ROTHAMSTED RESEARCH

How much is enough? The effect of nutrient profiling on carbon footprints of 22 common food products

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The issue of functional units

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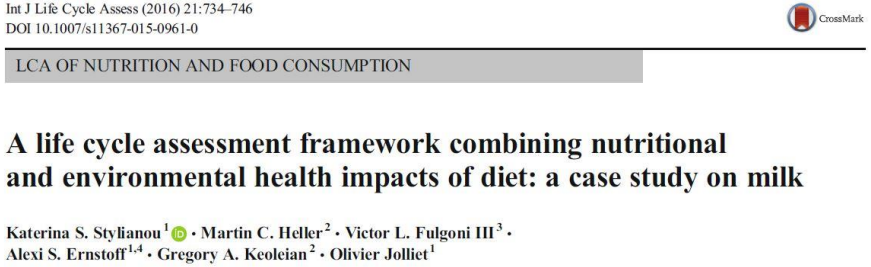
- The output of a system should be the function of a system (functional unit)
- LCA studies typically use mass (1 kg carcase weight) as the functional unit
- This does not account for differences in nutritional quality

Int J Life Cycle Assess (2016) 21:607–620
DOI 10.1007/s11367-016-1071-3

PREFACE — LCA OF NUTRITION AND FOOD CONSUMPTION

Environmental impacts of food consumption and nutrition: where are we and what is next?

Thomas Nemecek[1] · Niels Jungbluth[2] · Llorenç Milà i Canals[3] · Rita Schenck[4]



Int J Life Cycle Assess (2016) 21:734–746
DOI 10.1007/s11367-015-0961-0

LCA OF NUTRITION AND FOOD CONSUMPTION

A life cycle assessment framework combining nutritional and environmental health impacts of diet: a case study on milk

Katerina S. Stylianou[1] · Martin C. Heller[2] · Victor L. Fulgoni III[3] · Alexi S. Ernstoff[1,4] · Gregory A. Keoleian[2] · Olivier Jolliet[1]

RESEARCH ARTICLE

Environmental Life Cycle Assessment of Diets with Improved Omega-3 Fatty Acid Profiles

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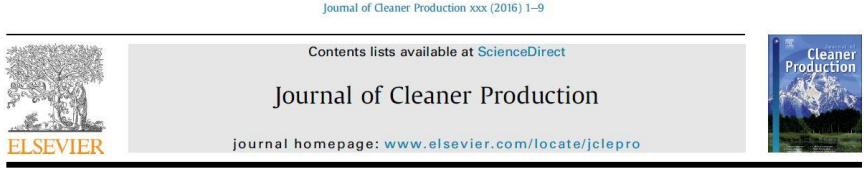

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Protein quality as functional unit – A methodological framework for inclusion in life cycle assessment of food

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The issue of functional units

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Study	Primary product(s)	Study region	Functional units	Number of nutrients (maximum)	Nutrient density included	System boundary	Impact categories[a]	Farm-level management included
Teixeira et al. (2013)	Pâté	France	100 g pâté; 1 kcal; 1 g protein	1	No	Cradle to cradle (full life cycle)	GWP	Yes
Tyszler et al. (2014)	Apples; oranges; chicken; beef; vegetarian burgers; cod; salmon	Netherlands	100 g; 1 portion	36	No	NS	GWP; EU; LU	No
Doran-Browne et al. (2015)	Lamb (with and without fat); beef (with and without fat); whole milk; skimmed milk; wheat flour; rapeseed oil	Australia	1% nutrient density; t product; t protein; GJ energy	12	Yes	Cradle to processing (prior to packaging)	GWP	Yes
Drewnowski et al. (2015)	483 foods and beverages	France	100 g; 100 kcal; nutrient densities correlated with mass or energy	15	Yes	Cradle to retail	GWP	No
Masset et al. (2015)	373 foods	France	100 g; 100 kcal; nutrient densities correlated with mass or energy	8	No	NS	GWP	No
Roibás et al. (2016)	Conventional UHT milk; enhanced UHT milk	Spain	1 l packaged milk; 55 µ Se/day	1	No	Cradle to dairy factory exit	GWP; WF	Yes
Tessari et al. (2016)	15 common food products	Italy	100 g edible product; 13 g total essential amino acids; edible mass required to supply all essential amino acids	9 (essential amino acids)	Yes[c]	NS	GWP; LU	No
Stylianou et al. (2016)	Weighted average of whole, skimmed, semi-skimmed and non-fat milk	United States	1 serving of milk (added to a diet or replacing other calorific sources)	NA	No	NS	HHD; EQ; RU; ES	No
Saarinen et al. (2017)	29 common Finnish foods	Finland	100 g; six nutrient density scores	12	Yes	Cradle to consumption	GWP	No
Sonesson et al. (2017)	Bread; chicken fillet; minced pork; minced beef; milk; pea soup	Sweden	1 kg product; 1 g protein; 1 g digestible protein; protein quality index	9 (essential amino acids)	Yes[c]	Cradle to preparation for consumption	GWP	No
Chaudhary et al. (2018)	Yellow pea; bread; breakfast cereals; pasta	Canada	Nutrition carbon footprint score (nutrient balance/carbon footprint per serving)	27	Yes	Cradle to food manufacturing	GWP	No
McAuliffe et al. (2018)	Beef; chicken; lamb; pork	United Kingdom	100 g meat; 1 g omega-3 fatty acids; 1 g non-competing omega-3 fatty acids; 1 % nutrient density score	13	Yes	Cradle to farm gate	GWP	Yes
Schaubroeck et al. (2018)	42 canteen meals	Belgium	1 meal serving	7	No	Cradle to food preparation at canteen	EF	No
Xu et al. (2018)	19 carbohydrate rich foods grouped as: rice; wheat; potato; maize; pulses	China	1 kg product; carbohydrates/kg product; protein/kg product; energy/kg product; 2 nutrient profiles scores	21	Yes	Cradle to processing (prior to retail)	GWP	Yes
Hallström et al. (2019)	37 types of seafood	Sweden	Seven different nutrient density scores	24	Yes	Cradle to fish-landing	GWP	Yes
Sonesson et al. (2019)	Bread; apples; tomatoes; milk; hard cheese; spread; chicken fillets	Sweden	Nutrient density score; nutrient score in relation to a dietary context	12	Yes	Cradle to processing	GWP	No

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Nutrient density scores (NDS) calculation

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Nutrient	Protein (g/d)	Fibre (g/d)	MUFA (g/d)	Vitamin A (µg/d)	Vitamin C (mg/d)	Vitamin D (µg/d)	Vitamin E (mg/d)	Vitamin B12 (µg/d)	Folate (µg/d)	Riboflavin (mg/d)	Thiamin (mg/d)	Ca (mg/d)	Fe (mg/d)	Mg (mg/d)	K (mg/d)	Zn (mg/d)	SFA (g/d)	TS (g/d)	Na (mg/d)
RDI	50	25	32.5	1500	60	10	15	2.4	400	1.7	1.5	1000	18.0	400	3500	15			
RDA																	20	30	2400

Score	Macronutrients	Vitamins	Minerals	Limited
NDS6-3	Protein, fibre	A, C	Ca, Fe	SFA, AS, Na
NDS9-3	Protein, fibre	A, C, E	Ca, Fe, Mg, K	SFA, AS, Na
NDS11-3	Protein, fibre	A, C, E, B-12	Ca, Fe, Mg, Zn, K	SFA, AS, Na
NDS15-3	Protein, fibre, monounsaturated fat	A, C, D, E, thiamin, riboflavin, B12, folate	Ca, Fe, Zn, K	SFA, AS, Na

- NDS calculated as the sum of recommended nutrients (in green) minus discouraged nutrients (in red) in relation to daily nutritive values
- Assessment is additive and equally weighted
- Rewards multifunctionality – e.g. Protein + fibre

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Previous findings of the effect of NDS choice

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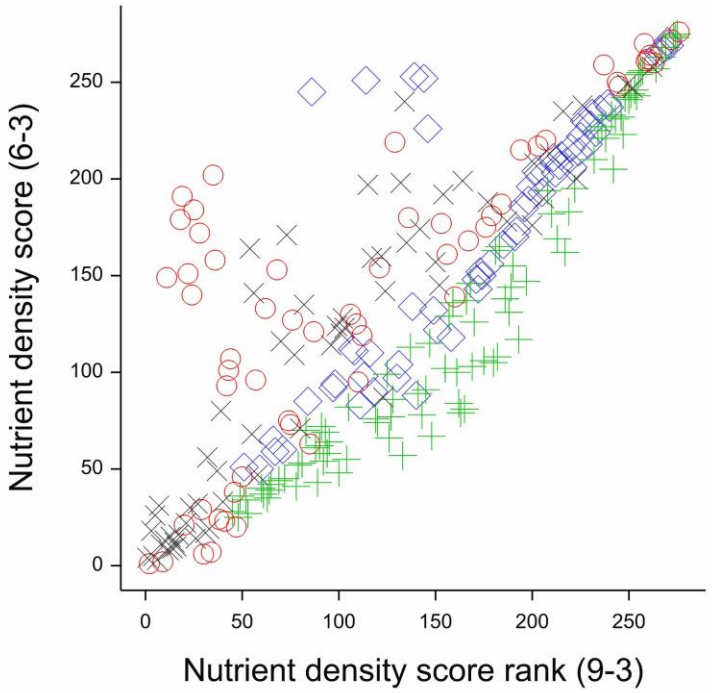
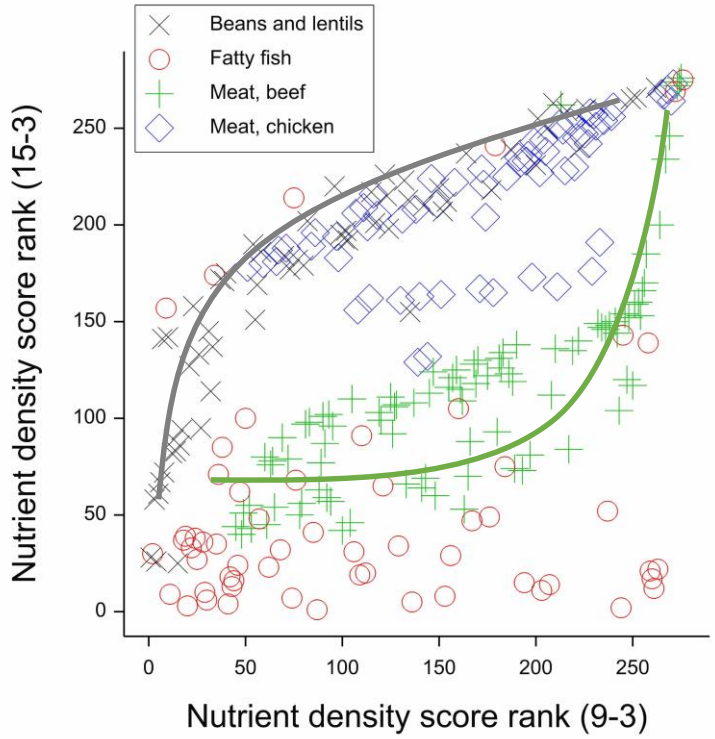
	NDS 6-3	NDS 9-3	NDS 15-3
Chick Pea	15.40	26.31	24.00
Salmon (fillet)	4.08	16.09	35.60
Beef (Sirloin)	8.80	7.25	18.10
Chicken (Breast)	7.11	6.84	6.69





- Relative rankings of food items reverse more in favour of beef and salmon when NDS15-3 replaces NDS9-3
- Chick peas had a lower NDS when maximum nutrients were considered (15-3)
- Salmon and beef had considerably higher scores more nutrients added
- Rankings are displayed in descending order
- Individual items within a food group vary considerably in terms of nutritional quality
- Favour multifunctionality e.g. nuts

***McAuliffe** et al., 2019. BSAS Edinburgh.*

Nutrient density scores (NDS) rankings

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	NDS 6-3	NDS 9-3	NDS 11-3	NDS 15-3	NDS 6-0	NDS 9-0	NDS 11-0	NDS 15-0
Peas	1	3	3	4	1	4	4	6
Beans and pulses	2	2	2	3	2	3	3	4
Nuts	3	1	1	1	3	1	1	1
Groundnuts	10	4	8	6	5	2	2	3
Tofu	13	13	15	15	18	19	19	17
Cheese	23	23	23	23	4	5	5	5
Eggs	17	18	16	11	13	15	10	10
Poultry	6	7	10	10	11	12	14	15
Pork	8	10	9	7	15	14	12	11
Sheep	9	12	4	5	12	13	6	7
Beef	15	15	6	8	9	10	7	8
Farmed fish	7	6	5	2	14	9	9	2
Crustaceans	20	20	17	19	16	16	11	14
Carrots	5	8	14	16	6	6	13	13
Potatoes	12	9	13	14	19	17	17	18
Rice	11	11	12	13	20	20	20	20
Tomatoes	14	14	18	17	17	18	18	19
Cucumber	18	17	19	18	23	23	23	23
Cabbage	4	5	11	12	7	7	16	16
Onions	19	19	20	20	21	21	21	21
Bread (wheat)	21	21	21	21	8	8	15	12
Apples	22	22	22	22	22	22	22	22

- Peas beans and nuts consistently had the highest NDS, except for groundnuts which were high in SFA
- Meat and fish tended to rank higher when more nutrients were included
- Many fruits, vegetables and carbs declined in score when more nutrients were included
- Bread performed considerably better when sugar and salt were excluded (as in *n*-0)

Nutrient density scores (NDS) rankings

ROTHAMSTED RESEARCH

	Item	NDS 6-3	NDS 9-3	NDS 11-3	NDS 15-3	NDS 6-0	NDS 9-0	NDS 11-0	NDS 15-0
Protein	Peas	1	3	3	4	1	4	4	6
	Beans and pulses	2	2	2	3	2	3	3	4
	Nuts	3	1	1	1	3	1	1	1
	Groundnuts	8	4	8	6	5	2	2	3
	Tofu	9	9	11	12	14	14	14	14
	Cheese	14	14	14	14	4	5	5	5
	Eggs	12	12	12	11	10	12	10	10
	Poultry	4	6	10	10	8	9	13	13
	Pork	6	7	9	7	12	11	12	11
	Sheep	7	8	4	5	9	10	6	7
	Beef	10	10	6	8	6	7	7	8
	Farmed fish	5	5	5	2	11	6	9	2
	Crustaceans	13	13	13	13	13	13	11	12
Carbs	Bread (wheat)	3	3	3	3	1	1	1	1
	Potatoes	2	1	2	2	2	2	2	2
	Rice	1	2	1	1	3	3	3	3
Fruit & veg	Carrots	2	2	2	2	1	1	1	1
	Tomatoes	3	3	3	3	3	3	3	3
	Cucumber	4	4	4	4	6	6	6	6
	Cabbage	1	1	1	1	2	2	2	2
	Onions	5	5	5	5	4	4	4	4
	Apples	6	6	6	6	5	5	5	5

- Ranking split into sub-groups but still using the same NDS nutrients
- Does not take account of nutrient quality only quantity
- Favours multifunctionality – need for specific NDS nutrients for sectors

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The Eatwell Guide (Public Health England)

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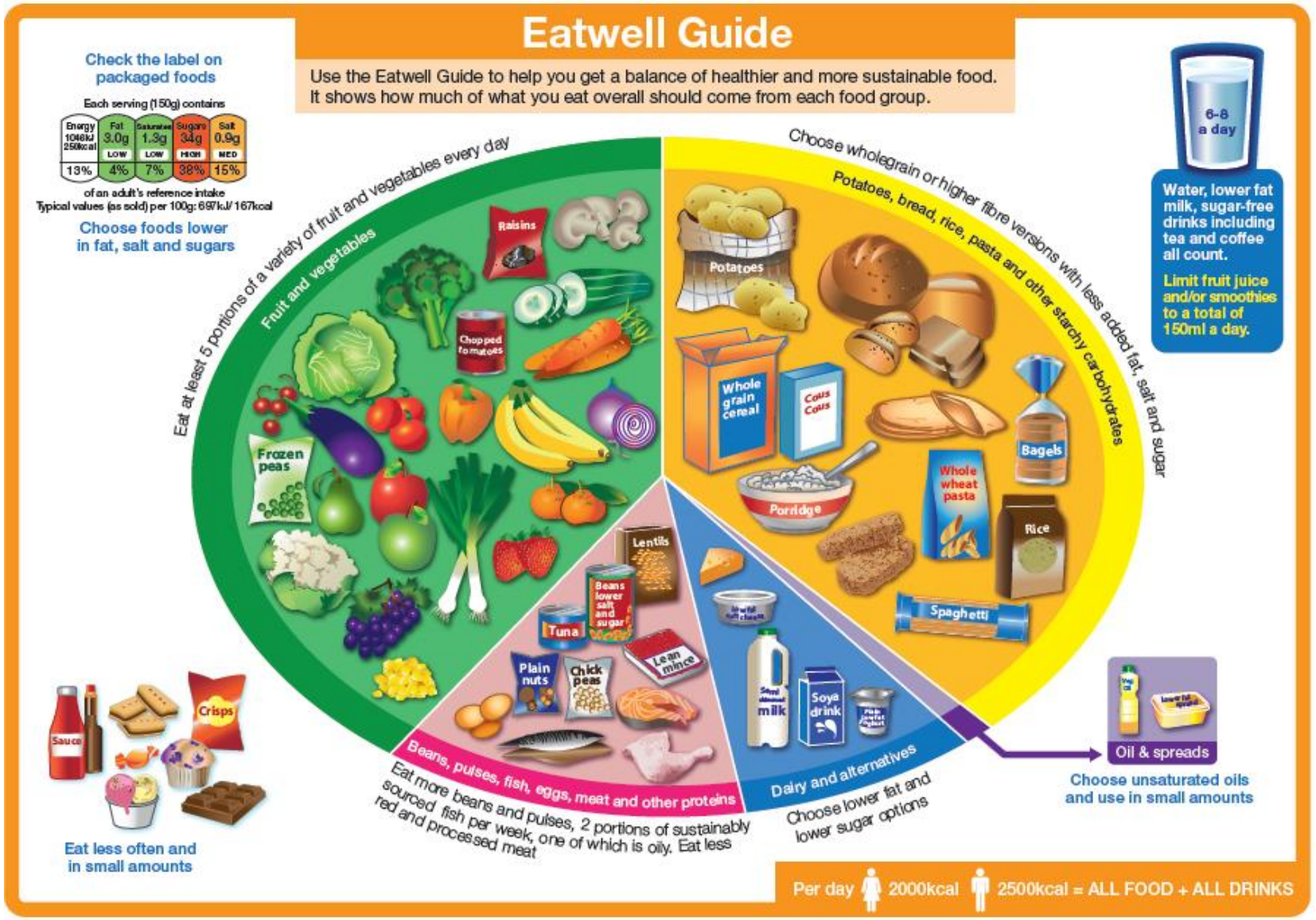

Food category	Recommended proportion
Fruit and vegetables	39%
Potatoes, bread, rice, pasta and other starchy carbohydrates	37%
Beans, pulses, fish, eggs, meat and other proteins	12%
Dairy and alternatives	8%
Oils and spreads	1%
Foods to eat less often and in small amounts	3%

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Basket analysis for marginal value of food items

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- Depending on what you eat a food item *with*, its true value is different (Stylianou et al., 2016)
- Here each basket represents the three main food groups: protein; energy (carbohydrates); water-soluble minerals and fibre (fruit and vegetables)
- 3 x 3 x 3 full factorial design (three items per food group)
- Each basket includes 660 kcal accounting for 88% of a 750 kcal meal (with allowance for seasonings and dessert)
- Carbon footprints were then calculated based under the defined NDS formulae

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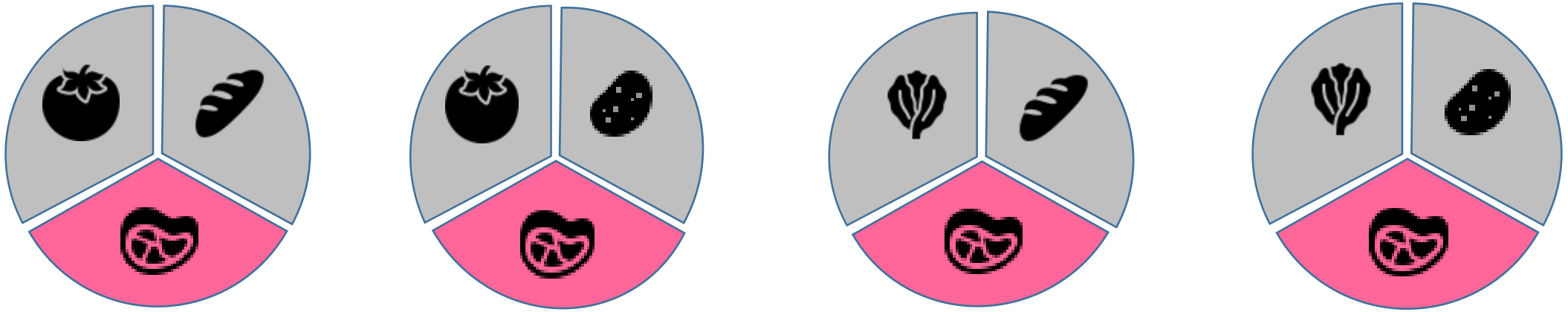
Basket analysis for marginal value of food items

ROTHAMSTED RESEARCH



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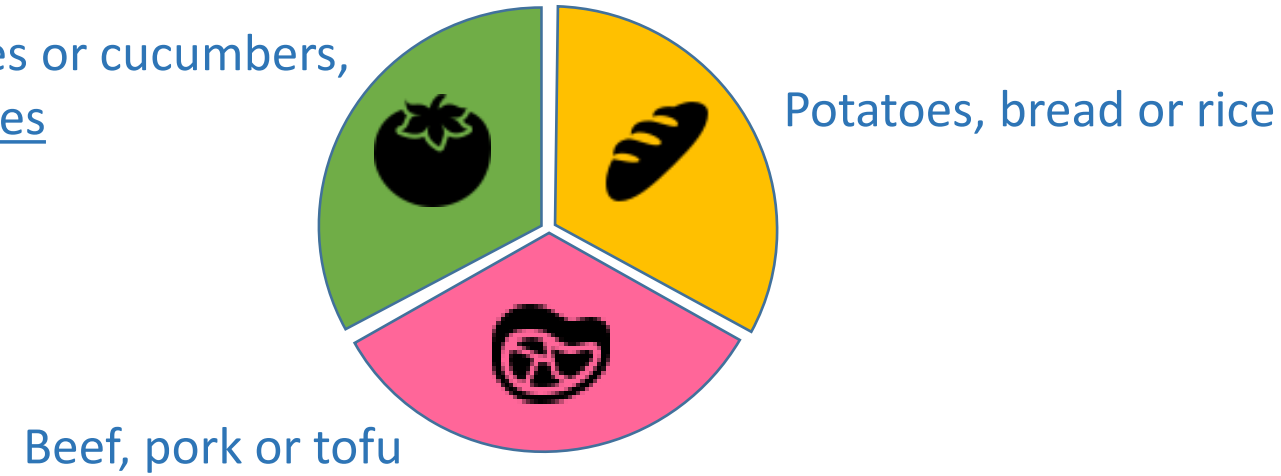
Basket analysis for marginal value of food items

ROTHAMSTED RESEARCH



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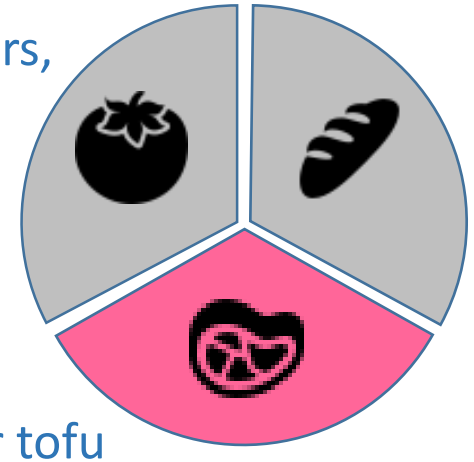
Basket analysis for marginal value of food items

ROTHAMSTED RESEARCH

Carrots, tomatoes or cucumbers, always with apples



Potatoes, bread or rice

Beef, pork or tofu

NDS scores for foods in protein group (% RI per meal, uncapped and capped)

	NDS 6		NDS 9		NDS 11		NDS 15	
Beef	14.7	5.7	12.4	4.2	28.4	16.7	23.9	14.8
Pork	16.3	4.7	14.8	3.7	19.7	10.6	23.0	10.9
Tofu	24.2	12.3	21.1	9.0	19.0	9.1	17.5	8.3

Average values across all combinations of carbs/vegs

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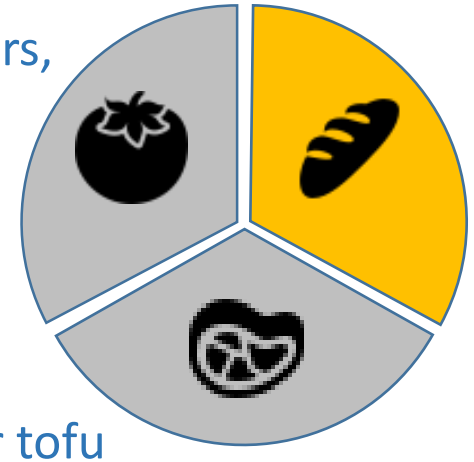
Basket analysis for marginal value of food items

ROTHAMSTED RESEARCH

Carrots, tomatoes or cucumbers, always with apples



Potatoes, bread or rice

Beef, pork or tofu

NDS scores for foods in carb group (% RI per meal) when consumed together with:

	NDS 6	NDS 9	NDS 11	NDS 15
Beef	8.3	7.4	6.9	6.5
Pork	8.3	7.2	7.5	6.9
Tofu	6.0	5.0	6.1	4.1

Average values across all combinations of carbs/vegs. Results similar for veg group.

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Basket analysis for marginal value of food items

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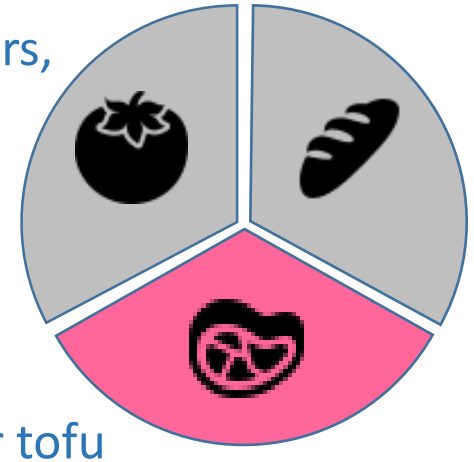
Carrots, tomatoes or cucumbers, always with apples



Potatoes, bread or rice

Beef, pork or tofu

Carbon footprint per %NDS (kg CO_2e)

	NDS 6	NDS 9	NDS 11	NDS 15
Beef	.316	.447	.107	.121
Pork	.175	.221	.077	.075
Tofu	.038	.052	.051	.056

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Basket analysis for marginal value of food items

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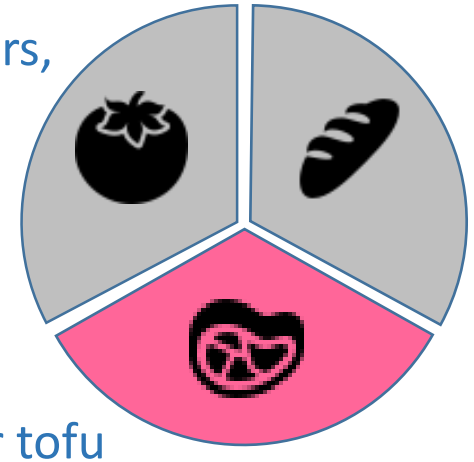
Carrots, tomatoes or cucumbers, always with apples



Potatoes, bread or rice

Beef, pork or tofu

Carbon footprint per %NDS (kg CO_2e)

	NDS 6	NDS 9	NDS 11	NDS 15
Beef	x8.4 tofu	.447	.107	x2.2 tofu
Pork	x4.6 tofu	.221	.077	x1.3 tofu
Tofu	.038	.052	.051	.056

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Nutrient density scores (NDS) rankings

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	Item	NDS 6-3	NDS 9-3	NDS 11-3	NDS 15-3	NDS 6-0	NDS 9-0	NDS 11-0	NDS 15-0	Protein (corrected)
Protein	Peas	1	3	3	4	1	4	4	6	9
	Beans and pulses	2	2	2	3	2	3	3	4	10
	Nuts	3	1	1	1	3	1	1	1	11
	Groundnuts	8	4	8	6	5	2	2	3	7
	Tofu	9	9	11	12	14	14	14	14	14
	Cheese	14	14	14	14	4	5	5	5	1
	Eggs	12	12	12	11	10	12	10	10	13
	Poultry	4	6	10	10	8	9	13	13	2
	Pork	6	7	9	7	12	11	12	11	3
	Sheep	7	8	4	5	9	10	6	7	6
	Beef	10	10	6	8	6	7	7	8	4
	Farmed fish	5	5	5	2	11	6	9	2	8
	Crustaceans	13	13	13	13	13	13	11	12	12
Carbs	Bread (wheat)	3	3	3	3	1	1	1	1	
	Potatoes	2	1	2	2	2	2	2	2	
	Rice	1	2	1	1	3	3	3	3	
Fruit & veg	Carrots	2	2	2	2	1	1	1	1	
	Tomatoes	3	3	3	3	3	3	3	3	
	Cucumber	4	4	4	4	6	6	6	6	
	Cabbage	1	1	1	1	2	2	2	2	
	Onions	5	5	5	5	4	4	4	4	
	Apples	6	6	6	6	5	5	5	5	

Conclusions

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- Studies are increasingly accounting for nutrient density in functional units of agri-food life cycle assessments
- Many of these studies use 9 nutrients to encourage and 3 to discourage without consideration of the effect of this choice
- Using a recent meta-analysis of all major food groups as a platform, this study investigated the carbon footprints of baskets containing common food items based on the Eatwell Guide
- Results demonstrate that environmental assessments are highly sensitive to the amount of nutrients included in density scores
- More importantly, these findings suggest that accounting for bioavailability would reverse relative rankings between animal and plant based products
- Future research should transparently and robustly test model assumptions and, ultimately, unbiased scoring methods should be applied in comparisons of food items in the *same* food group (e.g. apples with apples) rather than *across* groups

Acknowledgements

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