1 **Food EnviroScore: New methodology based on Life Cycle Assessment to easily**
2 **communicate Environmental Footprint of Food and Drink products**

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19 **Abbreviations:**

20 EFSI: European Food Environmental Footprint Single Index

21 PEF: Product Environmental Footprint

22 LCA: Life Cycle Assessment

23 NF: Normalization Factors

24

25 **Definitions:**

26 · Food item: Single food or drink unit i.e. Egg produced in Denmark, packed in cardboard box.

27 · Food product: Homogeneous group of items i.e. eggs, bovine meat, pork meat, bananas, etc.

28 · Food group: Aggregation of food products with one or more common characteristic i.e. animal
29 based food group.

30

31 **Supplementary Materials:**

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33 · **SP1.** Life Cycle Inventory and selected datasets for the representative products used to build
34 the 25 European Food Basket and to test the Delphi method

35 · **SP2.** Life cycle inventory assessment of 149 hypothetical alternatives food items

36 · **SP3.** Detailed description of the Delphi method and results

37 · **SP4.** Environmental impact characterization, EFSI, PEF single score and Food EnviroScore
38 results of all the food items studied.

39 **Abstract**

40

41 Food systems are cause and victim of the current environmental crisis. As food is not only a
42 commodity but a necessity, major changes in food consumption patterns are required to feed
43 upcoming growing population and to stay within planetary boundaries. In this study the
44 development and relative validity of the Food EnviroScore is described. The aim of the score is
45 to communicate the environmental impact of food products to consumers. A stepwise approach
46 was used. First, a set of normalization factors was developed to aggregate 16 environmental
47 impact categories into a single dimensionless index adjusted to the European food basket, coined
48 the European Food Environmental Footprint Single Index (EFSI). Next, the effectiveness of the
49 EFSI index was evaluated and the thresholds to translate the EFSI index into the easy-to-
50 understand Food EnviroScore (using an A,B,C,D,E scoring grid) was established. The index and
51 score are both based on the Product Environmental Footprint methodology. Last, a Delphi method
52 was used to assess the relative validity of the Food EnviroScore based on 149 food items
53 categorization. Overall, results showed higher environmental impact value for animal-based food
54 products (EFSI median 2.47 (IQR 3.50)) in comparison with plant-based products (EFSI median
55 1.16 (IQR 1.96)). EFSI was able to account for variability between (inter) and within (intra) food
56 products, particularly due to country of origin and mean of transportation, such as plane
57 transportation average EFSI value of 4.80 (IQR 4.48)) vs the average of 0.97 (IQR 0.69) value
58 for local transportation. Additionally, results indicate that differences in water stress are captured
59 better by the EFSI index ($r = 0.624$) than by other aggregated indexes, such as Single Score ($r =$
60 0.228) developed by the European Commission. In line with the EFSI results, the Food
61 EnviroScore reflects variability inter and intra categories. Moreover, good agreement was
62 achieved between the classification resulting from the Delphi method and Food EnviroScore
63 (weighted Kappa 0.642; $p = 0.0025$). Results confirm that the newly developed index and score
64 capture the environmental impact variability inter and intra food products, which should allow
65 consumers to make conscious decisions.

66

67

68 Introduction

69

70 The planet is under unprecedented pressure. There is a growing body of evidence on how climate
71 change, water scarcity, deforestation, biodiversity loss and pollution of ecosystems will
72 compromise the capacity for nations to feed future generations (IPBES, 2019; IPCC, 2019; Fanzo
73 *et al.*, 2018; Ripple *et al.*, 2017; Bajželj *et al.*, 2014). Food production and consumption have
74 been reported as primary drivers influencing environmental impact (Sala and Castellani, 2019).
75 Hence, a major change in the way food is produced and consumed is of tremendous importance
76 to reduce environmental degradation and to achieve Sustainable Development Goals (SDGs) (Gil
77 *et al.*, 2019; Kim *et al.*, 2019; Sachs *et al.*, 2019). Therefore, consumers have been proposed as
78 key actors to drive these changes. Recent studies advice consumers to reduce their consumption
79 of meat products while increasing plant-based products (Ripple *et al.*, 2019; Casson *et al.*, 2019).
80 However, most consumers are not ready for such a dietary shift. Poore and Nemecek (2018) found
81 that the same final product could present different environmental burden depending on the origin
82 or production practices. Hence, consumers can already lower the environmental burden of their
83 behaviours by making shifts within product categories, thus by switching to similar food products.
84 For instance, products with improvements in agricultural practices, energy and water savings
85 strategies, food waste reduction or shorten distribution distances could significantly lower
86 environmental degradation (Notarnicola *et al.*, 2015; Pereira and Vicente, 2010; Heller *et al.*, 2018;
87 San Martin *et al.*, 2018; Stoessel *et al.*, 2012). However, available information does not allow easy
88 comparison between products and does not reflect differences in the environmental impact
89 between and/or within food products (Khan and Lan, 2019; Poore and Nemecek, 2018).
90 Consequently, consumers are currently unable to make well-informed choices and fail to put
91 pressure on governments and producers (Vlaeminck *et al.*, 2014).

92

93 Nowadays, Life Cycle Assessment (LCA) (ISO 14040:2006) methodology provides
94 comprehensive information about the environmental impact of a product, including food and
95 drinks. However, there is a wide range of methods or initiatives to apply the LCA methodology,
96 which make results on environmental impact incomparable. This leads to increased costs for
97 companies and confusion for consumers. In order to increase the available information regarding
98 the environmental impact of food items and to provide a common way of measuring
99 environmental performance, the European Commission (EC) proposed the Product
100 Environmental Footprint (PEF) methodology (COM 2013/179/EU). The EU-PEF framework
101 aims to standardise the different LCA methodologies and minimise the impact on the economy.

102

103 Within the PEF method, efforts were done to provide simplified information about the
104 environmental impact of products. A set of normalization and weighing values were put forward

105 to calculate the so-called Single Score. However, the Single Score has limitations when it comes
106 to conveying environmental impact information to consumers. The numeric outcome produced
107 by the Single Score is hard to understand by non-experts. In addition, the reference framework to
108 calculate the Single Score is based on the environmental impact of all goods and services available
109 in the European Union, considering both food and non-food. Within this broad universe of
110 commodities, the intra- and inter-variability of the environmental impact of food products is not
111 reflected in the aggregated environmental impact value, due to the noise caused by other non-
112 food commodities.

113

114 Therefore, the goal of the current study is to develop a method to capture the 16 environmental
115 impacts in one score. Following the recommendations about communicating environmental
116 impacts towards consumers (Lupiáñez-Villanueva *et al.*, 2018), the current study develops an
117 easy to understand single score adapted to the European food universe. The newly developed
118 score aims to capture the intra- and inter-variability of the environmental impact of food products
119 and is easy to understand by using a colour-coded system that can steer consumers towards more
120 environmentally friendly food consumption. The score can simultaneously push agri-food system
121 actors to reduce the generation of environmental impacts throughout the supply chain (i.e. during
122 production, processing, distribution, storage, commercialization and consumption). The later
123 requires an index that is sufficiently sensible towards changes in food production and/or handling
124 practices.

125

126 2. Methodology

127

128 A stepwise approach was used to develop a communication scheme that easily informs consumers
129 regarding the level of environmental friendliness of any food item. The first step of this procedure
130 is the development of an environmental impact single index adjusted to the food universe.
131 Secondly, the sensitivity and effectiveness of the adjusted index is tested. The final step is the
132 creation of a scheme to convey the food environmental impact score to consumers.

133

134 2.1. Development of European Food Environmental Footprint Single Index

135 According to the ISO 14040:2006, the aggregation of the environmental impacts to calculate a
136 single score of a product requires a set of normalization and weighting factors, one for each of the
137 environmental impact categories. To calculate the aggregated environmental impact of food
138 products consumed within the European Union, new normalisation factors need to be developed.
139 We selected the environmental impact of the average European Food Basket as a reference
140 situation for the new normalization.

141

142 The European Food Basket considers food products that together constitute 90 % of the total food
143 consumed in Europe (EU-28) according to the FAO Food Balance Sheets (FAO, 2013). In
144 addition, we added the consumption of packed water to the final list of products due to its high
145 consumption in EU (Notarnicola *et al.*, 2017), although, it was not considered in the FAO Food
146 Balance Sheets. In total 23 food products were withheld ($N_1=23$). Next, for each food product a
147 representative food item was defined reflecting consumption, production practices and
148 distribution of products in Europe. For pasteurized milk (EDA *et al.*, 2018), packed water (EFBW
149 *et al.*, 2018), dry pasta (Laurenza *et al.*, 2018), Pilsen beer (De Smet *et al.*, 2018) and red wine
150 (Abad *et al.*, 2018) environmental impact results published by the EC were used. For the other 18
151 food items a PEF based life cycle inventory was created including the following assumptions:

152

- 153 i) Primary production data considering the country of origin and the most frequent production
154 practices was obtained from Ecoinvent 3.5 (Wernet *et al.*, 2016) and Agrifoodprint datasets
155 (Blonk Consultants, 2014).
- 156 ii) Food processing data representing the water and energy requirements for preparation steps
157 for each product, such as washing or cooking was included (ENEA, 2013; Vinyes *et al.*,
158 2017; Espinoza *et al.*, 2011).
- 159 iii) Data regarding packaging solutions was based on Notarnicola *et al.* (2017).
- 160 iv) International distribution was included for those representative food items that more than
161 20 % were imported (FAO, 2013). Data was retrieved from Eurostat (2013), including
162 country of origin and mean of transportation. Distances between country of origin and EU

- were based on a standard entry point by boat (Rotterdam, the Netherlands), plane (Frankfurt, Germany) or by train and lorry, (Rungis, France).
- v) National distribution was assumed to be 500 km by road (Notarnicola *et al.*, 2017).
 - vi) Data on storage by retailers was based on Humbert *et al.* (2018).
 - vii) Data related to consumption includes transport (both home delivery and own transport), cold storage or freezing, preparation, bio-waste (Humbert *et al.*, 2018) and packaging end-of-life (Zampori and Rana, 2019).
 - viii) Background datasets for water and energy supply, transport carriers and waste disposal were retrieved from the Ecoinvent 3.5 database (Wernet *et al.*, 2016).

Life Cycle Inventory and selected datasets for the representative items used to build the European Food Basket is available in Supplementary material 1 (SP1).

The whole dataset was entered in Simapro 9.0[®] software (PRé consultants, 2019) to calculate the environmental impact categories of the European Food Basket according to the International Reference Life Cycle Data System (ILCD) methodology (Fazio *et al.*, 2018). The 16 impact categories of the 23 representative food items were considered as the reference situation to define the new normalization factors for each environmental impact category in line with Benini *et al.* (2014). [Eq. 1].

$$NF_{(i)} = \frac{\sum_{fi=23} FC(fi) \times e(fi)}{Population} \text{ [Eq. 1]}$$

Where NF is the normalization factor per capita; fi is a representative food item included in the European Food Basket (with $p= 1, \dots, 23$); $FC(fi)$ the yearly European consumption (in kg) of food item p ; $Population$ is the number of EU-28 inhabitants; and e equals the environmental impact per kg of food item and refers to one of the 16 impact categories: climate change (kg CO₂ eq.), ozone depletion (kg CFC-11 eq.), ionising radiation (kBq U-235 eq.), photochemical ozone formation (kg NMVOC eq.), respiratory inorganics (disease inc.), non-cancer human health effects (CTUh), cancer human health effects (CTUh), acidification terrestrial and freshwater (mol H⁺ eq.), eutrophication freshwater (kg P eq.), eutrophication marine (kg N eq.), eutrophication terrestrial (mol N eq.), ecotoxicity freshwater (CTUh), land use (Pt), water scarcity (m³ eq.), resource use, energy carriers (MJ), resource use, mineral and metals (Kg Sb eq.).

Once the new normalization factors were defined, we used the weighing factors proposed by the European Commission (Sala *et al.*, 2018) for the aggregation of the impacts. The aggregation of these 16 environmental impact categories resulted in the European Food environmental footprint Single Index (EFSI). This new single score provides information of the environmental footprint

199 of food items, relative to the average per capita European food consumption impact. The selected
200 functional unit for all food items is “1 kg of packed food item, consumed at home”. It is important
201 to note that even if 16 impact categories are considered for the impact characterization and
202 normalization, Sala *et al.* (2018) dismissed impact categories related to toxicity (human toxicity
203 cancer and non-cancer effects, and ecotoxicity) due to lack of robustness of the methodologies to
204 calculate those impacts. Therefore, EFSI considers 13 impact categories.

205

206 **2.2. Evaluation of the effectiveness of the EFSI**

207 Step 2 comprises a sensitivity analysis and a correlation study. The main objective was to evaluate
208 the variability of the environmental impact between different food products (inter product
209 variability) and the effect of different production methods and origin within the same product
210 (intra product variability). With that purpose, a second dataset was created containing 21 food
211 products. For each product a range of hypothetical food items were analysed ($N_2=149$) based on
212 the available data. These hypothetical food items reflect current variability in origin and
213 distribution methods. Supplementary material 2 (SP2) provides information on the 149 food
214 items.

215

216 The EFSI values of these 149 food items were calculated with the normalization and weighting
217 factors computed in Step 1. The variability of the environmental impact within and among food
218 products was analysed using boxplots with RStudio (version 1.1.463) and Matlab 2017b (The
219 Mathworks, Inc). For further analysis, the 149 food items were grouped into animal-based, plant-
220 based and products with high degree of processing. Consequently, the differences between EFSI
221 and Single Score when capturing the variability of food environmental impact were evaluated by
222 boxplots (including comparison of median and interquartile range), an analysis of variance
223 (ANOVA) and a correlation study. Moreover, to rank the influence of the different environmental
224 impact categories on each index, the correlations of each environmental impact with each index
225 were analysed. Finally, to understand the connections between the different impacts, a correlation
226 matrix was built considering the results of the environmental impact characterization of all 149
227 food items ($N_2=149$).

228

229 **2.3. Development and validation of a communication score**

230 Step 3 is the creation and validation of an easy to understand 5 level score based on the EFSI,
231 coined the Food EnviroScore. This score is a traffic lights colour-coding system, ranging from
232 very low (A - green) to very high impact (E – red). The cut-off values were defined based on the
233 distribution of the EFSI values of representative food items, in line with the methodology used in
234 the development of the Nutri-Score (Julia *et al.*, 2014, Julia *et al.*, 2015, Rayner *et al.*, 2005,
235 Scarborough *et al.*, 2007). This dataset encompasses the 23 representative food items of the

236 European Food Basket and an additional set of 19 food items such as emerging foods (e.g.
237 avocado or prepacked meals) or alternative source of protein ($N_3=42$). The EFSI of the 42 food
238 items was calculated as described in Step 1 (see SP1). The above described mathematical
239 categorization process based on the EFSI distribution was followed by a validation step. In the
240 absence of a golden standard a Delphi method was used to obtain experts' opinions on the
241 environmental impact of food items. The Delphi method was carried out from February till April
242 2019 and seven experts participated. All the information regarding the protocol, questionnaire
243 and results are publicly available in the Supplementary material 3 (SP3). Experts categorized 38
244 food items. Their categorization was compared with the Food EnviroScore results of the
245 representative products ($N_3=42$). For the comparison, only these food items were withheld if 80%
246 of the experts agreed in the categorization. The weighted Kappa, that signals the overall
247 agreement, was calculated. Accuracy of the categorization between the Food EnviroScore results
248 and the experts' opinion was evaluated by a contingency table which portraits the coincidences
249 between the categorization by Delphi experts and by the Food EnviroScore when assessing the
250 same product.

251

252 Finally, we tested the performance of the categorization. For each item of N_3 (i.e. the set of 42
253 food items that includes representative items and additional food items like emerging products)
254 we compared the Food EnviroScore results with the score of hypothetical alternatives of each
255 ($N_2=149$). As such, the score of a representative orange is for example compared with the scores
256 of hypothetical oranges (e.g. orange produced in China and transported by plane). Therefore, a
257 second contingency table was built to represent the coincidences between the Food EnviroScore
258 results of the 42 representative food items and the scores of their hypothetic alternatives.

259

260 **3. Results**

261 **3.1. European food environmental footprint single index**

262 Table 1 presents the selected representative food items ($N_1=23$) of the European Food Basket
263 including consumption (kg/year) and 16 environmental impact characterization. In this European
264 Food Basket, animal-based items comprise 28 % of the total food consumption and overall
265 contribute to the 37 % of the environmental impact. Within the animal-based food group, milk is
266 consumed most. It encompasses 27 % of consumption, while beef accounts for the majority of
267 the environmental impact (31 % of the overall impact). Normalization and weighting values of
268 the EFSI are reported in Table 2.

269 **Table 1:** Environmental impact characterization including the 16 impact categories of the ILCD methodology of the representative food items of the European Food Basket.
 270 Where CC is climate change; ODP is ozone depletion potential; IR is Ionising radiation, HH; POF is photochemical ozone formation, HH; RI is respiratory inorganics; HH-nc
 271 is non-cancer human health effects; HH-c is cancer human health effects; ATF is acidification terrestrial and freshwater; EuF is eutrophication freshwater; EuM is eutrophication
 272 marine; EuT is eutrophication terrestrial; EcoTox is ecotoxicity freshwater; LU is Land Use; WS is water scarcity; and, RUe is resource use, energy carriers and RUm is resource
 273 use, mineral and metals.

274

Impact category	Unit	Milk, pasteurized*	Packed water *	Dry pasta*	Potatoes, fresh	Pilsen beer *	Pig meat	Sugar	Oranges	Tomato	Red wine *	Chicken meat	Apples
Consumpt.	Kg/year	1,21E+11	5,28E+10	5,34E+10	3,55E+10	3,42E+10	1,99E+10	1,76E+10	1,55E+10	1,29E+10	1,16E+10	1,15E+10	9,39E+09
CC	kg CO ₂ eq	1,07E+00	2,83E-01	2,92E+00	1,73E+00	7,19E-01	6,58E+00	1,05E-03	1,39E-03	2,62E-03	2,12E+00	7,43E+00	1,34E-03
ODP	kg CFC11 eq	5,19E-09	1,66E-10	6,27E-08	1,83E-07	6,22E-08	2,44E-07	1,12E-10	1,29E-10	1,48E-10	4,83E-08	1,05E-07	1,29E-10
IR	kBq U-235 eq	9,16E-02	5,07E-02	9,18E-02	3,76E-01	1,07E-01	3,96E-01	2,92E-05	3,10E-05	3,88E-04	2,15E-01	1,90E-01	3,71E-04
POF	kg NMVOC eq	3,63E-03	6,87E-04	9,11E-03	3,40E-03	1,81E-03	1,11E-02	3,45E-06	3,76E-06	9,12E-06	6,11E-03	8,65E-03	5,69E-06
RI	disease inc.	1,09E-07	7,86E-09	3,38E-07	4,19E-08	4,02E-08	6,22E-07	1,54E-10	4,97E-11	1,34E-10	1,18E-07	7,22E-07	4,60E-11
HH-nc	CTUh	N/A	N/A	N/A	4,73E-07	N/A	4,45E-06	-9,57E-08	4,44E-08	2,43E-07	N/A	3,97E-06	1,29E-07
HH-c	CTUh	N/A	N/A	N/A	2,49E-08	N/A	5,86E-08	1,77E-08	1,81E-08	1,37E-08	N/A	6,96E-08	2,15E-08
ATF	mol H+ eq	1,32E-02	9,71E-04	4,59E-02	7,79E-03	4,75E-03	8,87E-02	2,17E-05	9,43E-06	1,30E-05	1,17E-02	9,09E-02	9,78E-06
EuF	kg P eq	1,18E-04	1,90E-05	4,04E-04	1,02E-03	7,13E-05	1,01E-03	3,22E-07	9,44E-07	1,22E-06	2,15E-04	7,75E-04	8,42E-07
EuM	mol N eq	3,96E-03	3,13E-04	1,80E-02	3,59E-03	2,59E-03	2,72E-02	6,58E-06	2,29E-06	2,18E-06	5,90E-03	2,55E-02	3,76E-06
EuT	kg N eq	5,58E-02	3,12E-03	1,93E-01	1,82E-02	1,64E-02	3,76E-01	8,72E-05	2,28E-05	1,79E-05	3,38E-02	3,92E-01	2,53E-05
EcoTox	CTUe	N/A	N/A	N/A	10,58E+00	N/A	3,22E+01	9,11E-01	4,19E+00	9,12E+00	N/A	3,24E+01	6,80E+00
LU	Pt	1,57E+02	1,67E+00	6,41E+02	4,72E+01	5,27E+01	5,98E+02	1,03E-01	6,33E-02	2,28E-02	2,10E+02	6,73E+02	1,02E-01
WS	m ³ depriv.	3,95E-01	1,70E-01	1,34E+00	1,11E+00	7,74E-01	1,33E+00	2,69E-03	2,78E-03	3,49E-04	1,27E+00	9,59E-01	2,38E-03
RUe	MJ	8,43E+00	4,61E+00	3,60E+01	2,60E+01	9,68E+00	4,26E+01	1,10E-02	1,71E-02	2,93E-02	2,52E+01	3,24E+01	2,07E-02
RUm	kg Sb eq	1,39E-06	8,05E-06	6,38E-06	2,42E-06	4,41E-06	1,49E-06	-2,28E-09	-2,56E-08	1,80E-09	2,02E-05	1,32E-06	3,25E-09

275 * Data obtained from PEF studies: pasteurized milk (EDA *et al.*, 2018), packed water (EFBW *et al.*, 2018), dry pasta (Laurenza *et al.*, 2018), Pilsen beer (De
 276 Smet *et al.*, 2018) and red wine (Abad *et al.*, 2018). *N/A = Not reported in PEF studies

277

278 **Table 1 (cont.):** Environmental impact characterization including the 16 impact categories of the ILCD methodology of the representative food items of the European Food
 279 Basket. Where CC is climate change; ODP is ozone depletion potential; IR is Ionising radiation, HH; POF is photochemical ozone formation, HH; RI is respiratory inorganics;
 280 HH-nc is non-cancer human health effects; HH-c is cancer human health effects; ATF is acidification terrestrial and freshwater; EuF is eutrophication freshwater; EuM is
 281 eutrophication marine; EuT is eutrophication terrestrial; EcoTox is ecotoxicity freshwater; LU is Land Use; WS is water scarcity; and, RUe is resource use, energy carriers and
 282 RUm is resource use, mineral and metals.

Impact category	Unit	Beef	Eggs	Grapes	Onion	Banana	Frozen Cod	Maize flour	Rye flour	Canned tuna	Rice	Refined Sunflower oil
Consumpt.	Kg/year	7,59E+09	6,14E+09	5,01E+09	4,57E+09	4,41E+09	3,92E+09	3,92E+09	3,04E+09	2,60E+09	2,51E+09	2,48E+09
CC	kg CO₂ eq	6,62E+01	5,39E+00	1,04E-03	1,99E+00	1,22E-03	2,38E-00	1,01E-03	1,09E-03	1,64E-02	3,36E-03	3,88E+00
ODP	kg CFC11 eq	5,90E-06	1,13E-07	9,97E-11	1,94E-07	1,25E-10	2,41E-07	1,15E-10	8,86E-11	2,19E-09	1,93E-10	1,57E-07
IR	kBq U-235 eq	2,37E+00	-8,69E-02	3,34E-04	4,24E-01	3,64E-04	4,29E-01	9,04E-05	6,23E-05	1,13E-03	1,80E-04	1,09E-01
POF	kg NMVOC eq	5,15E-01	7,73E-03	2,73E-06	4,97E-03	4,75E-06	1,81E-02	2,48E-06	2,37E-06	1,92E-04	5,77E-06	8,47E-03
RI	disease inc.	8,26E-06	8,34E-07	3,01E-11	1,06E-07	3,66E-11	1,93E-07	9,33E-11	8,61E-11	2,24E-09	9,52E-11	2,20E-07
HH-nc	CTUh	4,90E-05	3,77E-06	1,45E-07	3,61E-06	3,76E-08	2,14E-07	6,12E-07	1,84E-06	4,27E-06	1,42E-08	3,82E-06
HH-c	CTUh	9,47E-07	6,13E-08	8,82E-09	3,18E-08	1,04E-08	2,35E-08	2,00E-08	1,94E-08	2,84E-06	4,03E-08	1,15E-07
ATF	mol H+ eq	1,57E+00	1,05E-01	5,62E-06	1,75E-02	8,68E-06	2,79E-02	1,18E-05	1,12E-05	2,89E-04	1,31E-05	2,94E-02
EuF	kg P eq	1,04E-02	7,40E-04	7,07E-07	8,83E-04	7,40E-07	9,83E-04	3,20E-07	3,45E-07	3,10E-06	9,01E-07	1,10E-03
EuM	mol N eq	5,95E-01	2,56E-02	1,73E-06	4,89E-03	4,07E-06	6,10E-03	9,71E-06	8,00E-06	8,27E-05	1,25E-05	2,08E-02
EuT	kg N eq	6,23E+00	4,59E-01	1,12E-05	5,90E-02	2,14E-05	6,52E-02	4,74E-05	4,41E-05	7,61E-04	3,68E-05	1,03E-01
EcoTox	CTUe	9,63E+01	2,91E+01	5,81E-01	3,73E+00	5,48E-01	1,42E+00	7,28E+00	7,36E+00	1,96E+02	1,93E+01	3,92E+02
LU	Pt	5,51E+03	6,28E+02	5,73E-02	4,61E+01	3,56E-02	1,55E+01	1,56E-01	1,81E-01	9,22E-01	2,44E-01	1,24E+03
WS	m³ depriv.	1,91E+01	8,49E-01	4,22E-03	1,06E+00	2,74E-03	8,17E-01	7,75E-04	1,70E-04	1,60E-02	2,73E-02	1,35E+00
RUe	MJ	5,01E+02	2,47E+01	1,64E-02	2,93E+01	1,85E-02	4,52E+01	1,14E-02	1,06E-02	1,82E-01	2,38E-02	3,56E+01
RUm	kg Sb eq	1,14E-04	-1,78E-05	1,77E-09	3,43E-06	2,66E-09	4,79E-06	-3,37E-09	-3,37E-09	2,00E-07	-2,04E-10	-1,19E-07

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Table 2. The European food environmental footprint single index normalization (EFSI-NF) and weighting factors. Where CC is climate change; ODP is ozone depletion potential; IR is Ionising radiation, HH; POF is photochemical ozone formation, HH; RI is respiratory inorganics; HH-nc is non-cancer human health effects; HH-c is cancer human health effects; ATF is acidification terrestrial and freshwater; EuF is eutrophication freshwater; EuM is eutrophication marine; EuT is eutrophication terrestrial; EcoTox is ecotoxicity freshwater; LU is Land Use; WS is water scarcity; and, RUe is resource use, energy carriers and RUm is resource use, mineral and metals.

Impact category	Unit	EFSI- NF	EFSI-NF, per capita *	Weighting factors ¹
CC	kg CO ₂ eq	1.23E+12	2.42E+03	22.19
ODP	kg CFC11 eq	6.55E+04	1.29E-04	6.75
IR	kBq U-235 eq	6.69E+10	1.31E+02	5.37
POF	kg NMVOC eq	5.49E+09	1.08E+01	5.10
RI	disease inc.	1.24E+05	2.44E-04	9.54
HH-nc	CTUh	5.62E+05	1.10E-03	0.00
HH-c	CTUh	1.06E+04	2.07E-05	0.00
ATF	mol H ⁺ eq	2.00E+10	3.93E+01	6.64
EuF	kg P eq	1.94E+08	3.81E-01	2.95
EuT	kg N eq	7.25E+09	1.42E+01	3.12
EuM	mol N eq	8.07E+10	1.58E+02	3.91
EcoTox	CTUe	2.32E+12	4.54E+03	0.00
LU	Pt	1.24E+14	2.43E+05	8.42
WS	m ³ depriv.	3.99E+11	7.83E+02	9.03
RUe	MJ	9.98E+12	1.96E+04	8.92
RUm	kg Sb eq	2.21E+06	4.33E-03	8.08

* Global NF, per capita shall be used (Global population in 2013: 509,718,000 people)

¹Sala *et al.*, 2018.

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3.2. Validation of the EFSI effectiveness

Results of the sensitivity analysis (Figure 1A) illustrate the impact variability inter and intra food products. EFSI considerably varies between food groups as the EFSI of plant-based group was lower (median 1.16 (IQR 1.96)) than the EFSI of animal-based products (median 2.47 (IQR 3.50)), while the EFSI of the processed group was slightly higher (median 1.63 (IQR 3.46)). For instance, “sugar, from sugar beet” has the lowest EFSI median (0.379, (IQR 0.197)), while the highest is for “beef” (11.51 (IQR 4.48)). Variability within products is also high, with IQR ranging from 0.197 to 6.35. This variability could be attributed to type of transportation as items transported by plane had a higher EFSI median (4.80 (IQR 2.14)) than products transported locally (median 0.97 (IQR 0.69)) and internationally by sea (median 1.22 (IQR 1.92)). Nevertheless, we found that the transportation mode contributes more on the EFSI values of plant-based products than of animal-based products. Air transport of plant-based products is responsible for up to 70 % to the total environmental impact, while transport over land by lorry or train is responsible for around 25 % and water transport for 10 %. However, those percentages are lower

for animal-based products: transport by air is responsible for 40 % of the environmental impact of animal-based products and transport by lorry or train for 3 %.

Figure 1B presents the inter- and intra-variability among food products calculated with the Single Score. The variability in environmental impact within food products reported by the EC Single Score is lower than the variability reported by EFSI (Figure 1A and 1B). Also, the ranking of food products according to median environmental impact changed: the food product with the lowest score was “sugar from sugar beet” with EFSI and “lettuce” with the Single Score, while the product with the highest impact, “beef”, remained the same.

Figure 1: Distribution of EFSI results (A) and Single Score results (B) of the 149 hypothetical food items alternatives of the 21 representative food products.

The overall correlation between EFSI and Single Score is high (0.88) and there were no significant differences between the correlation of each score and the 13 environmental impact categories ($p=0.22$; $F=1.54$). The correlations between each score and each environmental impact category (Table 3) showed that both scores have high correlation with climate change (EFSI 0.80 vs Single Score 0.94), acidification (EFSI 0.74 vs Single Score 0.96), marine eutrophication (EFSI 0.74 vs Single Score 0.95) and terrestrial eutrophication (EFSI 0.71 vs Single Score 0.95). The main difference is the higher correlation of the EFSI with water scarcity (EFSI 0.62 vs Single Score 0.23).

Table 3: Correlation between the 13* environmental impacts and respectively EFSI and Single Score

Impact Category	EFSI	Single Score
Climate change	0.804	0.940
Ozone depletion	0.603	0.536
Ionising radiation, HH	0.509	0.501
Photochemical ozone formation, HH	0.792	0.891
Respiratory inorganics	0.687	0.927
Acidification terrestrial and freshwater	0.727	0.959
Eutrophication freshwater	0.640	0.859
Eutrophication marine	0.739	0.954
Eutrophication terrestrial	0.707	0.948
Land use	0.555	0.779
Water scarcity	0.624	0.228
Resource use, energy carriers	0.699	0.702
Resource use, mineral and metals	0.461	0.485

In Figure 2 the correlation matrix of the environmental impacts illustrates that almost all environmental impacts categories have a correlation higher than 0.600 with climate change, except water scarcity (0.020), resource use mineral and metals (0.152), and land use (0.469). Actually, mineral and metal resource use and water scarcity have low correlations (< 0.600) with all the environmental impacts studied (< 0.424 and < 0.123 respectively). On the other side, correlations above 0.640 are reported among ozone depletion potential, ionizing radiation, photochemical ozone formation and resource use (energy and carriers). Moreover, similar correlations (≥ 0.699) are also found between respiratory inorganics, acidification and freshwater, marine and terrestrial eutrophication.

Figure 2. Correlation matrix of the 13 environmental impacts considered to calculate the EFSI and the Single Score. Where CC is climate change; ODP is ozone depletion potential; IR is Ionising radiation, HH;

POF is photochemical ozone formation, HH; RI is respiratory inorganics; ATF is acidification terrestrial and freshwater; EuF is eutrophication freshwater; EuM is eutrophication marine; EuT is eutrophication terrestrial; LU is Land Use; WS is water scarcity; RUe is resource use, energy carriers and RUm is resource use, mineral and metals.

355

3.2. Food EnviroScore: new tool for food environmental footprint communication

Table 4 presents the cut-off values for the five levels of the Food EnviroScore. Food items with EFSI results below 0.40 have been considered as very low environmental impact. ‘A score’ food items encompass for example orange, rye flour or soybean beverage. Products with EFSI values between 0.40 and 1.45 received a ‘B score’, low environmental impact, which includes food items such as pasta, grapes or potato. Food items with values between 1.45 and 2.00 are categorized as products with a medium environmental impact and received a ‘C score’. For instance, fruit juices or refined sunflower oil can be found in this category. The ‘D score’ products include those with EFSI values between 2.00 to 10.00. In this category, we find high environmental impact food items such as avocado, chicken meat or pig meat. Finally, products with EFSI values above 10.00, such as beef or canned tuna, have an ‘E score’, very high environmental impact.

Table 4: Cut-off values and categorization of EFSI index considering the relative environmental impact of the food items

Food EnviroScore	Environmental impact		EFSI
A	Very low	<	0.40
B	Low	≥	0.40
C	Medium	≥	1.45
D	High	≥	2.00
E	Very high	≥	10.00

369

The validation of the Food EnviroScore classification with the classification made by experts resulted in an overall good agreement (weighted Kappa 0.642; $p = 0.0025$) (See SP3). The contingency table (Table SP3.1) shows a high level of accuracy for items categorized as D and E, 80 % and 100 % respectively. However, at lower levels several deviations are reported between the classification based on the EFSI values which resulted in the Food EnviroScore and the classification made by the experts. For instance, products with an EnviroScore B and C have a correspondence of 46 % and 33 % respectively with the expert-based categorizations. Most deviations correspond only to movements of one level, backward or forward. Nevertheless, especially noteworthy is the case of two products with an EnviroScore of D and B, which show deviations of two levels. This is the case for strawberries and frozen cod. Experts participating in the Delphi round classified strawberries as B, while the Food EnviroScore assigns it a D score and frozen cod was scored as D by experts while Food EnviroScore assigns it a B score.

382

Based on the performance of the Food EnviroScore (Table 5), some deviations are found (weighted Kappa 0.45, $p < 0.05$) when comparing the overall agreement between the Food EnviroScore of the hypothetical alternative food items evaluated in step 2 and their respective representative food items. Overall, the highest agreement was found in the items with Food EnviroScore B and D (62 % and 78 % respectively) while items assigned to A and C presented higher deviations from their representative food item, respectively 17 % and 25 %. Small deviations, switch of one level, were influenced by changes in the production methods (27 %) and transportation (19 %). This is especially the case for animal-based products, where beef could, for example, score E or D depending on production differences (beef from beef cattle or from dairy cattle, accordingly). Large deviations, i.e. a switch of two or more levels, were mainly influenced by air (66 %) and terrestrial transportation over large distances, especially in plant-based products. For instance, oranges, typically scoring A or B, were classified as D when imported by plane, and apples, mostly categorized as B, scored D when transported from China by lorry. Indeed, in a scenario without the items transported by plane, we obtained a weighted Kappa of 0.71, which indicates that transport mode highly influenced the score that is assigned.

Table 5: Contingency table comparing results of the Food EnviroScore categorization of the representative products with the Food EnviroScore results of the hypothetical food item alternatives of each.

Food EnviroScore of the representative prod.(n=19)*	Food EnviroScore of the food item scenarios (n=130)*				
	A	B	C	D	E
A	17 %	67 %	0 %	17 %	0 %
B	4 %	62 %	7 %	27 %	0 %
C	0 %	17 %	25 %	58 %	0 %
D	0 %	0 %	22 %	78 %	0 %
E	0 %	0 %	0 %	50 %	50 %

*Only products that were present in both data set (representative and food item scenarios) were included. The food item scenarios (initially $N_2=149$) were 130 after the exclusion of sugar from sugar cane ($n=13$), apricot ($n=5$) and a cultivar of lettuce ($n=1$). The representative products (initially $N_3=42$) were 19 food items after the exclusion of 23 items (aubergine, avocado, bread, canned tuna, cauliflower, frozen cod, fruit juices, grapes, lentil canned, maize flour, olive oil, PEF beer, PEF butterfats, PEF milk, PEF packed water, PEF pasta, PEF wine, pineapple, prepacked meat (pork based), rye flour, salmon, soybean beverage and spinach), due to the lack of data.

All results of the impact characterization, normalization, EFSI, Food EnviroScore and Single Score of all the food items studied are shown in Supplementary Material 4 (SP4).

412 4. Discussion

413 According to the authors' knowledge, the Food EnviroScore is the first score that integrates
414 different environmental impact categories, allows to capture inter- and intra-product variability
415 in environmental impacts and translates this into an easy to understand score for consumers.
416 Overall, the newly developed score for food products shows good agreement with the commonly
417 used methodologies and with experts' opinion.

418

419 4.1. Why a new index?

420 There are methodologies that aggregate environmental impact categories, such as the Single Score
421 methodology (Sala *et al.*, 2018) and the ReCiPe 2016 endpoint (Huijbregts *et al.*, 2017). Both,
422 Single Score and ReCiPe, normalized the impacts based on the universe of every good and service
423 produced in a specific region, respectively for Europe and globally. In contrast, our approach
424 reduces the universe to the food environment, deleting the noise introduced by non-food products.
425 However, one of the potential limitations of our methodology is that the final values would
426 significantly deviate from the Single Score. Overall, EFSI does not differ significantly from the
427 Single Score, and main differences are attributed to the higher correlation of the EFSI with water
428 scarcity impact category. Indeed, as proved in our results, all the environmental impact categories
429 are moderately to highly correlated (Hinkle *et al.*, 2003) with both EFSI and the Single Score,
430 except from water scarcity. The single score considers the consequences of the water withdrawal
431 but only to a limited extent. Water consumption is of great importance in the food industry, and
432 more specifically in agriculture and livestock. For instance, farming accounts for almost 70 % of
433 all water withdrawals, and up to 95 % in some developing countries (FAO, 2012), while in Europe
434 agriculture accounts for almost 40 % of the total water withdrawal (Sordo-Ward *et al.*, 2019). As
435 food production is a major contributor to the water scarcity (FAO, 2012), it is important to ensure
436 that the proposed index considers distinctively potential impact derived from water consumption,
437 specifically in those countries or river basins with high water stress levels.

438

439 Another important aspect, when handling food products as a single group is the functional unit.
440 To compare the environmental impact across products LCA methodology requires a functional
441 unit that captures the obligatory properties of a product. However, functional units of food
442 products are difficult to define due to variation in perceived obligatory properties (Berardy *et al.*
443 2019). Most studies proposed mass-based functional unit, while some authors proposed protein
444 content and quality, energy content or the nutrient density as the basis of the comparison (Poore
445 and Nemecek, 2018; Sonesson *et al.*, 2017; van Dooren, 2016). In the EFSI methodology we
446 selected a functional unit based on the mass of the final product, following the rules established
447 by the PEF guidelines, where mass-based functional units are defined. However, in order to make
448 it comparable, we selected 1 kg of product as functional unit for all the product types, without

449 considering different portions that the PEF guidelines considers, such as 1 hl of beer and 100 ml
450 of packed water. This selection is also aligned with the current mandatory food labelling, since it
451 is easy to compare among products. Different types or amounts of functional unit per food
452 products would have introduced more uncertainties for the end-consumers and decreased the
453 comparability between food products (Cowburn and Stockley, 2005).

454

455 A potential source of bias is the environmental impact characterization of the European food
456 basket. When the environmental impact results of our European food basket are compared with
457 the recently published EU (Food) Basket of Products (Crenna *et al.*, 2019), hardly any difference
458 could be found. Climate change, acidification, land use, particulate matter and resource use, fossil
459 potential impact categories vary less than 20 % when comparing both studies, while we observed
460 higher differences in the magnitude order in terrestrial eutrophication, ionising radiation and
461 photochemical ozone formation. Since minor differences are reported on the assumptions made
462 for the inventory analysis, source of differences between the two baskets falls on the selection of
463 relevant products. For instance, Crenna *et al.* (2019) included cheese, butter and salmon in the
464 food basket. These are products with high impact on terrestrial eutrophication, ionising radiation
465 and photochemical oxidation. Those products are not included in our basket since we selected just
466 one representative food item for each food product as defined by FAO (FAO, 2013). Hence, in
467 our study, we considered cod fish, and not salmon, as representative of the demersal fish.
468 Similarly, for dairy product group we selected just milk as the most consumed dairy product,
469 without considering cheese. Moreover, despite the fact that FAO considered butter separately
470 from other dairy (butter is considered as fat), butter was neither selected because it was not
471 consumed in high quantity relative to other items in the food basket. According to Crenna *et al.*
472 (2019), butter represents only 0.6 % of the basket. However, although substantial, those
473 differences would not alter the final EFSI results since those impacts, terrestrial eutrophication,
474 ionising radiation and photochemical ozone formation, have 5% or less of the weighting factor.

475

476 **4.2. Social driver towards sustainable food consumption**

477 Sensitivity analysis shows that the new EFSI and Food EnviroScore are both selective and
478 sensitive at the same time. The results of the sensitivity analysis were in line with previous studies.
479 Overall, plant-based products have been categorized as low impact products (Springmann *et al.*,
480 2018; Poore and Nemecek, 2018). The newly developed index and score were also able to
481 discriminate according to differences in distribution mode (local vs international air) (Stoessel *et al.*
482 *al.*, 2012; Frankowska *et al.*, 2019a; Frankowska *et al.*, 2019b; Michalský and Hooda., 2015).
483 Moreover, differences in production environment (greenhouse vs field production) were found as
484 well (Frankowska *et al.*, 2019b). Soode-Schimonsky *et al.* (2017) reported significant differences
485 between strawberries produced in heated and unheated greenhouses, which was also captured by

486 the Food EnviroScore. Differences according to the country of origin were identified, particularly
487 for countries that have been reported as water stressed countries, such as Spain or Pakistan
488 (Finogenova *et al.*, 2019; Frankowska *et al.*, 2019b; Boulay *et al.*, 2018). The EFSI and Food
489 EnviroScore could differentiate between beef from beef-cattle and beef from dairy-cattle, which
490 have been previously identified as substantial differences in impact (Poore and Nemecek, 2018;
491 Tichenor *et al.*, 2017). The Food EnviroScore does not change when comparing organic and
492 conventional produced foods, as found as well by Meier *et al.* (2015).

493

494 Nevertheless, the current results are based on a limited number of data points and food products.
495 In order to further evaluate the robustness and sensitivity of the proposed EFSI and Food
496 EnviroScore additional case-studies should be included in the analysis. A second limitation of the
497 study that could be considered is the use of experts' opinion to validate the proposed categories
498 of the Food EnviroScore. Deviations between experts' consensus on score categorization and the
499 Food EnviroScore were expected. This was mainly due to the absence of a golden standard for
500 the interpretation of food environmental impacts, lack of knowledge on the overall environmental
501 impact of some products and because of the inherent variability of environmental impacts related
502 to food products. Nevertheless, the Food EnviroScore showed a good level of agreement.

503

504 The Food EnviroScore attempts to provide consumers understandable information to identify the
505 most sustainable alternative between different food products, for example by enabling comparison
506 between meat and plant-based alternatives. However, demonising particular food product is not
507 the final aim. On the contrary, as portrayed in the analysis, this method is also useful to evaluate
508 intra-product environmental impact variation. Therefore, the new score allows consumers to
509 improve the sustainability of their food basket, even if they do not contemplate to shift to a sole
510 plant-based diet (Chai *et al.*, 2019). Albeit aiming at smaller changes, it would contribute to the
511 mitigation of food environmental burden while their food preferences and cultures are maintained.
512 As it is mentioned in the study of Eker S. *et al.* (2019), small changes in dietary habits that are
513 widespread in society could reduce emissions by half. As such modest changes could be a more
514 effective way to reduce the overall environmental impact of the food system than big dietary shifts
515 adopted by a small proportion of the population.

516

517 Finally, the Food EnviroScore could raise awareness on the actual environmental impact of food
518 products. As it is shown in the study of Camilleri *et al.* (2019), there is a knowledge gap between
519 actual and perceived impact of the food consumption patterns. In the same study they demonstrate
520 that increasing consumer knowledge about the environmental impact of food choices could lead
521 towards more responsible consumption patterns. The proposed Food EnviroScore provides easy-

522 to-understand information as a strategy that could be used to reduce the knowledge gap related to
523 food environmental burden.

524

525 **4.3. Policy implementation**

526 Interventions to promote sustainable and healthy diets have been identified as a key strategy on
527 the Sustainable Development Goals transformations. According to Sachs *et al.* (2019), a
528 sustainable and healthy diet directly promotes SDGs 2, 3, 6, and 12-15. Hence, providing
529 environmental information at product level could lead to consumer choices towards products with
530 less environmental impact. Consequently, a higher demand of environmental-friendly food
531 products could incentivize food industry to improve their practices. This assumption is in line
532 with the Energy label of consumer electronics in EU (EU 2017/1369) and the nutritional labelling
533 initiatives (He *et al.* 2014). Both initiatives introduced respectively an optimisation of efficient
534 energy use and a food product reformulation. To conclude, from a policy point of view, the Food
535 EnviroScore can be used to communicate in an easy to understand way the environmental impact
536 of food products and as such food system actors will be encouraged to implement the best
537 environmental practices within their companies.

538

539 **5. Conclusions**

540 According to the authors' knowledge the proposed methodology is a first approximation to
541 communicate environmental footprint of food items in a transparent and science-based manner to
542 consumers. The methodology is unique as it is based on European PEF methodology and reflects
543 inter- and intra-food product variability in environmental impacts.

544

545 **Data availability**

546 The authors declare that all the results supporting the findings of this study are available within
547 the paper and its supplementary information file.

548

549 **Declaration of Interest Statement**

550 None.

551

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