LIFE CYCLE PROSPECTIVE ON SUSTAINABILITY, RESILIENCE, AND INSIGHTS OF OUR INDUSTRY

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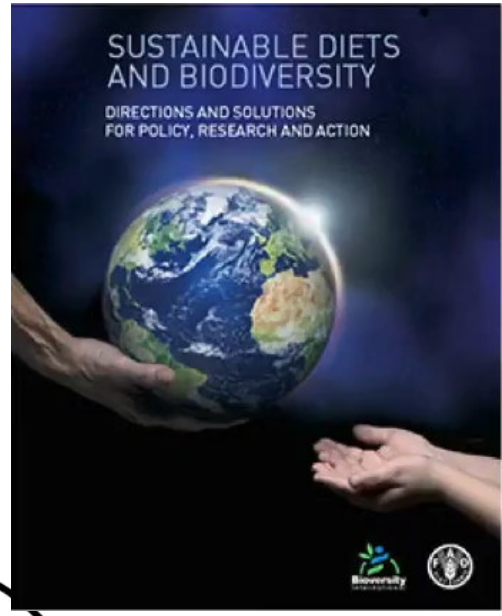
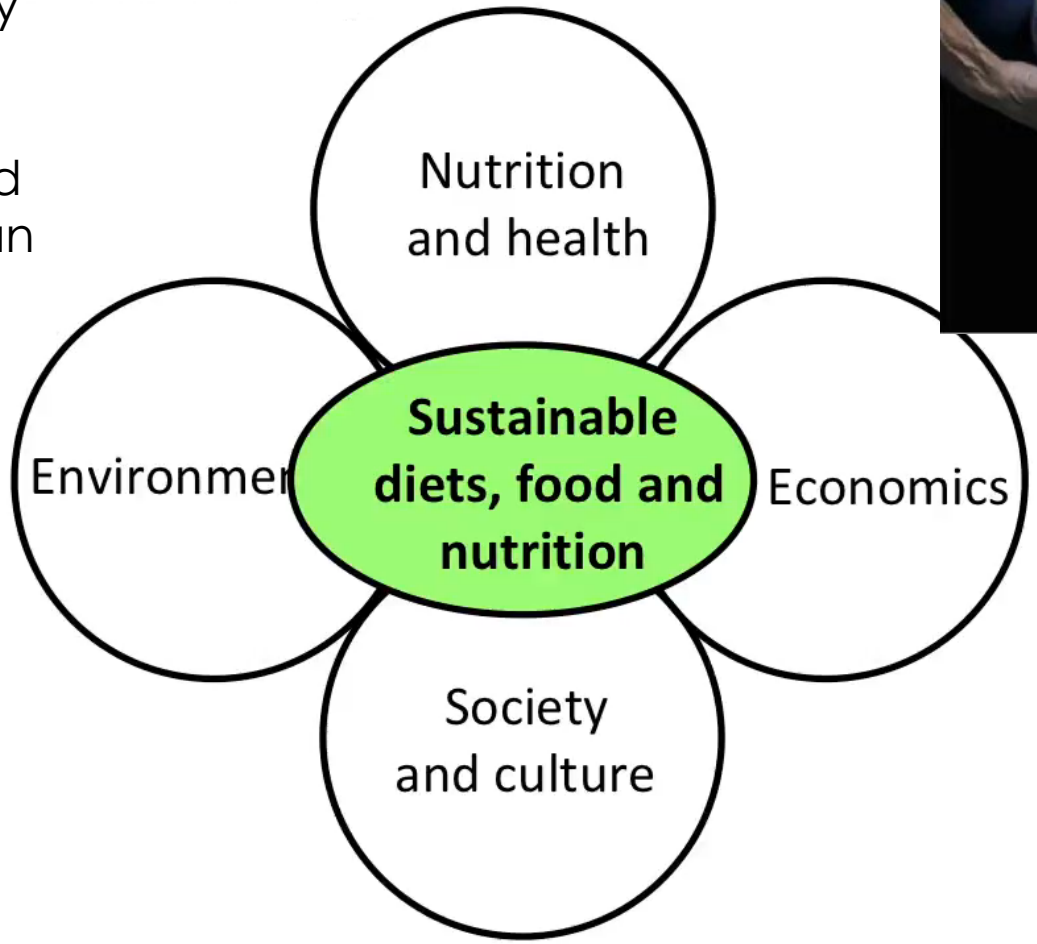
Sustainable Food Systems

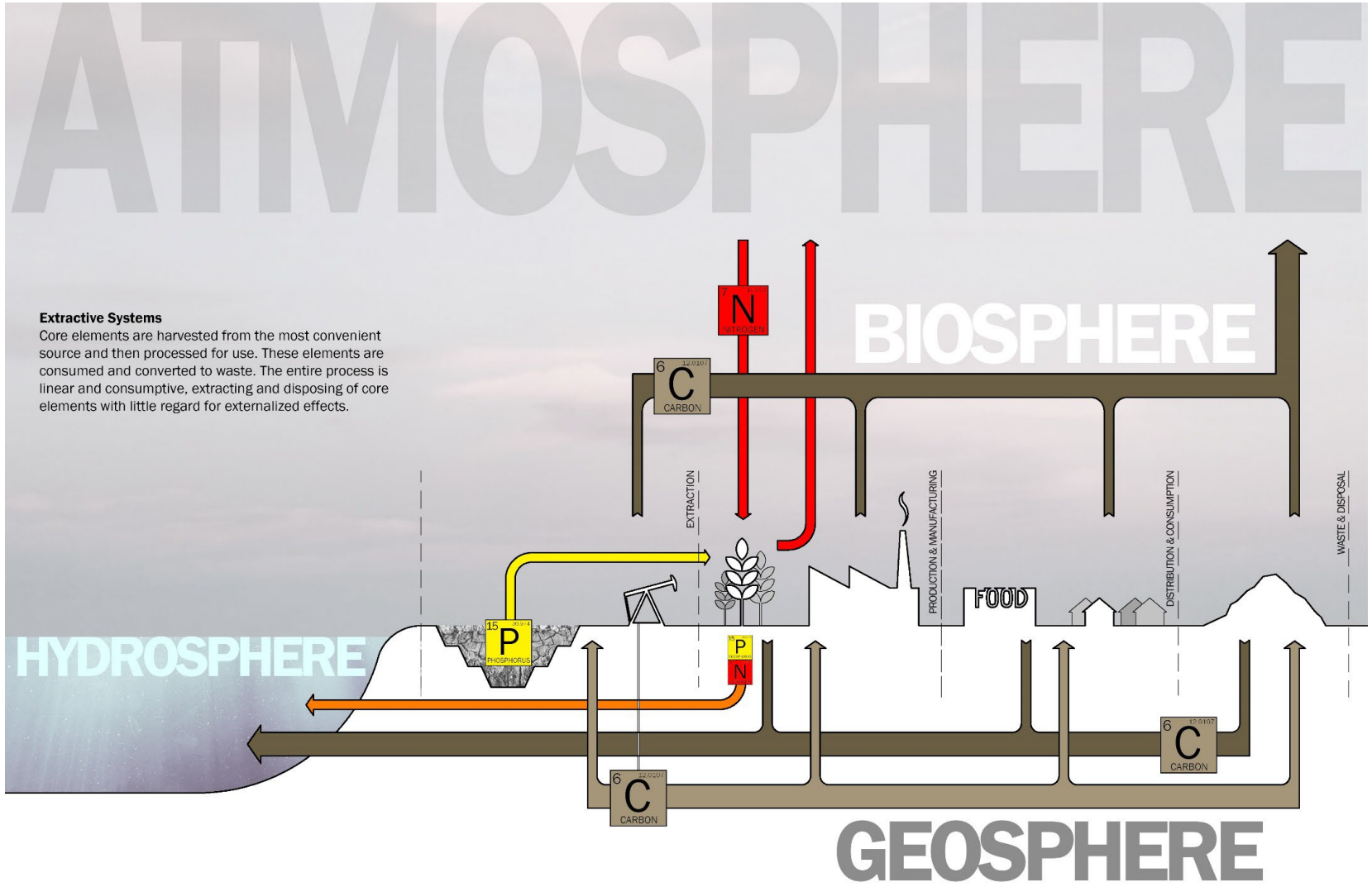
- Are protective and respectful of biodiversity and ecosystems; culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources (FAO, 2010).
- Tradeoffs:
  - Energy dense foods often nutrient poor and less expensive
  - Nutrient rich foods/diets often have higher environmental impact – many are animal sourced foods.
  - Cultural preferences





Drewnowski et al. (2018) Front. Nutr. 4:74.
doi: 10.3389/fnut.2017.00074

We have a problem with three elements in four spheres driving most environmental impacts

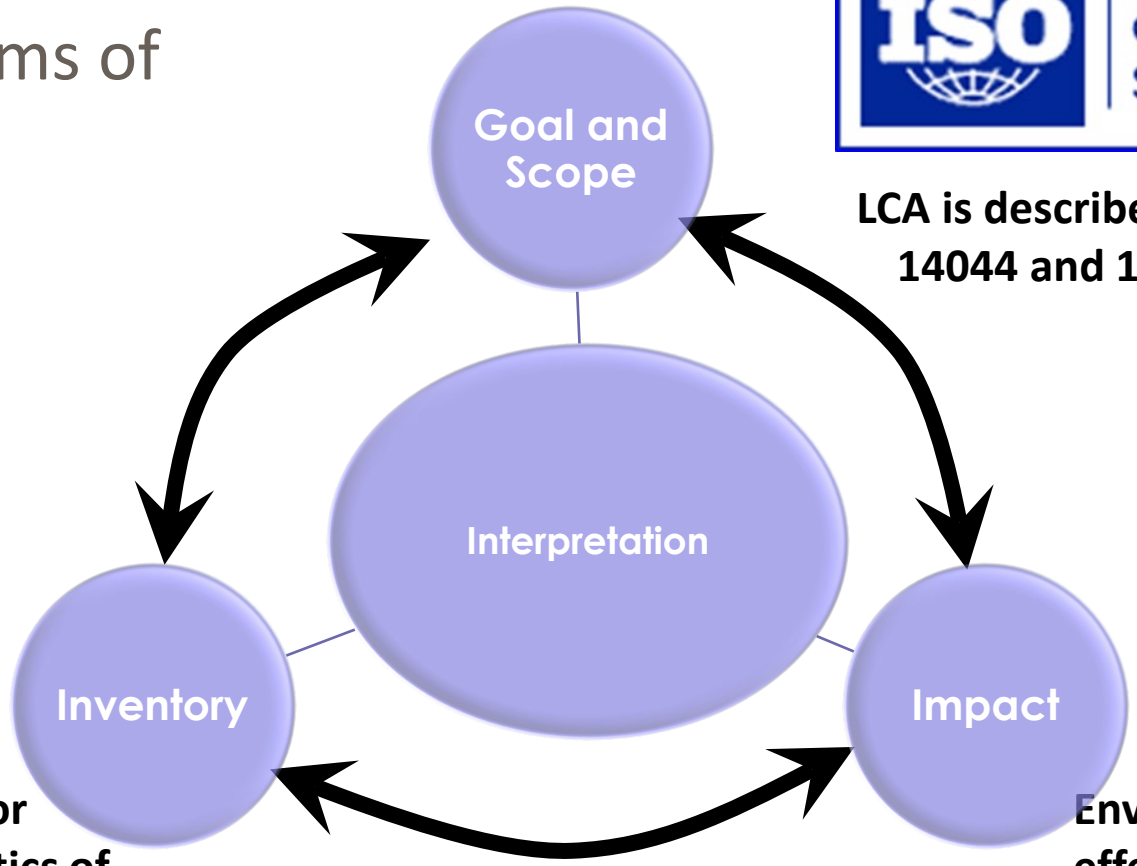


Lifecycle Assessment

Systematic quantification of inputs and outputs for a system in terms of a functional unit (FU).

- **Product Development / Improvement**
  - **Selection of best materials or process options (e.g. conservation)**
- ***Identification of 'hotspots' for innovation***
- ***Benchmarking***
- **Product labels / marketing**
- ***Strategic planning***
- **Inform public policy**

- **Not: site assessment, EIA limitation of LCIA stage**



LCA is described in ISO 14040, 14044 and 14046 Standards

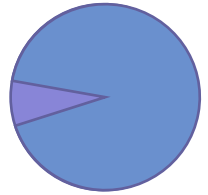
Attributes or characteristics of product or process

Environmental effects of product or process

‘Flavors’ of LCA: attributional and consequential

An *attributional product system* is composed of:

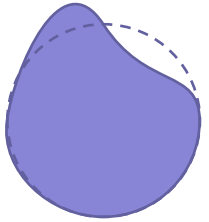
- an allocated share of the activities that have contributed to production, consumption, and disposal of a product,
- tracing the contributing activities backward in time,
- Thus, data on specific or market average suppliers are relevant



Engineering paradigm: processes linked *physically*

A *consequential product system* is composed of:

- the full share of those activities that are expected to change when producing, consuming, and disposing of a product,
- tracing the consequences of increased ***demand*** forward in time,
- Thus, data on marginal suppliers are relevant (whose activity responds to change in demand)

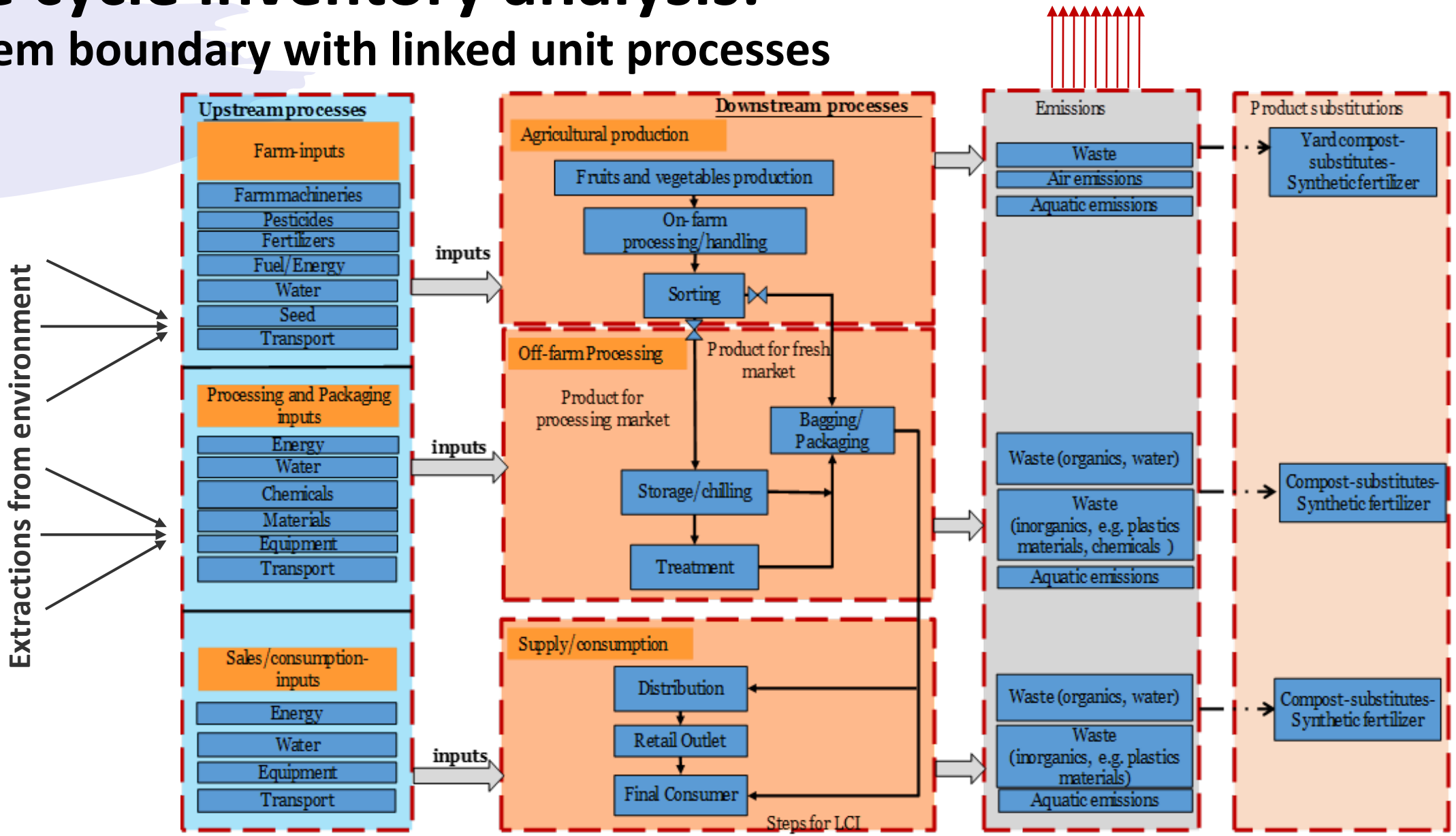


Economic paradigm: processes linked via *markets*

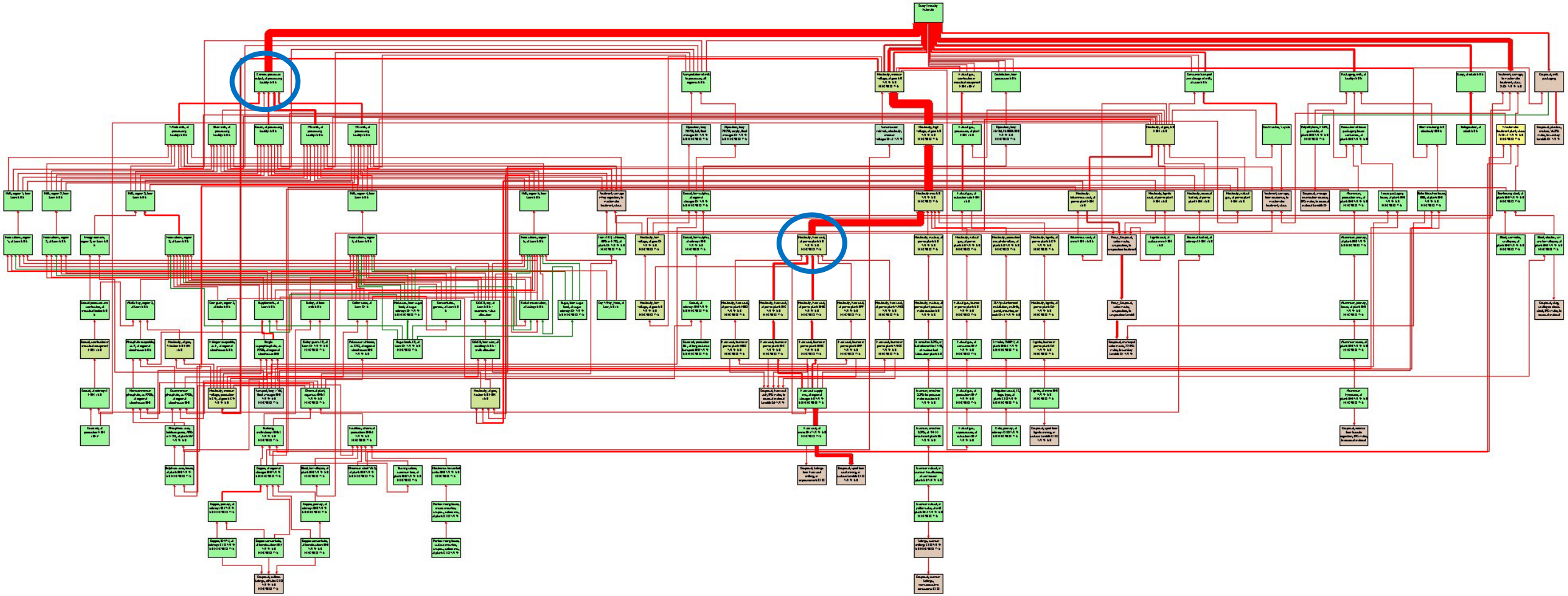
UNEP/SETAC (2011). Shonan LCA database guidance principles
Weidema, et al., 2018. Attributional or consequential Life Cycle Assessment: A matter of social responsibility. J. Clean. Prod. 174, 305–314.

Life cycle inventory analysis:

system boundary with linked unit processes



Some connections are more important

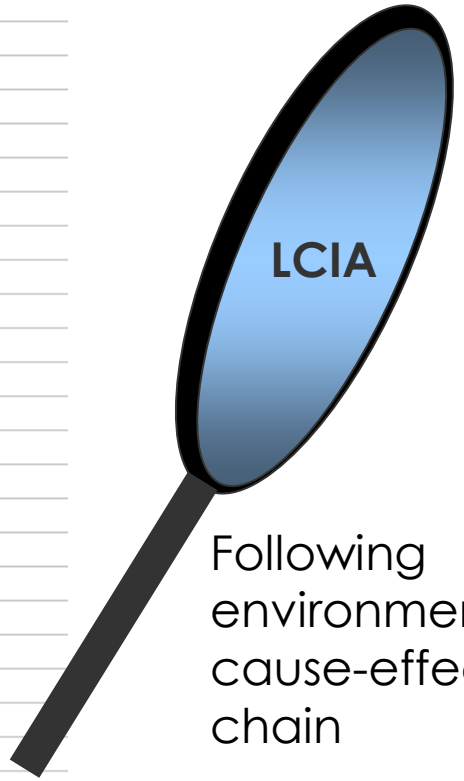


Life Cycle Impact Assessment

Hundreds of individual emissions

Inventory results (LCI)

Substance	Compartment	Unit	Total
Aluminum	Air	mg	27
Ammonia	Air	mg	776
Ammonium carbonate	Air	ng	441
Antimony	Air	µg	9.52
Antimony-124	Air	nBq	33
Antimony-125	Air	nBq	344
Argon-41	Air	Bq	7.34
Arsenic	Air	µg	97
Barium	Air	µg	100
Barium-140	Air	µBq	22.3
Benzaldehyde	Air	ng	17.5
Benzene	Air	mg	5.74
Benzene, ethyl-	Air	µg	149
Benzene, hexachloro-	Air	ng	56.2
Benzene, pentachloro-	Air	ng	80.9
Benzo(a)pyrene	Air	µg	23.7
Beryllium	Air	ng	227
Boron	Air	mg	9.87
Bromine	Air	µg	606
Butadiene	Air	pg	23.4
Butane	Air	mg	10.7
Butene	Air	µg	146
Cadmium	Air	µg	106
Calcium	Air	mg	1.36
Carbon-14	Air	Bq	28.6
Carbon dioxide, biogenic	Air	g	46.3
Carbon dioxide, fossil	Air	kg	20.8

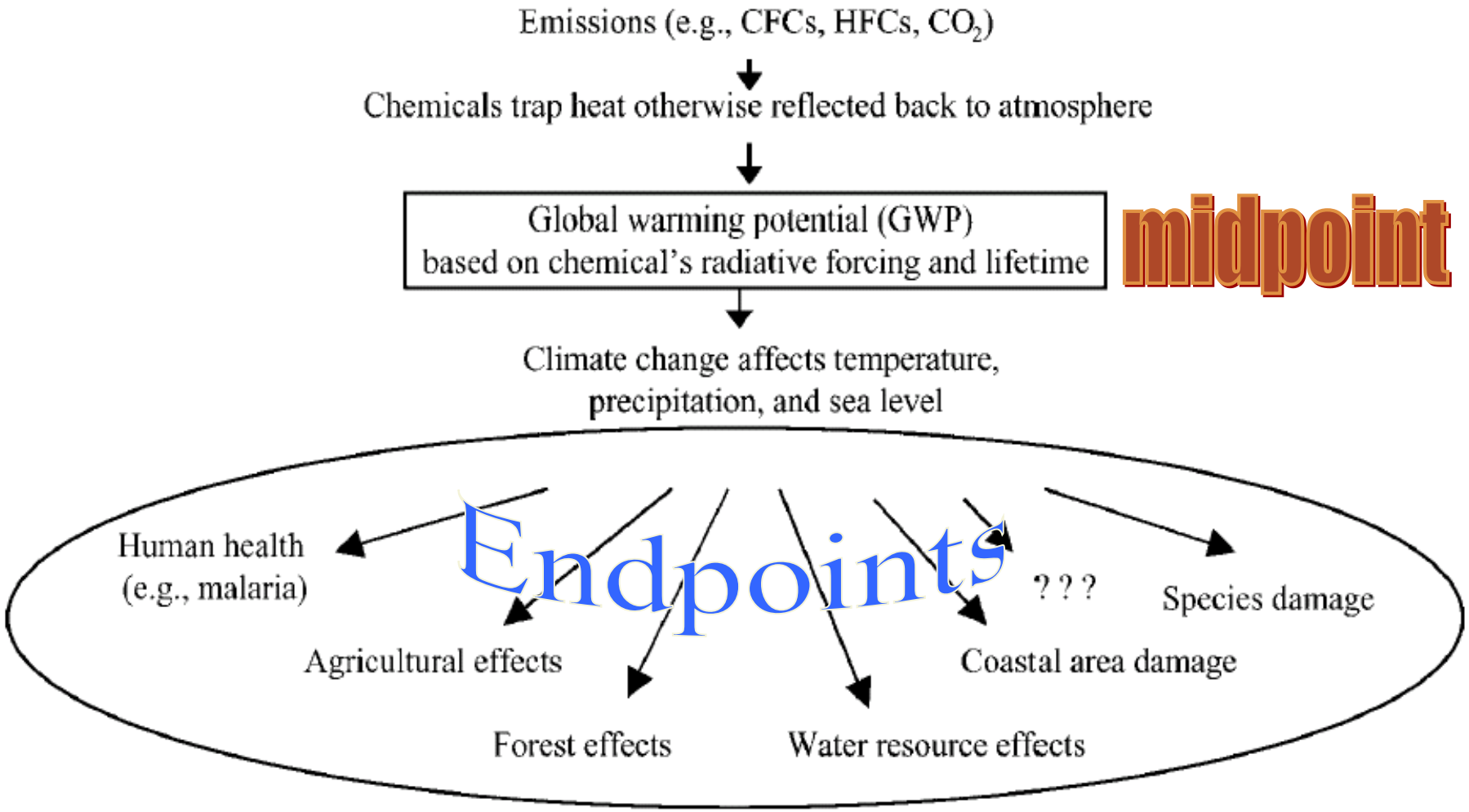


Following environmental cause-effect chain

Impact Assessment results

Impact category	Total
Carcinogens	2.35E-5
Resp. organics	3.03E-6
Resp. inorganics	0.0011
Climate change	0.000432
Radiation	1.21E-6
Ozone layer	5.16E-9
Ecotoxicity	1.15E-5
Acidification/ Eutrophication	0.000128
Land use	1.85E-6
Minerals	1.3E-6
Fossil fuels	0.00624

Impact Assessment: Climate Change



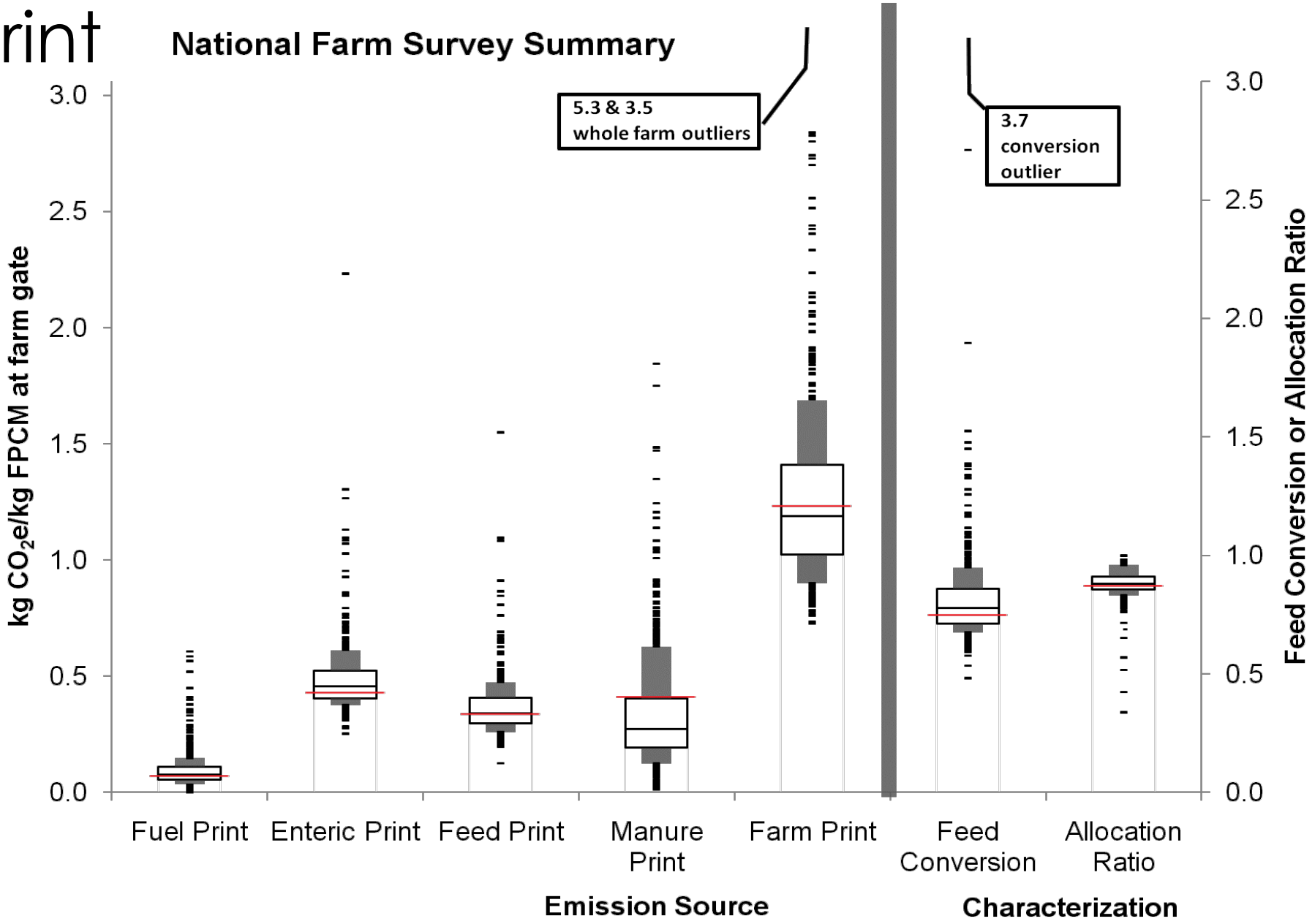
What can LCA tell us now?

ENVIRONMENTAL FOCUS ON PRODUCTION AND CONSUMPTION

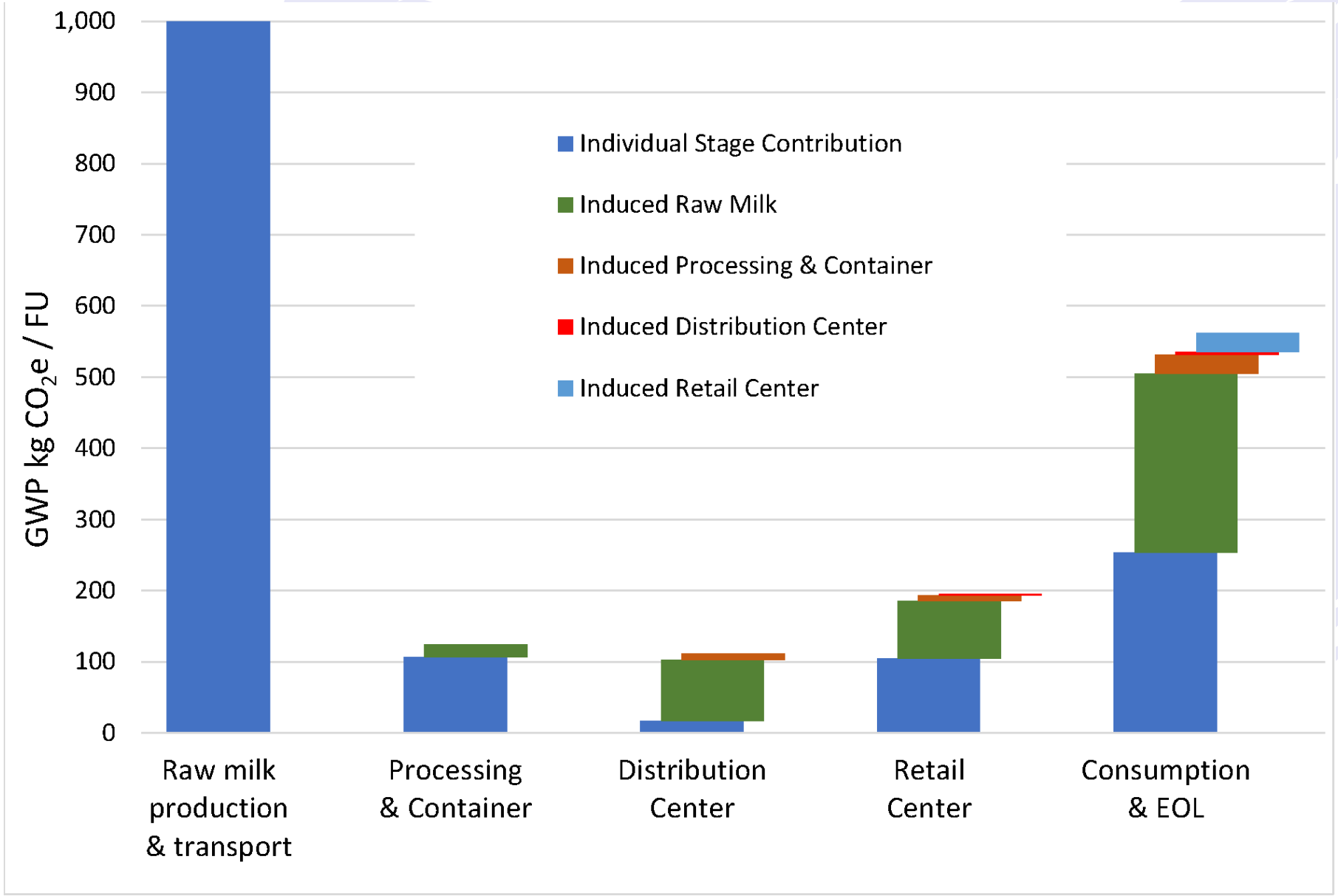
Carbon Footprint of Milk

Large variation in existing system implies opportunity for sector level improvement without radical or disruptive technology advancement:

We can make progress in the near term.

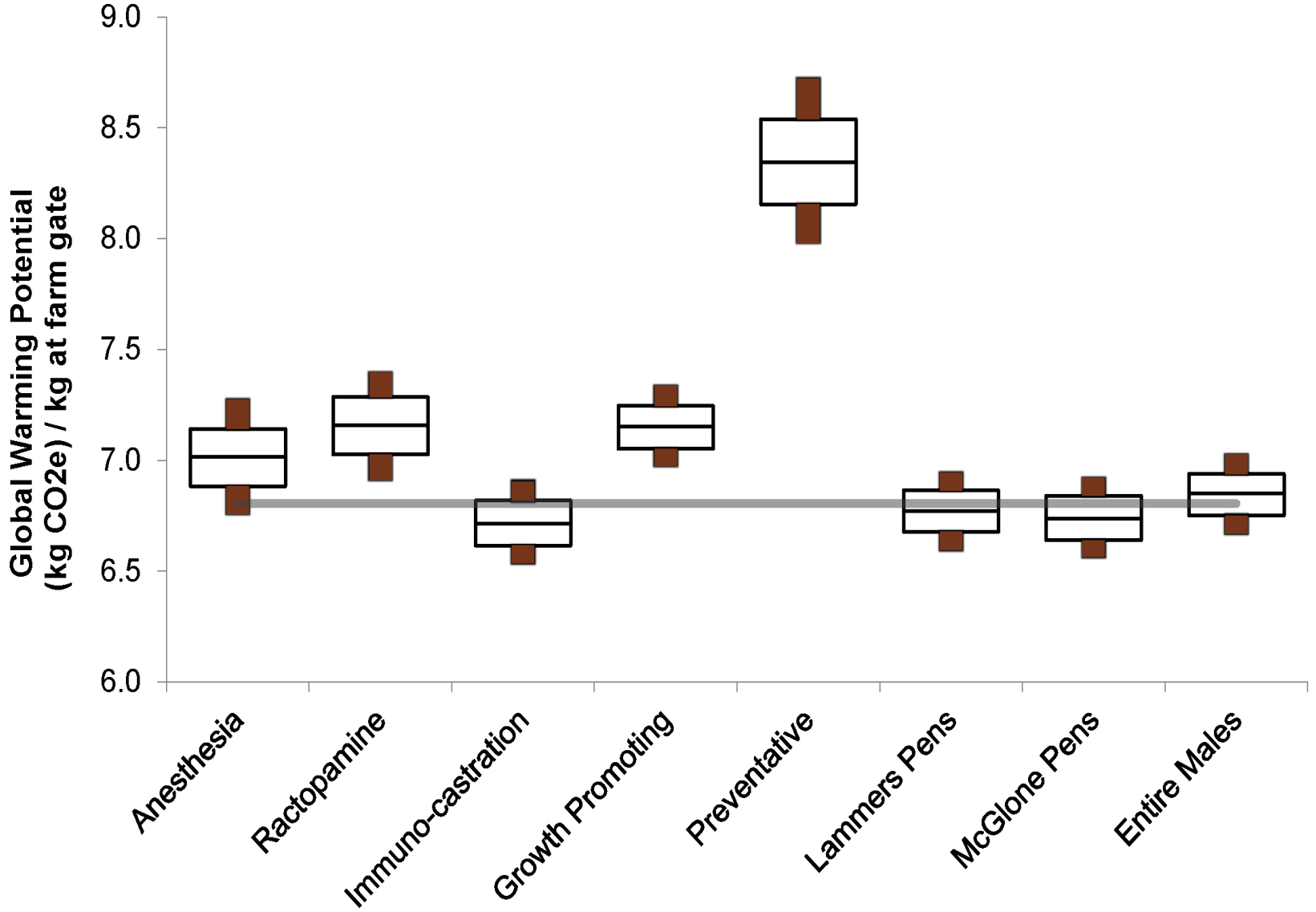


Food loss induced redistribution of GWP



Responsibility for upstream emissions is not normally attributed to downstream demand.

Estimated Change in GWP from Alternate US Pork Production Strategies: Tradeoffs

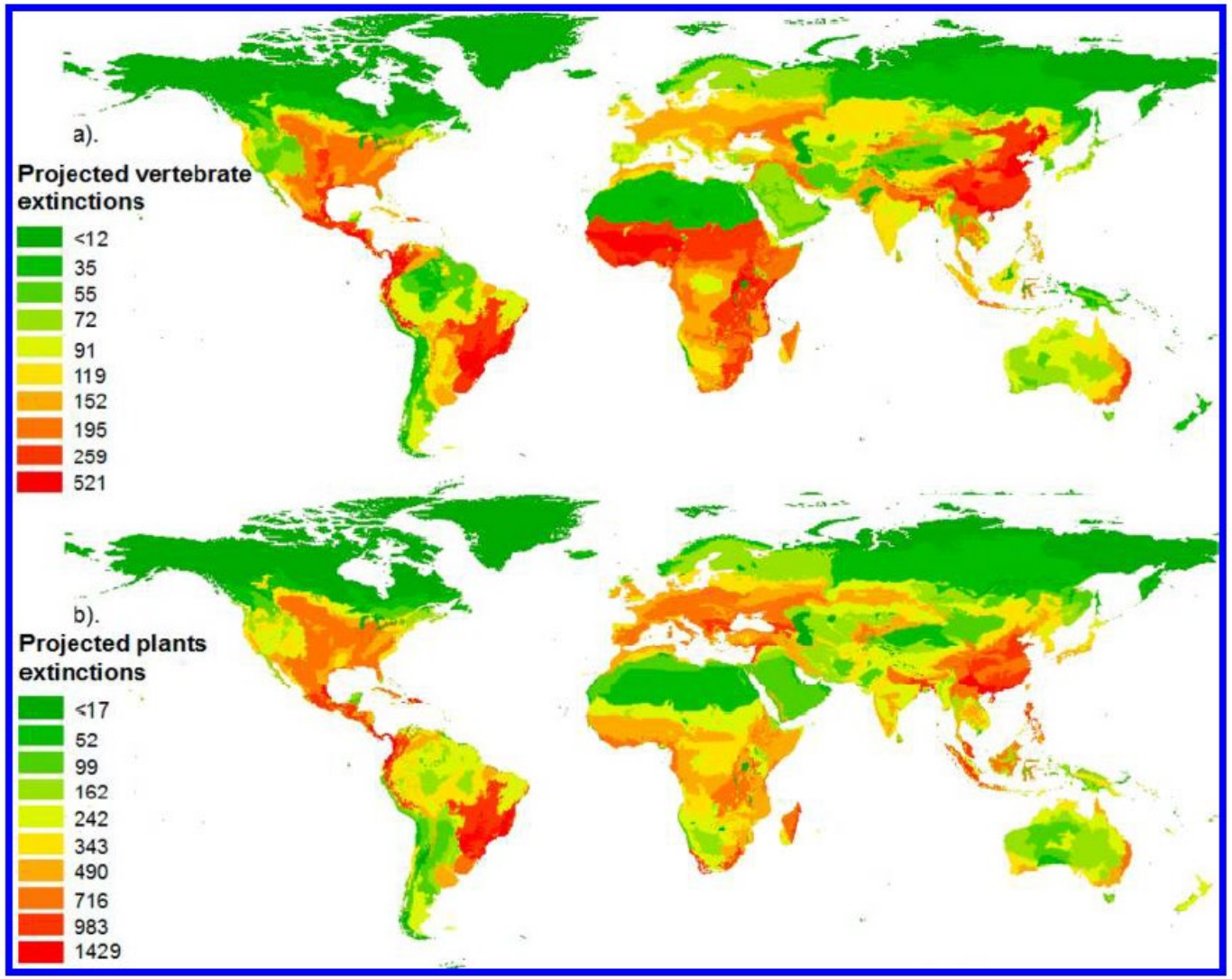


Output from simulation model used as input for LCA modeling in Simapro software (adds full upstream supply chain as well as Monte Carlo simulation)

Bandekar, et al., 2019. J. Anim. Sci. 97, 472–484. doi:10.1093/jas/sky425

Biodiversity CFs for projecting potential species losses

- Five taxa
  - Plants, reptiles, amphibians, mammals, and birds
- Five land use types
  - managed forests, plantations, pasture, cropland, urban
- Three intensity levels
  - minimal, light, and intense use
- Each of the 804 terrestrial ecoregions covered

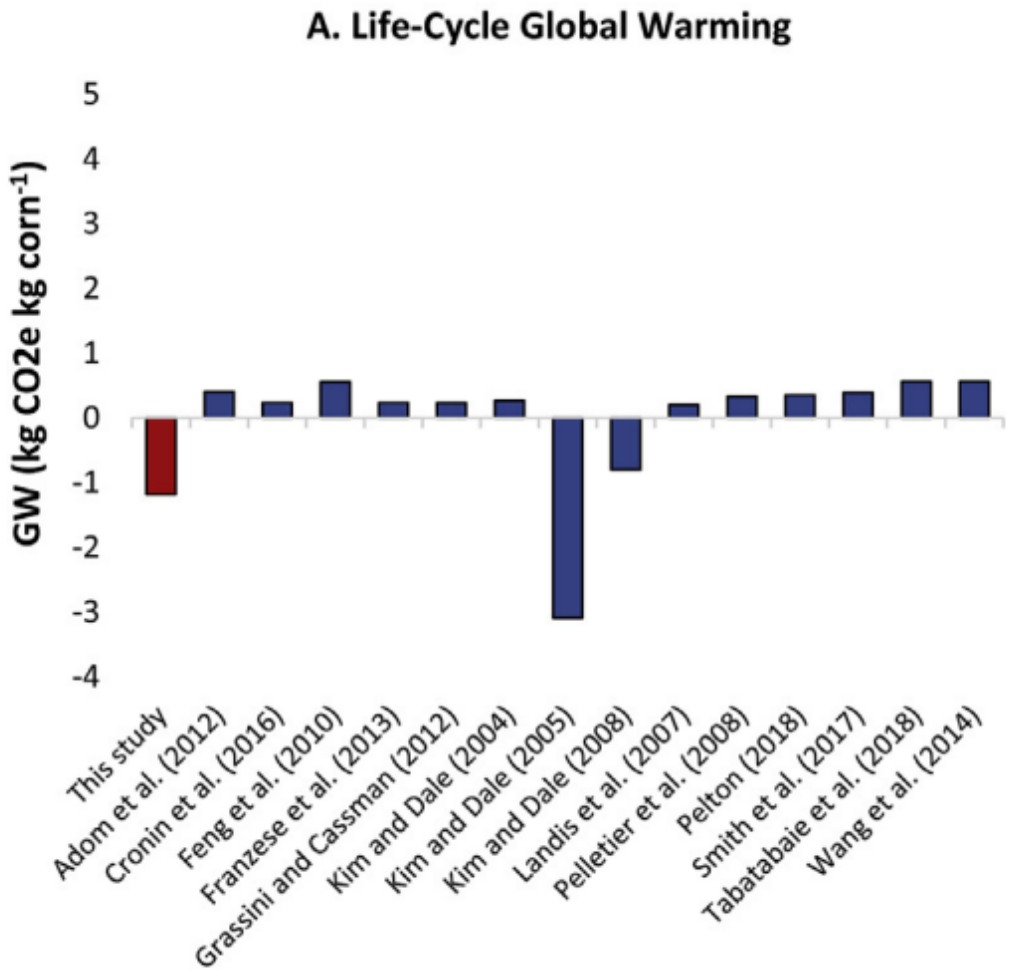


Chaudhary and Brookes. (2018)

Challenges in LCA of ag/food systems

- Data Availability – proxy & substitution can introduce error/ uncertainty
  - Incompatibility of sources, not all in public domain, extant data not always specific to food
  - LCI in agriculture often modeled (multiple models, variable predictions)
- Spatially Extensive – but LCA integrates the supply chain
  - Geospatially explicit LCI and LCIA in nascent stages
- Dynamic Systems – LCA is (generally) a static model
  - Is a static model still useful – yes, many situations.
- Impacts modeled – not benefits (evolving this direction)
- Incomplete metrics (in LCA framework)
  - Biodiversity, Ecosystem Services, Carbon Sequestration, Ocean Plastics, Soil Health, ***Nutrition***

Examples of LCA Variability: GHG Emissions from US Corn



Lee, E.K., Zhang, X., Adler, P.R., Kleppel, G.S. and Romeiko, X.X., 2020. Spatially and temporally explicit life cycle global warming, eutrophication, and acidification impacts from corn production in the US Midwest. *Journal of Cleaner Production*, *242*, p.118465.

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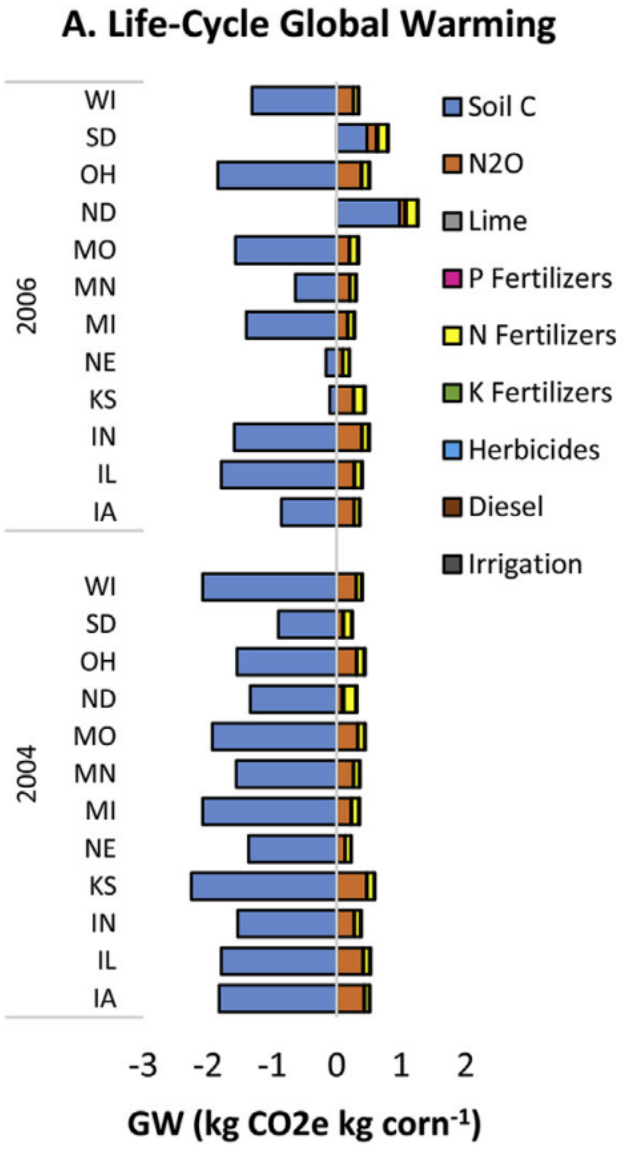

The life cycle GW impacts of corn among Midwest counties ranged from **-6.4** in Franklin County, IL to **20.2** kg CO2-eq./kg corn in Perkins County, SD.

On-farm N2O emissions (13 to19%) and GHGs from nitrogen fertilizer production (5 to 9%) together accounted for 18 to 28% of the net GW impacts, varying from 0.04 to 3.9 kg CO2-eq./kg corn.

Soil carbon changes, ranging from -7.3 to16.9 kg CO2-eq./kg corn, offset GHGs by 69 to 81% of the net life-cycle GW impacts.

Lee, E.K., Zhang, X., Adler, P.R., Kleppel, G.S. and Romeiko, X.X., 2020. Spatially and temporally explicit life cycle global warming, eutrophication, and acidification impacts from corn production in the US Midwest. *Journal of Cleaner Production*, *242*, p.118465.

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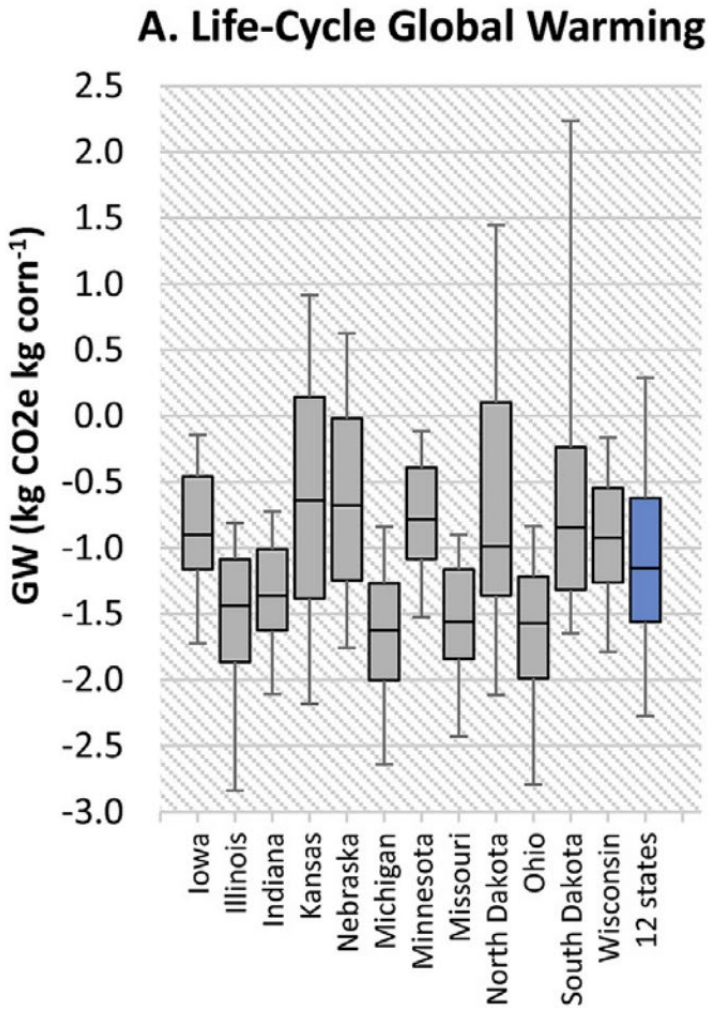
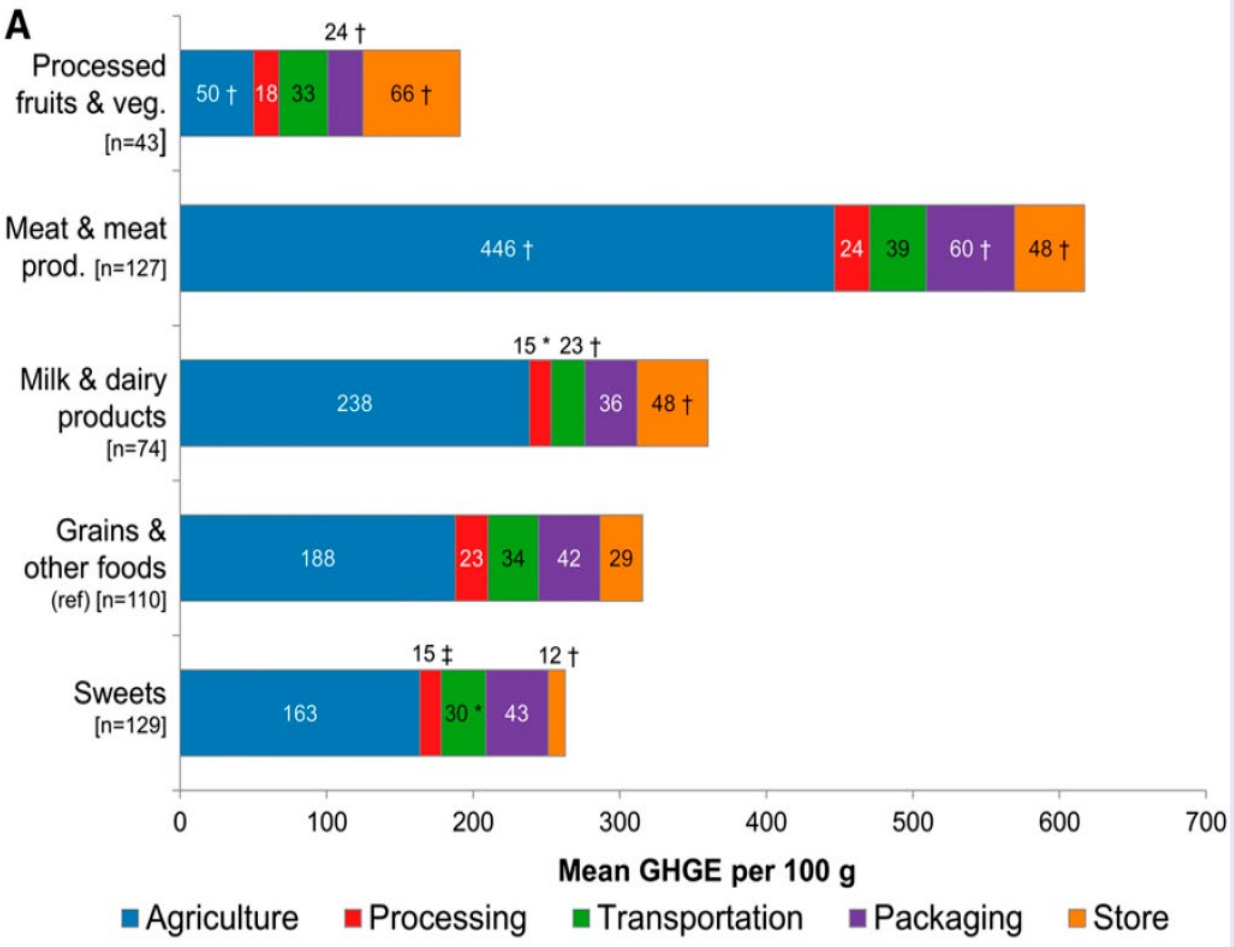


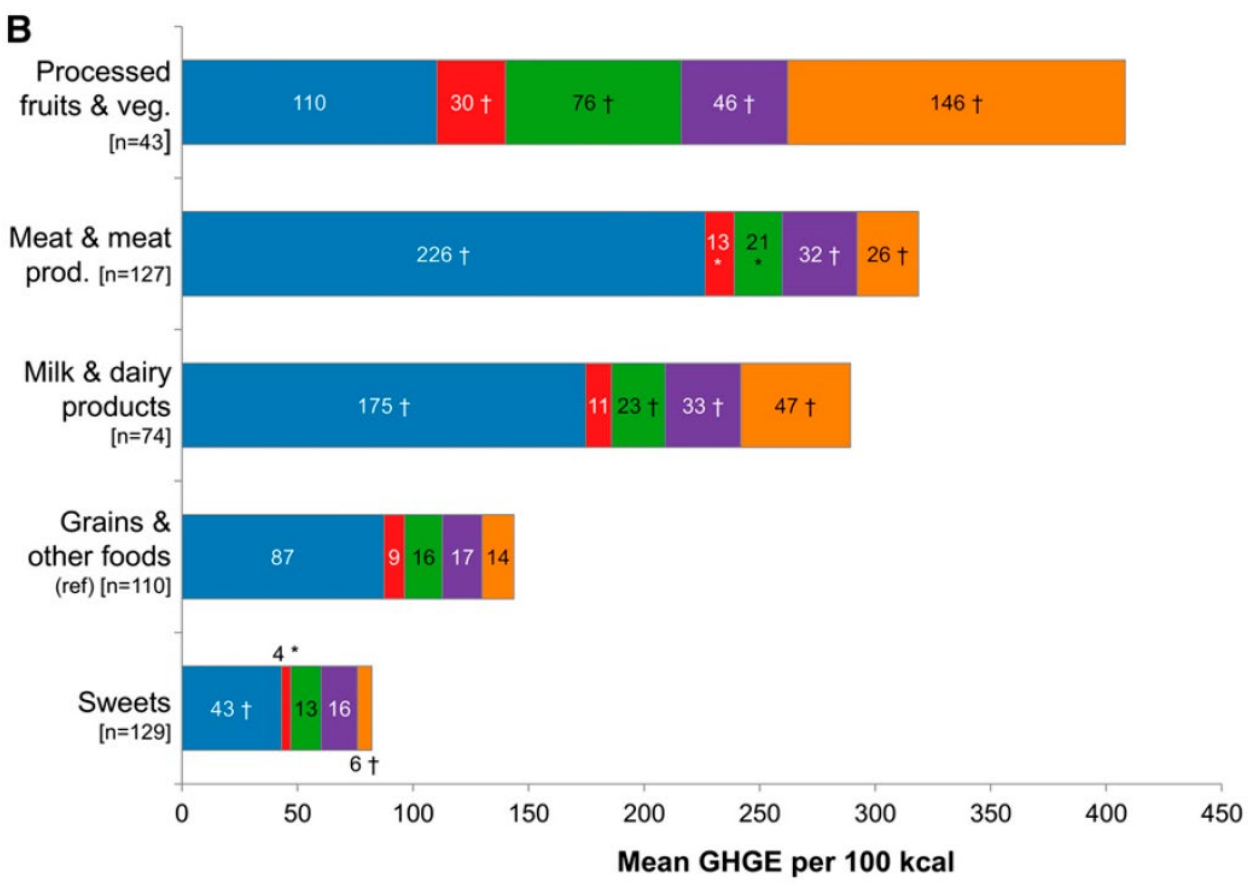
LCA of corn by Lee et al. (2020) showed high variation in GHG emissions from corn production in the US Midwest. They showed variation of almost 5 fold.

Contributing factors to this high variability included different soil types, precipitation, elevation and the amounts of fertilizers applied.

Lee, E.K., Zhang, X., Adler, P.R., Kleppel, G.S. and Romeiko, X.X., 2020. Spatially and temporally explicit life cycle global warming, eutrophication, and acidification impacts from corn production in the US Midwest. *Journal of Cleaner Production*, *242*, p.118465.

Challenge of Nutritional LCA





Drewnowski, A., et al., 2015. Am. J. Clin. Nutr. 101, 184–191.
DOI:10.3945/ajcn.114.092486

Assessment needs: Data, metrics, integrated modeling

- Data should be transparent (to maximum extent feasible), validated, widely available, inexpensive. (e.g., NAL digital commons)
- Need for comparable metrics that span sectors, industries and geographies
  - Sustainability metrics should be science-based: life cycle assessment as system model supported by production, nutrition, economic and social components
- The same data and models should be used by producers, retailers, policymakers, NGOs and consumers.

Data	Production, processing, consumption, waste, disposal. Nutrient composition, dietary intake and link to health outcomes. Economics (cost, value added) of production and consumption chains: livelihoods and affordability; costs.
Metrics	Environmental footprints/index Affordability index Nutrient quality index (foods & diet); Safety and health outcomes (DALYs). Cultural and other choice restrictions
Integrated Modeling	Production (process/big data/ statistical); Environment/health (LCA); Economic (GEM, PEM, LCC); Cultural/regulatory factors; effect of climate on production/nutrition => evaluation of alternatives, tradeoffs identified

LCA of Soybean endpoint categories – Heat Map

	Soybean production US	Land Occupation	Irrigation	Machine use	Transport	Pesticide production	Fertilizer production	Seeds	Drying of beans	Field Emission
Human Health	6.1E-07 DALY	0.0%	5.9%	37.4%	0.5%	1.5%	5.5%	2.8%	3.1%	43.4%
Ecosystem Quality	5.3E+00 PDF.m2.y	81.8%	0.4%	2.3%	0.0%	0.0%	0.1%	0.2%	0.4%	14.7%
Resources	3.6E+00 MJ	0.0%	18.4%	46.8%	1.3%	4.0%	13.5%	4.1%	11.8%	0.0%
Climate Change	5.3E-01 kg CO2 -eq	0.0%	7.5%	22.1%	0.6%	1.6%	6.3%	2.6%	7.3%	52.1%
Water withdrawal	1.1E-01 m3	0.0%	91.0%	1.7%	0.0%	0.8%	2.8%	2.3%	1.5%	0.0%
	per 1kg of soybean	Contribution Analysis								


Questions?