Environmental impacts of beef and milk-containing diets relative to other human activities

Michael Hauschild (mzha@dtu.dk)

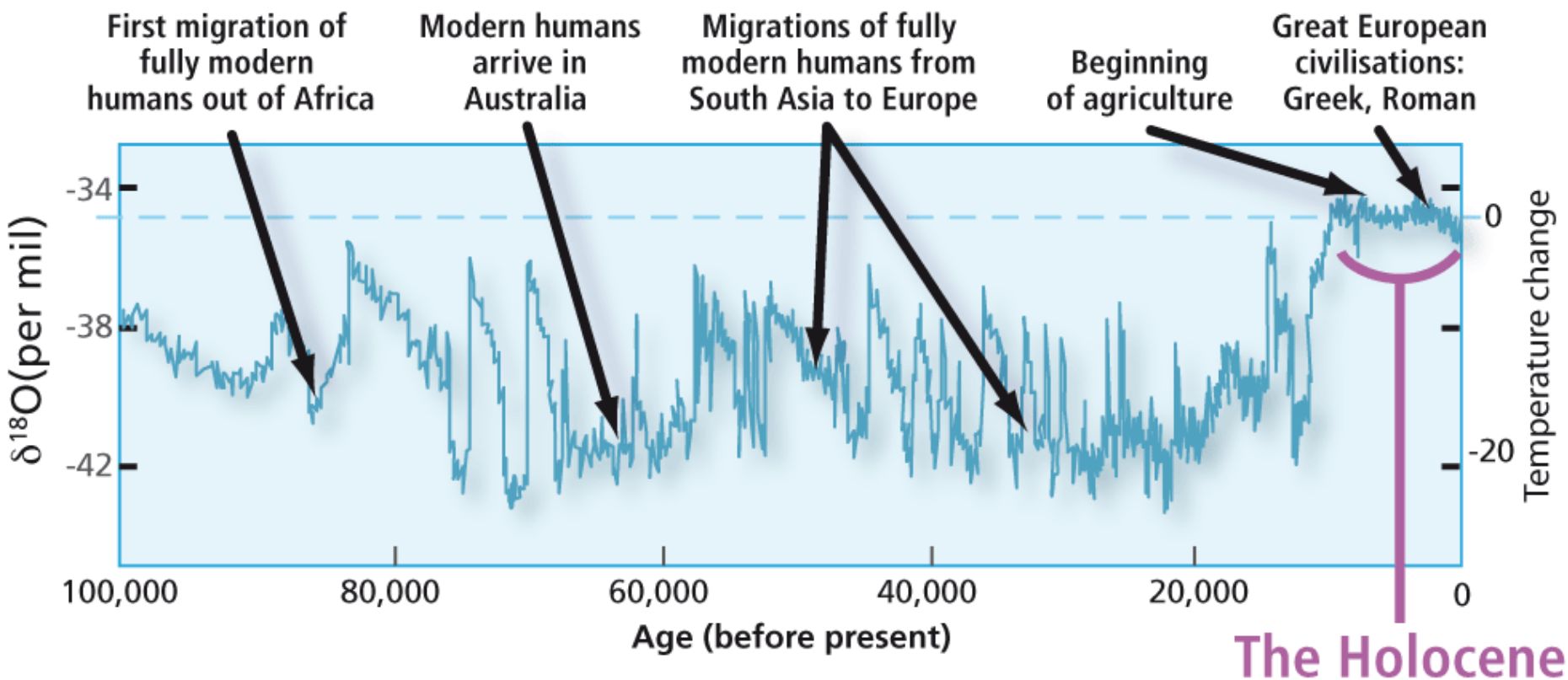
Quantitative Sustainability Assessment, QSA
DTU Management
Technical University of Denmark

Outline

- Absolute boundaries for sustainability
- The sustainability challenge to eco-efficiency
- How do we measure eco-efficiency?
- Relative and absolute assessments – efficiency and effectiveness
- Challenges for the food sector

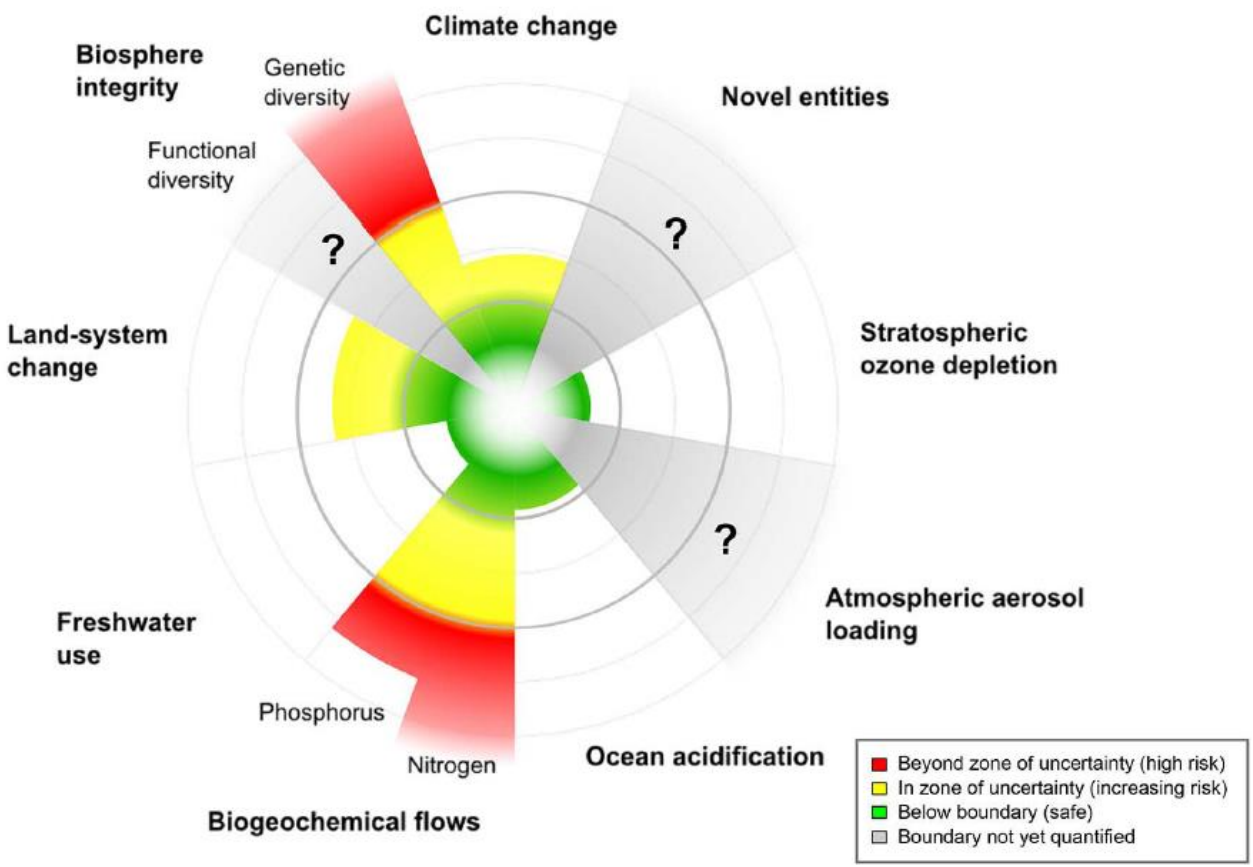
Planetary boundaries

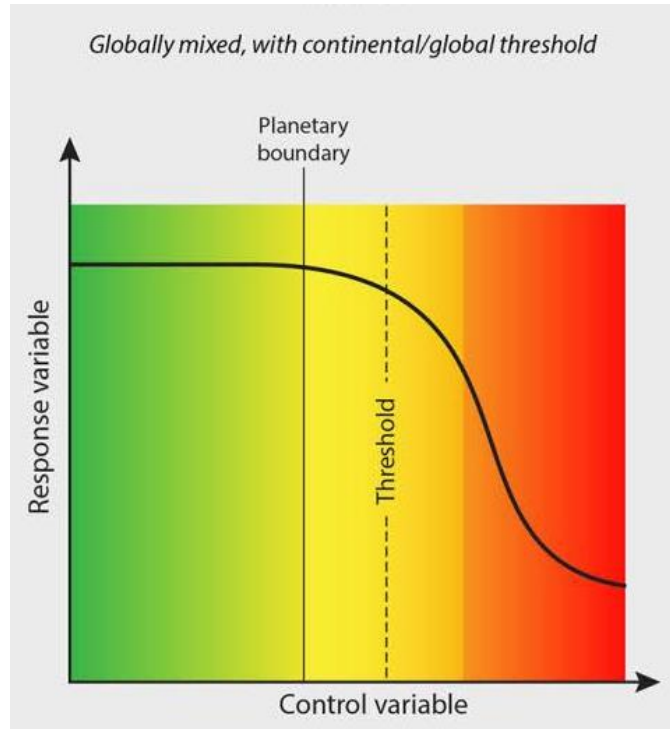
Keeping the planet in the holocene



International Geosphere Biosphere Programme: http://www.igbp.net/globalchange/anthropocene.4.1b8ae20512db692f2a680009238.html (accessed 29 10 2018)

Planetary boundaries





Steffen W, Richardson K, Rockström J et al. (2015b) Planetary boundaries: Guiding human development on a changing planet. Science 347(6223), 736-746

Eco-efficiency

Eco-efficiency is the "environmental price" of obtaining a service, meeting a need, creating a value

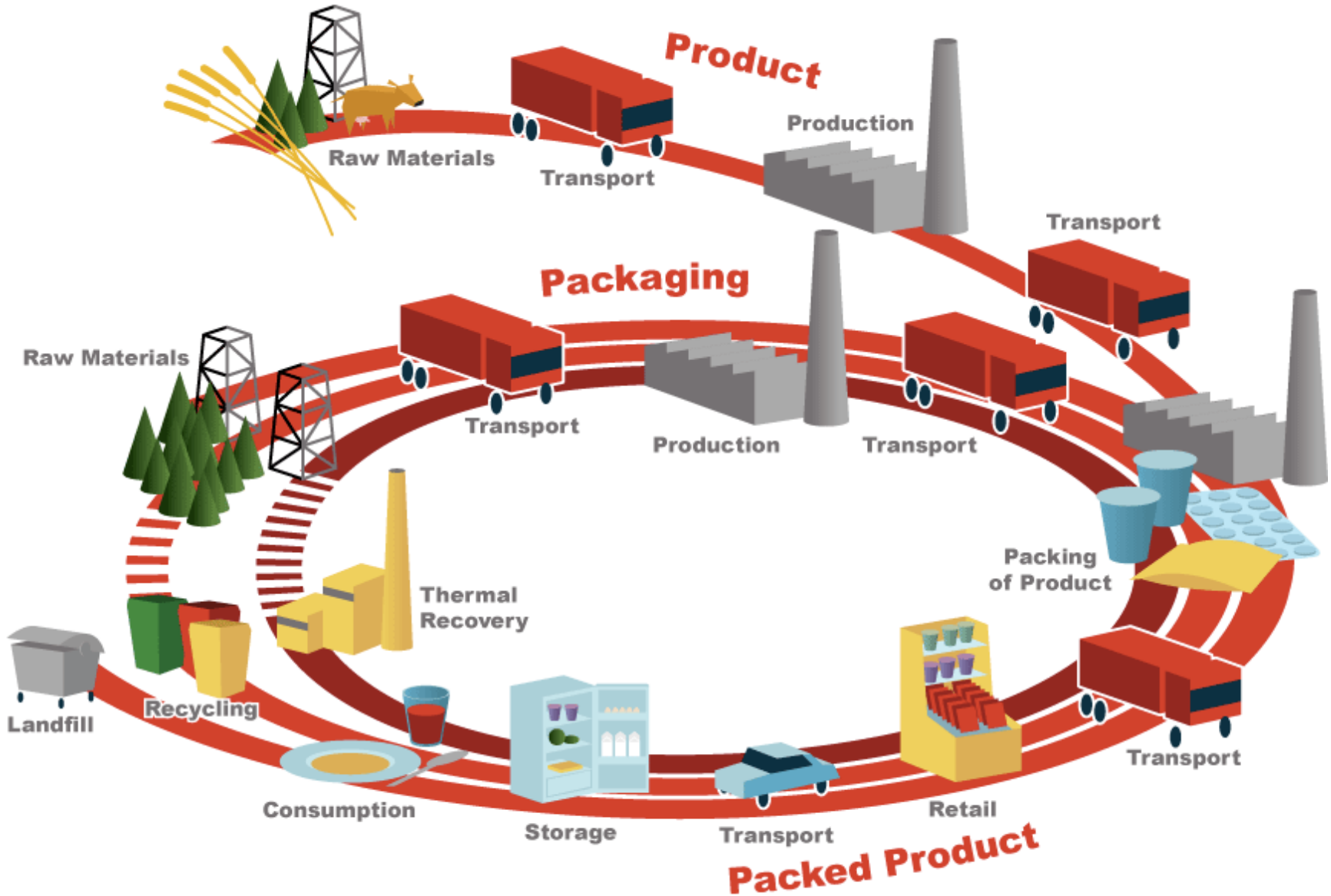
$$\textbf{\textit{Eco-efficiency}} = \frac{\textbf{\textit{Delivered service}}}{\textbf{\textit{Environmental impact}}}$$

Eco-efficiency means creating more with less

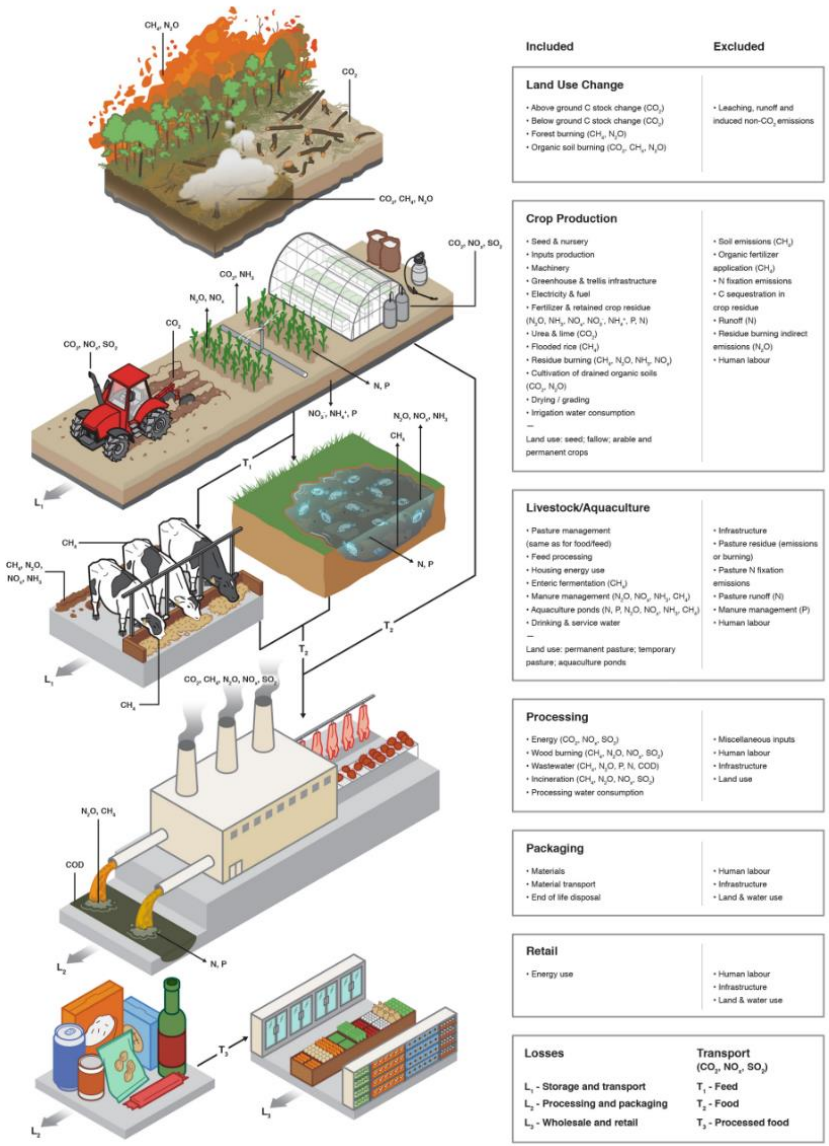
Overall eco-efficiency must increase at least one order of magnitude to

- meet the needs of a growing population
- supporting increasing standards of living
- … and stay within central planetary boundaries

How do we measure eco-efficiency?



Modelling the life cycle



Throughout the life cycle processes exchange substances and materials with the surroundings

- Resources and materials go in
- Products, emissions and waste go out

All these exchanges have the potential to impact on the environment and contribute to the environmental problems that we know

We have to study the environmental impacts throughout the life cycle

Poore and Nemecek (2018) Reducing food's environmental impacts through producers and consumers. Science 360, 987-992

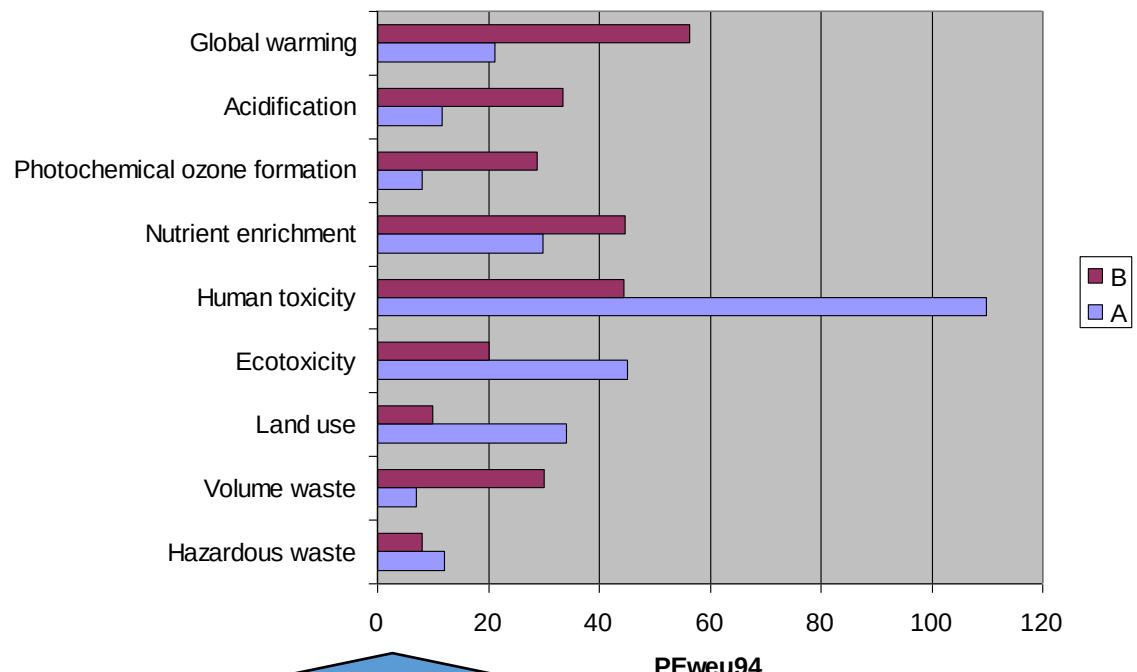
Life Cycle Assessment (LCA)

Inventory of environmental exchanges

		Emission	Emission
	CAS.no.	to air	to w ater
Substance		g	g
2-hydroxy-ethanacrylate	816-61-0	0,0348	
4,4-methylenebis cyclohexylamine	1761-71-2	5,9E-02	
Ammonia	7664-81-7	3,7E-05	4,2E-05
Arsenic (As)	7440-38-2	2,0E-06	
Benzene	71-43-2 (cur	5,0E-02	
Lead (Pb)	7439-92-1	8,5E-06	
Butoxyethanol	111-76-2	6,6E-01	
Carbondioxide	124-38-9	2,6E+02	
Carbonmonoxide (CO)	630-08-0	1,9E-01	
Cadmium (Cd)	7440-46-9	2,2E-07	
Chlorine (Cl2)	7782-50-5	4,6E-04	
Chromium (Cr VI)	7440-47-3	5,3E-06	
Dicyclohexane methane	86-73-6	5,1E-02	
Nitrous oxide(N2O)	10024-97-2	1,7E-02	
2,4-Dinitrotoluene	121-14-2	9,5E-02	
HMDI	5124-30-1	7,5E-02	
Hydro carbons (electricity, stationary combustic	-	1,7E+00	
Hydrogen ions (H+)	-		1,0E-03
i-butanol	78-83-1	3,5E-02	
i-propanol	67-63-0	9,2E-01	
copper (Cu)	7740-50-8	1,8E-05	
Mercury(Hg)	7439-97-6	2,7E-06	
Methane	74-82-8	5,0E-03	
Methyl i-butyl ketone	108-10-1	5,7E-02	
Monoethyl amine	75-04-7		7,9E-06
Nickel (Ni)	7440-02-0	1,1E-05	
Nitrogen oxide (NOx)	10102-44-0	1,1E+00	
NMVOC, diesel engine (exhaust)	-	3,9E-02	
NMVOC, pow er plants (stationary combustion)	-	3,9E-03	
Ozone (O3)	10028-15-6	1,8E-03	
PAH	ikke specifik	2,4E-08	
Phenol	108-95-2		1,3E-05
Phosgene	75-44-5	1,4E-01	
Polyeter polyol	ikke specifik	1,6E-01	
1,2-propylenoxide	75-56-9	8,2E-02	
Nitric acid	7782-77-6 (c	8,5E-02	
Hydrochloric acid	7647-01-0 (c	1,9E-02	
Selenium (Se)	7782-49-2	2,6E-05	
Sulphur dioxide(SO2)	7446-09-5	1,3E+00	
Toluene	108-88-3	4,8E-02	
Toluene-2,4-diamine	95-80-7	7,9E-02	
Toluene diisocyanat (TDI)	26471-62-5	1,6E-01	
Total-N	-		2,6E-05
Triethylamine	121-44-8	1,6E-01	
Unspecified aldehydes	-	7,5E-04	
Uspecified organic compounds	-	1,5E-03	
Vanadium	7440-62-2	1,8E-04	
VOC, diesel engine (exhaust)	-	6,4E-05	
VOC, stationary combustion (coal fired)	-	4,0E-05	
VOC, stationary combustion (natural gas fired)	-	2,2E-03	
VOC, stationary combustion (oil fired)	-	1,4E-04	
Xylene	1330-20-7	1,4E-01	
Zinc (Zn)	7440-66-6	8,9E-05	

Analysed system (life cycle)

Environmental profile of solutions



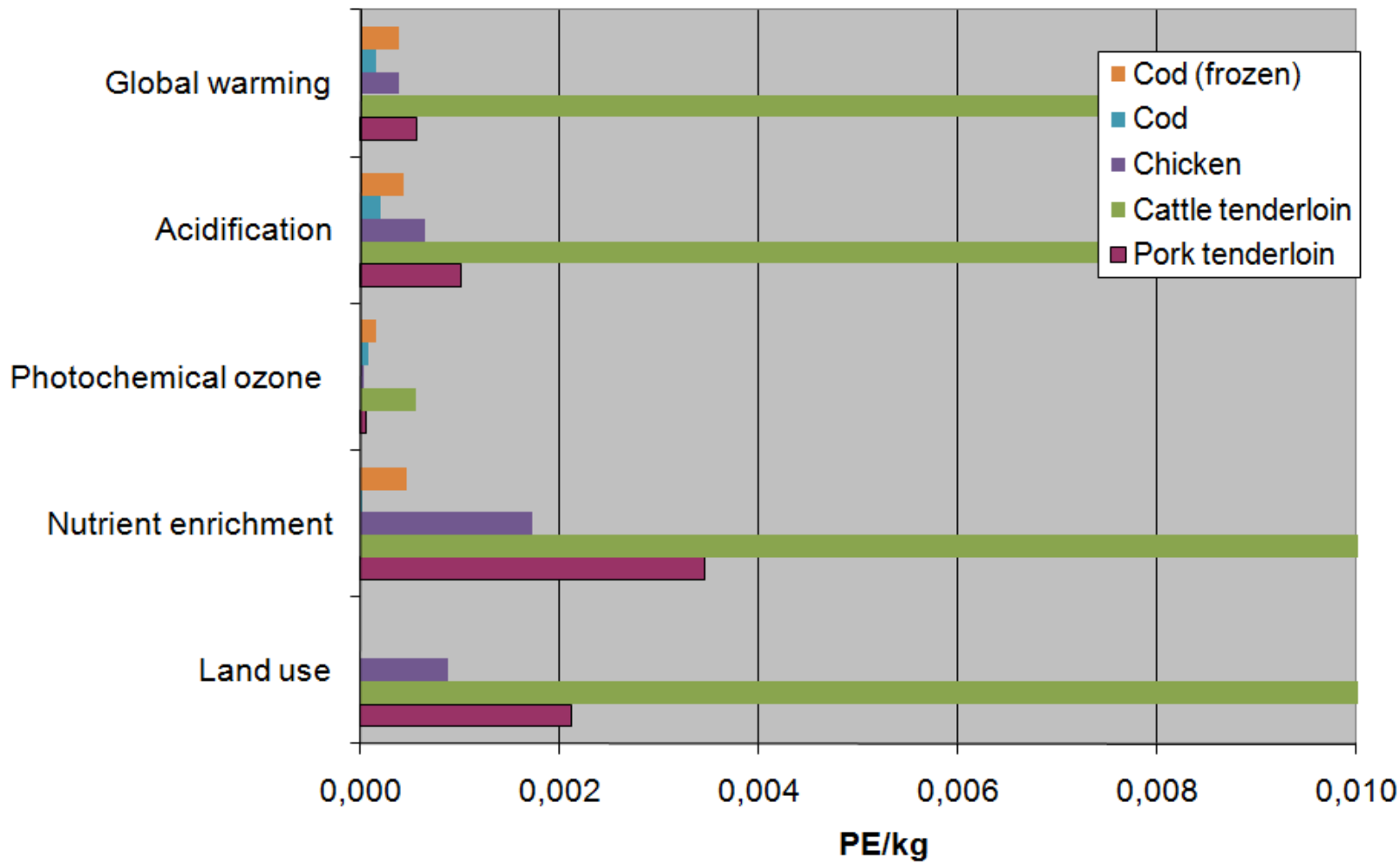
The Person equivalent – a common reference

Impact category	Annual impact level per person in 2010 (person.year)	
	Europe	The world
Climate change	9.2 ton CO_2-eq	8.1 ton CO_2-eq
Ozone depletion	0.022 kg CFC-11-eq	0.041 kg CFC-11-eq
Photochemical ozone formation	32 kg NMVOC-eq	57 kg NMVOC-eq
Terrestrial acidification	$7.4 \cdot 10^2$ mole H+ eq	$7.8 \cdot 10^2$ mole H+ eq
Terrestrial eutrophication	$5.5 \cdot 10^2$ mole N eq	$3.5 \cdot 10^2$ mole N eq
Freshwater eutrophication	1.49 kg P eq	0.62 kg P eq
Marine eutrophication	17 kg N eq	9.4 kg N eq
Freshwater ecotoxicity	$8.7 \cdot 10^3$ [PAF].m^3.day	$6.7 \cdot 10^2$ [PAF].m^3.day
Land use, soil quality	11 tons eroded soil	9 tons eroded soil
Land use, biodiversity loss	$7.5 \cdot 10^3$ m^2.year	$6.2 \cdot 10^3$ m^2.year
Water depletion	256 m^3	395 m^3

Laurent A, Olsen SI, Hauschild MZ (2011) Normalization in EDIP97 and EDIP2003: updated European inventory for 2004 and guidance towards a consistent use in practice. Int J Life Cycle Assess 16, 401-409
Benini L, Mancini L, Sala S, Manfredi S, Schau EM, Pant R (2014) Normalisation method and data for Environmental Footprints. Report EUR 26842 EN. Joint Research Centre. Institute for Environment and Sustainability. European Commission.
Bjørn A, Hauschild M (2015) Introducing carrying capacity based normalization in LCA: framework and development of midpoint level references. Int J Life Cycle Assess 20(7), 1005-1018, 2015

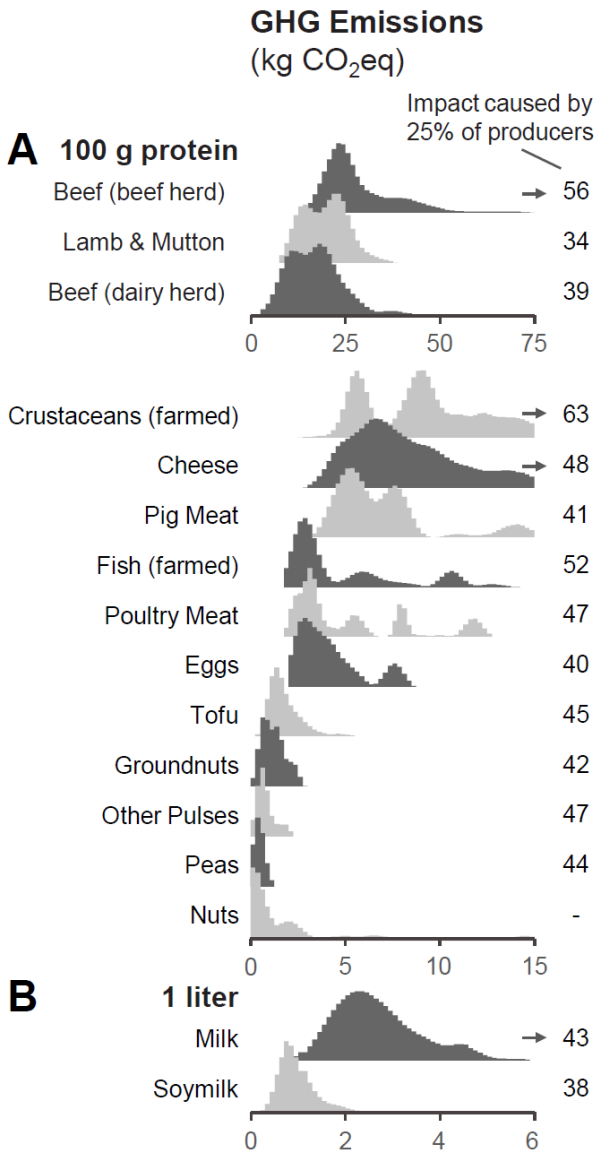
LCA of meat or fish

1 kg meat or fish



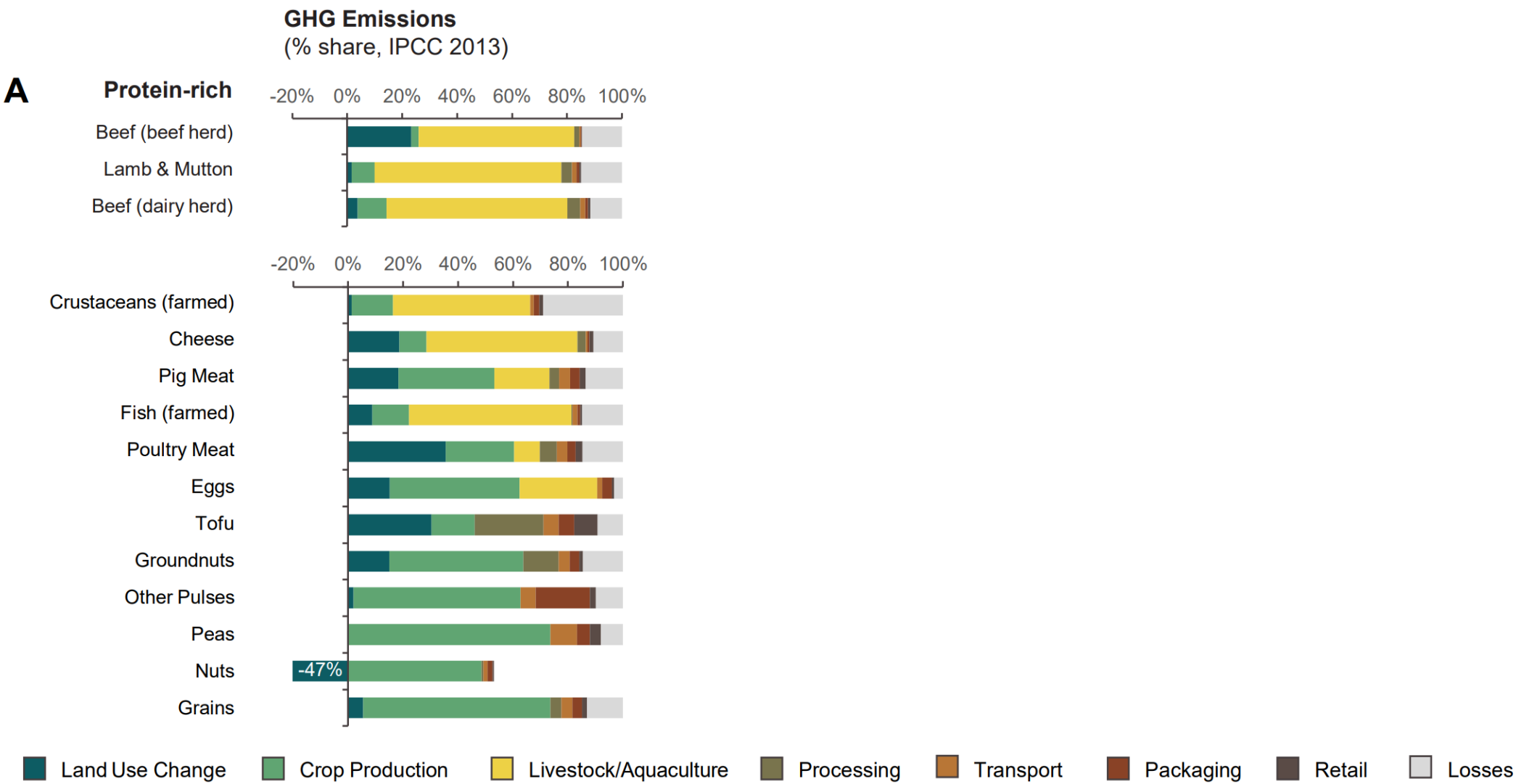
www.lcafood.dk

LCA dairy products and alternatives



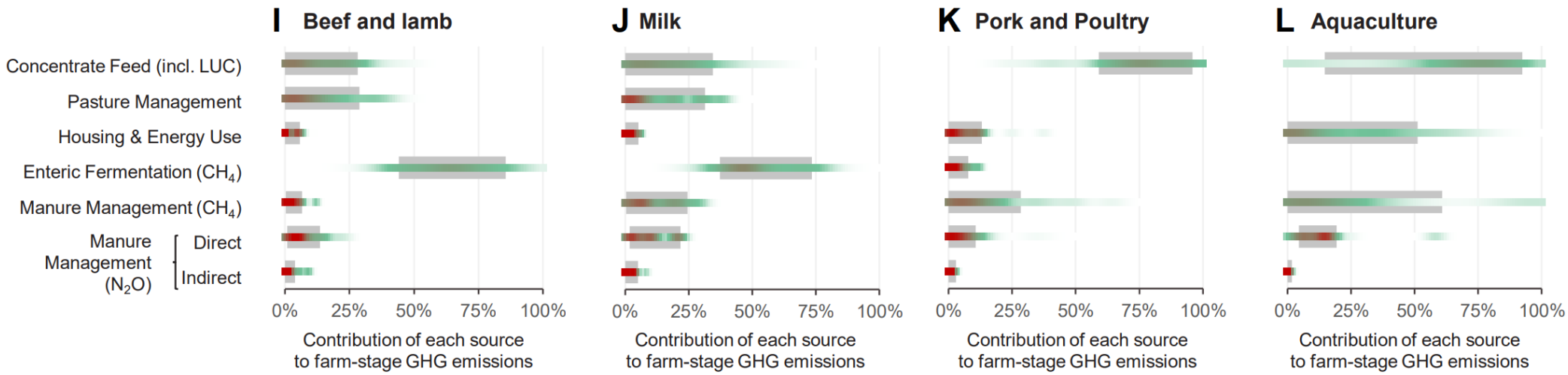
Poore and Nemecek (2018) Reducing food's environmental impacts through producers and consumers. Science 360, 987-992

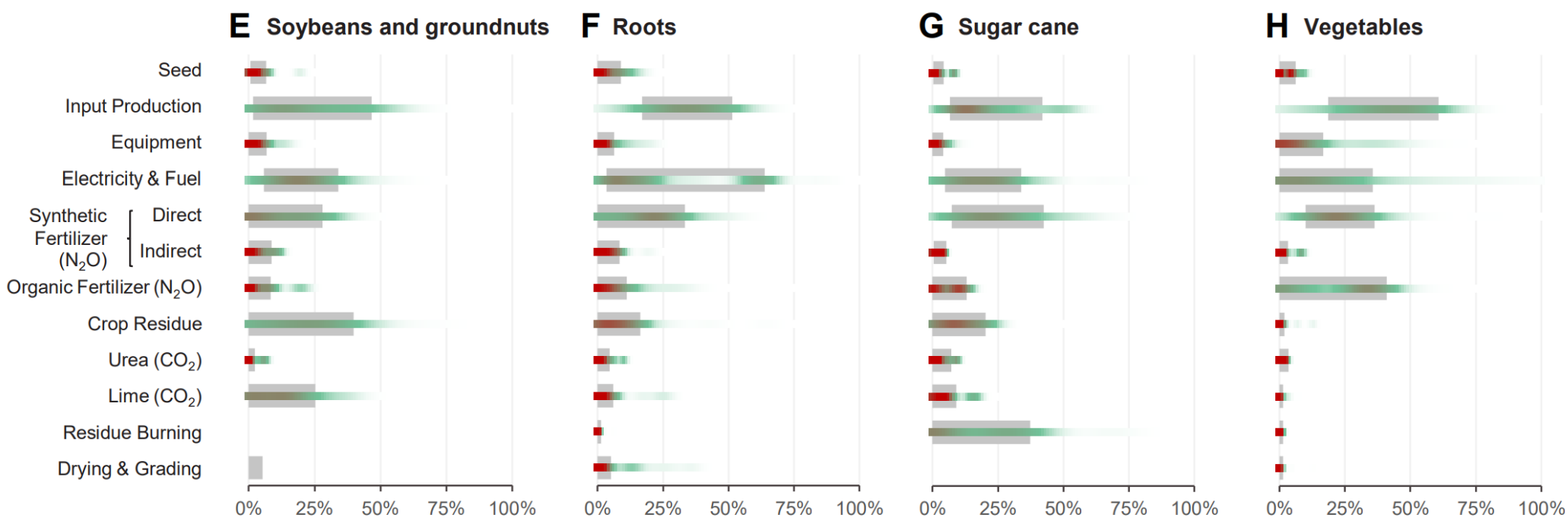
Where in the chain?



Poore and Nemecek (2018) Reducing food's environmental impacts through producers and consumers. Science 360, 987-992

Where in the chain?





Relative and absolute sustainability

LCA supports **relative assessments of environmental sustainability** (*"more sustainable than…"*)?

- Same or higher functionality with less environmental impact

Absolute sustainability (*"sustain-able"*)?

- Where is the boundary beyond which the activity becomes unsustainable?
- What is sustainable in absolute terms?

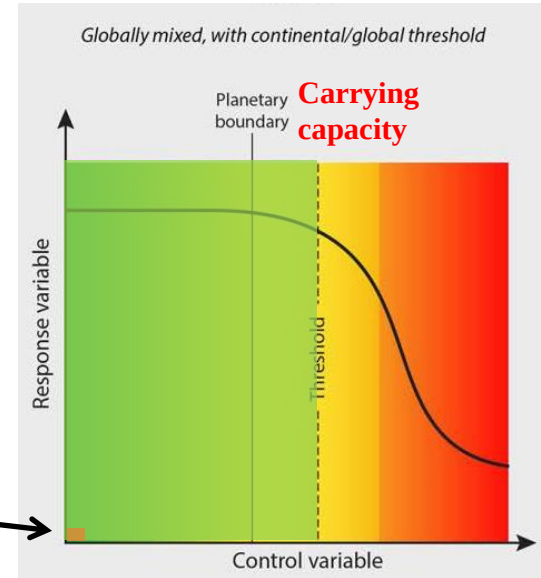
Sustainable?

Greenwashing
calls for
absolute metrics
in the sustainability
assessment
of products

The environmental space

- $PE_{i,j} = \frac{CC_{i,j}}{P_j}$
- PE: Person equivalent – the personal sustainability space
- CC: Carrying capacity
- P: Population
- i: Impact category
- j: Region

Annual personal impact budget



Steffen W, Richardson K, Rockström J et al. (2015b) Planetary boundaries: Guiding human development on a changing planet. Science 347(6223), 736-746

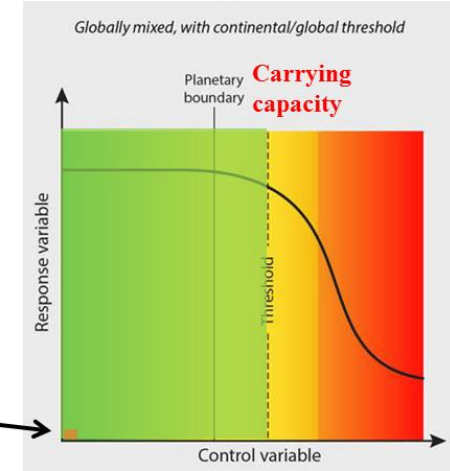
Sustainable per capita impacts

Impact category	Current impact	Sustainable impact
Climate change	8.1 ton CO_2-eq	0.98 ton CO_2-eq
Ozone depletion	0.041 kg CFC-11-eq	0.078 kg CFC-11-eq
Photochemical ozone formation	57 kg NMVOC-eq	2.5 kg NMVOC-eq
Terrestrial acidification	$7.8 \cdot 10^2$ mol H+ eq	$1.4 \cdot 10^3$ mol H+ eq
Terrestrial eutrophication	$3.5 \cdot 10^2$ mol N eq	$1.8 \cdot 10^3$ mol N eq
Freshwater eutrophication	0.62 kg P eq	0.46 kg P eq
Marine eutrophication	9.4 kg N eq	31 kg N eq
Freshwater ecotoxicity	$6.7 \cdot 10^2$ [PAF].m^3.day	$1.0 \cdot 10^4$ [PAF].m^3.day
Land use, soil quality	9 tons eroded soil	1.2 tons eroded soil
Water depletion	395 m^3	490 m^3

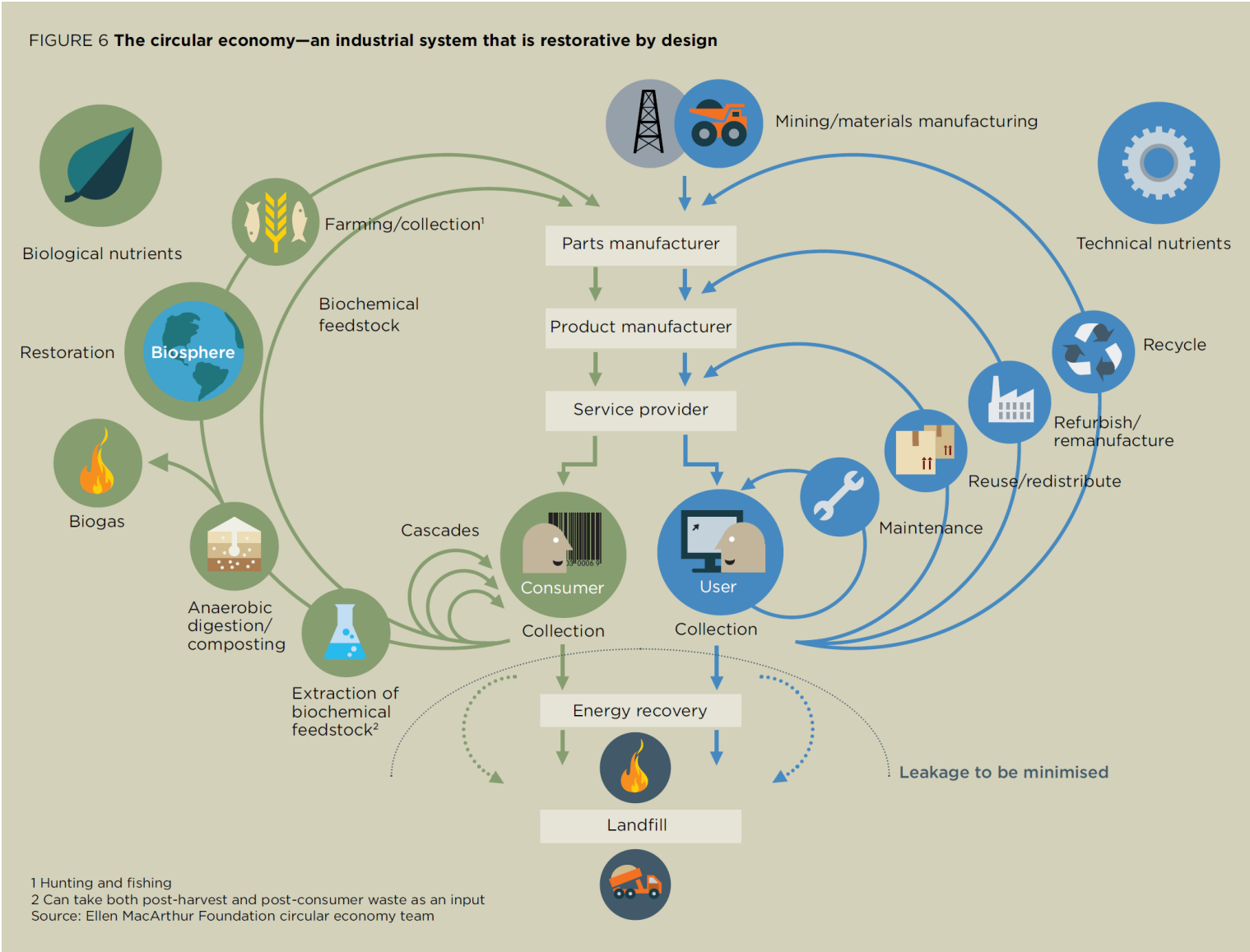
Laurent A, Olsen SI, Hauschild MZ (2011) Normalization in EDIP97 and EDIP2003: updated European inventory for 2004 and guidance towards a consistent use in practice. Int J Life Cycle Assess 16, 401-409
Bjørn A, Hauschild M (2015) Introducing carrying capacity based normalization in LCA: framework and development of midpoint level references. Int J Life Cycle Assess 20(7), 1005-1018, 2015

Measuring absolute sustainability

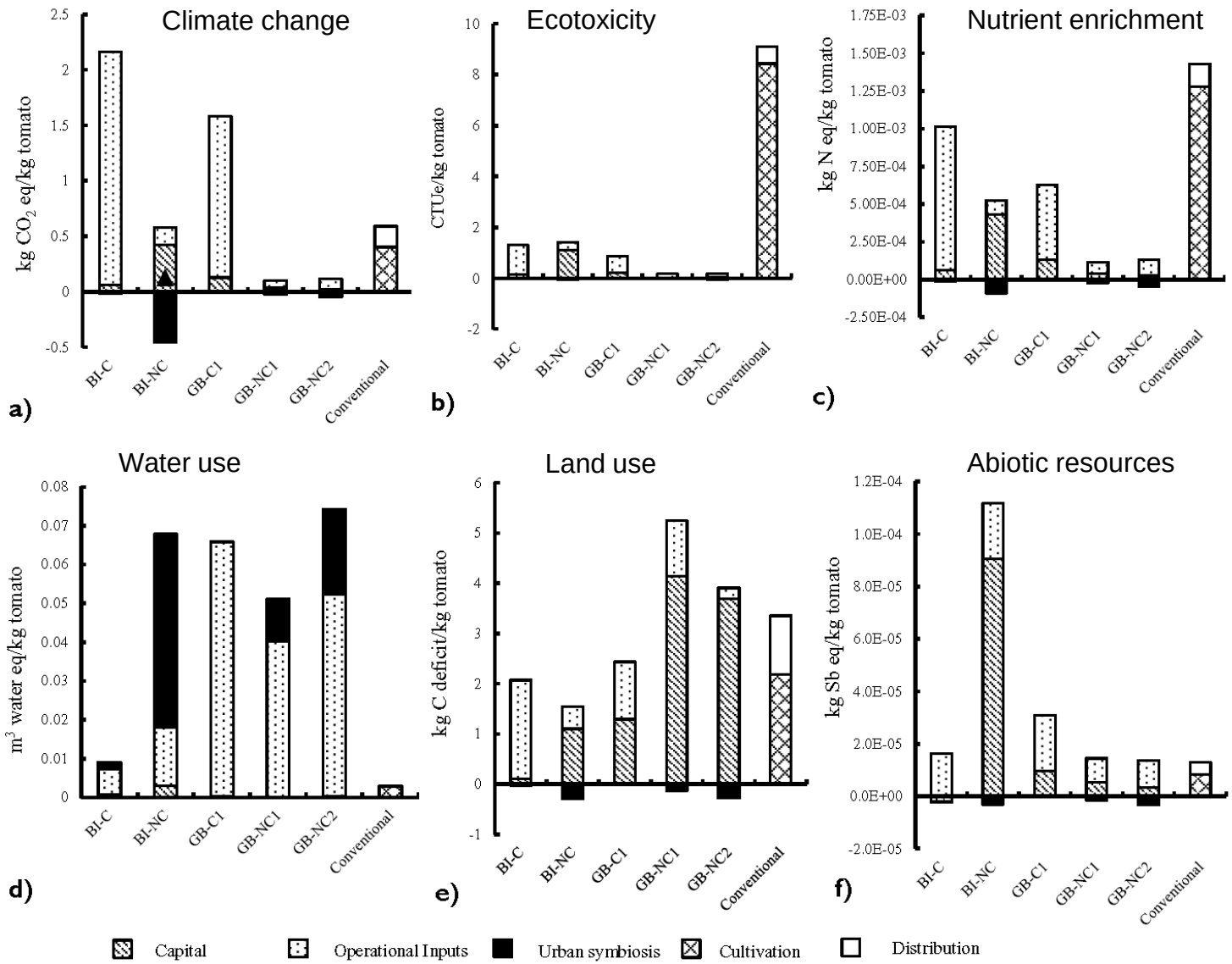
- Life cycle impacts but related to absolute sustain-ability targets
- Does the product stay within the space that it can claim?
- Which space can the product claim?
- How do we assign the sustainability space to our different activities?
- What is the space that should be assigned to food?
- How can we meet the needs of the present and future within this space?



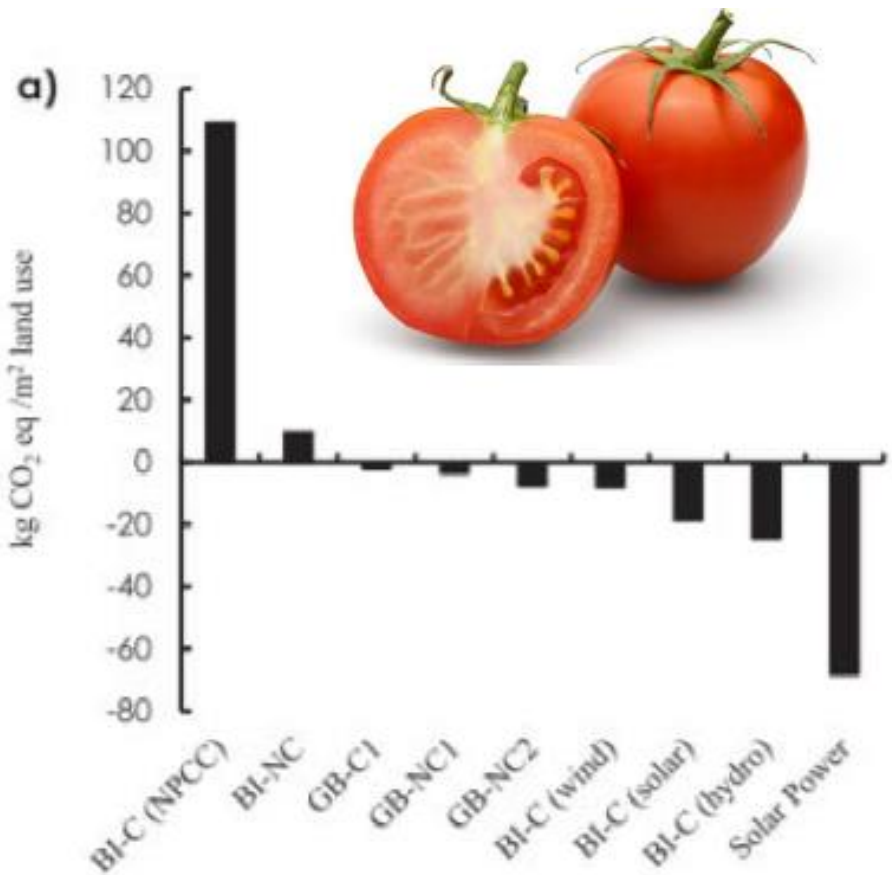
Circular economy

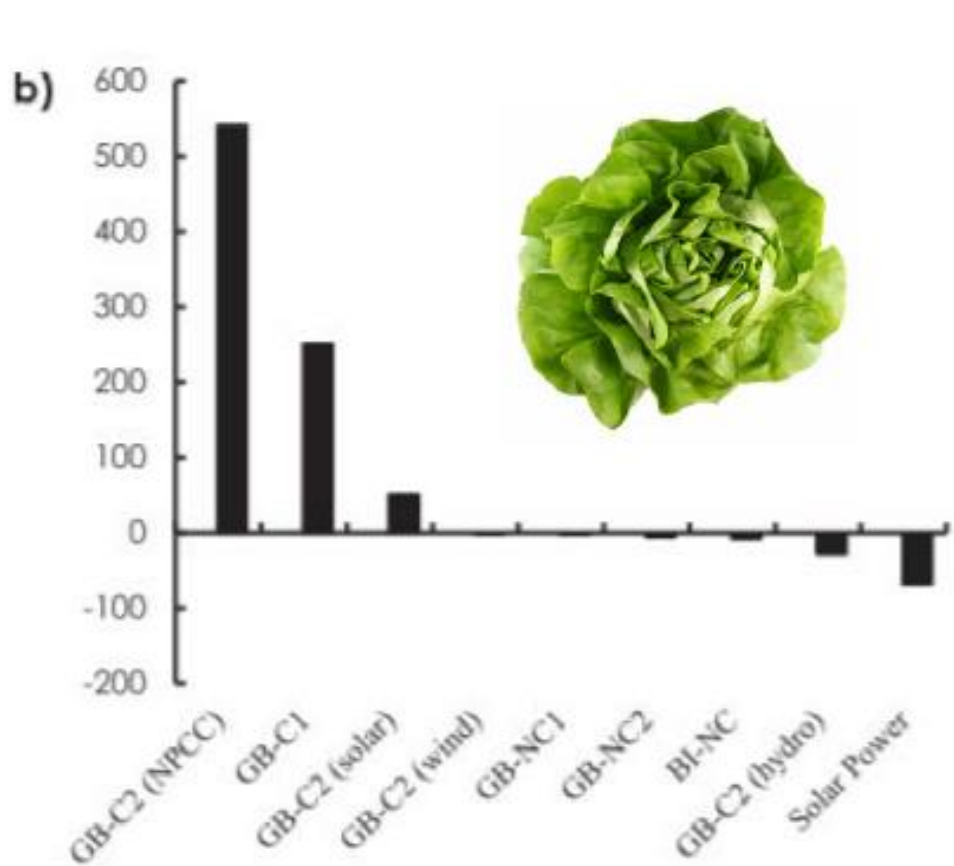


Urban farming



Mitigating climate change





Bloomberg Markets Tech Pursuits Politics Opinion Businessweek

American Chemical Society » News » News Releases » 2017 » June » Urban agriculture only provides small environmental benefits in northeastern US

FOR IMMEDIATE RELEASE | Wed Jun 21 18:06:00 EDT 2017

Urban agriculture only provides small environmental benefits in northeastern US

"Contributions of Local Farming to Urban Sustainability in the Northeast United States"
Environmental Science & Technology

Media Contact

Seeker VR VIDEO SPACE TECH EARTH HEALTH CULTURE

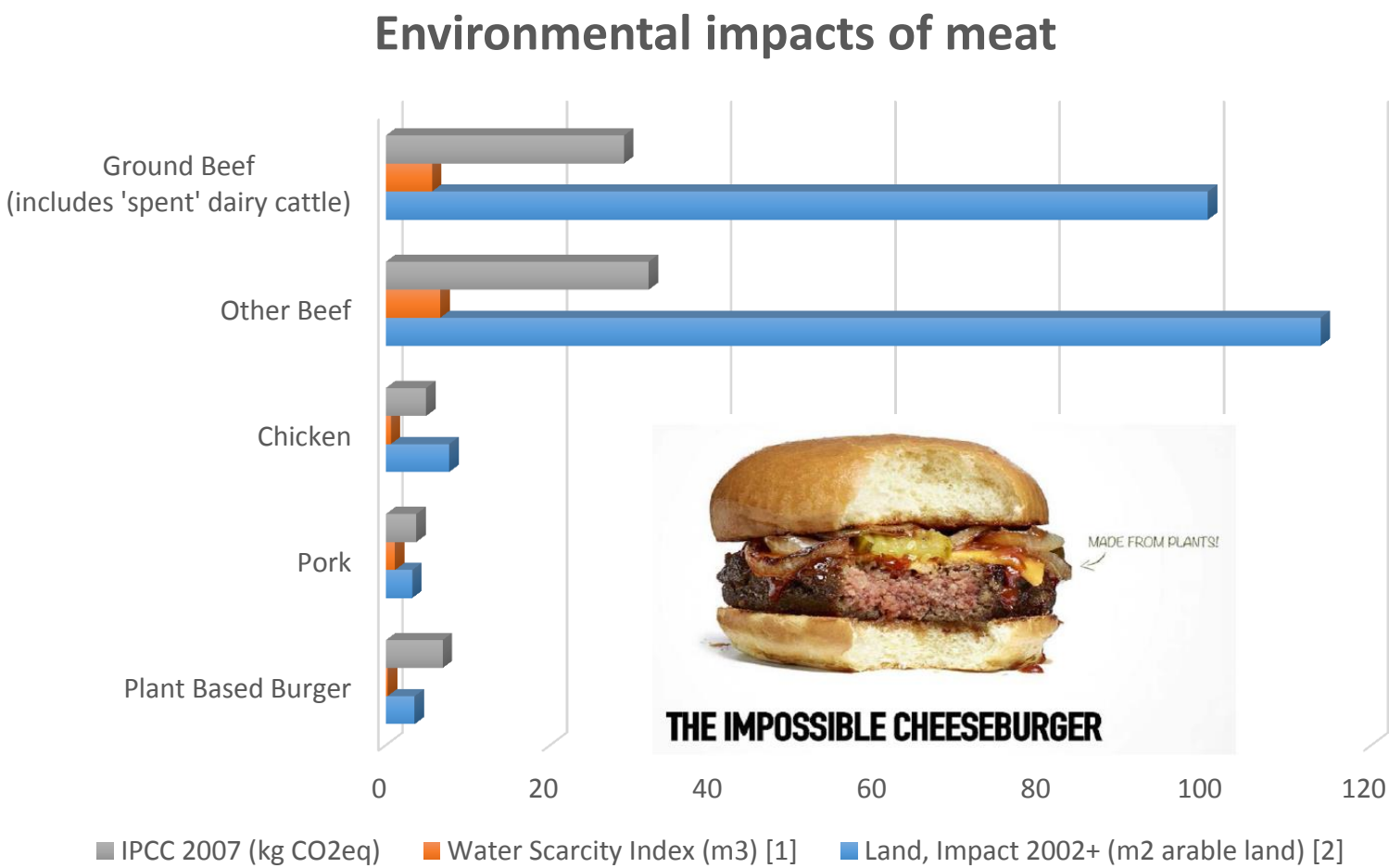
› CLIMATE

Urban Farming Isn't a Game Changer When It Comes to Carbon Emissions

A new study has found negligible reductions in carbon reduction from urban agriculture projects, which include commercial rooftop plots and public gardens.

BY JOHN DYER · JUNE 22, 2017 · 2:50 PM EDT

Meat alternatives



Goldstein et al. (2017) Partly unpublished work – for climate change impacts refer to Goldstein E, Moses R, Sammons N, Birkved M (2017) Potential to curb the environmental burdens of American beef consumption using a novel plant-based beef substitute. PLoS One, https://doi.org/10.1371/journal.pone.0189029

1: Hoekstra AY, Mekonnen MM, Chapagain AK, Mathews RE, Richter BD (2012) Global Monthly Water Scarcity: Blue Water Footprints versus Blue Water Availability. PLoS ONE 7(2): e32688.
2: Jolliet O, Margni M, Charles R, Humbert S, Payet J, Rebitzer G, et al. (2003) IMPACT 2002+: A new life cycle impact assessment methodology. Int J Life Cycle Assess. 8: 324–330. doi:10.1007/BF02978505

The challenge for food production

- Feeding growing population and growing middle class with dramatically less impact
- Eco-efficiency must increase 4-20 times to stay within the planet's limits
- Less meat, reduced food waste, less processed food
- Quantitative sustainability assessment methods help us
  - Assess whether novel food production techniques are
    - more sustainable
    - sustainable at all
  - Identify hotspots in the life cycle for improvement
  - Choose between alternatives
  - Handle trade offs between impact categories