Die Kohlenstoffbilanz der Bioenergienutzung: aktuelle Probleme und Überlegungen

Helmut Haberl

Institute of Social Ecology, Alpen-Adria Universitaet
Schottenfeldgasse 29, 1070 Vienna, Austria

Thanks to: K.-H. Erb, T. Beringer, W. Winiwarter et al.

ÖAW – KKL:
BIOMASSE IN ÖSTERREICH — QUO VADIS?
Wien, 9.11.2017

GHG emission budgets compatible with 1.5 and 2.0° targets

Table SPM.1 | Key characteristics of the scenarios collected and assessed for WGIII AR5. For all parameters, the 10th to 90th percentile of the scenarios is shown.[1,2] [Table 6.3]

CO_2eq Concentrations in 2100 [ppm CO_2eq] Category label (concentration range)[9]	Subcategories	Relative position of the RCPs[5]	Cumulative CO_2 emissions[3] [$GtCO_2$]		Change in CO_2eq emissions compared to 2010 in [%][4]		Temperature change (relative to 1850–1900)[5,6]				
			2011–2050	2011–2100	2050	2100	2100 Temperature change [°C][7]	Likelihood of staying below temperature level over the 21st century[8]: 1.5 °C	2.0 °C	3.0 °C	4.0 °C
< 430	Only a limited number of individual model studies have explored levels below 430 ppm CO_2eq										
450 (430–480)	Total range[1,10]	RCP2.6	550–1300	630–1180	−72 to −41	−118 to −78	1.5–1.7 (1.0–2.8)	*More unlikely than likely*	*Likely*	*Likely*	*Likely*
500 (480–530)	No overshoot of 530 ppm CO_2eq		860–1180	960–1430	−57 to −42	−107 to −73	1.7–1.9 (1.2–2.9)	*Unlikely*	*More likely than not*		
	Overshoot of 530 ppm CO_2eq		1130–1530	990–1550	−55 to −25	−114 to −90	1.8–2.0 (1.2–3.3)		*About as likely as not*		
							2.0–2.2 (1.4–3.6)		*More unlikely than likely*[12]		
							2.1–2.3 (1.4–3.6)				
							2.3–2.6 (1.5–4.2)				
							2.6–2.9 (1.8–4.5)		*Unlikely*	*More likely than not*	
							3.1–3.7 (2.1–5.8)	*Unlikely*[11]		*More unlikely than likely*	
							4.1–4.8 (2.8–7.8)		*Unlikely*[11]	*Unlikely*	*More unlikely than likely*

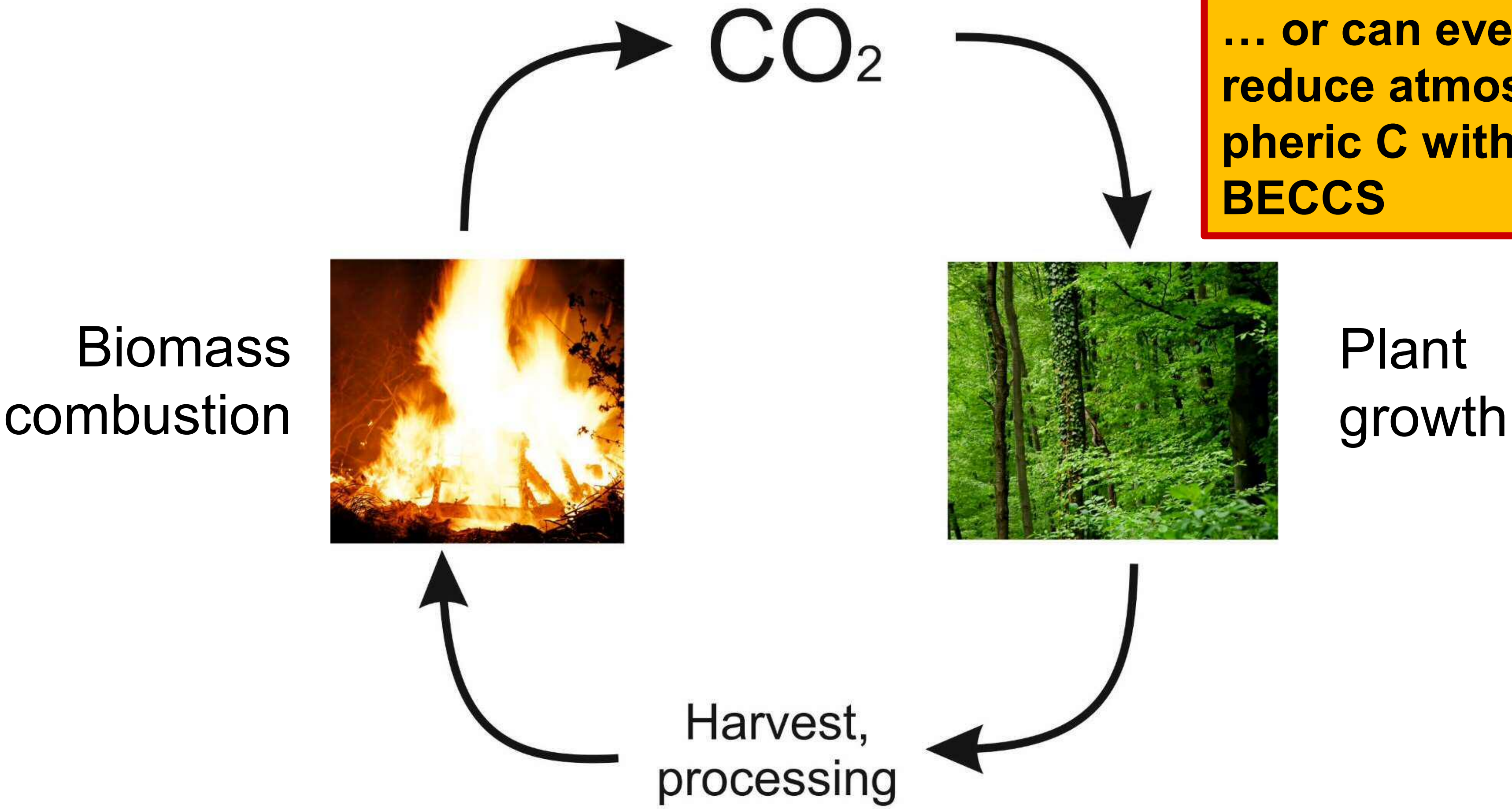
Fast & deep CO_2 emission reduction needed. Many low GHG scenarios rely heavily on BECCS. But how much can biomass/bioenergy *really* contribute?

IPCC AR5, 2014, WGIII, *Summary for Policymakers*

Conventional wisdom

CO_2 released during combustion is offset during plant growth, therefore biogenic CO_2 is climate-neutral…

… or can even reduce atmospheric C with BECCS



IPCC AR5, WGIII, chapter 11, p.877

The combustion of biomass generates gross GHG emissions roughly equivalent to the combustion of fossil fuels.

If bioenergy production is to generate a net reduction in emissions, it must do so by offsetting those emissions through increased net carbon uptake of biota and soils.

The appropriate comparison is then between the net biosphere flux in the absence of bioenergy compared to the net biosphere flux in the presence of bioenergy production. Direct and indirect effects need to be considered in calculating these fluxes.

Context: state of global land system

- Central challenge: feeding the nine billion → agricultural output needs to increase by +70-100% until 2050
- Humans use approximately three quarters of earth‘s lands → *land use competition*
- Humans appropriate ~ one-third of terrestrial aboveground NPP (doubled in the last century)
- Biodiversity is lost at alarming rates
- Many ecosystem services degraded (MEA)

Ecological Economics 119 (2015) 424–431

Contents lists available at ScienceDirect

Ecological Economics

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

Commentary

Competition for land: A sociometabolic perspective

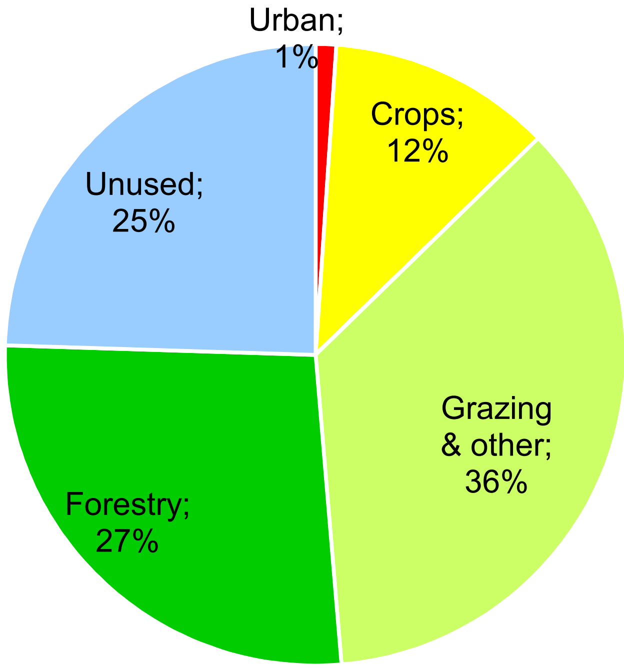
Helmut Haberl *

Institute of Social Ecology Vienna, Alpen-Adria Universitaet Klagenfurt, Wien, Graz, 1070 Wien, Schottenfeldgasse 29, Austria
Humboldt-Universität zu Berlin, Integrative Research Institute on Transformations in Human Environment Systems, Quartier Stadtmitte, Friedrichstraße 191, D-10117 Berlin, Germany

Haberl 2015, *Ecol Econ* **119**, 424-431

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.
Ellis *et al.*, 2013, PNAS **110**, 7978-7985

What do we really know about land assumed to be „unused“ or „wasteland“?

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

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

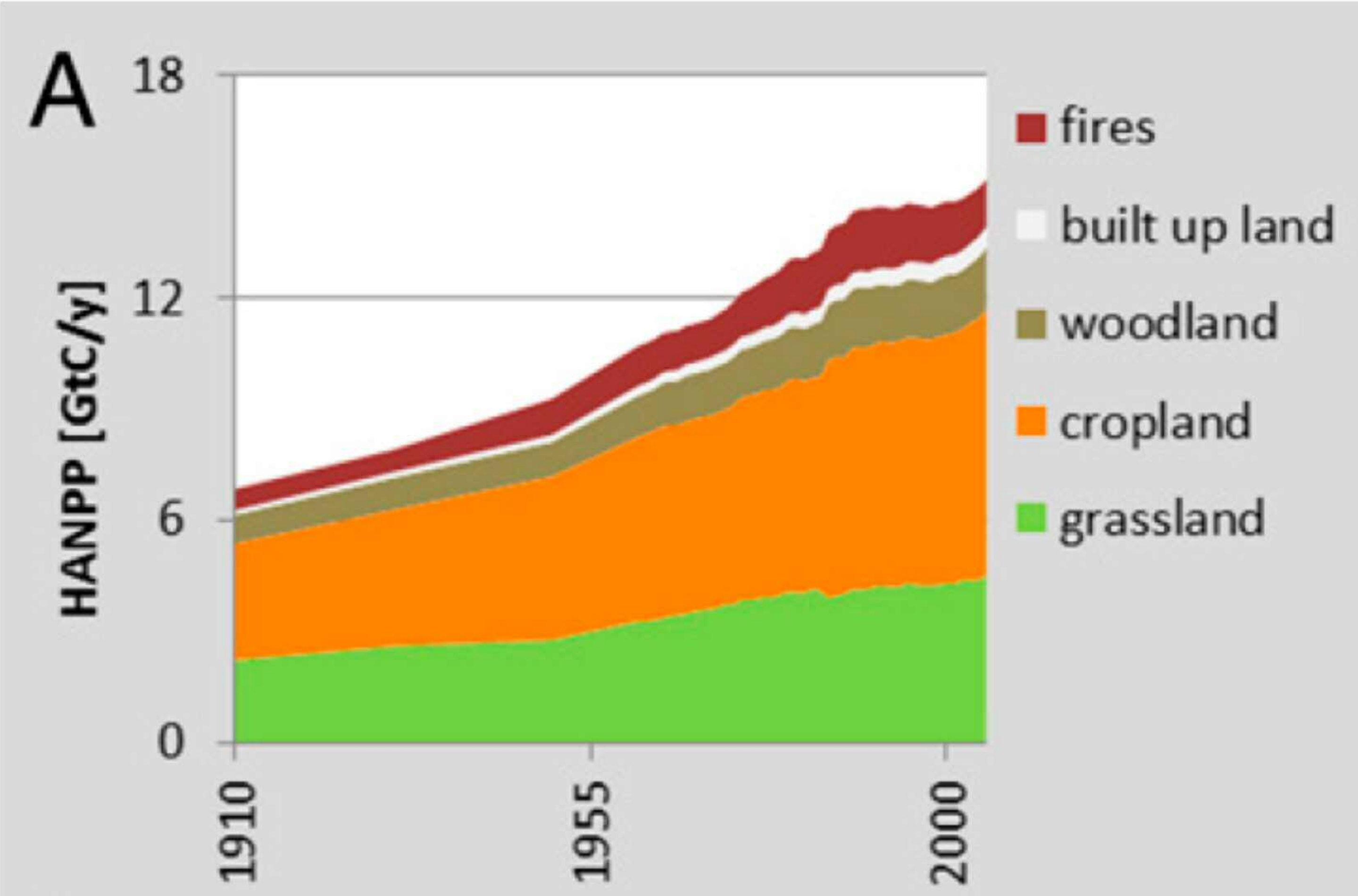
CrossMark

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

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

Global human appropriation of net primary production* 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

* land-use induced change of yearly biomass flows remaining in ecosystems compared to potential natural vegetation

Will it be C-neutral to raise HANPP to ~45% for bioenergy?

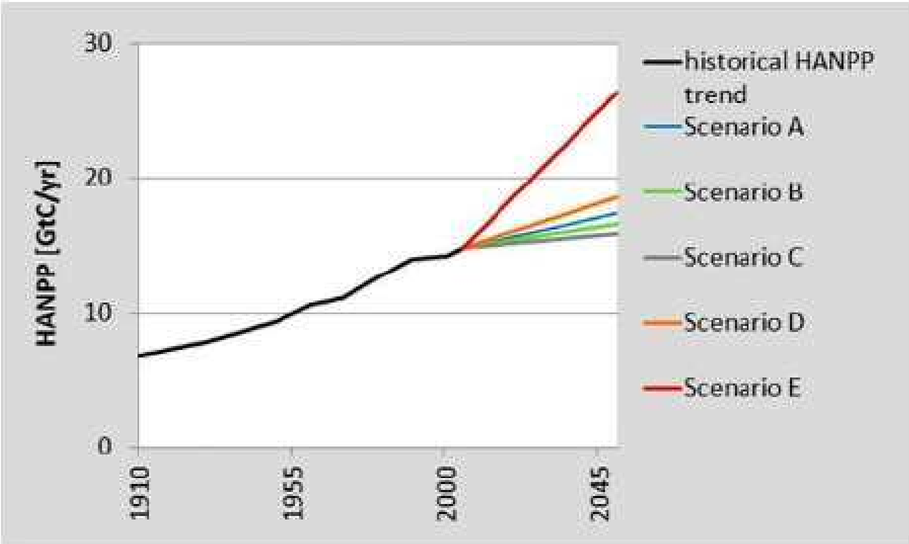


Fig. 4. Scenarios for the development on HANPP until 2050. Whereas scenarios A–C assume a continuation of past trends, scenarios D and E add additional primary biomass harvest to scenario B (see text and *SI Appendix* for details). Based on upper and lower boundary values for deployment levels of biomass for energy, we assumed an additional harvest for energy production of 50 EJ/y (scenario D) and 250 EJ/y (scenario E) over the present value. Continuation of past trends would result in moderate growth of HANPP until 2050. Increasing the production of bioenergy, however, could dramatically increase global HANPP (scenario E).

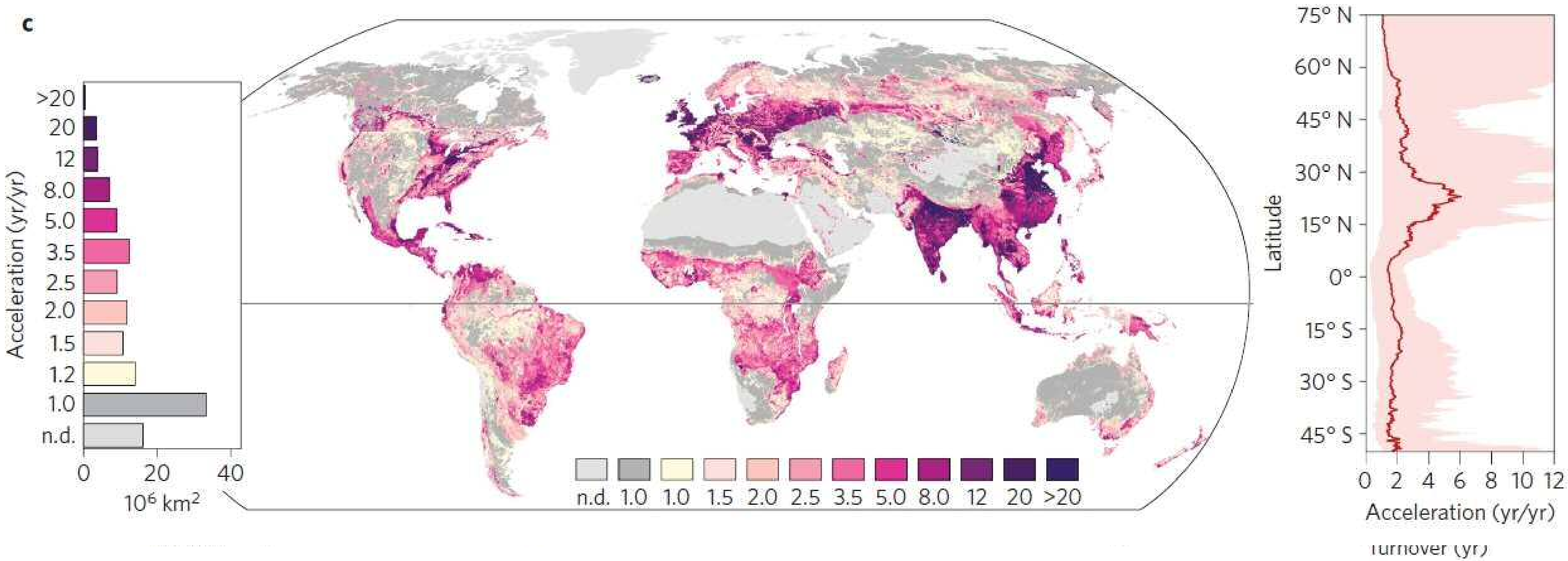
PNAS | June 18, 2013 | vol. 110 | no. 25 | 10327

TREND scenarios allow feeding the world and moderate bioenergy deployment

Large-scale bioenergy implementation (+250 EJ/yr in 2050) raises HANPP to ~45%

HANPP: biophysical indicator of land-use intensity, related to pressures on biodiversity, impacts on the natural carbon cycle and ecosystems in general

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

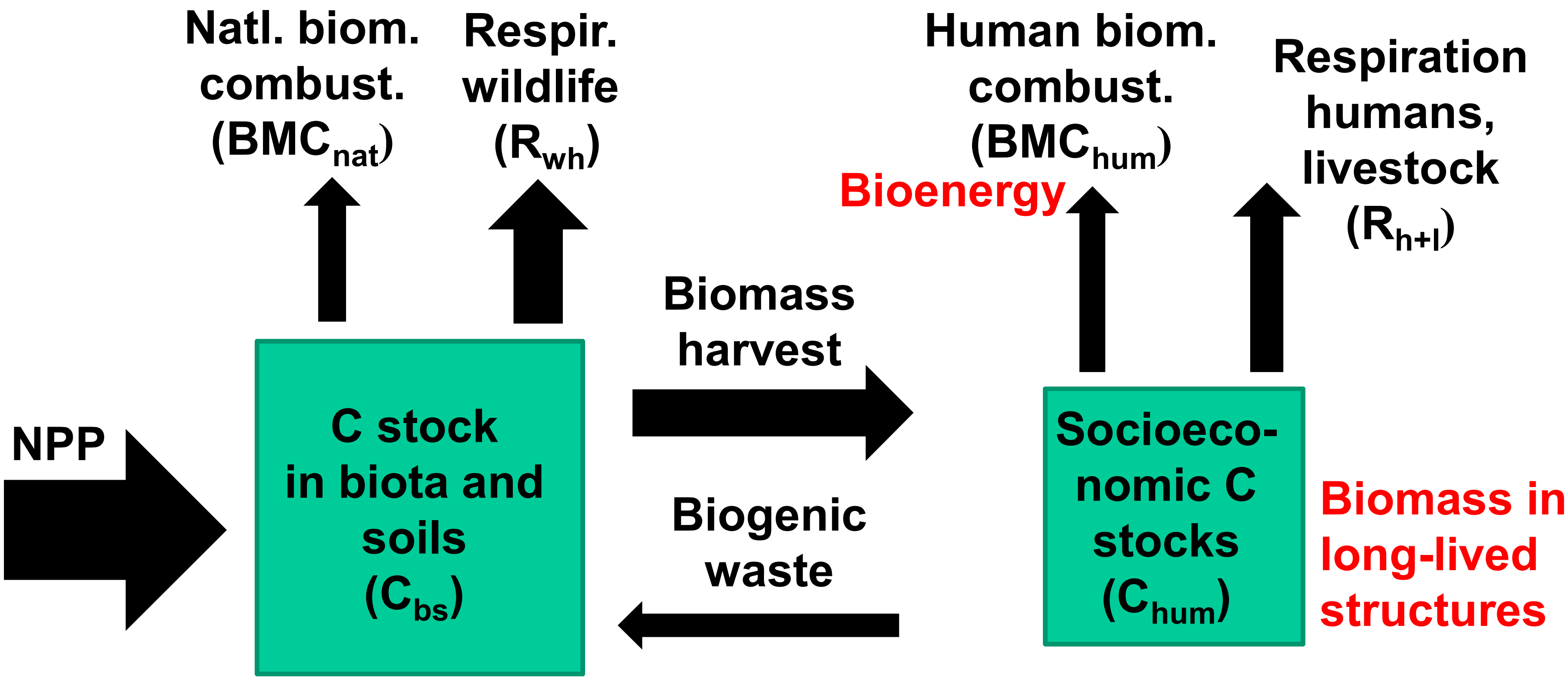
Erb et al., 2016, *Nature Geosci.*, DOI: 10.1038/NGEO2782

Stocks and flows of carbon (C) natural ecosystem

$$C \text{ sink} = \Delta \, C \text{ stock} = NPP - BMC_{nat} - R_{wh}$$

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

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

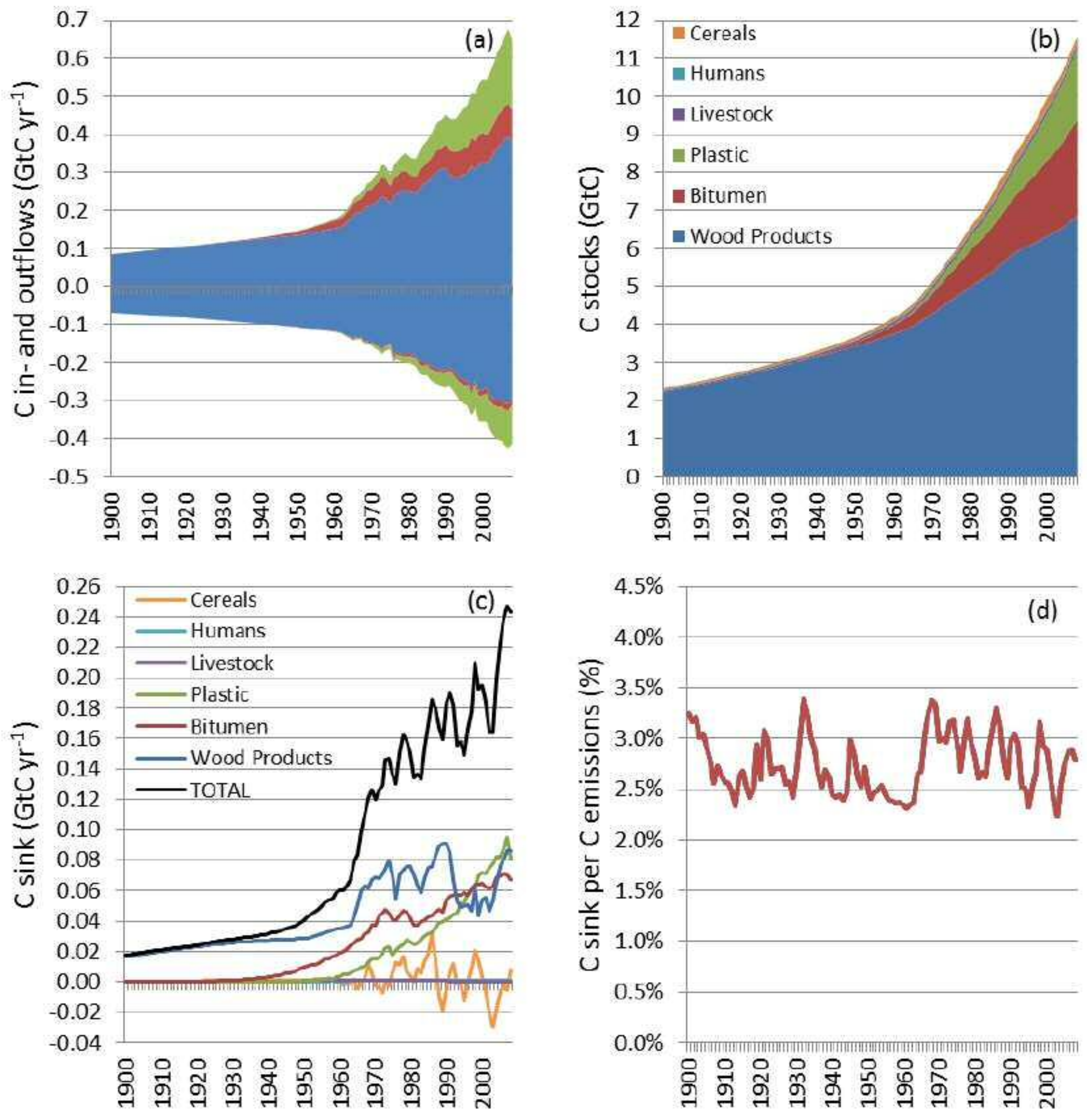


$$C\ sink = \Delta C_{bs} + \Delta C_{hum} = NPP - BMC_{nat} - R_{wh} - BMC_{hum} - R_{h+l}$$

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

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

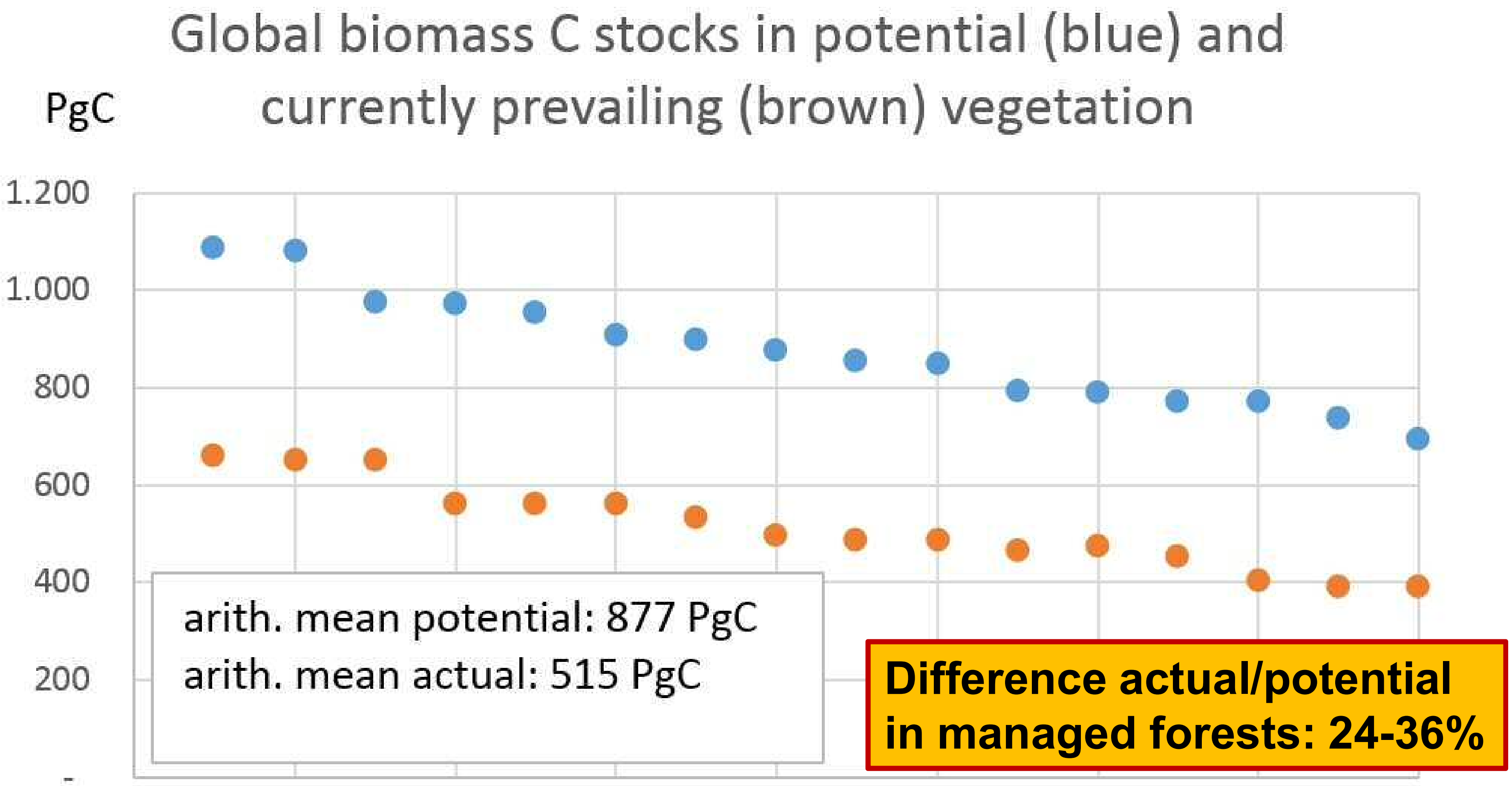
- **Huge data gaps on stocks and stock changes**
  - Few components are relatively well known (e.g. timber in forests)
  - Others are hugely uncertain (e.g. C in soils, organic wastes, socioeconomic stocks)
- **Confusion due to complex stock-flow dynamics**
  - Slow-in/fast-out („fast out“ is difficult to measure & often ignored)
  - 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 manage-ment simultaneously influence stocks and flows of C
  - Robust methods to attribute observed changes to causes are lacking



C in sozio-ökonomischen Beständen (global)

Lauk et al. 2012. *Env. Res. Lett.* **7**, 034023

Land management affects C stocks on land.
Strong effects beyond land-cover change!



Sources: Bazilevich et al., 1971, Pan et al., 2013, Prentice et al., 2011, West et al., 2010, Hurtt et al., 2011, Esser, 1987, Roy-Saugier-Mooney, 2001, Potter, 1999, Ajtay et al., 1979, Hall and Scurlock, 1993, Olson et al., 1983, Ruesch & Gibbs, 2008, Amthor et al., 1998, Watson et al., 2000, ongoing own study

Global LAND Project

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

Langfristiger Gleichgewichtswert von C-Beständen und Erntemenge in Abhängigkeit von der Rotationsperiode

Gesamte Waldfläche von Norwegen, derzeitiges Klima

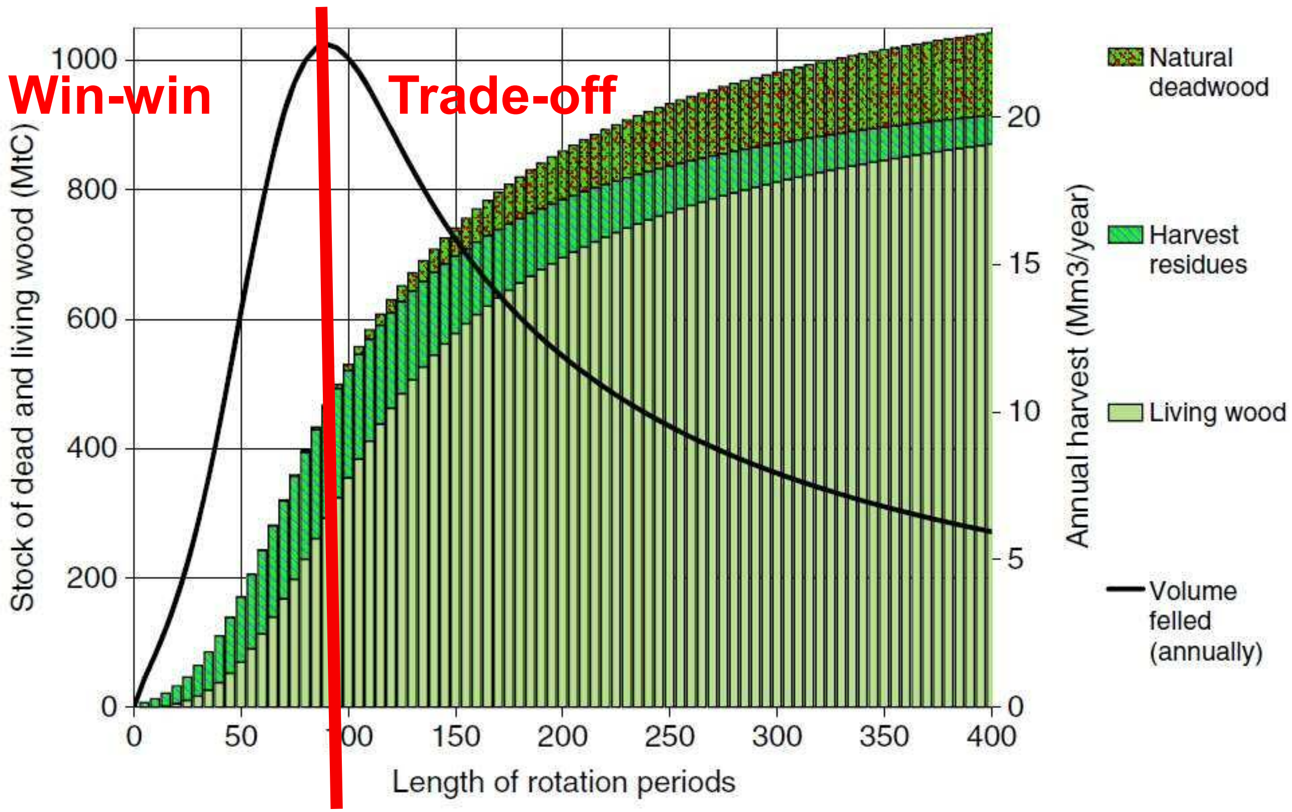
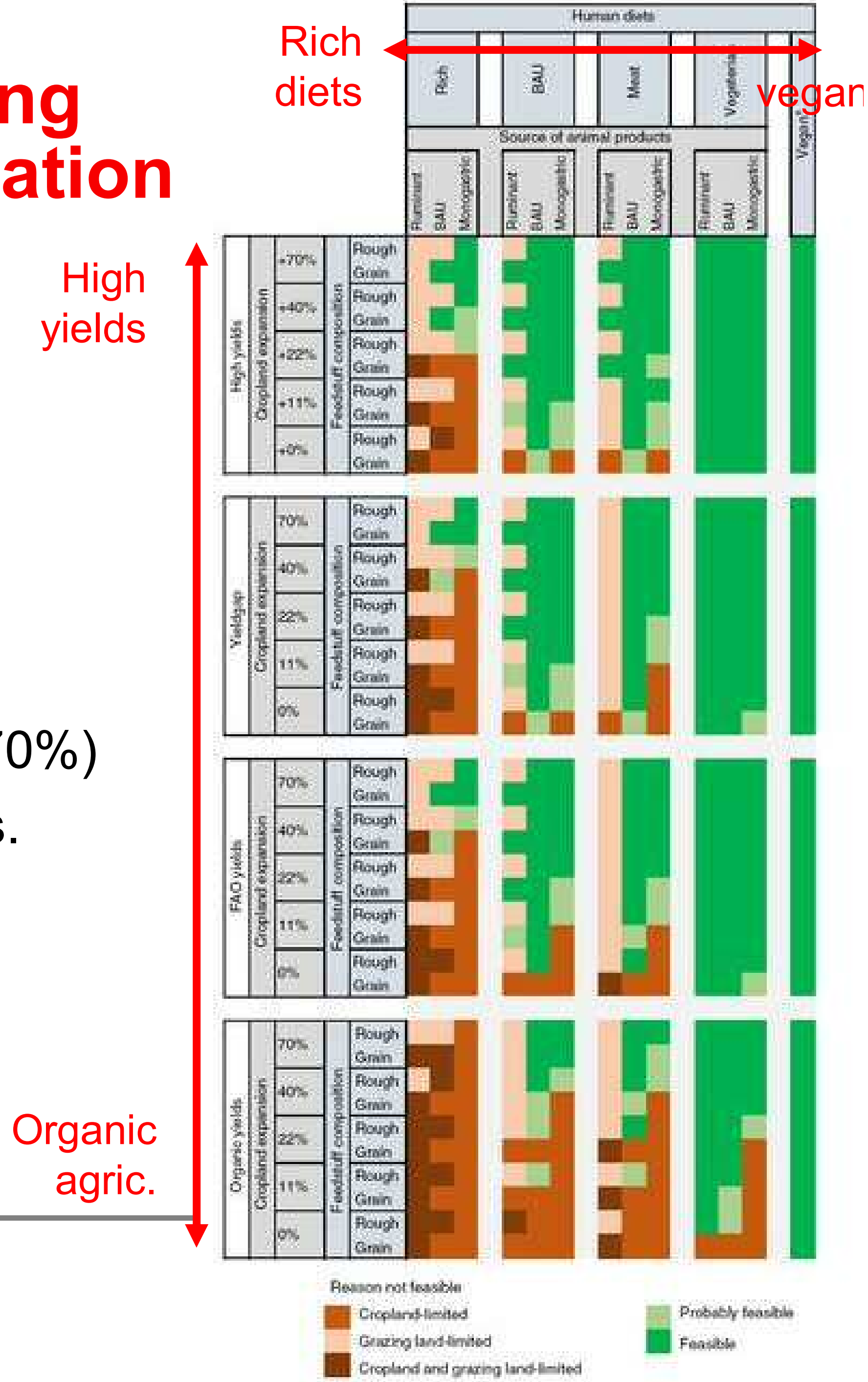


Fig. 2 The entire forest. Annual volume of timber felled (black curve) and quantity of carbon stored in dead and living wood (columns) in different steady states for rotation cycles of different lengths

Holtsmark 2012. *Climatic Change* **112**, 415–428.

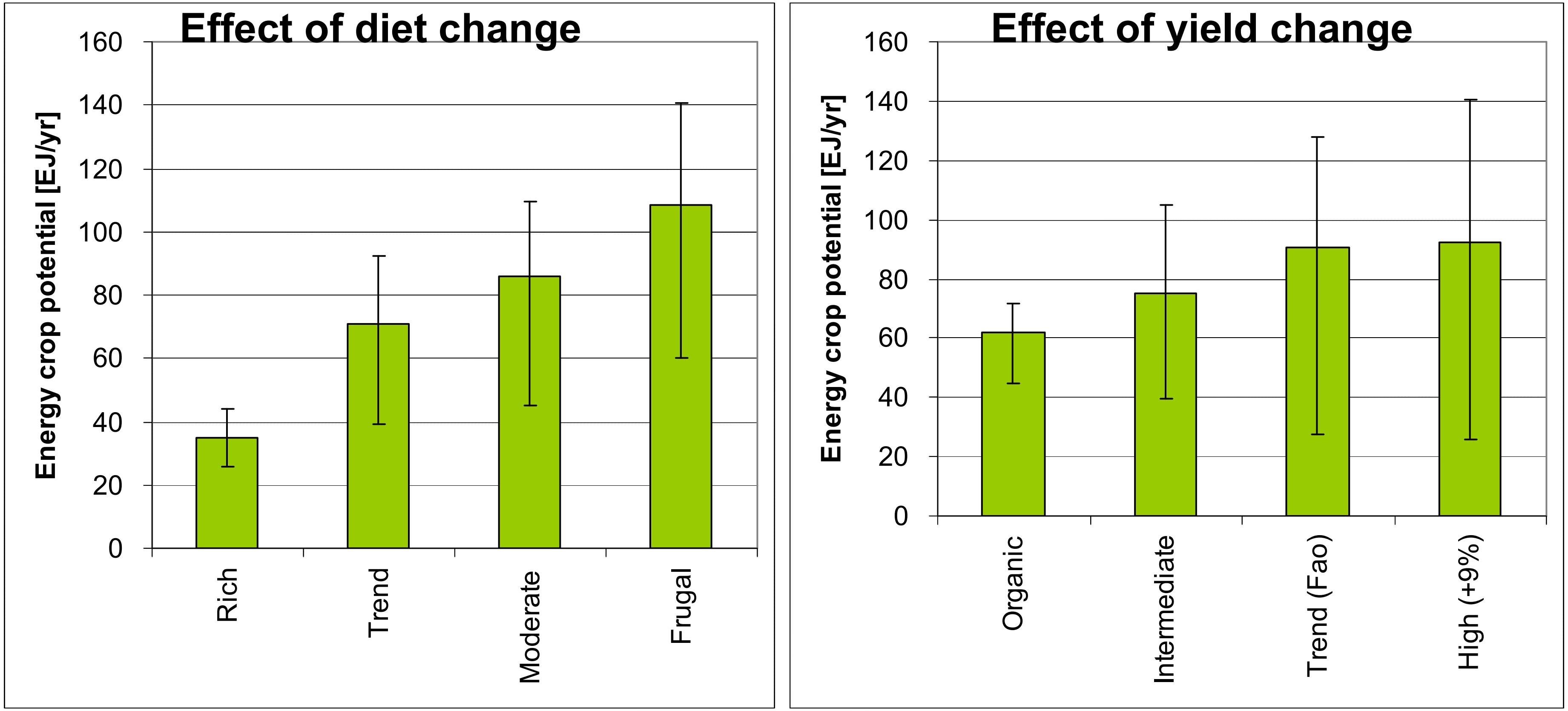
The options space for feeding the world 2050 w/o deforestation

- **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



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

Dependency of energy crop potential 2050 on diet and agricultural technology



Global LAND Project

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

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

Land-use history matters
Austria's fossil-fuel powered carbon sink

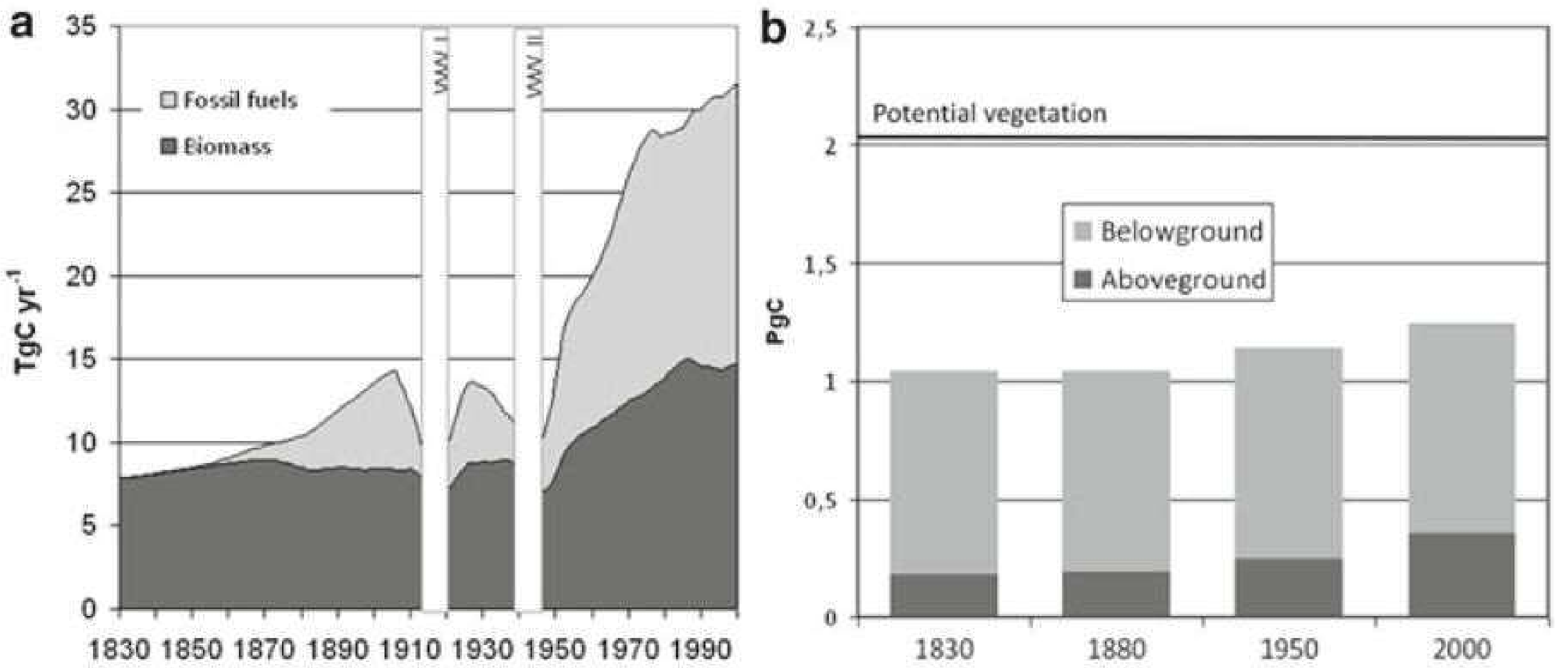


Fig. 13.4 Stocks and flows of C in Austria for the period 1830–2000. (**a**) Socioeconomic C flows per year (5-year moving average). WWI and WWII denotes the first and the second world war. (**b**) C stocks in biota and soils in petagrams of C for the years 1830, 1880, 1950 and 2000 ('above ground' are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

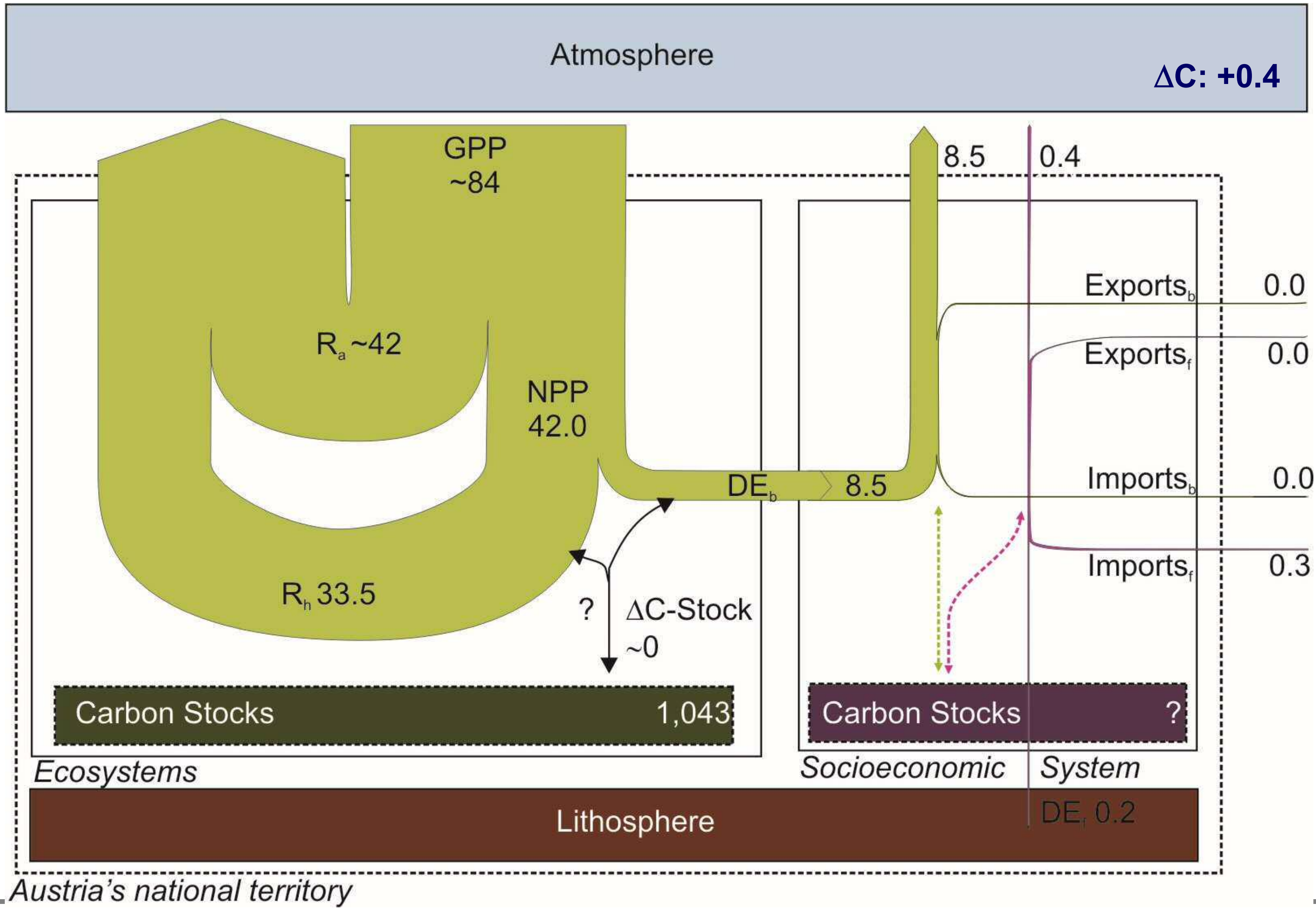
Increased productivity and rising C stocks resulted from fossil fuels inputs in agricul-ture (tract-ors, fertili-zer..) and CO_2 in the atmos-phere

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

Global LAND Project

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

„Pre-industrial“ Carbon balance
Austria 1830 - 1880



Annual Flows MtC/yr, Stocks: MtC

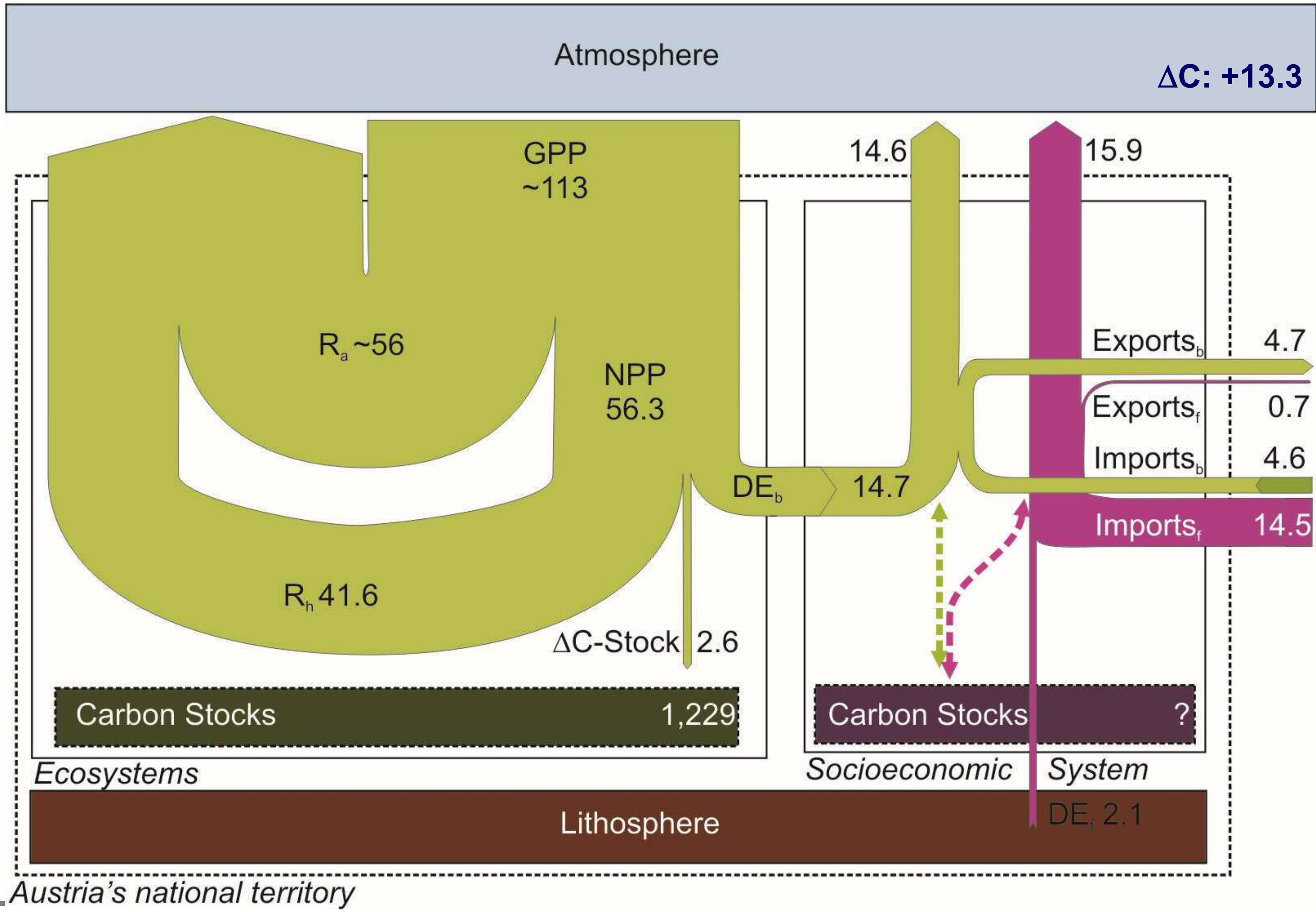
Source: Erb et al. J Industr. Ecol 2008

Global LAND Project

ALPEN-ADRIA UNIVERSITÄT KLAGENFURT I WIEN GRAZ

iff social ecology vienna

„Industrial“ Carbon Balance
Austria 1986 - 2000



Annual Flows MtC/yr, Stocks: MtC

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

ALPEN-ADRIA UNIVERSITÄT KLAGENFURT I WIEN GRAZ

social ecology vienna

Anthropogenic global C-fluxes: Severe attribution problems

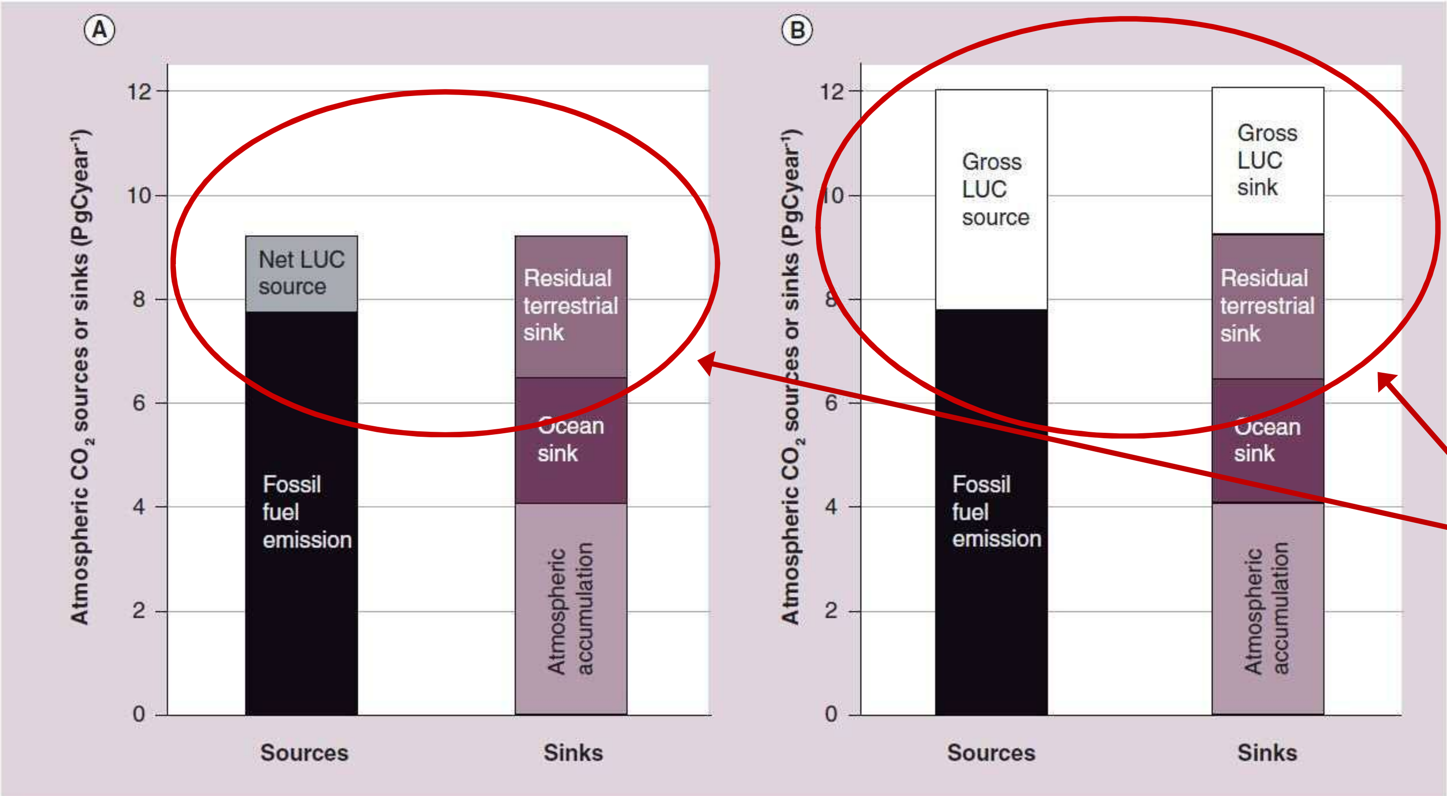
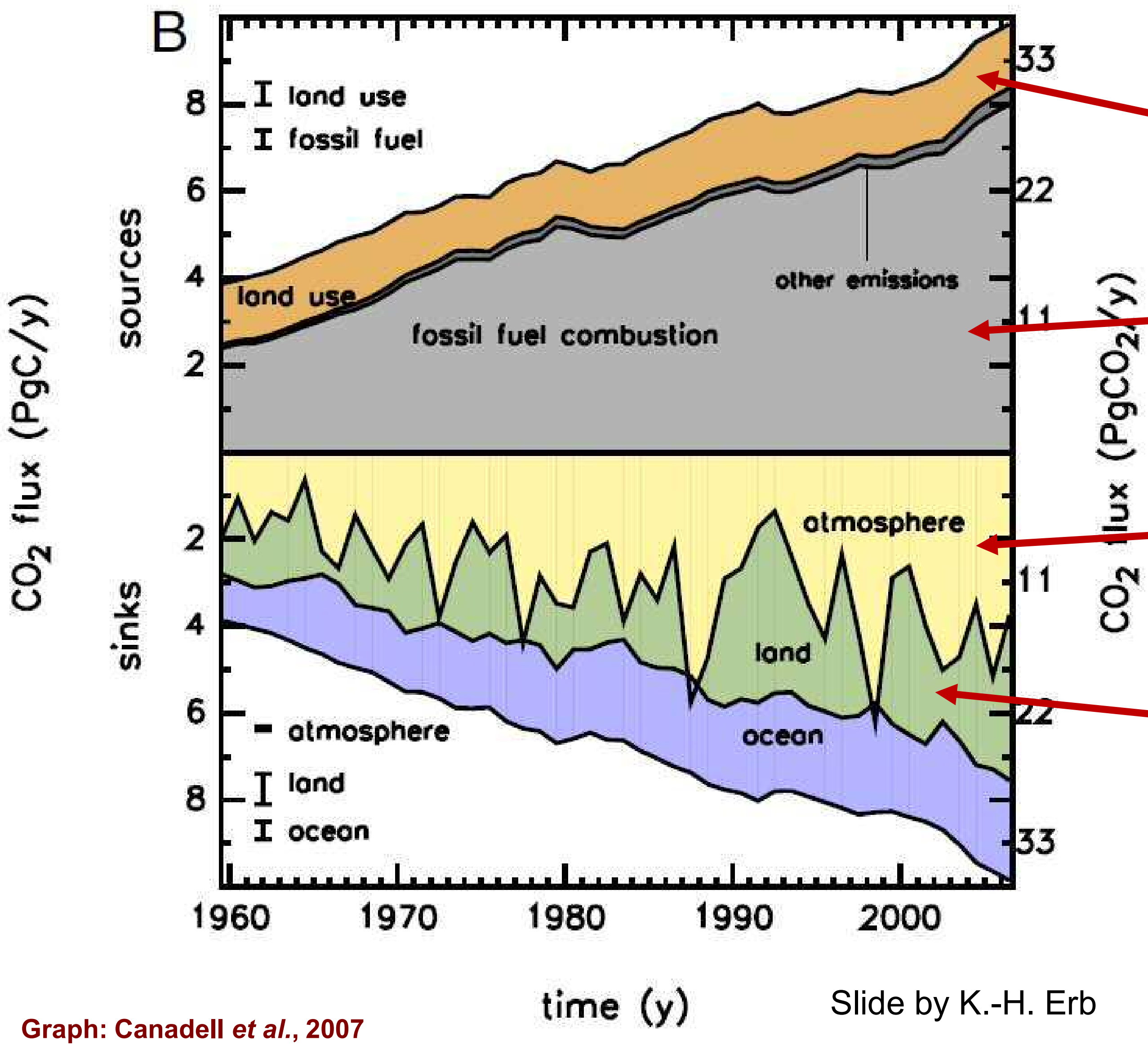


Figure 2. Anthropogenic CO_2 fluxes in the first decade of the 21st century (2000–2008 for all fluxes except gross land-use change sources and sinks, which are from 2000–2005) [3,13]. (A) The most common presentation of the global carbon cycle with land-use change presented as a net global source. (B)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



Land management
model derived!

From data

From measurement

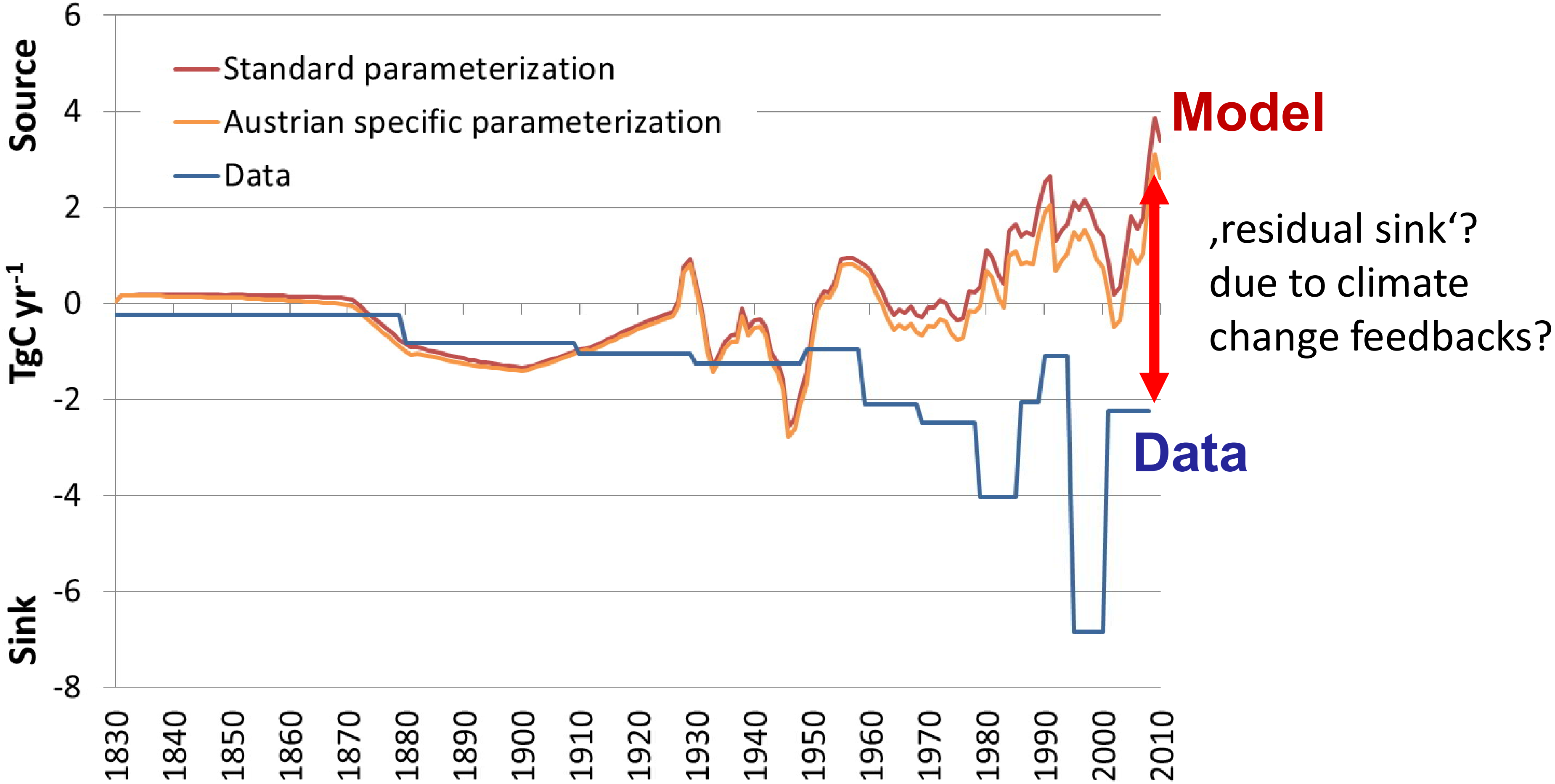
Suspected „environmental drivers“:
- CO_2 fertilization
- N depositon
- Warmer climate, more water in atmosphere

Slide by K.-H. Erb

Graph: Canadell *et al.*, 2007

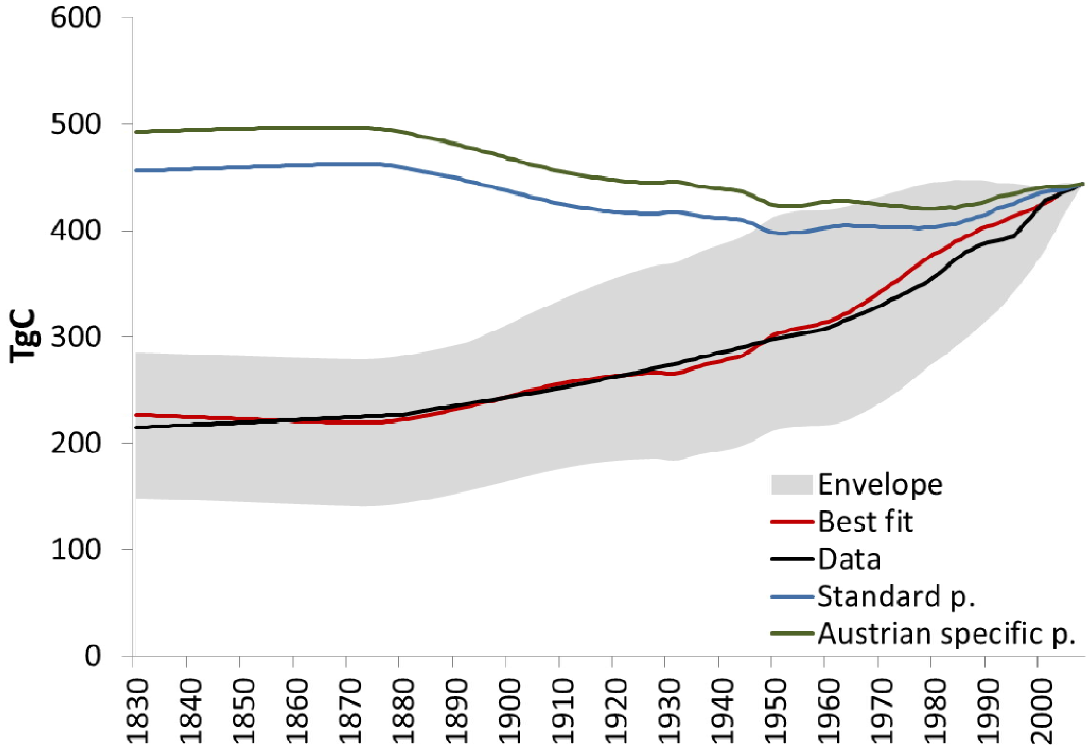
ALPEN-ADRIA UNIVERSITÄT KLAGENFURT I WIEN GRAZ
iff social ecology vienna

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



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

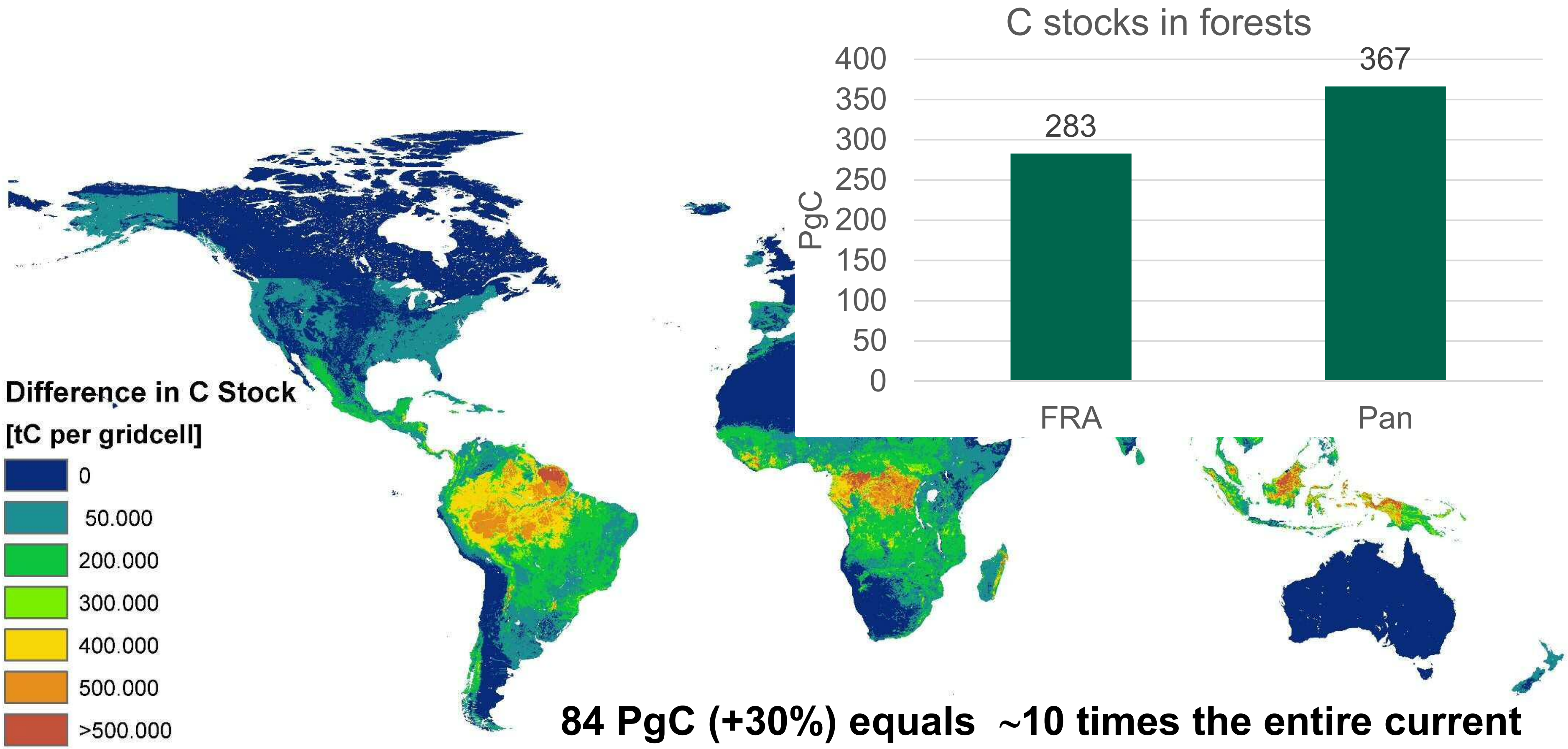


- Climate change can explain parts of the trend after 1950
- So far neglected management activies must have started to affect tree growth well before climate change
- Not considered in standard models!

→ Current understanding of C effects resulting from land management is not sufficient

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

Uncertainty of global C stocks in forests
e.g., FAO Forest Assessment *versus* Pan et al.



84 PgC (+30%) equals ~10 times the entire current yearly fossil-fuel related CO_2 emissions

Pan *et al.* 2011. *Science* **333**, 988-993
FAO, *Global Forest Resources Assessment (FRA)* 2010
Map: K.-H. Erb, C. Plutzar

Conclusions

- **The general assumption** that CO_2 released when burning biomass were C-neutral towards the atmosphere **is a scientifically invalid oversimplification**
- Full GHG effects of bioenergy depend on **systemic effects in the whole land system**, including the food system
- **Timing of deployment and energy crop yields** are of critical importance for the full GHG balance of future bioenergy
- Full C cycle effects of large bioenergy deployment are uncertain and poorly understood
  → **Given current data quality, there is a severe risk that full GHG effects of bioenergy deployment will not even be detectable *ex post,* for years or even decades**

Thanks for listening