SUPPLEMENTARY INFORMATION
https://doi.org/10.1038/s41893-018-0189-7

nature sustainability

In the format provided by the authors and unedited.

The potential of future foods for sustainable and healthy diets

A. Parodi[1], A. Leip[2], I. J. M. De Boer[1], P. M. Slegers[3], F. Ziegler[4], E. H. M. Temme[5], M. Herrero[6], H. Tuomisto[7,8,9], H. Valin[10], C. E. Van Middelaar[1], J. J. A. Van Loon[11] and H. H. E. Van Zanten[1]*

[1]Animal Production Systems Group, Wageningen University & Research, Wageningen, The Netherlands. [2]European Commission, Joint Research Centre, Ispra, Italy. [3]Operations Research and Logistics, Wageningen University & Research, Wageningen, The Netherlands. [4]Agrifood and Bioscience, RISE Research Institutes of Sweden, Gothenburg, Sweden. [5]National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands. [6]Commonwealth Scientific and Industrial Research Organisation (CSIRO), St Lucia, Queensland, Australia. [7]Department of Agricultural Sciences, Faculty of Agriculture and Forestry, University of Helsinki, Helsinki, Finland. [8]Helsinki Institute of Sustainability Science (HELSUS), University of Helsinki, Helsinki, Finland. [9]Natural Resources Institute Finland (Luke), Helsinki, Finland. [10]Ecosystems Services and Management Program, International Institute for Applied Systems Analysis, Laxenburg, Austria. [11]Laboratory of Entomology, Wageningen University & Research, Wageningen, The Netherlands.
*e-mail: hannah.vanzanten@wur.nl

Table of contents

Supplementary Figures 3

Supplementary Methods 8

SI.1 Selection of plant and animal-source foods 8

SI.2 Assumptions made for the recalculation of LCA studies 9

SI.2.1 Cultured meat: 9

SI.2.1.1 Tuomisto & de Mattos (2011) 9

SI.2.1.2 Tuomisto et al. (2014) 9

SI.2.1.3 Mattick et al. (2015) 10

SI.2.2 Mycoprotein 10

SI.2.2.1 Finnigan et al. (2010) and Finnigan et al. (2017) 11

SI.2.3 Chlorella 11

SI.2.3.1 Sills et al. (2013) 11

SI.2.3.2 Gnansounou et al 2016 14

SI.2.3.3 Smetana et al. (2017) 16

SI.2.4 Spirulina 16

SI.2.4.1 Sills et al. (2013) 16

SI.2.4.2 Smetana et al. (2017) 18

SI.2.5 Sugar kelp 19

SI.2.5.1 Seghetta et al. (2017) 19

SI.2.5.2 Seguetta et al. (2016) 19

SI.2.5.3 Pechsiri et al. (2016) 19

SI.2.5.4 Van Oirschot et al. (2017) 20

SI.2.6 Black Soldier fly 20

SI.2.6.1 Smetana et al. (2016) 20

SI.2.6.2 Salomone et al. (2017) 20

SI.2.7 Housefly 20

SI.2.7.1 Van Zanten et al. (2014) 20

SI.2.8 Mealworm 21

SI.2.8.1 Oonincx & de Boer (2012) 21

SI.2.8.2 Joensuu & Silvenius (2017) 21

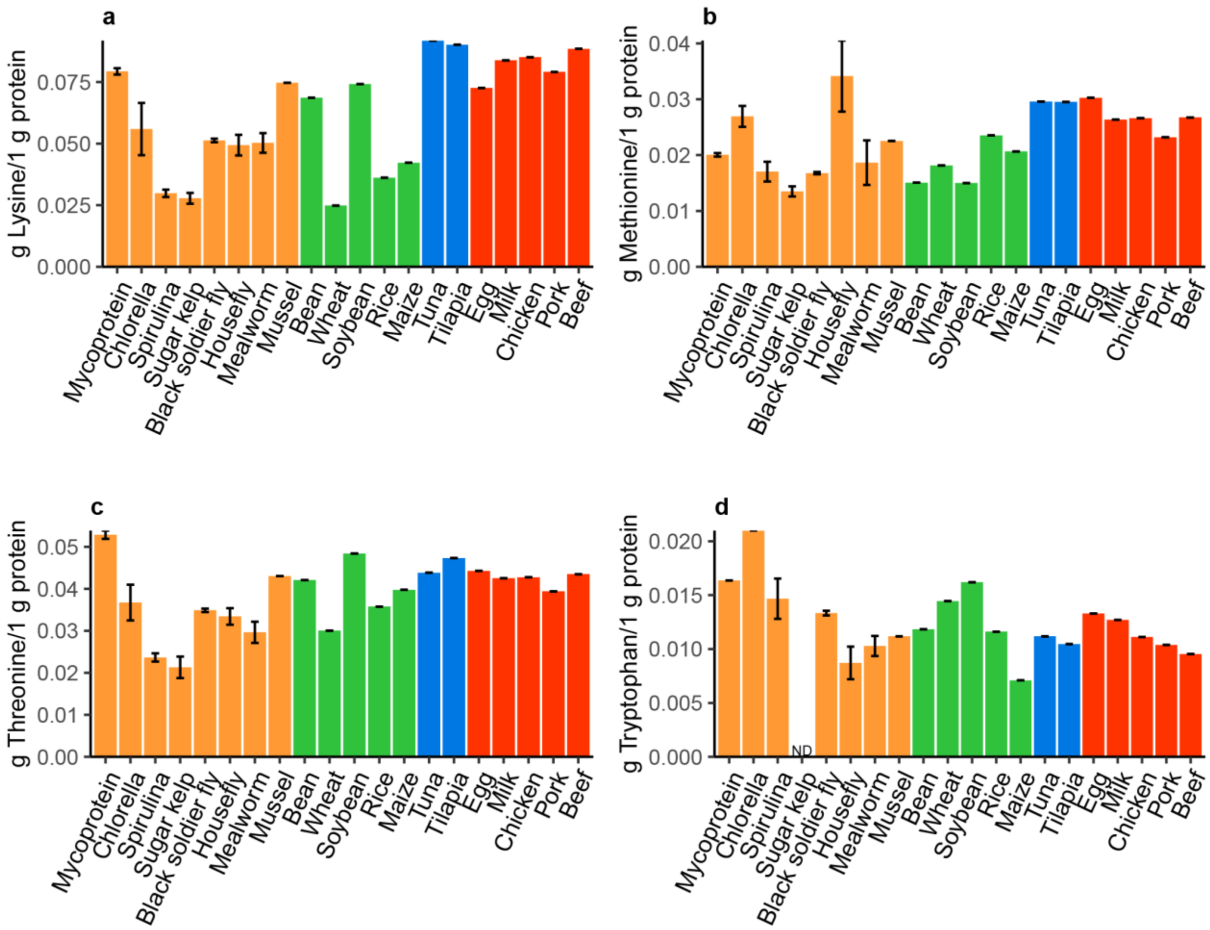
SI.2.8.3 Thévenot et al. (2018) 21

SI.2.9 Mussel 21

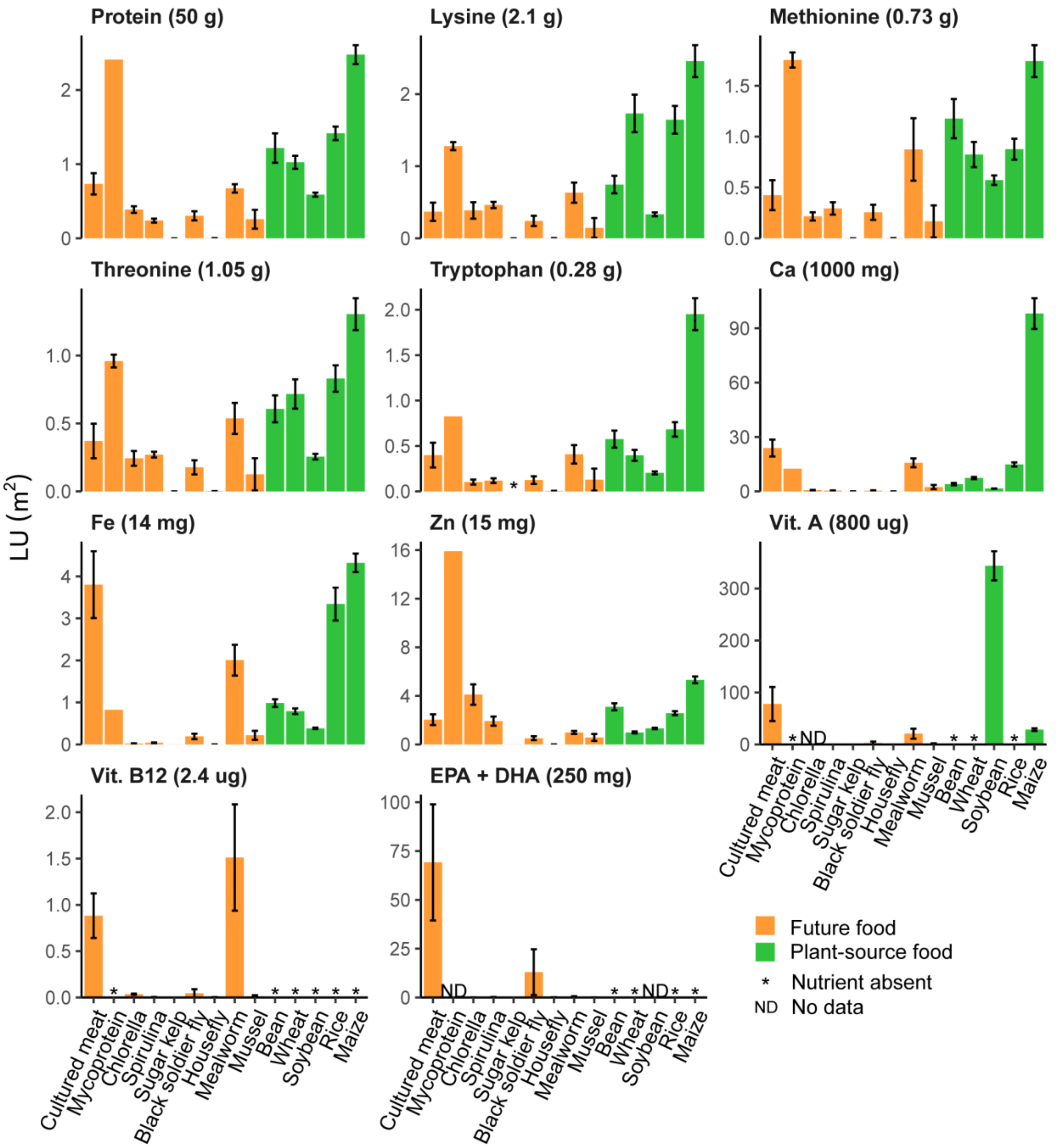
SI.2.9.1 Iribarren et al. (2010) 21

SI.2.9.2 Lourguioui et al. (2017) 22
SI.2.9.3 SARF (2010) 22
SI.2.9.4 Winther et al. (2009) 22
SI.2.9.5 Aubin et al. (2017) 22
SI.3 Environmental impact of plant-source foods 22
SI.4 Environmental impact of seafood 23
SI.4.1 Tuna 23
SI.4.1.1 Parker et al. 2015 23
SI.4.2 Tilapia 24
SI.4.2.1 Pelletier & Tyedmers (2010) 24
SI.4.2.2 Henriksson et al. (2018) 24
SI.4.2.3 Henriksson et al. (2017) 24
SI.5 Environmental impact of animal-source foods 24
Supplementary Discussion 26
SI.5.1 Carbon sequestration in grazing systems 26
SI.6 Food safety issues 26
SI.7 Specific compounds limiting digestibility 27
Supplementary References 29

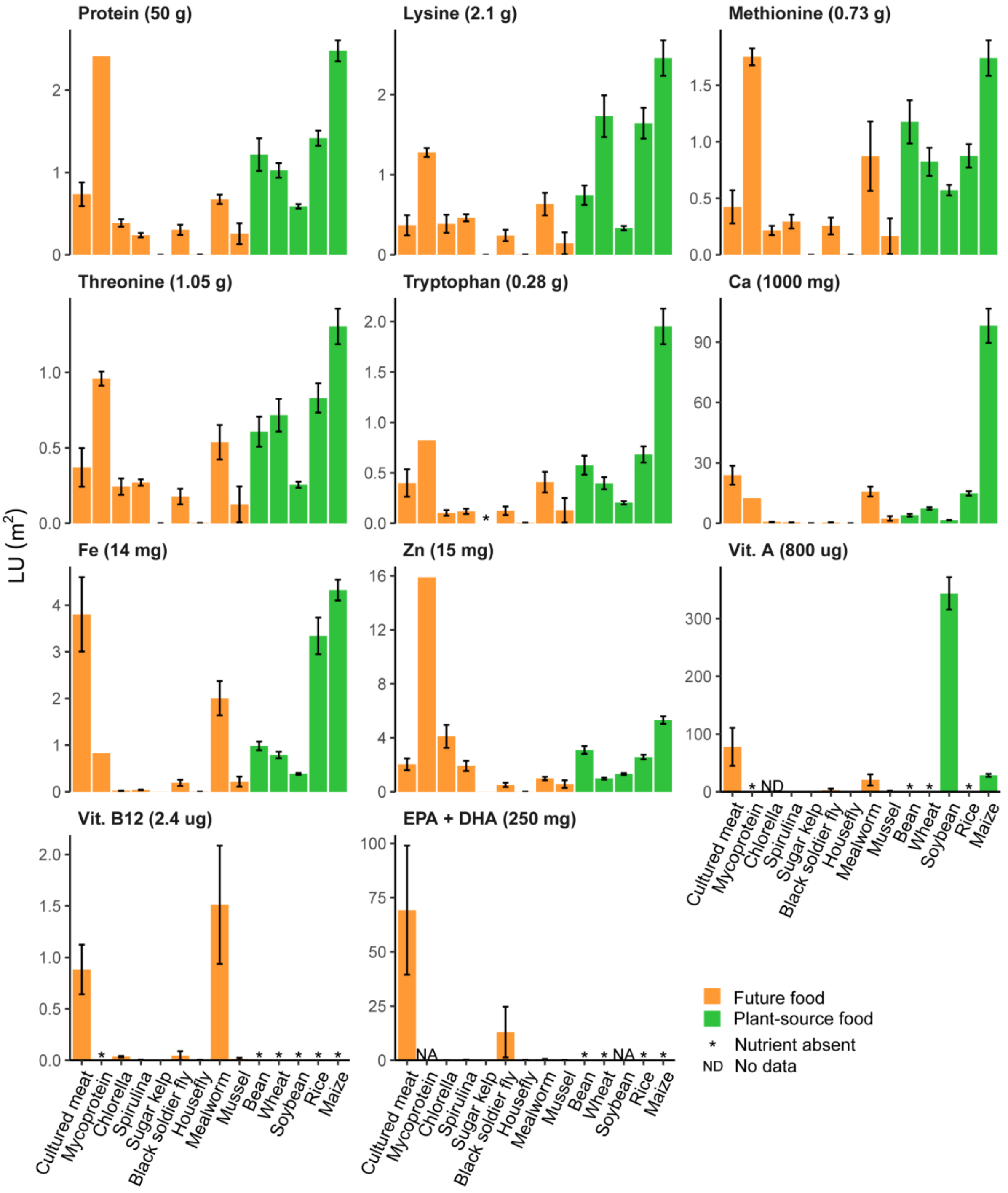
Supplementary Figures



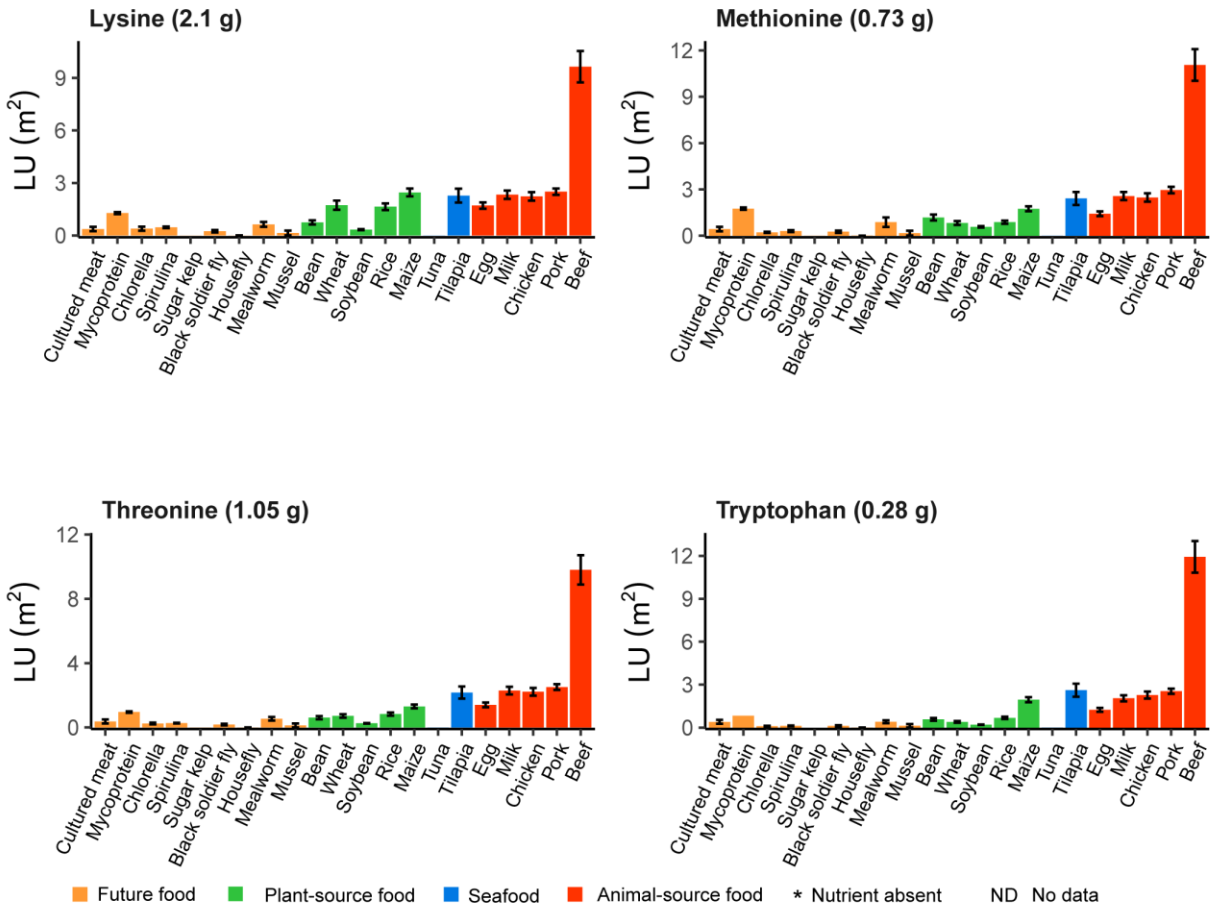
Supplementary Figure 1. Amino acid content per gram of protein for each food. The mean and standard error of the mean (s.e.m.) are shown for each case (see Supplementary Tables 1 and 5 for a list of data sources, mean and s.e.m. for each future food and nutrient). Bars without uncertainty levels are based on a single source. We selected these four amino acids for their limited availability in certain poor-quality proteins.



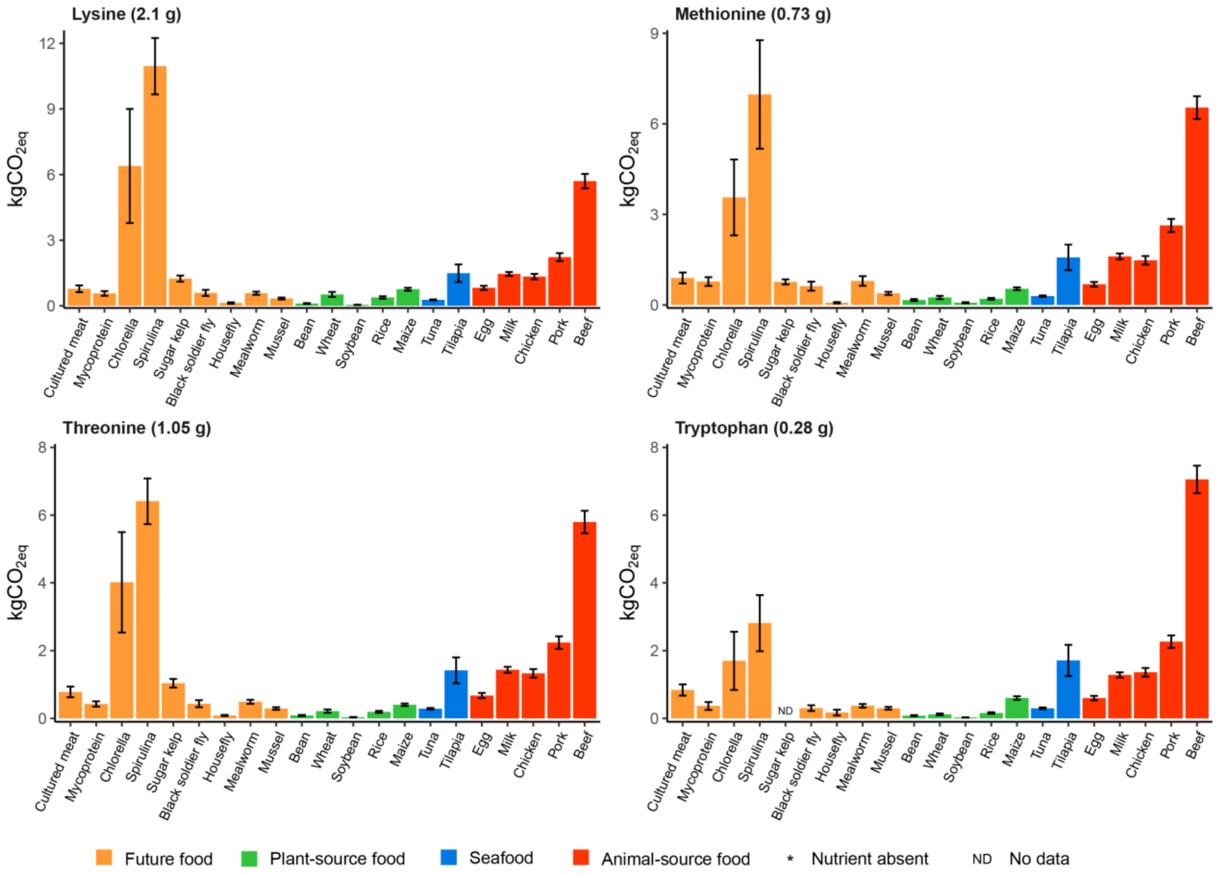
Supplementary Figure 2. Land use needed to satisfy the daily recommended intake of each essential nutrient with future foods and plant-source foods. The mean and standard error of the mean (s.e.m.) are shown for each case (see Supplementary Tables 7 and 8 for a list of data sources, mean and s.e.m. for each future food and nutrient).



Supplementary Figure 3. Greenhouse gas emissions to produce the daily recommended amount of each nutrient with each protein source. The mean and standard error of the mean (s.e.m.) are shown for each case (see Supplementary Tables 6 and 7 for a list of data sources, mean and s.e.m. for each future food and nutrient).



Supplementary Figure 4. Land use of various foods expressed per daily recommended intake of each essential amino acid. Expressing land use per unit of daily recommended intake does not imply that the daily nutrient requirements should be fulfilled by one type of food. The mean and standard error of the mean (s.e.m.) are shown for each case (see Supplementary Tables 7 and 8 for a list of data sources, mean and s.e.m. for each food and nutrient). We selected these four amino acids for their limited availability in certain poor-quality proteins.



Supplementary Figure 5. Greenhouse gas emissions resulting from producing the daily recommended amount of each amino acid with each protein source. The mean and standard error of the mean (s.e.m.) are shown for each case (see Supplementary Tables 7 and 8 for a list of data sources, mean and s.e.m. for each food and nutrient). We selected these four amino acids for their limited availability in certain poor-quality proteins.

Supplementary Methods

SI.1 Selection of plant and animal-source foods

Five traditional plant species considered to be important sources of proteins in current diets were selected and included in the analysis in order to place the nutritional and environmental impacts of future foods in perspective. The selection of these species was based on different criteria: common beans for being the pulse with the highest production volume, wheat, rice and maize for being the crops that supply the highest amounts of plant protein globally, and soybean for its high protein content (see Figure S1).

The selection of animal source foods (ASF) was based on the most consumed animal products on a global scale (Figure S2). The selected ASF were: beef, pork, chicken, eggs, milk.

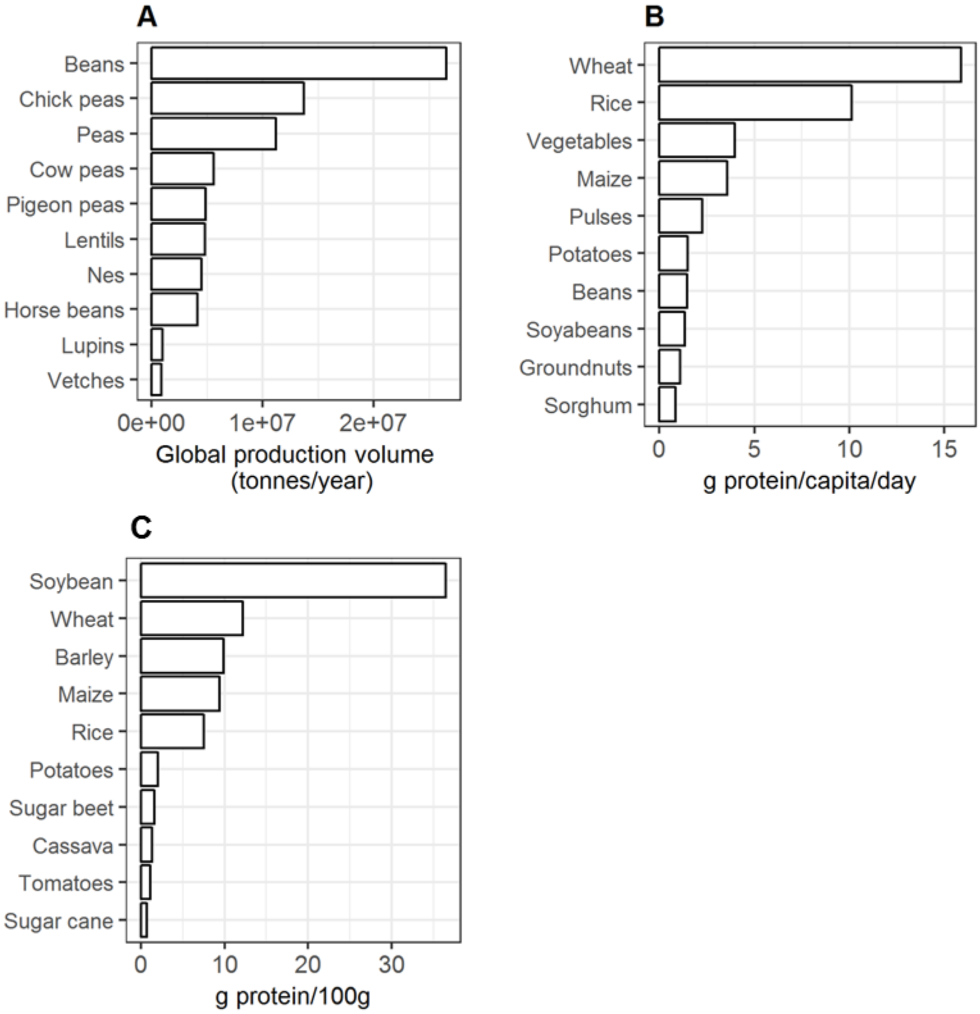


Figure S1. A: Pulses with the highest production volumes (2014); B: Supply of vegetal proteins per capita (2014); C: Protein content of the ten crops with the highest production volumes (2013). Sources: A-B: FAO (2017), C: FAO (2017), USDA (2017) and Pate et al. (2002).

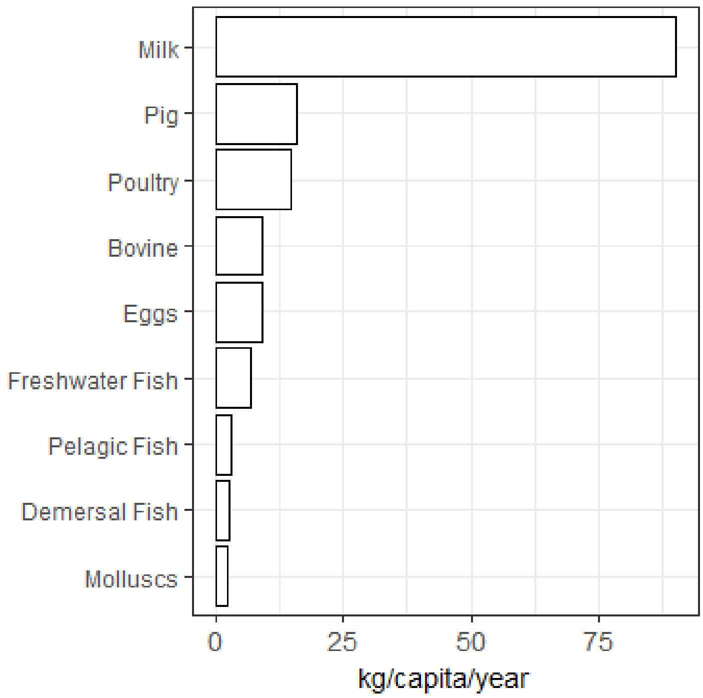


Figure S2. Most consumed ASF in 2013. Source: FAOSTAT.

SI.2 Assumptions made for the recalculation of LCA studies

SI.2.1 Cultured meat:

SI.2.1.1 Tuomisto & de Mattos (2011)

- We assumed that cultured meat has a dry matter content of 30%. Therefore, to calculate the impact of 1 kg of dry matter cultured meat, 3.33 kg of fresh cultured meat are needed.
- We used the impacts of the 100% allocation scenarios for the California, Spain and Thailand locations obtained from Table 4. However, as land use values were not available for the 100% allocation scenario for any of the locations, we used the land use of the baseline scenario (70% of the impacts of cyanobacteria production allocated to cultured meat) for each location.
- As the nutritional composition of cultured meat is unavailable, to estimate the environmental impact per nutrient, we assumed that cultured meat had the same nutritional content as beef, chicken and pork This assumption is justified because various cultured meat developers across the world are currently investing in the culturing of cells from cattle, pigs and poultry (Post 2018). Considering that nutritional profile of cultured meat can be tailored as it is possible to decide the quality and quantity of fat and micronutrients, it is still unknown what will be the additional impacts to reach a nutritional profile similar to conventional meats.

SI.2.1.2 Tuomisto et al. (2014)

- We assumed that cultured meat has a dry matter content of 30%. Therefore, to calculate the impact of 1 kg of dry matter cultured meat, 3.33 kg of fresh cultured meat are needed.
- We used the best and worst impacts of each of the production scenarios, i.e., cyanobacteria, wheat and corn, obtained from Table 3.
- As the nutritional composition of cultured meat is unavailable, to estimate the environmental impact per nutrient, we assumed that cultured meat had the same nutritional content as beef, chicken and pork This assumption is justified because various cultured meat developers across the world are currently investing in the culturing of cells from cattle, pigs and poultry (Post 2018). Considering that nutritional profile of cultured meat can be tailored as it is possible to decide the quality and quantity of fat and micronutrients, it is still unknown what will be the additional impacts to reach a nutritional profile similar to conventional meats.

SI.2.1.3 Mattick et al. (2015)

- We assumed that cultured meat has a dry matter content of 30%. Therefore, to calculate the impact of 1 kg of dry matter cultured meat, 3.33 kg of fresh cultured meat are needed.
- In this study, energy allocation was the allocation method used to determine the environmental impact of some of the inputs used to produce cultured meat (e.g., glucose made from corn starch). The authors did not report the environmental impact in cases where 100% of the impacts are allocated to cultured meat. The authors use a sensitivity analysis to show that the impacts are very similar to those found when economic or mass allocation is applied. As allocation was applied to some of the inputs used to produce cultured meat (e.g., growth media), but not to the final product (cultured meat), we assume that a scenario without any allocation will not differ significantly from the values provided.

- The impacts were obtained from Table S-14 of the SI section. As the study shows large confidence intervals for the impacts (based on a sensitivity analysis), we used three values for each impact: the mean, the mean plus the 90 percent confidence interval, and the mean minus the 90 percent confidence interval. To obtain the maximum value, the mean was multiplied by 3.4, while to obtain the minimum value, the mean was multiplied by 0.5. These values were obtained from Figure S-4 in the Supplementary Information section of Mattick et al. (2015).
  - As the nutritional composition of cultured meat is unavailable, to estimate the environmental impact per nutrient, we assumed that cultured meat had the same nutritional content as beef, chicken and pork This assumption is justified because various cultured meat developers across the world are currently investing in the culturing of cells from cattle, pigs and poultry (Post 2018). Considering that nutritional profile of cultured meat can be tailored as it is possible to decide the quality and quantity of fat and micronutrients, it is still unknown what will be the additional impacts to reach a nutritional profile similar to conventional meats.

SI.2.2 Mycoprotein

SI.2.2.1 Finnigan et al. (2010) and Finnigan et al. (2017)

- Environmental impacts were calculated based on mycoprotein and not based on Quorn mince, which is a processed food.
- We assumed that mycoprotein had a dry matter content of 25% (Marlow Foods 2009).
- The main author was contacted to request more details about the inputs, outputs and impacts of both studies, however it was not possible to access the data.

SI.2.3 Chlorella

For the future food micro-algae, the species Chlorella vulgaris was selected as it has already been produced and used commercially (Leu & Boussiba 2014). The LCA results were based on 3 studies, the data are discussed below. Additional information on, for example, reported productivities and water requirements can be found in the review by Mayers et al. (2016).

SI.2.3.1 Sills et al. (2013)

The study by Sills et al (2013) was used to obtain the environmental impacts, i.e. greenhouse gas emissions (GHGE) and energy use (EU) associated with the cultivation of *Chlorella vulgaris*. Sills et al (2013) calculated the environmental impacts of biofuel derived from microalgae cultivated in an open raceway pond system with residual CO_2. We only used the data from the cultivation stage, as the other processes included in the study are not relevant for food production, but for the production of biofuels. For this reason, we modelled a dewatering and drying route feasible for use in *C. vulgaris* food industry:

- Cultivation
- Microfiltration
- Centrifugation
- Spray drying

Sills et al. (2013) expressed the GHGE and EU associated with the cultivation phase using, as functional unit, 1 MJ of biodiesel. Assuming an oil content of 34% and a productivity of 25 $g/m^2/day$ (91.25 ton/ha/year) in dry matter basis, they found a GHGE of 0.088 kg CO_2e/MJ biodiesel and 1.4 MJ/MJ biodiesel. Considering that in current raceway ponds, productivities above 14 g.m2/day (51.1 ton./ha/year) have not been reported (Campbell et al. 2011) and that the lipid content for *C. vulgaris* commercialized as food supplement is lower than 14% (Tokuşoglu & ÜUnal 2003), we recalculated the GHGE and EU using more state-of-the-art parameters and changed the functional unit to 1 kg of algae DM.

Parameter	**Optimistic scenario**	**State-of-the-art scenario**
Daily dry matter productivity (g/m2/day)	25	14
Yearly productivity (ton/ha/year)	91.25	51.1
Oil content (%)	34	13

Oil extraction efficiency (%)	80	80
MJ/MJ of biodiesel	4.4	6.38

The calculations are divided in two main parts: environmental impacts of cultivation and the environmental impacts of the downstream processing steps:

Calculating the impacts of cultivation

To calculate the GHGE and EU per 1 kg of algae dry matter, we first calculated the total GHGE per ha using the following equation:

$$0.088 \text{ kg CO2e/MJ biofuel} = \frac{\text{GHGE per ha}}{\text{MJ biodiesel per ha}}$$

The total amount of MJ of biodiesel per ha can then be calculated using the following equation:

$$MJ\ biodiesel\ per\ ha\ =\ (kg\ algae\ per\ ha\ *\%\ oil\ content\ *$$
$$\%\ oil\ extraction\ efficiency\ *\ caloric\ value\ biodiesel\ MJ)$$

Assuming 41 MJ as the calorific value of biodiesel (Slegers et al. 2014), the MJ biodiesel per ha and the GHGE per ha for the optimistic scenario were:

$$MJ\ biodiesel\ per\ ha\ =\ (91250 \text{ kg} * 34\%\ * 80\%\ *\ 41\text{MJ})$$

$$MJ\ biodiesel\ per\ ha\ = 1{,}017{,}620 \text{ MJ}$$

$$GWP\ per\ ha = 89550.56 \text{ kg } CO_2\text{e}$$

Considering that Sills et al. (2013) found an energy use of 1.4 MJ/MJ biodiesel and that in the optimistic scenario the productivity is 91.25 ton/ha/year, the energy use and the GHGE per kg of dry matter algae for the optimistic scenario were:

$$MJ\ per\ kg\ of\ algae = \frac{(1017620 * 1.4)}{91250}$$

$$MJ\ per\ kg\ of\ algae = 15.61\ MJ$$

$$GHGE\ per\ kg\ algae\ dry\ matter = \frac{89550.56}{91250}$$

$$GHGE\ per\ kg\ algae\ dry\ matter = 0.98\ kg\ CO2\ eq$$

Assuming that the operational inputs and thus the subsequent GHGE per hectare are unaffected by the daily algae productivity or by the oil content of the algae (because the inputs are the same), it is possible to calculate the impacts for the state-of-the-art scenario:

$$MJ\ per\ kg\ of\ algae = \frac{(1017620 * 1.4)}{51100}$$

$$MJ\ per\ kg\ of\ algae = 27.87\ MJ$$

$$GHGE\ per\ kg\ algae\ dry\ matter = \frac{89550.56}{51100}$$

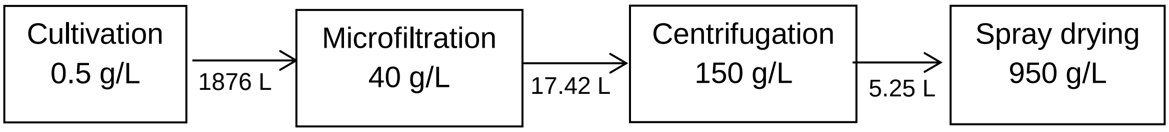
$$GHGE\ per\ kg\ algae\ dry\ matter = 1.75\ kg\ CO2\ eq$$

Hence, the environmental impacts of cultivation expressed per kg of algae DM were:

Scenario	**GHGE (kgCO_2e/kg algae)**	**EU (MJ/kg algae)**
Optimistic	0.98	15.61
State of the art	1.75	27.87

<u>Calculating the impacts of the downstream processing steps</u>

To calculate the impacts associated with the dewatering and drying techniques, we assumed that the concentration of *C. vulgaris* prior to harvest was 0.5 g/L (0.05%DM). The following concentrations were assumed after each dewatering/drying step:



The numbers below the arrows indicate the litres of water removed between the drying steps in order to get 1 kg of *C. vulgaris* at 95% DM

The energy consumption assumed for the different dewatering/drying steps are:

Process	**Units**	**Value**	**Reference**
Microfiltration	dkWh per m3 solution treated	0.5	Pahl et al. (2013)
Disk stacked centrifuge	kWh per m3 solution treated	1	Pahl et al. (2013)
Spray drying	kWh per L water removed	0.81*	Calculated

*As 0.81 kWh corresponds to heat energy and the others in electricity, we multiplied this value by an upstream factor of 1.05 (Slegers et al. 2014).

We used ecoinvent (Wernet et al. 2016) to obtain the Carbon Footprint Factors (CFP) related to the electricity mix in the United States:

CFP gCO_2e United States	
1 MJ	190
1 kWh	684

Using all these data, we calculated the environmental impact of each dewatering/drying step:

Step	GHGE (kg CO_2e)	EU (MJ)
Microfiltration (0.5 g/L to 40 g/L)	0.65	3.42
Centrifugation (40/L to 150g/L)	0.02	0.09
Spray drying (150g/L to 950g/L)	3.10	19.44
Total drying impact (95%DM)	3.77	22.95
Total drying impact (100%DM)	**3.97**	**24.15**

And finally, we calculated the total environmental impact to obtain 1 kg of dry matter chlorella:

Phase	GHGE (kg CO_2e)	EU (MJ)
Cultivation-optimistic scenario (100%DM)	0.98	15.61
Cultivation-state of the art scenario (100%DM)	1.75	27.87
Drying (100%DM)	3.97	24.15
Final impact optimistic scenario of 1 kg of DM chlorella	**4.95**	**39.76**
Final impact state of the art scenario of 1 kg of DM chlorella	**5.72**	**52.03**

SI.2.3.2 Gnansounou et al 2016

We used the study by Gnansounou et al. (2016) to obtain the environmental impacts (i.e. GHGE and LU) associated with the cultivation of *Chlorella vulgaris*. They performed an LCA for an algae biorefinery in India, having as major products biodiesel and animal feed or succinic acid. When producing either biodiesel, defatted algae (for animal feed) or succinic acid, it is first necessary to extract the oil from the algae, therefore the processes following the cultivation phase were not considered (algae destined for food contain all nutrients, including the oil). Thus, we only used the data from the cultivation stage. We used the same dewatering and drying route designed and described previously for Sills et al. (2013):

- Cultivation
- Microfiltration
- Centrifugation
- Spray drying

<u>Calculating the impacts of cultivation under the state-of-the-art scenario</u>

For cultivation, Gnansounou et al. (2016) assumed a lipid algae content of 25% and a productivity of 25 g./m2/day (91.25 ton/ha/year) in an open raceway pond in India. For the cultivation phase, they found a GHGE of 2.61 kg CO_2e/kg biodiesel (Gnansounou comp. pers, 2017). As we did for Sills et al. (2013), we created a state-of-the-art scenario assuming a lower productivity and a lower DM lipid content. Gnansounou et al. (2016) assumed an oil extraction efficiency of 91%, however Sills et al. (2013) assumed 80%; we used Gnansounou et al's (2016) assumption. A summary of the parameters used can be seen in the following table:

Parameter	**Optimistic scenario**	**State-of-the-art scenario**
Daily productivity (g.m2/day)	25	14
Yearly productivity (ton.ha/year)	91.25	51.1
Oil content (%)	25	13
Oil extraction efficiency (%)	91	91

We recalculated the impacts to express them per 1 kg of chlorella 100% DM. The results of the calculations were:

Indicator	**Optimistic scenario**	**State-of-the-art scenario**
Total biofuel production per ha (kg)	20759.37	6193.93
kg CO_2e/kg biofuel	2.61	8.75
kg CO_2e per ha	54181.96	54181.97
kg algae to get 1 kg biofuel	4.40	8.25
kg CO_2e/ kg algae	0.59	1.06

Calculating the impacts of the dewatering/ drying steps

We used the same assumptions for the dewatering/drying steps described by Sills et al. (2013), except for the CFP factors for the electricity mix. We obtained the CFP factors for India (where the energy mix is different than the US) based on ecoinvent (Wernet et al. 2016).

CFP India (gCO_2e)	
1 MJ	439
1 kWh	1580.4

The environmental impact of each dewatering/drying step was:

Step	**GHGE (kg CO_2e)**
Microfiltration(0.5 g/L to 40 g/L)	1.50
Centrifugation (40/L to 150g/L)	0.04
Spray drying (150g/L to 950g/L)	7.17
Total drying impact (95%DM)	8.71
Total drying impact (100%DM)	**9.17**

To conclude, the total environmental impacts to obtain 1 kg of dry matter chlorella:

Phase	**GHGE (kg CO_2e)**
Cultivation-optimistic scenario (100%DM)	**0.593775**
Cultivation-state of the art scenario (100%DM)	1.06
Drying (100%DM)	9.17
Final impact optimistic scenario of 1 kg dry matter chlorella	9.76
Final impact state of the art scenario of 1 kg dry matter chlorella	**10.23**

SI.2.3.3 Smetana et al. (2017)

- This study presents the impact of microalgae in four different functional units: 1kg of fresh microalgae, 1 kg of dried whole algae, 1 kg of defatted algae and 1 kg of algae oil. We selected the impacts of the functional unit 1 kg of dried whole algae, presented in Table 2 of Smetana et al. (2017).
- We selected the impacts associated with the production of Chlorella in a heterotrophic fermenter (indoor cultivation, no sunlight), an open raceway pond, and a tubular bioreactor.
- The environmental impacts reported by Smetana et al., (2017) are much greater than those re-calculated for other LCA in microalgae. We looked for detailed data and assumptions in Smetana et al. (2017) to discover the underlying reasons for these differences, however the amount of detailed data available are limited. We believe that the large differences are due to different assumptions in productivity (e.g., Smetana et al. (2017) assume a productivity of 15 tons/ha/year while others assume more than 50 tons/ha/year) and massive energy inputs (almost 450 MJ per kg of DM algae vs 40-50 MJ per kg of DM algae) associated with water heating, as the impacts were modelled for a production facility in Berlin.

SI.2.4 Spirulina

SI.2.4.1 Sills et al. (2013)

We also used Sills et al.’s (2013) study to calculate the environmental impacts related to the cultivation of *Arthrospira platensis*, a commercial cyanobacteria common in the food industry. The environmental impacts of the cultivation stage are assumed to be the same as those calculated for the optimistic scenario of *C. vulgaris*, however for the state-of-the-art scenario, we used a lipid content of 7.42%, as this is what has been found in commercial *A. platensis* sold as food (Tokuşoglu & ÜUnal 2003). Thus, the parameters used for the optimistic and state-of-the-art scenario were:

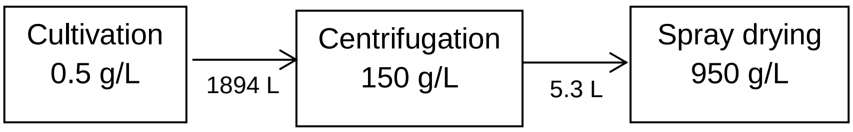
Parameter	**Optimistic scenario**	**State-of-the-art scenario**
Dry matter daily productivity (g.m2/day)	25	14

Yearly productivity (ton.ha/year)	91.25	51.1
Oil content (%)	34	7.42
Oil extraction efficiency (%)	80	80
MJ/MJ of biodiesel	1.4	11.46

Finally, we recalculated the impacts to express them per 1 kg of spirulina 100% DM. The results of the calculations were:

Unit	**Optimistic scenario**	**State-of-the-art scenario**
gCO_2e/MJ biodiesel	88	720.06
MJ/MJ biodiesel	1.4	11.46
MJ biodiesel produced with 1 kg spirulina 100% DM	11.15	2.43
$kgCO_2e$/kg algae 100% DM	0.98	1.75
MJ/kg spirulina 100% DM	15.61	27.88

A. platensis is a large filamentous cyanobacteria. This property makes it easier to settle/centrifuge, therefore the dewatering/drying steps and the energy consumption for these steps were assumed to be different than those for *C. vulgaris*:



The energy consumption assumed for the different dewatering/drying steps are:

Process	**Units**	**Value**	**Reference**
Disk stacked centrifuge	kWh per m3 solution treated	1	Pahl et al. (2013)
Spray drying	kWh per L water treated	0.81	Calculated

*As 0.81 kWh corresponds to heat energy and the others in electricity, we multiplied this value with an upstream factor of 1.05 (Slegers et al. 2014).

The conversion factor used to transform 1kWh to MJ was 3.6 MJ.

We used ecoinvent (Wernet et al. 2016) to obtain the Carbon Footprint Factors (CFP) related to the electricity mix in the United States:

CFP gCO_2e United States	
1 MJ	190
1 kWh	684

Using all these data, we calculated the environmental impact of each dewatering/drying step to obtain 1 kg of dry matter spirulina:

Step	GHGE (kg CO_2e)	EU (MJ)
Centrifugation (0.5/L to 150g/L)	0.65	3.42
Spray drying (150g/L to 950g/L)	3.10	16.33
Total drying impact (95%DM)	3.75	19.75
Total drying impact (100%DM)	**3.95**	**20.79**

And finally, the total environmental impact to obtain 1 kg of dry matter spirulina:

Phase	GHGE (kg CO_2e)	EU (MJ)
Cultivation-optimistic scenario (100%DM)	0.98	15.61
Cultivation-state of the art scenario (100%DM)	1.75	27.88
Drying (100%DM)	3.95	20.79
Final impact optimistic scenario of 1 kg dry matter spirulina	**4.93**	**36.40**
Final impact state of the art scenario of 1 kg dry matter spirulina	**5.70**	**48.67**

SI.2.4.2 Smetana et al. (2017)

- This study presents the impact of spirulina in four different functional units: 1 kg of fresh spirulina, 1 kg of dried whole spirulina, 1 kg of defatted spirulina, and 1 kg of spirulina oil. We selected the impacts of the functional unit 1 kg of dried whole spirulina, presented in Table 2 of Smetana et al. (2017).
- We selected the impacts associated with the production of spirulina in an open raceway pond and a tubular bioreactor.
- The environmental impacts reported in Smetana et al., (2017) are much greater than those re-calculated for other LCA in microalgae. We searched for detailed data and assumptions in Smetana et al. (2017) to find out the underlying reasons for these differences, however the amount of detailed data available are limited. We believe that the large differences are due to different assumptions in productivity (e.g., Smetana et al. (2017) assume a productivity of 15 tons/ha/year, while others assume more than 50 tons/ha/year) and massive energy inputs (almost 450 MJ per kg of DM algae vs 40-50 MJ per kg of DM algae) associated with water heating, as the impacts were modelled for a production facility in Berlin.

SI.2.5 Sugar kelp

SI.2.5.1 Seghetta et al. (2017)

- We only used the scenario ProS1 made for *Saccharina latissima*.
- As this is an LCA with system expansion (consequential approach), we only considered the impacts for cultivation, transport and drying. The values for climate change (kgCO_2e) and cumulative energy demand (MJ) were calculated from Figures 4a, 4b of Seghetta et al. (2017). The values used were:

Process	kg CO_2e/ha	MJ/ha
Cultivation	875	18750
Transport	15	0
Drying	100	45000

- The dry matter seaweed productivity per hectare for ProS1 scenario was 1500 kg/ha.
- 1.25 kg of seaweed meal (80% DM) was needed to get 1 kg of 100%DM seaweed.

SI.2.5.2 Seguetta et al. (2016)

- We only used the scenario A3, made for *Saccharina latissima*.
- As this is an LCA with system expansion (consequential approach), we only considered the impacts for cultivation, transport and drying. The values for climate change (kg$CO_{2\,eq}$) and cumulative energy demand (MJ) were calculated from Figures 4a, 4b of Seghetta et al. (2016). The values used were:

Process	kg CO_2e/ha	MJ/ha
Cultivation	830	17500
Transport	15	0
Drying	115	48500

- For the A3 scenario, the dry matter seaweed productivity assumed was 1300 kg/ha.
- 1.25 kg of seaweed meal (80% DM) was needed to get 1 kg of 100%DM seaweed.

SI.2.5.3 Pechsiri et al. (2016)

- We accounted for the impacts caused by spore preparation and inoculation (A1), juvenile maturation (A2), transport and fitting (B1), adult growth (B2), harvest and transport (C1), and unloading at dock (C2).
- We used the impacts expressed per case of 0.5 ha.
- We assumed two different productivities: 11.25 kg of wet weight per 1 m of polyester long line and 13.75 kg of wet weight per 1 m of polyester long line (Pechsiri et al., 2016).
- 1000 meters of polyester were needed per 0.5 ha (Pechsiri et al., 2016).
- We did not include the drying of the seaweed, as this was not included in the LCA.

SI.2.5.4 Van Oirschot et al. (2017)

- The impacts for the single layer (21700 kg CO_2e per ton of protein) and dual layer (21600 kg CO_2e per ton of protein) configurations were obtained from Figure 3 of Van Oirschot et al. (2017).
- All impacts were considered: infrastructure, seeding lines, harvest and transport, and drying.
- We used the same assumptions made by Van Oirschot et al. (2017) to calculate the environmental impact per kg of dry matter seaweed. These were: protein content in dry matter 7% and dry matter content of *Saccharina latissima* 15%.

SI.2.6 Black Soldier fly

SI.2.6.1 Smetana et al. (2016)

- This study provides max and min values in Table 2. The lowest environmental impact was assumed to be associated with the use of municipal food waste as source of feed, while the highest environmental impact was associated with the use of beet pulp as feed (based on Figure 3). This assumption was partially corroborated by the author of the study, mentioning that the impact methods used (ReCiPe and IMPACT 2002+) could also have an influence on the ranges of the graph.
- 1.14 kg of larvae meal (88% DM) was needed to get 1 kg of 100% DM (Smetana et al. 2016).

SI.2.6.2 Salomone et al. (2017)

- This study explores the use of BSF larva as animal feed. We assumed that safety aspects associated with human consumption will be controlled, and that the same system can be used for human consumption.

- As the environmental impact was expressed per kg of protein, we transformed the impacts per kg of dry matter product. As Salomone et al. (2015) mention that the protein content on dry mater basis was 48%, we assumed that 2.08 kg of DM larvae were needed to get 1 kg of protein.

SI.2.7 Housefly

SI.2.7.1 Van Zanten et al. (2014)

- *Musca domestica* is a species that lives in close association with humans and can be a vector of diseases (Rozendaal 2011). In this study, the larvae to be used as animal feed were fed with food waste and hen manure. We assumed that safety aspects associated with human consumption will be controlled, and that the same system can be used for human consumption.
- This study shows two scenarios. The first scenario is related to the use of residual heat to dry the larvae. Thus, no energy inputs are required for drying. In the second scenario, energy inputs for drying are accounted. We used both scenarios.

SI.2.8 Mealworm

SI.2.8.1 Oonincx & de Boer (2012)

- This study shows the environmental impact of the larvae of *Tenebrio molitor*, on a fresh matter basis. To transform the impacts to a dry matter basis, we used a dry matter content of 37.16%, as this was the average value from several studies (Bednářová et al. 2013; Barker et al. 1998; Sánchez-Muros et al. 2016; Yi et al. 2013). Therefore, to get 1 kg of dry matter mealworm, 2.69 kg of fresh product was needed.
- As this study does not consider the drying of larvae, the environmental impacts correspond to mealworms that have not been dried.

SI.2.8.2 Joensuu & Silvenius (2017)

- We selected the mean value of each of the scenarios: baseline (3.1 kg CO_2e/ kg fresh larvae), by-product diet (3 kg CO_2e/ kg fresh larvae) and by-products diet with low emission energy (2 kg CO_2e/ kg fresh larvae). The values were selected from Figure 3 of Joensuu & Silvenius (2017)**.**
- To transform the impacts to dry matter basis, we used a dry matter content of 37.16%, as this was the average value from several studies (Bednářová et al. 2013; Barker et al. 1998; Sánchez-Muros et al. 2016; Yi et al. 2013). Therefore, to get 1 kg of dry matter mealworm, 2.69 kg of fresh product was needed.

SI.2.8.3 Thévenot et al. (2018)

- We selected the impacts associated with the production of 1 kg of mealworms at farm gate presented in Table 4. The impacts do not include drying of mealworms.
- To transform the impacts to a dry matter basis, we used a dry matter content of 37.16%, as this was the average value from several studies (Bednářová et al. 2013; Barker et al. 1998; Sánchez-Muros et al. 2016; Yi et al. 2013). Therefore, to get 1 kg of dry matter mealworm, 2.69 kg of fresh product was needed.

SI.2.9 Mussel

SI.2.9.1 Iribarren et al. (2010)

- We only selected the GHG associated with the culture sub-sector showed in Table 6 of Iribarren et al. (2010). The GHG accounted for seed collection, pre-fattening the seed, rope thinning, harvesting, selection and previous packaging, construction, operation and maintenance of the auxiliary cultivation boats.
- As the impacts were expressed per kg of whole mussels, we first calculated the impacts per kg of edible weight and then per kg of dry matter edible weight. For these calculations, we assumed that *Mytilus galloprovincialis* had the same edible weight and water content as *Mytilus edulis.* We assumed that 24% of the whole mussel was edible (FAO 1989) and that the water content of the edible portion was 80.58% (USDA 2017).

SI.2.9.2 Lourguioui et al. (2017)

- This study estimates the environmental impact of *Mytilus galloprovincialis* in three scenarios: current scenario (CS), competitive scenario (Comp_S) and cooperative scenario (Coop_S). We selected the GHGE mean values of each scenario shown in Table 4 and the land use of the each scenario shown in Table 2.
- As the impacts were expressed per kg of whole mussels, we first calculated the impacts per kg of edible weight and then per kg of dry matter edible weight. For these calculations, we assumed that *Mytilus galloprovincialis* had the same edible weight and water content as *Mytilus edulis.* We assumed that 24% of the whole mussel was edible (FAO 1989) and that the water content of the edible portion was 80.58% (USDA 2017).

SI.2.9.3 SARF (2010)

- The GHG for 1 ton of Scottish suspended blue mussels (*Mytilus edulis*) were obtained from Table 4.2. The processes included were: hatchery, materials, farm operations and depuration. Packaging was not included.
- We assumed that 24% of the whole mussel was edible and that the water content of the edible portion was 80.58% (USDA 2017).

SI.2.9.4 Winther et al. (2009)

- The GHG obtained from this study correspond to the average values from three Norwegian blue mussel farms. We considered the following processes: cultivation (diesel, plastic and iron) and transport (diesel and ice).
- We assumed that 24% of the whole mussel was edible (FAO 1989) and that the water content of the edible portion was 80.58% (USDA 2017).

SI.2.9.5 Aubin et al. (2017)

- This study presents the environmental impacts of ready-to-cook French blue mussels at the farm gate under different assumptions, e.g., accounting for the carbon sequestered in wooden stakes, accounting for the carbon sequestered in mussel shells, not accounting for any carbon sequestered, etc. We selected the impacts of the category "Without C in shell and wooden stake" shown in Table 5 of Aubin et al. (2017). The land use was taken from Table 2.
- We assumed that 24% of the whole mussel was edible (FAO 1989) and that the water content of the edible portion was 80.58% (USDA 2017).
- While in the other LCA studies the land use is zero (suspended-lines system or raft system), in this study the land use is more than zero due to the "bouchot system" consisting of wooden stakes placed in the intertidal zone.

SI.3 Environmental impact of plant-source foods

The environmental impacts of plant-source foods were derived from Leip et al. (2014 & 2015). We used the direct and indirect GHG emissions of all countries of the European Union. GHG emissions sources of plant-source foods included:

- Direct N2O emissions from soils (synthetic fertilizers, manure, crop residues).
- N2O and CO2 emissions from cultivated histosols.
- CO2, N2O and CH4 emission from land use change (biomass and litter, mineralization of soil organic matter, biomass burning).
- Indirect N2O emissions from volatilization of ammonia and from nitrogen leaching and run-off.
- CO2 emissions from on-farm diesel and other fuel consumption, and consumption of electricity for crop production; CO2 emissions from machinery and buildings.
- CO2 emissions from production of seed, fertilizers, and plant protection chemicals.

SI.4 Environmental impact of seafood

SI.4.1 Tuna

SI.4.1.1 Parker et al. 2015

- No recent full-scale LCA for tuna is available, and based on the observation that fuel use dominates both energy use and greenhouse gas emissions of fishing (Ziegler et al. 2016), we used recent fuel-use data for fisheries (Parker et al. 2015) to estimate GHG emissions per kg of fish at landing. It is important to recognize that purse seining (the dominant fishing method for skipjack tuna) is one of the most efficient fishing methods (Parker & Tyedmers 2015).
- Data for fuel use for skipjack tuna in the Pacific, Indian and Atlantic ocean was taken from Parker et al. 2015 and found to be 349 l/tonne, 459 l/tonne and 445 l/tonne, respectively. To also account for non-fuel related emissions and energy use (e.g. vessel and gear construction, provision of ice, antifouling paint etc.), it was assumed that fuel-related emissions represented 75% of the total GHG emissions and a non-fuel related component of energy use and GHG was added: 25% for non-fuel related GHG emissions (Parker et al. 2018). The fuel use was then translated into greenhouse gas emissions using 3.1 kg CO_2e /l fuel (including production and combustion of fuel), resulting in a carbon footprint of 1.20 CO_2e/kg live weight for skipjack tuna fished in the Pacific, 1.53 CO_2e/kg live weight for skipjack tuna fished in the Atlantic Ocean, and 1.58 CO_2e/kg live weight for skipjack tuna fished in the Indian ocean.
- To allocate the impacts to the edible portion, all impacts were first converted to edible weight and then to dry matter edible weight. We assumed that the edible portion of Skipjack tuna is 62% (FAO 1989) and that the water content in the edible part is 70.58% (USDA 2017).
- Land use was zero in the case of fisheries (the potential use of seafloor areas was not included in the study). In addition, the fishing methods used in the cases included do not impact the seafloor.

SI.4.2 Tilapia

SI.4.2.1 Pelletier & Tyedmers (2010)

- In this study of Indonesian lake and pond aquaculture, we selected the impacts associated with the lake (1.52 CO_2e/kg live weight) and pond system (2.1 CO_2e/kg live weight). These impacts are shown in Figure 3 of Pelletier & Tyedmers (2010).
- Impacts were first converted to edible weight and then to dry matter edible weight. We assumed that the edible portion of Tilapia is 37% (FAO 1989) and that the water content in the edible part is 78.08% (USDA 2017).

SI.4.2.2 Henriksson et al. (2018)

- This study of tilapia farming in Bangladesh does not show the impacts for tilapia farmed in ponds without allocation. As the impacts are shown with mass allocation, we used those values.
- We selected the median of the GHG emissions (5.09 CO2e/kg live weight) and land use (4.74 m^2/kg live weight) from Table S27 of the Supplementary Information section of Henriksson et al. (2018).
- Impacts were first converted to edible weight and then to dry matter edible weight. We assumed that the edible portion of Tilapia is 37% (FAO 1989) and that the water content in the edible part is 78.08% (USDA 2017).

SI.4.2.3 Henriksson et al. (2017)

- This study, representative for Indonesian aquaculture, does not show the impacts without allocation. Impacts are shown for mass and economic allocation. We used the values calculated with mass allocation.
- We selected the median of the GHG emissions for pond (7.63 CO_2e/kg live weight) and cage systems (7.39 CO_2e/kg live weight), land use for pond (8.65 m^2/kg live weight) and cage system (8.39 m^2/kg live weight) from the SI file (Global-warming sheet and Land-use sheet).
- Impacts were first converted to edible weight and then to dry matter edible weight. We assumed that the edible portion of Tilapia is 37% (FAO 1989) and that the water content in the edible part is 78.08% (USDA 2017).

SI.5 Environmental impact of animal-source foods

The environmental impacts of animal-source foods derived from Leip et al. (2014 & 2015). We used the direct and indirect GHG emissions of all countries of the European Union. Emissions from feed production were not limited to production within the EU, but emissions from imported feeds were included from Weiss & Leip (2012) and Leip et al. (2010). GHG emissions of animal-source foods corresponded to:

- Emissions from feed production – as given in SI.3.
- CH4 emissions from enteric fermentation.
- Direct N2O and CH4 emissions from manure management (only housing and storage).
- Direct nitrous oxide emissions from grazing.

- CO_2 emissions from feed transport and processing.
- CO_2 emissions from on-farm diesel and other fuels consumption and consumption of electricity for livestock production; CO_2 emissions from machinery and buildings.

Supplementary Discussion

SI.5.1 Carbon sequestration in grazing systems

It is worth to highlight that well-managed grazing livestock systems could potentially aid the process of carbon sequestration in the soil (Garnett et al. 2017), and thus help to reduce atmospheric CO_2 concentrations. However, so far, evidences indicate that the sequestration potential from grazing management is time-limited (Smith 2014), has a negligible effect on overall livestock emissions, and that practices optimal for achieving carbon sequestration might have trade-offs with other environmental goals (Garnett et al. 2017). Future research on carbon sequestration rates at deeper soil levels (>1 m) are needed to reveal the true potential of managed grasslands to mitigate GHG emissions. However, given that grasslands are an important stock of carbon and that it is easier and faster for soils to lose carbon that it is for them to gain it (Johnston et al. 2009), it is crucial to maintain the existing soil carbon stocks by reducing land-use change. For that, future foods might play an important role.

SI.6 Food safety issues

The micro-algae *Chlorella* and *Spirulina* have been cultivated and consumed for a long time (Draaisma et al. 2013; Vigani et al. 2015; Wells et al. 2016; Tang & Suter 2011). Due to the long history of use, these species are, in general, considered to be safe for consumption, provided that cultivation is controlled and takes place in clean water (Wells et al. 2016; Tang & Suter 2011; European Commission 2015). The micro-algae species *Tetraselmis chuii* was the first micro-algae to be approved by the EU as novel food (European Commission 2015).

Seaweeds are found with different types and concentration of metals (e.g. arsenic, copper, etc.), depending on the species, collection time, and collection site. Some studies found excess metals, while other studies found no harmful quantities (Van der Spiegel et al. 2013). Some seaweeds also contain iodine in concentrations that limit consumption (Maehre et al. 2014; Yeh et al. 2014).

For blue mussels, it is important to be aware of that they may not be fit for consumption in certain periods due to the accumulation of algal toxins during blooms of toxic algae, which occur regularly. All commercially farmed blue mussels are controlled for content of algal toxins (DSP, ASP, PSP) before being sold. After the algal bloom is over, the mussels can be harvested, as the toxins disappear. Another safety risks associated with mussels is the presence of *Vibrio* bacteria in the water bodies where mussels are grown. In Norway this pathogen was found in low concentrations and did not pose any health risk to consumers (Bauer et al. 2006), while in Germany, *Vibrio* pathogens were common in blue-mussel growing areas, posing a relevant risk to public health (Lhafi & Kühneb 2007). In addition, microplastics have been found in commercial mussels in levels that present a route for human exposure (Li et al. 2018). All these aspects should be taken into account when selecting adequate places for the cultivation of mussels.

As for conventional animals, the safety of edible insects is ensured with the choice of appropriate and safe feeds (EFSA 2015). As a plus for insects, aflatoxins which spoil crops and therefore increase food waste, are well tolerated by BSF and mealworms, and do not accumulate in the edible portion (Bosch et al. 2017).

SI.7 Specific compounds limiting digestibility

The specific compounds present in human or animal foods that reduce nutrient utilization are also known as "anti-nutritional factors" (Thangaraj 2016). We have avoided the use of the term "anti-nutritional factors" because many of these compounds also have positive effects on human and animal health. We found no publications documenting the presence of these compounds in mycoprotein, mussels, cultured meat, spirulina and chlorella. The information found for seaweeds, microalgae and cyanobacteria and insects is presented below.

Seaweeds

Compounds that reduce the digestibility of nutrients such as polyphenols, trypsin and alpha-amylase inhibitors, tannins and phytic acids have been found in seaweeds (Oliveira et al. 2009; Vijayabaskar & Shiyamala 2012; Murugan et al. 2015; Cofrades et al. 2016). However, no study has directly explored the effects in the human digestibility of seaweed caused by these compounds. Instead, most of the literature related to seaweed focus on the bioactive properties and their associated human health effects of the same components reported as "anti-nutritional factors" (see Brown et al., 2014). For instance, it has been found that polyphenols (commonly referred as an "anti-nutritional factor") create insoluble high molecular complexes that limit the bioavailability of proteins and polysaccharides, but also show positive health benefits with their anti-oxidant (Vijayabaskar P & Shiyamala V 2012; Khairy & El-Sheikh 2015; Sathya et al. 2017), anti-inflammatory (Shibata et al., 2008) anti-proliferative (Nwosu et al. 2011) and potential anti-diabetic properties (Nwosu et al. 2011).

Some of the compounds present in seaweeds that reduce their digestibility can be found in lower concentrations than in common plant-source foods. For instance, phytic acid, a compound that cannot be absorbed by monogastric (including humans) and that binds to minerals (e.g. iron, zinc, calcium) making them unavailable (Gupta et al. 2015), was found in lower concentration in some seaweeds (0.45%) than in beans (1.45%), refined wheat (2% to 9.6 %), corn (0.77%) and soybean (1.5%) (Oliveira et al. 2009). Trypsin inhibitors, common in legumes (Avilés-Gaxiola et al. 2018) and also found in some seaweeds (Oliveira et al. 2009), inhibits the activity of the key pancreatic enzymes trypsin and chymotrypsin and therefore limit the digestion and absorption of dietary proteins (Gemede & Ratta 2014).

Many treatments have been used in plant-source foods to reduce trypsin inhibition below threshold limits (Avilés-Gaxiola et al. 2018; Gupta et al. 2015), including physical processes (e.g., heat, extrusion, ultrasound, soaking), chemical processes (reducing agents, chemical bases) and biological processes (e.g., fermentation). Even though, Oliveira et al. (2009) found that trypsin inhibitors from a mixture of seaweeds were not inactivated by heat processing, other treatments currently used for plant-source foods should be further explored.

In addition, it is important to consider that the presence and concentration of compounds that reduce the digestibility as well as the effect of the treatments to reduce them vary among the species. For instance, García-Casal et al. (2007) did not find phytic acid in four edible algae and reported them as a good sources of bioavailable iron, and Maehre et al., (2016) found in an *in-vitro* model that a heat treatment resulted in an 64%–96% increase in liberated amino acids in the red seaweed dulse (*Palmaria palmata*), but not in the brown seaweed winged kelp (*Alaria esculenta*).

Microalgae and cyanobacteria

So far, there is no publication documenting negative effects of compounds that reduce the utilization of nutrients from chlorella and spirulina. Again, the literature is mainly related to health applications of compounds present in these sources such as protease inhibitors (Ishihara et al. 2006), phycocyanobilin (McCarty 2007), carotenoids (Singh et al. 2005) and others (Fu et al. 2017; de Jesus Raposo et al. 2013).

Insects

Compounds that reduce digestibility such as phytic acid, tannin and oxalates have been reported for edible ants, termites, and moths, but in very small amounts, mostly lower than in many cereals and legumes (Chakravorty et al. 2016; Schlemmer et al. 2009; Omotoso 2006). Instead, insects have developed ways of dealing with the presence of these compounds in plants in order to increase the bioavailability of the nutrients contained in the plants (Klasing et al. 2000).

Moreover it has been found that chitin, a compound present in fungi, crustaceans and insects, is the main factor affecting the *in vitro* digestibility of insects (mealworms and black soldier fly) used as feed (Marono et al. 2015). However, substantial increases in protein digestibility (20%) have been achieved when chitin is removed (DeFoliart 1992). In addition, human gastric juice contains enzymes (chitinases) which can degrade chitin (Paoletti et al. 2007). These enzymes, however, are not present in all humans, as it was found to be absent in some Caucasian individuals and present with high activity in populations exposed to chitin-rich foods (Paoletti et al. 2007). Feeding behaviour has also been found to affect chitinase enzymes in farm and wild animals (Tabata et al. 2018; Strobel et al. 2013).

It should be also highlighted that chitin and its derivatives also have antitumor, antioxidant and antimicrobial activity (Younes et al. 2014).

Overall, we conclude that literature about the compounds that reduce digestibility (also called “anti-nutritional factors”) in future foods still needs further development and that these compounds can play a negative (reduced digestibility of some nutrients) as well as having a positive impact (improved health) on humans.

Supplementary References

Aubin, J. et al., 2018. Blue mussel (Mytilus edulis) bouchot culture in Mont-St Michel Bay: potential mitigation effects on climate change and eutrophication. *The International Journal of Life Cycle Assessment*, 23(5), pp.1030–1041.

Avilés-Gaxiola, S., Chuck-Hernández, C. & Serna Saldívar, S.O., 2018. Inactivation Methods of Trypsin Inhibitor in Legumes: A Review. *Journal of Food Science*, 83(1), pp.17–29.

Barker, D., Fitzpatrick, M.P. & Dierenfeld, E.S., 1998. Nutrient composition of selected whole invertebrates. *Zoo Biology*, 17(2), pp.123–134.

Bauer, A. et al., 2006. Occurrence of Vibrio parahaemolyticus, V. cholerae, and V. vulnificus in Norwegian Blue Mussels (Mytilus edulis). *Society*, 72(4), pp.3058–3061.

Bednářová, M. et al., 2013. Edible insects - species suitable for entomophagy under condition of Czech Republic. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 61(3), pp.587–593.

Brown, E.M. et al., 2014. Seaweed and human health. *Nutrition Reviews*, 72(3), pp.205–216.

Campbell, P.K., Beer, T. & Batten, D., 2011. Life cycle assessment of biodiesel production from microalgae in ponds. *Bioresource Technology*, 102(1), pp.50–56.

Chakravorty, J. et al., 2016. Nutritional and anti-nutritional composition of Oecophylla smaragdina (Hymenoptera: Formicidae) and Odontotermes sp. (Isoptera: Termitidae): Two preferred edible insects of Arunachal Pradesh, India. *Journal of Asia-Pacific Entomology*, 19(3), pp.711–720.

Cofrades, S. et al., 2016. Nutritional and Antioxidant Properties of Different Brown and Red Spanish Edible Seaweeds. *Food Sci Tech Int*, 16(5), pp.0361–10.

DeFoliart, G.R., 1992. Insects as human food: Gene DeFoliart discusses some nutritional and economic aspects. *Crop Protection*, 11(5), pp.395–399.

Draaisma, R.B. et al., 2013. Food commodities from microalgae. *Current Opinion in Biotechnology*, 24(2), pp.169–177.

EFSA, 2015. Risk profile related to production and consumption of insects as food and feed. European Food Safety Authority. *EFSA Journal*, 13(10), p.4257.

European Commission, 2015. Novel food catalogue. , p.1. Available at: http://ec.europa.eu/food/safety/novel_food/catalogue/search/public/index.cfm [Accessed April 4, 2018].

FAO, 2017. FAOSTAT. Available at: http://www.fao.org/faostat/ [Accessed July 1, 2018].

FAO, 1989. *Yield and nutritional value of the commercially more important fish species*, Food and Agriculture Organization of the United Nations.

Finnigan, T. et al., 2010. Mycoprotein, Life Cycle Analysis and the Food 2030 Challenge. *Aspects of Applied Biology*, 102, pp.81–90.

Finnigan, T., Needham, L. & Abbott, C., 2017. Mycoprotein: A Healthy New Protein with a

Low Environmental Impact. In *Sustainable Protein Sources*. Elsevier.

Fu, W. et al., 2017. Bioactive Compounds From Microalgae: Current Development and Prospects. *Studies in Natural Products Chemistry*, 54, pp.199–225.

García-Casal, M.N. et al., 2007. High iron content and bioavailability in humans from four species of marine algae. *The Journal of nutrition*, 137(12), pp.2691–5.

Garnett, T. et al., 2017. Grazed and confused. , p.127.

Gemede, H.F. & Ratta, N., 2014. Antinutritional Factors in Plant Foods: Potential Health Benefits and Adverse Effects. *International Journal of Nutrition and Food Sciences*, 3(4), pp.284–289.

Gupta, R.K., Gangoliya, S.S. & Singh, N.K., 2015. Reduction of phytic acid and enhancement of bioavailable micronutrients in food grains. *Journal of Food Science and Technology*, 52(2), pp.676–84.

Henriksson, P.J.G. et al., 2017. Indonesian aquaculture futures – Evaluating environmental and socioeconomic potentials and limitations. *Journal of Cleaner Production*, 162, pp.1482–1490.

Henriksson, P.J.G. et al., 2018. Measuring the potential for sustainable intensification of aquaculture in Bangladesh using life cycle assessment. *Proceedings of the National Academy of Sciences of the United States of America*, 115(12), pp.2958–2963.

Iribarren, D., Moreira, M.T. & Feijoo, G., 2010. Revisiting the Life Cycle Assessment of mussels from a sectorial perspective. *Journal of Cleaner Production*, 18(2), pp.101–111.

Ishihara, M. et al., 2006. Purification and characterization of extracellular cysteine protease inhibitor, ECPI-2, from Chlorella sp. *Journal of Bioscience and Bioengineering*, 101(2), pp.166–171.

de Jesus Raposo, M.F., de Morais, R.M.S.C. & de Morais, A.M.M.B., 2013. Health applications of bioactive compounds from marine microalgae. *Life Sciences*, 93(15), pp.479–486.

Joensuu, K. & Silvenius, F., 2017. Production of mealworms for human consumption in Finland: a preliminary life cycle assessment. *Journal of Insects as Food and Feed*, 3(3), pp.211–216.

Johnston, A.E., Poulton, P.R. & Coleman, K., 2009. Chapter 1 Soil Organic Matter: Its Importance in Sustainable Agriculture and Carbon Dioxide Fluxes. *Advances in Agronomy*, 101, pp.1–57.

Khairy, H.M. & El-Sheikh, M.A., 2015. Antioxidant activity and mineral composition of three Mediterranean common seaweeds from Abu-Qir Bay, Egypt. *Saudi Journal of Biological Sciences*, 22(5), pp.623–630.

Klasing, K.C. et al., 2000. Increasing the Calcium Content of Mealworms (Tenebrio molitor) to Improve Their Nutritional Value for Bone Mineralization of Growing Chicks. *Source: Journal of Zoo and Wildlife Medicine*, 31(4), pp.512–517.

Leip, A. et al., 2010. Evaluation of the livestock sector’s contribution to the EU greenhouse gas emissions (GGELS) - final report. , p.323.

Leip, A. et al., 2015. Impacts of European livestock production: nitrogen, sulphur, phosphorus and greenhouse gas emissions, land-use, water eutrophication and biodiversity. *Environmental Research Letters*, 10(11), p.115004.

Leip, A. et al., 2014. The nitrogen footprint of food products in the European Union. *The Journal of Agricultural Science*, 152(S1), pp.20–33.

Leu, S. & Boussiba, S., 2014. Advances in the Production of High-Value Products by Microalgae. *Industrial Biotechnology*, 10(3), pp.169–183.

Lhafi, S.K. & Kühneb, M., 2007. Occurrence of Vibrio spp. in blue mussels (Mytilus edulis) from the German Wadden Sea. *International Journal of Food Microbiology*, 116(2), pp.297–300.

Li, J. et al., 2018. Microplastics in mussels sampled from coastal waters and supermarkets in the United Kingdom. *Environmental Pollution*, 241, pp.35–44.

Lourguioui, H. et al., 2017. A perspective for reducing environmental impacts of mussel culture in Algeria. *Int J Life Cycle Assess* , 22, pp.1266–1277.

Maehre, H.K. et al., 2014. Characterization of protein, lipid and mineral contents in common Norwegian seaweeds and evaluation of their potential as food and feed. *Journal of the science of food and agriculture*, 94(15), pp.3281–90.

Maehre, H.K. et al., 2016. Heat treatment increases the protein bioaccessibility in the red seaweed dulse (Palmaria palmata), but not in the brown seaweed winged kelp (Alaria esculenta). *Journal of Applied Phycology*, 28(1), pp.581–590.

Marlow Foods, 2009. Nutritional profile of Quorn™ mycoprotein. , p.21. Available at: http://www.mycoprotein.org/assets/nutritional_profile_of_quorn.pdf [Accessed March 7, 2017].

Marono, S. et al., 2015. Crude Protein Digestibility of Tenebrio Molitor and Hermetia Illucens Insect Meals and its Correlation with Chemical Composition Traits. *Italian Journal of Animal Science*, 14(3), p.3889.

Mattick, C.S. et al., 2015. Anticipatory Life Cycle Analysis of In Vitro Biomass Cultivation for Cultured Meat Production in the United States. *Environmental Science & Technology*, 49(19), pp.11941–11949.

Mayers, J.J. et al., 2016. Integrating Microalgal Production with Industrial Outputs—Reducing Process Inputs and Quantifying the Benefits. *Industrial Biotechnology*, 12(4), pp.219–234.

McCarty, M.F., 2007. Clinical Potential of *Spirulina* as a Source of Phycocyanobilin. *Journal of Medicinal Food*, 10(4), pp.566–570.

Murugan, A.C. et al., 2015. New insights into seaweed polyphenols on glucose homeostasis. *Pharmaceutical Biology*, 53(8), pp.1087–1097.

Nwosu, F. et al., 2011. Anti-proliferative and potential anti-diabetic effects of phenolic-rich extracts from edible marine algae. *Food Chemistry*, 126(3), pp.1006–1012.

Van Oirschot, R. et al., 2017. Explorative environmental life cycle assessment for system design of seaweed cultivation and drying. *Algal Research*, 27, pp.43–54.

Oliveira, M.N. de et al., 2009. Nutritive and non-nutritive attributes of washed-up seaweeds from the coast of Ceará, Brazil. *Food Chemistry*, 115(1), pp.254–259.

Omotoso, O.T., 2006. Nutritional quality, functional properties and anti-nutrient compositions of the larva of Cirina forda (Westwood) (Lepidoptera: Saturniidae). *Journal of Zhejiang University. Science. B*, 7(1), pp.51–5.

Oonincx, D.G.A.B. & De Boer, I.J.M., 2012. Environmental Impact of the Production of Mealworms as a Protein Source for Humans - A Life Cycle Assessment. *PLoS ONE*, 7(12), p.e51145.

Paoletti, M.G. et al., 2007. Human Gastric Juice Contains Chitinase That Can Degrade Chitin. *Annals of Nutrition and Metabolism*, 51(3), pp.244–251.

Parker, R.W.R. et al., 2018. Fuel use and greenhouse gas emissions of world fisheries. *Nature Climate Change*, 8(4), pp.333–337.

Parker, R.W.R., Azquez-Rowe, I. V & Tyedmers, P.H., 2015. Fuel performance and carbon footprint of the global purse seine tuna fleet. *Journal of Cleaner Production*, 103, pp.517–524.

Parker, R.W.R. & Tyedmers, P.H., 2015. Fuel consumption of global fishing fleets: Current understanding and knowledge gaps. *Fish and Fisheries*, 16(4), pp.684–696.

Pate, F.M. et al., 2002. Sugarcane as a Cattle Feed : Production and Utilization. *Florida Sugarcane Handbook*, pp.1–21.

Pechsiri, J.S. et al., 2016. Energy performance and greenhouse gas emissions of kelp cultivation for biogas and fertilizer recovery in Sweden. *Science of The Total Environment*, 573, pp.347–355.

Pelletier, N. & Tyedmers, P., 2010. Life Cycle Assessment of Frozen Tilapia Fillets From Indonesian Lake-Based and Pond-Based Intensive Aquaculture Systems. *Journal of Industrial Ecology*, 14(3), pp.467–481.

Post, M.J., 2018. Proteins in cultured beef. *Proteins in Food Processing*, pp.289–298.

Rozendaal, J. a., 2011. Houseflies. *Vector control: Methods for use by individuals and communities*, pp.6–9.

Salomone, R. et al., 2017. Environmental impact of food waste bioconversion by insects: Application of Life Cycle Assessment to process using Hermetia illucens. *Journal of Cleaner Production*, 140, pp.890–905.

Sánchez-Muros, M. et al., 2016. Nutritional evaluation of Tenebrio molitor meal as fishmeal substitute for tilapia (Oreochromis niloticus) diet. *Aquaculture Nutrition*, 22(5), pp.943–955.

SARF, 2010. *Carbon Footprint Of Scottish Suspended Mussels And Intertidal Oystersn Footprint Of Scottish Suspended Mussels And Intertidal Oysters*,

Sathya, R. et al., 2017. Antioxidant properties of phlorotannins from brown seaweed

Cystoseira trinodis (Forsskål) C. Agardh. *Arabian Journal of Chemistry*, 10, pp.S2608–S2614.

Schlemmer, U. et al., 2009. Phytate in foods and significance for humans: Food sources, intake, processing, bioavailability, protective role and analysis. *Molecular Nutrition & Food Research*, 53(S2), pp.S330–S375.

Shibata, T. et al., 2008. Antioxidant activities of phlorotannins isolated from Japanese Laminariaceae. *Journal of Applied Phycology*, 20(5), pp.705–711.

Sills, D.L. et al., 2013. Quantitative Uncertainty Analysis of Life Cycle Assessment for Algal Biofuel Production. *Environmental Science & Technology*, 47(2), pp.687–694.

Singh, S., Kate, B.N. & Banerjee, U.C., 2005. Bioactive Compounds from Cyanobacteria and Microalgae: An Overview. *Critical Reviews in Biotechnology*, 25(3), pp.73–95.

Slegers, P.M. et al., 2014. A model-based combinatorial optimisation approach for energy-efficient processing of microalgae. *Algal Research*, 5, pp.140–157.

Smetana, S. et al., 2017. Autotrophic and heterotrophic microalgae and cyanobacteria cultivation for food and feed: life cycle assessment. *Bioresource Technology*, 245, pp.162–170.

Smetana, S. et al., 2016. Sustainability of insect use for feed and food: Life Cycle Assessment perspective. *Journal of Cleaner Production*, 137, pp.741–751.

Smith, P., 2014. Do grasslands act as a perpetual sink for carbon? *Global Change Biology*, 20(9), pp.2708–2711.

Van der Spiegel, M., Noordam, M.Y. & Van der Fels-Klerx, H.J., 2013. Safety of novel protein sources (insects, microalgae, seaweed, duckweed, and rapeseed) and legislative aspects for their application in food and feed production. *Comprehensive Reviews in Food Science and Food Safety*, 12(6), pp.662–678.

Strobel, S. et al., 2013. Insectivorous Bats Digest Chitin in the Stomach Using Acidic Mammalian Chitinase F. Blachier, ed. *PLoS ONE*, 8(9), p.e72770.

Tabata, E. et al., 2018. Chitin digestibility is dependent on feeding behaviors, which determine acidic chitinase mRNA levels in mammalian and poultry stomachs. *Scientific Reports*, 8(1), p.1461.

Tang, G. & Suter, P.M., 2011. Vitamin A, Nutrition, and Health Values of Algae: Spirulina, Chlorella and Dunaliella. *Journal of Pharmacy and Nutrition Sciences*, 1(2), pp.111–118.

Thangaraj, P., 2016. Anti-nutritional Factors. In P. in D. Research, ed. *Pharmacological Assays of Plant-Based Natural Products*. Springer, pp. 43–47.

Thévenot, A. et al., 2018. Mealworm meal for animal feed: Environmental assessment and sensitivity analysis to guide future prospects. *Journal of Cleaner Production*, 170, pp.1260–1267.

Tokuşoglu, O. & ÜUnal, M.K., 2003. Biomass Nutrient Profiles of Three Microalgae: Spirulina platensis, Chlorella vulgaris, and Isochrisis galbana. *Journal of Food Science*, 68(4), pp.1144–1148.

Tuomisto, H.L., Ellis, M.J. & Haastrup, P., 2014. *Environmental impacts of cultured meat : alternative production scenarios* D. Schenck, R., Huizenga, ed., San Francisco.

Tuomisto, H.L. & Texteira de Mattos, M., 2011. Environmental Impacts of Cultured Meat Production. *Environ. Sci. Technol*, 45, pp.6117–6123.

USDA, 2017. USDA Food Composition Databases. Available at: https://ndb.nal.usda.gov/ndb/ [Accessed February 4, 2017].

Vigani, M. et al., 2015. Food and feed products from micro-algae: Market opportunities and challenges for the EU. *Trends in Food Science & Technology*, 42(1), pp.81–92.

Vijayabaskar, P. & Shiyamala, V., 2012. Antioxidant properties of seaweed polyphenol from Turbinaria ornata (Turner) J. Agardh, 1848. *Asian Pacific Journal of Tropical Biomedicine*, 2(1), pp.S90–S98.

Vijayabaskar P & Shiyamala V, 2012. Antioxidant properties of seaweed polyphenol from Turbinaria ornata (Turner) J. Agardh, 1848 Asian Pacific Journal of Tropical Biomedicine. *Asian Pacific Journal of Tropical Biomedicine*, pp.90–98.

Weiss, F. & Leip, A., 2012. Greenhouse gas emissions from the EU livestock sector: A life cycle assessment carried out with the CAPRI model. *Agriculture, Ecosystems & Environment*, 149, pp.124–134.

Wells, M.L. et al., 2016. Algae as nutritional and functional food sources: revisiting our understanding. *Journal of Applied Phycology*, 29(2), pp.949–982.

Wernet, G. et al., 2016. The ecoinvent database version 3 (part I): overview and methodology. *The International Journal of Life Cycle Assessment*, 21(9), pp.1218–1230.

Winther, U. et al., 2009. *Carbon footprint and energy use of Norwegian seafood products*,

Yeh, T.S., Hung, N.H. & Lin, T.C., 2014. Analysis of iodine content in seaweed by GC-ECD and estimation of iodine intake. *Journal of Food and Drug Analysis*, 22, pp.189–196.

Yi, L. et al., 2013. Extraction and characterisation of protein fractions from five insect species. *Food Chemistry*, 141(4), pp.3341–3348.

Younes, I. et al., 2014. Chitin extraction from shrimp shell using enzymatic treatment. Antitumor, antioxidant and antimicrobial activities of chitosan. *International Journal of Biological Macromolecules*, 69, pp.489–498.

Van Zanten, H.H.E. et al., 2014. From environmental nuisance to environmental opportunity: Housefly larvae convert waste to livestock feed. *Journal of Cleaner Production*, 102, pp.362–369.

Ziegler, F. et al., 2016. Expanding the concept of sustainable seafood using Life Cycle Assessment. *Fish and Fisheries*, 17(4), pp.1073–1093.

References – Supplementary Table **1**

Aubin, J. et al., 2018. Blue mussel (Mytilus edulis) bouchot culture in Mont-St Michel Bay: potential mitigation effects on climate change and eutrophication. *The International Journal of Life Cycle Assessment*, 23(5), pp.1030–1041.

Avilés-Gaxiola, S., Chuck-Hernández, C. & Serna Saldívar, S.O., 2018. Inactivation Methods of Trypsin Inhibitor in Legumes: A Review. *Journal of Food Science*, 83(1), pp.17–29.

Barker, D., Fitzpatrick, M.P. & Dierenfeld, E.S., 1998. Nutrient composition of selected whole invertebrates. *Zoo Biology*, 17(2), pp.123–134.

Bauer, A. et al., 2006. Occurrence of Vibrio parahaemolyticus, V. cholerae, and V. vulnificus in Norwegian Blue Mussels (Mytilus edulis). *Society*, 72(4), pp.3058–3061.

Bednářová, M. et al., 2013. Edible insects - species suitable for entomophagy under condition of Czech Republic. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 61(3), pp.587–593.

Brown, E.M. et al., 2014. Seaweed and human health. *Nutrition Reviews*, 72(3), pp.205–216.

Campbell, P.K., Beer, T. & Batten, D., 2011. Life cycle assessment of biodiesel production from microalgae in ponds. *Bioresource Technology*, 102(1), pp.50–56.

Chakravorty, J. et al., 2016. Nutritional and anti-nutritional composition of Oecophylla smaragdina (Hymenoptera: Formicidae) and Odontotermes sp. (Isoptera: Termitidae): Two preferred edible insects of Arunachal Pradesh, India. *Journal of Asia-Pacific Entomology*, 19(3), pp.711–720.

Cofrades, S. et al., 2016. Nutritional and Antioxidant Properties of Different Brown and Red Spanish Edible Seaweeds. *Food Sci Tech Int*, 16(5), pp.0361–10.

DeFoliart, G.R., 1992. Insects as human food: Gene DeFoliart discusses some nutritional and economic aspects. *Crop Protection*, 11(5), pp.395–399.

Draaisma, R.B. et al., 2013. Food commodities from microalgae. *Current Opinion in Biotechnology*, 24(2), pp.169–177.

EFSA, 2015. Risk profile related to production and consumption of insects as food and feed. European Food Safety Authority. *EFSA Journal*, 13(10), p.4257.

European Commission, 2015. Novel food catalogue. , p.1. Available at: http://ec.europa.eu/food/safety/novel_food/catalogue/search/public/index.cfm [Accessed April 4, 2018].

FAO, 2017. FAOSTAT. Available at: http://www.fao.org/faostat/ [Accessed July 1, 2018].

FAO, 1989. *Yield and nutritional value of the commercially more important fish species*, Food and Agriculture Organization of the United Nations.

Finnigan, T. et al., 2010. Mycoprotein, Life Cycle Analysis and the Food 2030 Challenge. *Aspects of Applied Biology*, 102, pp.81–90.

Finnigan, T., Needham, L. & Abbott, C., 2017. Mycoprotein: A Healthy New Protein with a Low Environmental Impact. In *Sustainable Protein Sources*. Elsevier.

Fu, W. et al., 2017. Bioactive Compounds From Microalgae: Current Development and

Prospects. *Studies in Natural Products Chemistry*, 54, pp.199–225.

García-Casal, M.N. et al., 2007. High iron content and bioavailability in humans from four species of marine algae. *The Journal of nutrition*, 137(12), pp.2691–5.

Garnett, T. et al., 2017. Grazed and confused. , p.127.

Gemede, H.F. & Ratta, N., 2014. Antinutritional Factors in Plant Foods: Potential Health Benefits and Adverse Effects. *International Journal of Nutrition and Food Sciences*, 3(4), pp.284–289.

Gupta, R.K., Gangoliya, S.S. & Singh, N.K., 2015. Reduction of phytic acid and enhancement of bioavailable micronutrients in food grains. *Journal of Food Science and Technology*, 52(2), pp.676–84.

Henriksson, P.J.G. et al., 2017. Indonesian aquaculture futures – Evaluating environmental and socioeconomic potentials and limitations. *Journal of Cleaner Production*, 162, pp.1482–1490.

Henriksson, P.J.G. et al., 2018. Measuring the potential for sustainable intensification of aquaculture in Bangladesh using life cycle assessment. *Proceedings of the National Academy of Sciences of the United States of America*, 115(12), pp.2958–2963.

Iribarren, D., Moreira, M.T. & Feijoo, G., 2010. Revisiting the Life Cycle Assessment of mussels from a sectorial perspective. *Journal of Cleaner Production*, 18(2), pp.101–111.

Ishihara, M. et al., 2006. Purification and characterization of extracellular cysteine protease inhibitor, ECPI-2, from Chlorella sp. *Journal of Bioscience and Bioengineering*, 101(2), pp.166–171.

de Jesus Raposo, M.F., de Morais, R.M.S.C. & de Morais, A.M.M.B., 2013. Health applications of bioactive compounds from marine microalgae. *Life Sciences*, 93(15), pp.479–486.

Joensuu, K. & Silvenius, F., 2017. Production of mealworms for human consumption in Finland: a preliminary life cycle assessment. *Journal of Insects as Food and Feed*, 3(3), pp.211–216.

Johnston, A.E., Poulton, P.R. & Coleman, K., 2009. Chapter 1 Soil Organic Matter: Its Importance in Sustainable Agriculture and Carbon Dioxide Fluxes. *Advances in Agronomy*, 101, pp.1–57.

Khairy, H.M. & El-Sheikh, M.A., 2015. Antioxidant activity and mineral composition of three Mediterranean common seaweeds from Abu-Qir Bay, Egypt. *Saudi Journal of Biological Sciences*, 22(5), pp.623–630.

Klasing, K.C. et al., 2000. Increasing the Calcium Content of Mealworms (Tenebrio molitor) to Improve Their Nutritional Value for Bone Mineralization of Growing Chicks. *Source: Journal of Zoo and Wildlife Medicine*, 31(4), pp.512–517.

Leip, A. et al., 2010. Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions (GGELS) - final report. , p.323.

Leip, A. et al., 2015. Impacts of European livestock production: nitrogen, sulphur, phosphorus and greenhouse gas emissions, land-use, water eutrophication and biodiversity. *Environmental Research Letters*, 10(11), p.115004.

Leip, A. et al., 2014. The nitrogen footprint of food products in the European Union. *The Journal of Agricultural Science*, 152(S1), pp.20–33.

Leu, S. & Boussiba, S., 2014. Advances in the Production of High-Value Products by Microalgae. *Industrial Biotechnology*, 10(3), pp.169–183.

Lhafi, S.K. & Kühneb, M., 2007. Occurrence of Vibrio spp. in blue mussels (Mytilus edulis) from the German Wadden Sea. *International Journal of Food Microbiology*, 116(2), pp.297–300.

Li, J. et al., 2018. Microplastics in mussels sampled from coastal waters and supermarkets in the United Kingdom. *Environmental Pollution*, 241, pp.35–44.

Lourguioui, H. et al., 2017. A perspective for reducing environmental impacts of mussel culture in Algeria. *Int J Life Cycle Assess* , 22, pp.1266–1277.

Maehre, H.K. et al., 2014. Characterization of protein, lipid and mineral contents in common Norwegian seaweeds and evaluation of their potential as food and feed. *Journal of the science of food and agriculture*, 94(15), pp.3281–90.

Maehre, H.K. et al., 2016. Heat treatment increases the protein bioaccessibility in the red seaweed dulse (Palmaria palmata), but not in the brown seaweed winged kelp (Alaria esculenta). *Journal of Applied Phycology*, 28(1), pp.581–590.

Marlow Foods, 2009. Nutritional profile of Quorn^{TM} mycoprotein. , p.21. Available at: http://www.mycoprotein.org/assets/nutritional_profile_of_quorn.pdf [Accessed March 7, 2017].

Marono, S. et al., 2015. Crude Protein Digestibility of Tenebrio Molitor and Hermetia Illucens Insect Meals and its Correlation with Chemical Composition Traits. *Italian Journal of Animal Science*, 14(3), p.3889.

Mattick, C.S. et al., 2015. Anticipatory Life Cycle Analysis of In Vitro Biomass Cultivation for Cultured Meat Production in the United States. *Environmental Science & Technology*, 49(19), pp.11941–11949.

Mayers, J.J. et al., 2016. Integrating Microalgal Production with Industrial Outputs—Reducing Process Inputs and Quantifying the Benefits. *Industrial Biotechnology*, 12(4), pp.219–234.

McCarty, M.F., 2007. Clinical Potential of *Spirulina* as a Source of Phycocyanobilin. *Journal of Medicinal Food*, 10(4), pp.566–570.

Murugan, A.C. et al., 2015. New insights into seaweed polyphenols on glucose homeostasis. *Pharmaceutical Biology*, 53(8), pp.1087–1097.

Nwosu, F. et al., 2011. Anti-proliferative and potential anti-diabetic effects of phenolic-rich extracts from edible marine algae. *Food Chemistry*, 126(3), pp.1006–1012.

Van Oirschot, R. et al., 2017. Explorative environmental life cycle assessment for system design of seaweed cultivation and drying. *Algal Research*, 27, pp.43–54.

Oliveira, M.N. de et al., 2009. Nutritive and non-nutritive attributes of washed-up seaweeds from the coast of Ceará, Brazil. *Food Chemistry*, 115(1), pp.254–259.

Omotoso, O.T., 2006. Nutritional quality, functional properties and anti-nutrient compositions of the larva of Cirina forda (Westwood) (Lepidoptera: Saturniidae). *Journal of Zhejiang University. Science. B*, 7(1), pp.51–5.

Oonincx, D.G.A.B. & De Boer, I.J.M., 2012. Environmental Impact of the Production of Mealworms as a Protein Source for Humans - A Life Cycle Assessment. *PLoS ONE*, 7(12), p.e51145.

Paoletti, M.G. et al., 2007. Human Gastric Juice Contains Chitinase That Can Degrade Chitin. *Annals of Nutrition and Metabolism*, 51(3), pp.244–251.

Parker, R.W.R. et al., 2018. Fuel use and greenhouse gas emissions of world fisheries. *Nature Climate Change*, 8(4), pp.333–337.

Parker, R.W.R., Azquez-Rowe, I. V & Tyedmers, P.H., 2015. Fuel performance and carbon footprint of the global purse seine tuna fleet. *Journal of Cleaner Production*, 103, pp.517–524.

Parker, R.W.R. & Tyedmers, P.H., 2015. Fuel consumption of global fishing fleets: Current understanding and knowledge gaps. *Fish and Fisheries*, 16(4), pp.684–696.

Pate, F.M. et al., 2002. Sugarcane as a Cattle Feed : Production and Utilization. *Florida Sugarcane Handbook*, pp.1–21.

Pechsiri, J.S. et al., 2016. Energy performance and greenhouse gas emissions of kelp cultivation for biogas and fertilizer recovery in Sweden. *Science of The Total Environment*, 573, pp.347–355.

Pelletier, N. & Tyedmers, P., 2010. Life Cycle Assessment of Frozen Tilapia Fillets From Indonesian Lake-Based and Pond-Based Intensive Aquaculture Systems. *Journal of Industrial Ecology*, 14(3), pp.467–481.

Post, M.J., 2018. Proteins in cultured beef. *Proteins in Food Processing*, pp.289–298.

Rozendaal, J. a., 2011. Houseflies. *Vector control: Methods for use by individuals and communities*, pp.6–9.

Salomone, R. et al., 2017. Environmental impact of food waste bioconversion by insects: Application of Life Cycle Assessment to process using Hermetia illucens. *Journal of Cleaner Production*, 140, pp.890–905.

Sánchez-Muros, M. et al., 2016. Nutritional evaluation of Tenebrio molitor meal as fishmeal substitute for tilapia (Oreochromis niloticus) diet. *Aquaculture Nutrition*, 22(5), pp.943–955.

SARF, 2010. *Carbon Footprint Of Scottish Suspended Mussels And Intertidal Oystersn Footprint Of Scottish Suspended Mussels And Intertidal Oysters*,

Sathya, R. et al., 2017. Antioxidant properties of phlorotannins from brown seaweed Cystoseira trinodis (Forsskål) C. Agardh. *Arabian Journal of Chemistry*, 10, pp.S2608–S2614.

Schlemmer, U. et al., 2009. Phytate in foods and significance for humans: Food sources, intake, processing, bioavailability, protective role and analysis. *Molecular Nutrition & Food Research*, 53(S2), pp.S330–S375.

Shibata, T. et al., 2008. Antioxidant activities of phlorotannins isolated from Japanese Laminariaceae. *Journal of Applied Phycology*, 20(5), pp.705–711.

Sills, D.L. et al., 2013. Quantitative Uncertainty Analysis of Life Cycle Assessment for Algal Biofuel Production. *Environmental Science & Technology*, 47(2), pp.687–694.

Singh, S., Kate, B.N. & Banerjee, U.C., 2005. Bioactive Compounds from Cyanobacteria and Microalgae: An Overview. *Critical Reviews in Biotechnology*, 25(3), pp.73–95.

Slegers, P.M. et al., 2014. A model-based combinatorial optimisation approach for energy-efficient processing of microalgae. *Algal Research*, 5, pp.140–157.

Smetana, S. et al., 2017. Autotrophic and heterotrophic microalgae and cyanobacteria cultivation for food and feed: life cycle assessment. *Bioresource Technology*, 245, pp.162–170.

Smetana, S. et al., 2016. Sustainability of insect use for feed and food: Life Cycle Assessment perspective. *Journal of Cleaner Production*, 137, pp.741–751.

Smith, P., 2014. Do grasslands act as a perpetual sink for carbon? *Global Change Biology*, 20(9), pp.2708–2711.

Van der Spiegel, M., Noordam, M.Y. & Van der Fels-Klerx, H.J., 2013. Safety of novel protein sources (insects, microalgae, seaweed, duckweed, and rapeseed) and legislative aspects for their application in food and feed production. *Comprehensive Reviews in Food Science and Food Safety*, 12(6), pp.662–678.

Strobel, S. et al., 2013. Insectivorous Bats Digest Chitin in the Stomach Using Acidic Mammalian Chitinase F. Blachier, ed. *PLoS ONE*, 8(9), p.e72770.

Tabata, E. et al., 2018. Chitin digestibility is dependent on feeding behaviors, which determine acidic chitinase mRNA levels in mammalian and poultry stomachs. *Scientific Reports*, 8(1), p.1461.

Tang, G. & Suter, P.M., 2011. Vitamin A, Nutrition, and Health Values of Algae: Spirulina, Chlorella and Dunaliella. *Journal of Pharmacy and Nutrition Sciences*, 1(2), pp.111–118.

Thangaraj, P., 2016. Anti-nutritional Factors. In P. in D. Research, ed. *Pharmacological Assays of Plant-Based Natural Products*. Springer, pp. 43–47.

Thévenot, A. et al., 2018. Mealworm meal for animal feed: Environmental assessment and sensitivity analysis to guide future prospects. *Journal of Cleaner Production*, 170, pp.1260–1267.

Tokuşoglu, O. & ÜUnal, M.K., 2003. Biomass Nutrient Profiles of Three Microalgae: Spirulina platensis, Chlorella vulgaris, and Isochrisis galbana. *Journal of Food Science*, 68(4), pp.1144–1148.

Tuomisto, H.L., Ellis, M.J. & Haastrup, P., 2014. *Environmental impacts of cultured meat :*

alternative production scenarios D. Schenck, R., Huizenga, ed., San Francisco.

Tuomisto, H.L. & Texteira de Mattos, M., 2011. Environmental Impacts of Cultured Meat Production. *Environ. Sci. Technol*, 45, pp.6117–6123.

USDA, 2017. USDA Food Composition Databases. Available at: https://ndb.nal.usda.gov/ndb/ [Accessed February 4, 2017].

Vigani, M. et al., 2015. Food and feed products from micro-algae: Market opportunities and challenges for the EU. *Trends in Food Science & Technology*, 42(1), pp.81–92.

Vijayabaskar, P. & Shiyamala, V., 2012. Antioxidant properties of seaweed polyphenol from Turbinaria ornata (Turner) J. Agardh, 1848. *Asian Pacific Journal of Tropical Biomedicine*, 2(1), pp.S90–S98.

Vijayabaskar P & Shiyamala V, 2012. Antioxidant properties of seaweed polyphenol from Turbinaria ornata (Turner) J. Agardh, 1848 Asian Pacific Journal of Tropical Biomedicine. *Asian Pacific Journal of Tropical Biomedicine*, pp.90–98.

Weiss, F. & Leip, A., 2012. Greenhouse gas emissions from the EU livestock sector: A life cycle assessment carried out with the CAPRI model. *Agriculture, Ecosystems & Environment*, 149, pp.124–134.

Wells, M.L. et al., 2016. Algae as nutritional and functional food sources: revisiting our understanding. *Journal of Applied Phycology*, 29(2), pp.949–982.

Wernet, G. et al., 2016. The ecoinvent database version 3 (part I): overview and methodology. *The International Journal of Life Cycle Assessment*, 21(9), pp.1218–1230.

Winther, U. et al., 2009. *Carbon footprint and energy use of Norwegian seafood products*,

Yeh, T.S., Hung, N.H. & Lin, T.C., 2014. Analysis of iodine content in seaweed by GC-ECD and estimation of iodine intake. *Journal of Food and Drug Analysis*, 22, pp.189–196.

Yi, L. et al., 2013. Extraction and characterisation of protein fractions from five insect species. *Food Chemistry*, 141(4), pp.3341–3348.

Younes, I. et al., 2014. Chitin extraction from shrimp shell using enzymatic treatment. Antitumor, antioxidant and antimicrobial activities of chitosan. *International Journal of Biological Macromolecules*, 69, pp.489–498.

Van Zanten, H.H.E. et al., 2014. From environmental nuisance to environmental opportunity: Housefly larvae convert waste to livestock feed. *Journal of Cleaner Production*, 102, pp.362–369.

Ziegler, F. et al., 2016. Expanding the concept of sustainable seafood using Life Cycle Assessment. *Fish and Fisheries*, 17(4), pp.1073–1093.

References – Supplementary Table **3**

Aubin, J. et al., 2018. Blue mussel (Mytilus edulis) bouchot culture in Mont-St Michel Bay: potential mitigation effects on climate change and eutrophication. *The International Journal of Life Cycle Assessment*, 23(5), pp.1030–1041.

Avilés-Gaxiola, S., Chuck-Hernández, C. & Serna Saldívar, S.O., 2018. Inactivation Methods of Trypsin Inhibitor in Legumes: A Review. *Journal of Food Science*, 83(1), pp.17–29.

Barker, D., Fitzpatrick, M.P. & Dierenfeld, E.S., 1998. Nutrient composition of selected whole invertebrates. *Zoo Biology*, 17(2), pp.123–134.

Bauer, A. et al., 2006. Occurrence of Vibrio parahaemolyticus, V. cholerae, and V. vulnificus in Norwegian Blue Mussels (Mytilus edulis). *Society*, 72(4), pp.3058–3061.

Bednářová, M. et al., 2013. Edible insects - species suitable for entomophagy under condition of Czech Republic. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 61(3), pp.587–593.

Brown, E.M. et al., 2014. Seaweed and human health. *Nutrition Reviews*, 72(3), pp.205–216.

Campbell, P.K., Beer, T. & Batten, D., 2011. Life cycle assessment of biodiesel production from microalgae in ponds. *Bioresource Technology*, 102(1), pp.50–56.

Chakravorty, J. et al., 2016. Nutritional and anti-nutritional composition of Oecophylla smaragdina (Hymenoptera: Formicidae) and Odontotermes sp. (Isoptera: Termitidae): Two preferred edible insects of Arunachal Pradesh, India. *Journal of Asia-Pacific Entomology*, 19(3), pp.711–720.

Cofrades, S. et al., 2016. Nutritional and Antioxidant Properties of Different Brown and Red Spanish Edible Seaweeds. *Food Sci Tech Int*, 16(5), pp.0361–10.

DeFoliart, G.R., 1992. Insects as human food: Gene DeFoliart discusses some nutritional and economic aspects. *Crop Protection*, 11(5), pp.395–399.

Draaisma, R.B. et al., 2013. Food commodities from microalgae. *Current Opinion in Biotechnology*, 24(2), pp.169–177.

EFSA, 2015. Risk profile related to production and consumption of insects as food and feed. European Food Safety Authority. *EFSA Journal*, 13(10), p.4257.

European Commission, 2015. Novel food catalogue. , p.1. Available at: http://ec.europa.eu/food/safety/novel_food/catalogue/search/public/index.cfm [Accessed April 4, 2018].

FAO, 2017. FAOSTAT. Available at: http://www.fao.org/faostat/ [Accessed July 1, 2018].

FAO, 1989. *Yield and nutritional value of the commercially more important fish species*, Food and Agriculture Organization of the United Nations.

Finnigan, T. et al., 2010. Mycoprotein, Life Cycle Analysis and the Food 2030 Challenge. *Aspects of Applied Biology*, 102, pp.81–90.

Finnigan, T., Needham, L. & Abbott, C., 2017. Mycoprotein: A Healthy New Protein with a Low Environmental Impact. In *Sustainable Protein Sources*. Elsevier.

Fu, W. et al., 2017. Bioactive Compounds From Microalgae: Current Development and Prospects. *Studies in Natural Products Chemistry*, 54, pp.199–225.

García-Casal, M.N. et al., 2007. High iron content and bioavailability in humans from four species of marine algae. *The Journal of nutrition*, 137(12), pp.2691–5.

Garnett, T. et al., 2017. Grazed and confused. , p.127.

Gemede, H.F. & Ratta, N., 2014. Antinutritional Factors in Plant Foods: Potential Health Benefits and Adverse Effects. *International Journal of Nutrition and Food Sciences*, 3(4), pp.284–289.

Gupta, R.K., Gangoliya, S.S. & Singh, N.K., 2015. Reduction of phytic acid and enhancement of bioavailable micronutrients in food grains. *Journal of Food Science and Technology*, 52(2), pp.676–84.

Henriksson, P.J.G. et al., 2017. Indonesian aquaculture futures – Evaluating environmental and socioeconomic potentials and limitations. *Journal of Cleaner Production*, 162, pp.1482–1490.

Henriksson, P.J.G. et al., 2018. Measuring the potential for sustainable intensification of aquaculture in Bangladesh using life cycle assessment. *Proceedings of the National Academy of Sciences of the United States of America*, 115(12), pp.2958–2963.

Iribarren, D., Moreira, M.T. & Feijoo, G., 2010. Revisiting the Life Cycle Assessment of mussels from a sectorial perspective. *Journal of Cleaner Production*, 18(2), pp.101–111.

Ishihara, M. et al., 2006. Purification and characterization of extracellular cysteine protease inhibitor, ECPI-2, from Chlorella sp. *Journal of Bioscience and Bioengineering*, 101(2), pp.166–171.

de Jesus Raposo, M.F., de Morais, R.M.S.C. & de Morais, A.M.M.B., 2013. Health applications of bioactive compounds from marine microalgae. *Life Sciences*, 93(15), pp.479–486.

Joensuu, K. & Silvenius, F., 2017. Production of mealworms for human consumption in Finland: a preliminary life cycle assessment. *Journal of Insects as Food and Feed*, 3(3), pp.211–216.

Johnston, A.E., Poulton, P.R. & Coleman, K., 2009. Chapter 1 Soil Organic Matter: Its Importance in Sustainable Agriculture and Carbon Dioxide Fluxes. *Advances in Agronomy*, 101, pp.1–57.

Khairy, H.M. & El-Sheikh, M.A., 2015. Antioxidant activity and mineral composition of three Mediterranean common seaweeds from Abu-Qir Bay, Egypt. *Saudi Journal of Biological Sciences*, 22(5), pp.623–630.

Klasing, K.C. et al., 2000. Increasing the Calcium Content of Mealworms (Tenebrio molitor) to Improve Their Nutritional Value for Bone Mineralization of Growing Chicks. *Source: Journal of Zoo and Wildlife Medicine*, 31(4), pp.512–517.

Leip, A. et al., 2010. Evaluation of the livestock sector’s contribution to the EU greenhouse gas emissions (GGELS) - final report. , p.323.

Leip, A. et al., 2015. Impacts of European livestock production: nitrogen, sulphur, phosphorus and greenhouse gas emissions, land-use, water eutrophication and biodiversity. *Environmental Research Letters*, 10(11), p.115004.

Leip, A. et al., 2014. The nitrogen footprint of food products in the European Union. *The Journal of Agricultural Science*, 152(S1), pp.20–33.

Leu, S. & Boussiba, S., 2014. Advances in the Production of High-Value Products by Microalgae. *Industrial Biotechnology*, 10(3), pp.169–183.

Lhafi, S.K. & Kühneb, M., 2007. Occurrence of Vibrio spp. in blue mussels (Mytilus edulis) from the German Wadden Sea. *International Journal of Food Microbiology*, 116(2), pp.297–300.

Li, J. et al., 2018. Microplastics in mussels sampled from coastal waters and supermarkets in the United Kingdom. *Environmental Pollution*, 241, pp.35–44.

Lourguioui, H. et al., 2017. A perspective for reducing environmental impacts of mussel culture in Algeria. *Int J Life Cycle Assess* , 22, pp.1266–1277.

Maehre, H.K. et al., 2014. Characterization of protein, lipid and mineral contents in common Norwegian seaweeds and evaluation of their potential as food and feed. *Journal of the science of food and agriculture*, 94(15), pp.3281–90.

Maehre, H.K. et al., 2016. Heat treatment increases the protein bioaccessibility in the red seaweed dulse (Palmaria palmata), but not in the brown seaweed winged kelp (Alaria esculenta). *Journal of Applied Phycology*, 28(1), pp.581–590.

Marlow Foods, 2009. Nutritional profile of Quorn^{TM} mycoprotein. , p.21. Available at: http://www.mycoprotein.org/assets/nutritional_profile_of_quorn.pdf [Accessed March 7, 2017].

Marono, S. et al., 2015. Crude Protein Digestibility of Tenebrio Molitor and Hermetia Illucens Insect Meals and its Correlation with Chemical Composition Traits. *Italian Journal of Animal Science*, 14(3), p.3889.

Mattick, C.S. et al., 2015. Anticipatory Life Cycle Analysis of In Vitro Biomass Cultivation for Cultured Meat Production in the United States. *Environmental Science & Technology*, 49(19), pp.11941–11949.

Mayers, J.J. et al., 2016. Integrating Microalgal Production with Industrial Outputs—Reducing Process Inputs and Quantifying the Benefits. *Industrial Biotechnology*, 12(4), pp.219–234.

McCarty, M.F., 2007. Clinical Potential of *Spirulina* as a Source of Phycocyanobilin. *Journal of Medicinal Food*, 10(4), pp.566–570.

Murugan, A.C. et al., 2015. New insights into seaweed polyphenols on glucose homeostasis. *Pharmaceutical Biology*, 53(8), pp.1087–1097.

Nwosu, F. et al., 2011. Anti-proliferative and potential anti-diabetic effects of phenolic-rich extracts from edible marine algae. *Food Chemistry*, 126(3), pp.1006–1012.

Van Oirschot, R. et al., 2017. Explorative environmental life cycle assessment for system design of seaweed cultivation and drying. *Algal Research*, 27, pp.43–54.

Oliveira, M.N. de et al., 2009. Nutritive and non-nutritive attributes of washed-up seaweeds from the coast of Ceará, Brazil. *Food Chemistry*, 115(1), pp.254–259.

Omotoso, O.T., 2006. Nutritional quality, functional properties and anti-nutrient compositions of the larva of Cirina forda (Westwood) (Lepidoptera: Saturniidae). *Journal of Zhejiang*

University. Science. B, 7(1), pp.51–5.

Oonincx, D.G.A.B. & De Boer, I.J.M., 2012. Environmental Impact of the Production of Mealworms as a Protein Source for Humans - A Life Cycle Assessment. *PLoS ONE*, 7(12), p.e51145.

Paoletti, M.G. et al., 2007. Human Gastric Juice Contains Chitinase That Can Degrade Chitin. *Annals of Nutrition and Metabolism*, 51(3), pp.244–251.

Parker, R.W.R. et al., 2018. Fuel use and greenhouse gas emissions of world fisheries. *Nature Climate Change*, 8(4), pp.333–337.

Parker, R.W.R., Azquez-Rowe, I. V & Tyedmers, P.H., 2015. Fuel performance and carbon footprint of the global purse seine tuna fleet. *Journal of Cleaner Production*, 103, pp.517–524.

Parker, R.W.R. & Tyedmers, P.H., 2015. Fuel consumption of global fishing fleets: Current understanding and knowledge gaps. *Fish and Fisheries*, 16(4), pp.684–696.

Pate, F.M. et al., 2002. Sugarcane as a Cattle Feed : Production and Utilization. *Florida Sugarcane Handbook*, pp.1–21.

Pechsiri, J.S. et al., 2016. Energy performance and greenhouse gas emissions of kelp cultivation for biogas and fertilizer recovery in Sweden. *Science of The Total Environment*, 573, pp.347–355.

Pelletier, N. & Tyedmers, P., 2010. Life Cycle Assessment of Frozen Tilapia Fillets From Indonesian Lake-Based and Pond-Based Intensive Aquaculture Systems. *Journal of Industrial Ecology*, 14(3), pp.467–481.

Post, M.J., 2018. Proteins in cultured beef. *Proteins in Food Processing*, pp.289–298.

Rozendaal, J. a., 2011. Houseflies. *Vector control: Methods for use by individuals and communities*, pp.6–9.

Salomone, R. et al., 2017. Environmental impact of food waste bioconversion by insects: Application of Life Cycle Assessment to process using Hermetia illucens. *Journal of Cleaner Production*, 140, pp.890–905.

Sánchez-Muros, M. et al., 2016. Nutritional evaluation of Tenebrio molitor meal as fishmeal substitute for tilapia (Oreochromis niloticus) diet. *Aquaculture Nutrition*, 22(5), pp.943–955.

SARF, 2010. *Carbon Footprint Of Scottish Suspended Mussels And Intertidal Oystersn Footprint Of Scottish Suspended Mussels And Intertidal Oysters*,

Sathya, R. et al., 2017. Antioxidant properties of phlorotannins from brown seaweed Cystoseira trinodis (Forsskål) C. Agardh. *Arabian Journal of Chemistry*, 10, pp.S2608–S2614.

Schlemmer, U. et al., 2009. Phytate in foods and significance for humans: Food sources, intake, processing, bioavailability, protective role and analysis. *Molecular Nutrition & Food Research*, 53(S2), pp.S330–S375.

Shibata, T. et al., 2008. Antioxidant activities of phlorotannins isolated from Japanese

Laminariaceae. *Journal of Applied Phycology*, 20(5), pp.705–711.

Sills, D.L. et al., 2013. Quantitative Uncertainty Analysis of Life Cycle Assessment for Algal Biofuel Production. *Environmental Science & Technology*, 47(2), pp.687–694.

Singh, S., Kate, B.N. & Banerjee, U.C., 2005. Bioactive Compounds from Cyanobacteria and Microalgae: An Overview. *Critical Reviews in Biotechnology*, 25(3), pp.73–95.

Slegers, P.M. et al., 2014. A model-based combinatorial optimisation approach for energy-efficient processing of microalgae. *Algal Research*, 5, pp.140–157.

Smetana, S. et al., 2017. Autotrophic and heterotrophic microalgae and cyanobacteria cultivation for food and feed: life cycle assessment. *Bioresource Technology*, 245, pp.162–170.

Smetana, S. et al., 2016. Sustainability of insect use for feed and food: Life Cycle Assessment perspective. *Journal of Cleaner Production*, 137, pp.741–751.

Smith, P., 2014. Do grasslands act as a perpetual sink for carbon? *Global Change Biology*, 20(9), pp.2708–2711.

Van der Spiegel, M., Noordam, M.Y. & Van der Fels-Klerx, H.J., 2013. Safety of novel protein sources (insects, microalgae, seaweed, duckweed, and rapeseed) and legislative aspects for their application in food and feed production. *Comprehensive Reviews in Food Science and Food Safety*, 12(6), pp.662–678.

Strobel, S. et al., 2013. Insectivorous Bats Digest Chitin in the Stomach Using Acidic Mammalian Chitinase F. Blachier, ed. *PLoS ONE*, 8(9), p.e72770.

Tabata, E. et al., 2018. Chitin digestibility is dependent on feeding behaviors, which determine acidic chitinase mRNA levels in mammalian and poultry stomachs. *Scientific Reports*, 8(1), p.1461.

Tang, G. & Suter, P.M., 2011. Vitamin A, Nutrition, and Health Values of Algae: Spirulina, Chlorella and Dunaliella. *Journal of Pharmacy and Nutrition Sciences*, 1(2), pp.111–118.

Thangaraj, P., 2016. Anti-nutritional Factors. In P. in D. Research, ed. *Pharmacological Assays of Plant-Based Natural Products*. Springer, pp. 43–47.

Thévenot, A. et al., 2018. Mealworm meal for animal feed: Environmental assessment and sensitivity analysis to guide future prospects. *Journal of Cleaner Production*, 170, pp.1260–1267.

Tokuşoglu, O. & ÜUnal, M.K., 2003. Biomass Nutrient Profiles of Three Microalgae: Spirulina platensis, Chlorella vulgaris, and Isochrisis galbana. *Journal of Food Science*, 68(4), pp.1144–1148.

Tuomisto, H.L., Ellis, M.J. & Haastrup, P., 2014. *Environmental impacts of cultured meat : alternative production scenarios* D. Schenck, R., Huizenga, ed., San Francisco.

Tuomisto, H.L. & Texteira de Mattos, M., 2011. Environmental Impacts of Cultured Meat Production. *Environ. Sci. Technol*, 45, pp.6117–6123.

USDA, 2017. USDA Food Composition Databases. Available at:

https://ndb.nal.usda.gov/ndb/ [Accessed February 4, 2017].

Vigani, M. et al., 2015. Food and feed products from micro-algae: Market opportunities and challenges for the EU. *Trends in Food Science & Technology*, 42(1), pp.81–92.

Vijayabaskar, P. & Shiyamala, V., 2012. Antioxidant properties of seaweed polyphenol from Turbinaria ornata (Turner) J. Agardh, 1848. *Asian Pacific Journal of Tropical Biomedicine*, 2(1), pp.S90–S98.

Vijayabaskar P & Shiyamala V, 2012. Antioxidant properties of seaweed polyphenol from Turbinaria ornata (Turner) J. Agardh, 1848 Asian Pacific Journal of Tropical Biomedicine. *Asian Pacific Journal of Tropical Biomedicine*, pp.90–98.

Weiss, F. & Leip, A., 2012. Greenhouse gas emissions from the EU livestock sector: A life cycle assessment carried out with the CAPRI model. *Agriculture, Ecosystems & Environment*, 149, pp.124–134.

Wells, M.L. et al., 2016. Algae as nutritional and functional food sources: revisiting our understanding. *Journal of Applied Phycology*, 29(2), pp.949–982.

Wernet, G. et al., 2016. The ecoinvent database version 3 (part I): overview and methodology. *The International Journal of Life Cycle Assessment*, 21(9), pp.1218–1230.

Winther, U. et al., 2009. *Carbon footprint and energy use of Norwegian seafood products*,

Yeh, T.S., Hung, N.H. & Lin, T.C., 2014. Analysis of iodine content in seaweed by GC-ECD and estimation of iodine intake. *Journal of Food and Drug Analysis*, 22, pp.189–196.

Yi, L. et al., 2013. Extraction and characterisation of protein fractions from five insect species. *Food Chemistry*, 141(4), pp.3341–3348.

Younes, I. et al., 2014. Chitin extraction from shrimp shell using enzymatic treatment. Antitumor, antioxidant and antimicrobial activities of chitosan. *International Journal of Biological Macromolecules*, 69, pp.489–498.

Van Zanten, H.H.E. et al., 2014. From environmental nuisance to environmental opportunity: Housefly larvae convert waste to livestock feed. *Journal of Cleaner Production*, 102, pp.362–369.

Ziegler, F. et al., 2016. Expanding the concept of sustainable seafood using Life Cycle Assessment. *Fish and Fisheries*, 17(4), pp.1073–1093.

References – Supplementary Table 4

FAO & WHO. Codex Alimentarius. Guidelines on nutrition labelling. Codex Alimentarius. (1985).

WHO. Protein and amino acid requirements in human nutrition. Report of a Joint WHO/FAO/UNU Expert Consultation. (2007).

EFSA. Scientific opinion on dietary reference values for fats, including saturated fatty acids, polyunsaturated fatty acids, monounsaturated fatty acids, trans fatty acids, and cholesterol. European Food Safety Authority. EFSA J. 8, 1461 (2010).

References – Supplementary Table 6

Agrovision, 2016. Annual published average company data of Dutch pig farms. (in Dutch: Kengetallenspiegel), Deventer, The Netherlands.

Denton, J.H. & Mellor, D.B., Cost and yield comparisons of ready-to-cook chicken products,

Nour, A.Y.M. et al., 1983. Changes in Primal Cut Yield with Increasing Weight of Large and Small Cattle. Journal of Animal Science, 57(5), pp.1166–1172.

USDA, 2017. USDA Food Composition Databases. Available at: https://ndb.nal.usda.gov/ndb/ [Accessed February 4, 2017].

References – Supplementary Table 7

Aubin, J. et al., 2018. Blue mussel (Mytilus edulis) bouchot culture in Mont-St Michel Bay: potential mitigation effects on climate change and eutrophication. *The International Journal of Life Cycle Assessment*, 23(5), pp.1030–1041.

Avilés-Gaxiola, S., Chuck-Hernández, C. & Serna Saldívar, S.O., 2018. Inactivation Methods of Trypsin Inhibitor in Legumes: A Review. *Journal of Food Science*, 83(1), pp.17–29.

Barker, D., Fitzpatrick, M.P. & Dierenfeld, E.S., 1998. Nutrient composition of selected whole invertebrates. *Zoo Biology*, 17(2), pp.123–134.

Bauer, A. et al., 2006. Occurrence of Vibrio parahaemolyticus, V. cholerae, and V. vulnificus in Norwegian Blue Mussels (Mytilus edulis). *Society*, 72(4), pp.3058–3061.

Bednářová, M. et al., 2013. Edible insects - species suitable for entomophagy under condition of Czech Republic. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 61(3), pp.587–593.

Brown, E.M. et al., 2014. Seaweed and human health. *Nutrition Reviews*, 72(3), pp.205–216.

Campbell, P.K., Beer, T. & Batten, D., 2011. Life cycle assessment of biodiesel production from microalgae in ponds. *Bioresource Technology*, 102(1), pp.50–56.

Chakravorty, J. et al., 2016. Nutritional and anti-nutritional composition of Oecophylla smaragdina (Hymenoptera: Formicidae) and Odontotermes sp. (Isoptera: Termitidae): Two preferred edible insects of Arunachal Pradesh, India. *Journal of Asia-Pacific Entomology*, 19(3), pp.711–720.

Cofrades, S. et al., 2016. Nutritional and Antioxidant Properties of Different Brown and Red Spanish Edible Seaweeds. *Food Sci Tech Int*, 16(5), pp.0361–10.

DeFoliart, G.R., 1992. Insects as human food: Gene DeFoliart discusses some nutritional and economic aspects. *Crop Protection*, 11(5), pp.395–399.

Draaisma, R.B. et al., 2013. Food commodities from microalgae. *Current Opinion in Biotechnology*, 24(2), pp.169–177.

EFSA, 2015. Risk profile related to production and consumption of insects as food and feed.

European Food Safety Authority. *EFSA Journal*, 13(10), p.4257.

European Commission, 2015. Novel food catalogue. , p.1. Available at: http://ec.europa.eu/food/safety/novel_food/catalogue/search/public/index.cfm [Accessed April 4, 2018].

FAO, 2017. FAOSTAT. Available at: http://www.fao.org/faostat/ [Accessed July 1, 2018].

FAO, 1989. *Yield and nutritional value of the commercially more important fish species*, Food and Agriculture Organization of the United Nations.

Finnigan, T. et al., 2010. Mycoprotein, Life Cycle Analysis and the Food 2030 Challenge. *Aspects of Applied Biology*, 102, pp.81–90.

Finnigan, T., Needham, L. & Abbott, C., 2017. Mycoprotein: A Healthy New Protein with a Low Environmental Impact. In *Sustainable Protein Sources*. Elsevier.

Fu, W. et al., 2017. Bioactive Compounds From Microalgae: Current Development and Prospects. *Studies in Natural Products Chemistry*, 54, pp.199–225.

García-Casal, M.N. et al., 2007. High iron content and bioavailability in humans from four species of marine algae. *The Journal of nutrition*, 137(12), pp.2691–5.

Garnett, T. et al., 2017. Grazed and confused. , p.127.

Gemede, H.F. & Ratta, N., 2014. Antinutritional Factors in Plant Foods: Potential Health Benefits and Adverse Effects. *International Journal of Nutrition and Food Sciences*, 3(4), pp.284–289.

Gupta, R.K., Gangoliya, S.S. & Singh, N.K., 2015. Reduction of phytic acid and enhancement of bioavailable micronutrients in food grains. *Journal of Food Science and Technology*, 52(2), pp.676–84.

Henriksson, P.J.G. et al., 2017. Indonesian aquaculture futures – Evaluating environmental and socioeconomic potentials and limitations. *Journal of Cleaner Production*, 162, pp.1482–1490.

Henriksson, P.J.G. et al., 2018. Measuring the potential for sustainable intensification of aquaculture in Bangladesh using life cycle assessment. *Proceedings of the National Academy of Sciences of the United States of America*, 115(12), pp.2958–2963.

Iribarren, D., Moreira, M.T. & Feijoo, G., 2010. Revisiting the Life Cycle Assessment of mussels from a sectorial perspective. *Journal of Cleaner Production*, 18(2), pp.101–111.

Ishihara, M. et al., 2006. Purification and characterization of extracellular cysteine protease inhibitor, ECPI-2, from Chlorella sp. *Journal of Bioscience and Bioengineering*, 101(2), pp.166–171.

de Jesus Raposo, M.F., de Morais, R.M.S.C. & de Morais, A.M.M.B., 2013. Health applications of bioactive compounds from marine microalgae. *Life Sciences*, 93(15), pp.479–486.

Joensuu, K. & Silvenius, F., 2017. Production of mealworms for human consumption in Finland: a preliminary life cycle assessment. *Journal of Insects as Food and Feed*, 3(3), pp.211–216.

Johnston, A.E., Poulton, P.R. & Coleman, K., 2009. Chapter 1 Soil Organic Matter: Its Importance in Sustainable Agriculture and Carbon Dioxide Fluxes. *Advances in Agronomy*, 101, pp.1–57.

Khairy, H.M. & El-Sheikh, M.A., 2015. Antioxidant activity and mineral composition of three Mediterranean common seaweeds from Abu-Qir Bay, Egypt. *Saudi Journal of Biological Sciences*, 22(5), pp.623–630.

Klasing, K.C. et al., 2000. Increasing the Calcium Content of Mealworms (Tenebrio molitor) to Improve Their Nutritional Value for Bone Mineralization of Growing Chicks. *Source: Journal of Zoo and Wildlife Medicine*, 31(4), pp.512–517.

Leip, A. et al., 2010. Evaluation of the livestock sector’s contribution to the EU greenhouse gas emissions (GGELS) - final report. , p.323.

Leip, A. et al., 2015. Impacts of European livestock production: nitrogen, sulphur, phosphorus and greenhouse gas emissions, land-use, water eutrophication and biodiversity. *Environmental Research Letters*, 10(11), p.115004.

Leip, A. et al., 2014. The nitrogen footprint of food products in the European Union. *The Journal of Agricultural Science*, 152(S1), pp.20–33.

Leu, S. & Boussiba, S., 2014. Advances in the Production of High-Value Products by Microalgae. *Industrial Biotechnology*, 10(3), pp.169–183.

Lhafi, S.K. & Kühneb, M., 2007. Occurrence of Vibrio spp. in blue mussels (Mytilus edulis) from the German Wadden Sea. *International Journal of Food Microbiology*, 116(2), pp.297–300.

Li, J. et al., 2018. Microplastics in mussels sampled from coastal waters and supermarkets in the United Kingdom. *Environmental Pollution*, 241, pp.35–44.

Lourguioui, H. et al., 2017. A perspective for reducing environmental impacts of mussel culture in Algeria. *Int J Life Cycle Assess* , 22, pp.1266–1277.

Maehre, H.K. et al., 2014. Characterization of protein, lipid and mineral contents in common Norwegian seaweeds and evaluation of their potential as food and feed. *Journal of the science of food and agriculture*, 94(15), pp.3281–90.

Maehre, H.K. et al., 2016. Heat treatment increases the protein bioaccessibility in the red seaweed dulse (Palmaria palmata), but not in the brown seaweed winged kelp (Alaria esculenta). *Journal of Applied Phycology*, 28(1), pp.581–590.

Marlow Foods, 2009. Nutritional profile of Quorn™ mycoprotein. , p.21. Available at: http://www.mycoprotein.org/assets/nutritional_profile_of_quorn.pdf [Accessed March 7, 2017].

Marono, S. et al., 2015. Crude Protein Digestibility of Tenebrio Molitor and Hermetia Illucens Insect Meals and its Correlation with Chemical Composition Traits. *Italian Journal of Animal Science*, 14(3), p.3889.

Mattick, C.S. et al., 2015. Anticipatory Life Cycle Analysis of In Vitro Biomass Cultivation for Cultured Meat Production in the United States. *Environmental Science & Technology*, 49(19), pp.11941–11949.

Mayers, J.J. et al., 2016. Integrating Microalgal Production with Industrial Outputs—Reducing Process Inputs and Quantifying the Benefits. *Industrial Biotechnology*, 12(4), pp.219–234.

McCarty, M.F., 2007. Clinical Potential of *Spirulina* as a Source of Phycocyanobilin. *Journal of Medicinal Food*, 10(4), pp.566–570.

Murugan, A.C. et al., 2015. New insights into seaweed polyphenols on glucose homeostasis. *Pharmaceutical Biology*, 53(8), pp.1087–1097.

Nwosu, F. et al., 2011. Anti-proliferative and potential anti-diabetic effects of phenolic-rich extracts from edible marine algae. *Food Chemistry*, 126(3), pp.1006–1012.

Van Oirschot, R. et al., 2017. Explorative environmental life cycle assessment for system design of seaweed cultivation and drying. *Algal Research*, 27, pp.43–54.

Oliveira, M.N. de et al., 2009. Nutritive and non-nutritive attributes of washed-up seaweeds from the coast of Ceará, Brazil. *Food Chemistry*, 115(1), pp.254–259.

Omotoso, O.T., 2006. Nutritional quality, functional properties and anti-nutrient compositions of the larva of Cirina forda (Westwood) (Lepidoptera: Saturniidae). *Journal of Zhejiang University. Science. B*, 7(1), pp.51–5.

Oonincx, D.G.A.B. & De Boer, I.J.M., 2012. Environmental Impact of the Production of Mealworms as a Protein Source for Humans - A Life Cycle Assessment. *PLoS ONE*, 7(12), p.e51145.

Paoletti, M.G. et al., 2007. Human Gastric Juice Contains Chitinase That Can Degrade Chitin. *Annals of Nutrition and Metabolism*, 51(3), pp.244–251.

Parker, R.W.R. et al., 2018. Fuel use and greenhouse gas emissions of world fisheries. *Nature Climate Change*, 8(4), pp.333–337.

Parker, R.W.R., Azquez-Rowe, I. V & Tyedmers, P.H., 2015. Fuel performance and carbon footprint of the global purse seine tuna fleet. *Journal of Cleaner Production*, 103, pp.517–524.

Parker, R.W.R. & Tyedmers, P.H., 2015. Fuel consumption of global fishing fleets: Current understanding and knowledge gaps. *Fish and Fisheries*, 16(4), pp.684–696.

Pate, F.M. et al., 2002. Sugarcane as a Cattle Feed : Production and Utilization. *Florida Sugarcane Handbook*, pp.1–21.

Pechsiri, J.S. et al., 2016. Energy performance and greenhouse gas emissions of kelp cultivation for biogas and fertilizer recovery in Sweden. *Science of The Total Environment*, 573, pp.347–355.

Pelletier, N. & Tyedmers, P., 2010. Life Cycle Assessment of Frozen Tilapia Fillets From Indonesian Lake-Based and Pond-Based Intensive Aquaculture Systems. *Journal of Industrial Ecology*, 14(3), pp.467–481.

Post, M.J., 2018. Proteins in cultured beef. *Proteins in Food Processing*, pp.289–298.

Rozendaal, J. a., 2011. Houseflies. *Vector control: Methods for use by individuals and communities*, pp.6–9.

Salomone, R. et al., 2017. Environmental impact of food waste bioconversion by insects: Application of Life Cycle Assessment to process using Hermetia illucens. *Journal of Cleaner Production*, 140, pp.890–905.

Sánchez-Muros, M. et al., 2016. Nutritional evaluation of Tenebrio molitor meal as fishmeal substitute for tilapia (Oreochromis niloticus) diet. *Aquaculture Nutrition*, 22(5), pp.943–955.

SARF, 2010. *Carbon Footprint Of Scottish Suspended Mussels And Intertidal Oystersn Footprint Of Scottish Suspended Mussels And Intertidal Oysters*,

Sathya, R. et al., 2017. Antioxidant properties of phlorotannins from brown seaweed Cystoseira trinodis (Forsskål) C. Agardh. *Arabian Journal of Chemistry*, 10, pp.S2608–S2614.

Schlemmer, U. et al., 2009. Phytate in foods and significance for humans: Food sources, intake, processing, bioavailability, protective role and analysis. *Molecular Nutrition & Food Research*, 53(S2), pp.S330–S375.

Shibata, T. et al., 2008. Antioxidant activities of phlorotannins isolated from Japanese Laminariaceae. *Journal of Applied Phycology*, 20(5), pp.705–711.

Sills, D.L. et al., 2013. Quantitative Uncertainty Analysis of Life Cycle Assessment for Algal Biofuel Production. *Environmental Science & Technology*, 47(2), pp.687–694.

Singh, S., Kate, B.N. & Banerjee, U.C., 2005. Bioactive Compounds from Cyanobacteria and Microalgae: An Overview. *Critical Reviews in Biotechnology*, 25(3), pp.73–95.

Slegers, P.M. et al., 2014. A model-based combinatorial optimisation approach for energy-efficient processing of microalgae. *Algal Research*, 5, pp.140–157.

Smetana, S. et al., 2017. Autotrophic and heterotrophic microalgae and cyanobacteria cultivation for food and feed: life cycle assessment. *Bioresource Technology*, 245, pp.162–170.

Smetana, S. et al., 2016. Sustainability of insect use for feed and food: Life Cycle Assessment perspective. *Journal of Cleaner Production*, 137, pp.741–751.

Smith, P., 2014. Do grasslands act as a perpetual sink for carbon? *Global Change Biology*, 20(9), pp.2708–2711.

Van der Spiegel, M., Noordam, M.Y. & Van der Fels-Klerx, H.J., 2013. Safety of novel protein sources (insects, microalgae, seaweed, duckweed, and rapeseed) and legislative aspects for their application in food and feed production. *Comprehensive Reviews in Food Science and Food Safety*, 12(6), pp.662–678.

Strobel, S. et al., 2013. Insectivorous Bats Digest Chitin in the Stomach Using Acidic Mammalian Chitinase F. Blachier, ed. *PLoS ONE*, 8(9), p.e72770.

Tabata, E. et al., 2018. Chitin digestibility is dependent on feeding behaviors, which determine acidic chitinase mRNA levels in mammalian and poultry stomachs. *Scientific Reports*, 8(1), p.1461.

Tang, G. & Suter, P.M., 2011. Vitamin A, Nutrition, and Health Values of Algae: Spirulina, Chlorella and Dunaliella. *Journal of Pharmacy and Nutrition Sciences*, 1(2), pp.111–118.

Thangaraj, P., 2016. Anti-nutritional Factors. In P. in D. Research, ed. *Pharmacological Assays of Plant-Based Natural Products*. Springer, pp. 43–47.

Thévenot, A. et al., 2018. Mealworm meal for animal feed: Environmental assessment and sensitivity analysis to guide future prospects. *Journal of Cleaner Production*, 170, pp.1260–1267.

Tokuşoglu, O. & ÜUnal, M.K., 2003. Biomass Nutrient Profiles of Three Microalgae: Spirulina platensis, Chlorella vulgaris, and Isochrisis galbana. *Journal of Food Science*, 68(4), pp.1144–1148.

Tuomisto, H.L., Ellis, M.J. & Haastrup, P., 2014. *Environmental impacts of cultured meat : alternative production scenarios* D. Schenck, R., Huizenga, ed., San Francisco.

Tuomisto, H.L. & Texteira de Mattos, M., 2011. Environmental Impacts of Cultured Meat Production. *Environ. Sci. Technol*, 45, pp.6117–6123.

USDA, 2017. USDA Food Composition Databases. Available at: https://ndb.nal.usda.gov/ndb/ [Accessed February 4, 2017].

Vigani, M. et al., 2015. Food and feed products from micro-algae: Market opportunities and challenges for the EU. *Trends in Food Science & Technology*, 42(1), pp.81–92.

Vijayabaskar, P. & Shiyamala, V., 2012. Antioxidant properties of seaweed polyphenol from Turbinaria ornata (Turner) J. Agardh, 1848. *Asian Pacific Journal of Tropical Biomedicine*, 2(1), pp.S90–S98.

Vijayabaskar P & Shiyamala V, 2012. Antioxidant properties of seaweed polyphenol from Turbinaria ornata (Turner) J. Agardh, 1848 Asian Pacific Journal of Tropical Biomedicine. *Asian Pacific Journal of Tropical Biomedicine*, pp.90–98.

Weiss, F. & Leip, A., 2012. Greenhouse gas emissions from the EU livestock sector: A life cycle assessment carried out with the CAPRI model. *Agriculture, Ecosystems & Environment*, 149, pp.124–134.

Wells, M.L. et al., 2016. Algae as nutritional and functional food sources: revisiting our understanding. *Journal of Applied Phycology*, 29(2), pp.949–982.

Wernet, G. et al., 2016. The ecoinvent database version 3 (part I): overview and methodology. *The International Journal of Life Cycle Assessment*, 21(9), pp.1218–1230.

Winther, U. et al., 2009. *Carbon footprint and energy use of Norwegian seafood products*,

Yeh, T.S., Hung, N.H. & Lin, T.C., 2014. Analysis of iodine content in seaweed by GC-ECD and estimation of iodine intake. *Journal of Food and Drug Analysis*, 22, pp.189–196.

Yi, L. et al., 2013. Extraction and characterisation of protein fractions from five insect species. *Food Chemistry*, 141(4), pp.3341–3348.

Younes, I. et al., 2014. Chitin extraction from shrimp shell using enzymatic treatment. Antitumor, antioxidant and antimicrobial activities of chitosan. *International Journal of Biological Macromolecules*, 69, pp.489–498.

Van Zanten, H.H.E. et al., 2014. From environmental nuisance to environmental opportunity: Housefly larvae convert waste to livestock feed. *Journal of Cleaner Production*, 102, pp.362–369.

Ziegler, F. et al., 2016. Expanding the concept of sustainable seafood using Life Cycle Assessment. *Fish and Fisheries*, 17(4), pp.1073–1093.