Land-use change in a resource-constrained world – can it help mitigating climate change?

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Thanks to: K.-H. Erb, V. Gaube, S. Gingrich, T. Kastner, F. Krausmann, C. Lauk, C. Plutzar et al.

Swiss Global Change Day
Schweizerisches Forum für Klima und Global Change Forschung Proclim bei der Schweizerischen Akademie der Wissenschaften (SCnat), Bern, 1.4.2015

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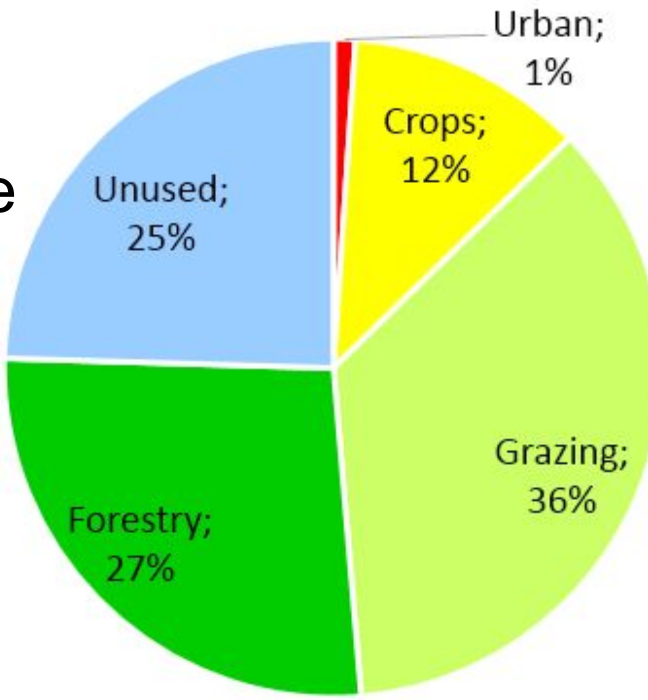
Challenges

- Agricultural output is expected to rise by 70-100% until 2050, driven by the growth of population and GDP
  (FAO, Millennium Assessment, Tilman…)
- It is proposed to raise global bioenergy production by 100-600% until 2050 to reduce GHG emissions and replace finite fossil energy
  (IPCC-SRREN, EU and US policies…)
- At the same time
  - Urbanization consumes fertile land
  - Land is expected to help mitigating climate change through carbon sequestration
  - Biodiversity loss is progressing rapidly; many ecosystems are degraded; conservation would require more land for nature

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.

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Caveat 1: we know little about allegedly „unused“ lands (a.k.a. „wastelands“)

- **Example:** Use of „wastelands“ in Tamil Nadu, South India, for biofuel production using *Jatropha*
- **Method:** Material and energy flow analysis based on fieldwork
- **Finding:** Biofuels jeopardize existing local subsistence systems. *Jatropha* would replace existing bioenergy production with *Prosopis* which currently provides 2.5-10 times more useful energy than Jatropha could
- **Energy security would be weakened, not strengthened.**

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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

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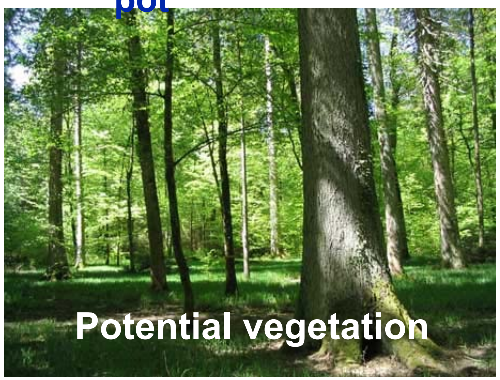
Baka & Bailis, 2014. *Ecol. Econ.*, **108**, 8-17

Linking land and biomass flows: the 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 apporiation of NPP (HANPP)

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

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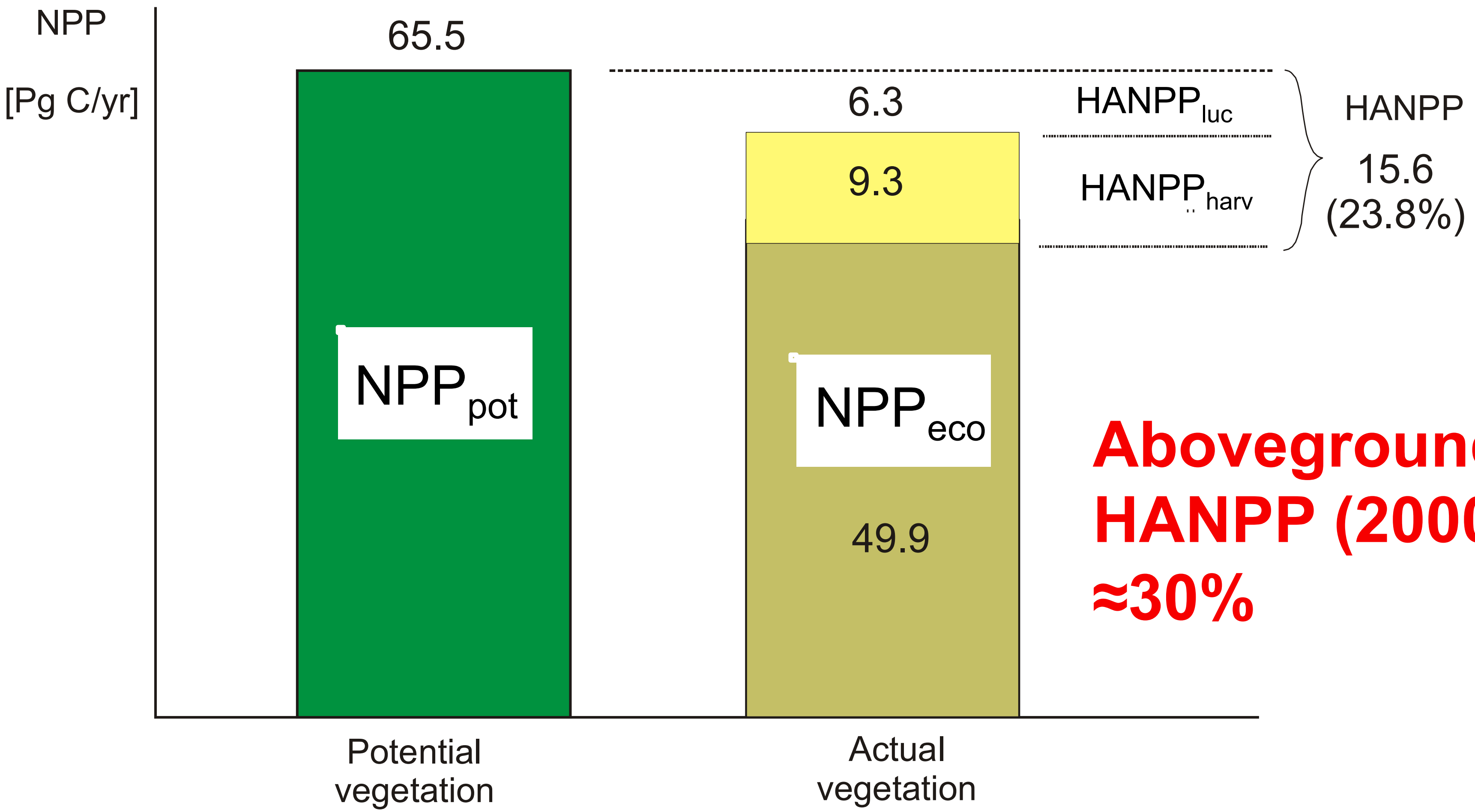
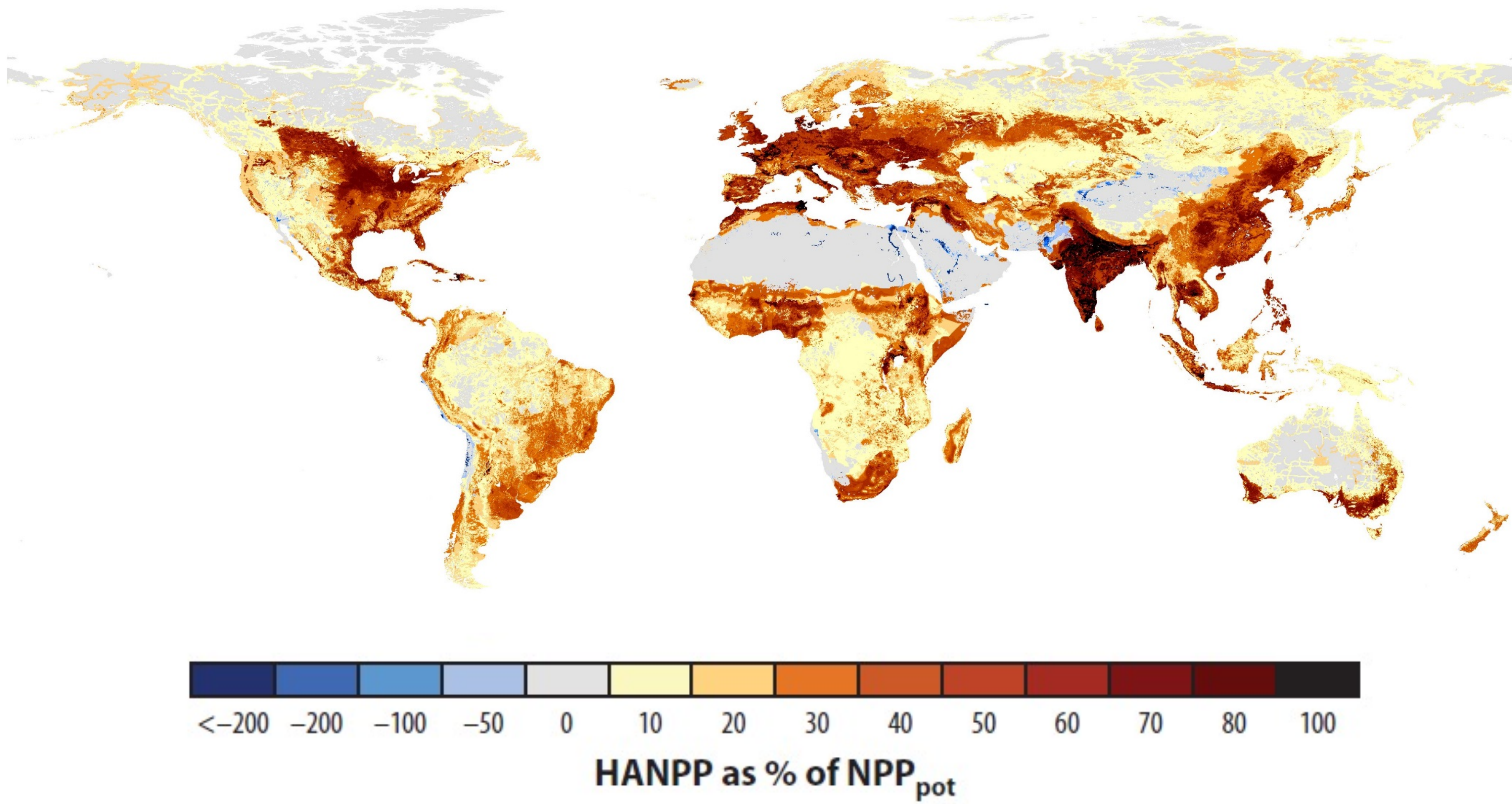
Aggregate global HANPP (year 2000)



Aboveground HANPP (2000) ≈30%

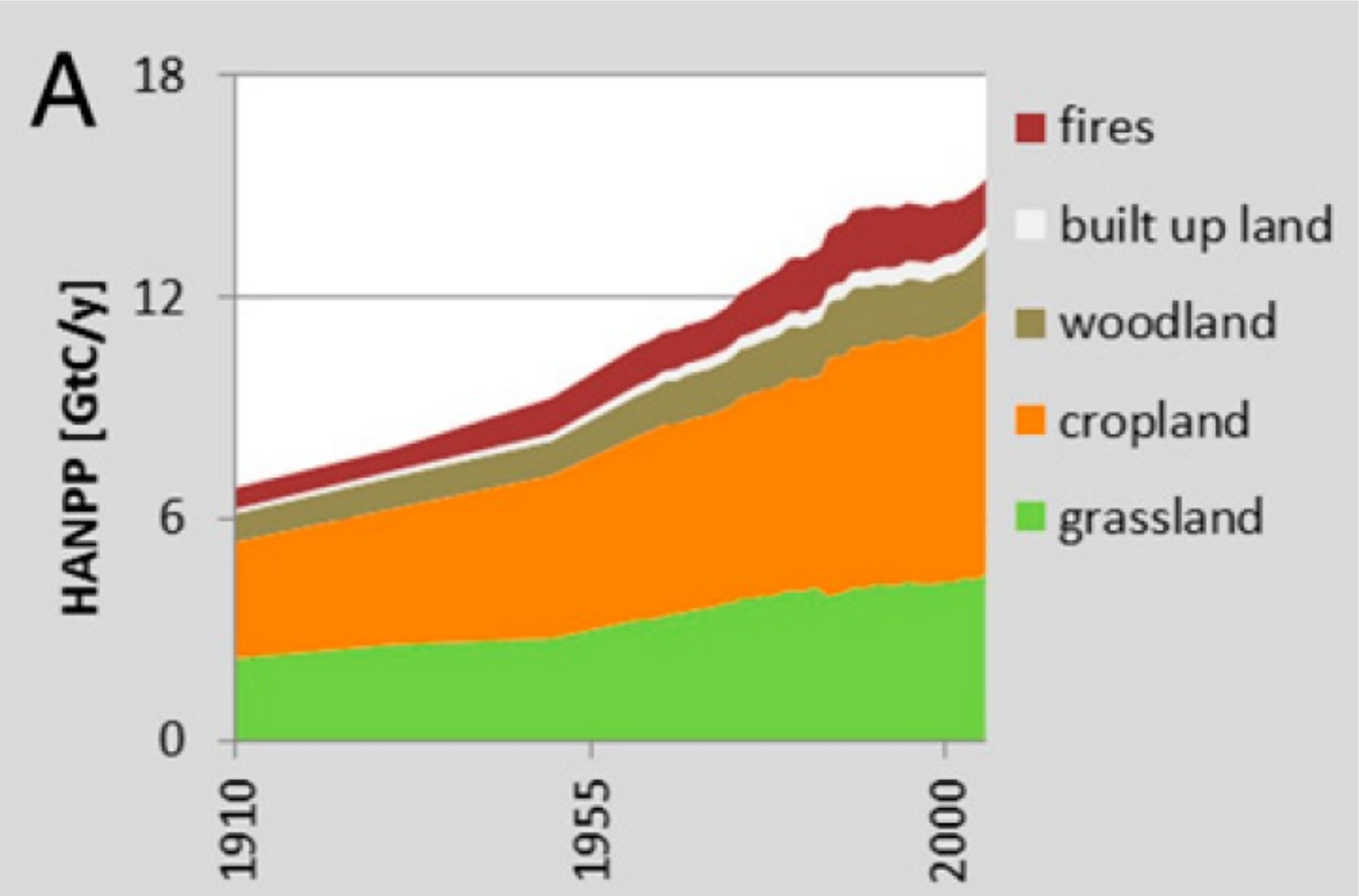
Haberl et al., 2007. *PNAS,* **104**, 12942-12947

Global pattern of HANPP



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

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

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How much is 25-30% global HANPP?
Breakdown by land use classes

	Area	NPP_{pot}	NPP_{act}	NPP_{eco}	HANPP	Comments
	[Mkm^2]			[Gt/yr]		
Settlements	1.4	1.6	0.6	0.4	1.2	Global area expansion expected
Cropland	15.2	18.6	12.1	3.1	15.5	Increase of harvest requires raising NPP; area expansion expected
Forestry	35.0	50.3	50.3	47.0	3.3	Some increases in harvest possible; cropland expansion may reduce area
Other used land, often grazed	46.9	46.0	40.9	37.1	8.9	Some increase in harvest possible; cropland expansion may reduce area
Unused	32.0	14.5	14.5	14.5	--	High ecological costs of increasing harvest
Total	130.4	131.0	118.4	102.1	28.9	

Excluding human-induced fires (3.5-3.8 Gt/yr) which cannot be allocated to land-use classes

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Haberl, *Ecol. Econ.*, doi: 10.1016/j.ecolecon.2014.10.002, in press

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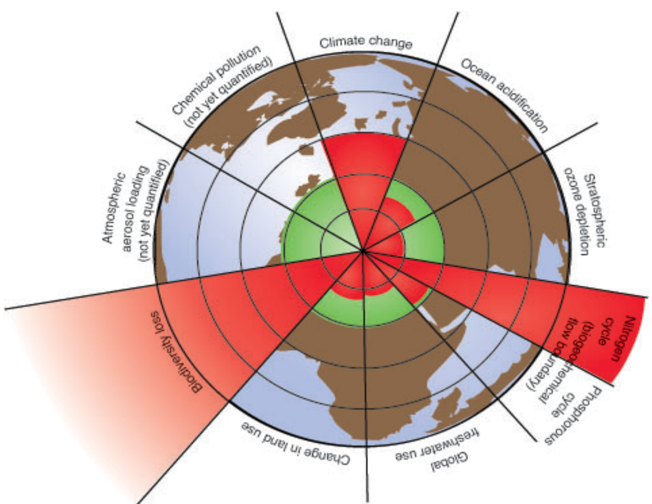
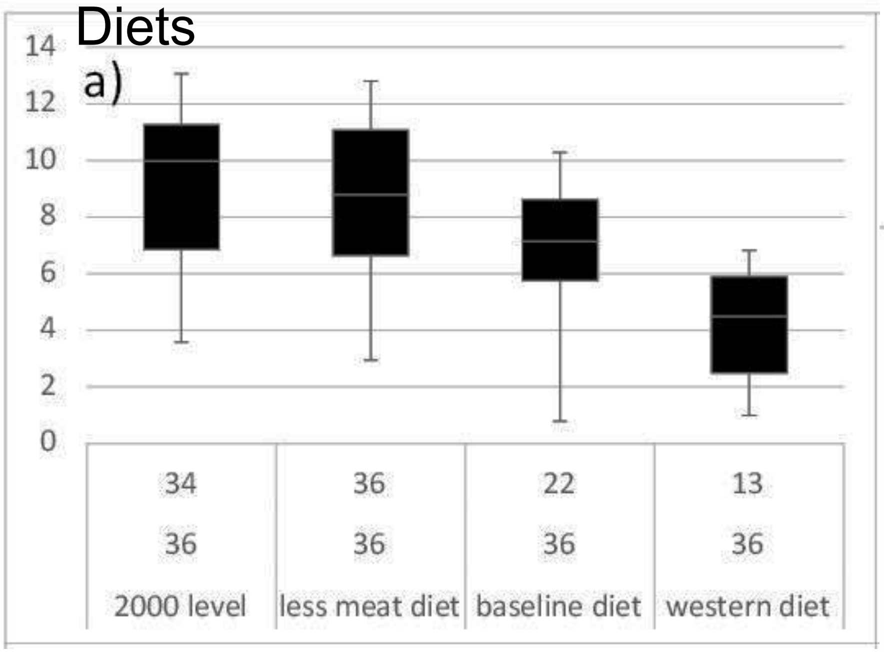
Limits/boundaries

- **Within land cover types**
  - **Constraints related to plant functional type**: biomass harvest can not exceed 20-30% of NPP in forests 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!*)[1]
  - **Trade-offs with other planetary boundaries:** raising NPP affects freshwater availability, nitrogen or phosphorous cycles, GHG emissions (e.g. feedbacks with C sequestration) & biodiversity
- **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

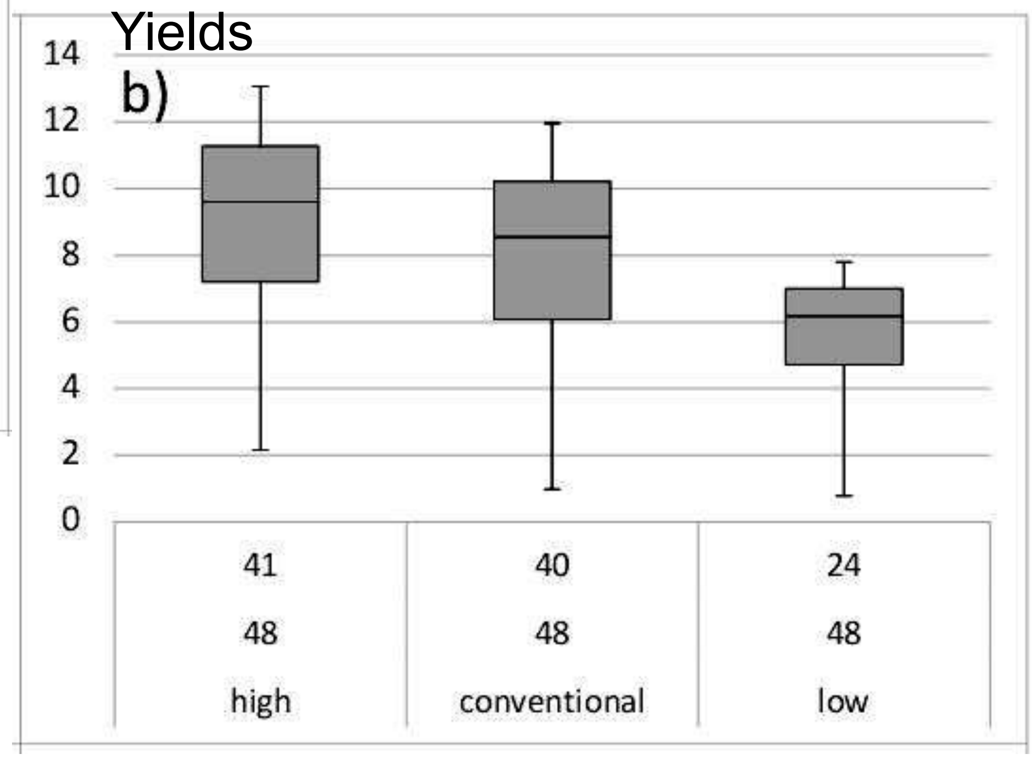


[1] Schulze *et al.* 2012. *GCB Bioenergy*, **4**, 611-616

Global land availability 2050 for non-food purposes depending on diets and crop yields



Caveat 2: Global adoption of western diets leaves little land for everything else



Caveat 3: Low cropland yields (e.g., organic farming) can not support rich diets and leave little land for everything else

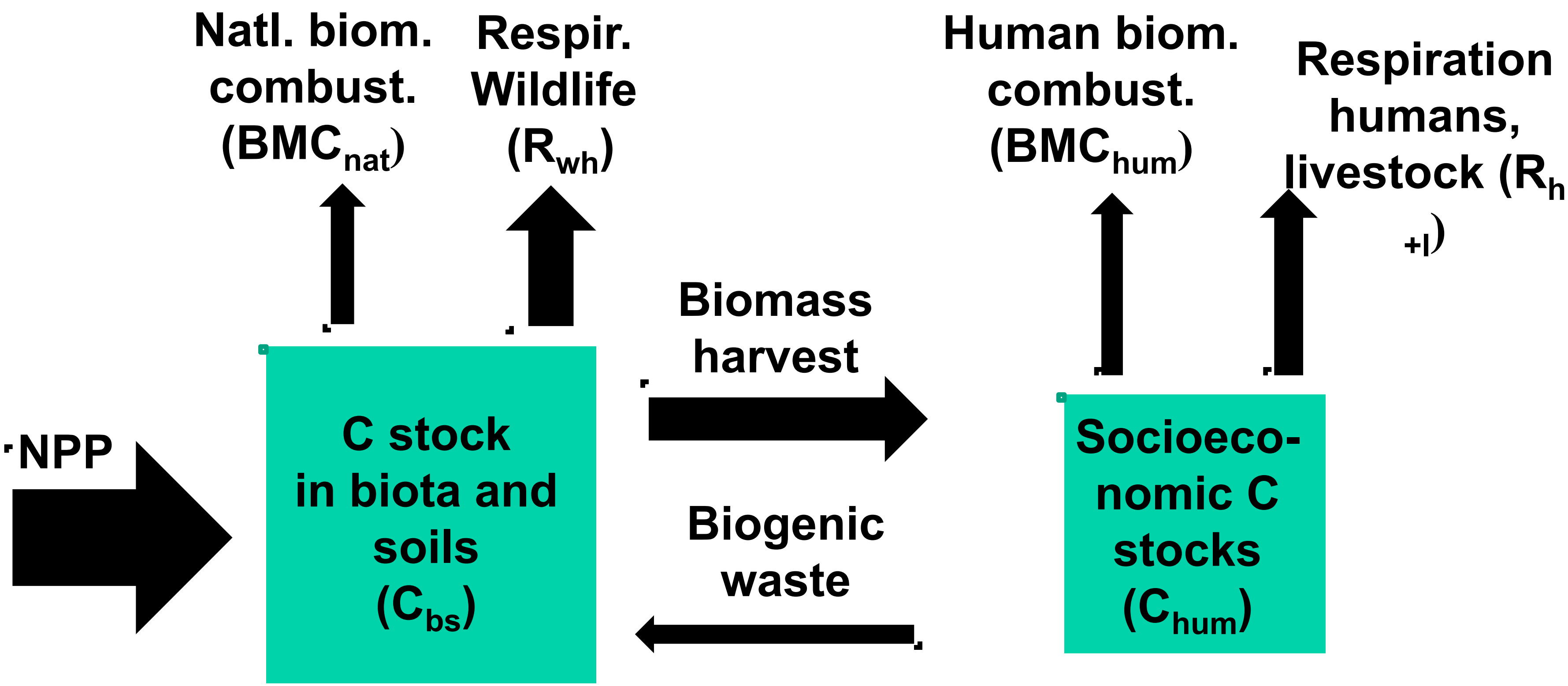
Haberl et al., in: Haberl et al., *Social Ecology*, Springer, in press

Stocks and flows of carbon (C) natural ecosystem

$$C\ sink/source = \Delta\ C\ stock = NPP - BMC_{nat} - R_{wh}$$

Haberl, 2013. *GCB Bioenergy*, **5**, 351-357

Stocks and flows of carbon (C) socio-ecological system



$$C\ sink = \Delta C_{bs} + \Delta C_{hum} = NPP - BMC_{nat} - R_{wh} - BMC_{hum} - R_{h+l}$$

Haberl, 2013. *GCB Bioenergy*, **5**, 351-357

Caveat 4: The socioecological C balance is poorly understood. Full C effects of land-related activities are uncertain

- **Huge data gaps on stocks and stock changes**
  - Few components are relatively well known (e.g. timber in forests)
  - Others are hugely uncertain (e.g. C in soils, organic wastes, socioeconomic stocks)
- **Confusion due to complex stock-flow dynamics**
  - Slow-in/fast-out („fast out“ often ignored or difficult to measure)
  - Legacy effects (e.g. C sink in Europe is a recovery from past depletion)
- **Difficult attribution problems**
  - Climate change, N deposition, land-use change and forest management simultaneously influence stocks and flows of C
  - Robust methods to attribute observed changes to causes are lacking

Anthropogenic global C-fluxes: Severe attribution problems

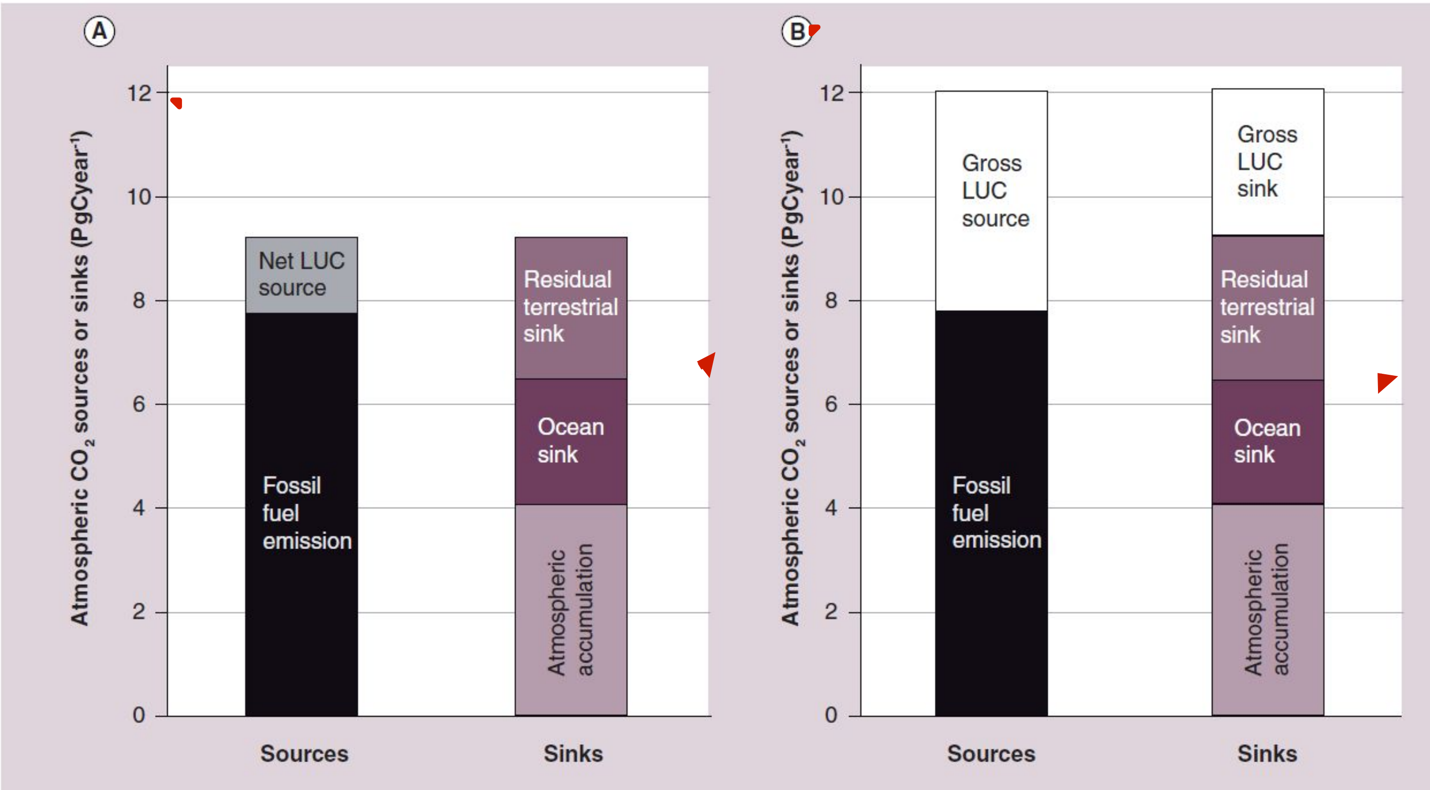
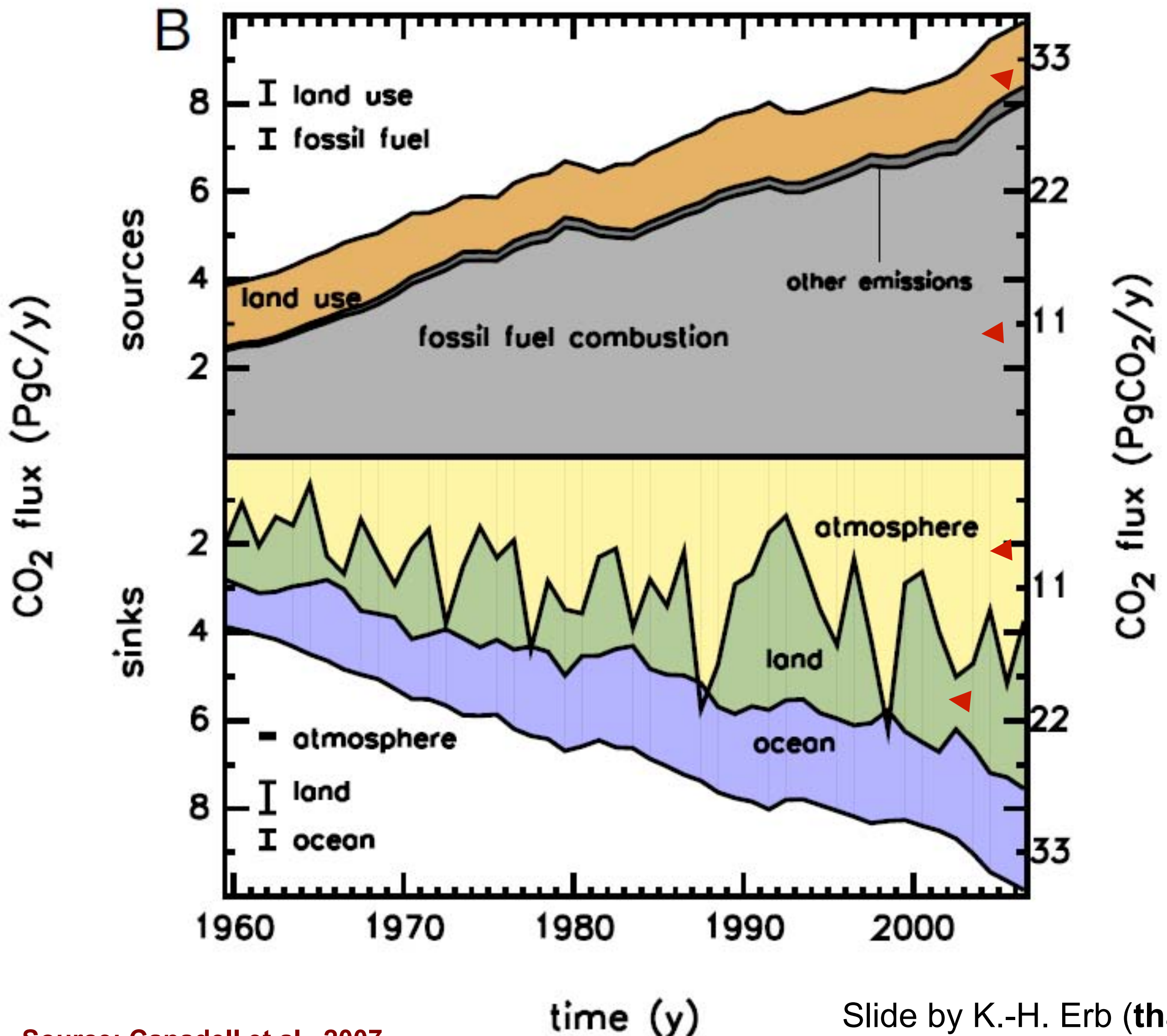


Figure 2. Anthropogenic CO_2 fluxes in the first decade of the 21st century (2000–2008 for all fluxes except gross land-use change sources and sinks, which are from 2000–2005) [3,13]. **(A)** The most common presentation of the global carbon cycle with land-use change presented as a net global source. **(B)** The expanded carbon cycle with land-use change of ecosystems that are a gross source of CO_2 presented separately from those that are gross sinks.

Attribution of flows based on models – how good are they?

Richter & Houghton, 2011.
Future Science - Carbon Management **2**, 41–47.

The „missing carbon sink“ and its (suspected) drivers

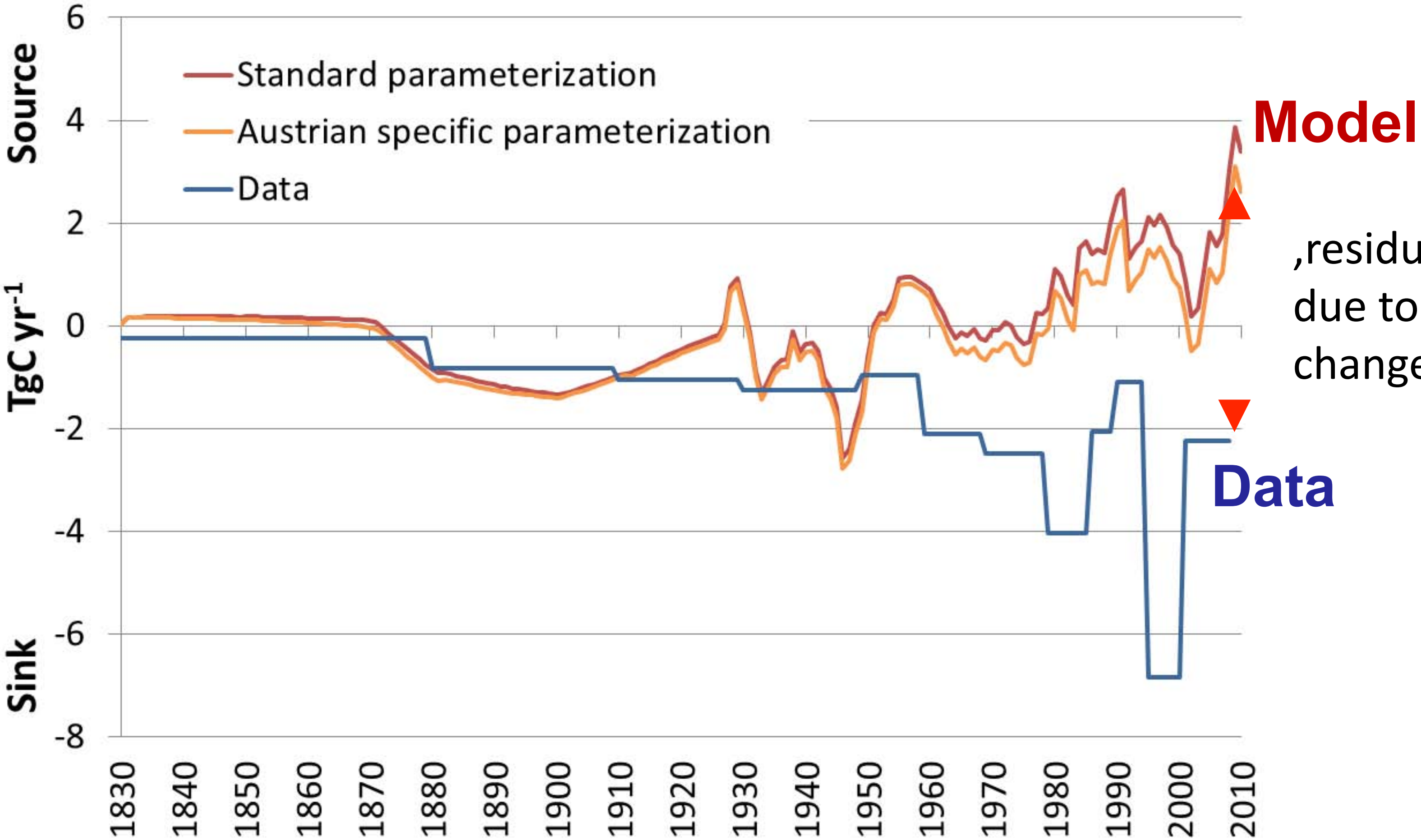


- Management **model derived!**
- From data
- From measurement
- Suspected „environmental drivers“:
  - CO_2 fertilization
  - N depositon
  - Warmer climate, more water in atmosphere

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

Source: Canadell et al., 2007

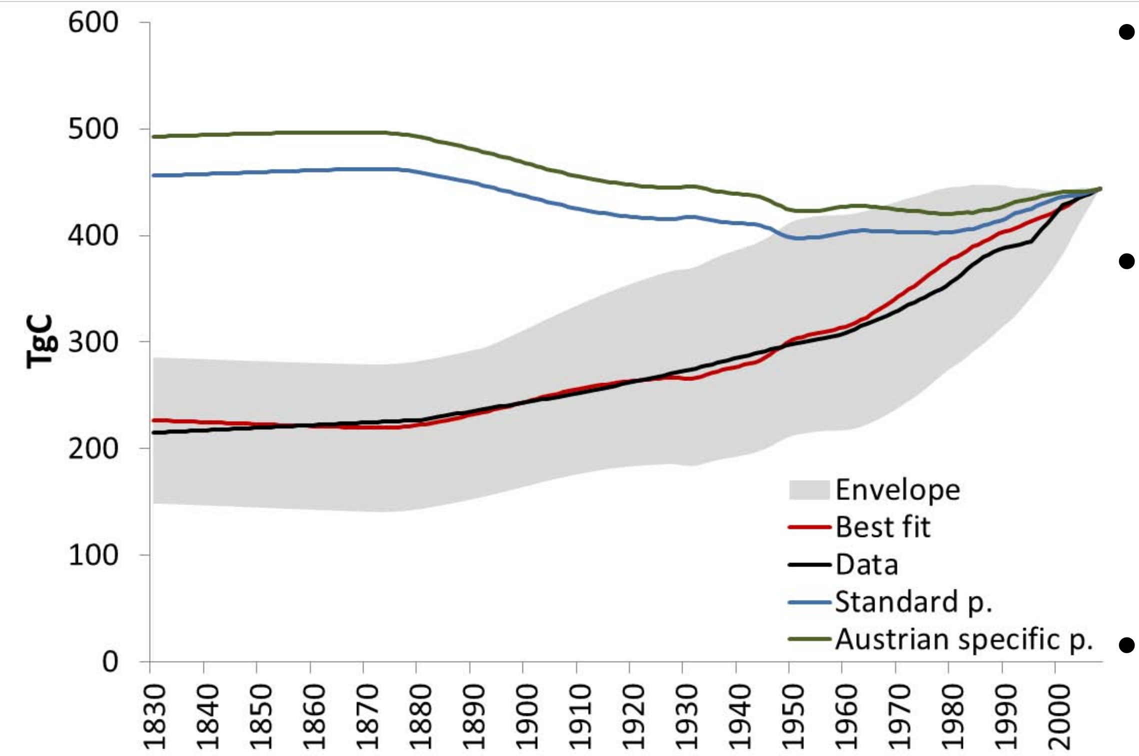
Austrian 1830-2010: Houghton‘s standard book-keeping model vs. data-based reconstruction



‚residual sink‘?
due to climate
change feedbacks?

Erb, et al. 2013. *Nature Clim. Change* **3**, 854–856

Tweaked model: climate change can not explain the observed trajectory; so far neglected management must have played a role



- Climate change can explain parts of the trend after 1950
- So far neglected management activies must have started to affect tree growth well before climate change
- Not considered in standard models!

→ Caveat 5: Current understanding of C effects resulting from land management is not satisfactory

Erb, et al. 2013. *Nature Clim. Change* **3**, 854–856

Irony: a fossil-fuel powered carbon sink
Austria 1830-2000

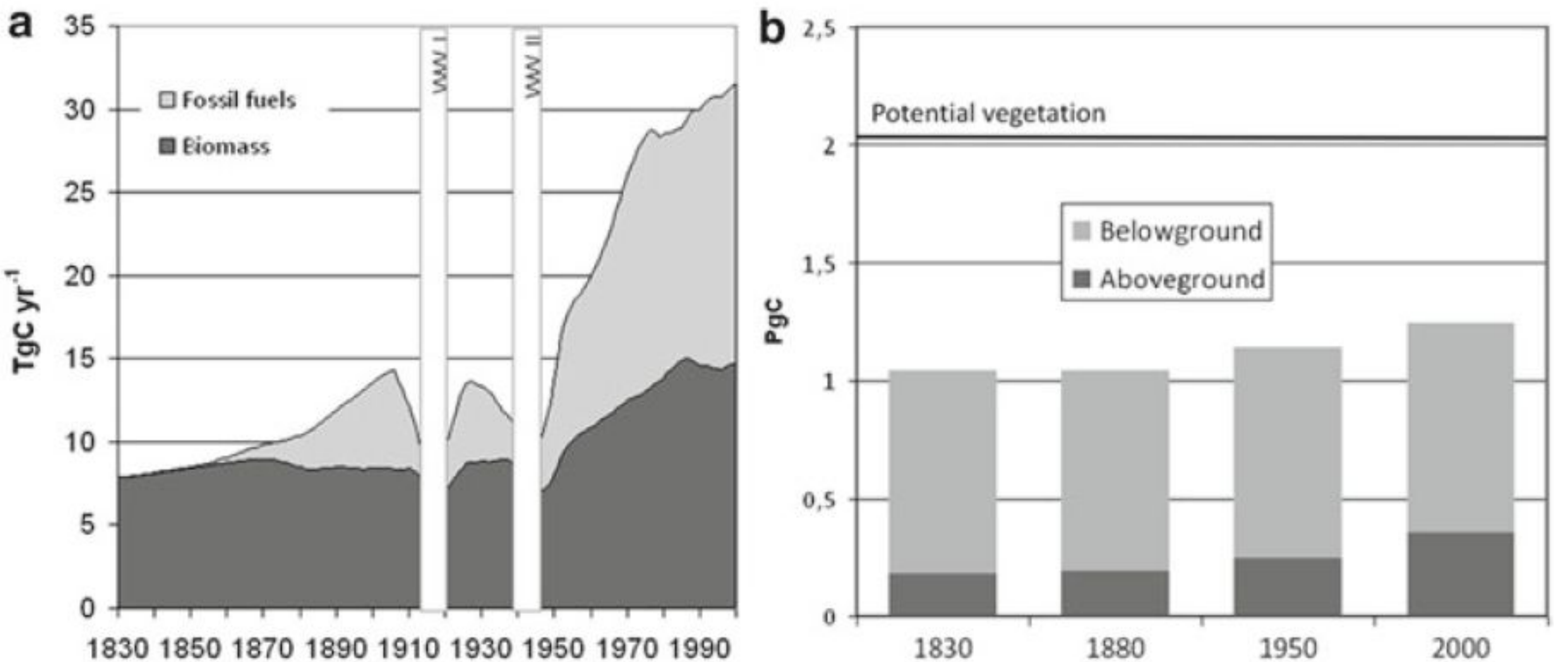


Fig. 13.4 Stocks and flows of C in Austria for the period 1830–2000. (**a**) Socioeconomic C flows per year (5-year moving average). WWI and WWII denotes the first and the second world war. (**b**) C stocks in biota and soils in petagrams of C for the years 1830, 1880, 1950 and 2000 ('above ground' are aboveground parts of plants, 'belowground' includes SOC and belowground parts of plants) (Source: Redrawn after Erb et al. (2008), Gingrich et al. (2007))

Increased productivity and rising C stocks resulted from fossil fuels inputs in agri-culture (tractors, fertilizier …) and CO_2 in the atmos-phere

Haberl et al., 2013. In: R. Lal et al. *Ecosystem Services and Carbon Sequestration in the Biosphere*. Springer, 313-331.

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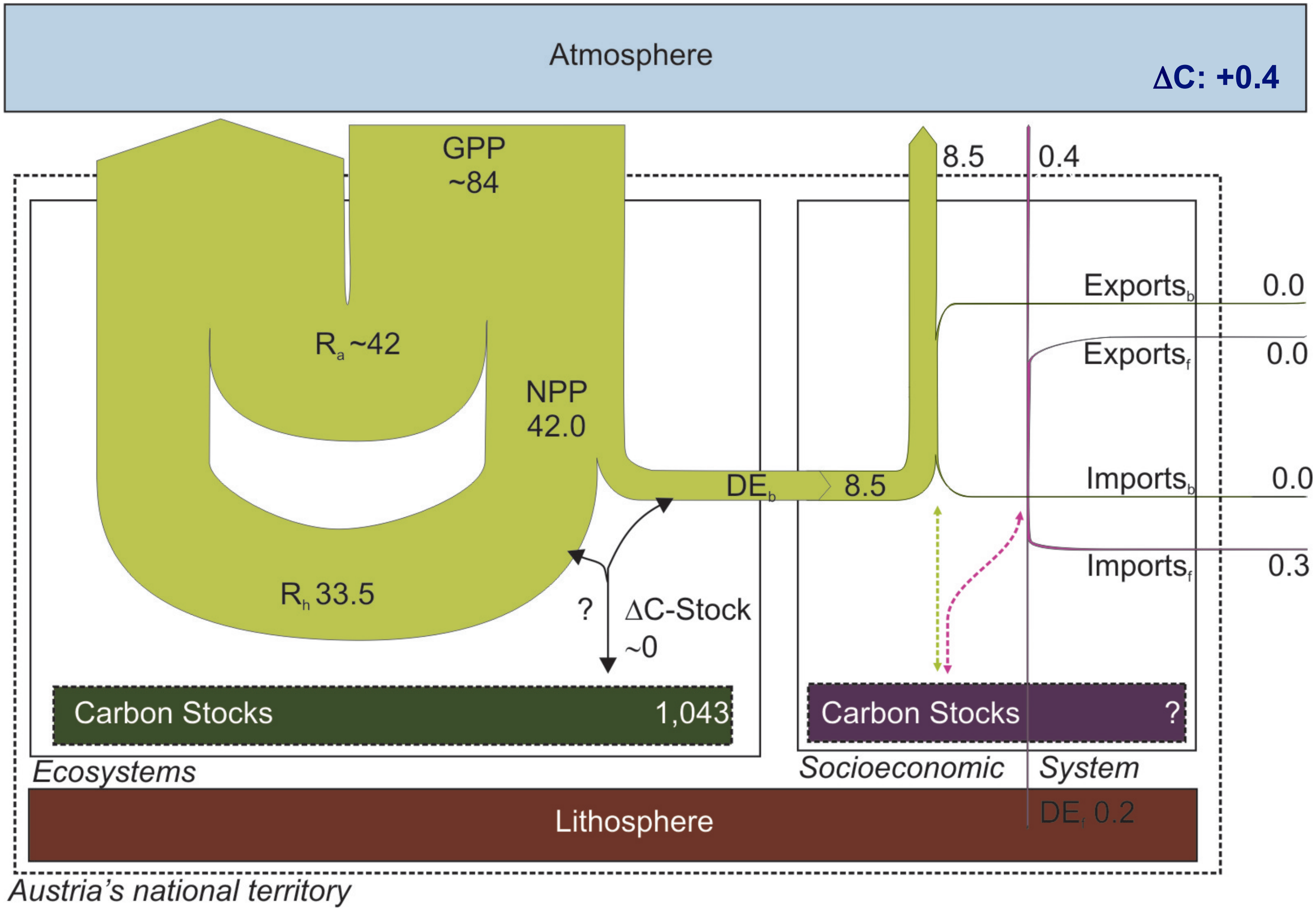
„Pre-industrial“ Carbon balance
Austria 1830 - 1880



Annual Flows MtC/yr, Stocks: MtC

Source: Erb et al. J Industr. Ecol 2008

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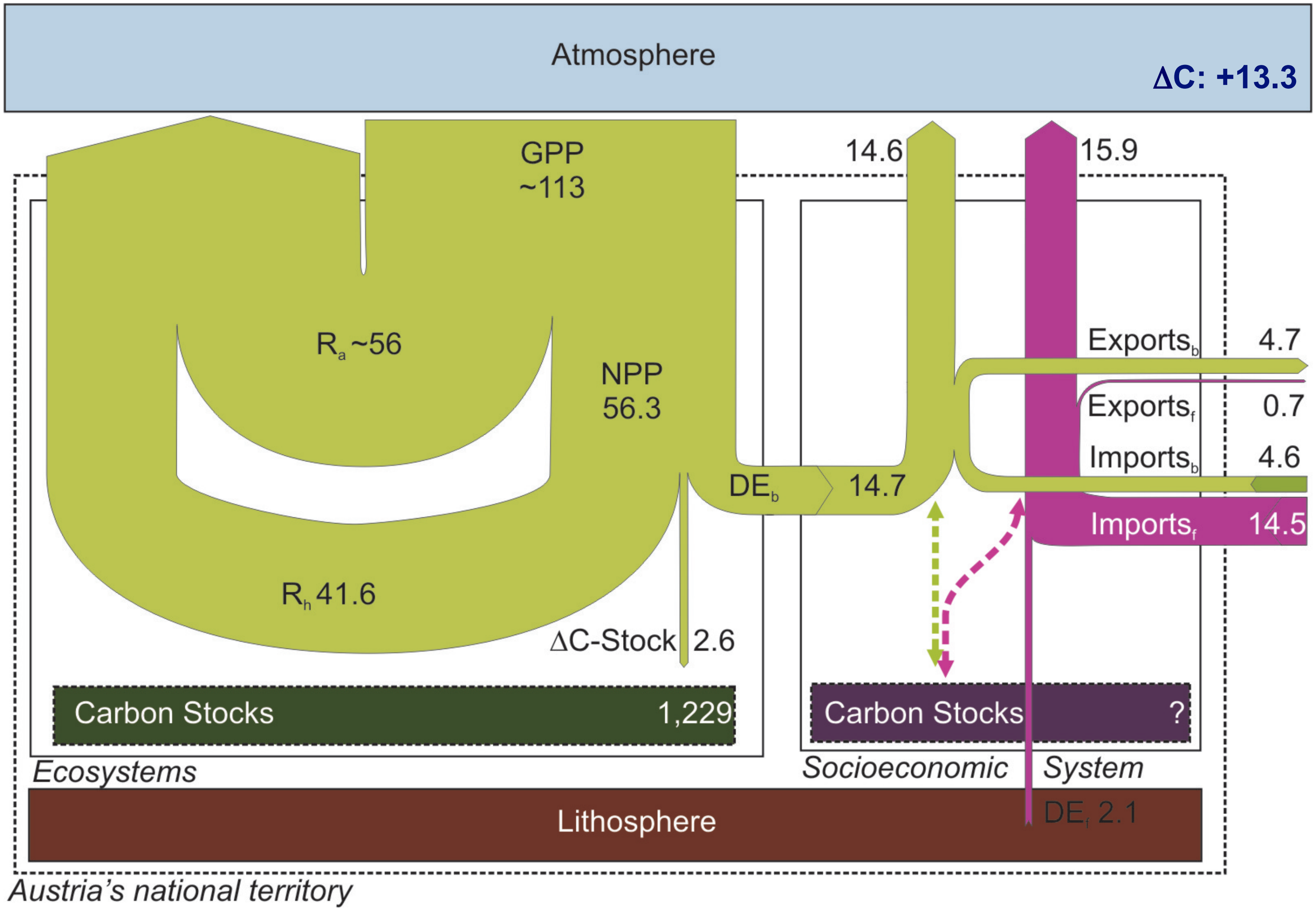
„Industrial“ Carbon Balance
Austria 1986 - 2000



Annual Flows MtC/yr, Stocks: MtC

Source: Erb et al. J Industr. Ecol. 2008

C balance effects of large bioenergy programmes

- **Conventional wisdom:** biomass combustion is C neutral because CO_2 from burning biomass is balanced by plant growth (conceptually flawed, see Plevin et al.[1])
- **Socioecological mass balance perspective:** Biomass combustion is only C neutral if the additional CO_2 released by burning biomass is compensated by
  - Increased NPP
  - Reduced respiration of wild-living heterotrophs (including decay)
  - Reduced unused biomass burning
  - Reduced respiration of humans and livestock

→ Caveat 6: It is very unlikely that large-scale bioenergy deployment would be carbon-neutral *(and we don't know)*

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[1] Plevin *et al*. 2014. *J Industr. Ecol*. **18**, 73–83.
[2] Haberl, 2013, *GCB Bioenergy*, **5**, 351-357

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Conclusions: land may contribute to climate-change mitigation, but…

- We know with reasonably certainty that the largest potentials are on the demand side
  - Changing diets (less animal products, reducing food-chain losses)
  - Energy saving
- Sustainable intensification – silver bullet or oxymoron?
  - Effects on biogeochemical cycles: H_2O, N, P…
  - New risk spirals?
- Bioenergy and carbon sequestration in biota and soils are a form of *Geoengineering under uncertainty*
  - Huge data and knowledge gaps, in particular related to systemic effects. Difficult to monitor and regulate appropriately
  - Institutions, power and legitimicy (who decides? for whom?)

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Thank you for your attention