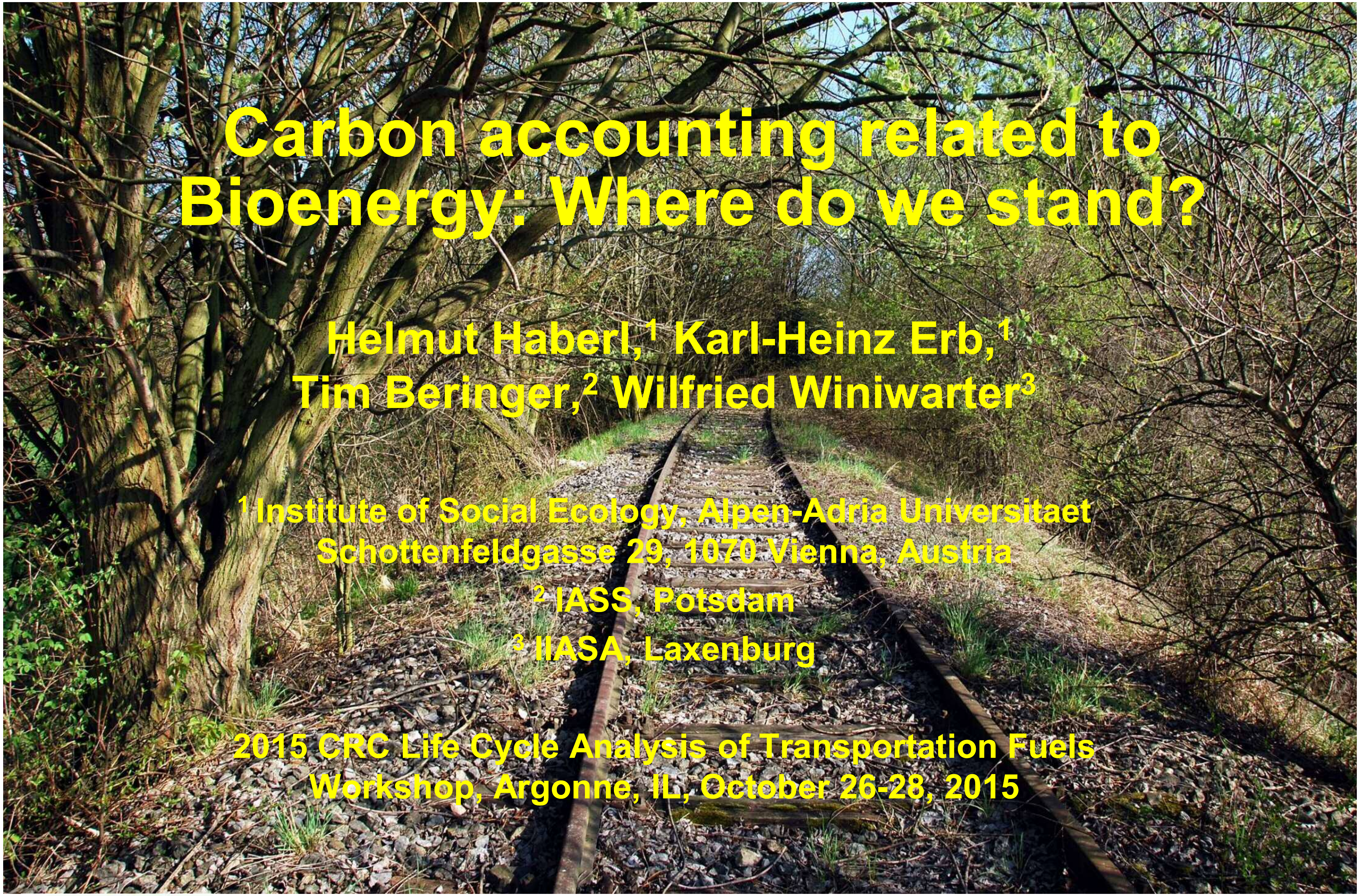

Carbon accounting related to Bioenergy: Where do we stand?

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2015 CRC Life Cycle Analysis of Transportation Fuels
Workshop, Argonne, IL, October 26-28, 2015

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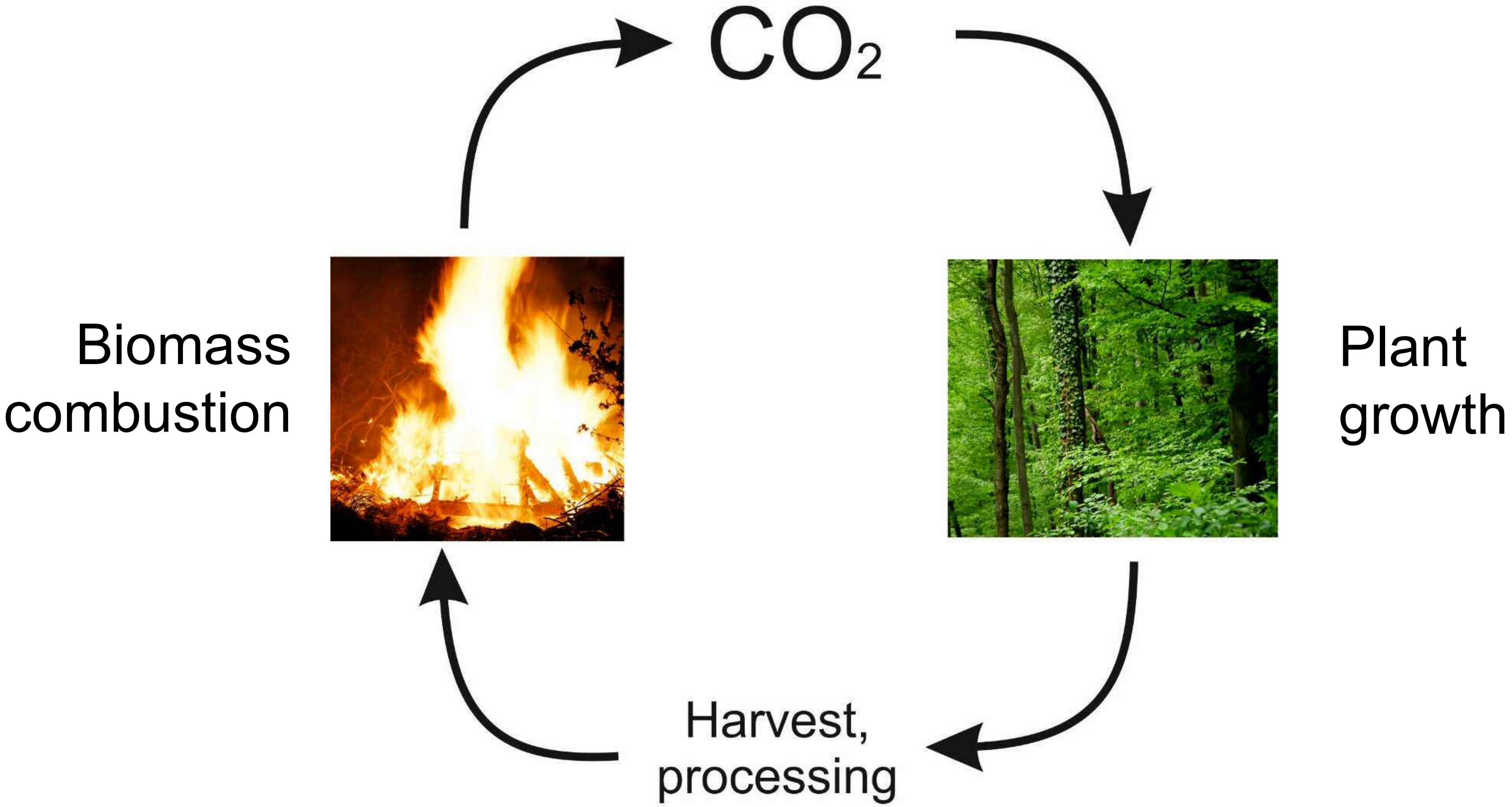
Conventional wisdom

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



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

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Commentary

Competition for land: A sociometabolic perspective

Helmut Haberl *

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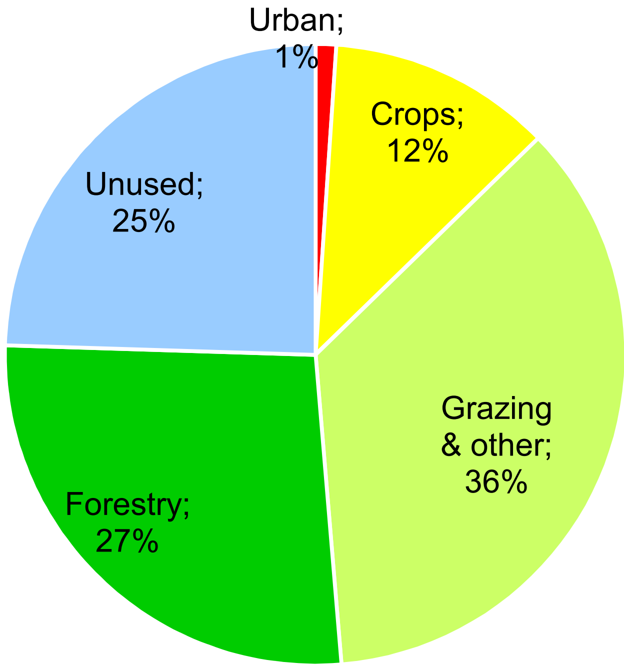
Haberl 2015, *Ecol Econ* **119**, 424-431

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.**

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

Ecological Economics 108 (2014) 8–17

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Analysis

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

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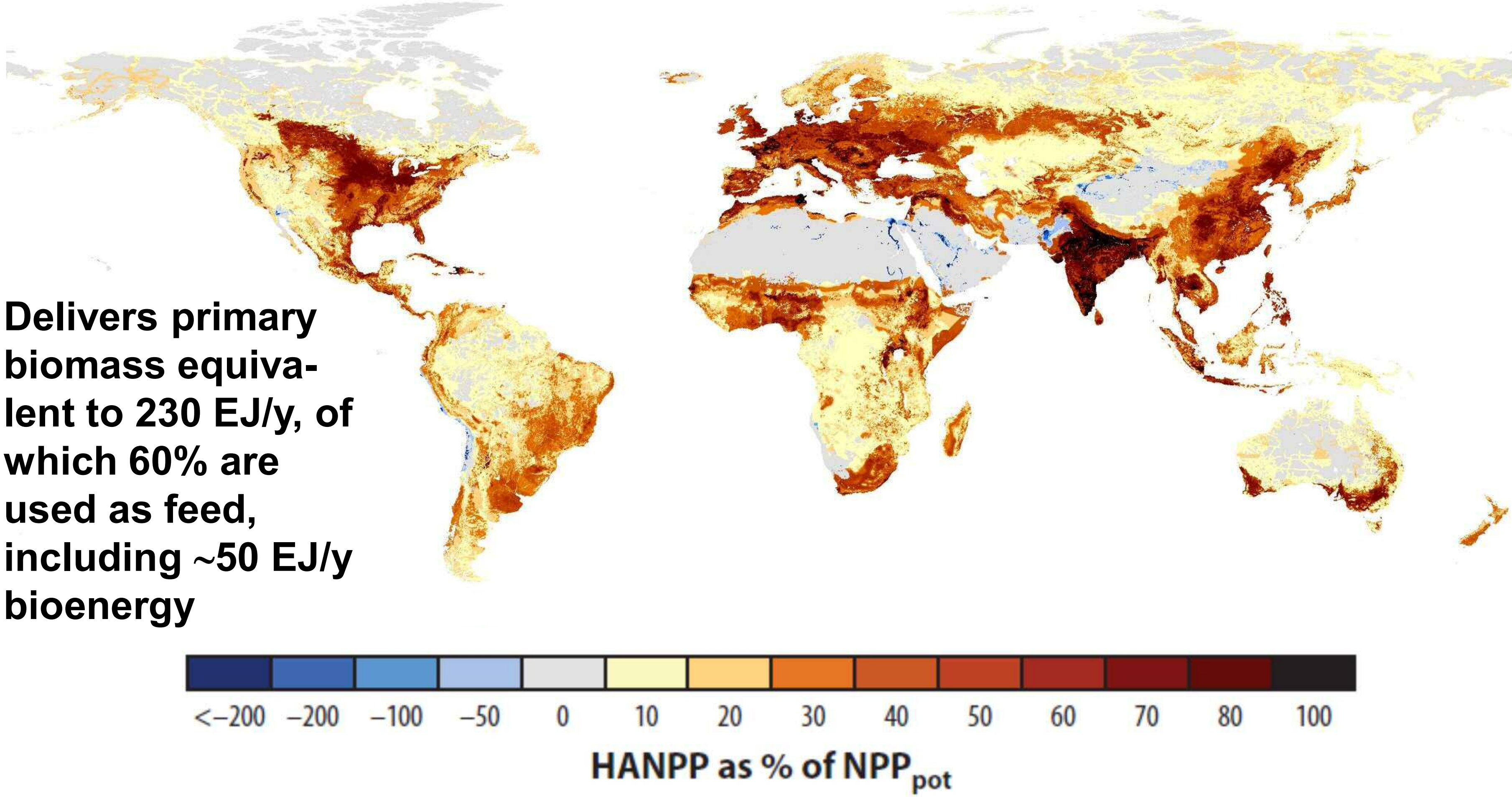
Yale School of Forestry and Environmental Studies, 195 Prospect Street, New Haven, CT 06511, USA

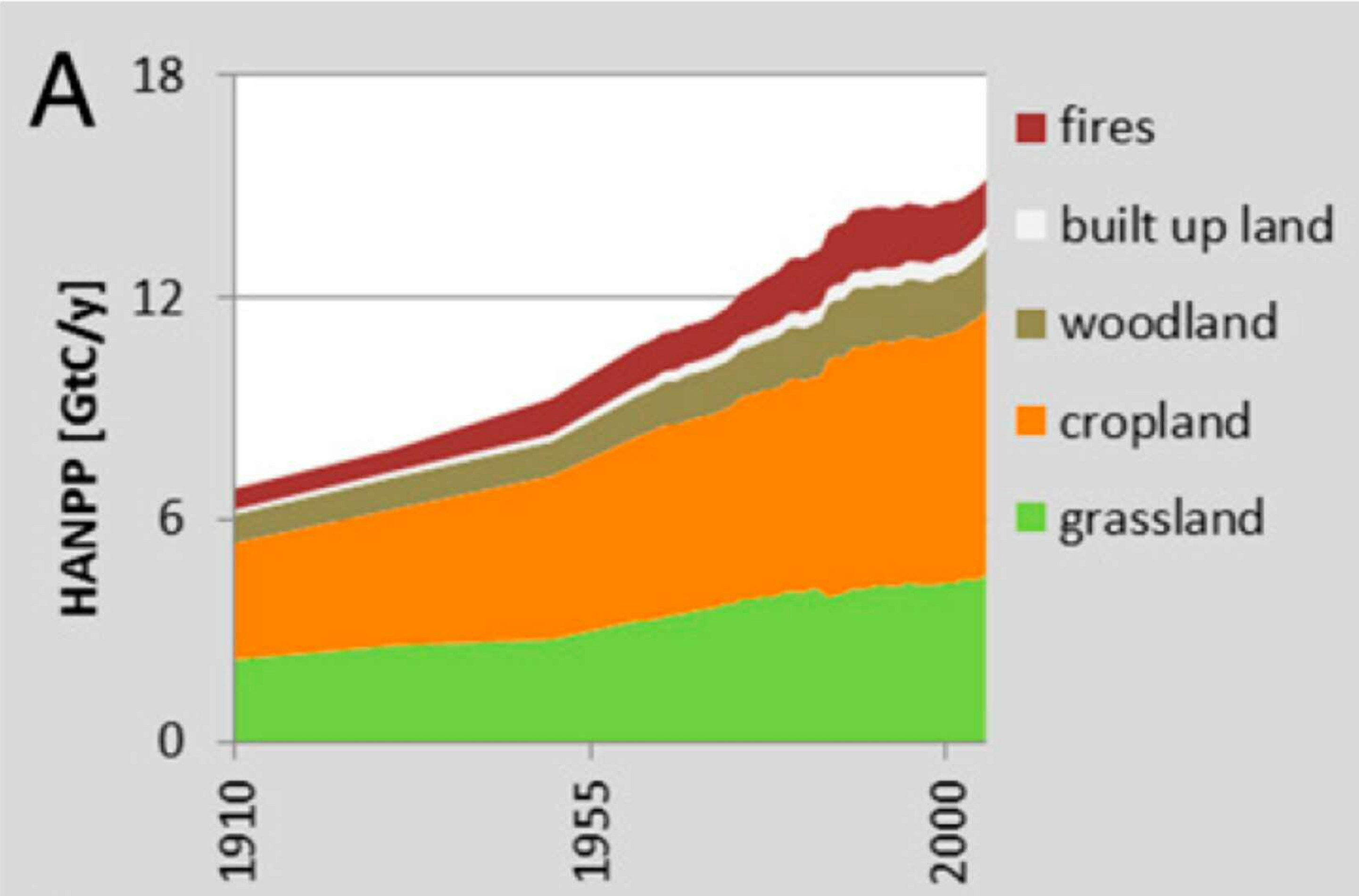
Global terrestrial human appropriation of net primary production (HANPP) in 2000

Delivers primary biomass equiva-lent to 230 EJ/y, of which 60% are used as feed, including ~50 EJ/y bioenergy



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

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

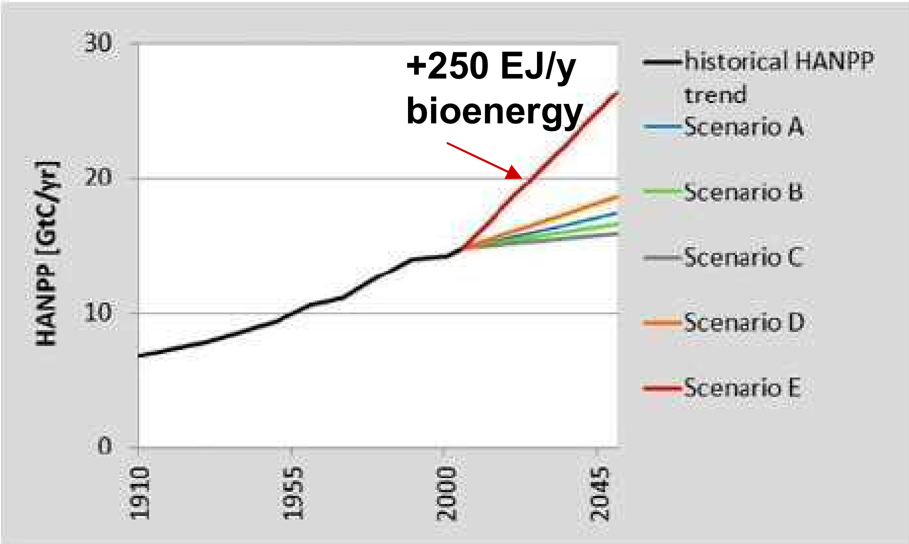


Fig. 4. Scenarios for the development on HANPP until 2050. Whereas scenarios A–C assume a continuation of past trends, scenarios D and E add additional primary biomass harvest to scenario B (see text and *SI Appendix* for details). Based on upper and lower boundary values for deployment levels of biomass 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

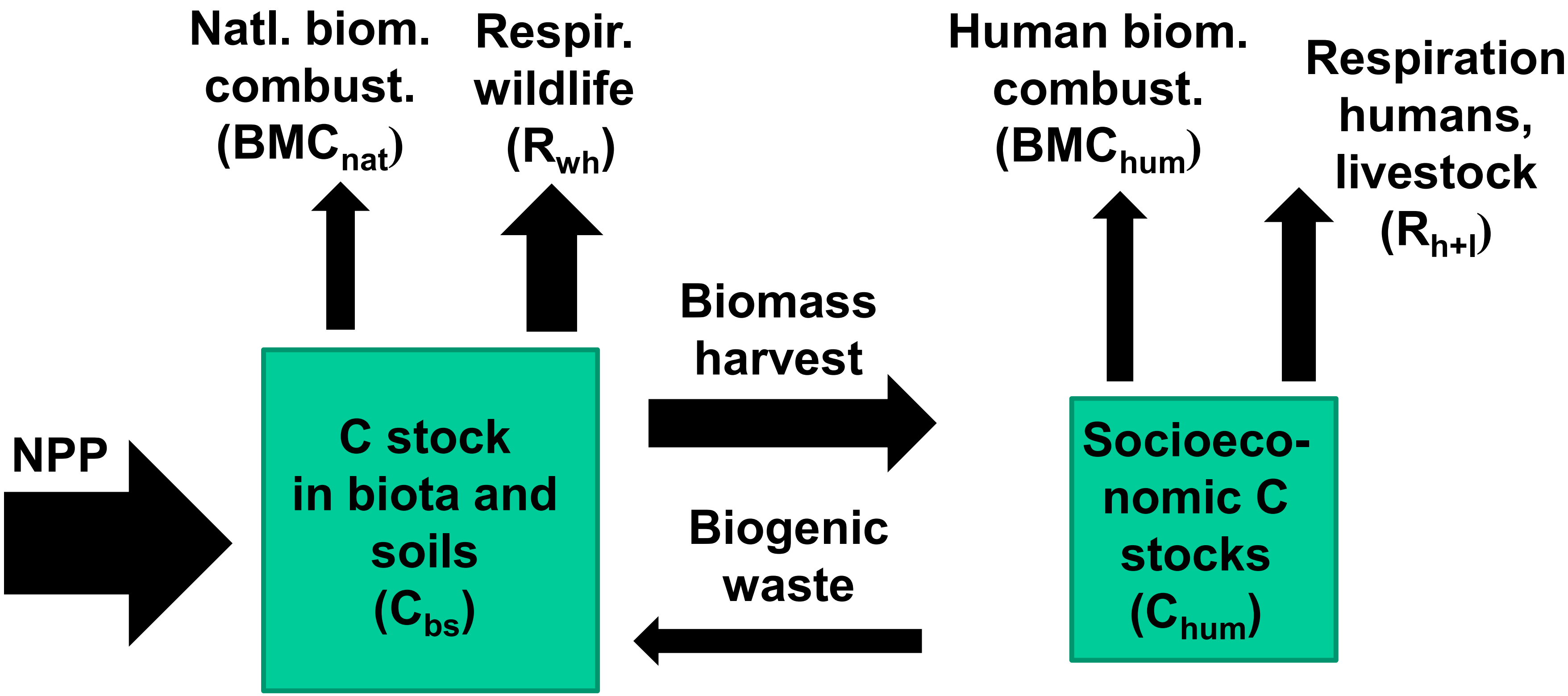
TREND scenarios allow feeding the world and moderate bioenergy deployment

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

Stocks and flows of carbon (C) natural ecosystem

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

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



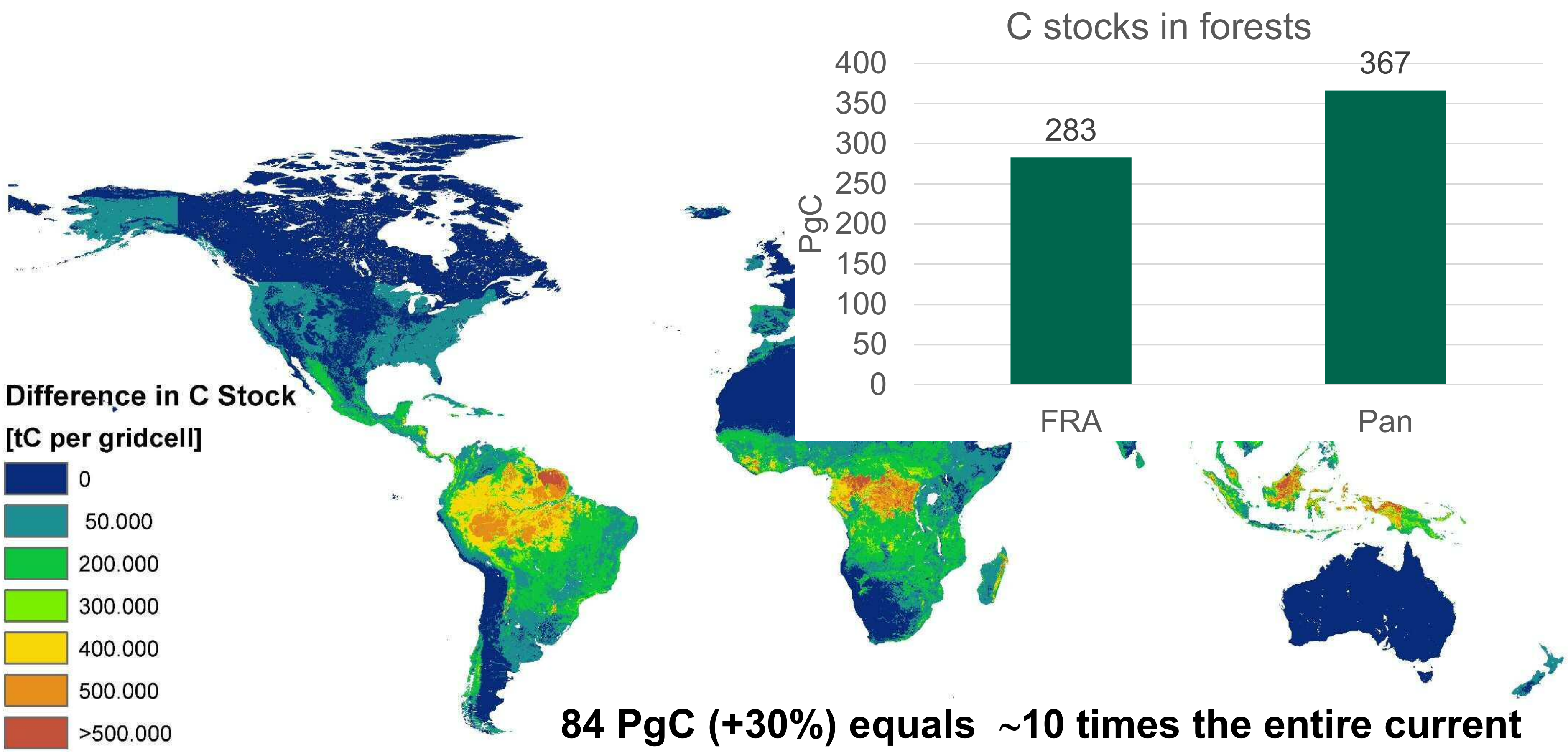
$$\text{C sink} = \Delta C_{bs} + \Delta C_{hum} = NPP - BMC_{nat} - R_{wh} - BMC_{hum} - R_{h+l}$$

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 management simultaneously influence stocks and flows of C
  – Robust methods to attribute observed changes to causes are lacking

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

Anthropogenic global C-fluxes: Severe attribution problems

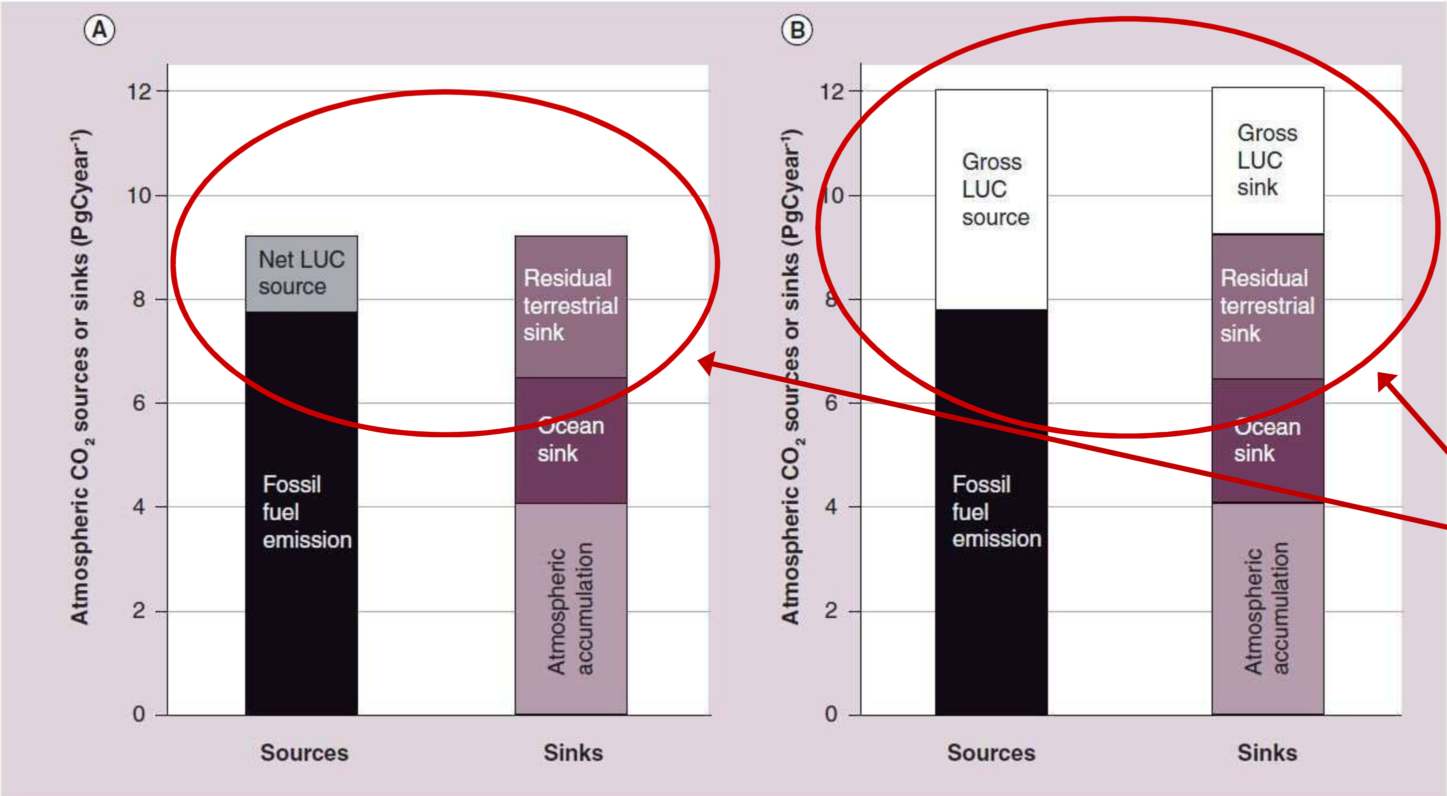
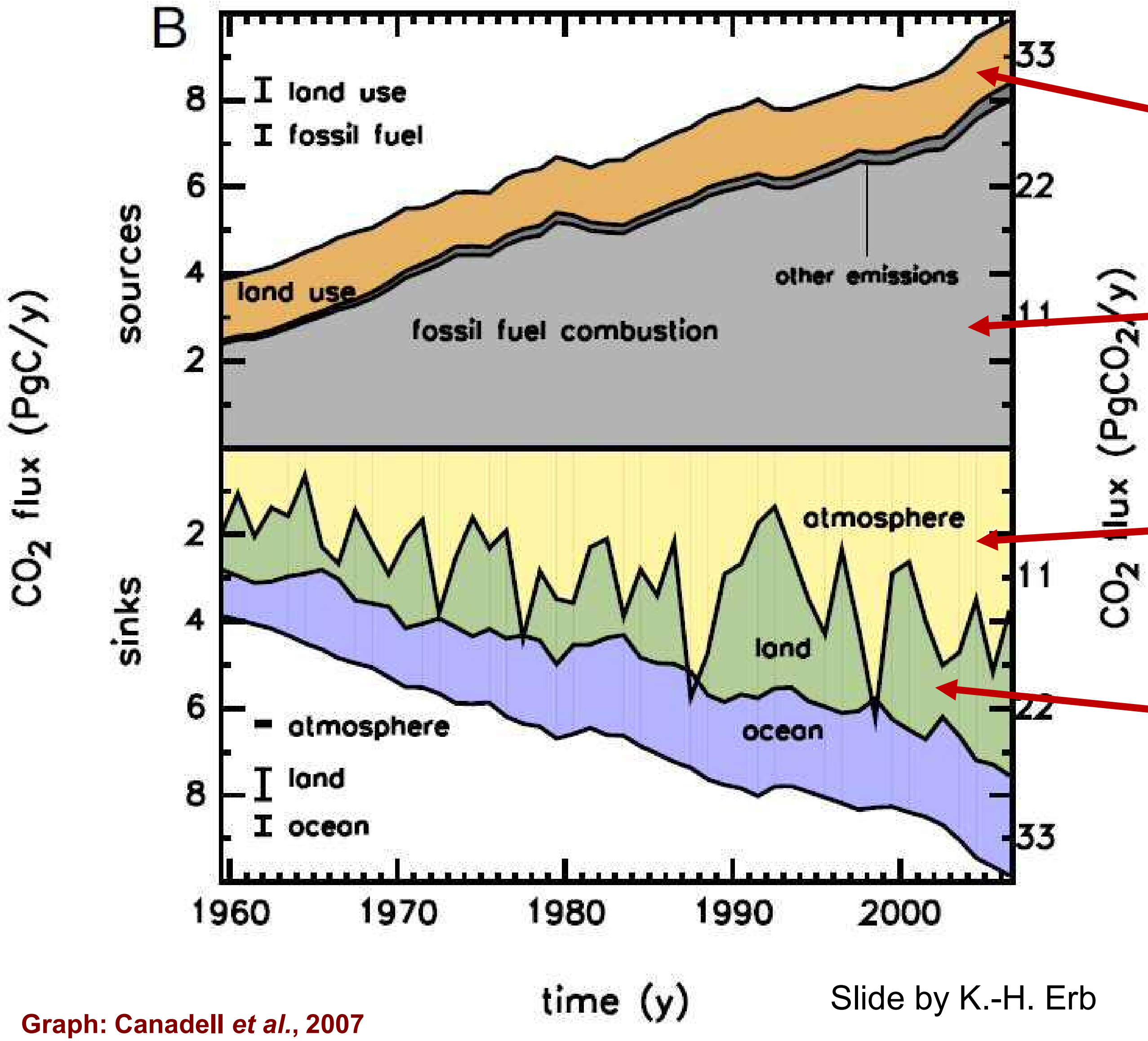


Figure 2. Anthropogenic CO_2 fluxes in the first decade of the 21st century (2000–2008 for all fluxes except gross land-use change sources and sinks, which are from 2000–2005) [3,13]. (A) The most common presentation of the global carbon cycle with land-use change presented as a net global source. (B)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

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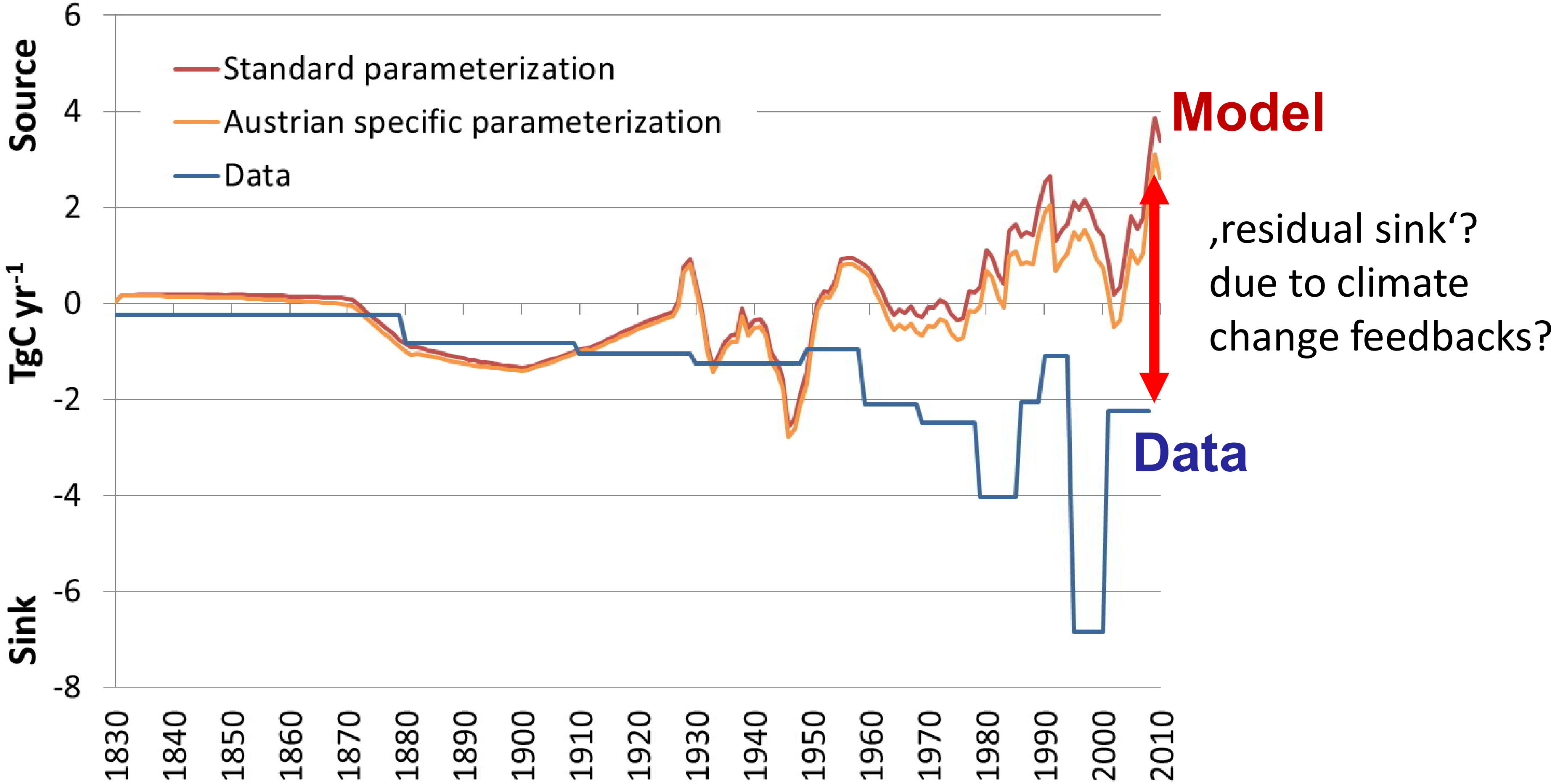
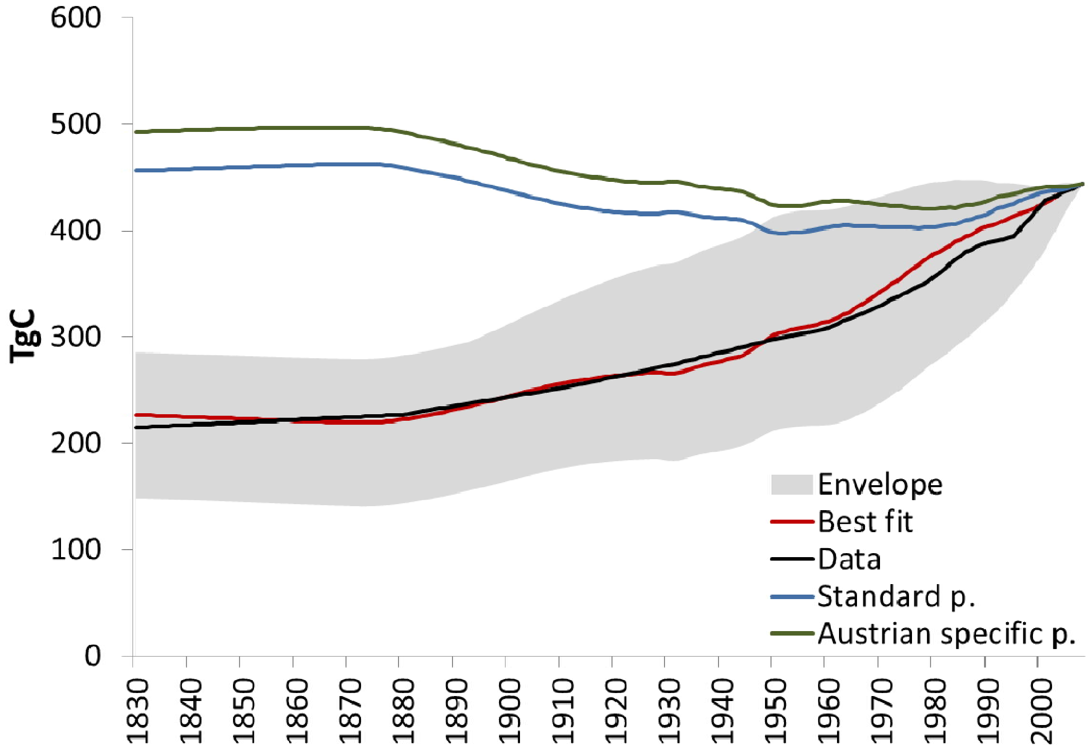
Austrian 1830-2010: Houghton's standard book-keeping model vs. data-based reconstruction



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 and climate feedback is not satisfactory

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

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Irony: a fossil-fuel powered carbon sink

Austria 1830-2000

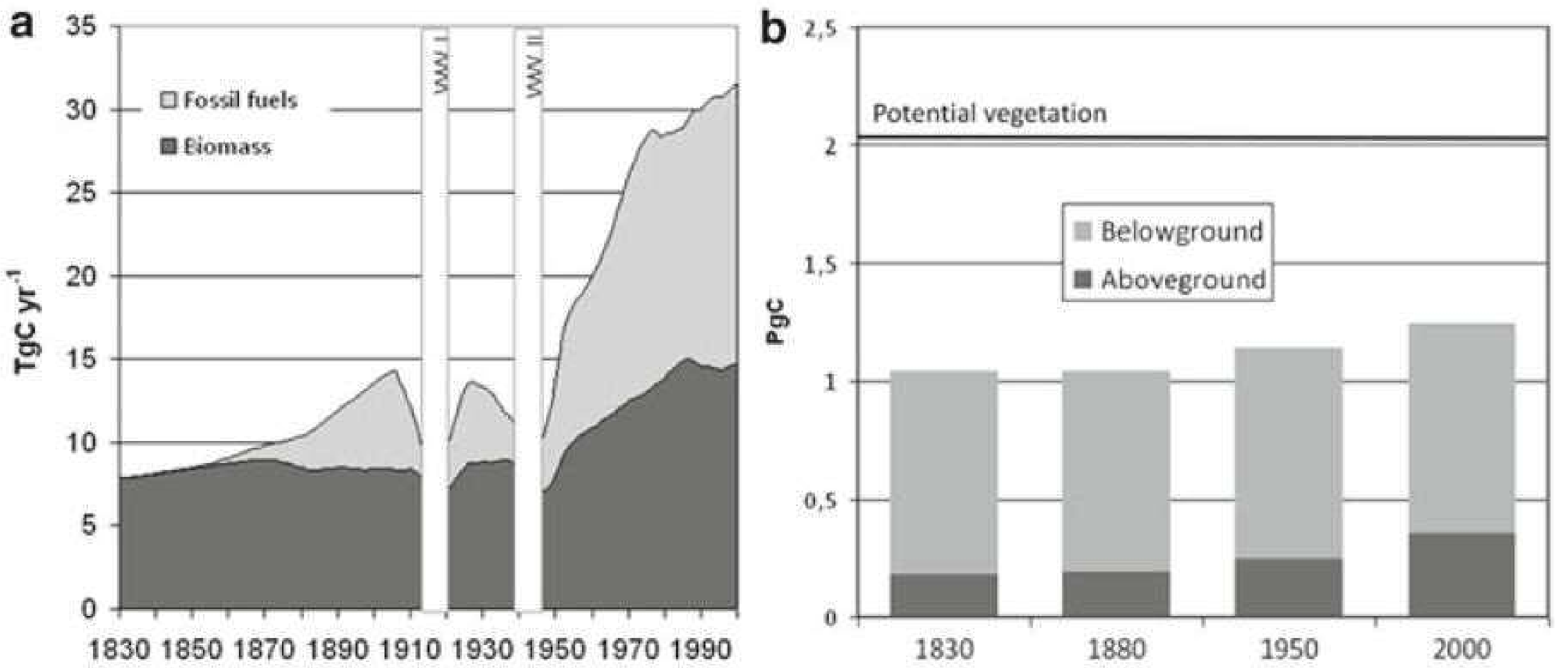
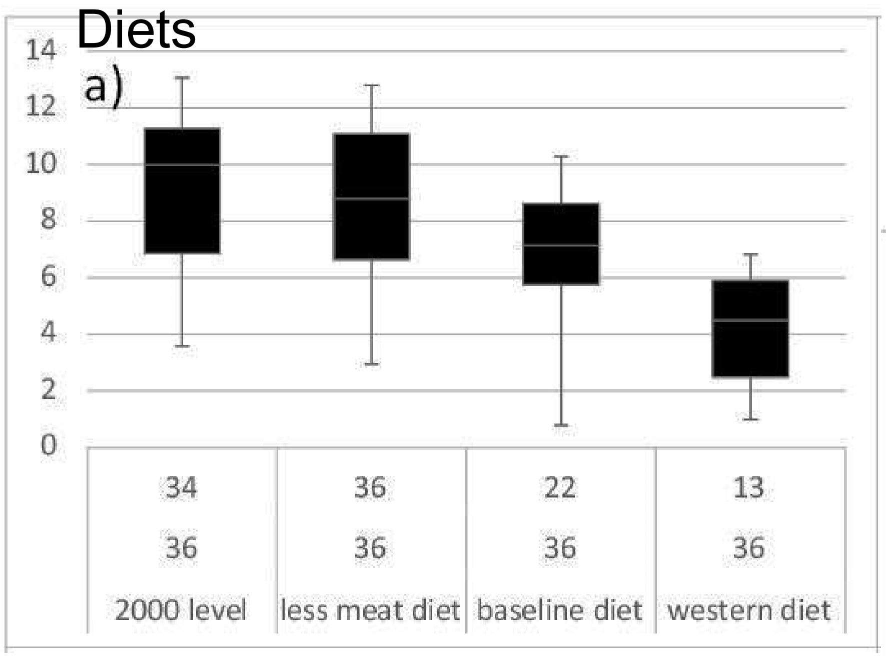


Fig. 13.4 Stocks and flows of C in Austria for the period 1830–2000. (**a**) Socioeconomic C flows per year (5-year moving average). WWI and WWII denotes the first and the second world war. (**b**) C stocks in biota and soils in petagrams of C for the years 1830, 1880, 1950 and 2000 ('above ground' are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

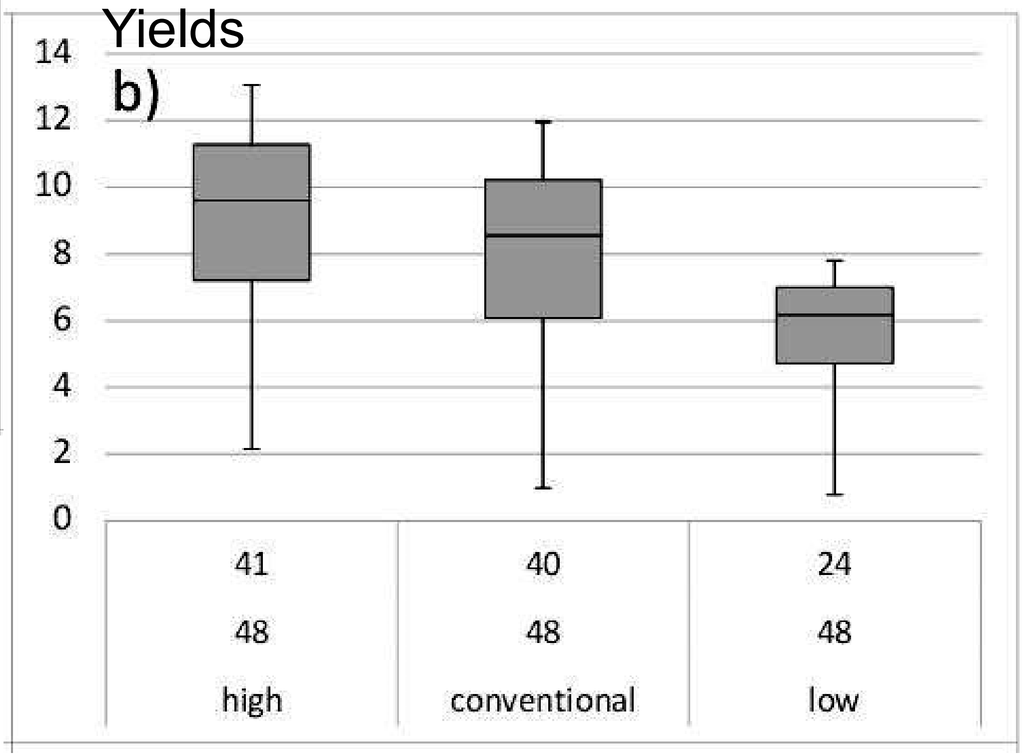
Increased productivity and rising C stocks resulted from fossil fuels inputs in agriculture (tractors, fertilizer..) and CO_2 in the atmosphere

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

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



Global adoption of western diets leaves little land for everything else



Low cropland yields can not support rich diets and leave little land for everything else

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Erb et al. 2012, *Energy Policy*, **47**, 260-269
Haberl et al., 2016, in: Haberl et al., *Social Ecology*, Springer, in press

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Conclusions

- Full GHG effects of bioenergy depend on systemic effects in the whole land system, above all agricultural technogy (land & livestock management) and consumption
- Full C cycle effects of large bioenergy deployment are uncertain and poorly understood
  → **There is a risk that, with current methods, full GHG effects of bioenergy deployment will not even be detectable *ex post,* for years or even decades**
- Timing of bioenergy deployment and energy crop yields are of critical importance for the full GHG balance of future bioenergy

Thanks for listening