The option space for feeding the world in 2050 without deforestation: exploring the role of diets and agricultural technology

Helmut Haberl

Thanks to: K.-H. Erb, F. Krausmann,
T. Kastner, C. Lauk, A. Mayer, M. Theurl *et al.*

Institute of Social Ecology Vienna (SEC)
Alpen-Adria Universität
Schottenfeldgasse 29, 1070 Wien, Österreich

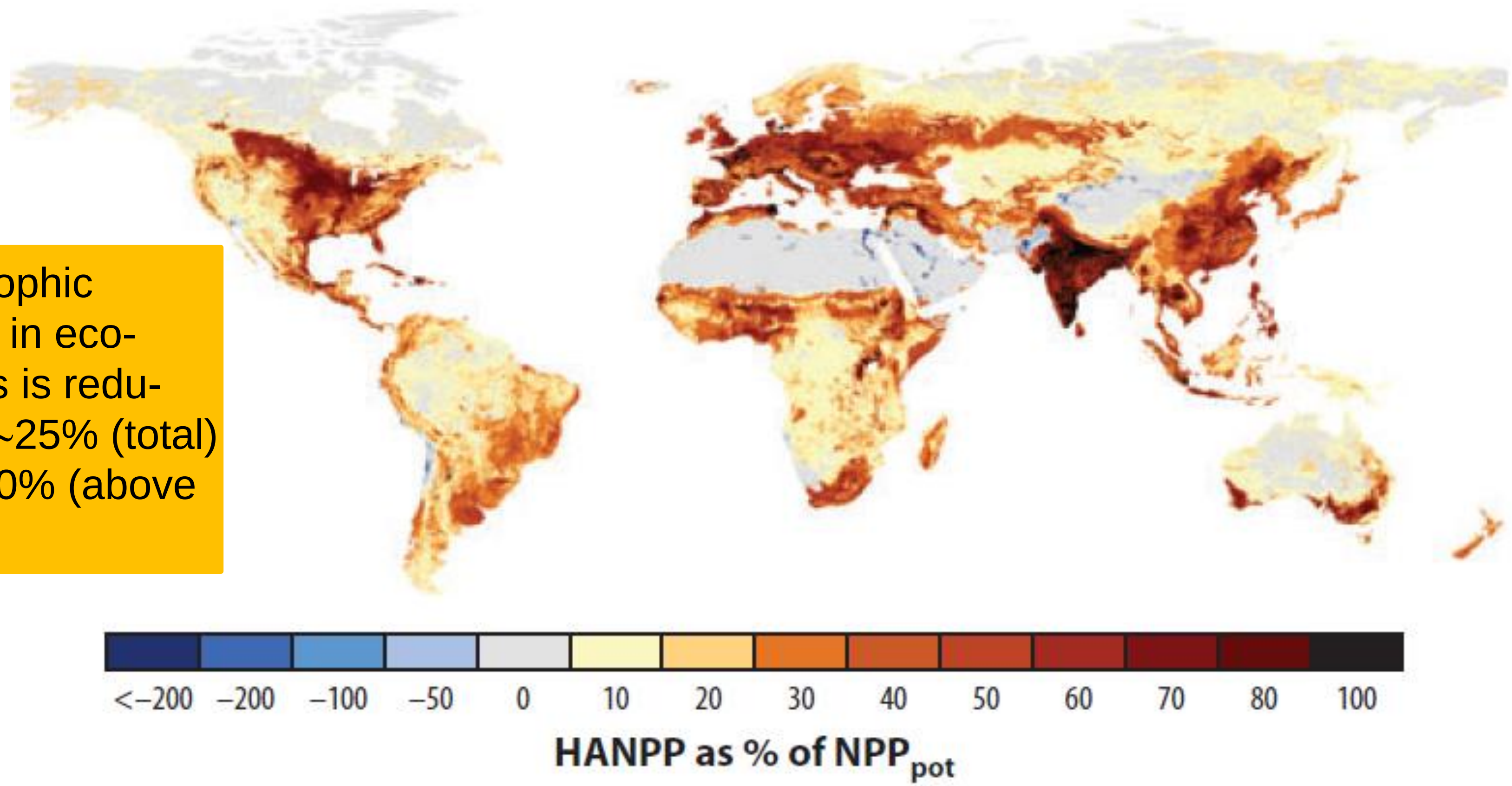
13th International Wheat Genetics Symposium
23rd-28th April 2017, Tulln, Austria

Global LAND Project
Austrian Academy of Sciences
Österreichische Akademie der Wissenschaften
ÖAW
FWF Der Wissenschaftsfonds.
BM.W_F
Bundesministerium für Wissenschaft und Forschung
ALPEN-ADRIA UNIVERSITÄT KLAGENFURT | WIEN GRAZ
iff social ecology vienna

Pressures on global land systems

- Land use change is a pervasive driver of global environmental change. ~75% of the land on earth is used by humans
- Driven by growing population and GDP, agricultural output may ~double until 2050
- Global bioenergy use may rise 2-5 fold until 2050 to replace fossil energy and perhaps(?) reduce GHG emissions
- At the same time
  - Urbanization consumes fertile land
  - Land required for carbon sequestration and biodiversity protection
  - Growing consumer demand for organic food
  - Concerns over animal welfare may require more land

Used planet: humans „appropriate“ 25-30% of global terrestrial NPP



NPP (trophic energy) in eco-systems is redu-ced by ~25% (total) and ~ 30% (above ground)

Haberl et al., 2014. *Ann.Rev.Env.Res.*, **39**, 363–391
(data from: Haberl et al., 2007. *PNAS,* **104**, 12942-12947)

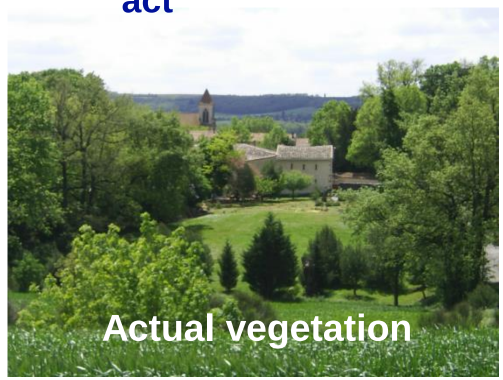
The human appropriation of net primary production (HANPP) approach

NPP_{pot}

Productivity of potential vegetation

(hypothetical vegetation assumed to prevail in the absence of land use; e.g., forests, grasslands, savannahs, deserts, shrubs, et

NPP_{act}



Productivity of actual vegetation

(including croplands, grasslands, built-up area, etc.

NPP_{eco}

Energy remaining in the ecosystem after harvest

Productivity change ($HANPP_{LUC}$)

Harvest ($HANPP_{harv}$)

Human approriation of NPP (HANPP)

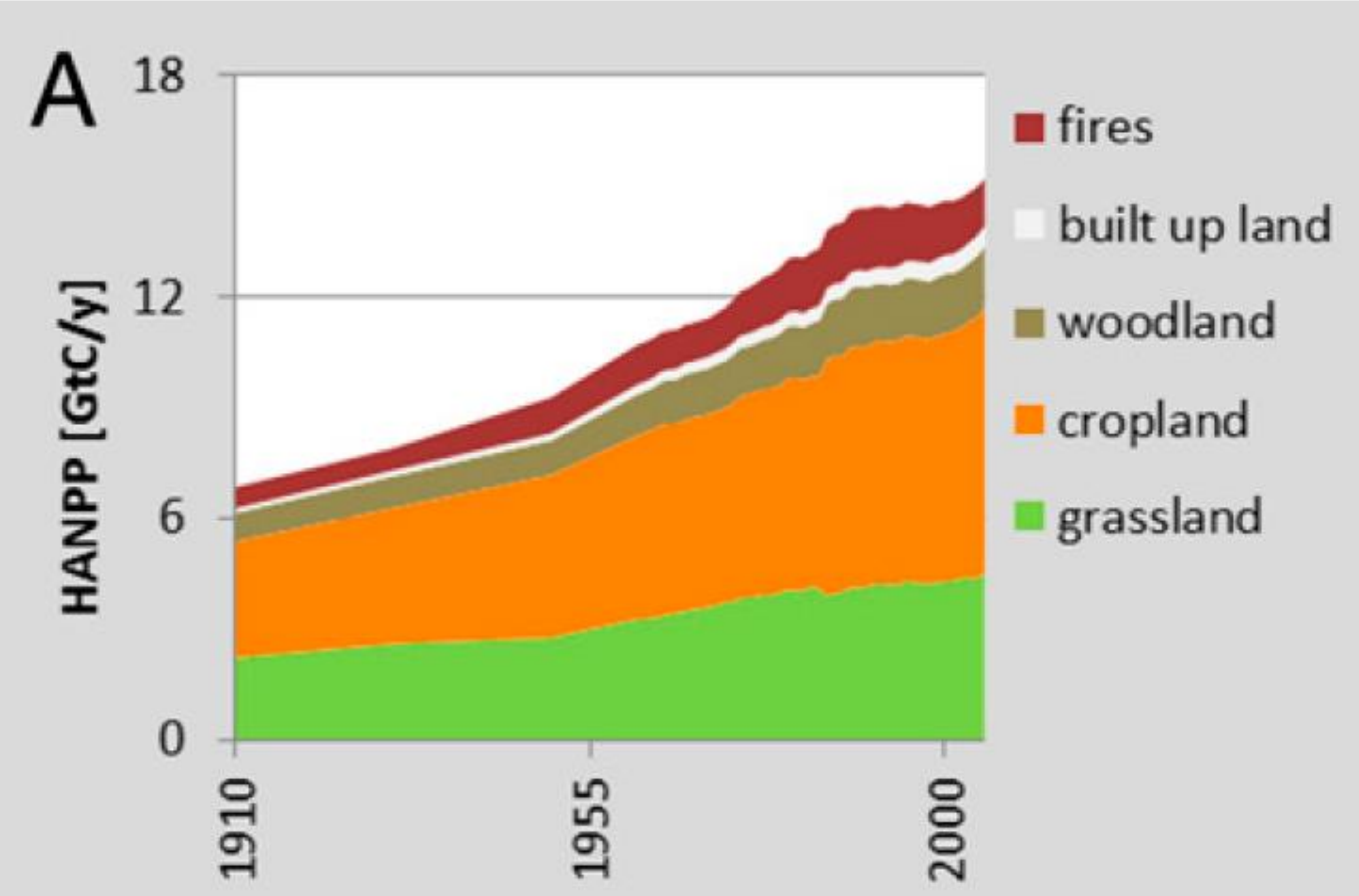
Global LAND Project

Slide by K.-H. Erb (**thanks!**)

ALPEN-ADRIA UNIVERSITÄT KLAGENFURT | WIEN GRAZ

iff social ecology vienna

Global HANPP doubled in the last century
(population and the economy grew much faster)



1910-2007: HANPP grew from 13% to 25%

(factor 2)

Population: factor 4

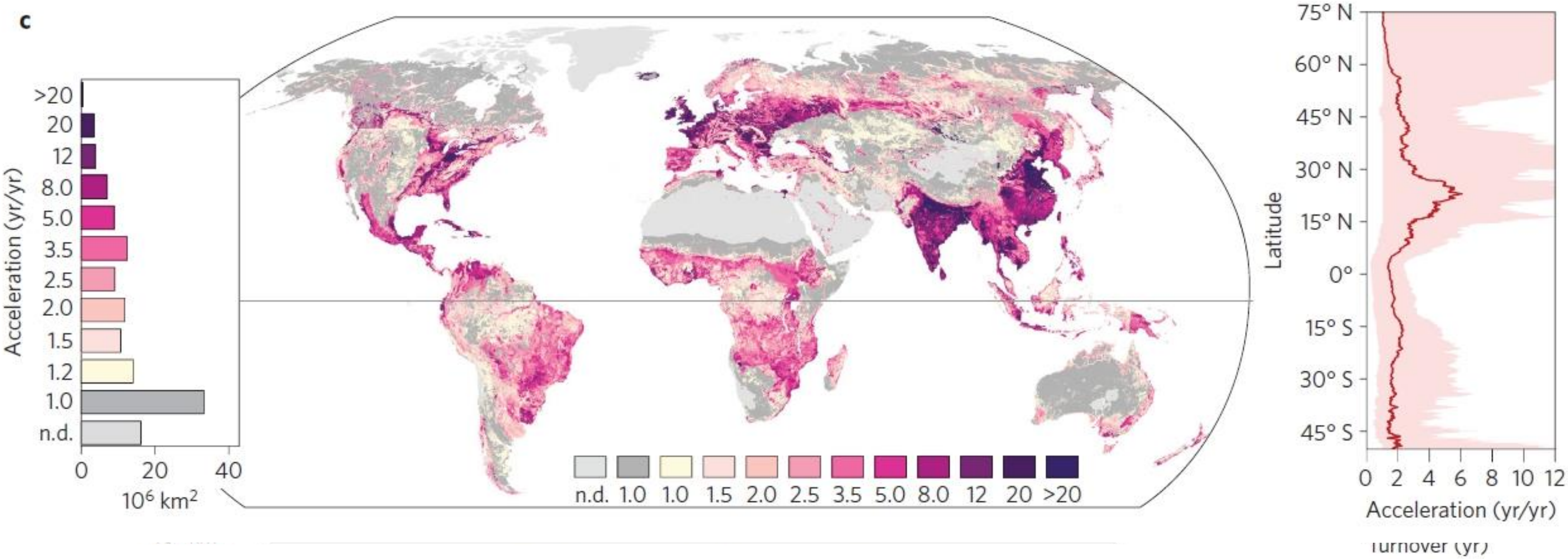
GDP: factor 17

Krausmann et al., 2013, *PNAS*, **110**, 10324-10329

Global LAND Project

ALPEN-ADRIA UNIVERSITÄT KLAGENFURT | WIEN GRAZ
iff social ecology vienna

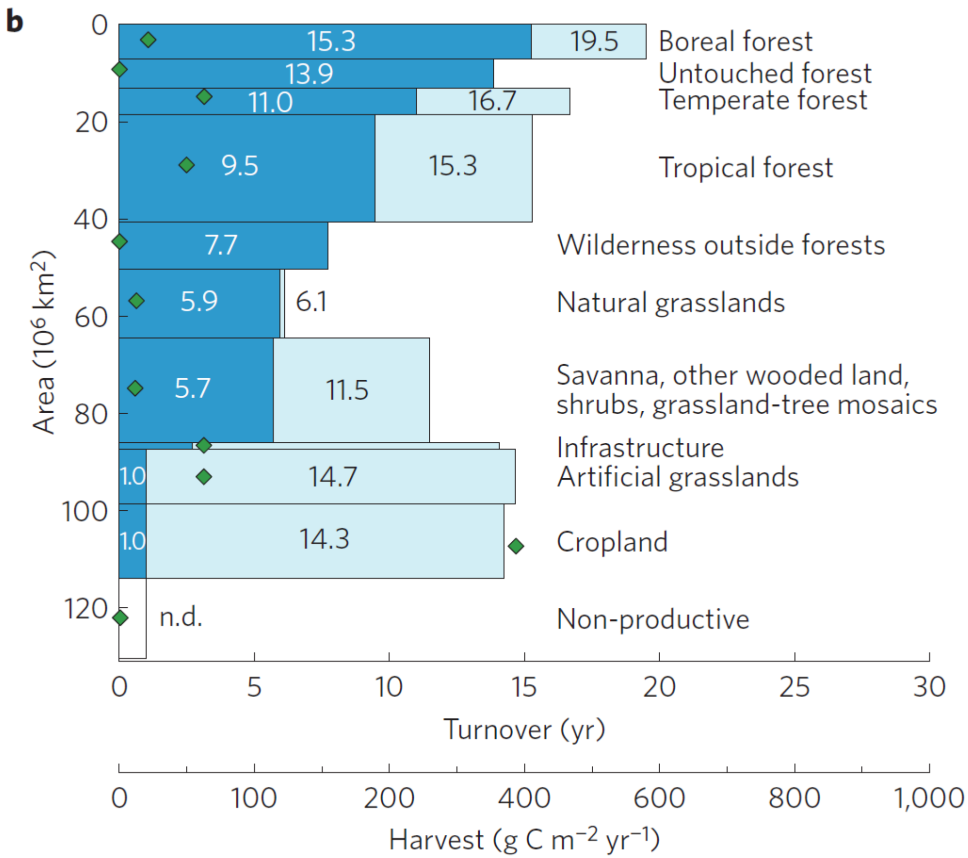
Speeding up the carbon cycle
Land use halves residence time of C in land ecosystems



Reduction of residence time: residence time in actual vegetation / residence time in potential vegetation

nature geoscience LETTERS
PUBLISHED ONLINE: 22 AUGUST 2016 | DOI: 10.1038/NGEO2782

Acceleration of the C cycle
Breakdown to land-use types



(green diamonds)

- Massive acceleration on converted land (agriculture, infrastructure), but smaller areas
- Moderate impacts due to land modification. But large areas affected
- Negatively correlated with land-use intensity / yields

Cropland loss from global urban expansion until 2030

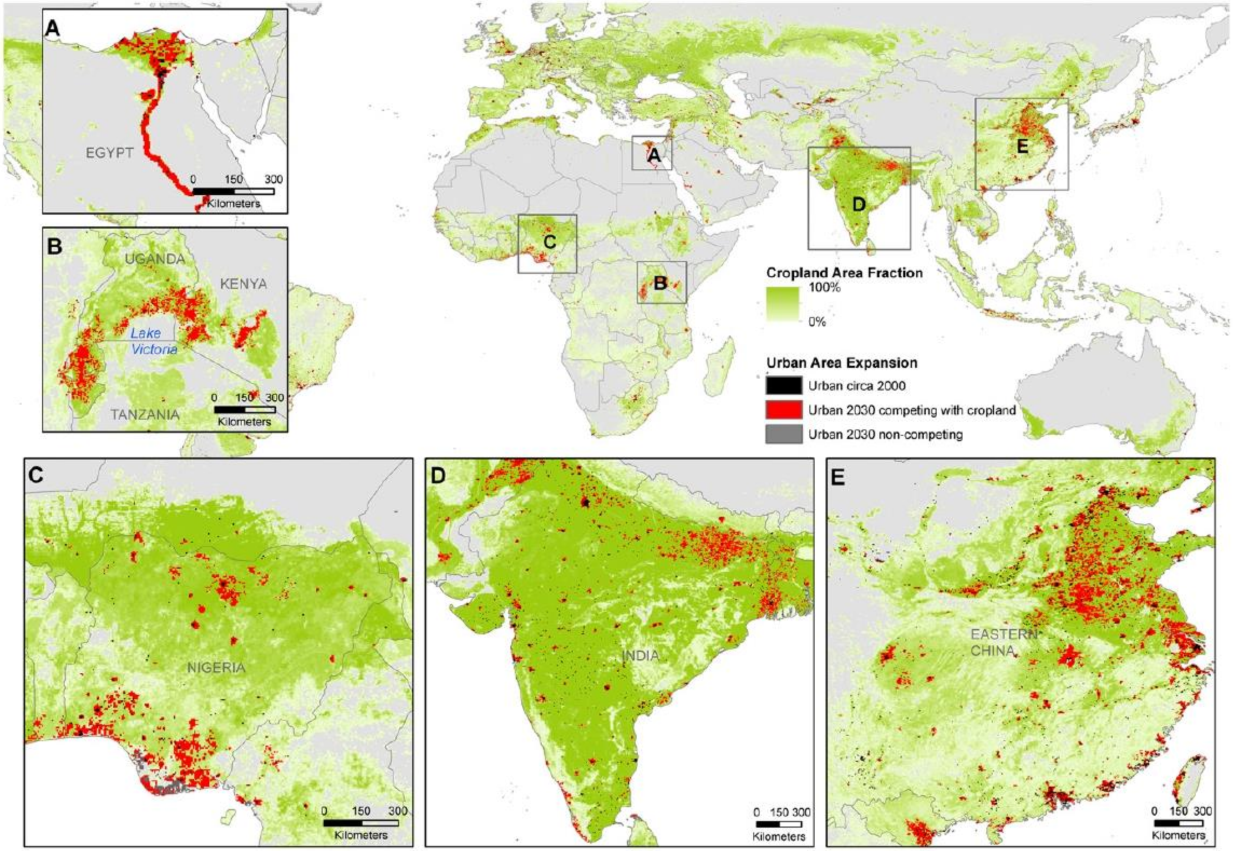
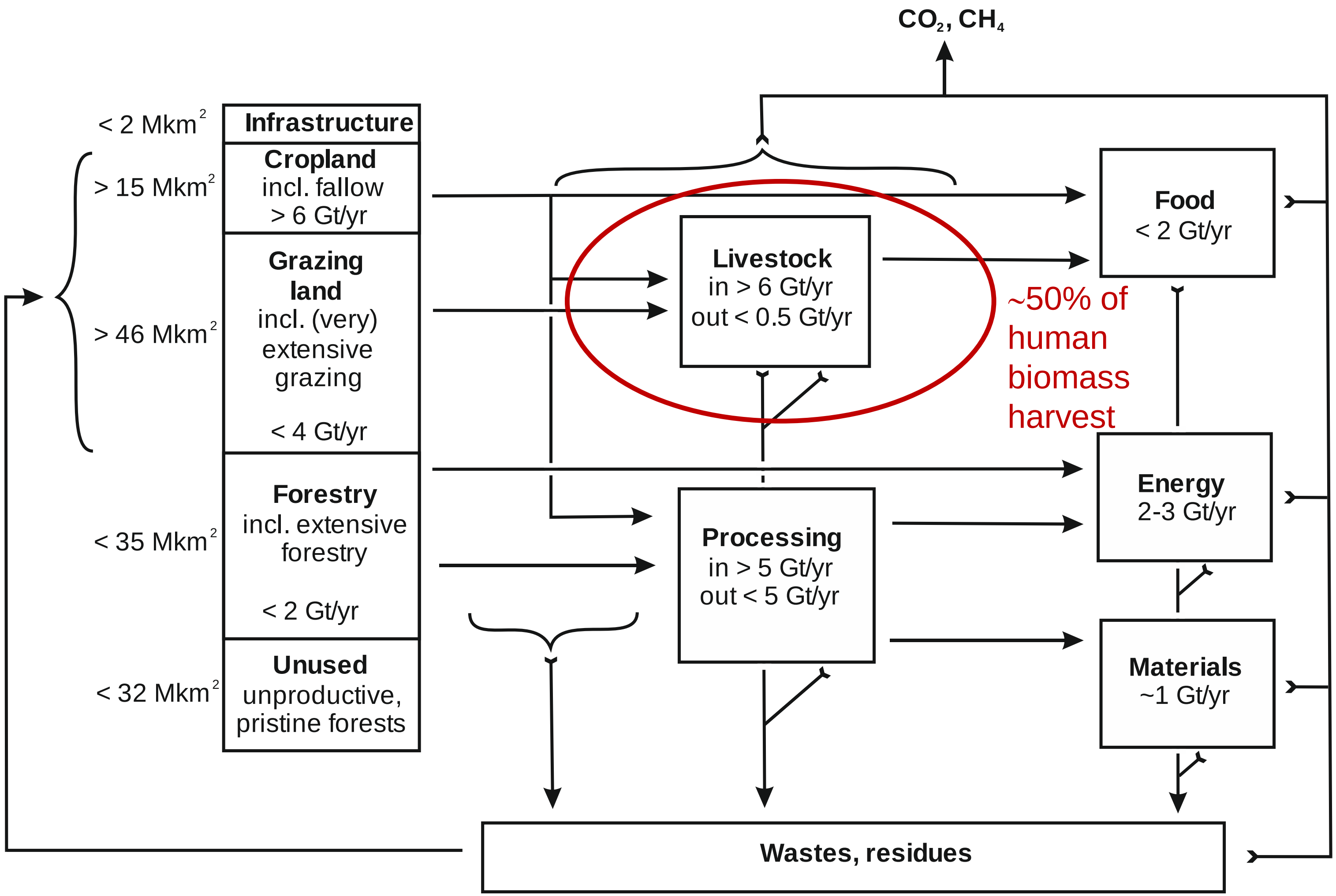


Fig. 1. Maps show where projected urban expansion until 2030 is expected to result in cropland loss. Competing areas (red) hold croplands but have a high probability (>75%; medium scenario) of becoming urbanized by 2030. (*A–E*) Close-ups of urban area expansion hot spots. Data on urban expansion are from ref. 4, and data on cropland are from ref. 16.

Urban expansion will consume 1.8-2.4% of current global cropland. This land currently produces 3-4% of all crops globally.

Bren d'Amour *et al.* 2016. *PNAS* doi: 10.1073/pnas.1606036114

Global land use and socioeconomic biomass flows



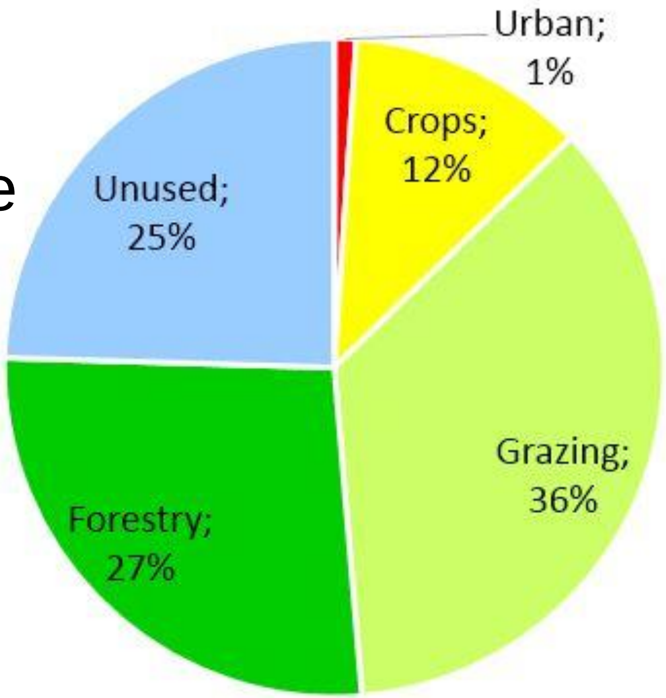
Land area
1 Mkm^2
= 10^6 km^2
= 10^{12} m^2

Yearly flows of dry-matter biomass
1 Gt/yr =
10^9 tons/year
= 10^{12} kg/yr
= 10^{15} g/yr
= 1 Pg/yr

Haberl, 2015, *Ecol. Econ.*, **119**, 424-431
IPCC, AR5 (2014), WGIII, ch11

Current global land use

- Three quarters of the world‘s ice-free land is used by humans
- Big differences in land-use intensity
- The remaining unused land is largely infertile (deserts, alpine or arctic tundra, etc.), except for remnants of pristine forests (5-7% of the ice-free land)



→ **Most additional services will come from land that is already in use (intensification & land-use competition↑)**

Erb *et al.* 2007. *J Land Use Sci.* **2**, 191-224;
Haberl 2015, *Ecol. Econ.*, **119**, 424-431

What do we *really* know about the current use of „unused“ lands?

- **Example:** Use of „wastelands“ (Indian govt.) in Tamil Nadu, South India, for biofuel production using *Jatropha*
- **Method:** Material and energy flow analysis based on fieldwork
- **Finding:** Introduction of Jatropha would replace existing local subsistence systems. *Jatropha* would replace existing bioenergy production using *Prosopis* which currently provides 2.5-10 times more useful energy than Jatropha could
- **Energy security would be weakened.**

Baka & Bailis, 2014. *Ecol. Econ.*, **108**, 8-17

Ecological Economics 108 (2014) 8–17

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

ELSEVIER

Analysis

Wasteland energy-scapes: A comparative energy flow analysis of India's biofuel and biomass economies

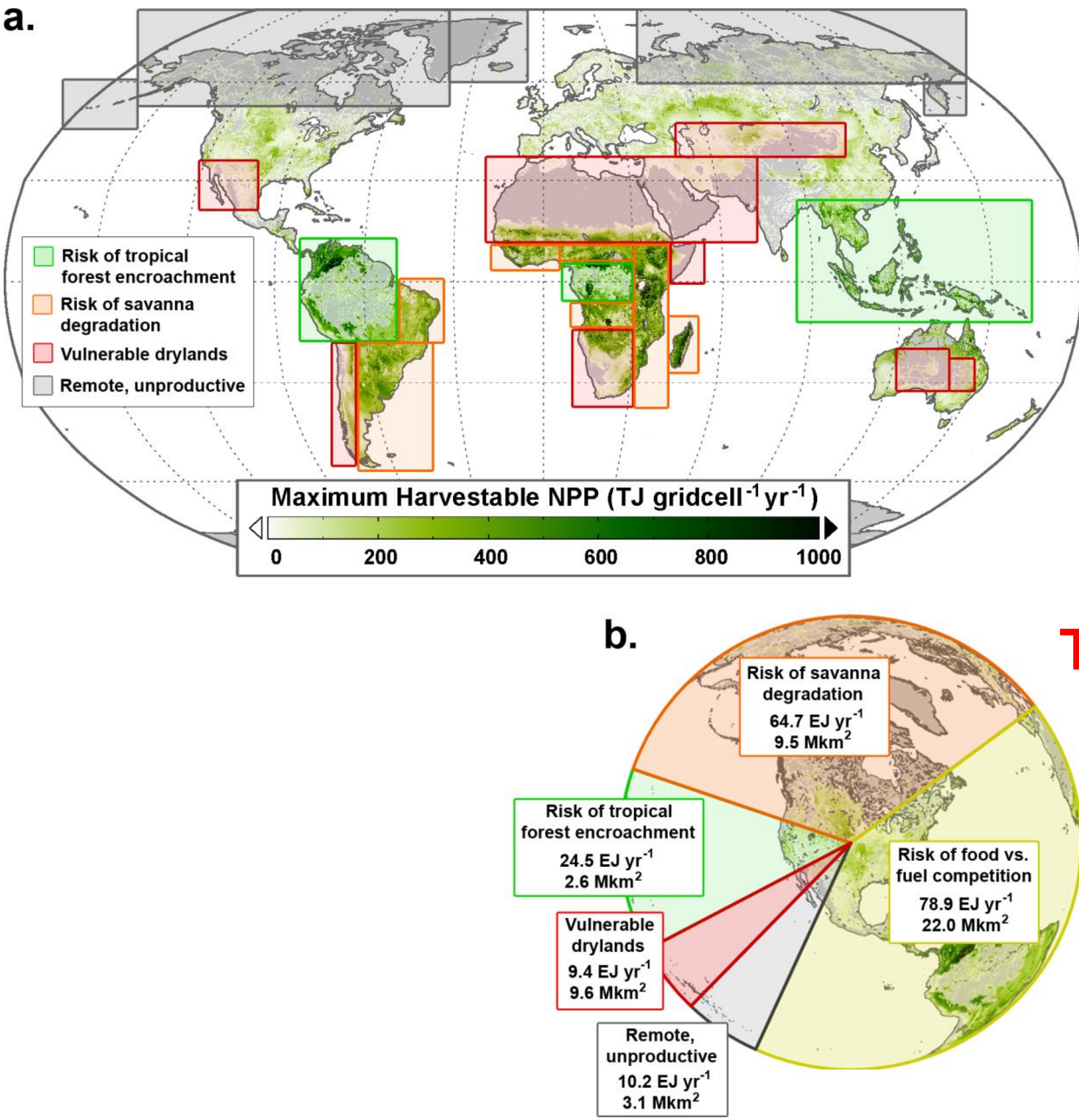
CrossMark

Jennifer Baka *, Robert Bailis

Geography and Environment, London School of Economics and Political Science, Houghton Street, London WC2A 2AE, UK
Yale School of Forestry and Environmental Studies, 195 Prospect Street, New Haven, CT 06511, USA

Increasing biomass supply from „grazing and other“ lands:

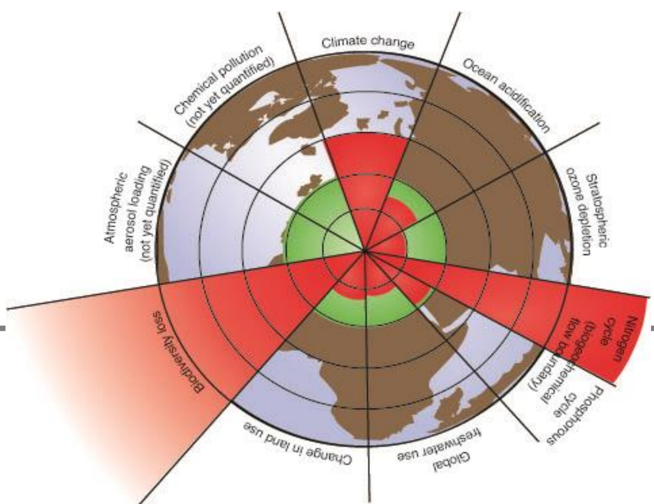
Trade-offs and risks



Haberl *et al.*, 2013, *Env. Res. Lett*. **8,** 031004

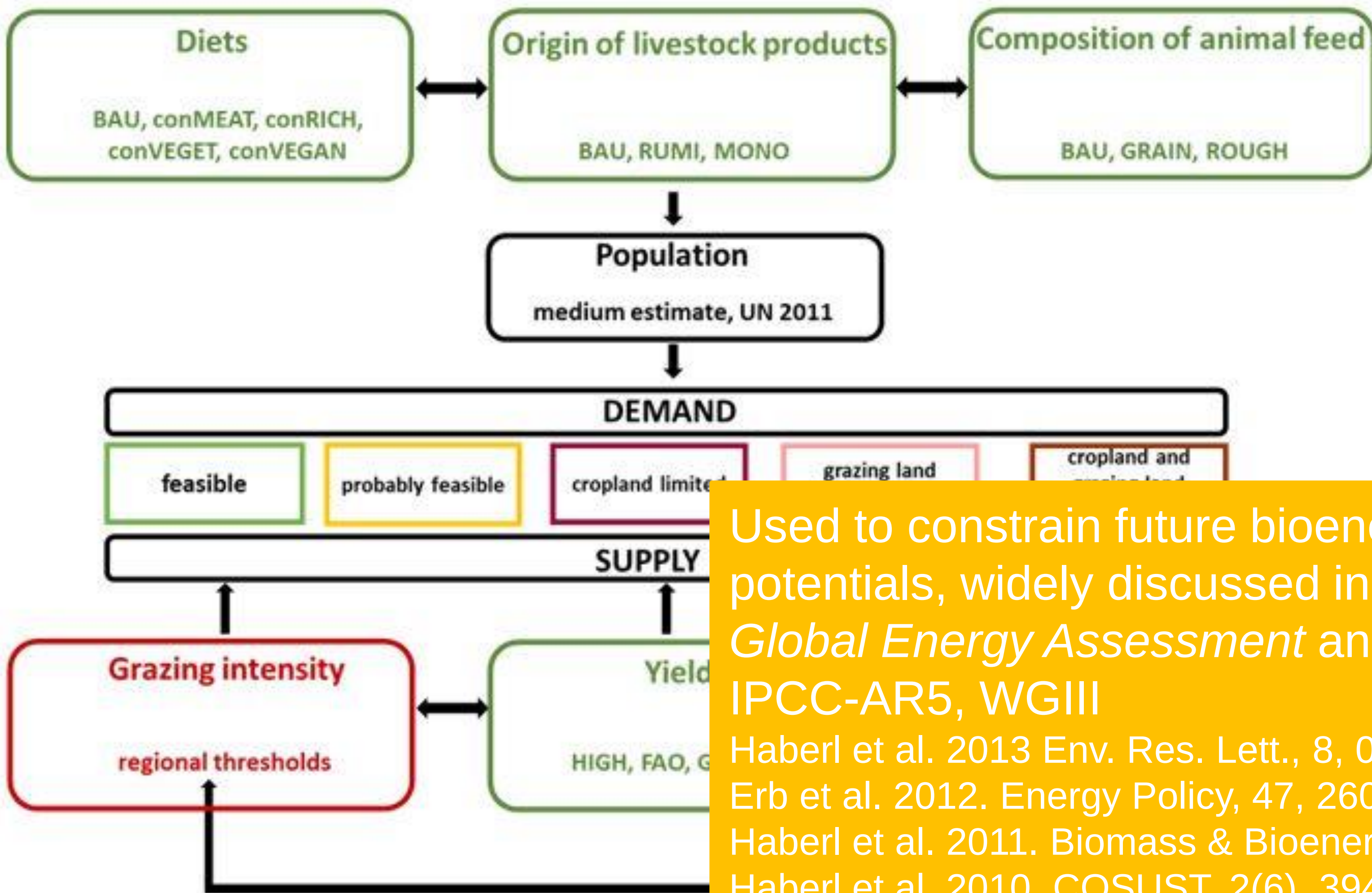
Challenges for producing more on land

- **Within land cover types**
  - **Constraints related to plant functional type**: biomass harvest can not exceed 20-30% of NPP in forests[1] or 10-50% of NPP in grasslands (depending on land quality) due to biomass allocation to belowground or other non-harvestable components and risk of degradation (*more research needed!*)
  - **Trade-offs with other planetary boundaries:** raising NPP may affect freshwater availability, nitrogen or phosphorous cycles, GHG emissions (e.g. feedbacks with C sequestration), biodiversity, etc.
- **Raising biomass harvest by changing land cover**
  - **Land suitability** (e.g., suitability for cropping)
  - **Trade-offs** with other planetary boundaries, e.g. carbon or biodiversity



[1] Schulze *et al.* 2012. *GCB Bioenergy*, **4**, 611-616

BioBaM – a biophysical model to evaluate systemic effects in global land use 2050



Used to constrain future bioenergy potentials, widely discussed in the *Global Energy Assessment* and in IPCC-AR5, WGIII

Haberl et al. 2013 Env. Res. Lett., 8, 031004.
Erb et al. 2012. Energy Policy, 47, 260-269
Haberl et al. 2011. Biomass & Bioener. 35, 4753
Haberl et al. 2010. COSUST, 2(6), 394-403.

Erb et al., 2016 *Nature Communications*, **7**, 11382, doi: 10.1038/10.1038/NCOMMS11382.

Global LAND Project

nature COMMUNICATIONS

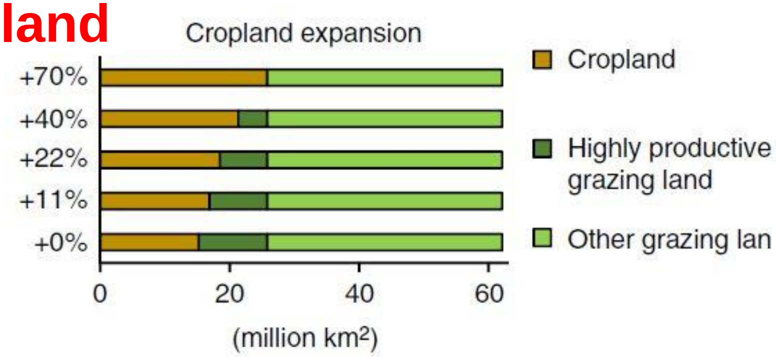
ALPEN-ADRIA UNIVERSITÄT KLAGENFURT I WIEN GRAZ
iff social ecology vienna

Characteristics of BioBaM

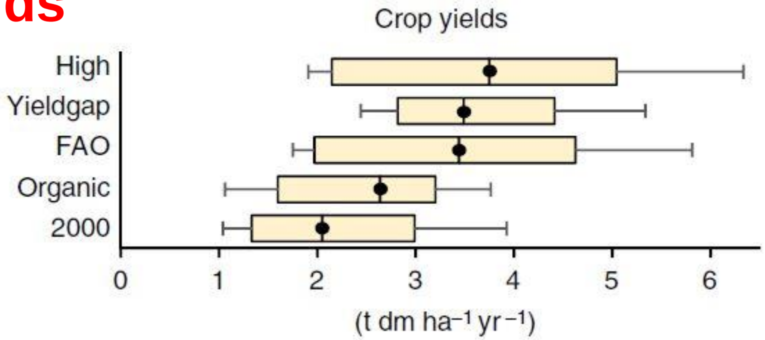
- Based on high-quality consistent land-use and biomass flow databases for the year 2000
- Resolution: Land-use data ~10km grid, biomass-flow data national, scenario definitions currently 11 world regions, ~10 crop aggregates.
- Transparent diagnostic model based on thermodynamic (mass-balance) principles: evaluates biophysical feasibility of combinations of assumtions on area change, yield change, biomass coversion efficiency and demand.
- Regional shortages closed by trade if possible
- No system dynamics, no optimization, no mechanistic modelling, except for mass balancing – assumptions from literature or other models

Scenarios for 2050: Variants for different parameters

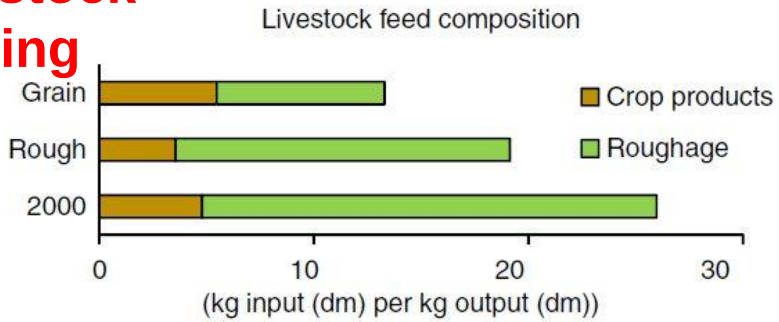
Cropland



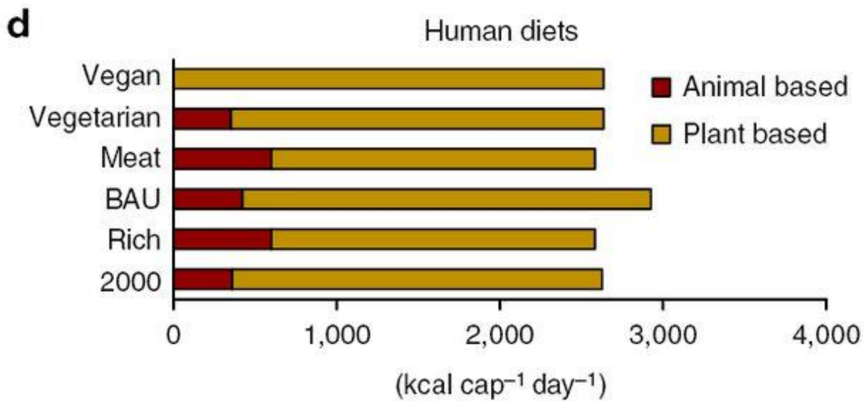
Yields



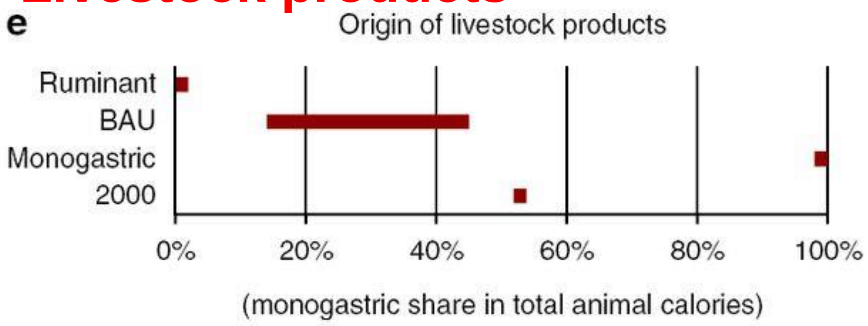
Livestock feeding



Diets



Livestock products



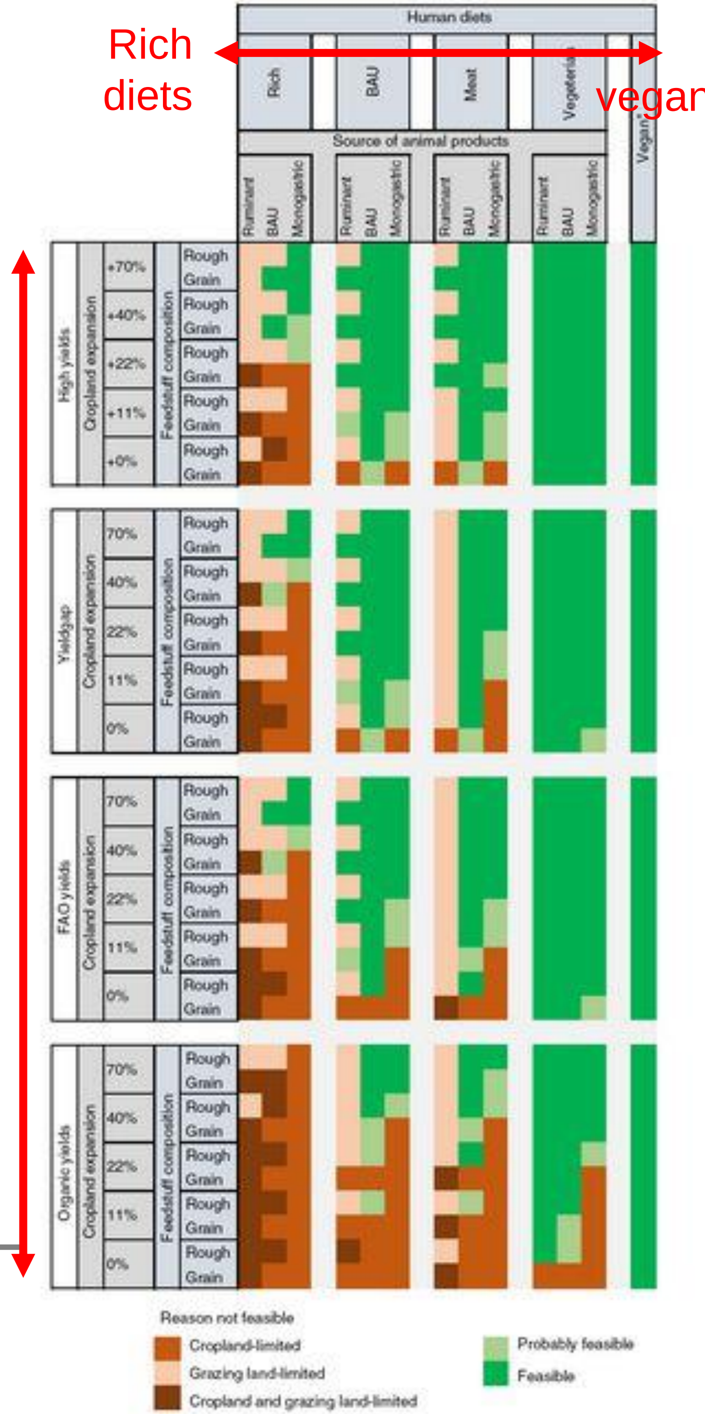
Erb *et al*. 2016. *Nature Comm*., doi: 10.1038/10.1038/NCOMMS11382

The options space for feeding the world 2050 w/o deforestation

- **x-axis:**
  - diets from rich to vegan,
  - different main sources of animal products
- **y-axis:**
  - yields (organic/low to high),
  - cropland expansion (from 0% to +70%)
  - feedstuff composition (roughage vs. grains)
- **Message:** strong feedbacks between diets, land use, yields, livestock, and bioenergy

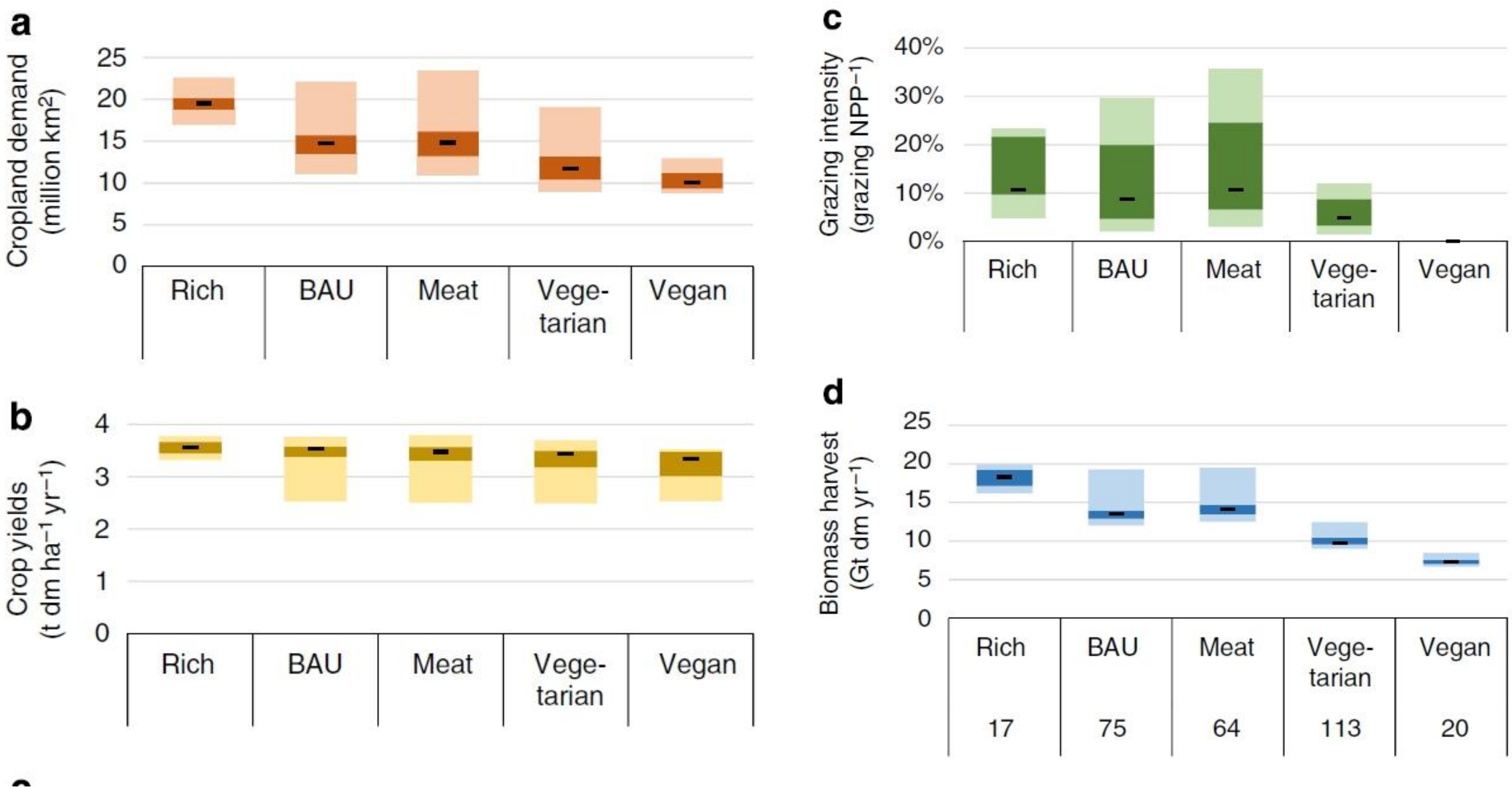
High yields

Organic agric.



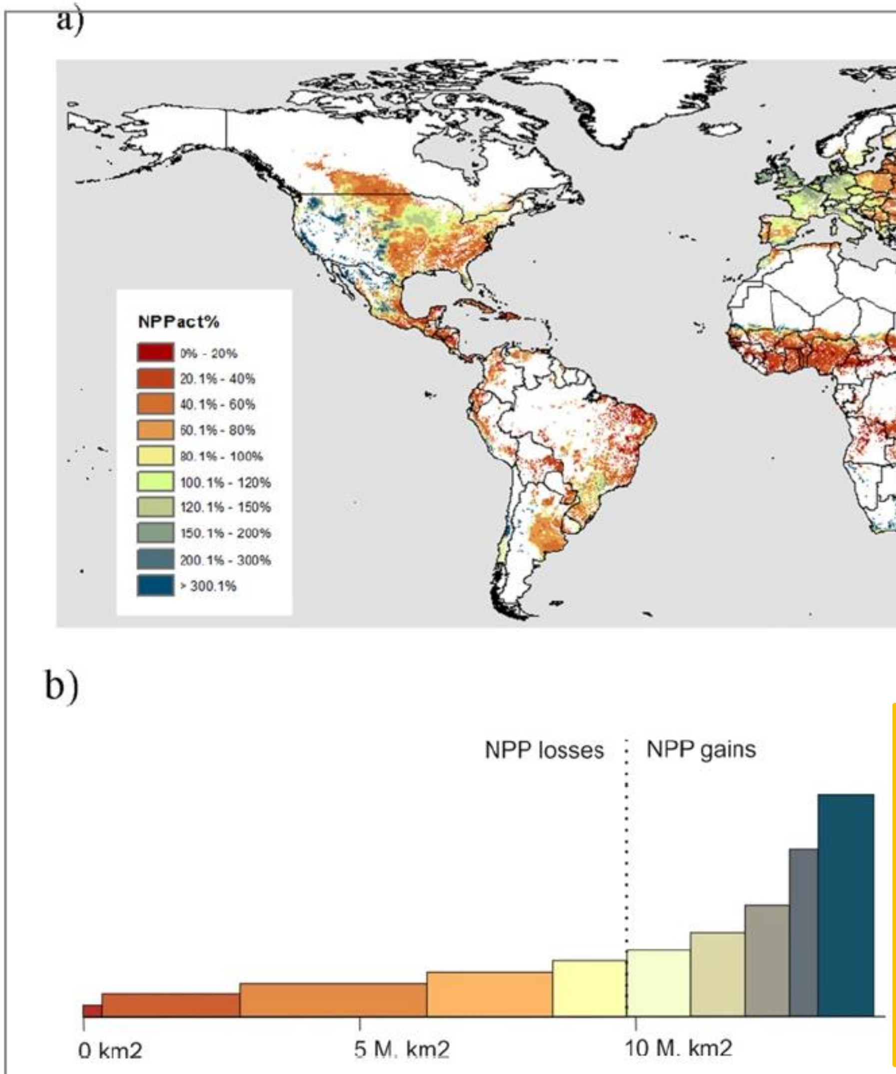
Erb *et al*. 2016. *Nature Comm*., doi: 10.1038/10.1038/NCOMMS11382

Exploring the option space



Erb et al., 2016 *Nature Communications*, **7**, 11382, doi: 10.1038/10.1038/NCOMMS11382.

Zooming in on croplands: a HANPP$_{luc}$ perspective

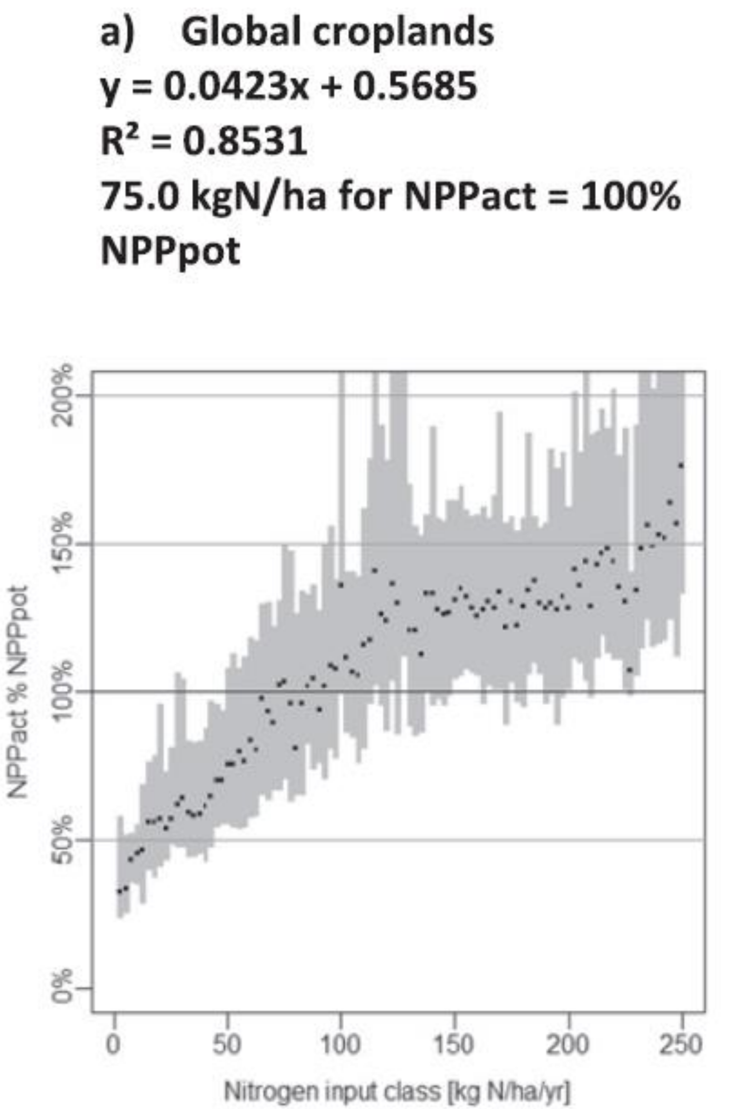


- → From NPP losses >90% to NPP gains >300%
- → NPP gains in drylands & industrialized countries
- → Globally NPP$_{act}$ on croplands is 14% lower than NPP$_{pot}$
- → 36% of global croplands show productivity gains

Figure 2. (a) NPP$_{act}$ as percentage of NPP$_{pot}$ (denoted as NPP$_{act\%}$) around 2000; (b) km^2 of cropland per class of NPP$_{act\%}$ indicated by the box-width. Color codes in (a) and (b) match.

Niedertscheider *et al.* 2016. *Env. Res. Lett.* **11**, 014008

N costs of raising NPP_{act} on croplands



Increasing Nitrogen inputs raises actual productivity and hence reduces $HANPP_{luc}$ (R^2 = 0.86)

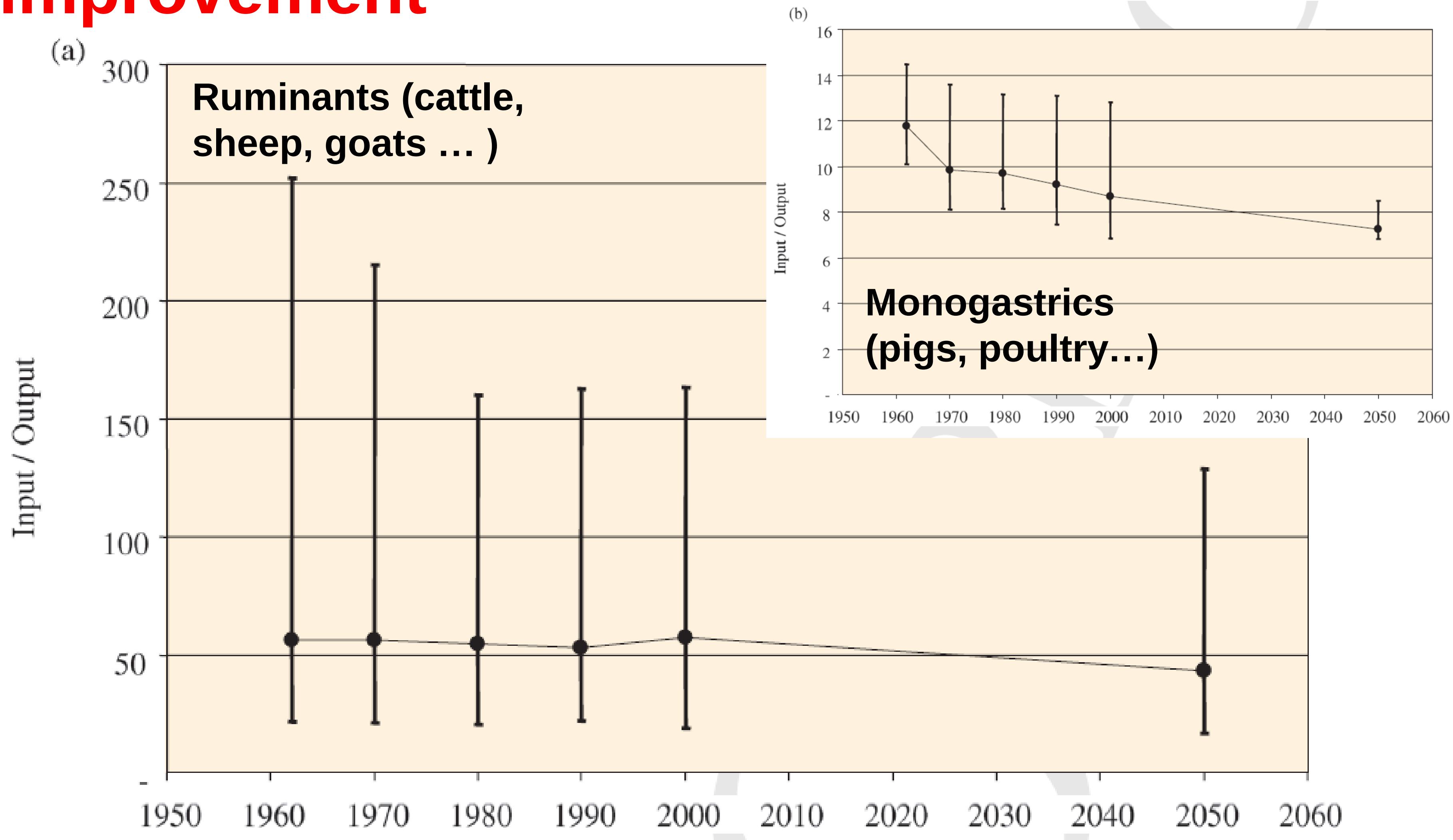
After surpassing NPP_{pot}, gains in NPP_{act} (i.e. reductions in $HANPP_{luc}$) become more costly in terms of additional N input required, and responses to increased inputs are uncertain

Global LAND Project

Niedertscheider *et al.* 2016. *Env. Res. Lett.* **11**, 014008

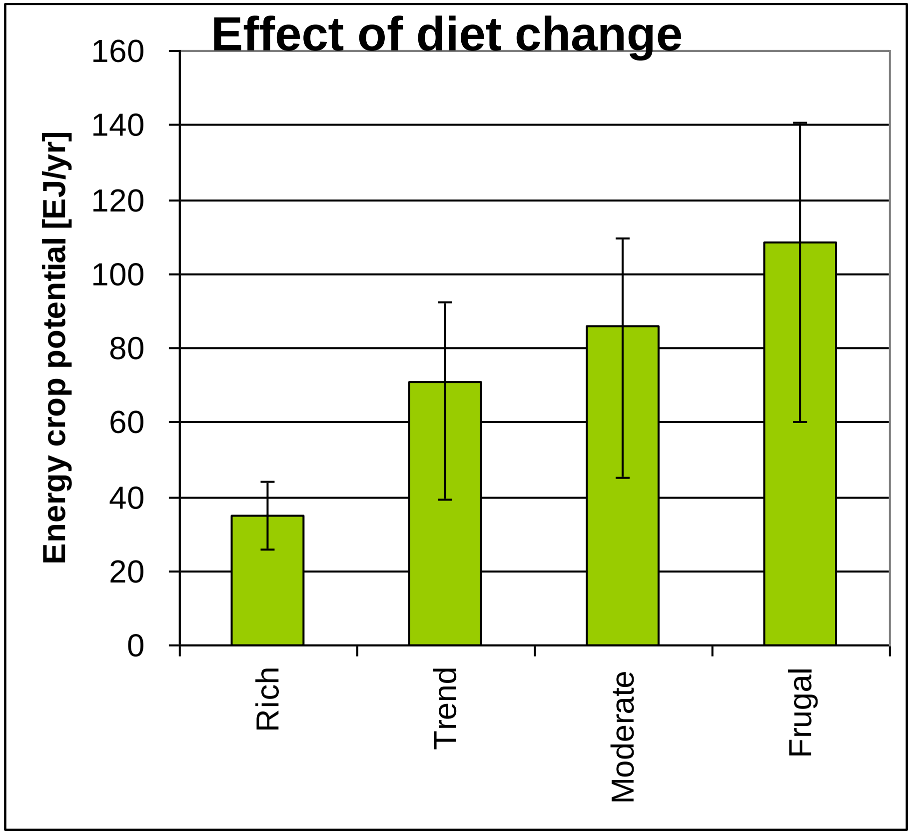
ALPEN-ADRIA UNIVERSITÄT KLAGENFURT I WIEN GRAZ
iff social ecology vienna

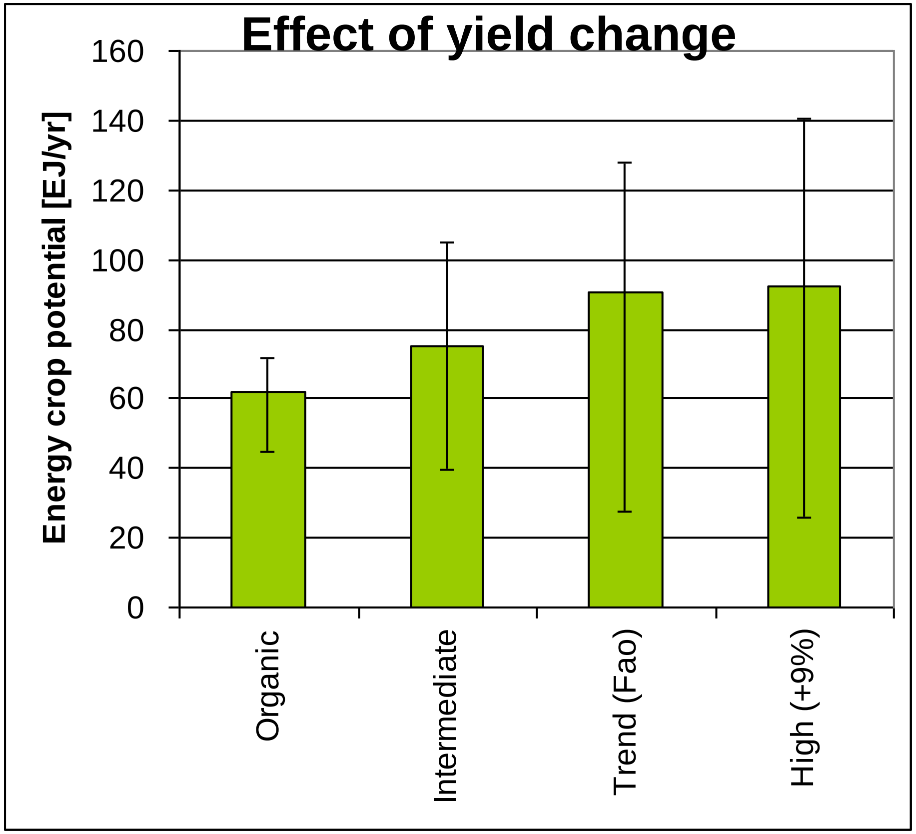
Livestock feeding efficiencies: room for improvement



Global Energy Assessment 2012, Chapter 20;
Data derived from FAO (Krausmann, Wirsenius)

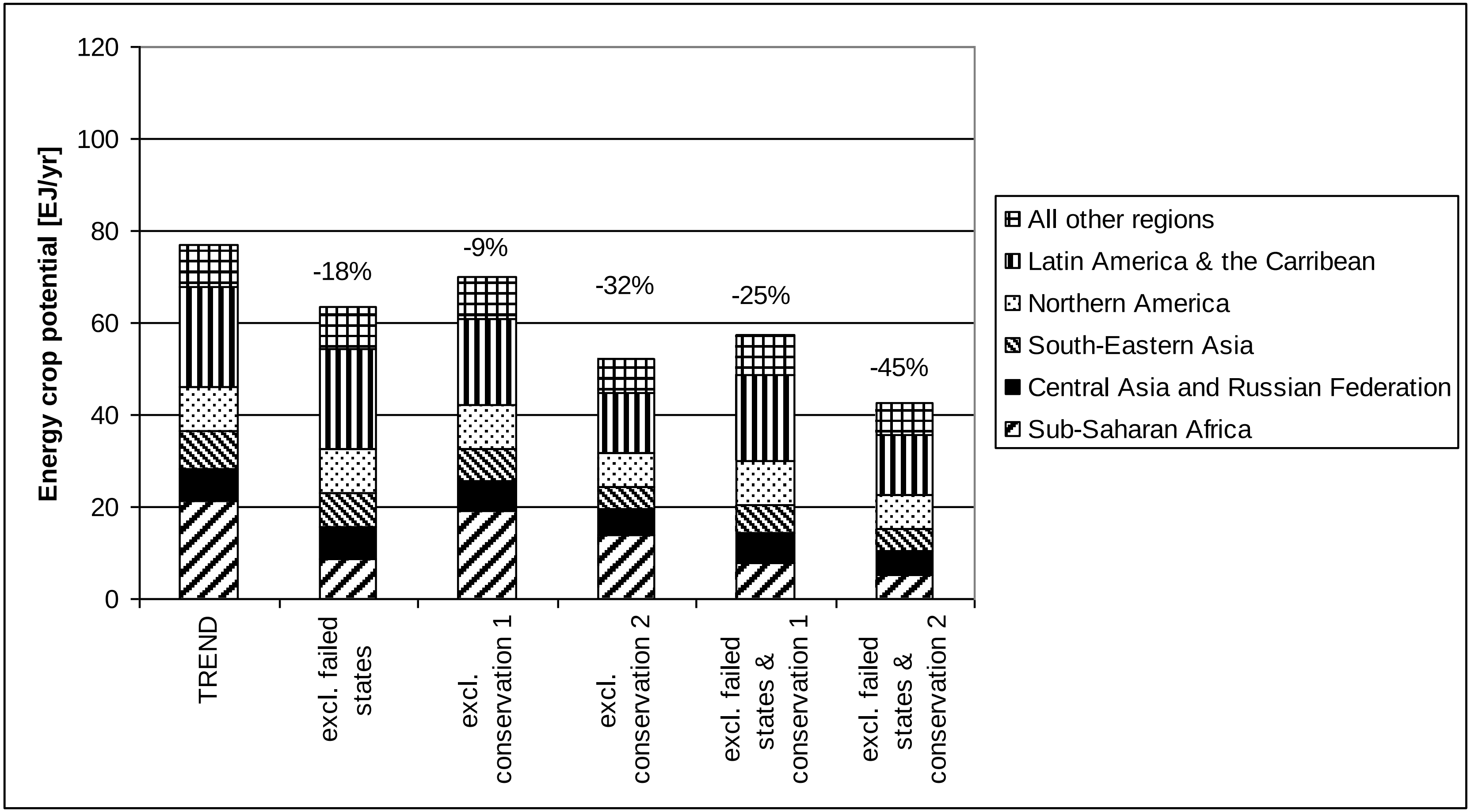
Dependency of energy crop potential 2050 on diet and agricultural technology





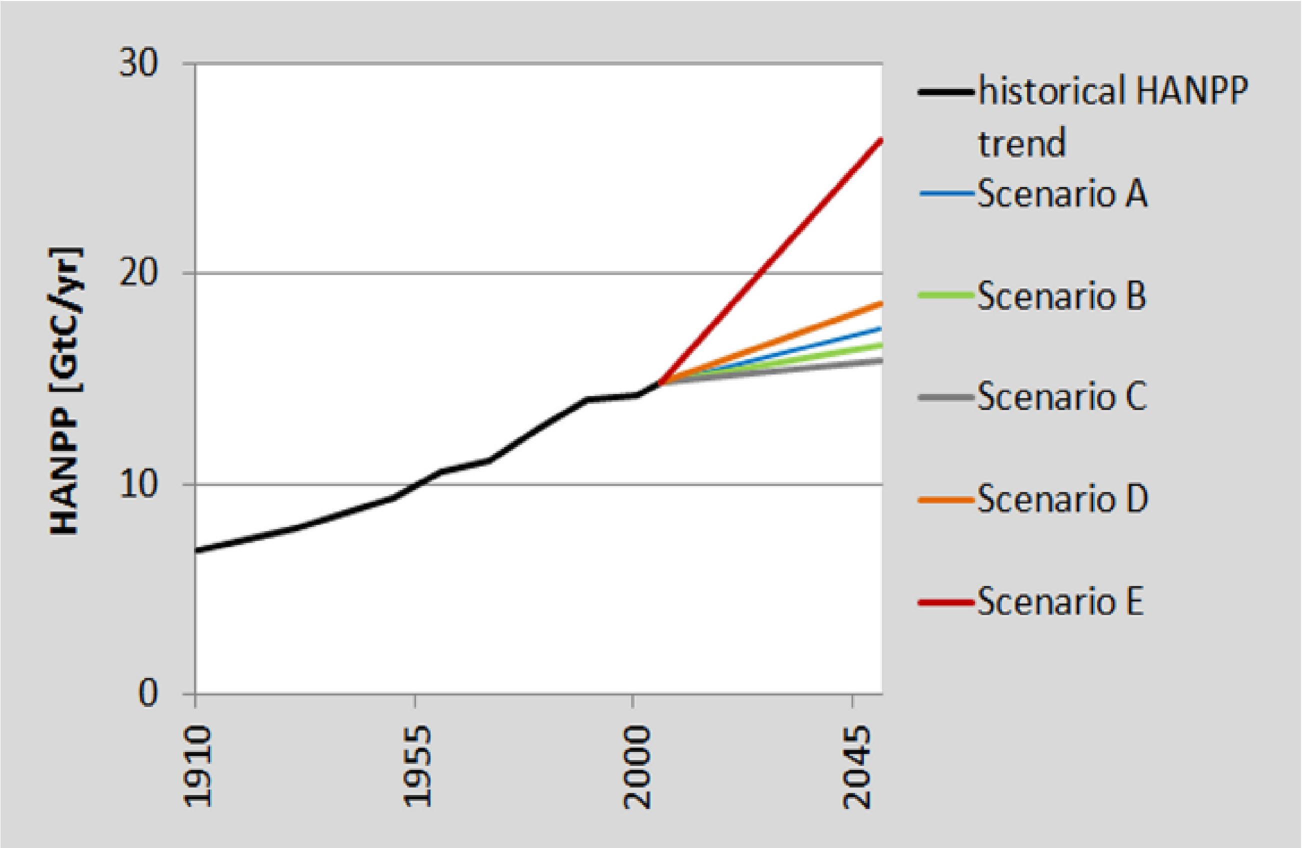
Erb et al., 2012, *Energy Policy* **47**, 260-269

Effect of exclusion of protected areas and failed states on biomass potentials



Erb et al., 2012, *Energy Policy* **47**, 260-269

Future HANPP depends above all on bioenergy expansion



Additional bioenergy until 2050

Scenarios A-C: Continuation of current trends

Scenario D: +50 EJ/y

Scenario E: +250 EJ/y

Krausmann et al., 2013, *PNAS*, **110**, 10324-10329

GHG reduction in land use

Largest potentials are at the demand side

Table 2 Changes in global land use and related GHG reduction potentials in 2050 assuming the implementation of measures to increase C sequestration on farmland, and use of spare land for either bioenergy or afforestation

Cases	Food crop area	Livestock grazing area	C sink on farmland*	Afforestation of spare land†,‡	Bioenergy on spare land†,§	Total mitigation potential	Difference in mitigation from reference case
	[Gha]		Gt CO_2eq. yr^{-1}				
Reference	1.60	4.07	3.5	6.1	1.2–9.4	4.6–12.9	0
Diet change	1.38	3.87	3.2	11.0	2.1–17.0	5.3–20.2	0.7–7.3
Yield growth	1.49	4.06	3.4	7.3	1.4–11.4	4.8–14.8	0.2–1.9
Feeding efficiency	1.53	4.04	3.4	7.2	1.4–11.1	4.8–14.5	0.2–1.6
Waste reduction	1.50	3.82	3.3	10.1	1.9–15.6	5.2–18.9	0.6–6.0
Combined	1.21	3.58	2.9	16.5	3.2–25.6	6.1–28.5	1.5–15.6

*Cropland for food production and livestock grazing land. Potential C sequestration rates with improved management derived from global technical potentials in Smith *et al.* (2008).

†Spare land is cropland or grazing land not required for food production, assuming increased but still sustainable stocking densities of livestock based on Haberl *et al.* (2011) and Erb *et al.* (2012a).

‡Assuming 11.8 tCO_2. eq ha^{-1} yr^{-1} (Smith *et al.*, 2000).

§High bioenergy value: short-rotation coppice or energy grass directly replaces fossil fuels, energy return on investment 1 : 30, dry-matter biomass yield 10 t ha^{-1} yr^{-1} (Smith *et al.*, 2012b). Low bioenergy value: ethanol from maize replaces gasoline and reduces GHG by 45%, energy yield 75 GJ ha^{-1} yr^{-1} (Chum *et al.*, 2011).

Take-home messages (1)

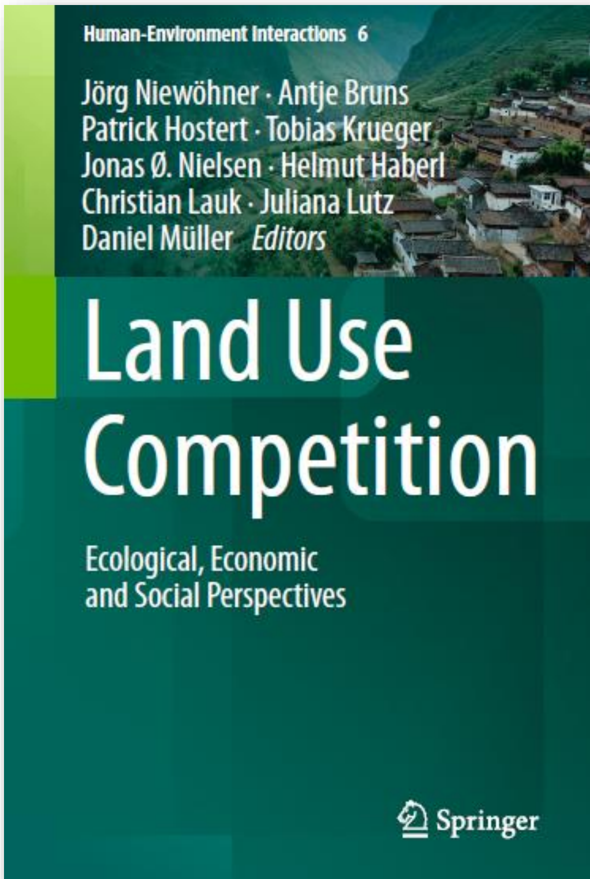
- Rising demand will result in increasing pressure towards intensification and land-use competition
- Raising yields does not automatically reduce land-use competition – it easy to „eat up“ all its benefits
- Organic agriculture can feed the world, but not at high consumption levels
- Environmentally favourable options that reduce yields (e.g. organic agriculture) may intensify land competition if not combined with modest diets
- Bioenergy: tread carefully

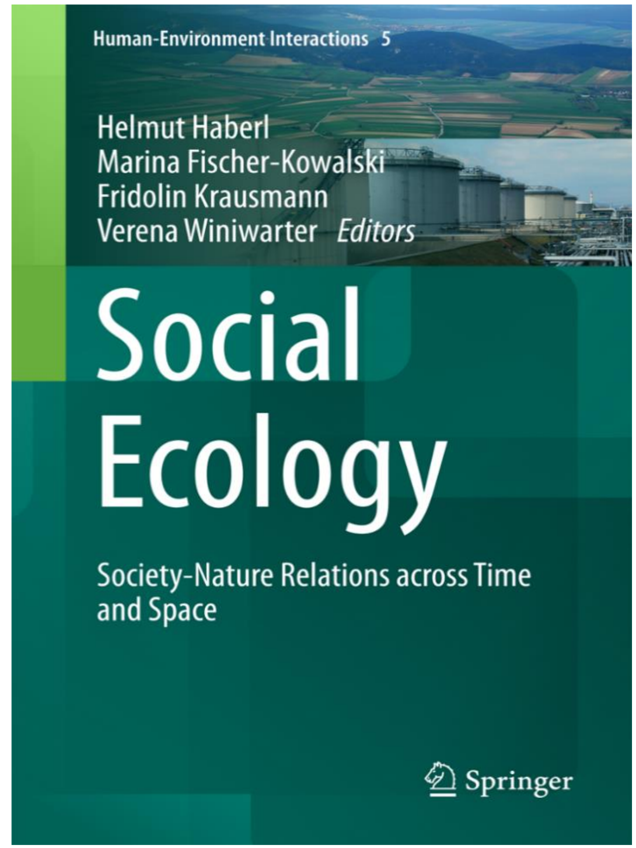
Take-home messages (2)

- Raising feeding efficiencies can help, but may carry other trade-offs (e.g. animal welfare, maintenance of ecologically valuable extensive grasslands, use of marginal areas for food production)
- Demand-side options may have fewest detrimental side-effects, but may be difficult to promote
  - Cascade utilization (better integrate supply chains of food, fibre and bio-energy by re-using and recycling biomass)
  - Reduce losses in supply chains (e.g. reduce food wastes)
  - Reducing animal products in diets

Thanks for your attention, now some PR

Download data & publications at: www.aau.at/sec
New books:





Global LAND Project

ALPEN-ADRIA UNIVERSITÄT
KLAGENFURT | WIEN GRAZ
iff social ecology vienna