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ABSTRACT

In the present context of environmental damages, food systems constitute one of the key burdens on the environment and resources. Dietary patterns emerge as a main leverage to preserve a healthy environment.

The aim is to compare the environmental impacts of different diets with different levels of animal product consumption, while accounting for the type of farming systems (organic or conventional) of the food consumed.

Dietary environmental impacts of the diet of 29,210 NutriNet-Santé participants were estimated using databases developed within the BioNutriNet project. Four diets, differing from their animal-based food proportion, were studied: omnivorous, pesco-vegetarian, vegetarian, and vegan. Three individual environmental indicators were assessed (greenhouse gas emissions, cumulative energy demand and land occupation) and combined in one aggregated partial score (pReCiPe, partial ReCiPe). Means of these indicators adjusted for energy intake were estimated across diet groups using covariance analysis.

About 95% of the study sample was omnivorous. Organic consumption was much higher among non–omnivorous than other groups. The pReCiPe were 64%, 61%, and 69% lower for diet of pesco-vegetarians, vegetarians and vegans respectively, in comparison to the omnivorous diet. Regarding the three individual environmental indicators included in the pReCiPe index, the same trend was observed but trade-offs exist in organic with cumulative energy lowered and land occupation augmented.

A positive link between animal-sourced food consumption and total environmental impact was observed in this large sample of French adults. By far, omnivorous had the highest-level of greenhouse gas emissions, cumulative energy demand and land occupation while vegan diets had the lowest. Further research on environmental indicators distinguishing farming practices is needed to allow a more comprehensive evaluation of the impact.

1 **INTRODUCTION**

2 Over the past decades, environmental damage, such as climate disruption, the sixth mass

3 extinction of biodiversity, deforestation, water use and human interference with the nitrogen

4 and phosphorus cycles, has intensified (1−3). This damage is the consequence of the current

5 society's dominant model, specifically that of agriculture and food consumption, causing

6 major pressures on the environment (4,5). If there is no change in the food system by 2050,

7 the increase in greenhouse gas (GHG) emissions, cropland use, freshwater use, and nitrogen

8 and phosphorus application would drive biophysical processes beyond planetary boundaries

9 (2,4,6).

10 There is a growing body of scientific literature dealing with environmental impacts of food

11 production and consumption, with data mainly focusing on agriculture-related greenhouse gas

12 emissions (3,7,8).

13 The food system represents 20 to 30% of the global GHG emissions (9,10). Therefore, at both

14 collective and individual level, food behaviors and food choices represent major levers of

15 action against the ongoing environmental disaster. These emissions could be attenuated by

16 reduction of meat consumption, illustrated by many studies showing that removing entirely

17 meat from a healthy diet will (11) result in a reduction by about one-third of GHG emissions

18 (12), or that diet-related GHG emissions are twice lower for vegans than for meat eaters (13).

19 Livestock, in particular, exhibits significant pressures on the environment including extensive

20 land use and energy demand, biodiversity loss, N surplus and water use. Beyond the

21 ecosystem services of livestock including grasslands for the biodiversity and carbon storage

22 (14,15), Aleksandrowicz et al. showed that diets reducing the amount of animal-based foods

23 had the largest environmental benefits (first vegans, then vegetarians, and pesco-vegetarians),

24 not only in terms of GHG emissions, but also in terms of land use and energy demand (8).

25 Land cropping, especially when intensively cultivated, contributes to greenhouse gases,

26 deforestation, biodiversity loss, water use and pollution through fertilizers and synthetic

27 pesticides as well as soil pollution and erosion (16,17).

28 Although strong positive correlation between organic food consumption and vegetarianism

29 have been observed (18,19) driving by some similar motives, namely ethic and environment

30 preservation, few studies have considered the type of farming practices when studying the

31 environmental impacts of diets (20). These farming models may play an important positive

32 role in terms of environmental impacts. Thus, there is a lack of information regarding organic

33 farming in previous studies that usually consider only the prevailing conventional agriculture.

34 Organic farming is, with respect to many indicators, more environment-friendly than

35 conventional farming (17,21,22). Indeed, organic systems are characterized by higher energy

36 efficiency (17,23), better soil biophysics and biologic quality (21,24) and contribute positively

37 to plant and animal biodiversity (both in cropland and wild life) (9,11,12). Regarding GHG

38 emissions, organic farming performs better than conventional, but only per area (26,27).

39 Indeed, organic farming has lower yield and, as a result, does not reduce significantly the

40 GHG and increases the land use per product unit (23,24,27). At the individual diet level, we

41 previously reported that regular organic food consumers exhibited environmental benefits.

42 Disentangling the role of food patterns (plant-based diet) and farming system (organic or

43 conventional) revealed that organic farming system led to a slight reduction in cumulative

44 energy demand but to a rise of land occupation (28). Thus, the studies investigating

45 environmental impacts related to different diets, in particular vegetarian and vegans, without

46 consider farming practices, may have underestimated some impacts as these consumers are

47 more prone to choose organic food.

48 In that context, the aim of this study is to compare the environmental pressure and impact of

49 diets of participants of the large cohort NutriNet-Santé study across different diets

50 (omnivorous, pesco-vegetarians, vegetarians, and vegan), while distinguishing farming

51 practice (organic or conventional) in the assessment of impacts.

52 **2.METHODS AND DATA**

53 **2.1 NutriNet-Santé Study**

54 The NutriNet-Santé Study (29) is a prospective cohort conducted in French volunteers' adults.

55 Since 2009, data are collected by questionnaires through a secured on-line platform. On a

56 yearly basis, the participants are required to provide information as regards sociodemographic

57 and socioeconomic status, weight, height, smoking status, alcohol consumption, health events,

58 medication use and food consumption. They are also regularly requested to fill-in additional

59 questionnaires focusing on diet-related topics.

60 This study is piloted in line with the Declaration of Helsinki, and all processes were officially

61 accepted by the Institutional Review Board of the French Institute for Health and Medical

62 Research (IRB Inserm 0000388FWA00005831) and the Commission Nationale de

63 l'Informatique et des Libertés (CNIL908). The volunteers completed and signed electronically

64 an informed consent. The NutriNet-Santé Study is registered in ClinicalTrials.gov

65 (NCT03335644).

66 **2.2 Data Collection**

67 **2.2.1 Dietary intake assessment and diet group classification**

68 In 2014, food consumption over the last year was estimated through the Org-FFQ, a self-

69 administered organic food-frequency questionnaire (Org-FFQ) (11) with photographs

70 improving estimation of the portion size. The Org-FFQ was developed from a validated FFQ

71 (30) with additional questions inquiring organic food consumption. Thus, volunteers reported

72 their consumption frequency and the portion consumed for 264 food items grouped in 17

73 groups. Participants also specified the frequency of consumption as organic for 257 food and

74 beverage items (existing with organic label). Then to the question "How often was the product

75 of organic origin?", the respondents could answer by: never, rarely, half-of-the-time, often or

76 always. Then, each modality was assigned a percentage, respectively 0%, 25%, 50%, 75%

77 and 100% to estimate the organic food consumption (in g) for each food item (28).

78 Daily nutritional intakes were calculated using the NutriNet-Santé food composition table

79 (31).

80 For this study, NutriNet-Santé participants were classified into one of the following diet

81 groups: 1) omnivorous: diet that included meat or fish intake almost every day, 2) pesco-

82 vegetarian: diet that did not include meat (<1g/day), but included dairy products, eggs, fish

83 and seafood, 3) vegetarian: diet that did not include animal flesh (<1g /day) but included dairy

84 products and eggs and 4) vegan: diet that did not include any animal flesh (<1g /day) or any

85 animal products (no eggs or dairy products, <1g/day)).

86 We also calculated the PANDiet (probability of adequate nutrient intake score), a 100-point

87 index reflecting the nutritional quality of the whole diet. PANDiet is the average of a

88 moderation and an adequation subscores which are based on the Probability of Adequate

89 Nutrient intake (32).

90 **2.2.2 Environmental impact assessment**

91 Details of the assessment of the environmental impact, LCA and sources by product and

92 production method have been extensively detailed elsewhere (33). Briefly, diet-related

93 environmental impacts were assessed using a French database (DIALECTE (34)) of

94 environmental measure for raw agricultural products and completed with other published

95 data. Environmental data came from 2,086 farms with different farming practices (46% were

96 organic farms). The Life Cycle Assessment (LCA) methodology was applied to the data

97 pertaining to resources consumption and environmental impacts for about 60 agricultural

98 commodities. Due to a lack of data for organic food system, LCA were calculated at the farm

99 gate only.

100   Three environmental indicators were evaluated: greenhouse gas emissions (GHGe) (kgCO$_2$

101   eq/kg), cumulative energy demand (CED) (in MJ/kg) and land occupation (LO) (in m²/kg).

102   GHG emissions covered the sum of three GHGs (carbon dioxide CO$_2$, methane CH$_4$ and

103   nitrous oxide N$_2$O). The CED encompassed renewable and unrenewable energy consumption

104   as (35). The Dia'terre® method was used for GHGe and CED (36). The land occupation (LO)

105   corresponded to the area required to produce agricultural commodities within one year.

106   Economic and transformation weights were applied to translate commodities to consumption

107   (33).

108   The environmental impacts of individual diet were estimated by multiplying the

109   environmental impacts by the food quantity consumed (g/day), while accounting for the

110   method of food production. The three above-mentioned indicators were combined in a single

111   indicator to get a more synthetic measure of the overall environmental impacts. To account

112   for existing trade-offs between environmental pressures, the ReCiPe aggregating several

113   pressure indicators has been proposed. This approach considers the matching of midpoint-

114   oriented and endpoint-oriented indicators (37). As GHGe, CED and land occupation represent

115   about 90% of the total environmental dimension of the ReCiPe, the partial ReCiPe (pReCiPe)

116   for environmental impact assessment of food product and diet has been defined (38). This

117   score was computed, as follows:

118   pReCiPe = [0.0459 * GHGe + 0.0025 * CED + 0.0439 * LO]

119   Where GHGe is greenhouse gas emissions, in kgCO$_2$ eq/kg, CED is cumulative energy

120   demand, in MJ/kg and LO is land occupation, in m²/kg. The highest the pReCiPe index is

121   high the environmental impact. We also computed the pRecipe index and the three individual

122   indicators for 100% organic and 100% conventional diet by attributing organic or

123   conventional environmental value to all the foods consumed.

124   **2.2.3 Covariates**

125   The covariates used were those closest to the filling date of the Org-FFQ (39). The variables

126   were gender, age, living area (rural, i.e. a population below 2,000 inhabitants or urban, i.e. a

127   population above 2,000 inhabitants), education (< school diploma, high school diploma and

128   post-secondary graduate) and monthly income per household unit (<1,200 euros, between

129   1,200 and 1,800 euros, between 1,800 and 2,700 euros, and > 2,700 euros), physical activity,

130   (< 30 min/day, 30 to 60 min/day, and > 60 min/day), tobacco status (former smoker, non-

131   smoker, and current smoker). The daily diet monetary cost (€/day) was estimated for each

132   participant by multiplying the quantities consumed (g/day) by the corresponding item prices

133   (€/g), while accounting for farming practice and place of purchase as previously extensively

134   described (28).

135   **2.3 Statistical analyses**

136   Among the 37,685 NutriNet-Santé participants who completed de Org-FFQ, 8,475 individuals

137   were excluded. Exclusion criteria were: missing covariates (n=380), under- or over-reporters

138   (n=2,109), living overseas (n=743) and no data regarding the place of purchase (n=5,243).

139   Therefore, the final sample included 29,210 participants (**Supplemental Figure 1**).

140   Participants' characteristics were reported as means (SD) or percentages. P-values referred to

141   chi-square test for categorical variables or variance analysis (ANOVA) for continuous

142   variables. ANCOVA (analysis of covariance) models were performed (for other

143   characteristics) to estimate the nutritional and environmental characteristics according to the

144   diets, providing means (95% CI) adjusted for energy intake**.** For the nutrients, energy

145   adjustment was performed using the residual method (40). P-values were estimated via

146   covariance analysis. For statistical tests, the type I error was set at 5%. Data management and

147   statistical analyses were conducted using SAS 9.4 software (SAS Institute Inc.).

148   **3. RESULTS**

149   **3.1 Socio-demographic characteristics of participants across diets**

150   The sociodemographic characteristics of the study sample are presented in **Table 1**. A total of

151   74.7 % were women and the mean age (SD) was 53.5 (13.99). About 95% of the participants

152   were omnivorous. Pesco-vegetarians (1.59%), vegetarians (1.39%) and vegans (1.02%) were

153   younger, more likely to live in urban area, more often graduated and had more often lower

154   income than omnivorous. They were also more often less physically active and drank on

155   average less alcohol than omnivorous. However, there was no significant difference for

156   tobacco status. Finally, vegetarians had the lowest diet monetary cost and vegans the highest.

157   **3.2 Nutritional characteristics**

158   Nutrient and food group intakes (in g/day) according to each diet group were presented in

159   **Table 2**. The energy intake was higher in the omnivorous than in the 3 other diet groups.

160   Pesco-vegetarians, vegetarians and vegans had higher intake of carbohydrates,

161   polyunsaturated fats, fibers and lower intake of saturated fats than omnivorous. As expected,

162   the ratio of vegetable to total proteins was far higher for vegans (0.95), vegetarians (0.72) and

163   pesco-vegetarians (0.58) than for omnivorous (0.32). Organic food consumption was

164   positively associated with the reduction of animal-based products in the diet, with the highest

165   organic food ratio in the diet observed among vegans (0.67 vs 0.28 among omnivorous).

166   Micronutrient intakes are shown in **Supplemental Table 1**. The PANDiet score was higher

167   among vegans than among omnivorous.

168   **3.3 Environmental impacts**

169   **Table 3** presents the values of the aggregated environmental impact (as expressed by the

170   pReCiPe) as well as the values of three individual indicators reflecting environmental

171   pressures, for each type of diet. The pReCiPe index was the highest for omnivorous, and

172   decreased when shifting toward more plant-based diet. However, the pReCiPe of pesco-

173   vegetarians and vegetarians were not statistically different. Regarding the individual

174   environmental impacts, omnivorous had by far the highest GHG emissions, CED and LO

175 values, whereas vegans showed the lowest ones. Moreover, pesco-vegetarian, vegetarian

176 diets' indicators values were similar and higher than those of vegans. Scenarios referring to a

177 100% conventional diet or 100% organic diet are presented in **Table 4**. While 100%

178 conventional diets exhibited a lower pReCiPe value compared to 100% organic diets,

179 particularly for omnivorous, environmental pressures were differentially affected by farming

180 practices. Thus, GHGe were quite similar for both scenarios. CED was higher for 100%

181 conventional diets while land occupation was higher for 100% organic diets.

182 In addition, differences across the type of diets were less pronounced in 100% conventional

183 diets. However, omnivorous were always those who exhibited the highest environmental

184 pressures. pReCiPe by food groups for each diet type is presented in **Figures 1**. After animal

185 foods, the highest environmental impacts were attributable to the fruit and vegetables, starchy

186 foods, oil and ready meals.

187 **4. DISCUSSION**

188 The present study assessed the environmental impacts of four types of diets (differing by the

189 proportion of animal-based food) in a large sample of French adults, participants from the

190 NutriNet-Santé cohort.

191 We observed significant differences between various types of diets, with respect to each

192 indicator of environmental pressure and with respect to the aggregated index (as assessed by

193 the pReCiPe). The more animal food in the diet, the higher the value of pReCiPe index.

194 However, pesco-vegetarians exhibited a similar pReCiPe value compared to vegetarians

195 although pesco-vegetarians had higher intakes of animal-based food than vegetarians. It is

196 noteworthy that land occupation related to fish and seafood consumption may have been

197 underestimated in the present study. Consequently, diet-related environmental impacts were

198 ranked (in ascending order) as follows: omnivorous, vegetarian, pesco-vegetarian and then

199 vegan. Notably, the omnivorous' diet had by far the highest environmental impacts. Extents

200   of reduction of the aggregated indicator, i.e. the pReCiPe, of environmental impact were 64%,

201   61%, and 69% for pesco-vegetarians, vegetarians and vegans respectively, compared with the

202   omnivorous. Although the two first reductions were not statistically significantly different.

203   Also, using LCA differentiating farming practices (organic or conventional), we showed that

204   vegans' diet emitted 78% less GHG, required 53% less energy and 67% less land occupation

205   than omnivorous' diet. These results are in line with several recent works documenting

206   associations between dietary patterns and a set of environmental impacts (GHG emissions,

207   land occupation, and water use) in modelled and observed data (8,10,20). Indeed, a reduction

208   in meat consumption is a major leverage for reducing diet-related environmental impacts, and

209   in particular GHG emissions (4,5,23,41,9). Aleksandrowicz et al., in a systematic review

210   focusing on GHG emissions, land occupation, and water use, concluded that the least

211   impacting diets on the environment, compared to omnivorous diets, were in descending

212   sequence the vegan diet, followed by the vegetarian, and then the pesco-vegetarian (8). In a

213   recent study, in line with our results, based on simulation and covering 140 countries, vegan

214   diets exhibited a reduced per capita GHG footprint by 70% compared to current diets (42). As

215   extensively documented, these results are largely due to higher environmental impacts of

216   animal-based products, especially ruminant meat, compared to plant-based products.

217   Recently, the EAT-Lancet commission on healthy diets from sustainable food systems (4)

218   was fashioned to assess which diets and food production systems would ensure the

219   achievement of the UN Sustainable Development Goals (SDGs) and Paris Agreement. They

220   concluded in their commission, "that a dietary change towards increased adoption of plant-

221   based diets has high mitigation potential, which is probably needed to limit global warming to

222   a less than 2°C increase" (4). Similarly, a recent modeling study conducted for 140 different

223   countries underlined that vegan diets exhibited a 70% reduction GHG footprint per capita

224   compared to current diets (42). However, GHG emissions' reduction certainly depends on the

225   amount and type of meat included in the diet, but also on the environmental impact of the

226   meat substitute (16,43). For instance, plant-based diet may exhibit various pressure. While

227   legumes, presenting interesting nutritional profiles, exhibited 250 times lower GHGe

228   ruminant meats (11), rice production emits five times more GHGe than wheat production

229   when considering gram of protein as function unit (11).

230   However, most of these studies did not distinguish between farming practices, even though

231   organic food consumption has been markedly and positively correlated with plant-based diet

232   (18,28). While organic production usually reduces CED compared to conventional

233   production, it often increases land use and has comparable on GHG emissions (when

234   considered by amount of food) (23,24,27). We found that a 100% organic omnivorous diet

235   exhibited higher environmental pressures, suggesting that following an organic diet without

236   changing towards a more plant-based diet is of little help, at least as regards the studied

237   indicators. It should be however noted that organic farming may contribute to maintain

238   biodiversity and limit water and soil pollution (21,22).

239   Herein, a reduction of GHGe of 76% was observed when comparing vegans to omnivorous.

240   In comparison, in a work conducted by Scarborough et al (44) in the EPIC-Oxford cohort

241   study, aimed at comparing GHGe four different groups, namely meat-eaters, fish-eaters,

242   vegetarians and vegans (defined using self-reporting), GHGe ($kgCO_2eq/day$) were 7.19 for

243   high meat eaters, 5.63 for medium meat-eaters and 2.89 for vegans (corresponding to a

244   reduction of 60% compared to high meat-eaters). Since it has been documented that organic

245   farming has no substantial effect on GHGe (23,24,27), with some variations according to the

246   food product considered, these can be explained by the stages accounting in the LCA in the

247   present study which focus on the cradle-to-farm perimeter. Of note, in the present study as

248   well as in a modeling study (9), pesco-vegetarian and vegetarian diets exhibited relatively

249   similar GHGe (9). Most of French studies did not focus on self-selected diets and used

250   modeling approaches (20,45,46). A French work based on INCA2 data has compared pre-

251   defined diets (i.e. "Lower-Carbon," "Higher-Quality," and "More Sustainable" diets) and

252   concluded that food choices could lead to a 20% reduction in GHGe (47). As expected, this is

253   far lower than the differences observed between the groups in the present study and hardly

254   comparable as in the INCA2 study, participants were mostly omnivorous. Another recent

255   study has optimized several European diets to identify the dietary changes to operate by

256   applying stepwise 10% decrease in GHGe (48). In all these models, a reduction in the

257   consumption of animal products was necessary, with some variations between countries. In

258   this study, it was also observed that reductions in GHGe higher than 60% could be achieved

259   only with drastic diet changes, which is the case for vegetarian diet. Furthermore, in line with

260   our results, this study showed that, for large reductions in overall GHGe, animal food

261   consumption decreased leading to higher contributions of fruits, vegetables and starchy foods

262   to GHGe.

263   There are fewer studies that have investigated land occupation associated with different types

264   of diets and those available are mostly not based on observational data (8). The present results

265   are consistent with the available literature in terms of differences in land occupation according

266   to diet, with significantly lower land use, despite smaller differences than for GHGs, for diets

267   avoiding animal products and in particular for vegan diets.

268   However, farming practices were not considered in the previous observational studies while it

269   has been documented that organic farming requires higher land use but lower energy demand

270   than conventional one (23,24,27). In this study, organic farming for food production led to

271   higher pReCiPe for omnivorous' diet only. For other diets, excluding meat, compensation

272   between indicators (higher land use, lower energy demand) results in few differences in

273   pReCiPes for 100% organic and 100% conventional scenarios. An interesting modelling study

274   evaluated environmental impact of omnivorous, vegetarian, vegan considering 100% organic

275   or 100% conventional diet (49). In this study, consistently with the present findings, for a type

276   of diet, land use was higher in organic than in conventional for a given diet. As regards

277   GHGe, we have previously shown that organic farming has overall no effect (28). Finally,

278   logically, vegetarian diets have always environmental impacts between those of meat

279   consumers and those of vegans.

280   Based on actual data, as vegans and all types of vegetarians consumed a higher proportion of

281   organic food than meat eaters, some differences observed in the previous studies may have

282   been overestimated for some indicators. Similarly to the present findings, a modeling study

283   (9) reported slight differences in environmental pressures between pesco-vegetarian and other

284   vegetarian diets. However, land use of fishing is often considered as null. In the study of

285   Baroni et al. (49), pesco-vegetarians were not considered. It would be therefore of great

286   importance to consider other environmental indicators such as water footprint or biodiversity

287   (50). A recent small study conducted in Italy documented higher environmental pressures

288   (GHGe, water and ecological footprints) for omnivorous diets than for ovo-lacto-vegetarians

289   and vegans diets and interestingly highlighted that vegetarians and vegans were more

290   adherent to the Mediterranean diet, whose sustainability s has been consistently documented

291   (9,51–54).

292   Overall, to the best of our knowledge, this study is the first, to introduce farming practices in

293   the LCA assessment of the diets. Despite accounting higher land occupation in organic

294   farming, the vegan diet, whatever the indicator considered, remained less resource-intensive

295   and environmentally damaging than other diets. It is noteworthy that omnivorous in the

296   present study exhibited relatively high consumption of meat (>120g/d on average with a wide

297   variability in intake). It is therefore essential to identify possible food substitutions, as they

298   may induce counterproductive effects. First, with regard to environmental pressures of meat,

299   interestingly, a recent modeling study, based on baseline data from 5 European countries,

300   identified sustainable diets who did not entirely exclude meat (55). It should be born in mind

301   that the present study considers three indicators but other environmental pressures not

302   accounted herein are also of great interest when considering pressure of livestock (15,56). In

303   addition, there is also a great variability in livestock methods (57). Second, environmental

304   impacts of the meat substitutes (16) may be questionable. For instance, plant-based meat

305   substitutes may exhibit important environment pressure but current data are scarce (16,43).

306   Third, besides cultural acceptability, a vegan diet may exhibit some disadvantages in terms of

307   nutrition, raising health concerns in particular among young people (9,58,59).

308   Some limitations should be considered. First, as the NutriNet-Santé cohort is composed of

309   volunteers, participants are certainly more concerned about food issues. Therefore, the

310   consumption data are not representative of the French population consumption, which may

311   limit the generalization of the results. Regarding the environmental impact assessment, herein,

312   the stages of food transportation and processing, as well as the environmental cost of food

313   waste and losses were not accounted for. The use of a FFQ, which is prone to an

314   overestimation of intakes, has probably led to some imprecisions in the estimations.

315   Moreover, due to the lack of data regarding pressure of sea farming (land occupation and

316   other reliable indicators) the present results minimize seafood and fish environmental impacts,

317   and consequently impacts of pesco-vegetarian diets. Finally, other indicators related to water

318   use, biodiversity, excess nitrogen or soil quality were not available, which limited a more

319   comprehensive assessment of the environmental footprint.

320   However, this study has also major strengths. To our knowledge, this is the first study

321   considering different farming practices, hereby organic and conventional, in the evaluation of

322   diet-related environmental impacts. Furthermore, environmental impacts were computed for

323   three indicators: GHG emissions, LO and CED while most of previous studies generally only

324   assess carbon footprint (60). Furthermore, in order to consider environmental impacts more

325 globally, the pReCiPe index was used. Regarding the data collection, the large size of the

326 sample allowed to provide a large range of eating habits, food consumption choices, and

327 validated dietary data were available.

328 **CONCLUSION**

329 The present observational study conducted in French adults highlighted that omnivorous, with

330 respect to GHGe, cumulative energy demand and land occupation, have by far the diets with

331 the most serious consequences on resources and environment when compared to diets with

332 restricted animal food. These findings also emphasize the positive link between organic

333 consumption and plant-based diets underlying the significance of accounting for farming

334 practices in environmental pressure assessment, as organic production may offer potential

335 environmental benefits/disadvantages depending on the indicator considered. In future

336 research, other environmental indicators should be considered, including, for instance,

337 biodiversity and ecotoxicity impacts, nitrate and pesticide leaching, soil quality or water use.

338 A systemic and holistic assessment only will make it possible to consider diets' consequences

339 on the environment in a broader scale. However, environmental indicators distinguishing

340 several farming practices are scarce underlining the need for more research in this field to

341 conduct a broadly evaluation.

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342   REFERENCES

343   1.   Rockström J, Steffen W, Noone K, Persson A, Chapin FS, Lambin EF, et al. A safe operating
344   space for humanity. Nature. 2009 Sep 24;461(7263):472–5.

345   2.   Steffen W, Richardson K, Rockström J, Cornell SE, Fetzer I, Bennett EM, et al. Planetary
346   boundaries: Guiding human development on a changing planet. Science [Internet]. 2015 Feb 13
347   [cited 2020 Feb 5];347(6223). Available from:
348   https://science.sciencemag.org/content/347/6223/1259855

349   3.   IPCC. Climate Change and Land: an IPCC special report on climate change, desertification, land
350   degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial
351   ecosystems. [Internet]. 2019 [cited 2020 Feb 5]. Available from:
352   https://www.ipcc.ch/srccl/chapter/technical-summary/

353   4.   Willett W, Rockström J, Loken B, Springmann M, Lang T, Vermeulen S, et al. Food in the
354   Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems.
355   Lancet. 2019 02;393(10170):447–92.

356   5.   Springmann M, Clark M, Mason-D'Croz D, Wiebe K, Bodirsky BL, Lassaletta L, et al. Options
357   for keeping the food system within environmental limits. Nature. 2018 Oct;562(7728):519–25.

358   6.   How to feed nine billion within the planet's boundaries | FAO [Internet]. [cited 2020 Feb 5].
359   Available from: http://www.fao.org/agroecology/database/detail/fr/c/463434/

360   7.   Macdiarmid JI, Kyle J, Horgan GW, Loe J, Fyfe C, Johnstone A, et al. Sustainable diets for the
361   future: can we contribute to reducing greenhouse gas emissions by eating a healthy diet?
362   AmJClinNutr. 2012 Sep;96(1938-3207 (Electronic)):632–9.

363   8.   Aleksandrowicz L, Green R, Joy EJM, Smith P, Haines A. The Impacts of Dietary Change on
364   Greenhouse Gas Emissions, Land Use, Water Use, and Health: A Systematic Review. PLoS
365   ONE. 2016;11(11):e0165797.

366   9.   Tilman D, Clark M. Global diets link environmental sustainability and human health. Nature.
367   2014 Nov 27;515(7528):518–22.

368   10.   Chai BC, van der Voort JR, Grofelnik K, Eliasdottir HG, Klöss I, Perez-Cueto FJA. Which Diet
369   Has the Least Environmental Impact on Our Planet? A Systematic Review of Vegan, Vegetarian
370   and Omnivorous Diets. Sustainability. 2019 Jan;11(15):4110.

371   11.   González-García S, Esteve-Llorens X, Moreira MT, Feijoo G. Carbon footprint and nutritional
372   quality of different human dietary choices. Sci Total Environ. 2018 Dec 10;644:77–94.

373   12.   van de Kamp ME, van Dooren C, Hollander A, Geurts M, Brink EJ, van Rossum C, et al.
374   Healthy diets with reduced environmental impact? - The greenhouse gas emissions of various
375   diets adhering to the Dutch food based dietary guidelines. Food Res Int. 2018;104:14–24.

376   13. Scarborough P, Appleby PN, Mizdrak A, Briggs ADM, Travis RC, Bradbury KE, et al. Dietary
377   greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK. Clim
378   Change. 2014;125(2):179–92.

379   14. Bengtsson J, Bullock JM, Egoh B, Everson C, Everson T, O'Connor T, et al. Grasslands—more
380   important for ecosystem services than you might think. Ecosphere. 2019;10(2):e02582.

381   15. Dumont B, Ryschawy J, Duru M, Benoit M, Chatellier V, Delaby L, et al. Review: Associations
382   among goods, impacts and ecosystem services provided by livestock farming. animal.
383   undefined/ed;1–12.

384   16. Hallström E, Carlsson-Kanyama A, Börjesson P. Environmental impact of dietary change: a
385   systematic review. Journal of Cleaner Production. 2015 Mar 15;91:1–11.

386   17. Reganold JP, Wachter JM. Organic agriculture in the twenty-first century. Nature Plants. 2016
387   Feb 3;2(2):15221.

388   18. Lacour C, Seconda L, Allès B, Hercberg S, Langevin B, Pointereau P, et al. Environmental
389   Impacts of Plant-Based Diets: How Does Organic Food Consumption Contribute to
390   Environmental Sustainability? Front Nutr. 2018;5:8.

391   19. Baudry J, Méjean C, Allès B, Péneau S, Touvier M, Hercberg S, et al. Contribution of Organic
392   Food to the Diet in a Large Sample of French Adults (the NutriNet-Santé Cohort Study).
393   Nutrients. 2015;7(10):8615–32.

394   20. Perignon M, Vieux F, Soler L-G, Masset G, Darmon N. Improving diet sustainability through
395   evolution of food choices: review of epidemiological studies on the environmental impact of
396   diets. Nutr Rev. 2017 Jan;75(1):2–17.

397   21. Gomiero T, Pimentel D, Paoletti MG. Environmental Impact of Different Agricultural
398   Management Practices: Conventional vs. Organic Agriculture. Critical Reviews in Plant
399   Sciences. 2011 Jan;30(1–2):95–124.

400   22. Muller A, Schader C, Scialabba NE-H, Brüggemann J, Isensee A, Erb K-H, et al. Strategies for
401   feeding the world more sustainably with organic agriculture. Nature Communications. 2017 Nov
402   14;8(1):1290.

403   23. Clark M, Tilman D. Comparative analysis of environmental impacts of agricultural production
404   systems, agricultural input efficiency, and food choice. Environmental Research Letters. 2017
405   Jun 1;12(6):064016.

406   24. Tuomisto HL, Hodge ID, Riordan P, Macdonald DW. Does organic farming reduce
407   environmental impacts? – A meta-analysis of European research. Journal of Environmental
408   Management. 2012 Dec;112:309–20.

409   25. Reganold JP, Wachter JM. Organic agriculture in the twenty-first century. Nat Plants. 2016
410   03;2:15221.

411   26. Mondelaers K, Aertsens J, Van Huylenbroeck G. A meta-analysis of the differences in
412   environmental impacts between organic and conventional farming. British Food Journal. 2009
413   Sep 26;111:1098–119.

414 27. Meier MS, Stoessel F, Jungbluth N, Juraske R, Schader C, Stolze M. Environmental impacts of
415   organic and conventional agricultural products--are the differences captured by life cycle
416   assessment? J Environ Manage. 2015 Feb 1;149:193–208.

417 28. Baudry J, Pointereau P, Seconda L, Vidal R, Taupier-Letage B, Langevin B, et al. Improvement
418   of diet sustainability with increased level of organic food in the diet: findings from the
419   BioNutriNet cohort. Am J Clin Nutr. 2019 Apr 1;109(4):1173–88.

420 29. Hercberg S, Castetbon K, Czernichow S, Malon A, Mejean C, Kesse E, et al. The Nutrinet-Santé
421   Study: a web-based prospective study on the relationship between nutrition and health and
422   determinants of dietary patterns and nutritional status. BMC Public Health. 2010 May 11;10:242.

423 30. Kesse-Guyot E, Castetbon K, Touvier M, Hercberg S, Galan P. Relative validity and
424   reproducibility of a food frequency questionnaire designed for French adults. Ann Nutr Metab.
425   2010;57(3–4):153–62.

426 31. Etude Nutrinet-Santé. Table de composition des aliments. Paris: Economica; 2013. 296 p.

427 32. Gavelle E de, Huneau J-F, Mariotti F. Patterns of Protein Food Intake Are Associated with
428   Nutrient Adequacy in the General French Adult Population. Nutrients. 2018 Feb 17;10(2).

429 33. Seconda L, Baudry J, Allès B, Boizot-Szantai C, Soler L-G, Galan P, et al. Comparing
430   nutritional, economic, and environmental performances of diets according to their levels of
431   greenhouse gas emissions. Climatic Change. 2018 May 1;148(1):155–72.

432 34. Pointereau P, Langevin B, Gimaret M. DIALECTE, a comprehensive and quick tool to assess
433   the agro-environmental performance of farms. 2019 Apr 25; Available from:
434   https://www.researchgate.net/publication/265288497_DIALECTE_a_comprehensive_and_quick
435   _tool_to_assess_the_agro-environmental_performance_of_farms

436 35. Frischknecht R, Jungbluth N, Althaus HJ, Bauer C, Doka G, Dones R, et al. Implementation of
437   Life Cycle Impact Assessment Methods Report 3.

438 36. ADEME. Dia'terre®. Synthèse du guide de la méthode et guide des valeurs. 2015.

439 37. Goedkoop M, Heijungs R, Huijbregts M, De Schryver A, Struijs J, van Zelm R. ReCiPe 2008: A
440   Life Cycle Impact Assessment Method Which Comprises Harmonised Category Indicators at the
441   Midpoint and the Endpoint Level. 2013;132.

442 38. Kramer GF, Tyszler M, Veer PV, Blonk H. Decreasing the overall environmental impact of the
443   Dutch diet: how to find healthy and sustainable diets with limited changes. Public Health Nutr.
444   2017 Jun;20(9):1699–709.

445 39. Touvier M, Méjean C, Kesse-Guyot E, Vergnaud A-C, Hercberg S, Castetbon K.
446   Sociodemographic and economic characteristics associated with dairy intake vary across
447   genders. J Hum Nutr Diet. 2011 Feb;24(1):74–85.

448 40. Willett W, Stampfer MJ. Total energy intake: implications for epidemiologic analyses. Am J
449   Epidemiol. 1986 Jul;124(1):17–27.

450 41. Jones AD, Hoey L, Blesh J, Miller L, Green A, Shapiro LF. A Systematic Review of the
451   Measurement of Sustainable Diets. Advances in Nutrition: An International Review Journal.
452   2016 Jul 1;7(4):641–64.

453 42. Kim BF, Santo RE, Scatterday AP, Fry JP, Synk CM, Cebron SR, et al. Country-specific dietary
454   shifts to mitigate climate and water crises. Global Environmental Change. 2019 Aug 7;101926.

455 43. Hu FB, Otis BO, McCarthy G. Can Plant-Based Meat Alternatives Be Part of a Healthy and
456   Sustainable Diet? JAMA. 2019 Aug 26;1–3.

457 44. Rose D, Heller MC, Willits-Smith AM, Meyer RJ. Carbon footprint of self-selected US diets:
458   nutritional, demographic, and behavioral correlates. Am J Clin Nutr. 2019 Mar 1;109(3):526–34.

459 45. van Dooren C. A Review of the Use of Linear Programming to Optimize Diets, Nutritiously,
460   Economically and Environmentally. Front Nutr. 2018;5:48.

461 46. Gazan R, Brouzes CMC, Vieux F, Maillot M, Lluch A, Darmon N. Mathematical Optimization
462   to Explore Tomorrow's Sustainable Diets: A Narrative Review. Adv Nutr. 2018 Sep 1;9(5):602–
463   16.

464 47. Masset G, Vieux F, Verger EO, Soler L-G, Touazi D, Darmon N. Reducing energy intake and
465   energy density for a sustainable diet: a study based on self-selected diets in French adults. Am J
466   Clin Nutr. 2014 Apr 2;

467 48. Vieux F, Perignon M, Gazan R, Darmon N. Dietary changes needed to improve diet
468   sustainability: are they similar across Europe? Eur J Clin Nutr. 2018;72(7):951–60.

469 49. Baroni L, Cenci L, Tettamanti M, Berati M. Evaluating the environmental impact of various
470   dietary patterns combined with different food production systems. EurJ ClinNutr. 2007
471   Feb;61(2):279–86.

472 50. Scarborough P, Appleby PN, Mizdrak A, Briggs AD, Travis RC, Bradbury KE, et al. Dietary
473   greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK.
474   ClimChange. 2014;125(0165-0009 (Print)):179–92.

475 51. Burlingame B, Dernini S. Sustainable diets: the Mediterranean diet as an example. Public Health
476   Nutr. 2011 Dec;14(1475-2727 (Electronic)):2285–7.

477 52. Dernini S, Berry EM, Serra-Majem L, La Vecchia C, Capone R, Medina FX, et al. Med Diet 4.0:
478   the Mediterranean diet with four sustainable benefits. Public Health Nutr. 2017
479   May;20(7):1322–30.

480 53. Alessandra DM, Maria V, Cecilia C, Augusto S, Marcello V. The Adherence of the Diet to
481   Mediterranean Principle and Its Impacts on Human and Environmental Health. International
482   Journal of Environmental Protection and Policy. 2014 Jan 1;2(2):64.

483 54. Rosi A, Mena P, Pellegrini N, Turroni S, Neviani E, Ferrocino I, et al. Environmental impact of
484   omnivorous, ovo-lacto-vegetarian, and vegan diet. Sci Rep. 2017 21;7(1):6105.

485 55. Vieux F, Privet L, Soler LG, Irz X, Ferrari M, Sette S, et al. More sustainable European diets
486   based on self-selection do not require exclusion of entire categories of food. Journal of Cleaner
487   Production. 2020 Mar 1;248:119298.

488 56. Lebacq T, Baret PV, Stilmant D. Sustainability indicators for livestock farming. A review.
489   Agron Sustain Dev. 2013 Apr 1;33(2):311–27.

490 57. Röös E, Patel M, Spångberg J, Carlsson G, Rydhmer L. Limiting livestock production to pasture
491   and by-products in a search for sustainable diets. Food Policy. 2016 Jan 1;58:1–13.

492 58. Dinu M, Abbate R, Gensini GF, Casini A, Sofi F. Vegetarian, vegan diets and multiple health
493   outcomes: A systematic review with meta-analysis of observational studies. Crit Rev Food Sci
494   Nutr. 2017 Nov 22;57(17):3640–9.

495 59. Springmann M, Godfray HCJ, Rayner M, Scarborough P. Analysis and valuation of the health
496   and climate change cobenefits of dietary change. PNAS. 2016 Apr 12;113(15):4146–51.

497 60. Auestad N, Fulgoni VL. What current literature tells us about sustainable diets: emerging
498   research linking dietary patterns, environmental sustainability, and economics. Adv Nutr. 2015
499   Jan;6(1):19–36.

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502 **Figure 1: pReCiPe of each food group according to the type of diet**

503 Abbreviation: NAD, nonalcoholic drinks

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