietary protein patterns (de Gavelle et al. 2019), and they were limited to 20 changes
355 of portion sizes (each food having around 5 portions sizes), which limited the deviation from observed diets.
356 Very few studies have implemented such acceptability constraints. Horgan et al. have designed constraints
357 aiming at modeling, firstly, changes of portions sizes, then adding new foods and finally removing foods, which

358 was in line with the hypotheses in our study (Horgan et al. 2016). However, our findings have some limitations
359 and uncertainties. We chose scenarios which considered that the introduction of a food not already consumed by
360 individuals but consumed by a cluster of people with a similar dietary pattern was acceptable, which had not
361 been tested. However, this could be viewed as a probabilistic approach to identify foods that were indeed
362 consumed by individuals but were not found in their records covering a 7-day period. The difference of death
363 avoided between SP and SN could not be tested statistically using the confidence intervals around of avoided
364 death generated using the PRIME model because these intervals are not related to inter-individual variability but
365 uncertainty derived from propagation of model parameter uncertainty. However, the estimate of the premature
366 death avoided by the difference between SN and SP had a uncertainty interval that did not include 0, and thus we
367 concluded that SP did avoid more premature deaths than SN. The food and contamination data concerned the
368 period 2006-2009 and did not provide precise information on the foods considered (for example if the food was
369 organic or produced locally). This lead to uncertainties about the extrapolation of the results to the current
370 situation, as food intake profiles have evolved since 2006 (e.g. the mean intake of organic foods has increased
371 between 2006-2007 and 2014-2015 (Anses 2017)). Another limitation affecting this study is that we considered
372 that the food prices were not affected by the rearrangements, which would not be true in the case of changes
373 involving the entire population. Indeed, under our modeling of an increase in legume consumption in the
374 population (5-fold increase under SP), the price of legumes would have increased in line with demand. Yet,
375 changes in food intakes remain limited. The data used to assess GHGE estimates was extracted from a review
376 study based on European data, and not only French data. There might be differences between GHGE estimates in
377 France and the mean estimate in the European Union, as the agricultural and livestock production systems or the
378 electricity production system are not the same in each country. However there is no complete database about
379 GHGE of food commodities in France, and the database used in the present study was the most recent and
380 complete. Using aggregated data from European system also allow more generalization to the GHGE impact of
381 the changes that were identified here on a nutritional criterion. Finally, the sustainability parameters considered
382 during this study were not all-encompassing as many environmental parameters (eutrophication, water footprint,
383 land use or biodiversity indicators, etc.) were not included. Although reductions in environmental footprints
384 indicators such as land and water use were associated with those of GHGE with more sustainable dietary patterns
385 involving restrictions on animal-based foods (Aleksandrowicz et al. 2016; Pimentel and Pimentel 2003), we did
386 not measure these indicators during the study, nor any other non-environmental indicators of sustainability.

387 In summary, we were able to identify that modifications to portion sizes of protein foods in the diets of
388 French adults that markedly improved the overall nutrient adequacy. The risk related to exposure to
389 contaminants did not evolve to any great extent except for dioxins, furans and nickel, and most changes were
390 dependent on the intake of specific food groups such as fatty fish, bread, pizzas, vegetables and legumes.
391 Introducing constraints to increase the intake of plant protein slightly limited the improvement in nutrient
392 adequacy but gave rise to more marked reductions in the number of premature deaths avoided and improvements
393 in other sustainability parameters (diet-related GHGEs and diet cost).

Contributors

The authors' contributions were as follows - E.G., J-F.H. and F.M. designed research, with the contribution of C.O. and L-G.S. E.G., M.P., P.L., J-F.H. and F.M. conducted the research; P.L., V.S. and L-G.S. provided essential materials; E.G., M.P. and P.L. analyzed data and performed statistical analysis; E.G., J-F.H., V.S., C.O., H.F., L-G.S. and F.M. wrote the paper; E.G. and F.M. had primary responsibility for final content.

Conflict of Interest

394 The authors declare that they have no conflict of interest.

395

Fig. 1 Mean contributions (%) of different food groups to protein intake in the observed diets and rearranged diets after 20 steps of the stepwise model in men (a) and women (b) in the INCA2 population (2006-2007) (n=1,678). Under scenario N, dual changes to portion size (i.e. a reduction in one protein food and an increase in another) were permitted between foods already consumed by the individual and “new” protein foods could be also introduced to balance reductions in the protein foods consumed, inasmuch as these foods formed part of the food repertoire of the cluster to which the individual belonged. Scenario P was the same except that the overall percentage of plant protein in individual diets had to increase at each iteration. “+” means that the mean contribution was higher than in the observed diets and “-“ means it was lower, as tested by pairwise post hoc comparisons with Bonferroni correction (P<0.05). For example, after 20 steps under scenario N in women, lean meat contributed to 7.4% of total protein intake in men, which was significantly higher than the 5.9% recorded in the observed diets. The food groups shown contributed to >2% of total protein intake in at least one gender in the observed diets, SN or SP.

Fig. 2 Mean GHGE levels associated with observed diets and rearranged diets after 20 steps of the stepwise model under scenarios N and P among men (a) and women (nb) in the INCA2 population (n=1,678). Under scenario N, dual changes in portion size (i.e. a reduction in one protein food and an increase in another) were permitted between foods already consumed by the individuals and “new” protein foods could be introduced to balance reductions in the protein foods consumed, inasmuch as these new foods formed part of the food repertoire of the cluster to which the individual belonged. Scenario P was the same except that it was necessary for the overall percentage of plant protein in individual diets to increase at each iteration. “+” means that the mean contribution was higher than in the observed diets and “-“ means it was lower, as tested by pairwise post hoc comparisons with Bonferroni correction (P<0.05). Labeled means without a common letter differ, as tested by pairwise post hoc comparisons with Bonferroni correction (P<0.05). Men and women were stratified so that the labels of men and women were independent. The food groups shown contributed to >2% of total protein intake in at least one gender in the observed or rearranged diets, and gained or lost >1% in the rearranged diets.

Fig. 3 Annual numbers of premature deaths (and uncertainty intervals) avoided in the 2006 French population by implementation of the dietary modifications under scenarios N (SN) and P (SP), as estimated by the PRIME model, for men (a) and women (b)

- 398 Aleksandrowicz L, Green R, Joy EJM, Smith P, Haines A (2016) The Impacts of Dietary Change on
399 Greenhouse Gas Emissions, Land Use, Water Use, and Health: A Systematic Review PLoS One
400 11:e0165797 doi:10.1371/journal.pone.0165797
- 401 Amirabdollahian F, Ash R (2010) An estimate of phytate intake and molar ratio of phytate to zinc in
402 the diet of the people in the United Kingdom Public Health Nutr 13:1380-1388
- 403 Anses (2011a) Actualisation des apports nutritionnels conseillés pour les acides gras -
404 <https://www.anses.fr/fr/system/files/NUT2006sa0359Ra.pdf> Rapport d'expertise collective
- 405 Anses (2011b) Étude de l'alimentation totale française 2 (EAT 2) -
406 <https://www.anses.fr/fr/system/files/PASER2006sa0361Ra2.pdf> Rapport d'expertise
407 collective
- 408 Anses (2016a) Actualisation des repères du PNNS : élaboration des références nutritionnelles
409 - www.anses.fr/fr/system/files/NUT2012SA0103Ra-2.pdf Rapport d'expertise collective
- 410 Anses (2016b) Actualisation des repères du PNNS : étude des relations entre consommation de
411 groupes d'aliments et risque de maladies chroniques non transmissibles
412 - www.anses.fr/en/system/files/NUT2012SA0103Ra-3.pdf Rapport d'expertise collective
- 413 Anses (2016c) ANSES-CIQUAL French food composition table version 2016 - Retrieved 12/01/2017
414 from the Ciqual homepage <https://ciqual.anses.fr/>
- 415 Anses (2016d) Étude de l'alimentation totale infantile - [https://www.anses.fr/en/content/infant-
416 total-diet-study-itds](https://www.anses.fr/en/content/infant-total-diet-study-itds) Rapport d'expertise collective
- 417 Anses (2016e) Updating of the PNNS guidelines: revision of the food-based dietary guidelines -
418 <https://www.anses.fr/en/system/files/NUT2012SA0103Ra-1EN.pdf> Anses opinion - Collective
419 expert report
- 420 Anses (2017) Étude individuelle nationale des consommations alimentaires 3 (INCA 3) -
421 <https://www.anses.fr/fr/system/files/NUT2014SA0234Ra.pdf> Rapport d'expertise collective
- 422 Anses (2018) TRVs built and chosen by Anses - database - [https://www.anses.fr/fr/content/vtr-
423 construites-et-choisies-par-l-e2%80%99anses-base-de-donn%C3%A9es](https://www.anses.fr/fr/content/vtr-construites-et-choisies-par-l-e2%80%99anses-base-de-donn%C3%A9es). Maisons-Alfort
- 424 Appleby PN, Key TJ (2016) The long-term health of vegetarians and vegans Proc Nutr Soc 75:287-293
425 doi:10.1017/s0029665115004334
- 426 Armah SM, Carriquiry A, Sullivan D, Cook JD, Reddy MB (2013) A Complete Diet-Based Algorithm for
427 Predicting Nonheme Iron Absorption in Adults J Nutr 143:1136-1140
428 doi:10.3945/jn.112.169904
- 429 Aston LM, Smith JN, Powles JW (2012) Impact of a reduced red and processed meat dietary pattern
430 on disease risks and greenhouse gas emissions in the UK: a modelling study BMJ Open 2
431 doi:10.1136/bmjopen-2012-001072
- 432 Bauer UE, Briss PA, Goodman RA, Bowman BA (2014) Prevention of chronic disease in the 21st
433 century: elimination of the leading preventable causes of premature death and disability in
434 the USA The Lancet 384:45-52 doi:[https://doi.org/10.1016/S0140-6736\(14\)60648-6](https://doi.org/10.1016/S0140-6736(14)60648-6)
- 435 Bianchi F, Garnett E, Dorsel C, Aveyard P, Jebb SA (2018) Restructuring physical micro-environments
436 to reduce the demand for meat: a systematic review and qualitative comparative analysis
437 The Lancet Planetary Health 2:e384-e397 doi:[https://doi.org/10.1016/S2542-5196\(18\)30188-
438 8](https://doi.org/10.1016/S2542-5196(18)30188-8)
- 439 Biesbroek S et al. (2014) Reducing our environmental footprint and improving our health:
440 greenhouse gas emission and land use of usual diet and mortality in EPIC-NL: a prospective
441 cohort study Environmental Health 13:27 doi:10.1186/1476-069x-13-27
- 442 Biesbroek S, Monique Verschuren WM, van der Schouw YT, Sluijs I, Boer JMA, Temme EHM (2018)
443 Identification of data-driven Dutch dietary patterns that benefit the environment and are
444 healthy Climatic Change 147:571-583 doi:10.1007/s10584-018-2153-y
- 445 Black AE (2000) Critical evaluation of energy intake using the Goldberg cut-off for energy intake:
446 basal metabolic rate. A practical guide to its calculation, use and limitations Int J Obes
447 24:1119
- 448 Burlingame B, Dernini S Sustainable Diets and Biodiversity: Directions and Solutions for Policy,
449 Research and Action. International Scientific Symposium, Biodiversity and Sustainable Diets

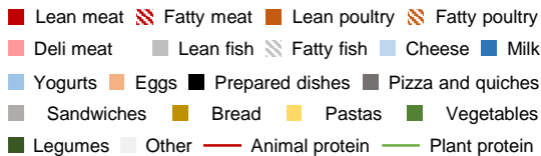
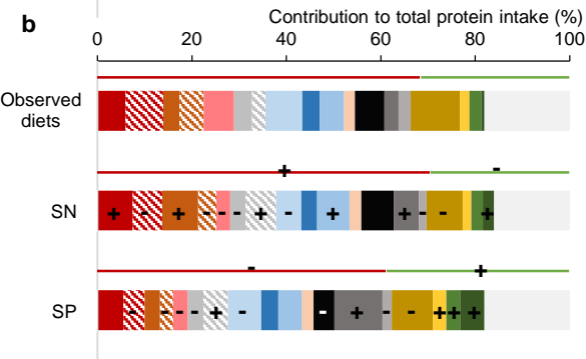
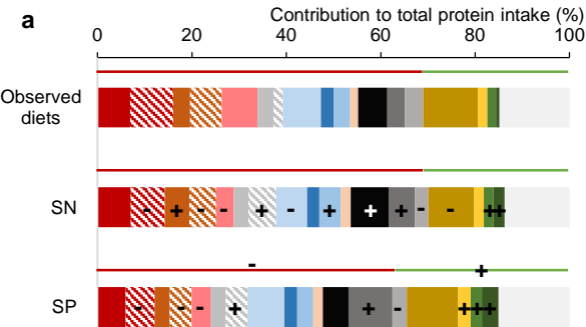
- 450 United Against Hunger. In, FAO Headquarters, Rome, Italy, 2012. Food and Agriculture
 451 Organization of the United Nations (FAO),
 452 Camilleri GM, Verger EO, Huneau J-F, Carpentier F, Dubuisson C, Mariotti F (2013) Plant and animal
 453 protein intakes are differently associated with nutrient adequacy of the diet of French adults
 454 J Nutr 143:1466-1473
 455 Castetbon K et al. (2009) Dietary intake, physical activity and nutritional status in adults: the French
 456 nutrition and health survey (ENNS, 2006–2007) Br J Nutr 102:733-743
 457 doi:10.1017/s0007114509274745
 458 Centre d'Information des Viandes (2005) INAPORC : Etude nutritionnelle de la viande de porc
 459 fraiche. <http://www.lessentieldesviandes-pro.org>. Accessed 08/03/2017
 460 Centre d'Information des Viandes & INRA (2009) Valeurs nutritionnelles des
 461 viandes. <http://www.lessentieldesviandes-pro.org/pdf/PDF-tous%20morceaux.pdf>. Accessed
 462 08/03/2017
 463 Cleveland DA, Gee Q (2017) 9 - Plant-Based Diets for Mitigating Climate Change. In: Mariotti F (ed)
 464 Vegetarian and Plant-Based Diets in Health and Disease Prevention. Academic Press, pp 135-
 465 156. doi:https://doi.org/10.1016/B978-0-12-803968-7.00009-5
 466 Cobiac L, Irz X, Leroy P, Réquillart V, Scarborough P, Soler L-G (2018) Accounting for consumers'
 467 preferences in the analysis of dietary recommendations Eur J Clin Nutr doi:10.1038/s41430-
 468 018-0317-5
 469 Darmon N, Drewnowski A (2015) Contribution of food prices and diet cost to socioeconomic
 470 disparities in diet quality and health: a systematic review and analysis Nutr Rev 73:643-660
 471 doi:10.1093/nutrit/nuv027
 472 de Gavelle E, Huneau J-F, Bianchi C, Verger E, Mariotti F (2017) Protein Adequacy Is Primarily a
 473 Matter of Protein Quantity, Not Quality: Modeling an Increase in Plant:Animal Protein Ratio
 474 in French Adults Nutrients 9:1333
 475 de Gavelle E, Huneau J-F, Mariotti F (2018) Patterns of Protein Food Intake Are Associated with
 476 Nutrient Adequacy in the General French Adult Population Nutrients 10:226
 477 de Gavelle E, Huneau J-F, Fouillet H, Mariotti F (2019) The Initial Dietary Pattern Should Be
 478 Considered when Changing Protein Food Portion Sizes to Increase Nutrient Adequacy in
 479 French Adults J Nutr 149:488-496 doi:10.1093/jn/nxy275
 480 Dubuisson C, Lioret S, Touvier M, Dufour A, Calamassi-Tran G, Volatier J-L, Lafay L (2010) Trends in
 481 food and nutritional intakes of French adults from 1999 to 2007: results from the INCA
 482 surveys Br J Nutr 103:1035-1048
 483 EFSA (2005) Opinion of the Scientific Committee on a request from EFSA related to a harmonised
 484 approach for risk assessment of substances which are both genotoxic and carcinogenic EFSA
 485 Journal 3:282
 486 EFSA CONTAM Panel (2015) Scientific Opinion on the risks to public health related to the presence of
 487 nickel in food and drinking water EFSA Journal 13:4002 doi:doi:10.2903/j.efsa.2015.4002
 488 EFSA CONTAM Panel (2018) Risk for animal and human health related to the presence of dioxins and
 489 dioxin-like PCBs in feed and food EFSA Journal 16:e05333 doi:10.2903/j.efsa.2018.5333
 490 EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) (2010) Scientific Opinion on Dietary
 491 Reference Values for fats, including saturated fatty acids, polyunsaturated fatty acids,
 492 monounsaturated fatty acids, trans fatty acids, and cholesterol EFSA Journal 8:1461
 493 doi:10.2903/j.efsa.2010.1461
 494 FAO (2018) FAOSTAT - <http://www.fao.org/faostat/en/#data/CL>
 495 FranceAgriMer (2015) Impact de la crise économique sur la consommation de viande et évolution
 496 des comportements alimentaires Les synthèses de FranceAgriMer 21
 497 Gerber PJ et al. (2013) Tackling climate change through livestock: a global assessment of emissions
 498 and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO),
 499 Godfray HCJ et al. (2018) Meat consumption, health, and the environment Science 361
 500 doi:10.1126/science.aam5324

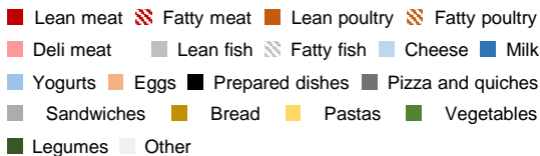
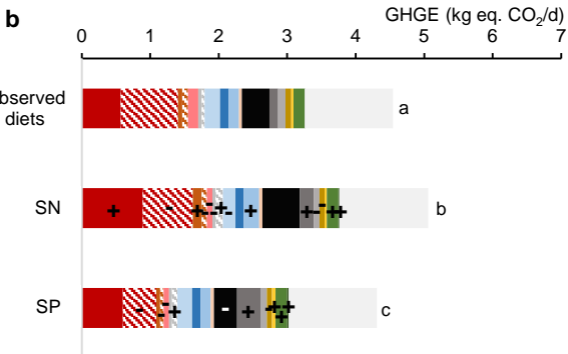
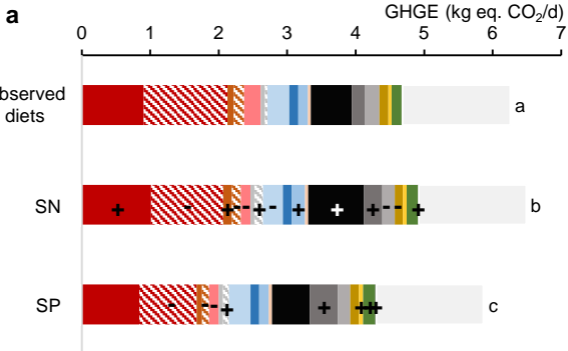
- 501 Hallberg L, Hulthen L (2000) Prediction of dietary iron absorption: an algorithm for calculating
502 absorption and bioavailability of dietary iron *Am J Clin Nutr* 71:1147-1160
- 503 Hartikainen H, Pulkkinen H (2016) Summary of the chosen methodologies and practices to produce
504 GHGE-estimates for an average European diet *Natural Resources and Bioeconomy Studies* 58
- 505 Henry C (2005) Basal metabolic rate studies in humans: measurement and development of new
506 equations *Public Health Nutr* 8:1133-1152
- 507 Horgan GW, Perrin A, Whybrow S, Macdiarmid JI (2016) Achieving dietary recommendations and
508 reducing greenhouse gas emissions: modelling diets to minimise the change from current
509 intakes *International Journal of Behavioral Nutrition and Physical Activity* 13:46
510 doi:10.1186/s12966-016-0370-1
- 511 Kantar WorldPanel (2006) French household consumer panel—Kantar worldpanel. Available
512 from: <http://www.kantarworldpanel.com/global/Sectors>
- 513 Kongkachuichai R, Napatthalung P, Charoensiri R (2002) Heme and Nonheme Iron Content of Animal
514 Products Commonly Consumed in Thailand *J Food Compos Anal* 15:389-398
515 doi:<http://dx.doi.org/10.1006/jfca.2002.1080>
- 516 Macdiarmid JI, Kyle J, Horgan GW, Loe J, Fyfe C, Johnstone A, McNeill G (2012) Sustainable diets for
517 the future: Can we contribute to reducing greenhouse gas emissions by eating a healthy
518 diet? *Am J Clin Nutr* 96:632-639 doi:10.3945/ajcn.112.038729
- 519 Masset G, Vieux F, Verger EO, Soler L-G, Touazi D, Darmon N (2014) Reducing energy intake and
520 energy density for a sustainable diet: a study based on self-selected diets in French adults *Am*
521 *J Clin Nutr* 99:1460-1469 doi:10.3945/ajcn.113.077958
- 522 Miller LV, Krebs NF, Hambidge KM (2007) A mathematical model of zinc absorption in humans as a
523 function of dietary zinc and phytate *J Nutr* 137:135-141
- 524 Millour S et al. (2011) Pb, Hg, Cd, As, Sb and Al levels in foodstuffs from the 2nd French total diet
525 study *Food Chem* 126:1787-1799 doi:<https://doi.org/10.1016/j.foodchem.2010.12.086>
- 526 Niva M, Vainio A, Jallinoja P (2017) 10 - Barriers to Increasing Plant Protein Consumption in Western
527 Populations. In: Mariotti F (ed) *Vegetarian and Plant-Based Diets in Health and Disease*
528 *Prevention*. Academic Press, pp 157-171. doi:[https://doi.org/10.1016/B978-0-12-803968-](https://doi.org/10.1016/B978-0-12-803968-7.00010-1)
529 [7.00010-1](https://doi.org/10.1016/B978-0-12-803968-7.00010-1)
- 530 Noël L et al. (2012) Li, Cr, Mn, Co, Ni, Cu, Zn, Se and Mo levels in foodstuffs from the Second French
531 TDS *Food Chem* 132:1502-1513 doi:<https://doi.org/10.1016/j.foodchem.2011.12.009>
- 532 Norat T et al. (2005) Meat, Fish, and Colorectal Cancer Risk: The European Prospective Investigation
533 into Cancer and Nutrition JNCI: *Journal of the National Cancer Institute* 97:906-916
534 doi:10.1093/jnci/dji164
- 535 Nougadère A et al. (2012) Total diet study on pesticide residues in France: Levels in food as
536 consumed and chronic dietary risk to consumers *Environ Int* 45:135-150
537 doi:<https://doi.org/10.1016/j.envint.2012.02.001>
- 538 Orlich MJ, Singh P, Sabaté J, et al. (2013) Vegetarian dietary patterns and mortality in adventist
539 health study 2 *JAMA Internal Medicine* 173:1230-1238
540 doi:10.1001/jamainternmed.2013.6473
- 541 Perignon M, Vieux F, Soler L-G, Masset G, Darmon N (2017) Improving diet sustainability through
542 evolution of food choices: review of epidemiological studies on the environmental impact of
543 diets *Nutr Rev* 75:2-17 doi:10.1093/nutrit/nuw043
- 544 Phillips SM, Fulgoni VL, Heaney RP, Nicklas TA, Slavin JL, Weaver CM (2015) Commonly consumed
545 protein foods contribute to nutrient intake, diet quality, and nutrient adequacy *Am J Clin*
546 *Nutr* 101:1346S-1352S doi:10.3945/ajcn.114.084079
- 547 Pimentel D, Pimentel M (2003) Sustainability of meat-based and plant-based diets and the
548 environment *Am J Clin Nutr* 78:660S-663S doi:10.1093/ajcn/78.3.660S
- 549 Poquet D, Chambaron-Ginhac S, Issanchou S, Monnery-Patris S (2017) Interroger les représentations
550 sociales afin d'identifier des leviers en faveur d'un rééquilibrage entre protéines animales et
551 végétales : approche psychosociale *Cahiers de Nutrition et de Diététique* 52:193-201
552 doi:<http://dx.doi.org/10.1016/j.cnd.2017.05.002>

- 553 Rohrmann S et al. (2013) Meat consumption and mortality - results from the European Prospective
554 Investigation into Cancer and Nutrition BMC Med 11:63 doi:10.1186/1741-7015-11-63
- 555 Scarborough P, Appleby PN, Mizdrak A, Briggs ADM, Travis RC, Bradbury KE, Key TJ (2014a) Dietary
556 greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK
557 Climatic Change 125:179-192 doi:10.1007/s10584-014-1169-1
- 558 Scarborough P, Harrington RA, Mizdrak A, Zhou LM, Doherty A (2014b) The Preventable Risk
559 Integrated Model and Its Use to Estimate the Health Impact of Public Health Policy Scenarios
560 Scientifica 2014:21 doi:10.1155/2014/748750
- 561 Seconda L et al. (2018) Comparing nutritional, economic, and environmental performances of diets
562 according to their levels of greenhouse gas emissions Climatic Change 148:155-172
563 doi:10.1007/s10584-018-2195-1
- 564 Sirot V, Fremy J-M, Leblanc J-C (2013) Dietary exposure to mycotoxins and health risk assessment in
565 the second French total diet study Food Chem Toxicol 52:1-11
566 doi:https://doi.org/10.1016/j.fct.2012.10.036
- 567 Sirot V, Tard A, Venisseau A, Brosseau A, Marchand P, Le Bizec B, Leblanc J-C (2012) Dietary
568 exposure to polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans and
569 polychlorinated biphenyls of the French population: Results of the second French Total Diet
570 Study Chemosphere 88:492-500 doi:https://doi.org/10.1016/j.chemosphere.2012.03.004
- 571 Sirot V, Volatier JL, Calamassi-Tran G, Dubuisson C, Ménard C, Dufour A, Leblanc JC (2009) Core food
572 of the French food supply: second Total Diet Study Food Additives & Contaminants: Part A
573 26:623-639 doi:10.1080/02652030802695506
- 574 Springmann M, Godfray HCJ, Rayner M, Scarborough P (2016) Analysis and valuation of the health
575 and climate change cobenefits of dietary change Proceedings of the National Academy of
576 Sciences 113:4146-4151 doi:10.1073/pnas.1523119113
- 577 Tilman D, Clark M (2014) Global diets link environmental sustainability and human health Nature
578 515:518 doi:10.1038/nature13959
- 579 U.S. Department of Health and Human Services and U.S. Department of Agriculture (2015) 2015–
580 2020 Dietary guidelines for Americans - Available
581 at <http://health.gov/dietaryguidelines/2015/guidelines/> (accessed on 01/03/2018) vol 8th
582 Edition. Washington (DC)
- 583 Vanhonacker F, Van Loo EJ, Gellynck X, Verbeke W (2013) Flemish consumer attitudes towards more
584 sustainable food choices Appetite 62:7-16 doi:https://doi.org/10.1016/j.appet.2012.11.003
- 585 Verger EO, Holmes BA, Huneau JF, Mariotti F (2014) Simple Changes within Dietary Subgroups Can
586 Rapidly Improve the Nutrient Adequacy of the Diet of French Adults J Nutr 144:929-936
587 doi:10.3945/jn.113.188284
- 588 Verger EO, Mariotti F, Holmes BA, Paineau D, Huneau J-F (2012) Evaluation of a diet quality index
589 based on the probability of adequate nutrient intake (PANDiet) using national French and US
590 dietary surveys PLoS One 7:e42155
- 591 Vieux F, Soler L-G, Touazi D, Darmon N (2013) High nutritional quality is not associated with low
592 greenhouse gas emissions in self-selected diets of French adults Am J Clin Nutr
593 doi:10.3945/ajcn.112.035105
- 594 Willett WC, Howe GR, Kushi LH (1997) Adjustment for total energy intake in epidemiologic studies
595 Am J Clin Nutr 65:1220S-1228S

596

597





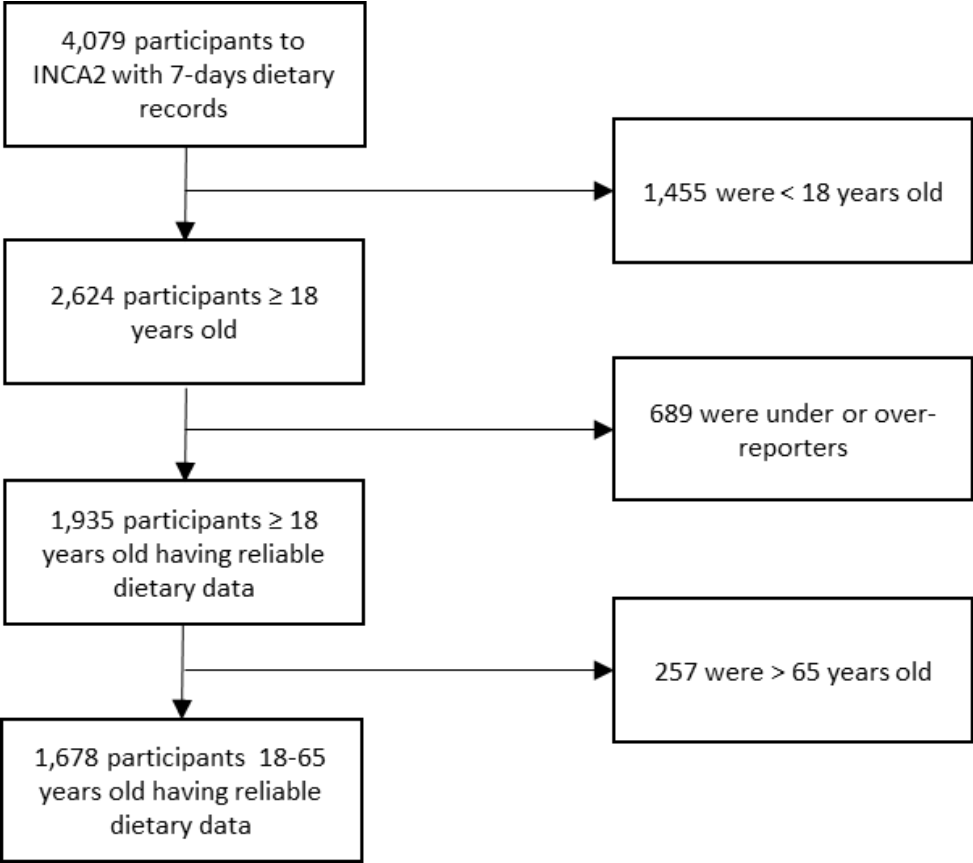
Supplementary Material.

Modeling gradual changes in protein intake to increase nutrient adequacy leads to greater sustainability when systematically targeting plant protein

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Online Resource 1. Flow chart explaining the sampling of French subjects from the INCA2 study

Online Resource 2. Percentage of food items considered as “protein foods” by food group of the INCA2 nomenclature.

Food groups	Number of protein food items¹ (as % of total food items in the food group)
Meat	35 (100%)
Poultry and game	23 (100%)
Sandwiches, snacks	29 (100%)
Deli meat	53 (96%)
Fish	71 (93%)
Legumes	10 (91%)
Offal	15 (88%)
Prepared dishes	69 (88%)
Cheese	91 (87%)
Eggs and derivatives	11 (85%)
Pizzas, quiches and salted pastries	17 (81%)
Bread and bread products	18 (72%)
Milk	15 (71%)
Pastas	3 (60%)
Dairy products	36 (59%)
Rice or wheat	2 (50%)
Desserts, puddings and milk jelly	13 (41%)
Foods intended for particular nutritional uses	6 (37%)
Dried fruits and oilseeds	8 (32%)
Soups and broths	6 (32%)
Other hot drinks	3 (27%)
Other cereals	1 (25%)
Breakfast cereals	5 (21%)
Other fat	1 (17%)
Potatoes and related	2 (17%)
Coffee	1 (14%)
Vegetables (excl. potatoes)	10 (10%)
Cakes	4 (9%)
Pastries	1 (8%)
Sweet or savory cookies and bars	1 (3%)
Nonalcoholic soft drinks	1 (2%)
Butter	0 (0%)
Oil	0 (0%)
Margarine	0 (0%)
Fruit	0 (0%)
Ice cream and frozen desserts	0 (0%)
Chocolate	0 (0%)
Sugars and derivatives	0 (0%)
Water	0 (0%)
Alcoholic beverages	0 (0%)
Stewed fruit and compote	0 (0%)
Condiments and sauces	0 (0%)

Supplementary Material.

¹Some foods were excluded as they were ingredients (e.g. gelatin) (n = 9), or were considered to be too expensive in France (> €50/kg, e.g. lobster) (n = 6). Finally, 564 protein foods were accounted for in the models.

Online Resource 3. Implementation of the PANDiet score to the present study. The PANDiet score, expressed as the average of an adequacy subscore (accounting for 27 nutrients), and a moderation subscore (accounting for six nutrients, plus 12 potential penalty values). DHA and EPA + DHA are weighted by 1/2 as DHA is counted twice. Niacin equivalents were calculated as the sum of dietary niacin and 1/60 dietary tryptophan. The upper reference value for sugars excludes lactose. The tolerable upper intake limit for vitamin A concerns retinol only. ALA, Alpha Linolenic Acid. DHA, Docosahexaenoic Acid. EIEA, Energy Intake Excluding Alcohol. EPA, Eicosapentaenoic acid. LA, Linoleic Acid. NE, Niacin Equivalent. SFA, Saturated Fatty Acid.

PANDiet score			
Average of Adequacy and Moderation subscores			
Adequacy subscore			
Nutrient	Reference value (/day)	Variability	Source
Protein	0.66 g/kg bw	12.5%	(FAO Expert Consultation 2011)
LA	3.08% EIEA	15%	(Anses 2011)
ALA	0.769% EIEA	15%	(Anses 2011)
DHA	0.192 g	15%	(Anses 2011)
EPA + DHA	0.385 g	15%	(Anses 2011)
Fiber	23 g	15%	(Anses 2016)
Vitamin A	570 (men) or 490 (women) µg	15%	(Anses 2016)
Thiamin	0.3 mg/1000 kcal	20%	(EFSA Panel on Dietetic Products 2016b)
Riboflavin	1.3 mg	15%	(EFSA Panel on Dietetic Products 2017)
Niacin	5.44 mg NE/1000kcal	10%	(Anses 2016)
Panhotenic acid	3.62 (men) or 2.94 (women) mg	30%	(Anses 2016)
Vitamin B-6	1.5 (men) or 1.3 (women) mg	10%	(EFSA Panel on Dietetic Products 2016c)
Folate	250 µg	15%	(Anses 2016)
Vitamin B-12	3.33 µg	10%	(Anses 2016)
Vitamin C	90 mg	10%	(Anses 2016)
Vitamin D	10 µg	25%	(Anses 2016)
Vitamin E	5.8 (men) or 5.5 (women) mg	40%	(Anses 2016)
Calcium	860 (<= 24 y.o.) or 750 (>24 y.o.)	15% or 13%	(Anses 2016)
Copper	1.0 (men) or 0.8 (women) mg	15%	(Anses 2016)
Iodine	107 µg	20%	(Anses 2016)
Bioavailable iron	0.95 mg for men and non-menstruating women. Lognormal distribution for menstruating women (See formula in de Gavelle et al. (de Gavelle et al. 2018))		(Anses 2016)
Magnesium	5 mg/kg bw	15%	(Anses 2016)

Moderation subscore			
Nutrient	Reference value (/day)	Variability	Source
Protein	2.2 g/kg bw	12.5%	(Anses 2016)
Total fat	44% EIEA	5%	(Anses 2016)
SFA	12% EIEA	15%	(Anses 2011)
Carbohydrates	60.5% EIEA	5%	(Anses 2016)
Sugars	100 g	15%	(Anses 2016)
Sodium	3312 (men) or 2483 (women) mg	30%	(Anses 2016)

Tolerable Upper Intake Limits		Source
Vitamin A	3000 µg	(Anses 2016)
Niacin	900 mg	(Anses 2016)
Vitamin B6	25 mg	(Anses 2016)
Folate	1170 µg	(Anses 2016)
Vitamin D	100 µg	(Anses 2016)
Vitamin E	300 mg	(Anses 2016)
Calcium	2500 mg	(Anses 2016)
Copper	10 mg	(Anses 2016)
Iodine	600 µg	(Anses 2016)
Dissociable magnesium	250 mg	(Anses 2016)
Selenium	300 µg	(Anses 2016)
Zinc	25 mg	(Anses 2016)

Supplementary Material.

Manganese	1.56 (men) or 1.39 (women) mg	40%	(Anses 2016)
Phosphorus	Calcium (mol) / 1.65 c.f. phosphorus section	7.5% + CV Calcium (mg)	(EFSA Panel on Dietetic Products 2015)
Potassium	2692 mg	15%	(EFSA Panel on Dietetic Products 2016a)
Selenium	54 µg	15%	(Anses 2016)
Bioavailable zinc	0.642 + 0.038 b.w.	10%	(Anses 2016)

Online Resource 4. Details about the dual modifications of portions sizes of protein foods.

As reported by Bianchi et al. (Bianchi et al. 2018), the foods were grouped into “serving size sub-groups” ($n = 132$), which corresponded to the sets of foods items consumed at the same time in similar amounts. As the models allowed an increase or decrease in the quantity consumed of the protein foods, possible variations in quantity were defined for each sub-group as “portion size steps”. The portion size step for some sub-groups, defined for foods sold in units or packs (e.g. yogurts) ($n = 18$), was the quantity in one unit or pack. For the other 114 sub-groups, the portion size step was defined as follows:

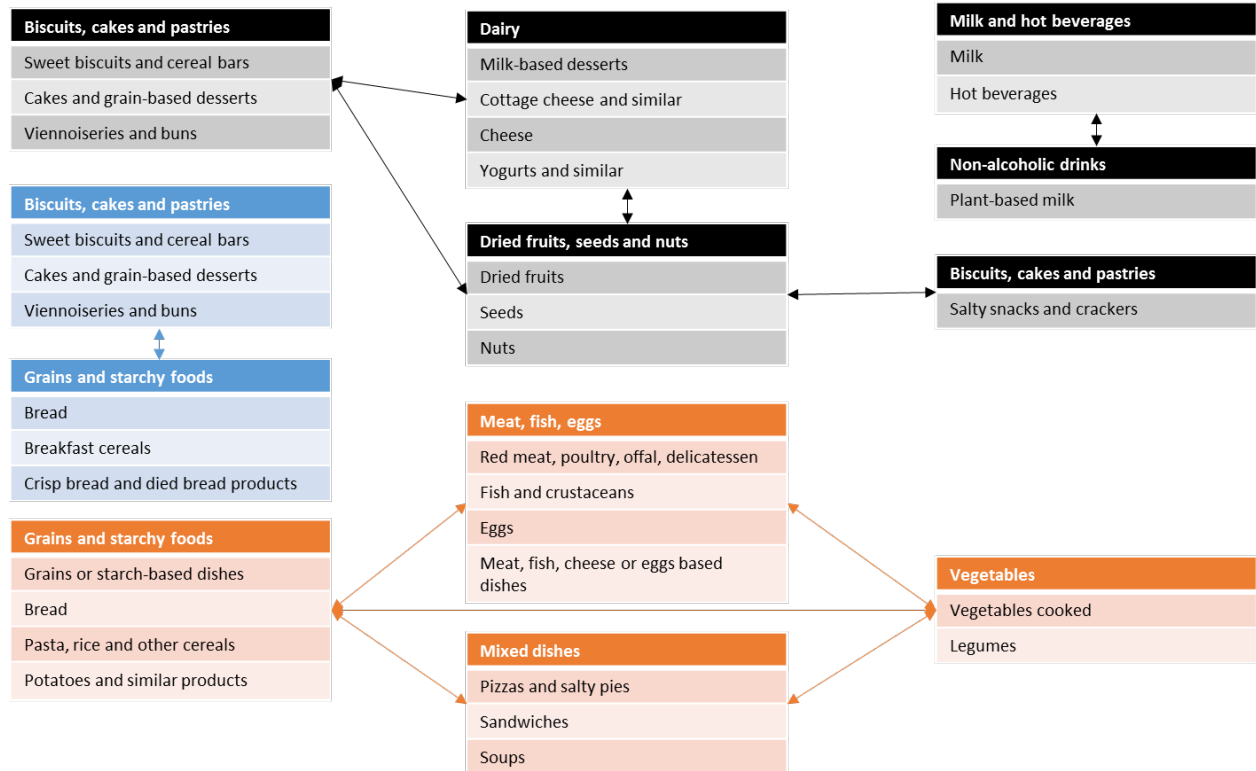
$$STEP_i = \left(\frac{(P25_i - P10_i) + (P50_i - P25_i) + (P75_i - P50_i) + (P90_i - P75_i)}{4} \right)$$

Each step in the models consisted in decreasing (or increasing) the declared serving size by one portion size step lower (or higher). The quantity of food introduced from outside the food repertoire was one portion size step. The lowest portion permitted when reducing the portion size was 0 g and the highest portion permitted was defined as the 90th percentile of intake of the serving sub-group. The paired modifications of portions were constrained between food groups that could be substituted according to the French cultural meal scheme (e.g. modifications to portions of meat could not be paired with yogurts). The rules of compatibility between food groups for paired modifications, adapted from Bianchi et al. (2018), are described in Online Resource 5.

Finally, the steps of the model in each individual diet could not lead to an increase or decrease in the initial energy intake of more than 10%, and to protein and indispensable amino acids intakes lower than the Estimated Average Requirement.

Supplementary Material.

Online Resource 5. Diagram presenting the possible paired modifications of portion sizes (one protein food gets a lower portion and one protein food gets a higher portion), depending on the meal, between food subgroups belonging to different food groups. The name of the food group is presented in bold in the first row of each box. The names of the food subgroups belonging to the group are presented from the second row to the last row of the box. The paired modifications are allowed between protein foods within the food groups and with other food groups when an arrow connects two food groups only. The paired modifications of portions of protein foods belonging to food subgroups whose name are written in orange are allowed in lunch and dinner only, those whose name are written in blue are allowed in breakfast only and those whose name is written in black are allowed in every occasion.



Online Resource 6

Censored data are defined as values below detection or quantification limits. The censored data were processed according to EFSA, FAO and WHO recommendations (EFSA et al. 2011):

Two concentration assumptions were made: the lower-bound (LB) assumption and the upper-bound (UB) assumption. The low assumption is a scenario where the undetected values are estimated to be 0 and the detected but unquantified values are estimated to be equal to the LOD. The high assumption is a scenario where the undetected values are estimated to be equal to the LOD and the detected but unquantified values are estimated to be equal to the LOQ. The LB scenario is therefore minimalist, the UB scenario maximalist.

As only total arsenic and mercury forms were analyzed, the speciation hypothesis for inorganic arsenic and methylmercury are described as follows:

- for seafood food items, the percentage of inorganic arsenic was taken from the results of French studies on dietary exposure to arsenic (Leufroy et al. 2011; Sirot et al. 2009), as detailed in the iTDS report (Anses 2016a),
- for water, 100% of the arsenic was supposed to be inorganic,
- for the other food items, 70% of the arsenic was supposed to be inorganic, as recommended by the EFSA (European Food Safety Authority (EFSA) 2014).
- for fish items, it was considered that 100% of mercury was methylmercury and 20% inorganic mercury and for mollusks and crustaceans that 80% of mercury was methylmercury and 50% inorganic mercury. For other foods, it was considered that 100% of mercury was inorganic (Anses 2016b).

As in previous publications (de Gavelle et al. 2016; Nougadère et al. 2011), the estimated daily intake (EDI) of each substance “j” for each individual “i” was calculated with a semi probabilistic approach as follows:

$$EDI_{i,j} = \frac{\sum_{k=1}^n C_{i,k} \times L_{k,j}}{BW_i} \quad \text{in } \mu\text{g/kg of body weight/day}$$

n: number of foods consumed by individual i for which concentration data are available

$C_{i,k}$: consumption of food item k by individual i (g/day), calculated as an average consumption on the recorded days

$L_{k,j}$: mean level of substance j in food k (if possible regional and seasonal mean) ($\mu\text{g/g}$)

BW_i : body weight of individual i (kg)

Online Resource 7. Mean GHGE estimate of the INCA2 food groups after assignment of INCA2 items to GHGE estimates from Hartikainen and Pulkkinen 2016¹

INCA2 food groups	Mean GHGE estimate (kg CO₂eq/kg food)
Meat	33.5
Poultry and game	6.2
Sandwiches, snacks	7.2
Deli meat	5.6
Fish	3.7
Legumes	0.5
Offal	22.2
Prepared dishes	6.6
Cheese	8.3
Eggs and derivatives	2.9
Pizzas, quiches and salted pastries	5.4
Bread and bread products	1.0
Milk	1.6
Pastas	1.0
Dairy products	1.7
Rice or wheat	1.3
Desserts, puddings and milk jelly	5.3
Foods intended for particular nutritional uses	1.0
Dried fruits and oilseeds	2.0
Soups and broths	0.5
Other hot drinks	0.3
Other cereals	1.0
Breakfast cereals	1.1
Other fat	8.6
Potatoes and related	0.8
Coffee	0.6
Vegetables (excl. potatoes)	1.3
Cakes	2.1
Pastries	2.1
Sweet or savory cookies and bars	2.1
Nonalcoholic soft drinks	0.6
Butter	9.5
Oil	3.4
Margarine	1.7
Fruit	0.7
Ice cream and frozen desserts	6
Chocolate	3.1
Sugars and derivatives	1.0
Water	0.1
Alcoholic beverages	1.5
Stewed fruit and compote	1.5
Condiments and sauces	1.1

¹ The mean GHGE estimate was weighted by the total intake of the food item in the INCA2 study

Supplemental References

- Anses (2011) Actualisation des apports nutritionnels conseillés pour les acides gras - <https://www.anses.fr/fr/system/files/NUT2006sa0359Ra.pdf> Rapport d'expertise collective
- Anses (2016a) Étude de l'alimentation totale infantile - Tome 2 – Partie 1 Méthodologie, limites et incertitudes - Annexe 7 - <https://www.anses.fr/fr/system/files/ERCA2010SA0317Ra-Tome2-Part1.pdf> Rapport d'expertise collective
- Anses (2016b) Updating of the PNNS guidelines: revision of the food-based dietary guidelines - <https://www.anses.fr/en/system/files/NUT2012SA0103Ra-1EN.pdf> Anses opinion - Collective expert report
- Anses (2016) Actualisation des repères du PNNS : élaboration des références nutritionnelles - www.anses.fr/fr/system/files/NUT2012SA0103Ra-2.pdf Rapport d'expertise collective
- Bianchi CM et al. (2018) A clear trade-off exists between the theoretical efficiency and acceptability of dietary changes that improve nutrient adequacy during early pregnancy in French women: Combined data from simulated changes modeling and online assessment survey PLoS One 13:e0194764
- de Gavelle E et al. (2016) Chronic dietary exposure to pesticide residues and associated risk in the French ELFE cohort of pregnant women Environ Int 92-93:533-542
doi:<https://doi.org/10.1016/j.envint.2016.04.007>
- de Gavelle E, Huneau J-F, Mariotti F (2018) Patterns of Protein Food Intake Are Associated with Nutrient Adequacy in the General French Adult Population Nutrients 10:226
- EFSA, FAO, WHO (2011) Towards a harmonised Total Diet Study approach: a guidance document EFSA Journal 9:66 doi:10.2903/j.efsa.2011.2450
- EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) (2015) Scientific opinion on dietary reference values for phosphorus EFSA journal 13:4185 doi:10.2903/j.efsa.2015.4185
- EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) (2016a) Scientific opinion of dietary reference values for potassium EFSA Journal 14:e04592 doi:10.2903/j.efsa.2016.4592
- EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) (2016b) Scientific opinion on dietary reference values for thiamin EFSA journal 14:4653 doi:10.2903/j.efsa.2016.4653
- EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) (2016c) Scientific opinion on dietary Reference Values for vitamin B6 EFSA Journal 14:e04485-n/a doi:10.2903/j.efsa.2016.4485
- EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) (2017) Scientific opinion on dietary Reference Values for riboflavin EFSA Journal 15:e04919 doi:10.2903/j.efsa.2017.4919
- European Food Safety Authority (EFSA) (2014) Dietary exposure to inorganic arsenic in the European population EFSA Journal 12:3597 doi:10.2903/j.efsa.2014.3597
- FAO Expert Consultation (2011) Dietary protein quality evaluation in human nutrition FAO Food Nutr Pap 92:1-66
- Leufroy A, Noël L, Dufailly V, Beauchemin D, Guérin T (2011) Determination of seven arsenic species in seafood by ion exchange chromatography coupled to inductively coupled plasma-mass spectrometry following microwave assisted extraction: Method validation and occurrence data Talanta 83:770-779 doi:<https://doi.org/10.1016/j.talanta.2010.10.050>
- Nougadère A, Reninger J-C, Volatier J-L, Leblanc J-C (2011) Chronic dietary risk characterization for pesticide residues: A ranking and scoring method integrating agricultural uses and food contamination data Food Chem Toxicol 49:1484-1510
doi:<https://doi.org/10.1016/j.fct.2011.03.024>
- Sirot V, Guérin T, Volatier JL, Leblanc JC (2009) Dietary exposure and biomarkers of arsenic in consumers of fish and shellfish from France Sci Total Environ 407:1875-1885
doi:<https://doi.org/10.1016/j.scitotenv.2008.11.050>