Food system sustainability performance metrics: for F&V crops

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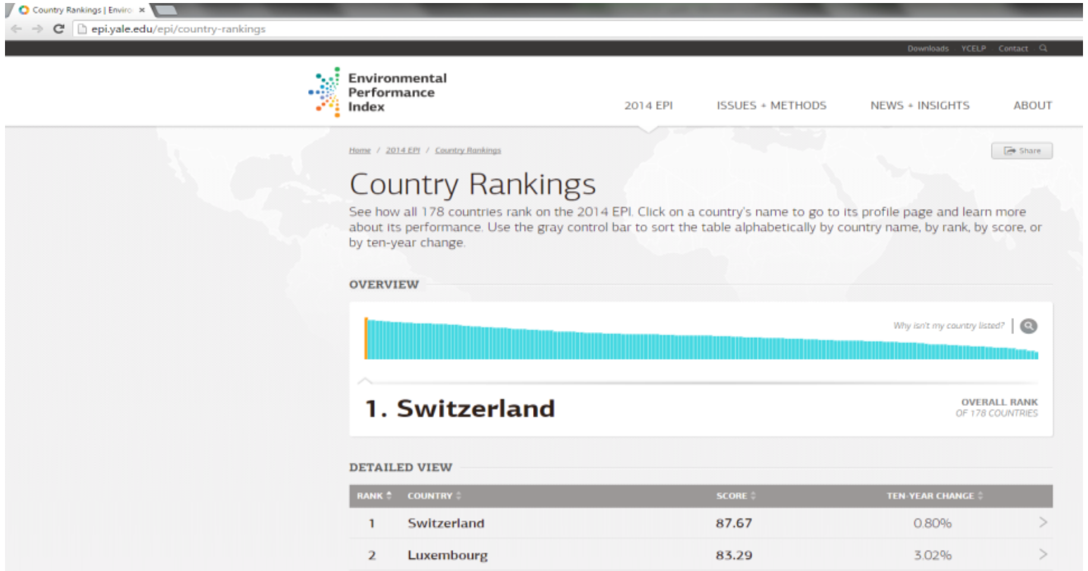
Food, Human Health and Sustainable Development Goals

2010 Global and U.S. burden of disease					
Global			**United States (U.S.)**		
Risk factor	**Deaths (Millions)**	**DALYs (Millions)**	**Risk factor**	**Deaths (Millions)**	**DALYs (Millions)**
Dietary risks	11.4	230.2	Dietary risks	0.7	11.5
High blood pressure	9.4	173.6	Tobacco smoking	0.5	9.7
Tobacco smoking	6.3	156.8	High blood pressure	0.4	6.4
Household air pollution from solid fuels	3.5	108.1	High body-mass index	0.4	8.9
High body-mass index	3.4	93.6	Physical inactivity and low physical activity	0.2	4.3
High fasting plasma glucose	3.4	89.0	High fasting plasma glucose	0.2	4.8
Ambient particulate matter pollution	3.2	76.2	High total cholesterol	0.2	2.8
Physical inactivity and low physical activity	3.2	69.3	Ambient particulate matter pollution	0.1	1.8
Alcohol use	2.7	97.2	Alcohol use	0.1	3.6
High total cholesterol	2.0	40.9	Drug use	0.03	2.4

Consumer awareness as first step towards designing demand side interventions

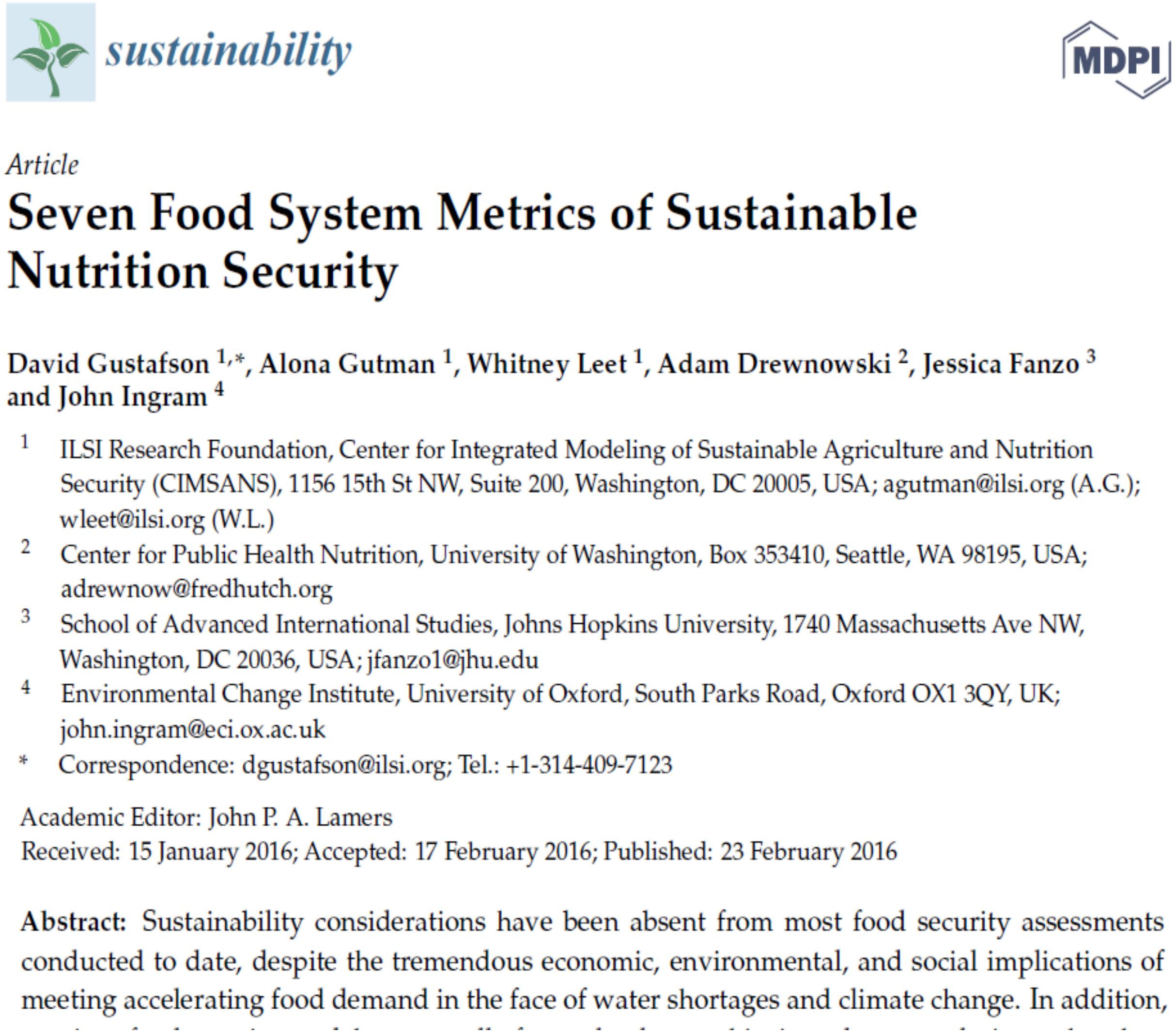
- Dietary changes provide novel opportunities for environment & human health, complementing technological and medicinal advancement
- Consumers – individuals, nations, organizations
- Consumer intervention success stories - Brazil soy moratorium, Roundtable on Sustainable Palm oil (RSPO), certified products
- Simplified picture can mislead towards complacency (e.g. EPI)



Gaps in global food system/dietary quantitative sustainabiliy assessment research

- Single country, single indicator, ‘siloed’ assessments
- United Nations’ 2030 sustainable development goals call for policies that take a systems approach and avoid trade-offs across different economic, social, environmental goals.
- On the nutrition side, focus has mostly been on calories, protein adequacy not accounting for micronutrients
- On the environmental side, GHG or water use has been most often used indicators
- Application of social and economic indicators is even rare

Sustainable Nutrition Security (SNS) Framework



sustainability

MDPI

Article

Seven Food System Metrics of Sustainable Nutrition Security

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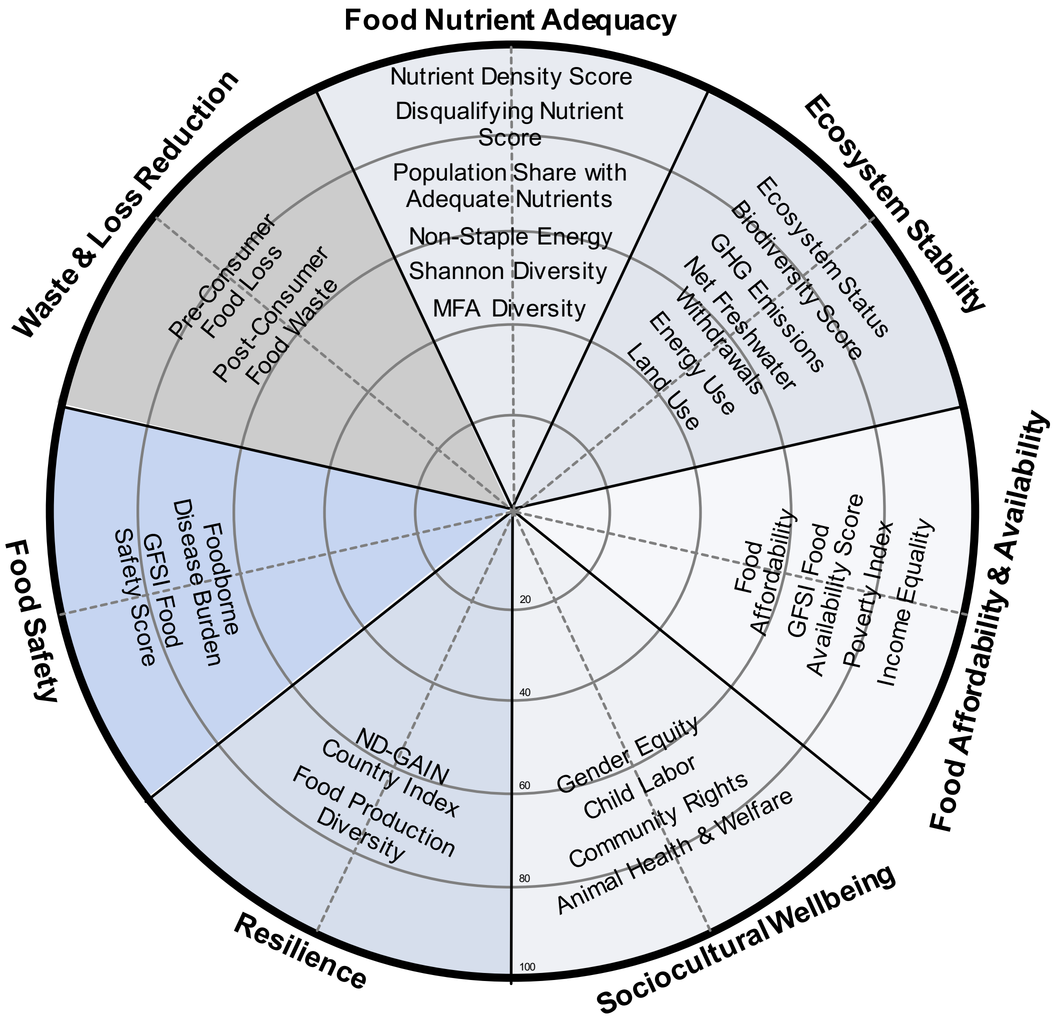
Abstract: Sustainability considerations have been absent from most food security assessments conducted to date, despite the tremendous economic, environmental, and social implications of meeting accelerating food demand in the face of water shortages and climate change. In addition,



Metric	Indicator	Median	Source	GDP correlation
Food Nutrient Adequacy		**61**		0.53
	Shannon Diversity of Food Supply	74	Remans et al.[33]	0.42
	Non-Staple Food Energy	46	Remans et al.[33]	0.72
	Modified Functional Attribute Diversity	77	Remans et al.[33]	0.70
	Population Share with Adequate Nutrients	76	This study	0.64
	Nutrient Balance Score	75	This study	0.46
	Disqualifying Nutrient Score	12	This study	-0.74
Ecosystem Stability		**47**		-0.36
	Ecosystem Status	43	Hsu et al. [34]	0.51
	Per-Capita GHG Emissions	51	This study	-0.79
	Per-Capita blue water consumption	50	This study	-0.75
	Per-Capita Land Use	50	Alexander et al.[9]	-0.09
	Per-Capita Non-Renewable Energy Use	28	World bank[35]	0.00
	Per-Capita Biodiversity Footprint	50	Chaudhary et	0.02
Affordability & Availability		**63**		0.83
	Food Affordability	54	GFSI[36]	0.85
	GFSI Food Availability Score	56	GFSI[36]	0.80
	Poverty Index	88	GFSI[36]	0.82
	Income Equality	62	World bank[37]	0.24
Sociocultural-Wellbeing		**60**		0.71
	Gender Equity	68	WEF[38]	0.43
	Extent of Child Labor	50	ILO[39]	0.59
	Respect for Community Rights	60	WRI[40]	0.63
	Animal Health & Welfare	60	API[41]	0.70
Resilience		**57**		0.64
	ND-GAIN Country Index	52	Chen et al.[42]	0.80
	Food Production Diversity	64	Remans et al.[33]	-0.20
Food Safety		**71**		0.76
	Global Burden of Foodborne Illnesses	50	WHO[43]	0.70
	Food Safety Score	88	GFSI[36]	0.80
Waste & Loss Reduction	Pre- & Post-Consumer Food Waste and Loss	**68**	FAO[44]	-0.68

Chaudhary et al. (2018) Multi-indicator sustainability assessment of global food systems. *Nature communications*,

Nutritional quality indicators

- **Nutrition balance score:** NBS = $100 \cdot \left(\frac{\sum_{k=1}^{25}\left(\frac{2000\ kcal}{E_k} \times \frac{a_k}{RDI_k}\right)}{25}\right)$
- **Disqualifying nutrient score** $DNS = 100 - 100 \cdot \left(\frac{\sum_{j=1}^{4}\left(\frac{2000}{E_j} \times \frac{a_j}{DRV_j}\right)}{4}\right)$
- **Percent of population with adequate intake (PAN):** % of people in a country with intakes of a particular nutrient above a demographically-weighted requirement threshold
- **Shannon Diversity:** $SD = -\sum_{i=1}^{N} p_i \cdot log\, p_i$
- **Modified Functional Attribute Diversity:** $MFAD = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} d_{i,j}}{N}$
- **Percent energy non-staples (PENS)**

Environmental indicators

- Carbon, blue water, land, acidification and eutrophication emission factors (e.g. kg CO2eq. Per kg of food item) are frequently available
  - LCA databases (e.g. Ecoinvent, Agrifootprint)
  - Meta-analysis data (e.g. Poore et al. (2018) *Science*)
- However biodiversity footprint factors have been rare
- Biodiversity contributes to ecosystem functions and its loss has economic/human-health consequences

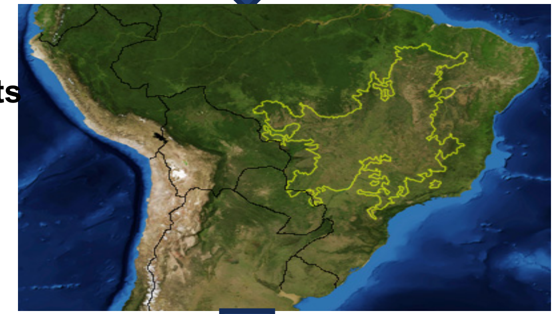
Product	m2/kg	kg CO2eq./kg	kg SO2eq/kg	kg $PO4^{3-}$eq/kg	Liters/kg
Wheat & Rye (Bread)	3.9	1.6	13.4	7.2	648
Maize (Meal)	2.9	1.7	11.7	4.0	216
Barley (Beer)	1.1	1.2	6.6	2.3	17
Oatmeal	7.6	2.5	10.7	11.2	482
Rice	2.8	4.5	27.2	35.1	2248
Potatoes	0.9	0.5	3.9	3.5	59
Cassava	1.8	1.3	3.4	0.7	0
Cane Sugar	2.0	3.2	18.0	16.9	620
Beet Sugar	1.8	1.8	12.6	5.4	218
Other Pulses	15.6	1.8	22.1	17.1	436
Peas	7.5	1.0	8.5	7.5	397
Nuts	13.0	0.4	45.2	19.2	4134
Groundnuts	9.1	3.2	22.6	14.1	1852
Soymilk	0.7	1.0	2.6	1.1	28
Tofu	3.5	3.2	6.7	6.2	149
Soybean Oil	10.5	6.3	15.7	11.7	415
Palm Oil	2.4	7.3	17.5	10.7	6
Sunflower Oil	17.7	3.6	28.0	50.7	1008
Rapeseed Oil	10.6	3.8	28.5	19.2	238
Olive Oil	26.3	5.4	37.6	37.3	2142
Tomatoes	0.8	2.1	17.2	7.5	370
Onions & Leeks	0.4	0.5	3.6	3.2	14
Root Vegetables	0.3	0.4	2.9	1.6	28
Brassicas	0.6	0.5	8.2	5.0	119
Other Vegetables	0.4	0.5	6.4	2.3	103
Citrus Fruit	0.9	0.4	4.0	2.2	83
Bananas	1.9	0.9	6.4	3.3	115
Apples	0.6	0.4	3.5	1.5	180
Berries & Grapes	2.4	1.5	12.3	6.1	420
Wine	1.8	1.8	12.8	4.6	79
Other Fruit	0.9	1.1	5.8	2.4	154
Coffee	21.6	28.5	83.1	110.5	26
Dark Chocolate	69.0	46.7	46.3	87.1	541
Bovine Meat (beef herd)	326.2	99.5	318.8	301.4	1451
Bovine Meat (dairy herd)	43.2	33.3	343.6	365.3	2714
Lamb & Mutton	369.8	39.7	139.0	97.1	1803
Pig Meat	17.4	12.3	142.7	76.4	1796
Poultry Meat	12.2	9.9	102.4	48.7	660
Milk	9.0	3.2	20.0	10.7	628
Cheese	87.8	23.9	165.5	98.4	5605
Eggs	6.3	4.7	53.7	21.8	578
Fish (farmed)	8.4	13.6	65.9	235.1	3691
Crustaceans (farmed)	3.0	26.9	133.1	227.2	3515

Product biodiversity footprinting

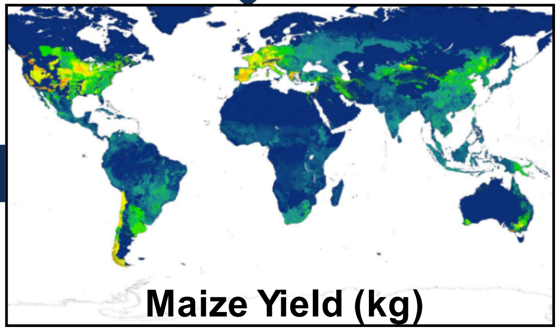
$$S_{lost,g,j}^{countryside} = S_{org,j} - S_{org,j} \cdot \left(\frac{A_{new,j} + \sum_{i=1}^{n} h_{g,i,j} \cdot A_{i,j}}{A_{org,j}} \right)^{z_j}$$

- Impacts for ~8000 crop x country combinations
- Connected with FAO food trade database

Local impacts

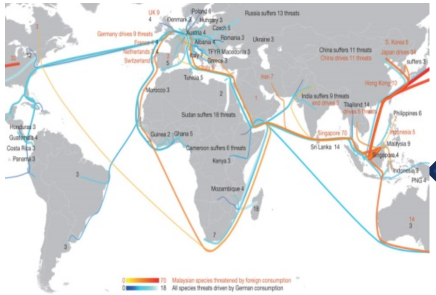


Regional impacts



Crop yields

Impacts per kg

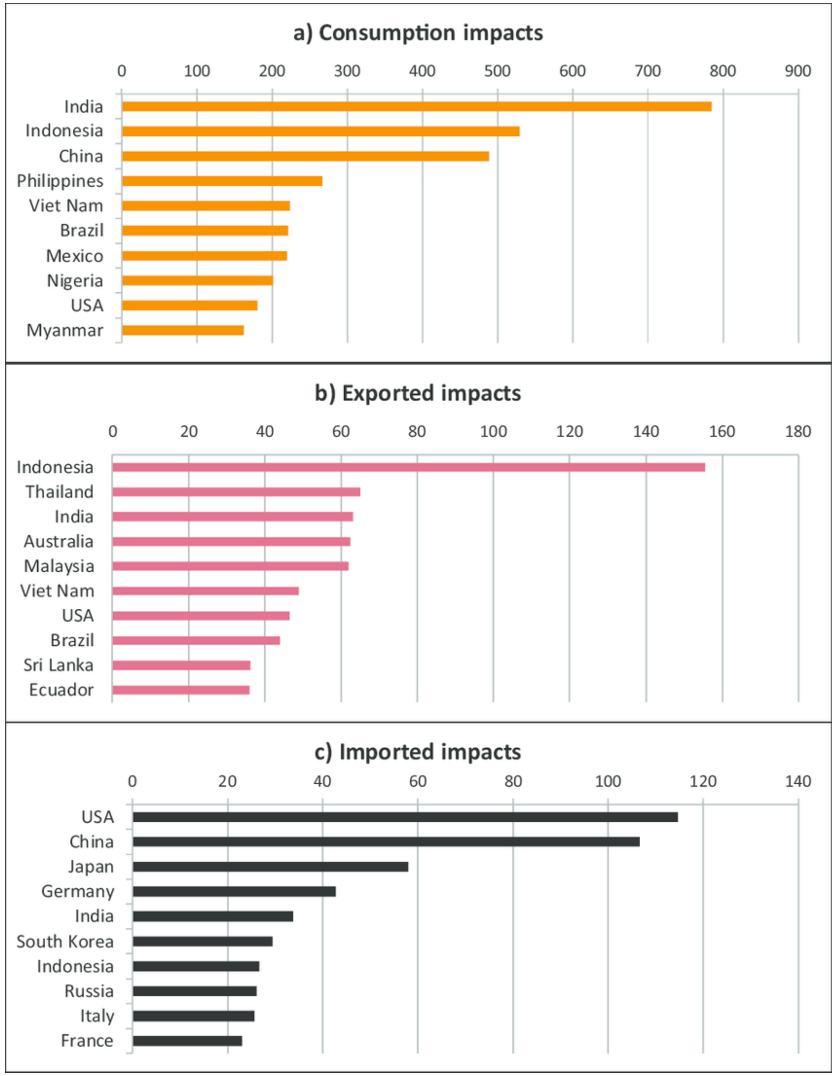


Biodiversity Impacts traded

Chaudhary, A. and Kastner, T., 2016. Land use biodiversity impacts embodied in international food trade. *Global Environmental Change*, *38*, 195-204
Chaudhary, A. and Brooks, T.M., 2017. National consumption and global trade impacts on biodiversity. *World Development*.

F&V biodiversity footprints (Projected species loss per kg)

Impacts in	Driven by	Mammals	Birds	Amphibians	Major causes	Rank area
Indonesia	USA	7	5	2	Rubber, cocoa, coffee	23
Indonesia	China	8	5	2	Palm oil, rubber	26
Mexico	USA	7	4	2	Coffee, vegetables, fruits	32
Indonesia	India	7	4	2	Palm oil, cashew, nuts	22
Thailand	China	8	4	1	Rubber, cassava, fruits	15
Malaysia	China	7	4	2	Palm oil, rubber	46
Indonesia	Japan	5	3	1	Rubber, coffee, cocoa	54
Ecuador	USA	5	3	2	Cocoa beans, coffee	189
Viet Nam	China	4	3	1	Cassava, rubber, rice	108
India	China	3	4	0	Cotton, castor, rapeseed	9
USA	China	2	5	1	Soybean, cotton	1
Australia	Indonesia	1	4	0	Wheat	11
Australia	Japan	1	4	0	Wheat, barley	10
Brazil	China	2	1	2	Soybean	2
USA	Mexico	2	4	0	Wheat, soybean, sorghum	3
Guatemala	USA	2	1	1	Coffee, bananas	243
Indonesia	Germany	2	2	1	Palm oil, rubber, coffee	125
Viet Nam	Indonesia	3	2	0	Rice	154
Indonesia	S. Korea	2	1	1	Rubber, coconut, palm oil	156
Sri Lanka	Russia	2	1	1	Tea	966



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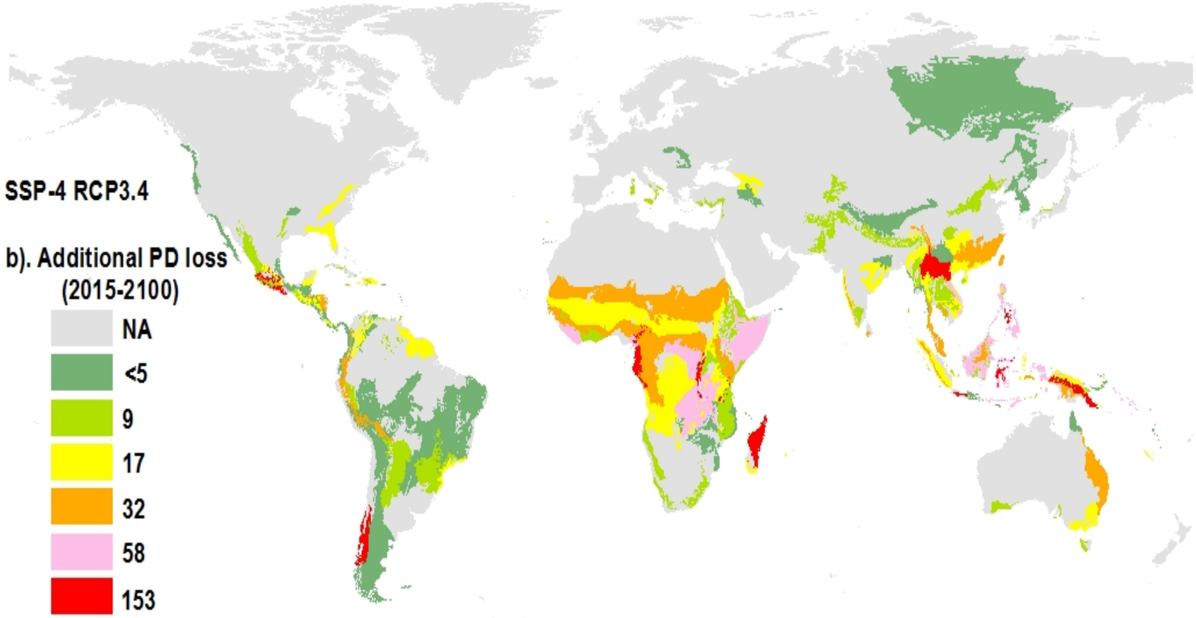
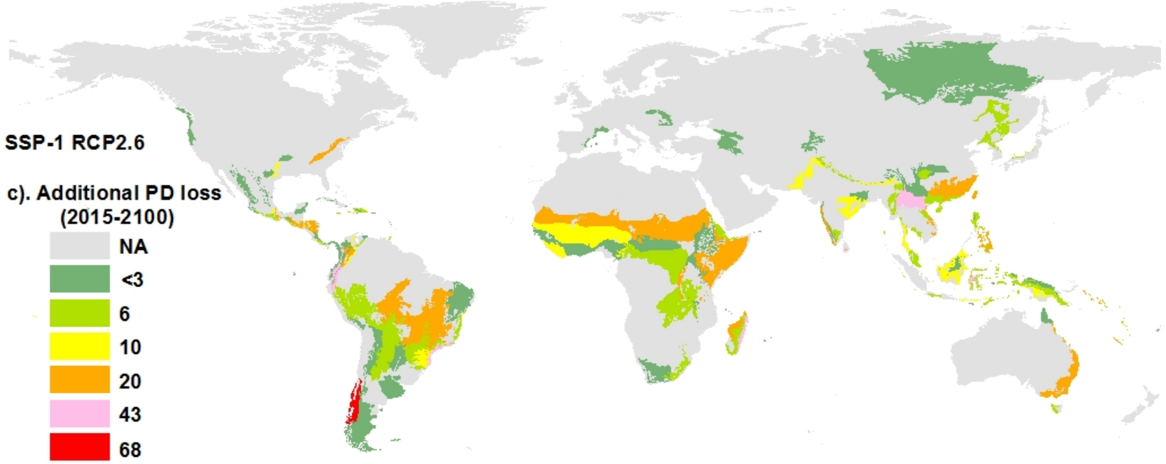
Future scenarios and hotspots of biodiversity loss

- The most aggressive climate mitigation scenario (RCP2.6 SSP-1), representing a world shifting towards a radically more sustainable path including increasing crop yields, reduced meat production and reduced tropical deforestation coupled with high trade, projects the lowest land use change driven global biodiversity loss followed by RCP8.5 SSP-5, RCP6.0 SSP-4 and RCP7.0 SSP-3.
- Interestingly, the scenario with the second most aggressive climate target (RCP3.4 SSP-4) projected the highest biodiversity loss among the five scenarios tested. This is because it represents a world with continued high consumption in rich countries and increased land clearing for crop production in species rich, low-income countries such as Indonesia, Madagascar, Tanzania, Philippines and DR Congo.





Chaudhary, A. and Mooers, A.O., 2017. Biodiversity loss under future global socio-economic and climate scenarios. *bioRxiv*, p.235705.

Application of SNS Framework to Global Diets – First results

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ARTICLE

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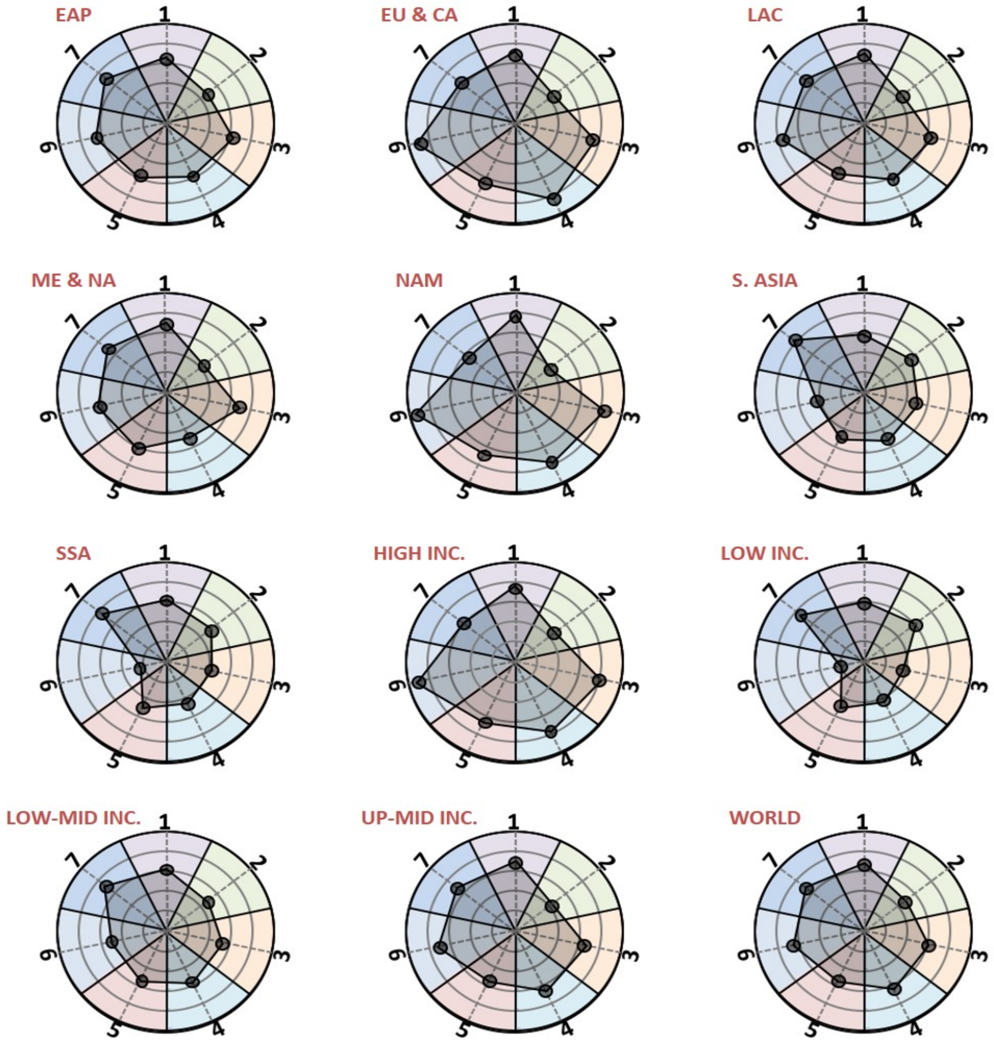
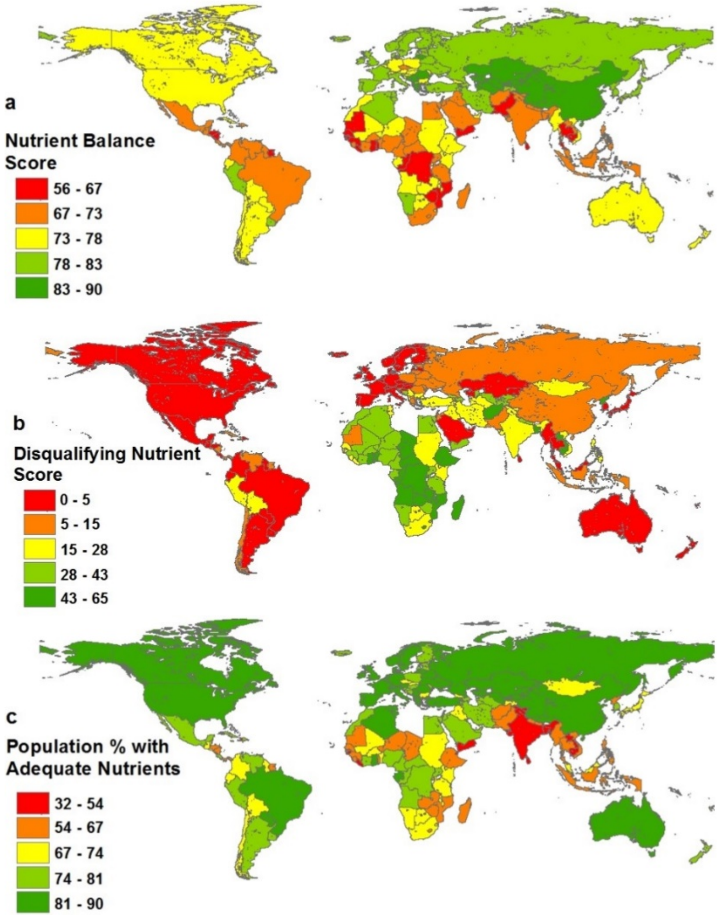
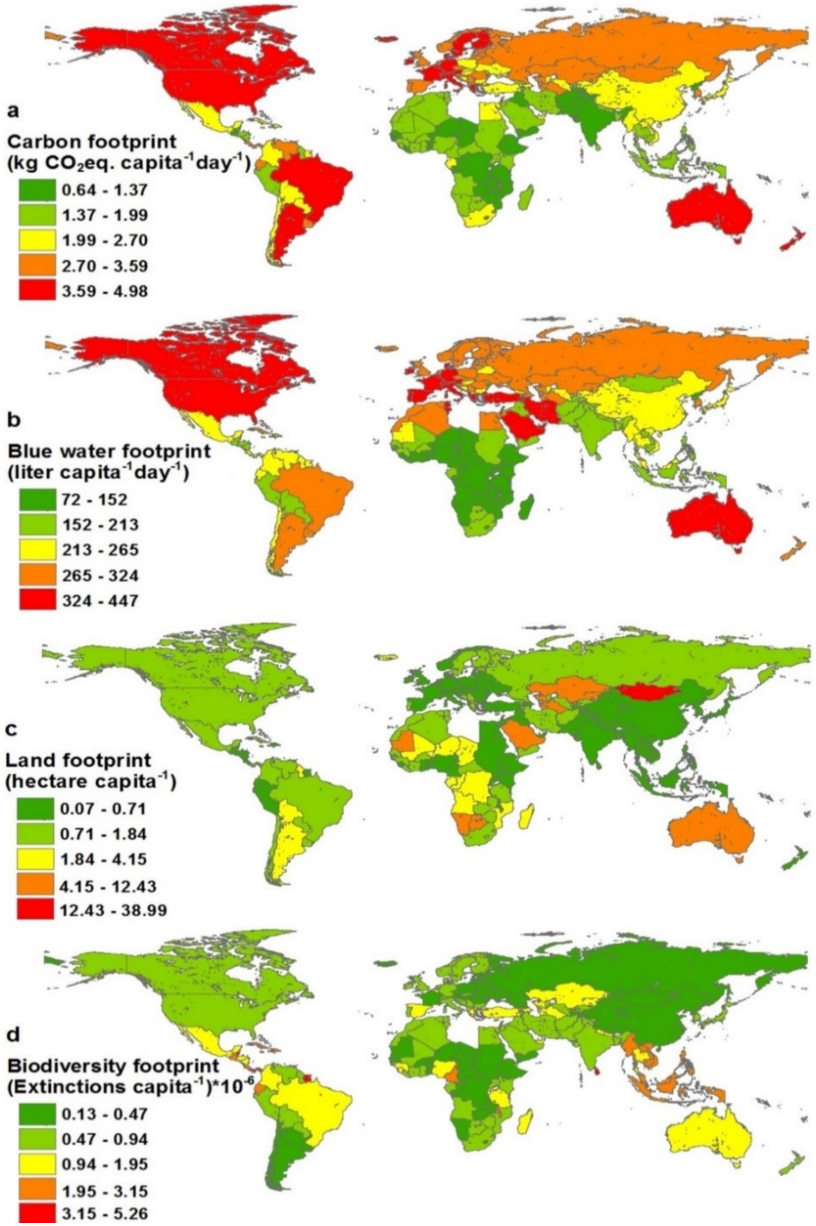
Multi-indicator sustainability assessment of global food systems

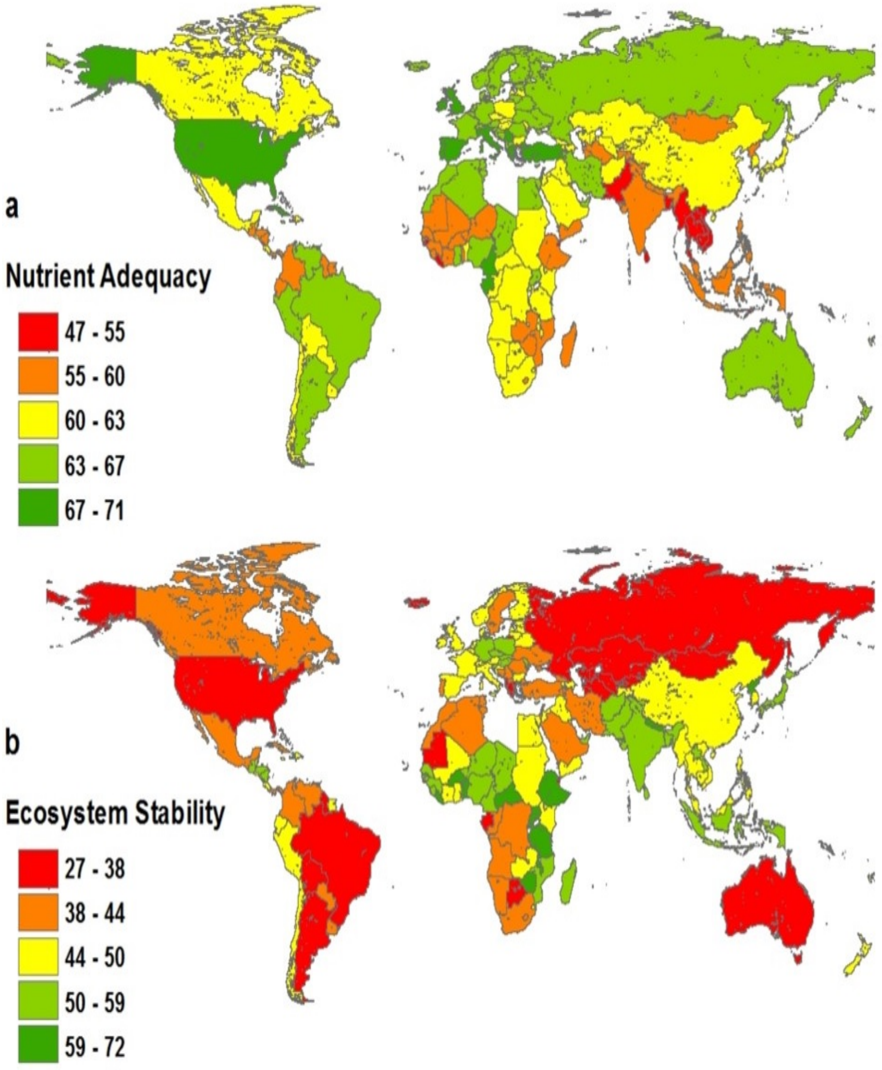
Abhishek Chaudhary [1], David Gustafson [2] & Alexander Mathys [1]

Food systems are at the heart of at least 12 of the 17 Sustainable Development Goals (SDGs). The wide scope of the SDGs call for holistic approaches that integrate previously "siloed" food sustainability assessments. Here we present a first global-scale analysis quantifying the status of national food system performance of 156 countries, employing 25 sustainability indicators across 7 domains as follows: nutrition, environment, food affordability and availability, sociocultural well-being, resilience, food safety, and waste. The results show that different countries have widely varying patterns of performance with unique priorities for improvement. High-income nations score well on most indicators, but poorly on environmental, food waste, and health-sensitive nutrient-intake indicators. Transitioning from animal foods toward plant-based foods would improve indicator scores for most countries. Our nation-specific quantitative results can help policy-makers to set improvement targets on specific areas and adopt new practices, while keeping track of the other aspects of sustainability.









Chaudhary et al. (2018) Multi-indicator sustainability assessment of global food systems. *Nature communications*,

When it comes to food system sustainability, there are no ‘developed’ countries, only developing.

Nutritional and Environmental consequences of Dietary transformation

Healthy global diet (HGD)	Vegetarian (VGT)	Vegan (VGN)
<50g sugar/cap/day	<50g sugar/cap/day	<50g sugar/cap/day
<43g of red meat/cap/day	0 g of meat/cap/day	0 g of meat/cap/day
≥ 5 portions (400g) of FV	≥ 6 portions (480g) of FV	≥ 7 portions (480g) of FV
2200 – 2300 kcal/cap/day	2200 – 2300 kcal/cap/day	2200 – 2300 kcal/cap/day
	≥ 1 serving (80g) of pulses	≥ 1 serving (80g) of pulses

Region	Scenario	NBS	DNS	PAN	Carbon Footprint	Water
East Asia & Pacific (EAP)	REF	74	14	68	2.33	225
	HGD	+3	+4	+9	+0.02	+30
	VGT	+1	+10	+5	-0.58	+27
	VGN	-1	+34	+2	-0.69	+38
Europe & Central Asia (EU&CA)	REF	80	10	82	3.04	303
	HGD	+1	+3	-4	-0.89	-68
	VGT	0	+10	-5	-1.48	-79
	VGN	-4	+50	-12	-2.01	-85
Latin America & Caribbean (LAC)	REF	73	7	72	2.36	229
	HGD	+5	+5	+5	-0.17	-10
	VGT	+4	+15	+2	-0.88	-19
	VGN	0	+43	-3	-1.14	-18
Middle East & North Africa (ME&NA)	REF	75	19	77	1.97	302
	HGD	+2	+4	-1	-0.32	-42
	VGT	+1	+13	-5	-0.88	-42
	VGN	-1	+33	-8	-1.10	-36
North America (NAM)	REF	77	0	84	4.25	348
	HGD	+3	0	-9	-1.74	-121
	VGT	+2	+10	-9	-2.64	-134
	VGN	-1	+50	-16	-3.12	-138
South Asia (S. Asia)	REF	68	24	56	1.52	207
	HGD	+6	+4	+17	+0.45	+69
	VGT	+5	+6	+15	+0.03	+74
	VGN	+3	+23	+12	-0.16	+81
Sub-Saharan Africa (SSA)	REF	71	38	68	1.48	141
	HGD	+3	-1	+9	+0.24	+35
	VGT	+1	+3	+5	-0.25	+33
	VGN	0	+13	+3	-0.37	+34

Food innovation has the potential to contribute towards food sustainability

Ingredient (g)	Pan bread*		Breakfast cereal*		Pasta*	
	Traditional	Reformulated	Traditional	Reformulated	Traditional	Reformulated
Whole yellow pea flour	0	83.25	0	536.00	0	301.69
Refined wheat bread flour†	555.00	471.75	0	0	0	0
Refined all-purpose wheat flour, unbleached†	0	0	1011.00	475.33	0	0
Durum Semolina flour†	0	0	0	0	1005.64	703.95
Water	391.36	391.36	53.33	53.33	251.41	251.41
Sugar	22.36	22.36	53.33	53.33	0	0
Shortening‡	22.36	22.36	0	0	0	0
Salt	7.27	7.27	5.33	5.33	0	0
Yeast (fresh)	22.36	22.36	0	0	0	0
Milk powder	11.18	11.18	0	0	0	0
Dough conditioner¥	11.18	11.18	0	0	0	0

Product	% of Total Flour per Formulation*		Indices of Nutritional Quality			Carbon Footprint		NCFS
	Wheat Flour	Yellow Pea Flour	QI	DI	NBS (%)	$kgCO_2eq$/ Kg food	gCO_2eq/ Serving†	(NBS/ gCOeq/serv
Pan Bread								
Traditional*	100	0	0.62	0.40	47	0.405	31.70	1.49
Reformulated	85	15	0.70	0.40	52	0.389	30.43	1.72
Breakfast Cereal								
Traditional	100	0	0.40	0.17	30	0.979	32.99	0.91
Reformulated	47	53	0.76	0.20	51	0.875	29.40	1.73
Pasta								
Traditional	100	0	0.57	0.03	43	0.610	65.20	0.67
Reformulated	70	30	0.74	0.04	51	0.532	56.85	0.90

Chaudhary, A., et al. 2018. Nutritional Combined Greenhouse Gas Life Cycle Analysis for Incorporating Canadian Yellow Pea into Cereal-Based Food Products. *Nutrients*, *10*(4), 490.

Key messages

- Sustainable food consumption behaviors (demand-side interventions) can contribute significantly towards improving global nutritional/health standards while reducing anthropogenic environmental footprint
- This can compliment supply side and other interventions such as improvements in agricultural production technology, closing yield gaps, reducing food losses and waste, plant breeding/genetic advancements
- Underscores the importance of holistic (multi-indicator) analysis
- Each country has unique priorities (high score in one but low in other)

What are the biggest unanswered questions and data gaps on F&V food systems?

- Detailed nutrient composition data for all food varieties (factor of 2 difference between amount of micronutrients in different varieties of Broccoli)
- Nutrient loss occuring during storage, transport, processing, cooking
- Region and production system-specific inventory or footprints unavailable (e.g. GHG emissions from organic F&V in SE-Asia/Africa)
- Global land use intensity or production systems gridded maps
- Quantitative indicators of ecosystem service impacts of F&V production (e.g. provisioing, regulating, supporting, cultural services)
  - The Economics of Ecosystem and Biodiversity (TEEB), The Natural Capital project

What can be done?

- Further interdisciplinary exchange between not only scientific fields but with media, arts, industry, culinary, politics actors
- investment in data collection,
- harmonization/consensus on suitable indicators to monitor progress and impact of policy interventions
- custumized region-specific solutions (e.g. tropical, water scarce, low-income regions) rather than one size fits all

Thank You

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