HANPP – A socio-ecological perspective on land use transitions

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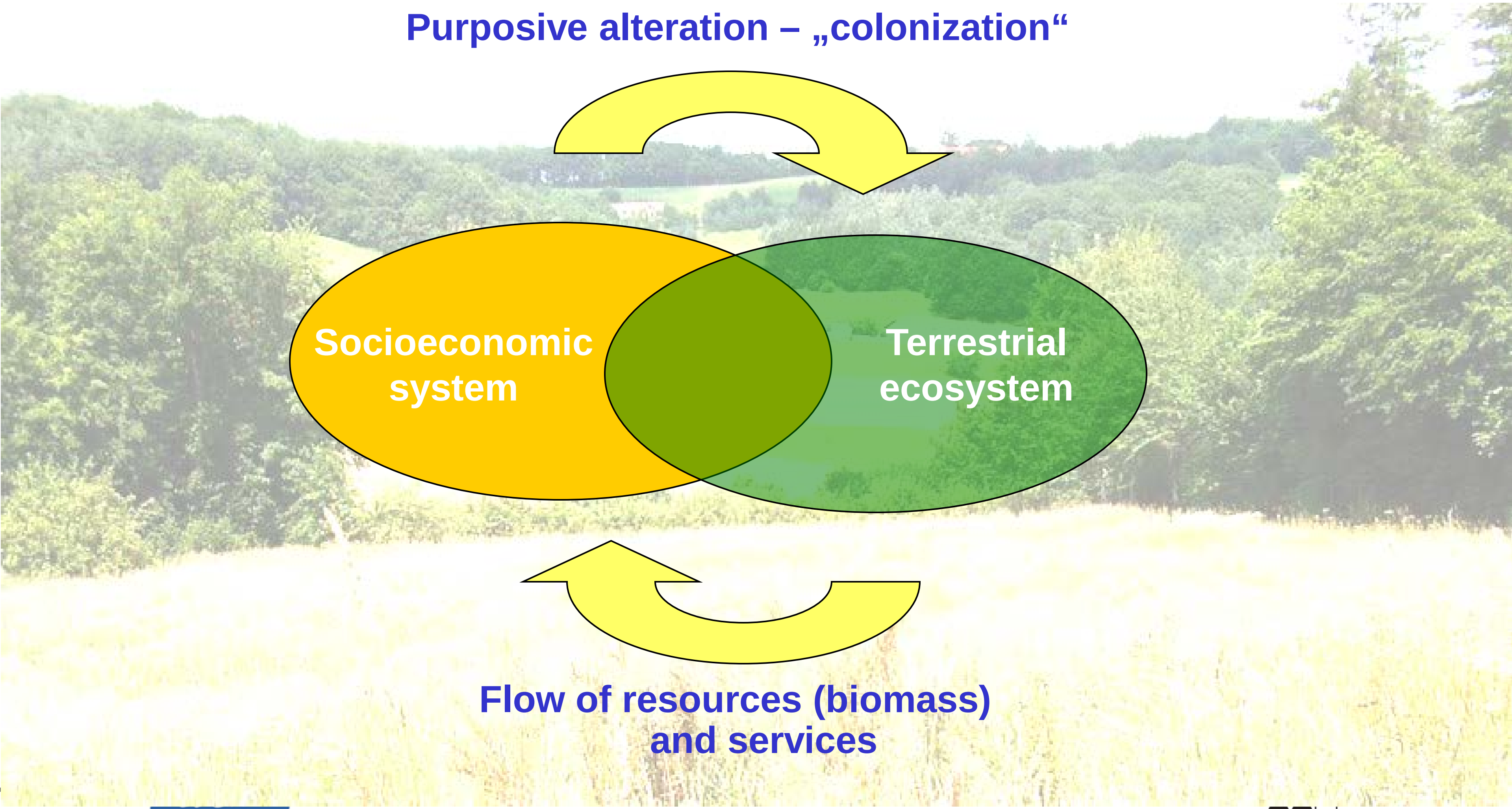
Overview

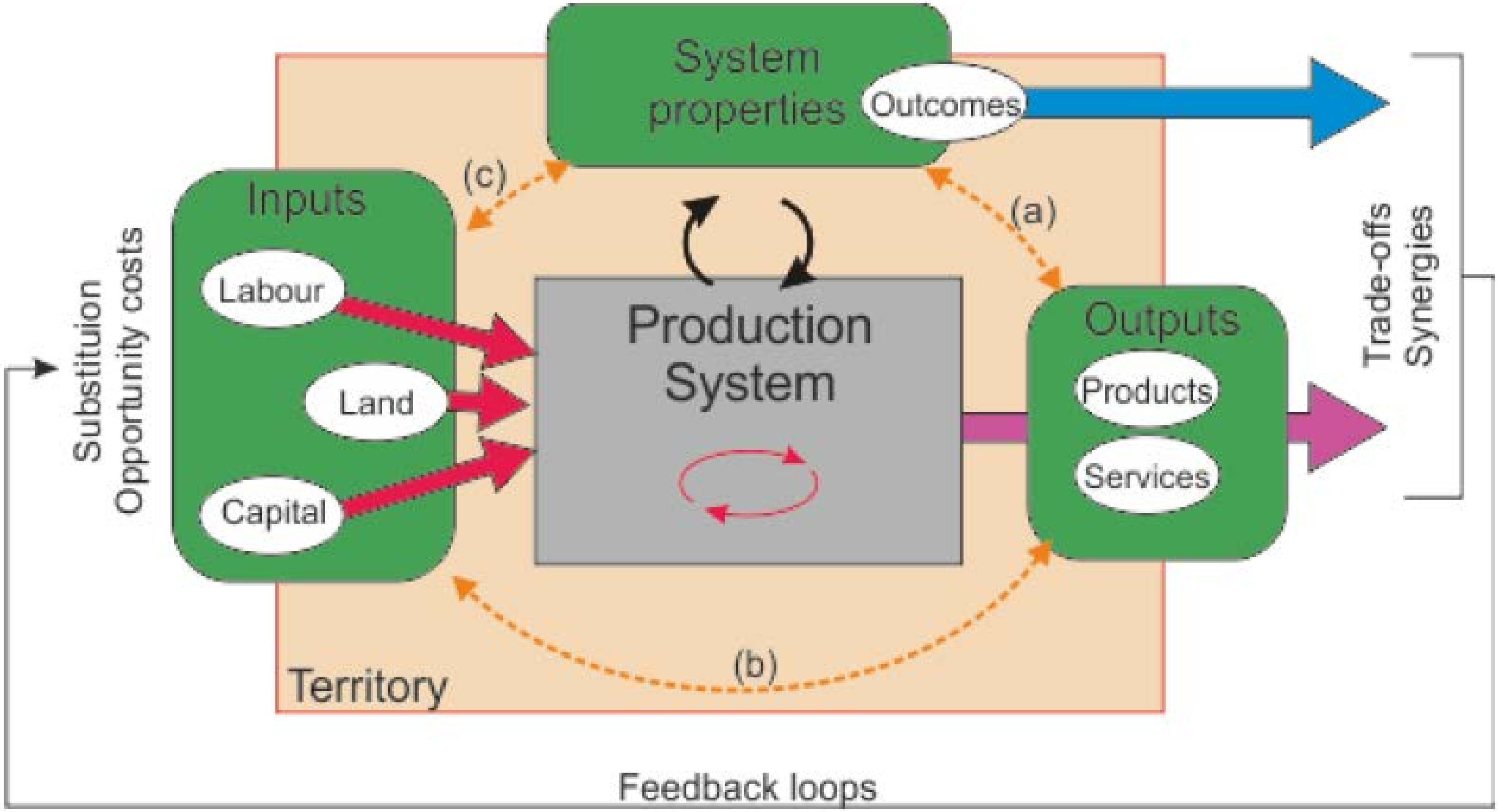
- What is HANPP?
  - Concept
  - Definition
- HANPP methods
- Global HANPP maps for 2000
- Global HANPP trajectories 1910-2007 – and beyond?
- Implications of HANPP
  - Biodiversity pressures
  - Land-use competition: Systemic feedbacks food / energy / ag. Intensity / bioenergy / GHG mitigation
- Conclusions

Land – a socioecological system



Measures of land-use intensity: inputs, outputs, system properties

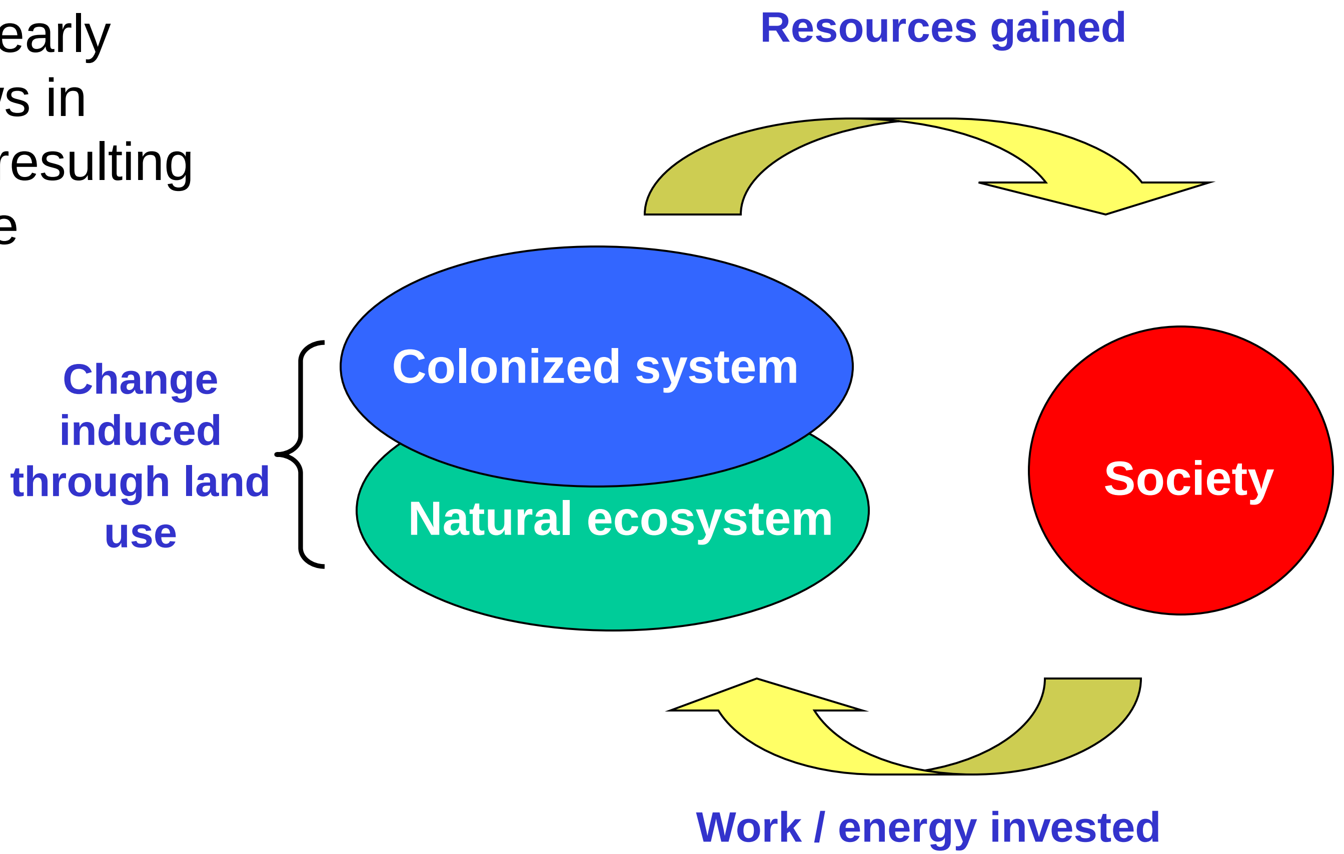
e.g. HANPP



Erb et al., 2013, submitted

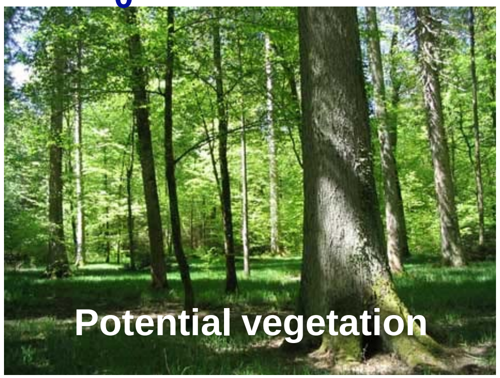
HANPP: a socio-ecological measure of land-use intensity

HANPP measures changes in yearly biomass flows in ecosystems resulting from land use

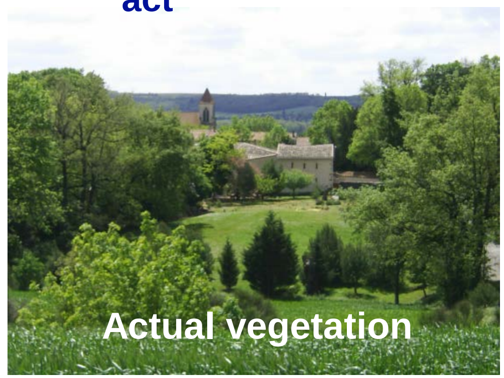


The HANPP approach

NPP_0



NPP_{act}



NPP_t

Productivity of potential vegetation

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

Productivity of actual vegetation

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

Energy remaining in the ecosystem after harvest

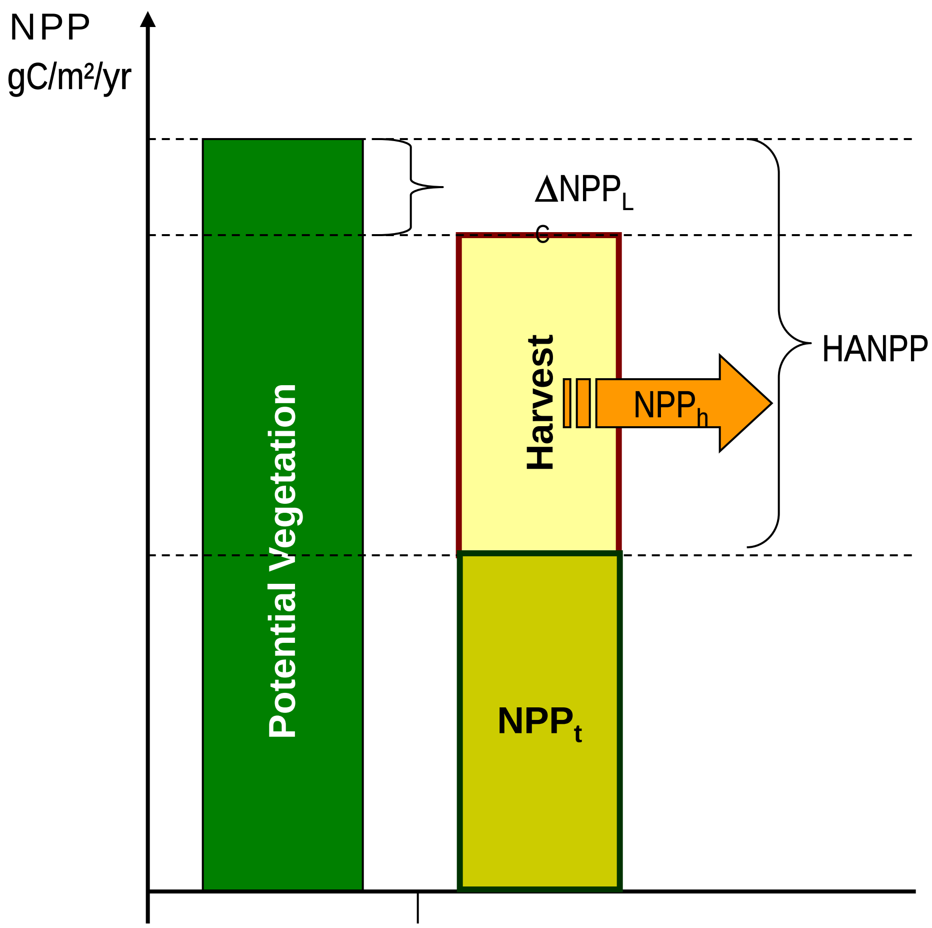
Productivity change (ΔNP

Harvest (NPPh)

H

- **Indicator of land-use intensity**
- **‚Pressure' indicator**
- **Human domination of ecosystems**

Definition of HANPP



- **Ecological perspective:**
  HANPP measures human impact on trophic energy in ecosystems

  $HANPP = NPP_0 – NPP_t$

- **Socioeconomic perspective:**
  HANPP is the sum of land-use induced changes in NPP and biomass harvest:

  $HANPP = \Delta NPP_{LC} + NPP_h$

Basic features of HANPP methods

- Measurement of flows in physical units
  - Tons of dry matter biomass per year [t DM/yr] or
  - Tons of carbon per year [t C/yr] or
  - Joules per year [J/yr]

- Spatially explicit
  - Existing database: c 10 x 10 km at the equator (5 min)
  - Feasible for Europe: 1 x 1 km or even lower (Corine)

- Data-rich calculation
  - FAO and other data for cropland, forestry, livestock, etc.
  - Modelling used only to fill data gaps (vegetation, livestock feed balances, etc.)

HANPP methods: Calculation approach for assessing global HANPP

- NPP_0: based on potential natural vegetation, calculated with models (in our case often LPJ-DGVM)

- NPP_h:
  - **Statistics** on the national and subnational level (agriculture, forestry)
  - Based on the international standard methodology for material and energy flow accounting (**MEFA**).
  - Flows not covered or underestimated by international statistics (e.g. biomass grazed by livestock) assessed on basis of demand-driven **modelling approaches** and regional estimates.

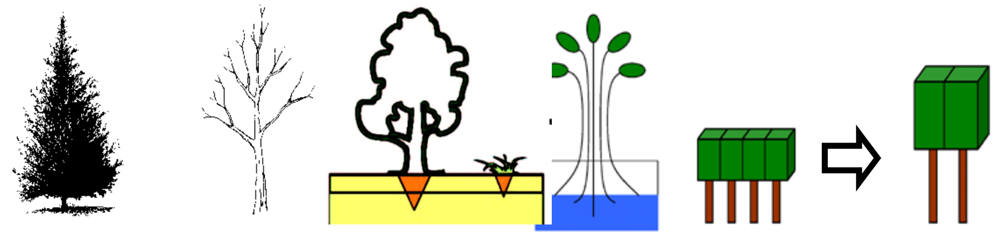
- NPP_{act}
  - **Mixed approaches**, combining statistics and modelling approaches
  - Conservative approach: in the absence of data, $\mathbf{NPP_{act} = NPP_0}$

The LPJ Dynamic Global Vegetation Model (Sitch et al., GCB, 2003)

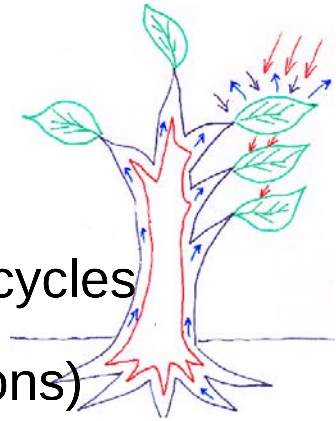
Climate, Soil, CO_2

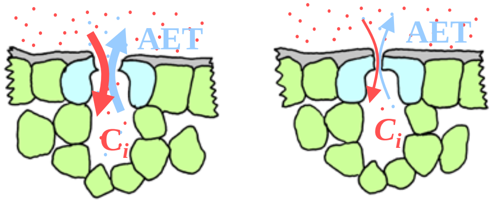
Space & Time Loops

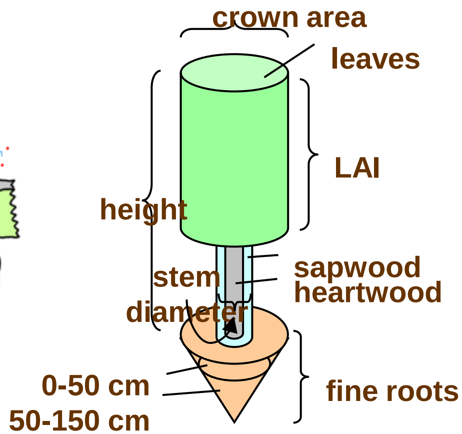
Transformed by process modules into



- 10 plant functional types
- competition, mortality, establishment
- fire, permafrost
- photosynthesis: coupled C and H_2O cycles
- C allocation (funct. and struct. relations)
- Carbon pools: 4 in vegetation, 4 in litter/soil
- Full hydrology

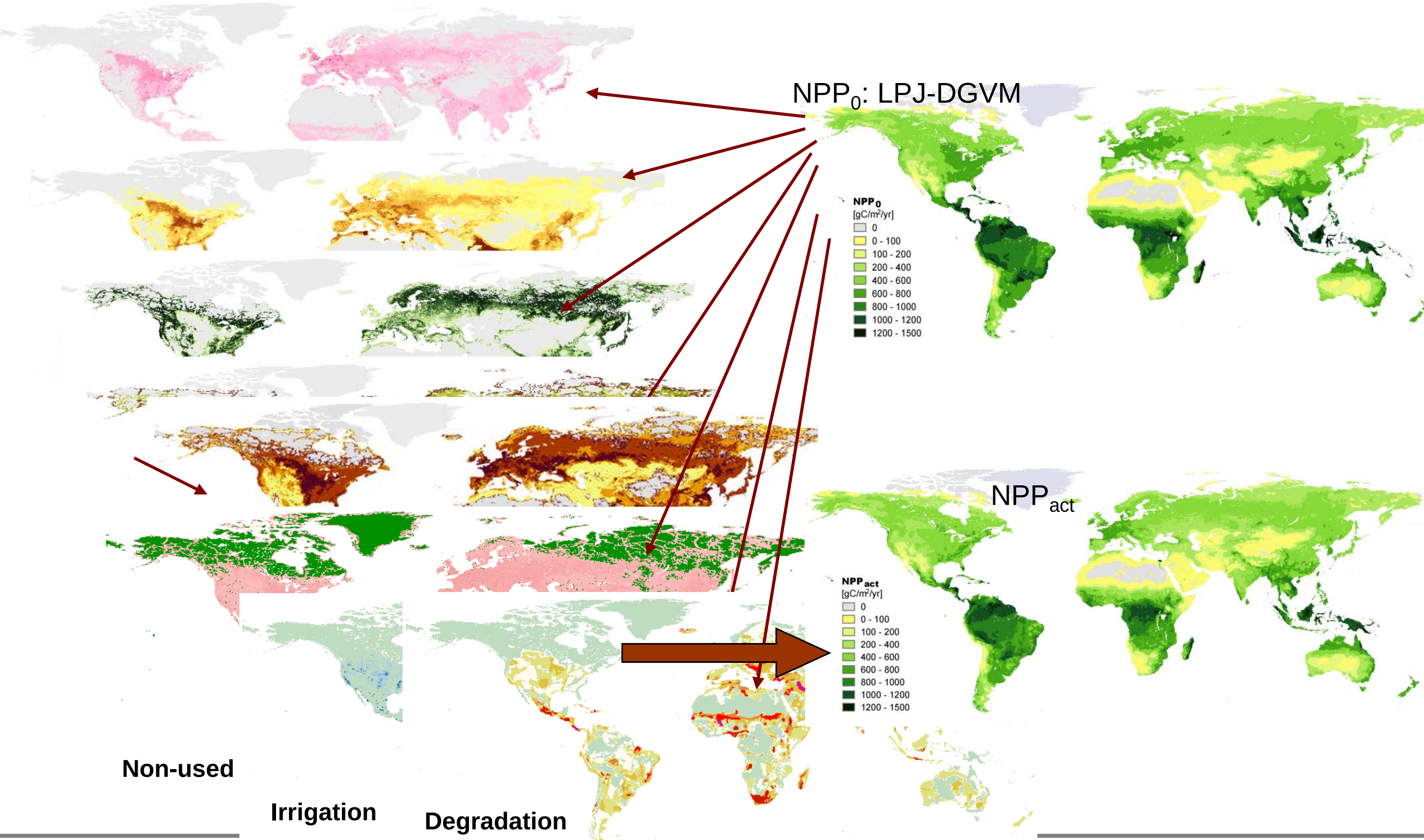






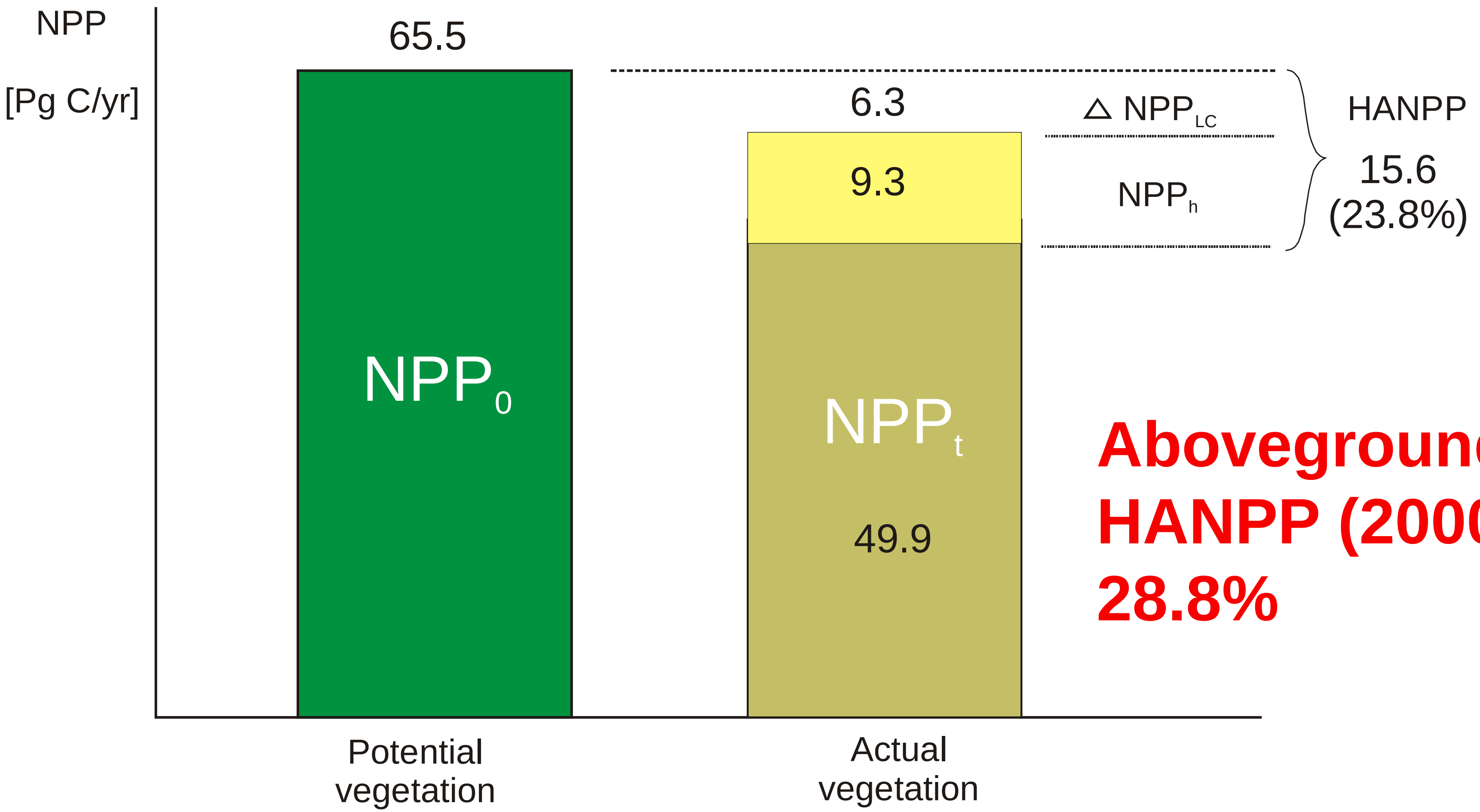
C budget, H_20 Budget, Vegetation Composition

Data integration: the land use dataset



Erb et al., 2007 *J Land Use Sci.*

Aggregate global HANPP (year 2000)



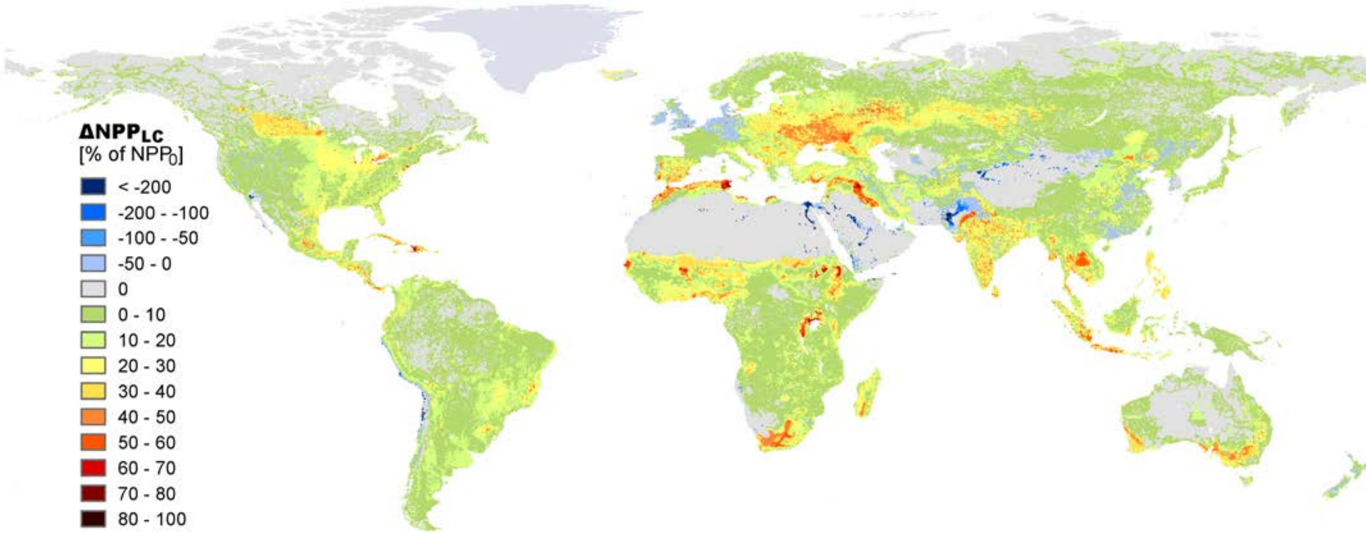
Aboveground HANPP (2000) 28.8%

Haberl et al., 2007. *PNAS*

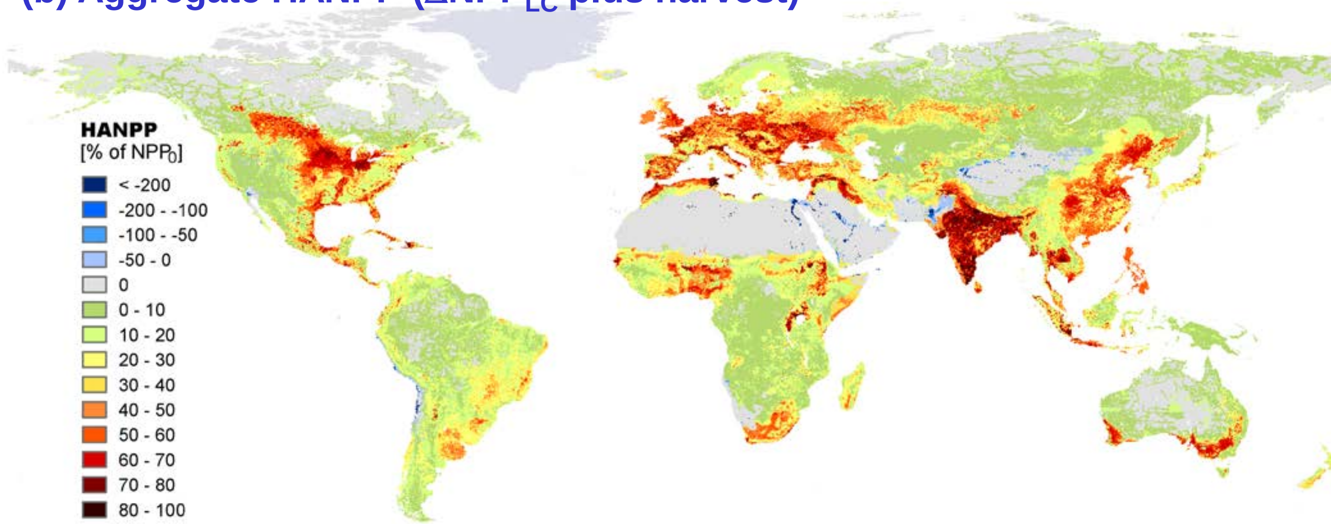
Mapping global HANPP 2000

→ **20-30% of yearly global land-based C flows affected by humans**

(a) Land-use induced changes in productivity (ΔNPP_{LC})



(b) Aggregate HANPP (ΔNPP_{LC} plus harvest)



Haberl et al., 2007. *PNAS*

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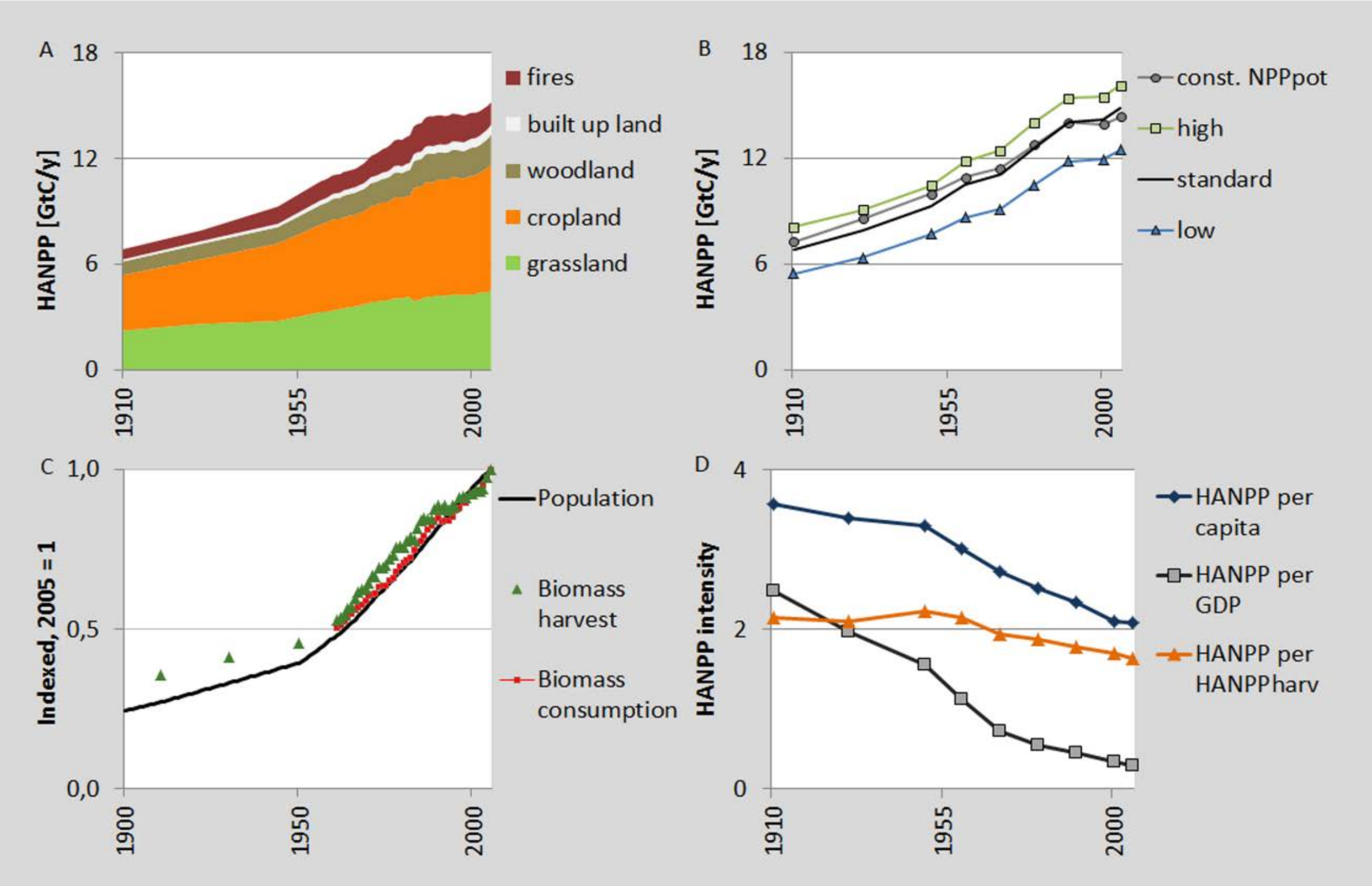
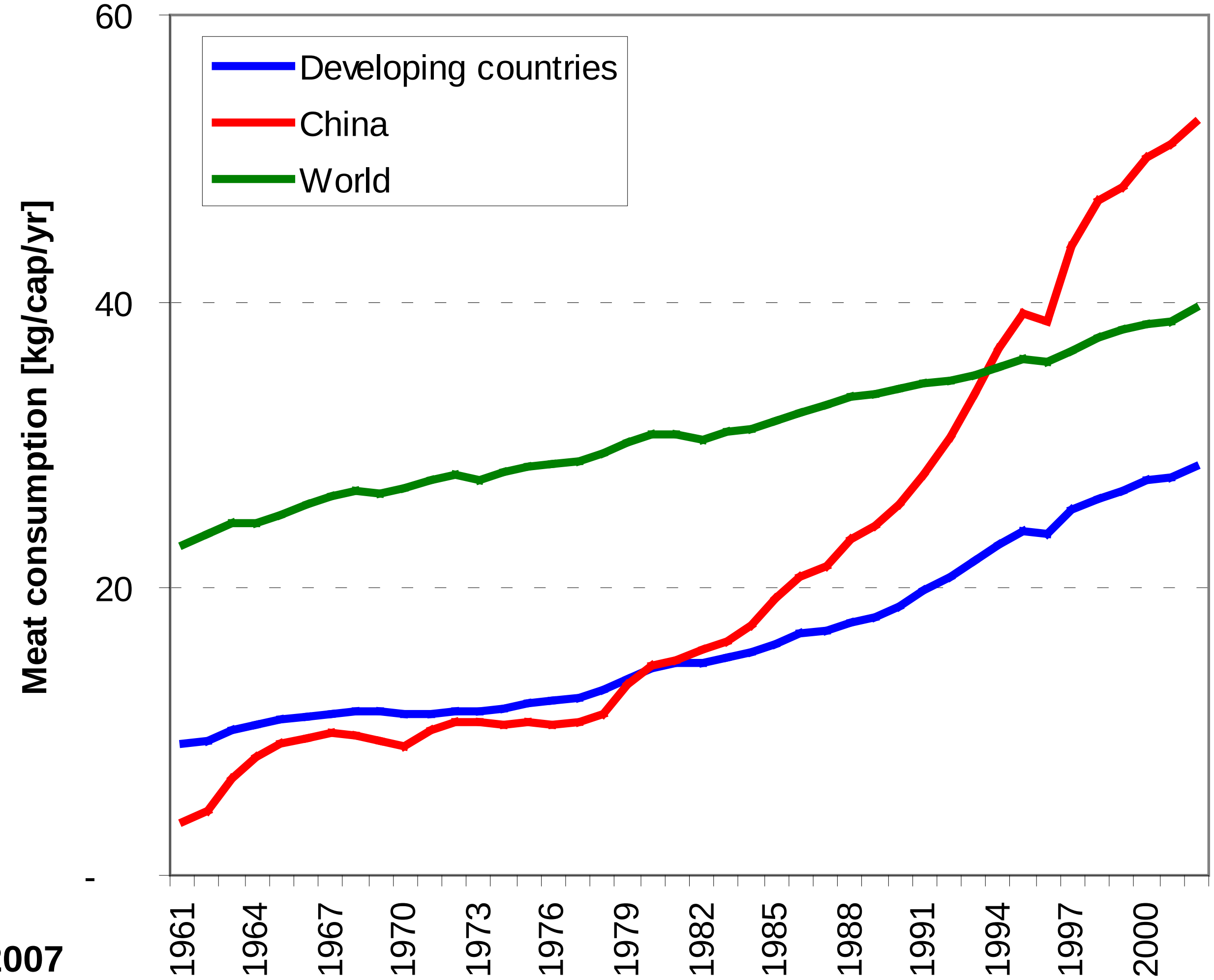
Global human appropriation of net primary production (HANPP) doubled in the 20th century



Population: Factor 4

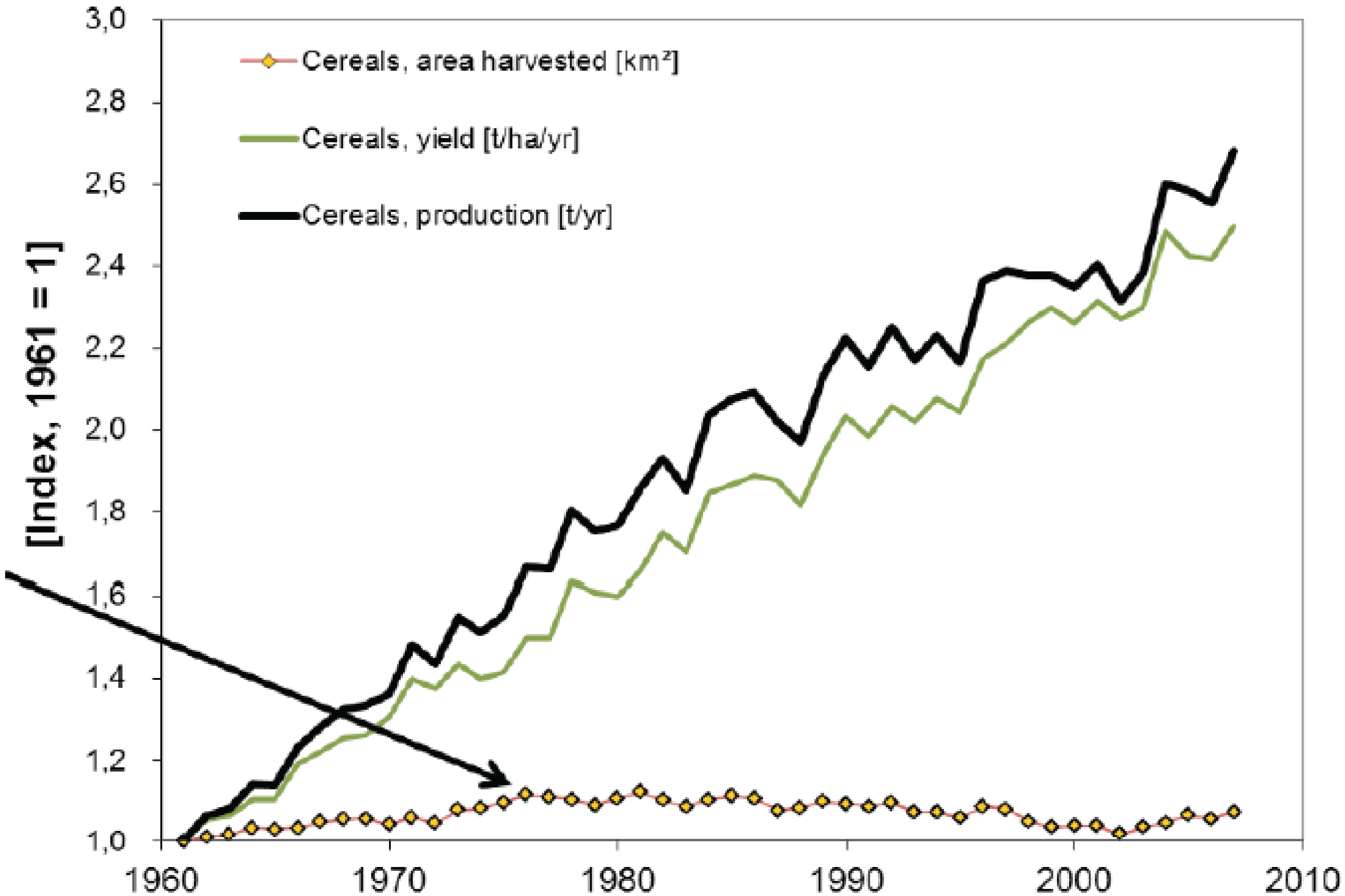
GDP: Factor 17

Changes in dietary patterns: Meat consumption



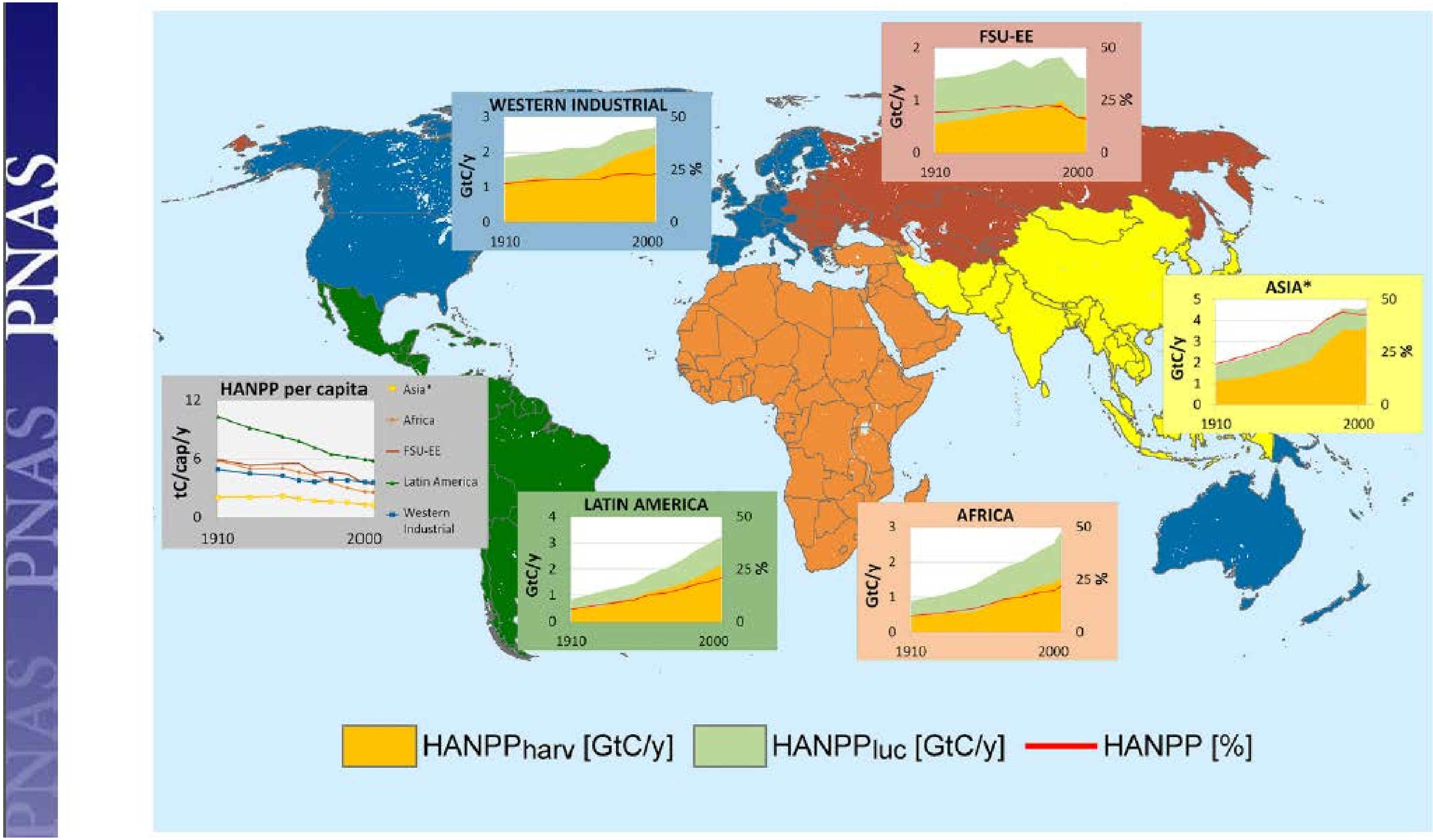
FAOSTAT 2007

Agricultural intensification
Global cereals: cropland area, yields, production



Erb, K.H. 2012, Ecol Econ 76: 8-14

Global HANPP 1910-2007: regional breakdown



Krausmann et al., PNAS, 2013

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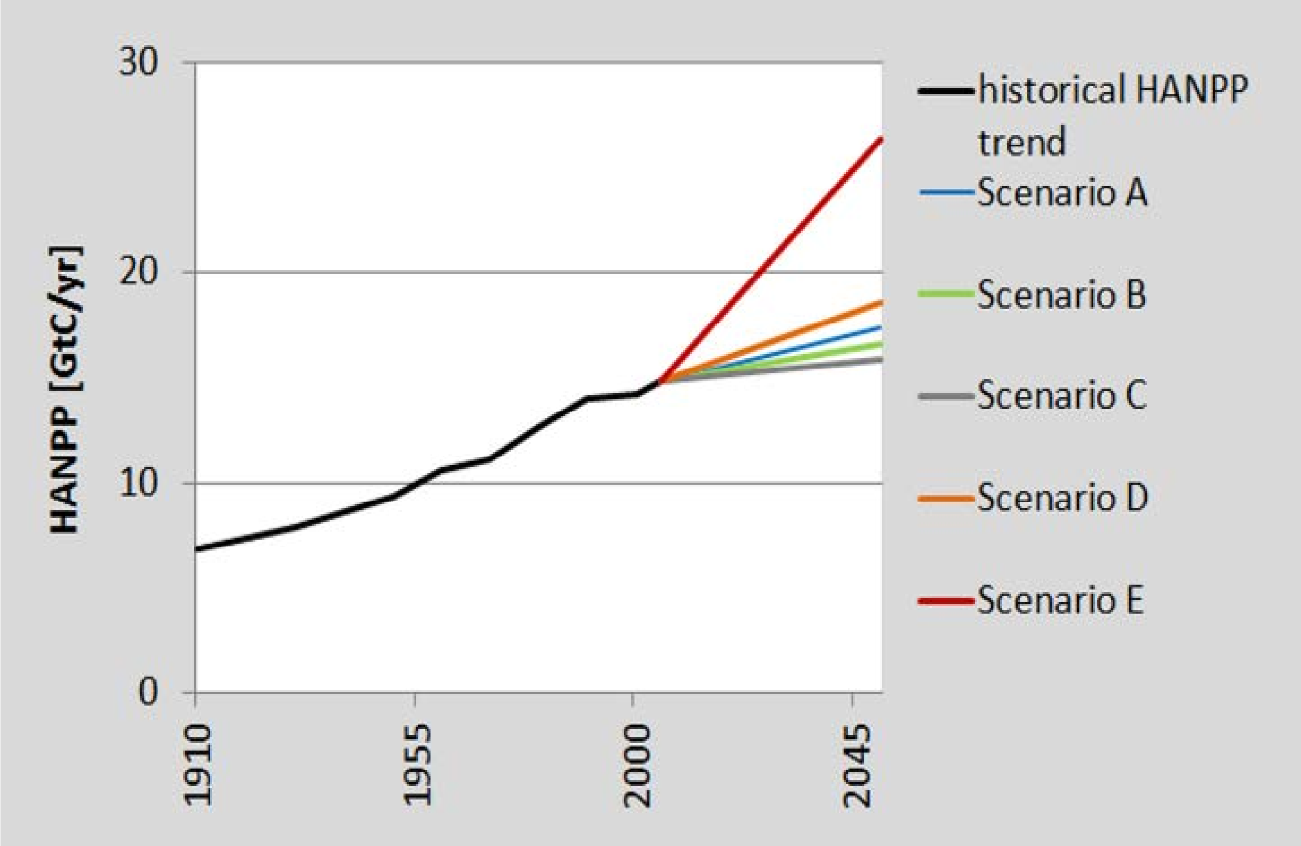
Future land use intensity (HANPP) depends foremost on future bioenergy expansion



Additional bioenergy until 2050

Scenarios A-C: Continuation of trends

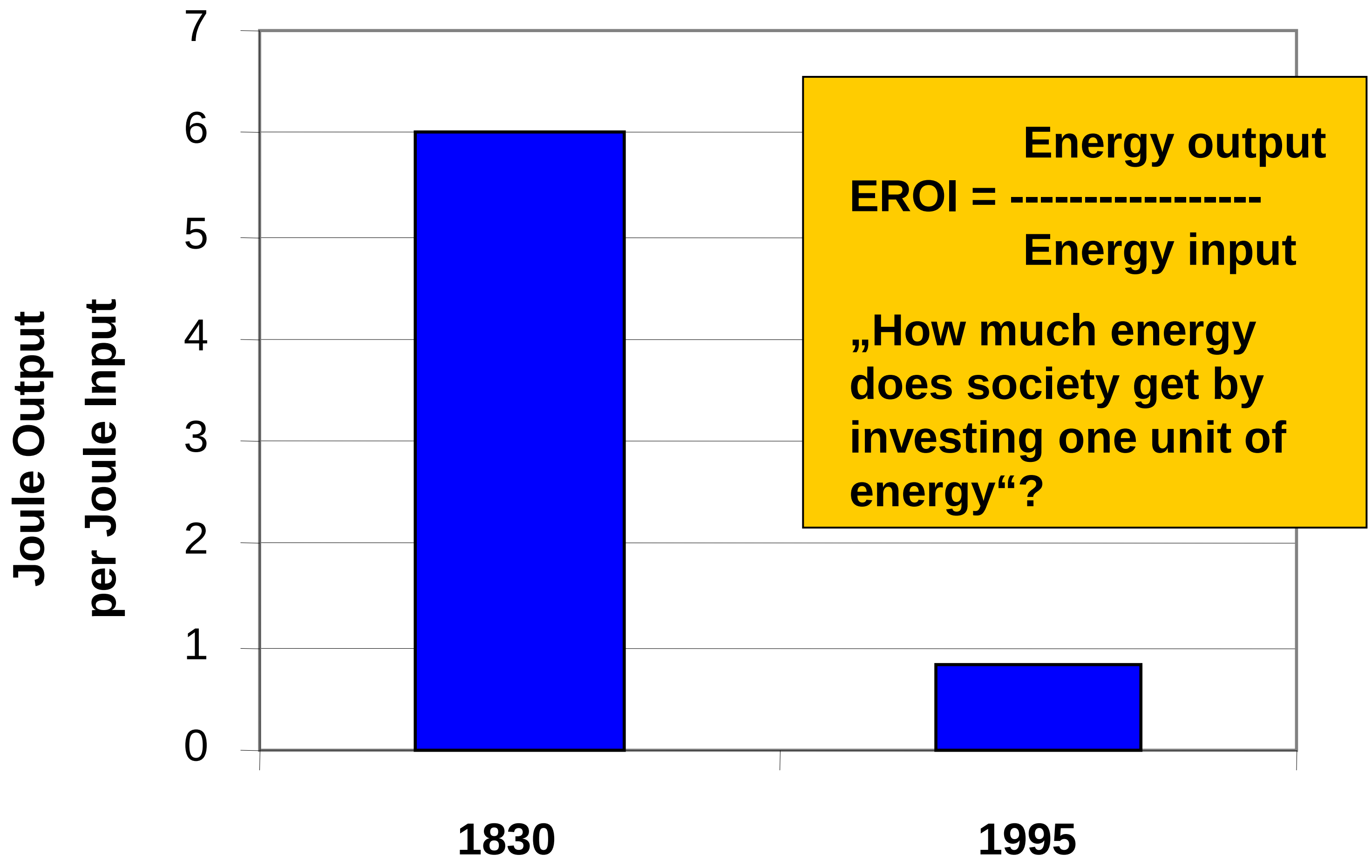
Scenario D: +50 EJ/y

Scenario E: +250 EJ/y

„Decoupling“?

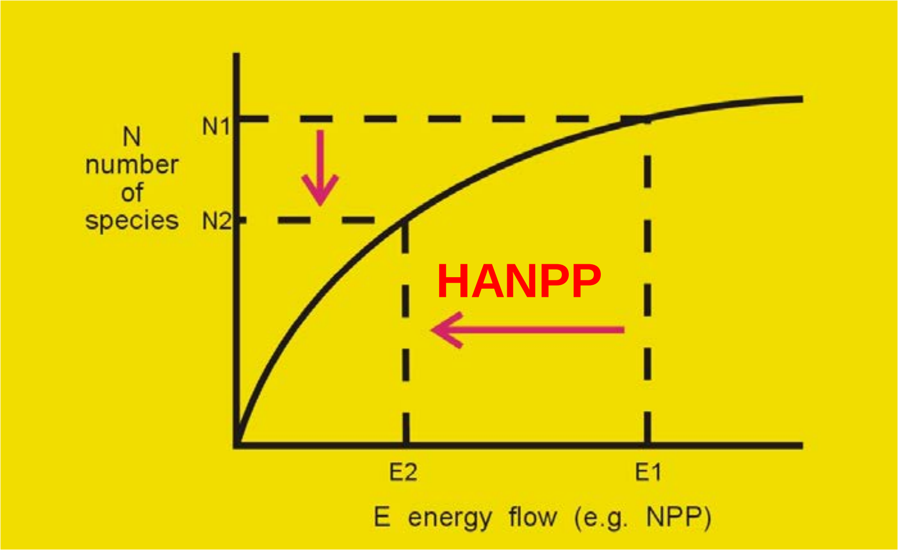
- Crop yield growth
  - Factors 4-7 for some crops and regions
  - Yields of organic agriculture are c40% lower than conventional-intensive cropping if crop rotation is considered
- More efficient bioenergy use
  - Livestock feeding requires 60% of global human-harvested biomass
  - Large differences in feeding efficiency
  - Trade-offs (humane farming, valuable grasslands, etc.)
- Bioenergy
  - Share in global primary energy mix was reduced in the last 100 years
  - Trend reversal would lead to „recoupling“

Costs of increased area efficiency
EROI of Austria‘s agricultural sector 1830 vs. 1995



HANPP and biodiversity: The species-energy hypothesis

- **Basic claim:** The number of species is positively related to the flow of energy in an ecosystem.
- **Corollary:** If humans reduce energy flow (e.g., through HANPP), then species richness will decline.
- **Notes**
  - Can explain species diversity gradient from equator to poles.
  - Not undisputed. Competing (complementary) hypotheses exist (e.g., intermediate disturbance hypothesis).



Brown, J.H. (1981) *Am. Zool.* **21**, 877-888.

Gaston, K.L. (2000) *Nature* **405**, 220-227.

Hutchinson, G.E. (1959) *Am. Nat.* **93**, 145-159.

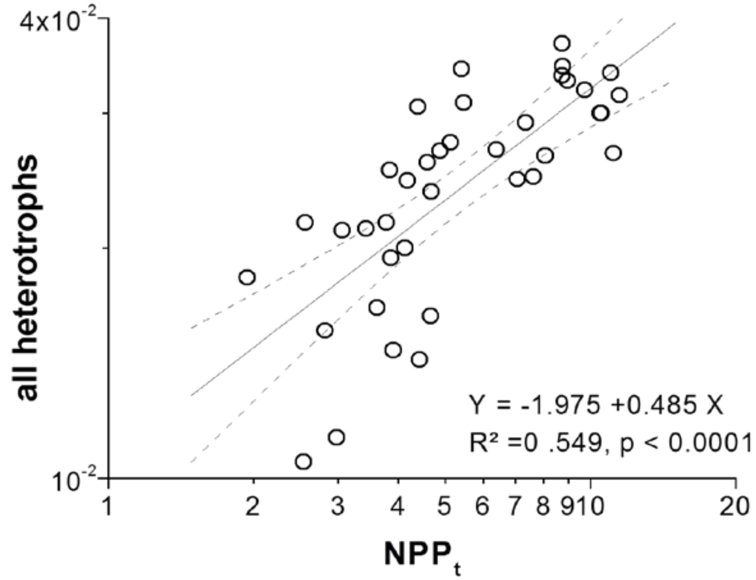
Rapson, G.L. et al. (1997) *J. Ecol.* **85**, 99-100.

Waide, R.B. et al. (1999) *Ann. Rev. Ecol. Syst.* **30**, 257-300.

Wright, D.H. (1983) *Oikos* **41**, 495-506.

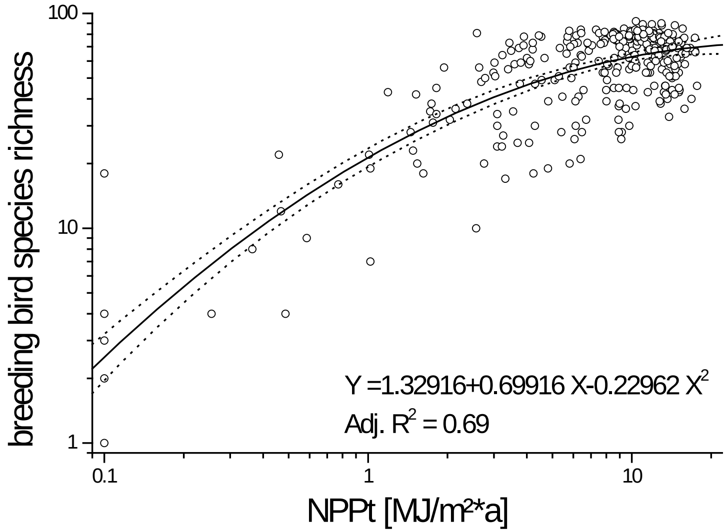
Wright, D.H. (1990) *Ambio* **19**, 189-194.

Empirical studies: species richness is well correlated with NPP_t – indirect support for HANPP/biodiversity hypothesis



Case study 1: Correlation between NPP_t and autotroph species richness (5 taxa) on 38 plots sized 600x600 m, East Austria

Haberl et al., 2004, *Agric., Ecosyst. & Envir*. 102, p213ff



Case study 2: Correlation between NPP_t and breeding bird richness in Austria, 328 randomly chosen 1x1 km squares.

Haberl et al., 2005. *Agric., Ecosyst. & Envir.* 110, p119ff

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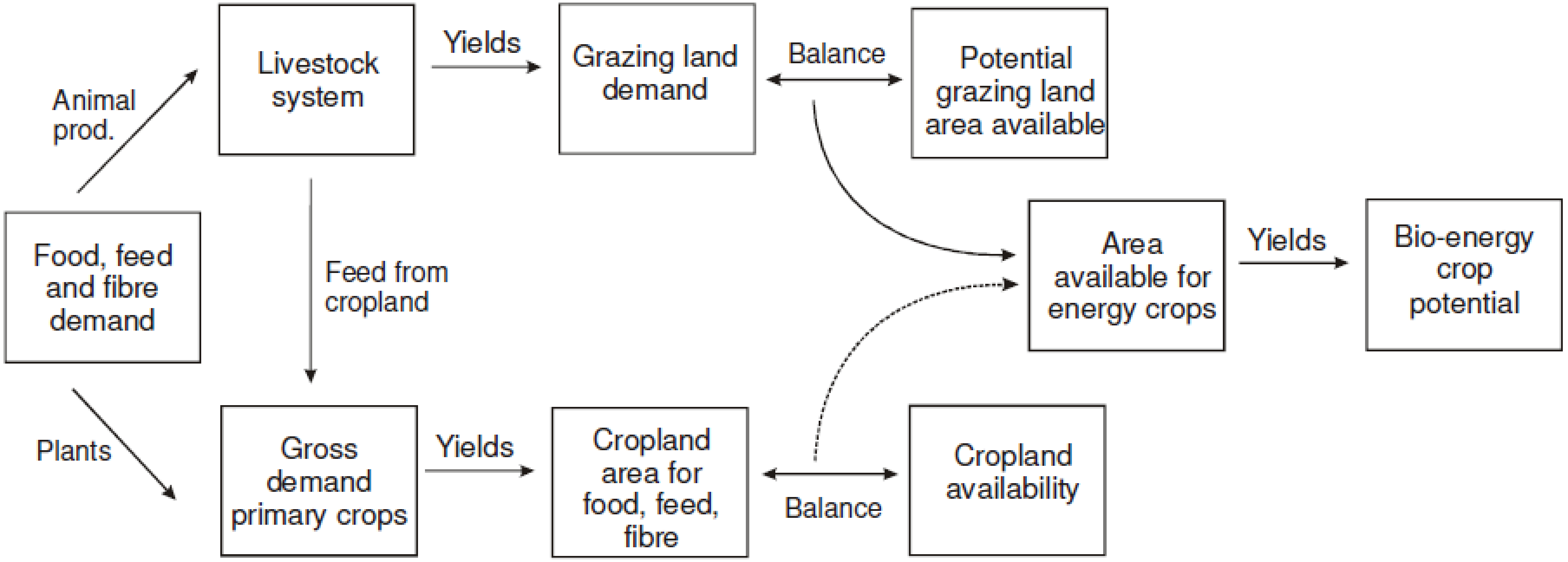
HANPP, feed, food and bioenergy:
Global yearly above-ground biomass flows

Process	Yearly energy flow [EJ/yr]
Terrestrial above-ground net primary production, potential	1 309
Human-induced reduction of productivity	68
Terrestrial above-ground net primary production, current	1 241
Terrestrial above-ground NPP excl. forests + wilderness	580
Human biomass harvest and destruction	337
Human biomass harvest used for economic purposes	225
- used for livestock (includes ‚recycled' biomass)	129
- used as food	28
- current bioenergy use (includes ‚recycled' biomass)	40
Bioenergy potential estimates 2050	60 – 1 200

Krausmann et al., 2007, *Ecol. Econ.*
Haberl et al., 2011, *Biomass Bioenergy*

Interactions food / feed / ag intensity / bioenergy potentials: biomass-balance model



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Haberl et al., 2010, *Curr. Opinion Env. Sust.*
Haberl et al., 2011, *Biomass Bioenergy*
Erb et al, 2012, *Energy Policy*

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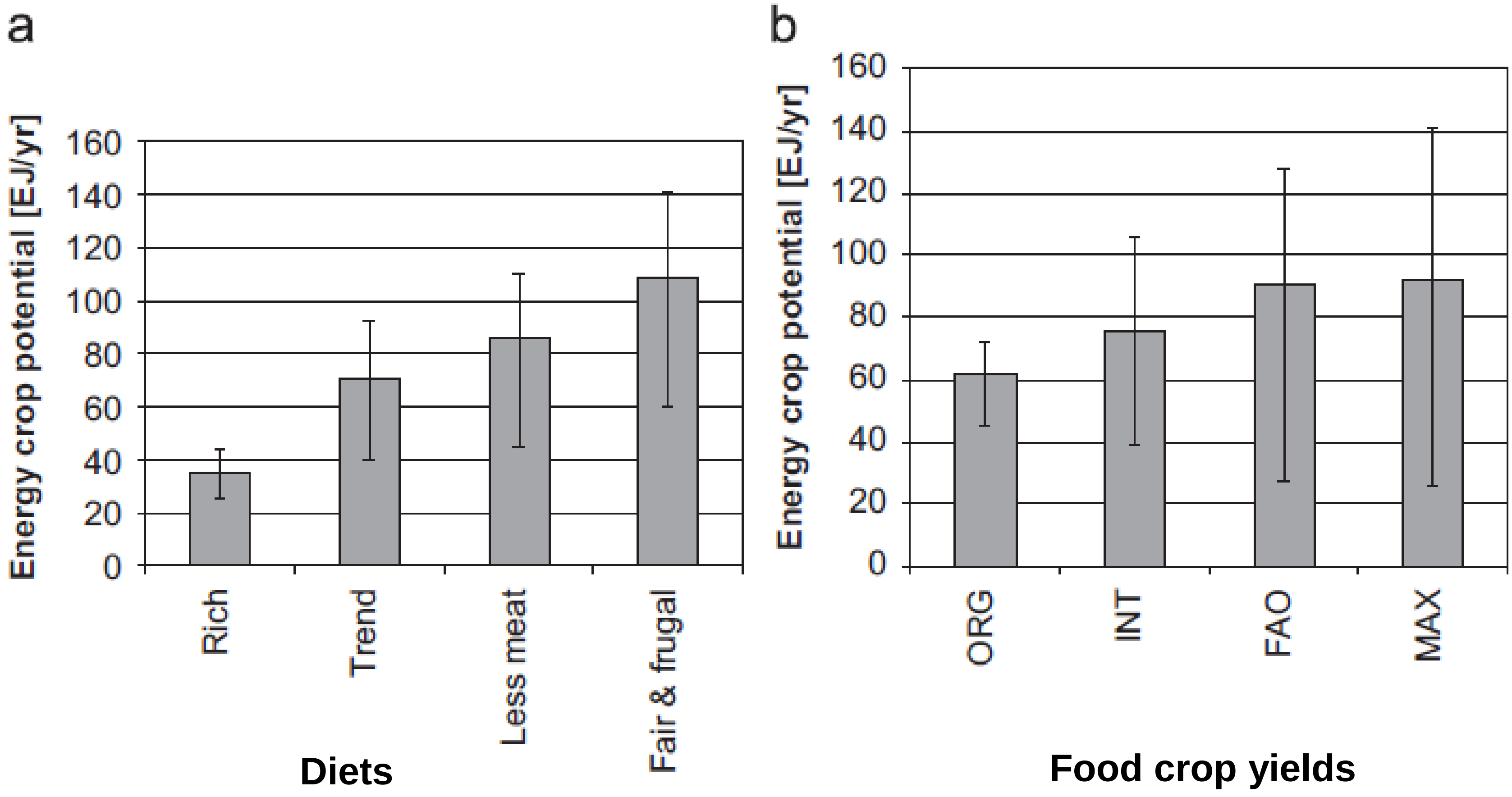
Global energy crop potentials 2050: Dependency on diets and food crop yields



Erb et al., Energy Policy,
47 (2012) 260–269

Interpretation

- Changes in diet have a strong effect on future bioenergy potentials: The richer the diet, the lower the bioenergy potential and vice versa

→ Policy implications?

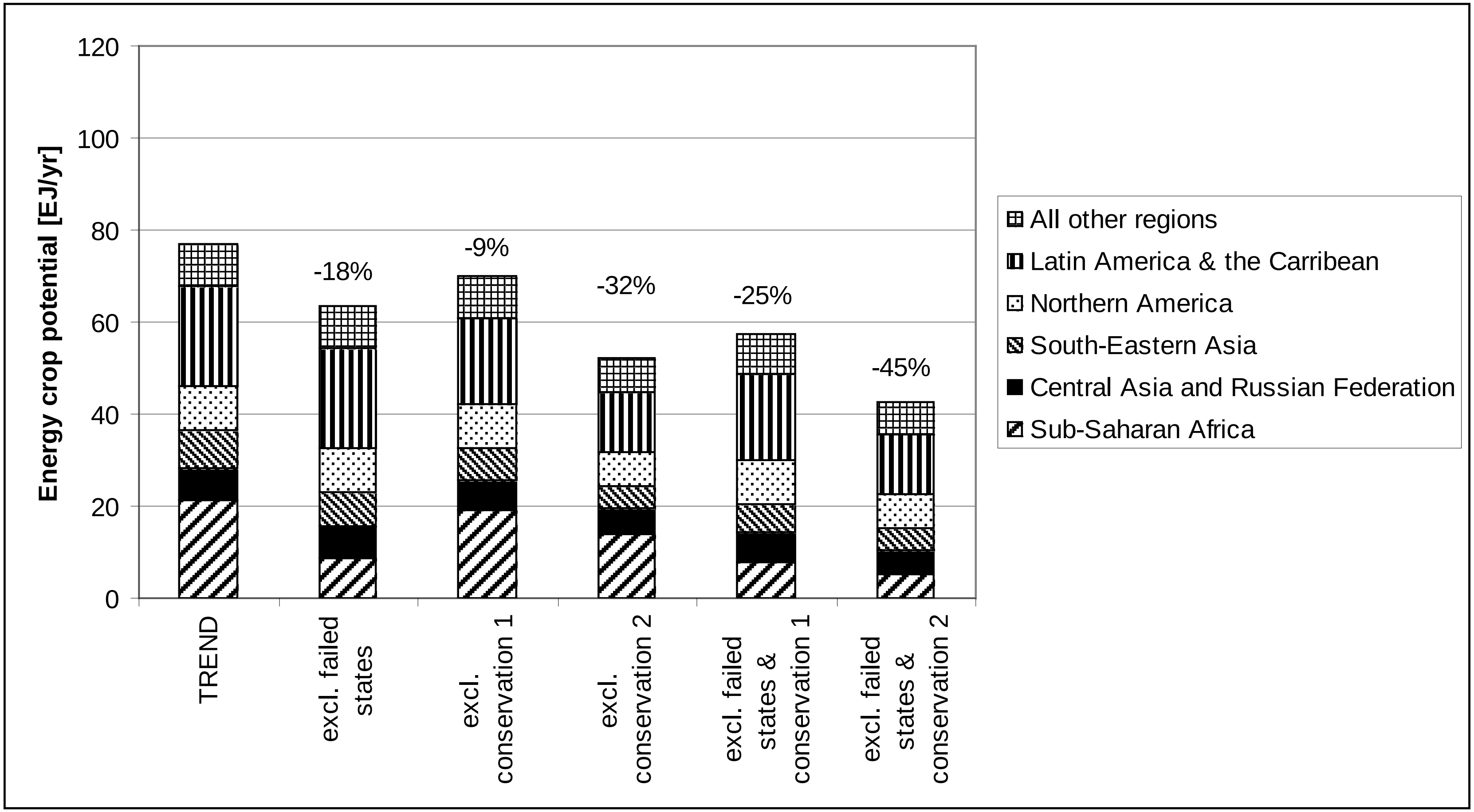
- Changes in agricultural intensity have a strong effect on bioenergy crop potentials *only if a constant diet is assumed*. If increased productivity is used to increase food consumption, the bioenergy potential may even shrink.

→ Policy implications?

Effects of setting aside land for biodiversity and considering political instability

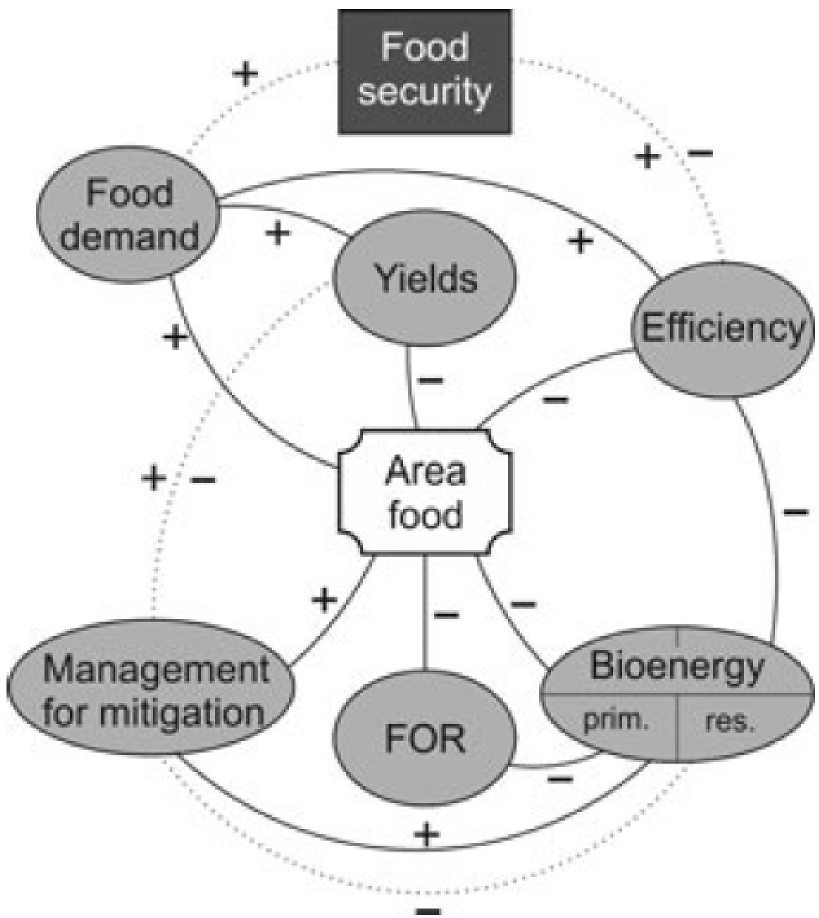
- Exclude
  - Biodiversity hotspots according to Myers (et al. 2000), endemic bird areas (Stattersfeld et al. 1998), centres of plant diversity (WWF and IUCN 1994), ‚global 200' (Olson and Dinerstein 2002)
  - Wilderness areas (Mittermeier et al. 2003), frontier forests (Bryant et al. 1997), ‚last of the wild' (Sanderson et al. 2002)
  - Protected areas (IUCN level I and II) (UNEP WCMC 2010)
- Strong / less restrictive scenarios based on exclusion of a higher or lower percentage of the area falling in one or more of these classes
- Exclude 'failed states' (Newman, 2009) based on the list of the Fund for Peace for (http://www.fundforpeace.org)

Effect of exclusion of protected areas and failed states on energy crop potentials



Erb et al., *Energy Policy* 2012

Systemic interlinkages of GHG reduction options in the land use sector



Smith et al., Global Change Biol. 2013

GHG reduction in land use: Largest potentials related to 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.*, 2012a,b). Low bioenergy value: ethanol from maize replaces gasoline and 6 reduces GHG by 45%, energy yield 75 GJ ha^{-1} yr^{-1} (Chum *et al.*, 2011).

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Smith et al., Global Change Biol. 2013

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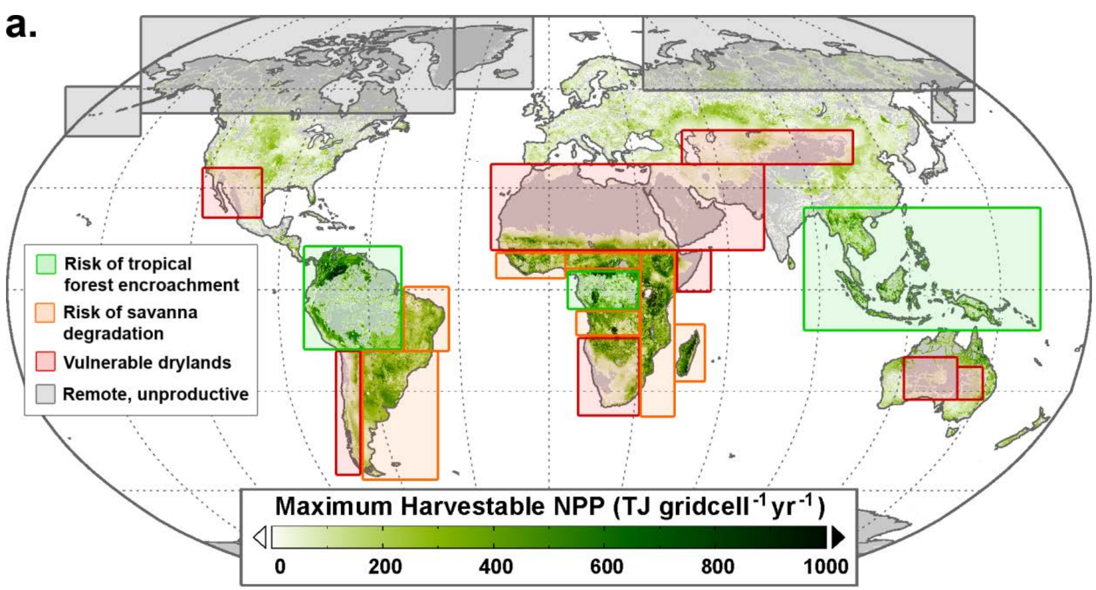
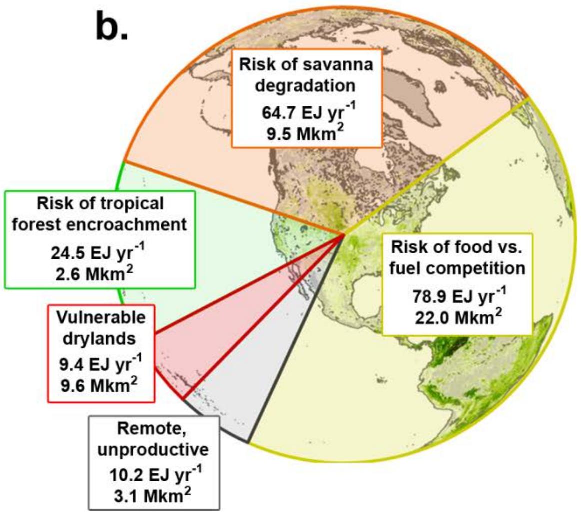


Potentially harvestable biomass vs. environmental risks



Haberl et al., submitted

Is biomass combustion climate-friendly?

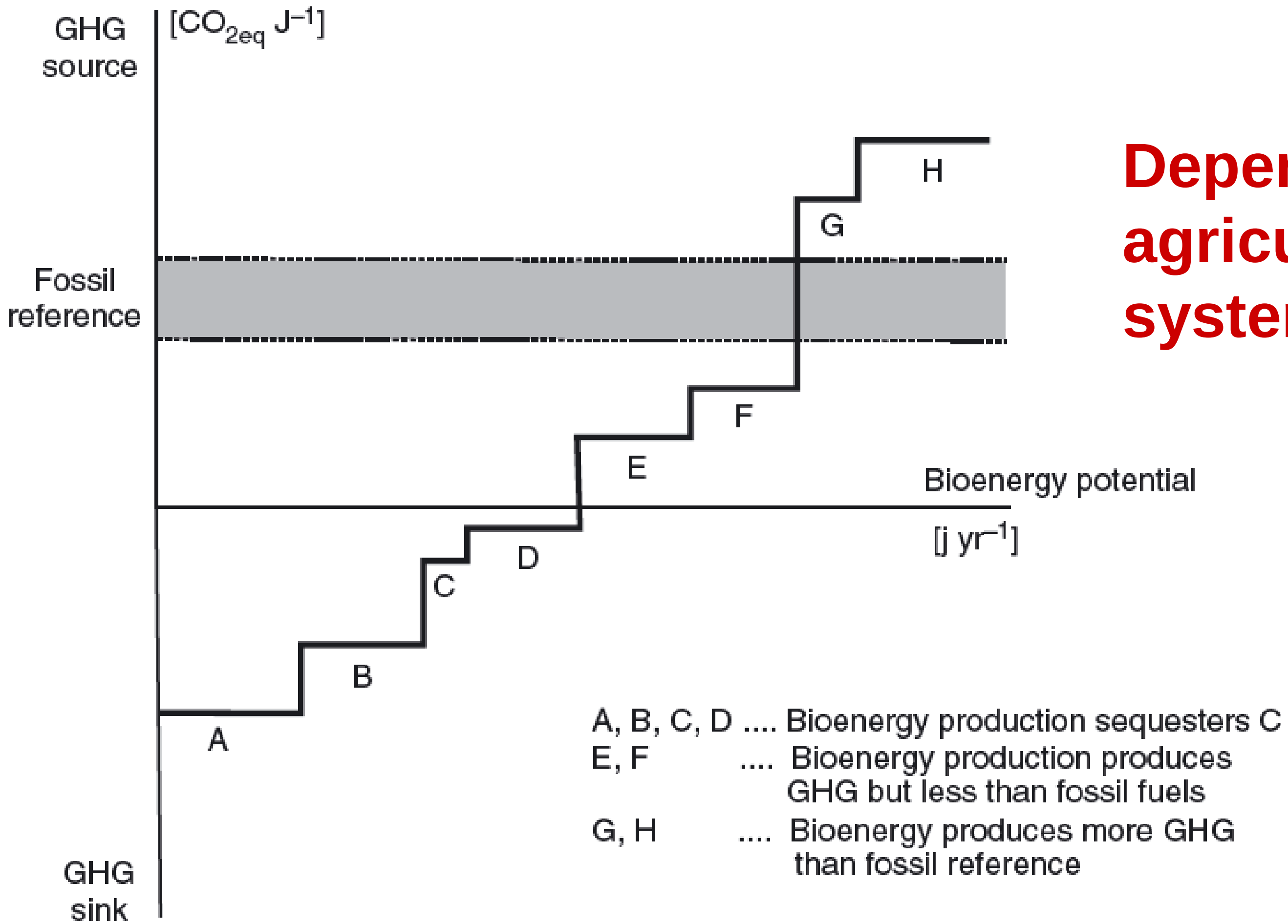
- Per unit of energy, biomass combustion releases about as much CO_2 as burning coal. CO_2 emissions of other fossils are lower:
  - petroleum products -25%
  - natural gas -50%
- **Assuming that these emissions are always balanced by plant growth is wrong**
  - In many cases, plants grow anyway and accumulate C if not used for bioenergy (‚terrestrial carbon sink').
  - In many cases, bioenergy production results in C stock loss (‚carbon debt').
- Emissions from biomass combustion are only balanced by plant growth to the extent that
  - The biomass is derived from additional plant growth beyond what would happen without bioenergy production
  - and/or the biomass would have decomposed (CO_2 returned to the atmosphere) if not used for bioenergy
- In addition, GHG emissions in the lifecycle need to be considered.

Fargione et al., 2008, *Science*, Searchinger et al., 2008, *Science*, Searchinger 2010 *Env. Res. Lett.*, Haberl et al. *Energy Policy* 2012

We don‘t know which percentage of the global bioenergy potential is climate-friendly

- Beneficial examples
  - Biomass grown on degraded lands in dryland areas (e.g., salinized croplands in Australia) or on degraded, erosion-prone tropical lands
  - Biomass residues and biogenic wastes that would otherwise decompose (if not needed to sustain soil fertility)
- Questionable to detrimental examples
  - Most current ‚first generation‘ biofuels from cropland (rape/soy oil, ethanol from maize)
  - Increasing harvests in existing forestry systems to produce more fuelwood
- Disastrous examples
  - Palm oil produced on cleared tropical forests, especially if peatlands are lost
  - Almost any energy bioenergy pathway that results in deforestation (directly or indirectly)

Needed: a GHG cost curve of bioenergy



Depends on the agriculture/food system!

Haberl *GCB Bioenergy* 2013

Conclusions

- HANPP: integrated socio-ecological indicator of land-use intensity
- Can be used to map land-use intensity
- Global HANPP doubled in the last century, but its growth was considerably below population and GDP growth
  - *Costs of „decoupling“*
- Drivers of future HANPP:
  - *Diets*
  - *Yields, feeding efficiency*
  - *Bioenergy*
- Biomass balance framework useful to analyze trade-offs and synergies
  - *Demand-side vs. Supply side*
  - *GHG costs of bioenergy*
- HANPP changes quantitatively and qualitatively during land-use transitions

Thanks for your attention