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Environmental footprints of food products and dishes in Germany

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1 Background and objectives

In recent years, public interest in the environmental impact of food production and consumption has increased, in particular in the CO_2 footprint of specific food products. However, data on CO_2 footprints of foodstuff differ considerably, including publicly available data from the World Food LCA Database [World Food LCA Database 2015], the CO_2 calculator "Klimatarier" [ifeu 2016] and the application to dishes [Eyrich et al. 2019]. While LCA experts are aware of the reasons for this, it is difficult for the general public to understand the details.

In addition to the CO_2 footprint, the use of natural resources for food production is increasingly discussed. Since the natural resources water, land and phosphate rock are limited, use competition leads to conflicts in many regions of the world.

This study aims to raise awareness in this matter. Three main issues are addressed and explained using suitable examples:

- Issue 1 deals with the influence of different processes on the environmental impact of food supply, including sub-aspects such as packaging, transport, etc. The aim is to enable readers to understand that carbon footprints depend on different parameters such as the type of agricultural production (conventional or organic farming), the system boundary (food at supermarket checkout or prepared on the plate), the type of packaging (glass jar or composite carton), and others. Therefore, the following sub-aspects of the CO_2 footprint will be examined in detail for almost 200 food products:
  - Conventional or organic farming
  - Average or seasonal / regional production
  - Domestic production or import by truck, ship or airplane
  - Different food packaging types
  - Fresh or frozen goods.
- Issue 2 addresses the fact that aside from the CO_2 footprint, other important environmental footprints are associated with food production as well. Thus, the phosphate rock, land use and water footprints of several food products are presented as examples as well.
- Issue 3 provides CO_2 footprints for selected, prepared dishes (system boundary: plate) in addition to the footprints for individual food products mentioned above. This illustrates the considerable influence of the preparation process and shows possible effects of recipe changes on the total footprint (such as soya instead of meat bolognese or pasta instead of rice).

In addition to raising awareness of these issues, readers should also be given the opportunity to use the numbers in their daily life, such as for assessing the environmental impacts of dietary choices available in Germany. Information on the use of the values is also included in this study.

2 Food products considered

Almost 200 different food products with various differentiations (cultivation, packaging, import etc., see above) were selected, divided into the following groups:

- Fruit and vegetables
- Milk products, eggs and milk substitutes
- Meat and alternative protein sources
- Products rich in starch, oil or sugar
- Beverages.

In all groups, various differentiations were made, which are particularly pronounced within the respective group. These are shown in the presentations of the respective results.

3 Methodology

The following methodological elements were applied to the calculation of all environmental footprints assessed in this study:

- **System boundary "supermarket checkout":** The system boundary covers agricultural production (including all upstream processes such as fertiliser production), food processing (including washing, sorting and, where appropriate, preserving), packaging (including disposal) and the distribution of individual foodstuffs (see Fig. 1).
- **System boundary "prepared on the plate":** Exclusively for the assessed *dishes*, a shopping trip by the end consumer is also considered. The subsequent kitchen processes, including in particular cold storage, preparation and dishwashing, are also covered.

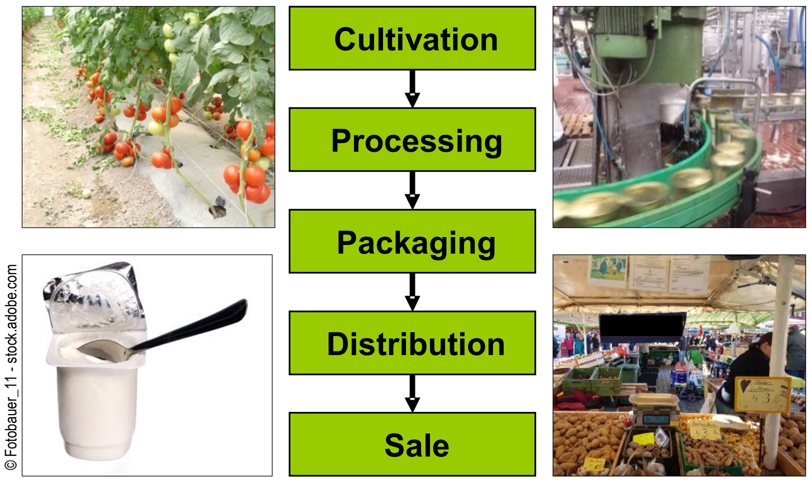

Fig. 1: Simplified illustration of the respective food-specific product systems. Transports are not included in this simplified scheme.

- **Reference unit for food products:** The respective environmental footprint of each food product is related to 1 kilogram of food "at the supermarket checkout". It must be pointed out that a comparison per kilogram of food is only meaningful if the food under consideration fulfils an identical nutritional function. Approximate comparisons can be made using a suitable reference value reflecting the main function of the compared foods in the diet (e.g. protein content). See also section 4.3.
- **Reference unit for dishes:** For the dishes the reference unit is defined as 1 serving of the particular dish.
- **Methodological framework:** The ISO 14040 and 14044 standards on product life cycle assessment [ISO 2006a; b] serve as a methodological framework for the calculation of all environmental footprints assessed, using the so-called attributional approach.
- **Representation of an average food product:** Unless stated otherwise, the food products represent an average food product sold in Germany, i.e. the calculation is based on the weighting of
  - the share of domestic production and imports
  - the import shares of different countries of origin
  - the cultivation methods (open field, greenhouse) throughout all months of the year (including seasonal / non-seasonal cultivation) and
  - the respective transports, such as the shares of sea and air transport.
- **Modelling of transport processes based on the current TREMOD model:** The greenhouse gas emissions related to transport processes are calculated based on the current TREMOD model [ifeu 2020] and the latest available vehicle data underlying the model.
- **Modelling of kitchen processes for a household of 4 persons:** To calculate the CO_2 footprints of prepared dishes, it was assumed that the kitchen processes are conducted in a household of 4 persons. Among others, this implies better efficiency for preparation processes (cooking, baking, mixing, etc.) than in a single household, but worse than in a commercial kitchen. For the assessment of dishes, the emissions associated with kitchen processes such as cold storage, preparation and dishwashing include the average time spent in the refrigerator or freezer, average preparation processes and energy consumption of appliances (such as dishwashers).

<u>CO_2 footprint:</u>

- In accordance with the ISO 14067 standard for the carbon footprint of products [ISO 2018], all greenhouse gas emissions are considered. Besides carbon dioxide (CO_2), these also include methane (CH_4) and nitrous oxide (N_2O) which are summed to CO_2 equivalents using conversion factors [IPCC 2013].
- Land use changes and associated greenhouse gas emissions (especially deforestation for agricultural purposes) were considered using an attributional land use change approach, for details see [Fehrenbach et al. 2020].
- In total, 188 food products and 8 dishes were assessed. The CO_2 footprint was calculated for all foodstuffs and dishes. Additionally, for 35 selected food products the phosphate rock, land use and water footprint as well as the energy demand was determined. For many food products, different options were assessed, e.g. "Brussels sprouts, fresh" and "Brussels sprouts, frozen". Two of the eight dishes were assessed with 11 optimised variants. The complete lists are shown in Table 1 to Table 7.

<u>Phosphate rock footprint</u>

- Phosphate as a non-renewable resource usually is imported. The main contributor to the phosphate rock footprint of food is phosphate used as a fertiliser for agricultural production. Moreover, phosphates are added to processed food. For details see [Reinhardt et al. 2019].
- The values for the 35 selected food products in Table 7 are expressed in grams of phosphate rock standard. This refers to the mass of phosphate rock consumed per 1 kilogram of food.

Land use footprint:

- The land use was calculated by weighing the land types (such as agriculture, roads, industrial land) with a factor describing the distance from undisturbed natural state. For details see [Fehrenbach et al. 2019].
- The values for the 35 selected food products in Table 7 are expressed in square metre years of natural land use. All different land types of the life cycle are converted into equivalents of completely sealed[1] land used for one year for the respective food product[2].

Water footprint:

- The water volumes consumed are weighted according to the water scarcity in the country of consumption. This and other methodological elements are essentially based on the AWARE method [Boulay et al. 2018].
- The values for the 35 selected food products in Table 7 are expressed in litres of water equivalents. This represents the equivalent of water volume of average scarcity needed for the food product.

Energy demand:

- The cumulative energy demand (primary energy) is calculated as non-renewable energy use (NREU), see e.g. [VDI (Verein Deutscher Ingenieure) 2012].
- The values for the 35 selected food products in Table 7 are expressed in kilowatt hours of primary energy equivalents.

4 Results

Section 4.1 provides the calculated CO_2 footprints. Section 4.1.1 – 4.1.5 present the CO_2 footprints of selected food products sorted by groups. The selected dishes are shown in section 4.1.6. Section 4.2 lists the phosphate rock, land use and water footprints as well as the energy demand of the 35 selected food products. Finally, section 4.3 provides guidance on the use and interpretation of the results.

[1] e.g. land sealed with asphalt. Technical term: artificial land.

[2] For example, the land use footprint of 1 kg of conventional beet sugar is mainly caused by agricultural cultivation and sugar production. Approximately 0.9 m² are used for cultivation for one year. Conventional sugar beet cultivation is classified as the most intensive agricultural type of cultivation. Consequently, it is multiplied by a factor of 0.5 (for details, including hemeroby classes, see [Fehrenbach et al. 2019]). In addition, approx. 0.0005 m² of industrial land is used for sugar production per kilogram of sugar. The sealed land is multiplied by a factor of 1.0 due to the maximum “distance to nature”. Thus, the industrial land is weighted twice as much as the cultivated land, but still contributes significantly less than 1% to the total land use footprint.

4.1 Results: CO_2 footprints

4.1.1 Fruit and vegetables

The following table shows the CO_2 footprints of various fruit and vegetable products. In particular, the variations include different cultivation methods, seasonal or non-seasonal production, import from certain countries or domestic production, different types of packaging and fresh goods compared to frozen goods.

Table 1: CO_2 footprints of selected fruit and vegetable products "at the supermarket checkout" in Germany in kilograms CO_2 equivalents per kilogram of food. Reference year: 2019.

No.	Foodstuff	CO_2 footprint [kg CO_2 eq / kg food]
1	Apple (organic), average	0.2
2	Apple, average	0.3
3	Apple, from New Zealand	0.8
4	Apple, regional in April	0.4
5	Apple, regional in autumn	0.3
6	Asparagus	0.7
7	Avocado (organic), from Peru	0.8
8	Avocado, average	0.6
9	Avocado, from Peru	0.8
10	Banana	0.6
11	Beans, in can	1.3
12	Beans, fresh	0.8
13	Beetroot, fresh	0.2
14	Beetroot, in glass jar	1.3
15	Bell pepper	0.6
16	Broccoli, fresh	0.3
17	Broccoli, frozen	0.7
18	Brussels sprouts, fresh	0.3
19	Brussels sprouts, frozen	0.6

No.	Foodstuff	CO_2 footprint [kg CO_2 eq / kg food]
20	Carrots	0.1
21	Cauliflower	0.2
22	Celery	0.2
23	Chick peas, in can	1.3
24	Corn, in can	1.2
25	Courgette	0.2
26	Cucumber (organic) with plastic film packaging	0.4
27	Cucumber (organic) without plastic film packaging	0.4
28	Cucumber with plastic film packaging	0.4
29	Cucumber without plastic film packaging	0.4
30	Eggplant	0.2
31	Fennel	0.2
32	Flax seed	1.4
33	Grapes, fresh, average	0.4
34	Grapes, fresh, from Germany, seasonal	0.3
35	Grapes, fresh, from Italy, seasonal	0.3
36	Kale, fresh	0.3
37	Kale, in glass jar	0.9
38	Kohlrabi (cabbage turnip)	0.2
39	Lamb's lettuce	0.3
40	Leek	0.2
41	Lentils (organic), dried	1.7
42	Lentils, in can	1.7
43	Lentils, dried	1.2
44	Mushrooms, fresh, bright or dark	1.3
45	Mushrooms, in can	2.4
46	Onions	0.2
47	Orange	0.3
48	Peach, in can	1.6
49	Peach, fresh	0.2
50	Pear	0.3
51	Peas, dried	2.3
52	Peas, fresh, green, in pods	0.4
53	Peas, frozen	1.2
54	Peas, green, in can	1.7
55	Peas, green, in glass jar	1.7

No.	Foodstuff	CO_2 footprint [kg CO_2 eq / kg food]
56	Pineapple, by air	15.1
57	Pineapple, by ship	0.6
58	Pineapple, in can	1.8
59	Pineapple, fresh, according to real transport average	0.9
60	Potato puree powder	0.9
61	Potatoes (organic)	0.2
62	Potatoes, fresh	0.2
63	Pumpkin	0.2
64	Radish	0.2
65	Red cabbage, fresh	0.2
66	Red cabbage, in glass jar	0.7
67	Rocket	0.3
68	Salad mix, washed	0.4
69	Spinach, fresh	0.2
70	Spinach, leaf spinach, frozen	0.6
71	Strawberries, fresh, "winter strawberries"	3.4
72	Strawberries, fresh, average	0.3
73	Strawberries, fresh, from Spain	0.4
74	Strawberries, fresh, regional, seasonal	0.3
75	Strawberries, frozen	0.7
76	Tomato puree	4.3
77	Tomatoes (organic), fresh	1.1
78	Tomatoes, cherry tomatoes	0.9
79	Tomatoes, fresh, average	0.8
80	Tomatoes, from Germany, heated greenhouse, "winter-tomato"	2.9
81	Tomatoes, from Germany, seasonal	0.3
82	Tomatoes, from Southern Europe, open land	0.4
83	Tomatoes, strained, in can	1.8
84	Tomatoes, strained, composite carton	1.6
85	Tomatoes, strained, in glass jar	1.9
86	White cabbage	0.1

4.1.2 Milk products, eggs and milk substitute products

The following table shows the CO_2 footprints of various milk, egg and milk substitute products. In particular, the variations include different cultivation methods (conventional, organic), fat contents of the products (full-fat, low-fat, skimmed) and packaging variations.

Table 2: CO_2 footprints of selected milk, egg and milk substitute products "at the supermarket checkout" in Germany in kilograms of CO_2 equivalents per kilogram of food. Reference year: 2019.

No.	Foodstuff	CO_2 footprint [kg CO_2 eq / kg food]
1	Butter	9.0
2	Butter (organic)	11.5
3	Cheese (organic), average	7.2
4	Cheese (organic), cream cheese	6.9
5	Cheese substitute, vegan, based on coconut oil	2.0
6	Cheese, average	5.7
7	Cheese, cream cheese	5.5
8	Cheese, feta	7.0
9	Cheese, hard cheese, like Emmental	6.0
10	Cheese, hard cheese, like parmesan	6.3
11	Cream	4.2
12	Cream (organic)	5.3
13	Cream substitute, based on oat	0.6
14	Curd (organic), 40 % fat	4.1
15	Curd substitute, soya	0.7
16	Curd, 40 % fat	3.3
17	Curd, low-fat curd, 10 % fat	2.4
18	Egg	3.0

No.	Foodstuff	CO_2 footprint [kg CO_2 eq / kg food]
19	Milk substitute, almond drink	0.3
20	Milk substitute, oat drink	0.3
21	Milk substitute, soya drink	0.4
22	Milk substitute, spelt drink	0.3
23	Milk (organic), ESL, whole milk, composite carton	1.7
24	Milk, ESL, low-fat, composite carton	1.2
25	Milk, ESL, whole milk, composite carton	1.4
26	Milk, UHT milk, low-fat, composite carton	1.1
27	Milk, UHT milk, whole milk, composite carton	1.3
28	Sour cream	3.0
29	Yoghurt (organic), natural, plastic cup, paper coated	1.9
30	Yoghurt substitute, soya, plastic cup, paper coated	0.6
31	Yoghurt, fruit, plastic cup, paper coated	1.7
32	Yoghurt, natural, plastic cup, paper coated	1.7

4.1.3 Meat and alternative protein sources

The following table shows the CO_2 footprints of various meat products and substitutes. In particular, the variations include different cultivation methods (conventional, organic), degrees of processing (fillet, bratwurst, sausage, nuggets), import from certain countries or domestic production as well as fresh goods compared to frozen goods.

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Table 3: CO_2 footprints of selected meat and meat substitute products "at the supermarket checkout" in Germany in kilograms of CO_2 equivalents per kilogram of food. Reference year: 2019.

No.	Foodstuff	CO_2 footprint [kg CO_2 eq / kg food]
1	Beef, average[3]	13.6
2	Beef (organic)[3]	21.7
3	Beef patty, frozen	9.0
4	Minced beef[4]	9.2
5	Minced beef (organic)[4]	15.1
6	Chicken, average	5.5
7	Chicken, frozen	5.7
8	Chicken, nuggets	3.3
9	Chicken, sausage slices	2.9
10	Fish, aquaculture	5.1
11	Fish, wild-catch, bulk good, frozen	2.4
12	Fish, wild-catch, fresh	4.0
13	Fish, wild-catch, speciality, frozen	10.0
14	Game meat, deer[5]	11.5
15	Lupine flour	0.4

[3] Both conventional beef (11 to >30 kg CO_2 eq / kg food) and organic beef (16 to >30 kg CO_2 eq / kg food) show wide ranges, with organic beef tending to perform slightly worse.

[4] Processed meat such as minced meat has lower CO_2 footprint than fine meat; the range is also smaller: 7 to 26 CO_2 eq / kg food for conventional beef mince.

[5] This average value mainly includes game meat produced on farms (fenced paddocks) and partly imported from overseas, for example deer meat produced in New Zealand.

No.	Foodstuff	CO_2 footprint [kg CO_2 eq / kg food]
16	Pork (organic)	5.2
17	Pork, average	4.6
18	Pork, frozen	4.6
19	Prawns, frozen	12.5
20	Sausage slices, beef, cold cuts	7.9
21	Sausage substitute, vegan bratwurst	1.7
22	Sausage, bratwurst, “Thüringer Rostbratwurst” (Thuringian bratwurst)	2.9
23	Seitan	2.5
24	Soya granules, Textured Vegetable Protein (TVP)	1.0
25	Tempeh	0.7
26	Tofu	1.0
27	Vegetable nuggets /-schnitzel	1.3

4.1.4 Products rich in starch, oil or sugar

The following table shows the CO_2 footprints of various products rich in starch, oil and sugar. In particular, the variations include different cultivation methods (conventional, organic), different fat levels (full-fat, half-fat), different types of packaging as well as fresh goods compared to frozen goods.

Table 4: CO_2 footprints of selected starch-, oil- and sugar-rich products "at the supermarket checkout" in Germany in kilograms of CO_2 equivalents per kilogram of food. Reference year: 2019.

No.	Foodstuff	CO_2 footprint [kg CO_2 eq / kg food]
1	Bread (organic), brown bread	0.6
2	Bread bun, white bread	0.7
3	Bread, brown bread	0.6
4	Bulgur	0.6
5	Chocolate, Milk chocolate, bar, 35 % cocoa content	4.1
6	Coconut oil	2.3
7	Fries	0.7
8	Gnocchi	0.6
9	Honey, jar	2.0
10	Margarine (organic), full-fat	2.5
11	Margarine, full-fat	2.8
12	Margarine, semi-fat	1.7
13	Oat flakes	0.6
14	Olive oil, glass disposable bottle	3.2
15	Palm fat[6]	2.9
16	Pasta	0.7
17	Pasta (organic)	0.8
18	Pastry products	1.6
19	Peanut butter	2.0
20	Fries, frozen	0.7

[6] Because of considerable differences in deforestation in individual countries of origin, this carbon footprint is highly dependent on the import mix and the environmental assessment of deforestation.

No.	Foodstuff	CO_2 footprint [kg CO_2 eq / kg food]
21	Rapeseed oil	3.3
22	Rice	3.1
23	Spelt, rice substitute	0.7
24	Sugar (organic), beet sugar	0.5
25	Sugar (organic), cane sugar	0.9
26	Sugar, beet sugar	0.7
27	Sugar, cane sugar	1.0
28	Sunflower oil, glass disposable bottle	3.2
29	Sunflower seeds	1.5
30	Walnuts, in shell	0.9

4.1.5 Beverages

The following table shows the CO_2 footprints of various beverages. The variations focus on different packaging types.

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Table 5: CO_2 footprints of selected beverages "at the supermarket checkout" in Germany in kilograms of CO_2 equivalents per kilogram of food. Reference year: 2019.

No.	**Foodstuff**	**CO_2 footprint [kg CO_2 eq / kg food]**
1	Beer, 0.5 L returnable glass bottle	0.9
2	Beer, 0.5 L tinplate can	1.0
3	Cocoa, ground	5.0
4	Coffee, ground	5.6
5	Juice, apple juice, 1.0 L composite carton	0.4
6	Juice, apple juice, 1.0 L returnable glass bottle	0.4
7	Juice, orange juice, 1.0 L composite carton	0.7
8	Lemonade, orange lemonade, 0.75 L disposable plastic botte	0.4
9	Mineral water, 0.7 L returnable glass bottle	0.2
10	Water, tap water	0.0
11	Wine, 0.75 L disposable glass botte	1.0

4.1.6 Dishes

The following table shows the CO_2 footprints of a few selected dishes. The selection is intended to

- demonstrate potential savings which can be achieved in common dishes by substituting certain foods, and also to
- illustrate the range of greenhouse gas emissions from meat, vegetarian and vegan dishes.

Table 6: CO_2 footprints of 8 dishes "prepared on the plate" in kilograms of CO_2 equivalents per serving. The kitchen processes are represented for a household of 4 persons (see section 3). The measures for dishes 1 and 2 both show the footprint of the dish with the applied. Reference year: 2019.

	CO_2 footprint [kg CO_2 eq / kg food]
Measures	
Dish 1: Beef patty with rice and fresh peas	**2.0**
with measure 1: Chicken breast fillet instead of beef patty	1.3
with measure 2: Veggie patty based on soya instead of beef patty	1.0
with measure 3: Pasta instead of rice	1.9
with measure 4: Potatoes instead of rice	1.9
with measure 5: Frozen peas instead of fresh peas	2.0
with measure 6: Fresh carrots instead of fresh peas	1.9
Dish 2: Lasagne	**1.6**
with measure 1: Minced pork instead of minced beef	1.0
with measure 2: Soya granules instead of minced beef	0.7
with measure 3: Vegan cheese substitute based on coconut oil instead of cheese	1.5
with measure 4: Oat drink instead of cow's milk	1.5
with measure 5: Strained tomatoes from composite carton instead of canned	1.5
Meat-based: high and low CO_2 footprints	
Dish 3: Beef goulash	2.6
Dish 4: Pollock fillet with cauliflower and couscous	0.6
Vegetarian: high and low CO_2 footprints	
Dish 5: Rice-vegetable gratin	1.0
Dish 4: Spaghetti with paprika cream sauce	0.6
Vegan: high and low CO_2 footprints	
Dish 7: Soya bolognese with rice	0.9
Dish 8: Penne Napoli	0.6

4.2 Results: Various environmental footprints

The following table shows the phosphate rock, land use and water footprints as well as the energy demands of a selection of 35 food products. The food products have been selected in order to include entries for as many different food categories as possible.

Table 7: Phosphate rock, land use and water footprints as well as energy demand of selected food products "at the supermarket checkout" in Germany, each per kilogram of food product (FP). Reference year: 2019.

No.	Foodstuff	**Phosphate rock footprint** [g phosphate rock std / kg FP]	**Land use footprint** [$m^2 \cdot y$ natural land use[7] / kg FP]	**Water footprint** [L water eq / kg FP]	**Energy demand** [kWh primary energy eq / kg FP]
1	Apple, average	1	0.1	1,500	0.8
2	Beef	70	7	20,000	8
3	Bread, brown bread	30	0.3	600	2
4	Butter	100	3	10,000	10
5	Cheese, average	60	1.5	6,000	8
6	Chicken, average	60	4	20,000	10
7	Cream substitute, based on oat	20	0.3	800	1.5
8	Curd, 40 % fat	30	0.8	3,000	6
9	Egg	10	3	900	6
10	Fish, aquaculture	20	3	15,000	15
11	Fish, wild-catch, bulk good, frozen	1	0	80	10
12	Fish, wild-catch, speciality, frozen	2	0	100	40
13	Juice, orange juice, 1.0 L composite carton	5	0.2	40,000	3
14	Margarine, full-fat	100	0.9	3,000	4
15	Milk substitute, oat drink	8	0.2	300	3
16	Milk substitute, soya drink	8	0.3	3,000	1.5
17	Milk, ESL, whole milk, composite carton	20	0.5	2,000	2
18	Minced beef	50	5	15,000	6

[7] See section "Land use footprint" in section 3 and the demonstrated example.

No.	Foodstuff	**Phosphate rock footprint** [g phosphate rock std / kg FP]	**Land use footprint** [m² · y natural land use / kg FP]	**Water footprint** [L water eq / kg FP]	**Energy demand** [kWh primary energy eq / kg FP]
19	Olive oil, disposable glass bottle[8]	300	3	900,000	10
20	Orange	2	0.1	15,000	1
21	Pasta	40	0.4	600	2
22	Potatoes, fresh	6	0.1	100	2
23	Rapeseed oil, disposable glass bottle	150	2	800	5
24	Rice	30	0.7	60,000	5
25	Sausage slices, beef, cold cuts	60	4	10,000	6
26	Seitan	200	2	3,000	5
27	Soya granules, Textured Vegetable Protein (TVP)	15	2	30,000	3
28	Spelt, rice substitute	30	0.6	600	1.5
29	Sugar, beet sugar	20	0.5	90	2
30	Sunflower oil, disposable glass bottle	200	1	7,000	5
31	Sunflower seeds	70	1	7,000	2
32	Tofu	3	0.5	7,000	3
33	Tomatoes, fresh, average	2	0.1	1,000	1.5
34	Vegetable nuggets /-schnitzel	20	0.5	1,000	5
35	Yoghurt substitute, soya, plastic cup, paper coated	1	0.3	3,000	3

[8] The environmental burden of olive production is almost entirely attributed to olive oil, as in many cases there is no high-quality use of the by-products (especially the press cake). In contrast, the press cake from rapeseed and sunflower oil are used as high-quality animal feed, which consequently bears a part of the environmental burden. The high water footprint is explained by the fact that olives are grown in countries with high water scarcity.

4.3 Guidance on interpretation and use of results

The following guidance should be considered when using and interpreting the results:

- **Deviations from literature:** Some of the CO_2 footprints shown in Table 1 to Table 5 deviate significantly from values reported in the literature (e.g. from values reported in the CO_2 calculator "Kimatarier" [ifeu 2016]). The main reason is the inclusion of proportional greenhouse gas emissions due to land use changes in accordance with [Fehrenbach et al. 2020] as explained in section 3. Other reasons are different system boundaries ("supermarket checkout" etc.), goods produced only in Germany compared to the annual average of sales including imports and more, as described in sections 1 and 3.
- **Contra-intuitive results:** Even for experts, some resulting values in sections 4.1 and 4.2 may be surprising. For example, this could include the average (including imports) or country-specific CO_2 footprints of food products or those of conventional or organic food[9]. Several particularly striking results are explained in footnotes.
- **Using the results to compare options for action:** The present study is based on methodological specifications that are not suitable to answer every possible question. For example, a standardised allocation of burdens to food (a so-called attributional approach) was used. Furthermore, the current average of the food was represented in most cases. For future-oriented questions, these specifications can only be used to a limited extent[10]. For these questions, scenarios have to be developed and the environmental footprints have to be calculated with adapted methods (e.g. using a consequential approach). Moreover, further footprints would have to be added.
- **Deliberate choice of the reference value for comparative statements:** The results in Table 1 to Table 5 and Table 7 are related to 1 kg of food. However, in most cases a comparison per kilogram of food is only meaningful if the food products fulfil an identical nutritional function. In particular when making comparative statements and recommendations, an appropriate reference value should be chosen (e.g. by converting the CO_2 footprints per kilogram in Table 1 to Table 5 to a typical serving size or to specific nutrient content such as protein). Moreover, sometimes meaningful comparisons between food products require that life cycle stages subsequent to the purchase are considered as well, in particular cold storage and preparation. Reliable comparisons can be achieved for complete dishes "prepared on the plate" with intentionally varied ingredient compositions while maintaining essentially the same nutritional values in the different variations.
- **Interpretation of land use and water footprint:** Since land occupation and water consumption are weighted according to the degree of their environmental burden, the results cannot be interpreted like ordinary square metres or litres of water (see section 3).

[9] Because of lower yields and associated larger land requirements, organic food usually is not favorable in terms of CO_2 footprint compared to conventional food. Greenhouse gas emissions are attributed proportionately to this land use; in Germany this is mainly due to the fact that former peatlands are used for agricultural purposes.

[10] Consumers might conclude that they should no longer buy organic food, as the methodology used here does not usually show any climate advantages or even disadvantages. Nevertheless, organic food is advantageous with regard to other environmental aspects (e.g. conservation of biodiversity). However, a restraint in purchasing would probably change only little about the agricultural use of former peatlands in Germany which is one of the main reasons why the increased land use of organic food has a negative impact. Thus, these emissions would only have to be attributed proportionately to other food products. In contrast, political decision-makers should use these results to question whether further agricultural use of former peatlands is compatible with sustainable consumption.

5 Literature

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