International Institute for Applied Systems Analysis
IIASA www.iiasa.ac.at

science for global insight

Thoughts on Bioenergy: from the Earth system's point of view

Thomas Gasser
(gasser@iiasa.ac.at)

IEA Bioenergy workshop
Chalmers University; May 16, 2017

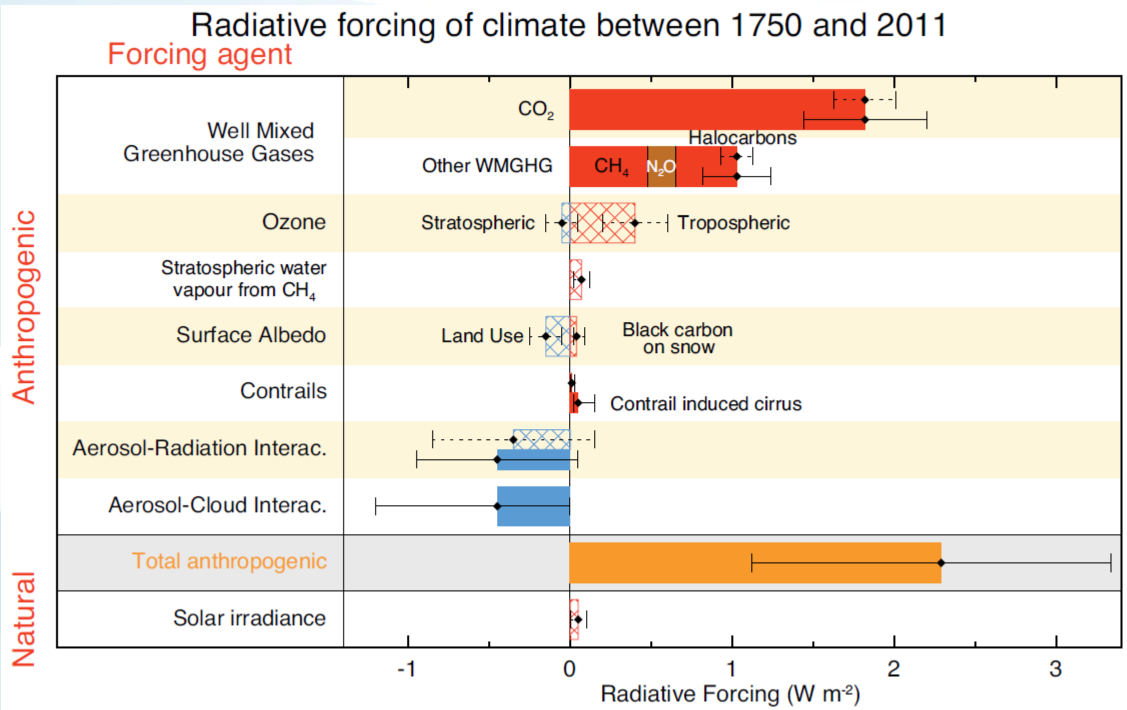
Thoughts on:

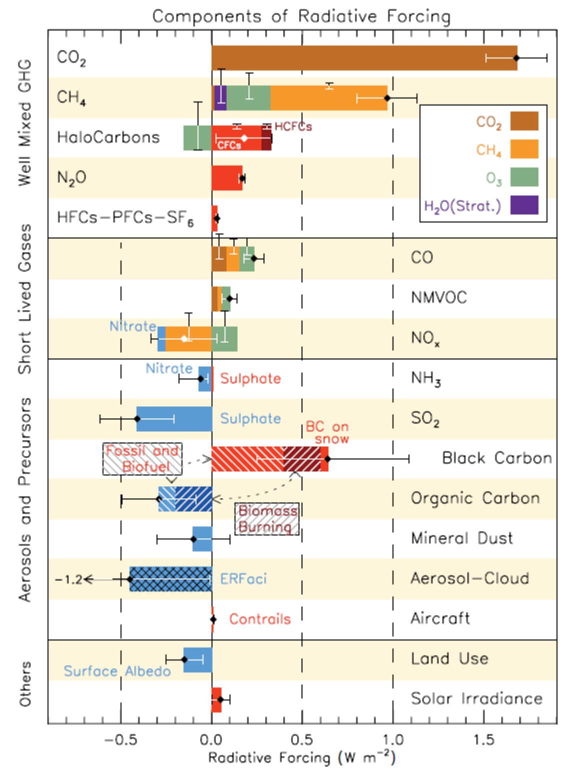
- Land-use (change) and the Earth system
- Land-use (change) and CO_2
- Emission budgets

Land-use (change) and the Earth system

Land-use (change) and the Earth system

- Typical IPCC attribution of anthropogenic RF:





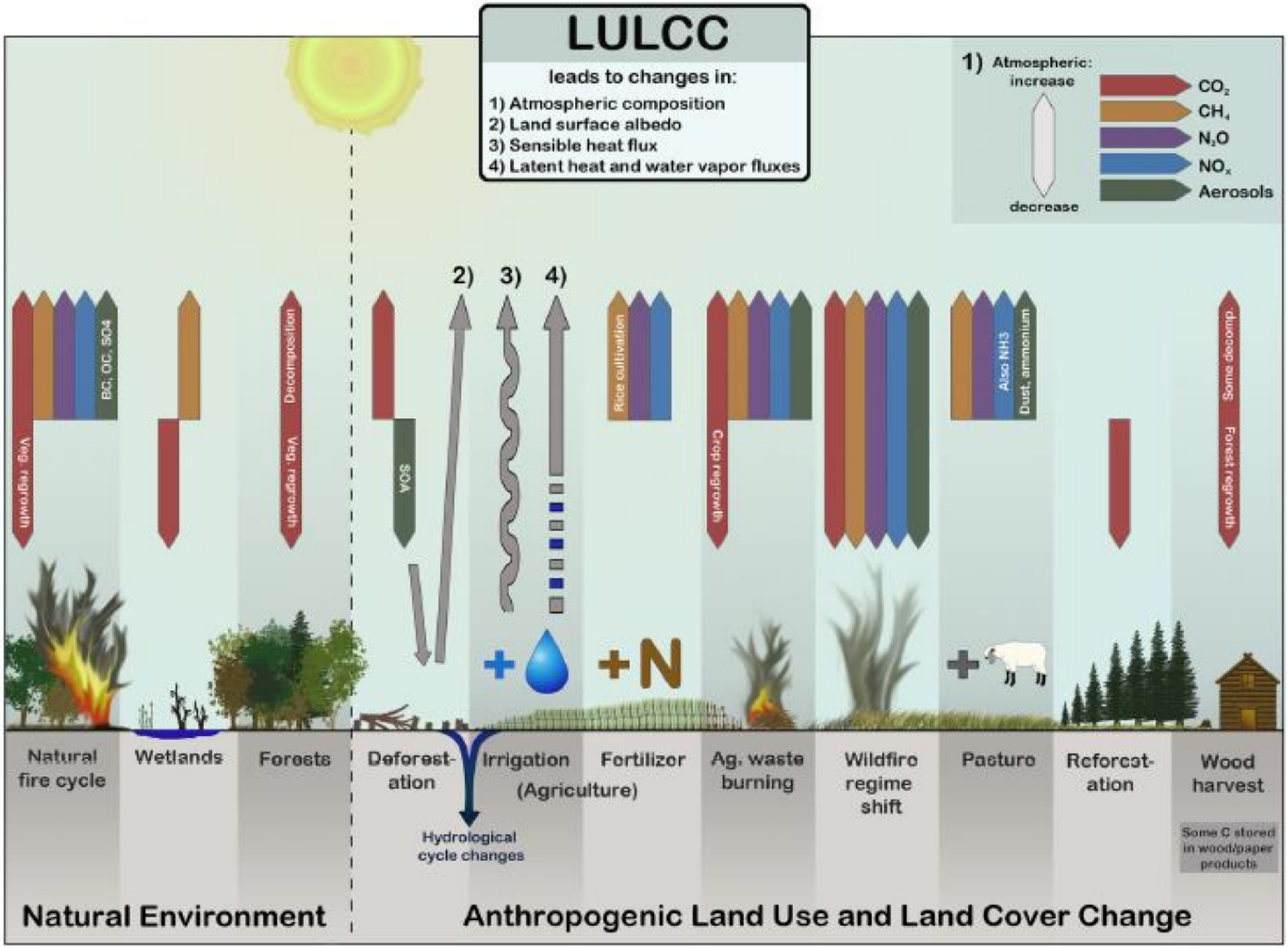
- Simple question:

Which of these are impacted by Land-Use and Land-Cover Change?

IIASA

[IPCC AR5, WG1 Ch.8]

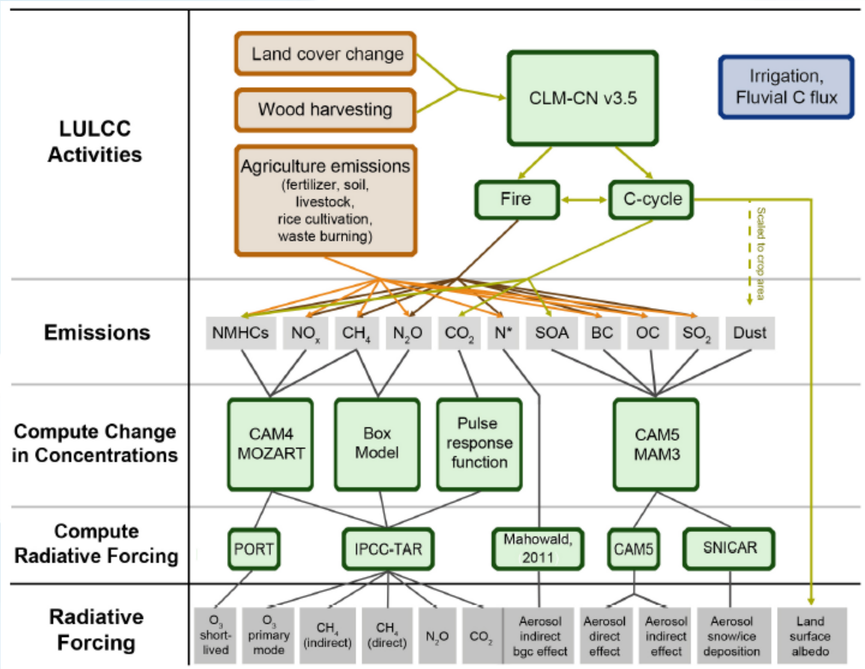
Land-use (change) and the Earth system



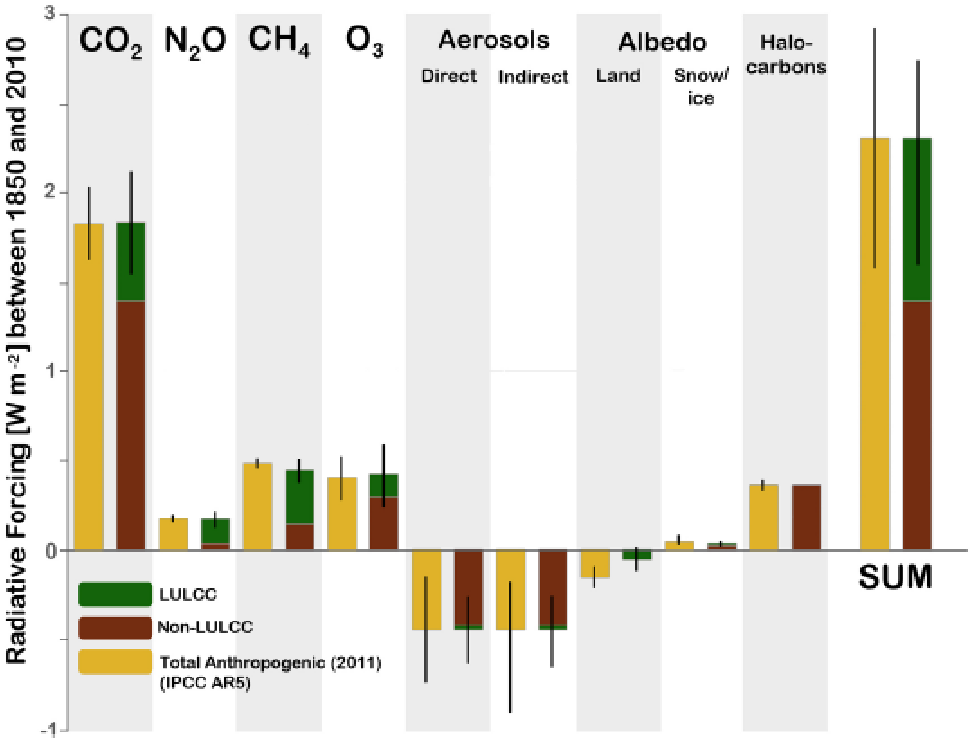
[Ward et al., 2014; *Potential climate forcing of land use and land cover change*]

Land-use (change) and the Earth system

➢ Some modeling…



➢ … to attribute RF to LULCC:



Two questions:

- How much of this is bioenergy? (system boundaries…)
- What about the future?

[Ward et al., 2014; *Potential climate forcing of land use and land cover change*]

Land-use (change) and CO_2

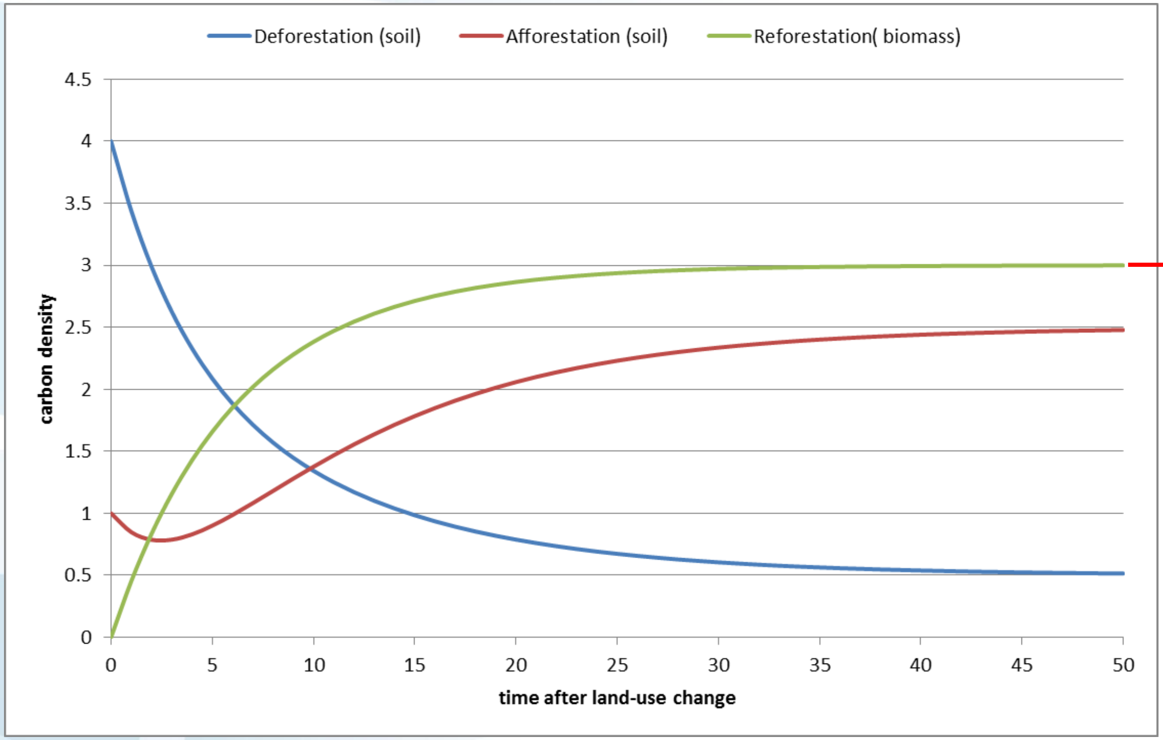
Land-use (change) and CO_2

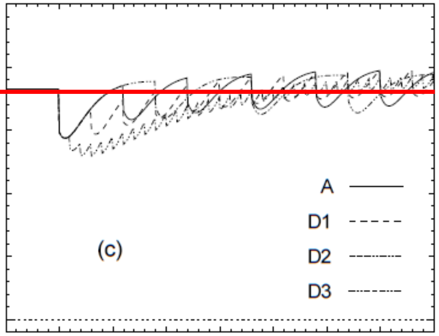
- Type 1 effects, induced by land-use change:
  - 1a: fluxes caused by transitioning from one steady-state to another
  - 1b: change in ‘natural’ fluxes caused by the difference between the two steady-states

- Type 2 effects, induced by land-use:
  - anthropogenic fluxes caused by continuous usage of the land (is the steady-state really steady?)

Land-use (change) and CO_2

- 1a: transitioning from one steady-state to another





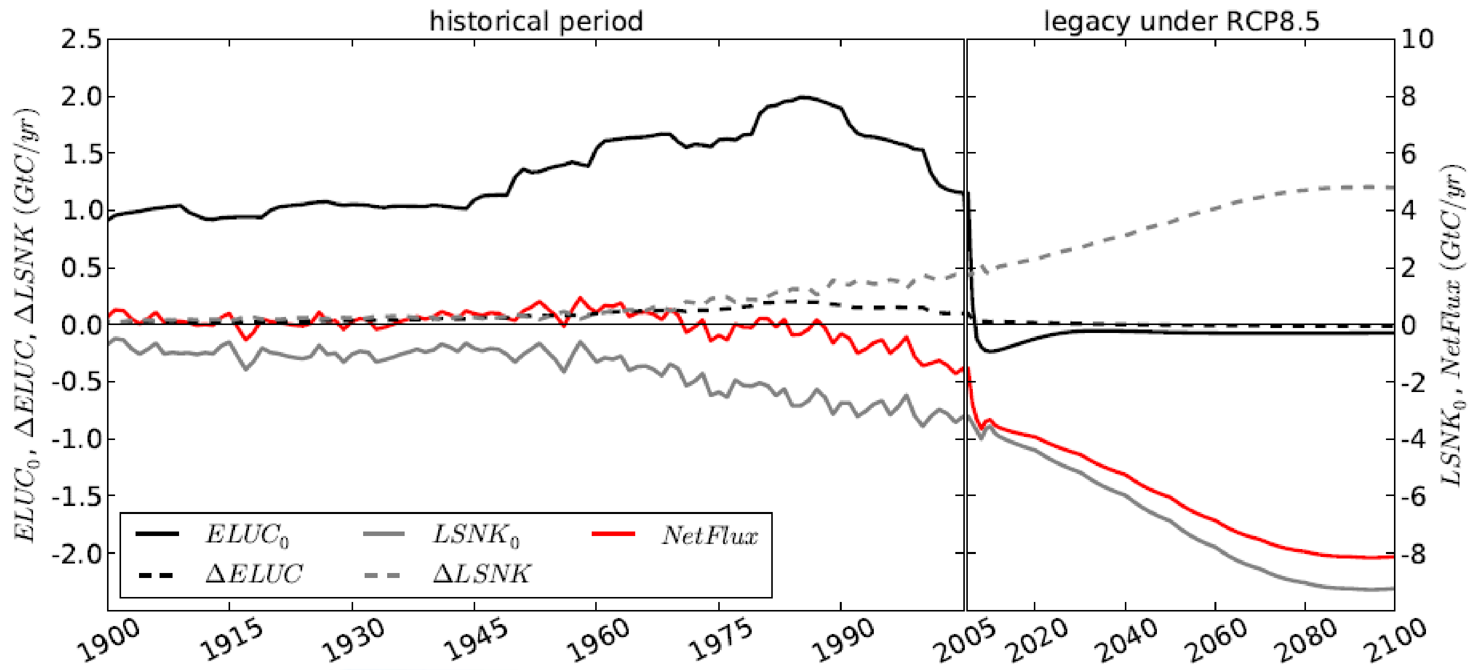
- We know the two steady-states, therefore:
- the total emission (after a long period of time) is the difference;
- yearly emissions are the derivative of this curve.

- This is the principle of book-keeping models.

Land-use (change) and CO_2

- 1b: difference between two steady-states:
- in physical properties (albedo, surface roughness)
- in biogeochemical fluxes (CH_4 in wetlands, SOAs, CO_2 sink)

- For the CO_2 sink: loss of potential sink = amplification effect
- scenario dependent
- not accounted for in book-keeping models

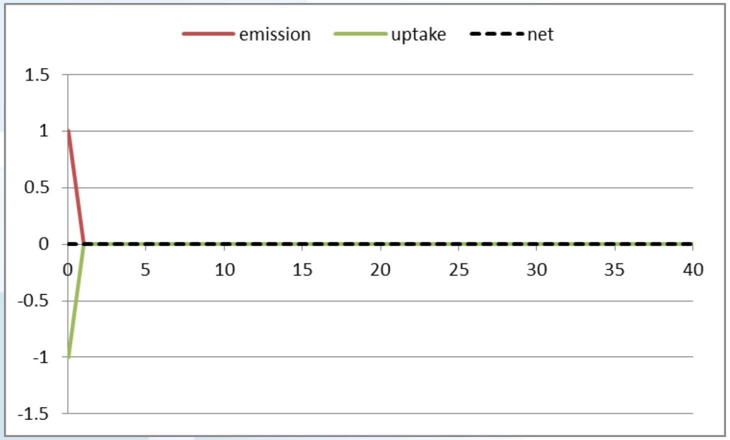


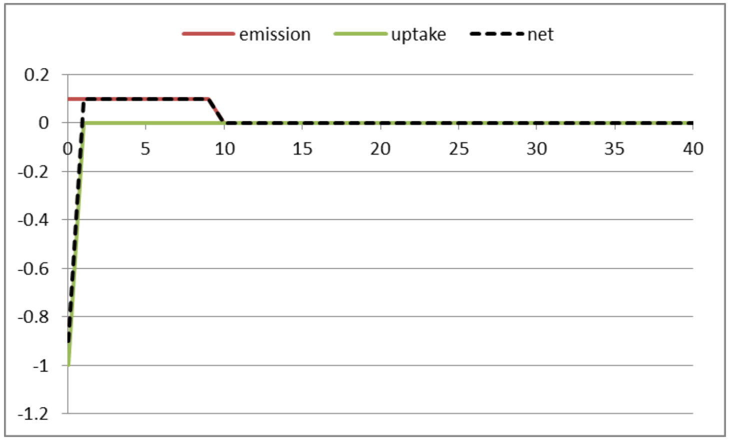
[Gasser & Ciais, 2013; *A theoretical framework for the net land-to-atmosphere CO2 flux (…)*]

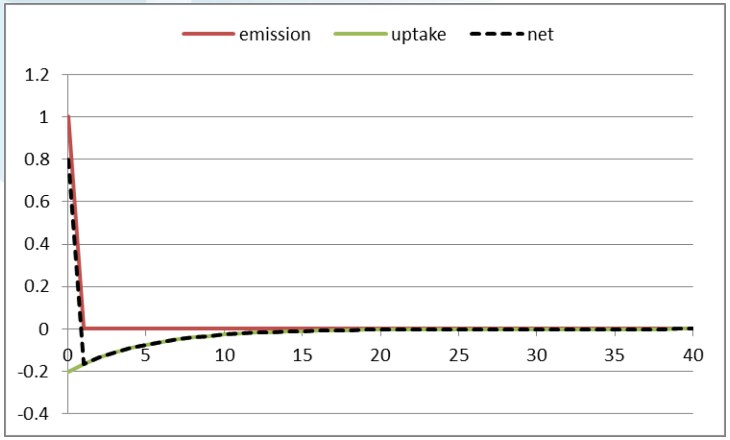
Land-use (change) and CO2

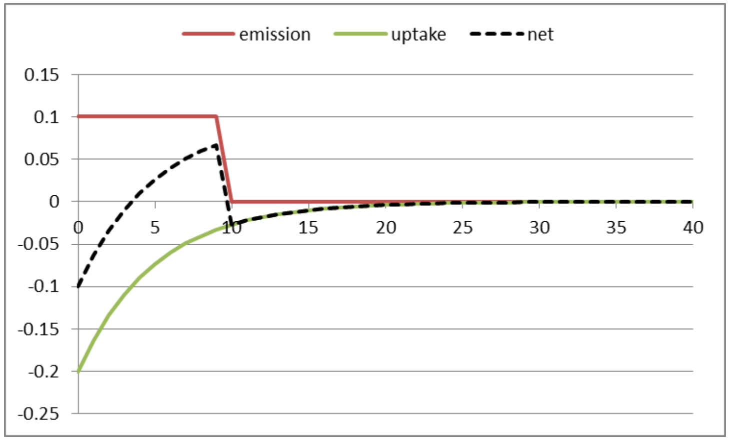
- 2: what happens during this steady-state:
- net carbon change (after a long period of time) is zero;
- but the cycle matters.

- Some examples:



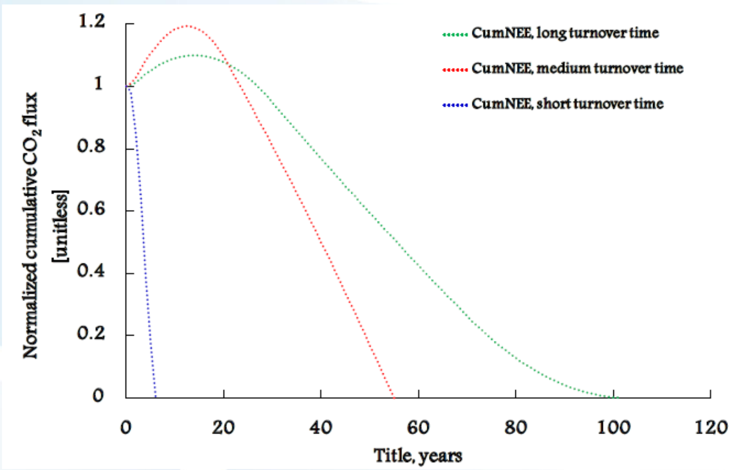


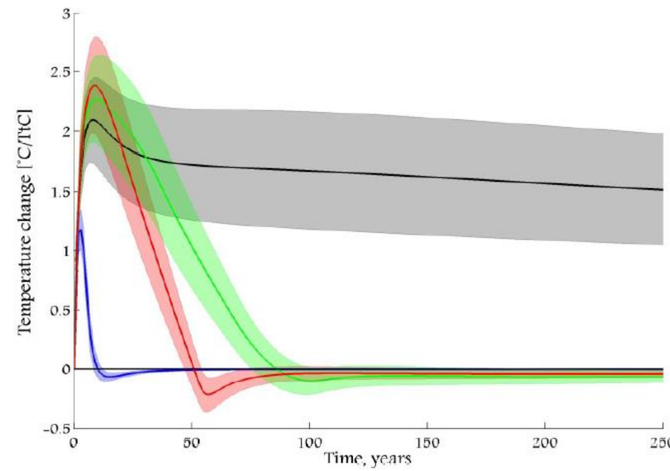




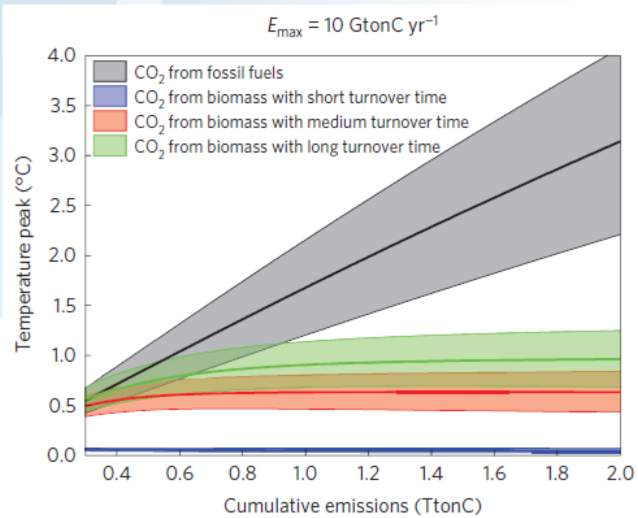
Land-use (change) and CO2

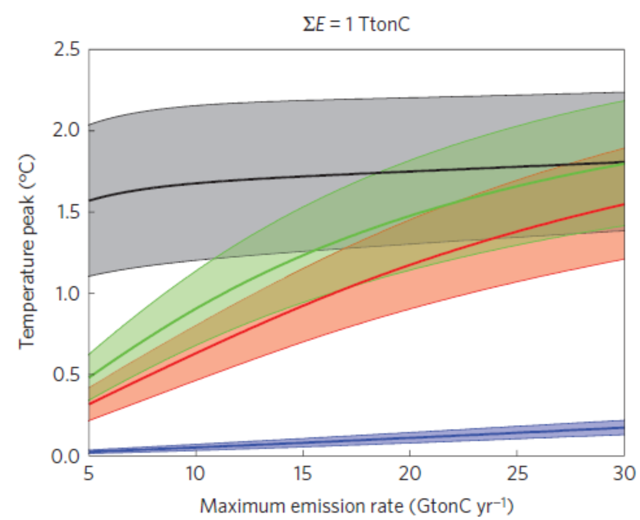
- ➢ Type 2 effect for bioenergy is determined by:
- turnover time (regrowth characteristic time)





- emission level (land-use intensity)





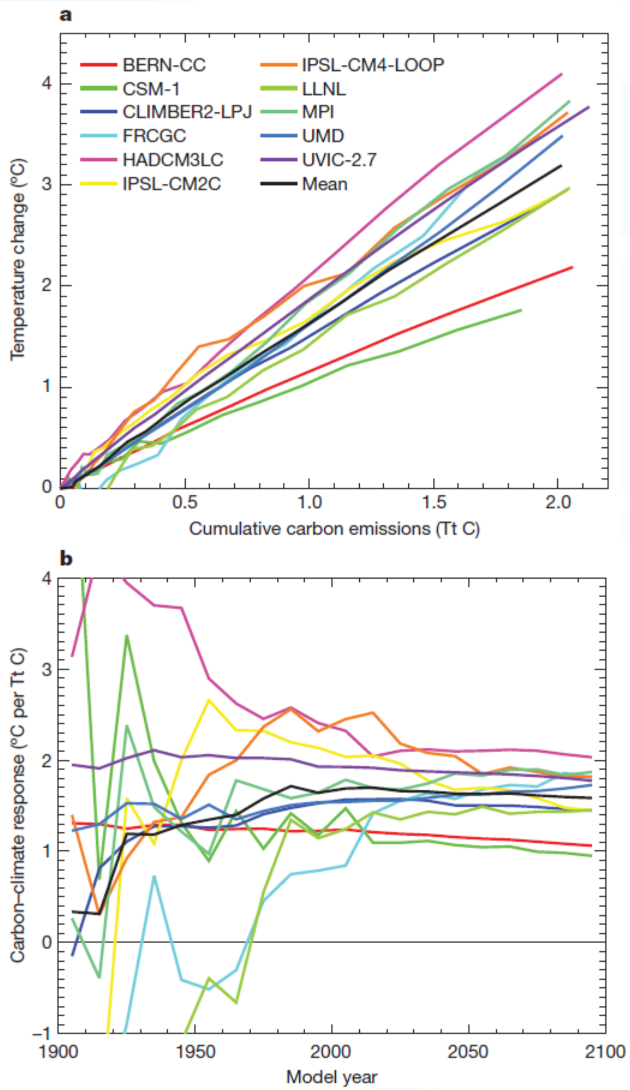
IIASA

[Cherubini et al., 2014; *Linearity between temperature peak and bioenergy CO2 emission rates*]

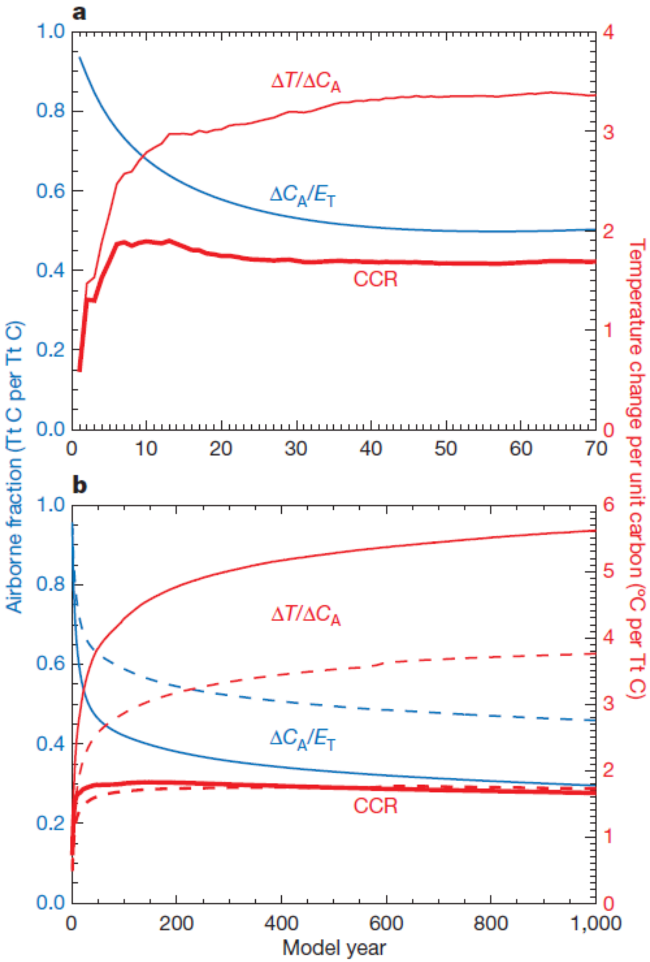
Emission budgets

Emission budgets

➢ Heuristic relationship in ESMs:



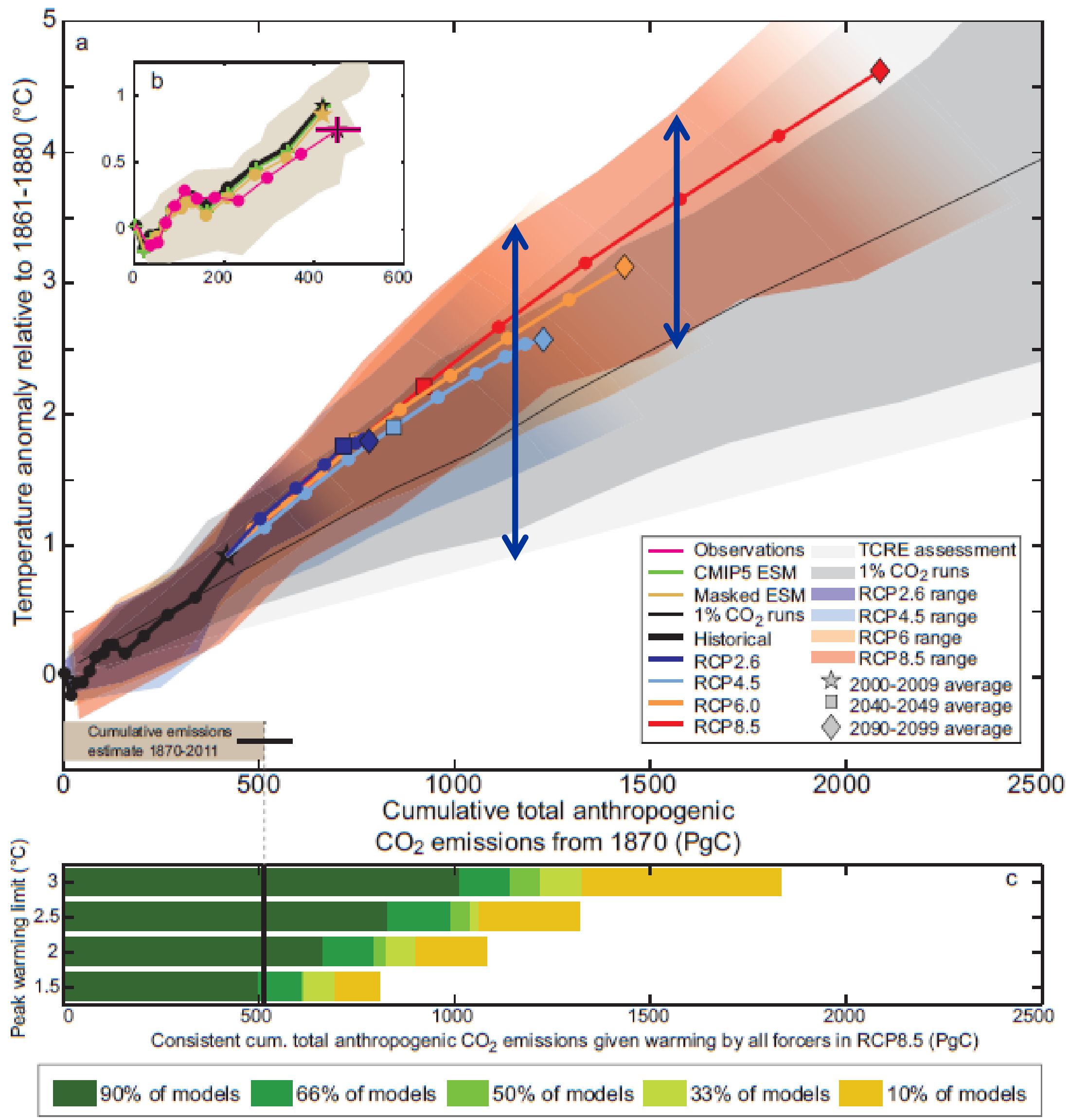
➢ Caused by compensation of two saturating effects:



[Matthews et al., 2009; *The proportionality of global warming to cumulative carbon emissions*]

Emission budgets

➢ Extremely policy-relevant…



➢… but highly uncertain!

➢ CCR = TCRE = 0.8-2.5 °C EgC^{-1}

➢ 1-σ constrained by observations…

[IPCC AR5, WG1 TS]

Emission budgets

➤ Some physical ground, at the multi-centennial scale:

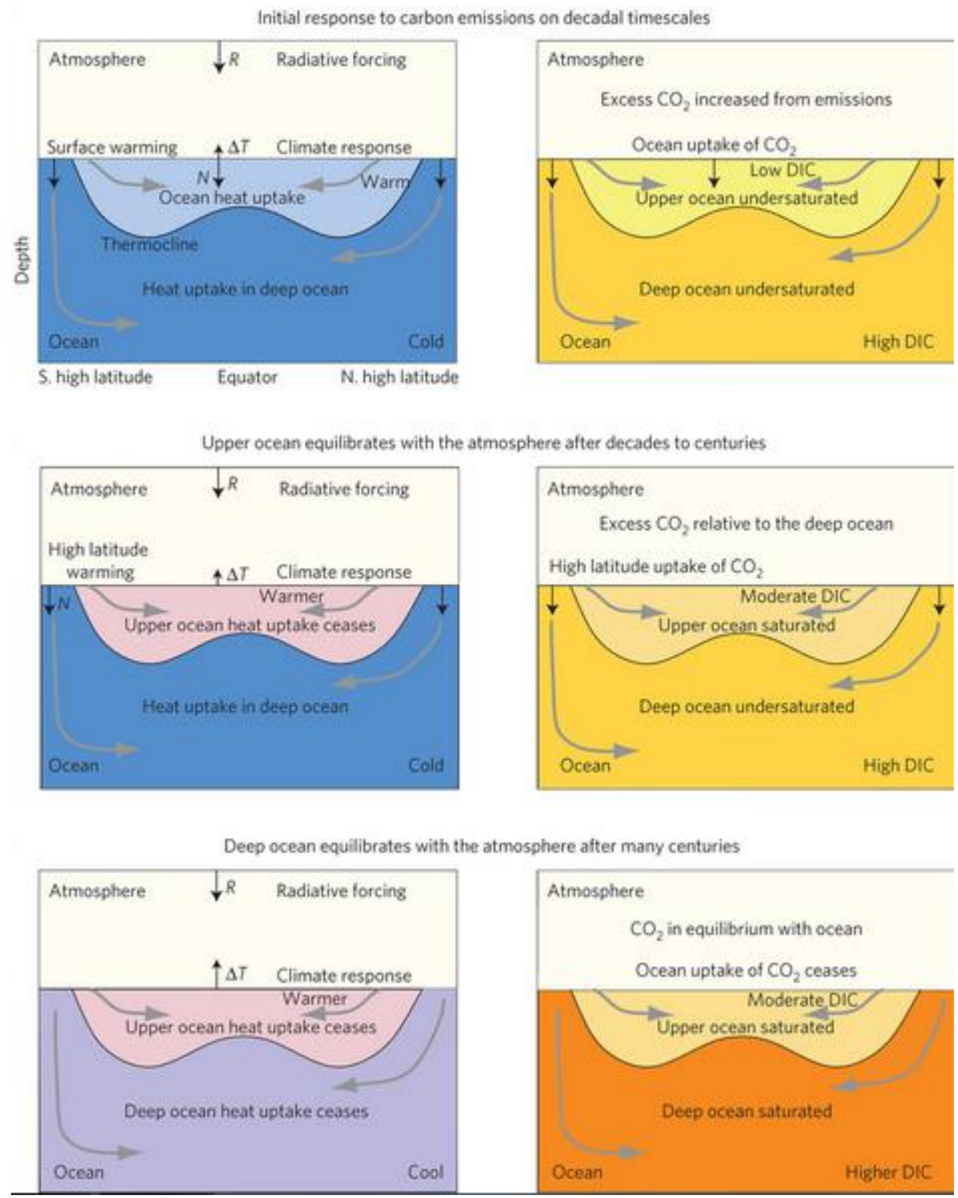
- saturating absorption bands of atmospheric CO2

  $RF \propto \log(CO2)$

- saturating CO2 absorption by the upper ocean

  $CO2 \propto \exp(\Sigma E)$

➤ And, for shorter time scales, approximatively same rate of carbon uptake and heat uptake by the ocean



[Goodwin et al., 2015; *Sensitivity of climate to cumulative carbon emissions due to compensation (…)*]

Emission budgets

- At a shorter time scale, accounting for dynamics, land carbon, non-CO2:

$$\Delta T(t) = \lambda\left(\frac{\alpha}{I_B}(\Sigma E(t) + C_{usat}(t) - C_{land}(t)) + R_X(t) - \varepsilon N(t)\right)$$

cumulative emissions

C-cycle feedbacks

non-CO2

planet energy imbalance

TCRE

- Steady-state: $\Delta T = \frac{\lambda\alpha}{I_B}(\Sigma E - C_{fdbk}(\Delta T)) + R_X$

fossil CO2 + land-use change CO2
+ bioenergy CO2 (non-renewable part)

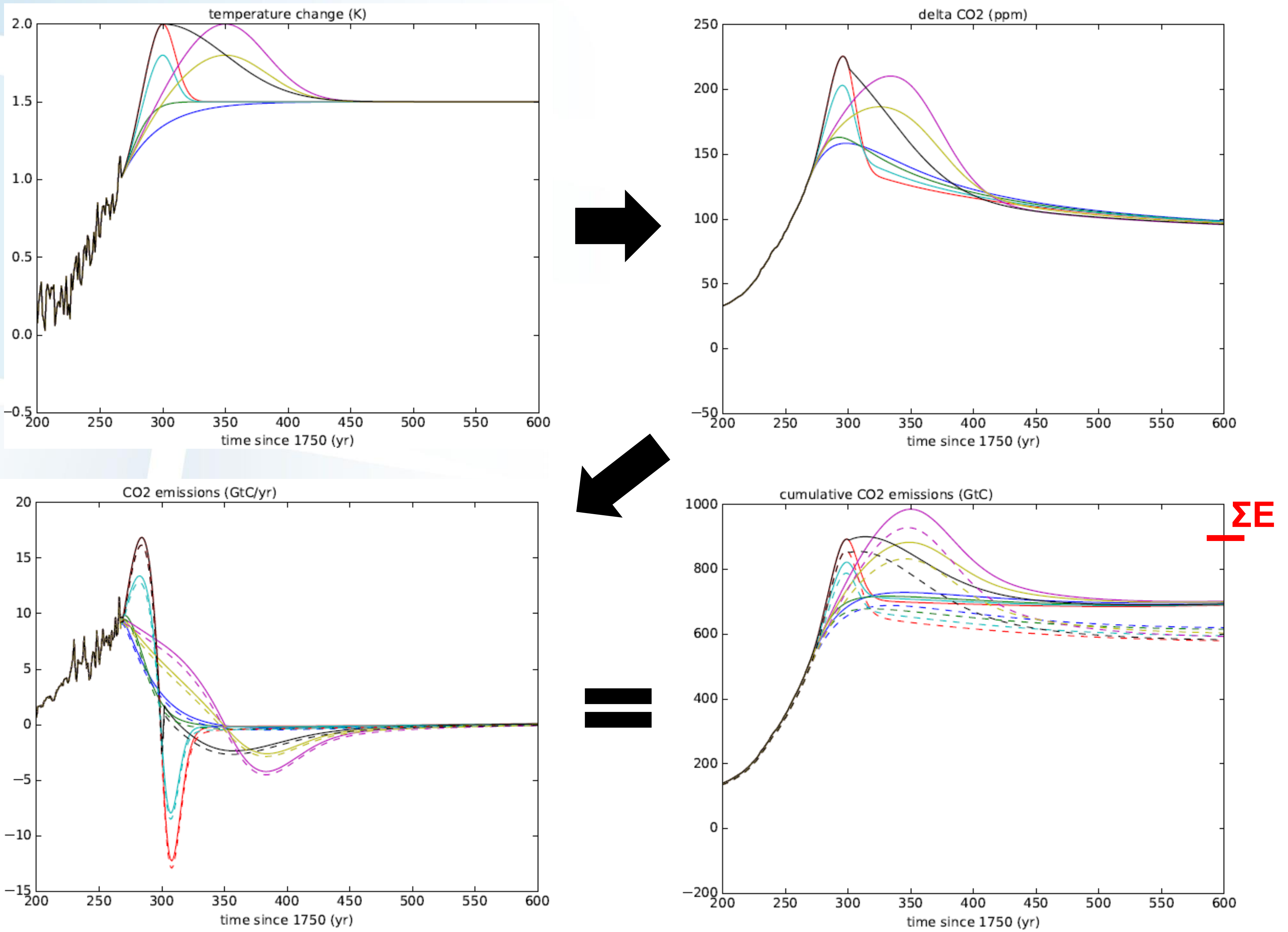
non-CO2 (shorted-lived + long-lived)
+ bioenergy CO2 (renewable part)

- Why dynamic matters? What about non-linearities?

IIASA

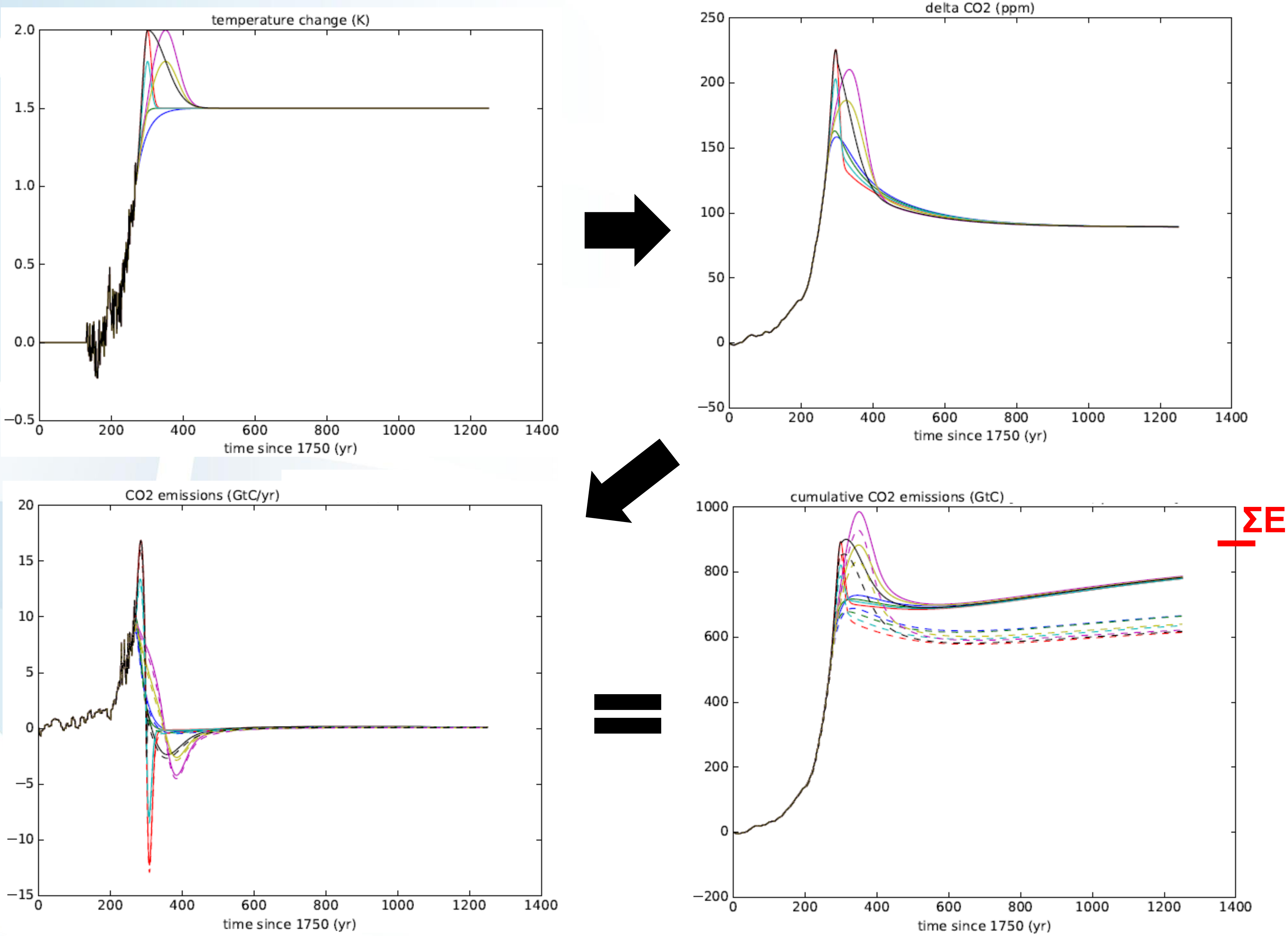
[Williams et al., 2016; *A framework to understand the transient climate response to emissions*]

Emission budgets



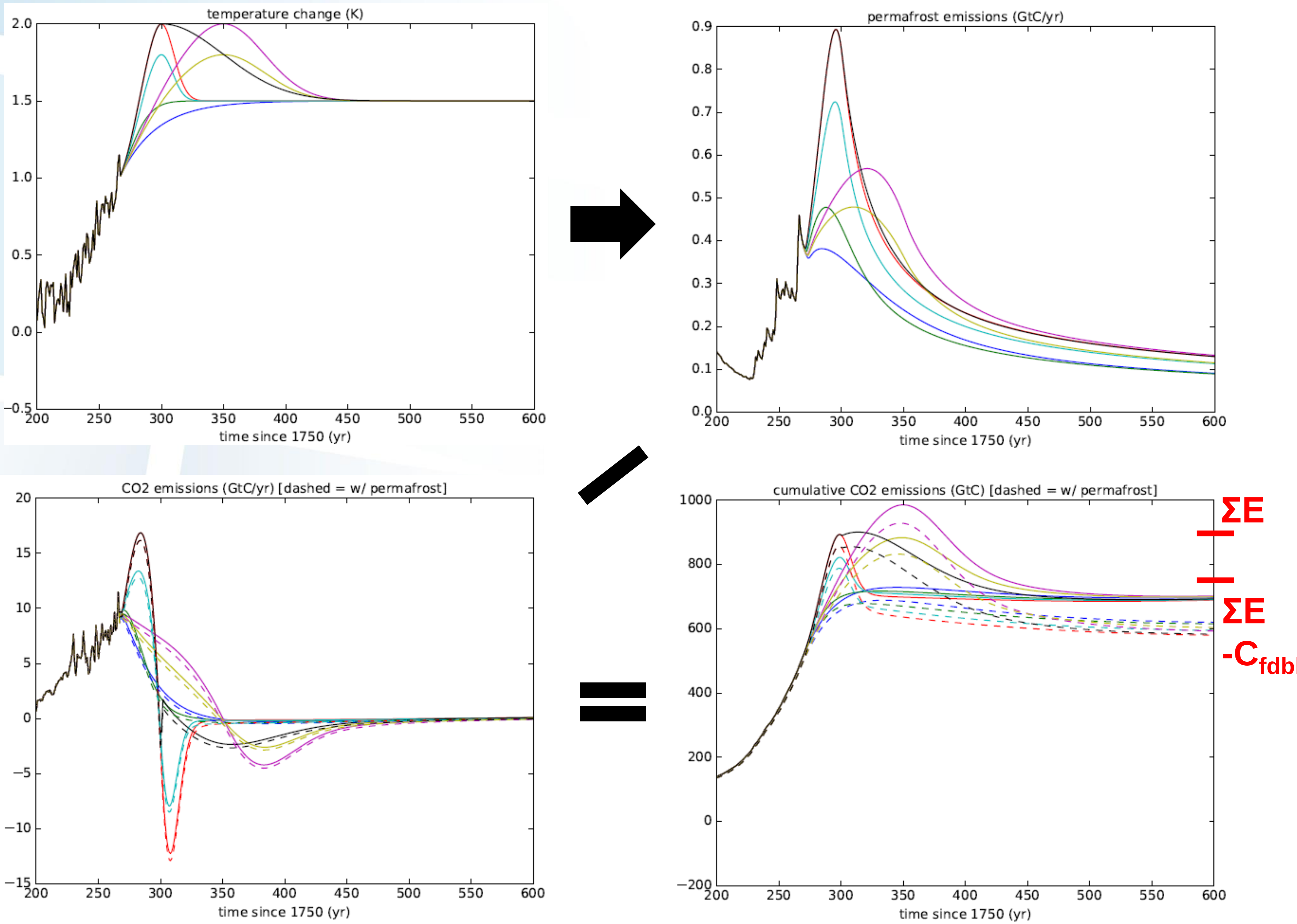
[Gasser et al., in prep.]

Emission budgets



[Gasser et al., in prep.]

Emission budgets



[Gasser et al., in prep.]

Concluding remarks:

- Non-CO2 are part of the debate! Especially non-radiative and local biophysical effects…

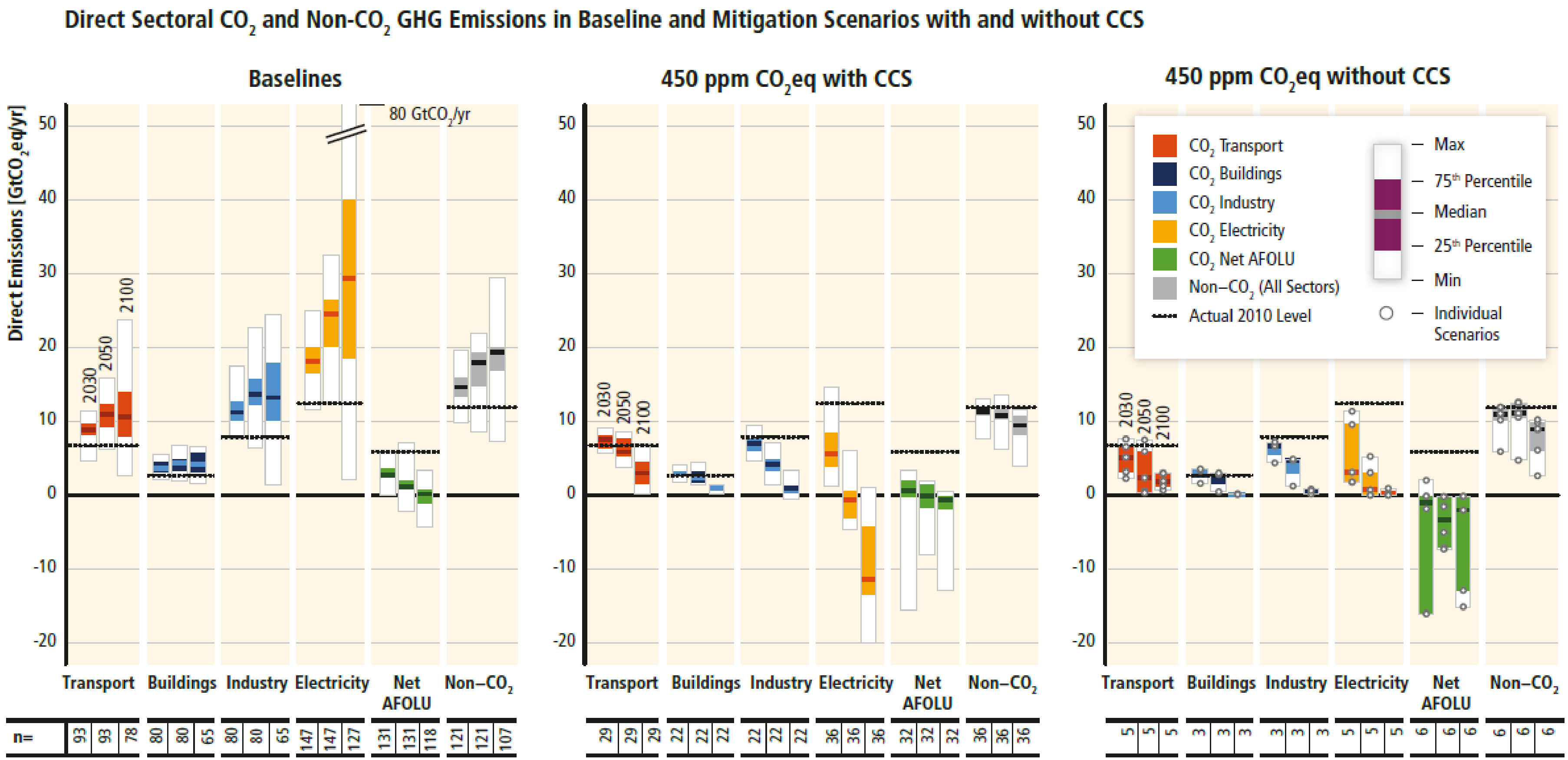
- Don't forget the land-use change needed to establish bioenergy crops/plantations.

- Timing of oxidation of harvested (wood) products vs. regrowth is key to 'steady-state' climate effect. Some part of bioenergy could be 'non-renewable'.

- Permafrost: current knowledge points to a relatively slow process, that will release mostly CO2. Nothing apocalyptic but it does reduce the budget!

More…

IPCC low-carbon scenarios

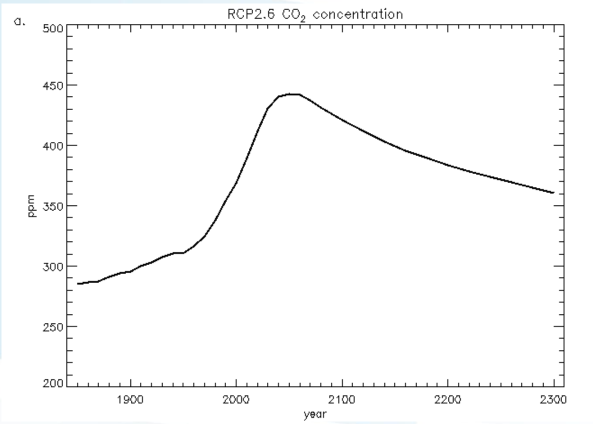


➢ (Caption of figure SPM.7) “Note that many models cannot reach about 450 ppm CO2eq concentration by 2100 in the absence of CCS, resulting in a low number of scenarios for the right panel”.

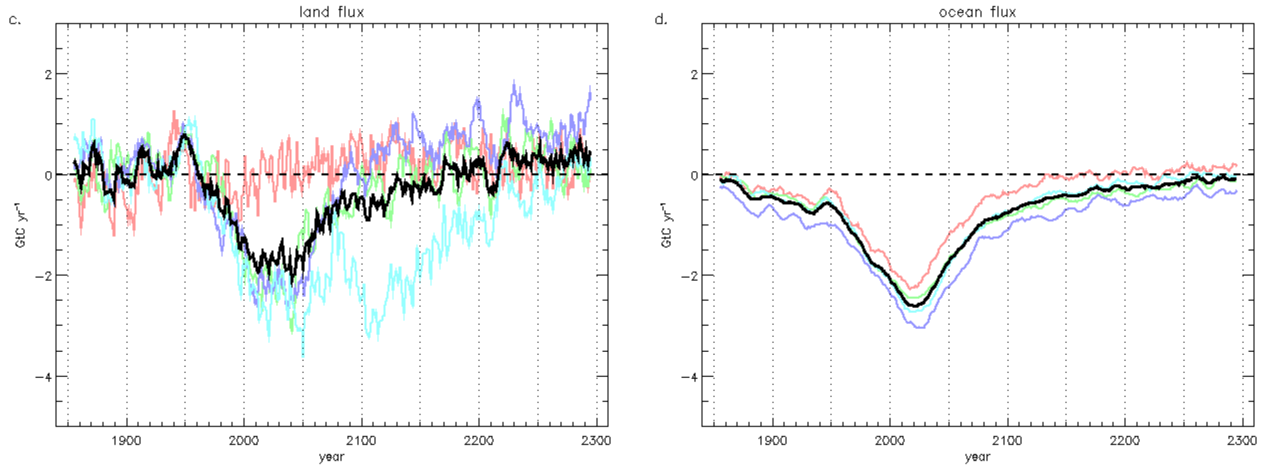
[IPCC AR5, WG3 SPM]

The carbon-cycle response in RCP2.6

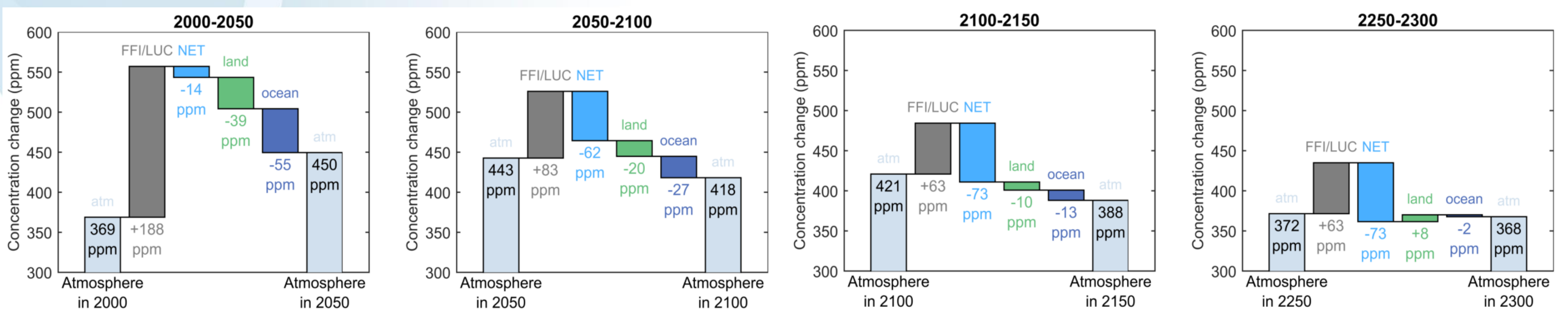
- Prescribed CO2:



- Carbon sinks response:

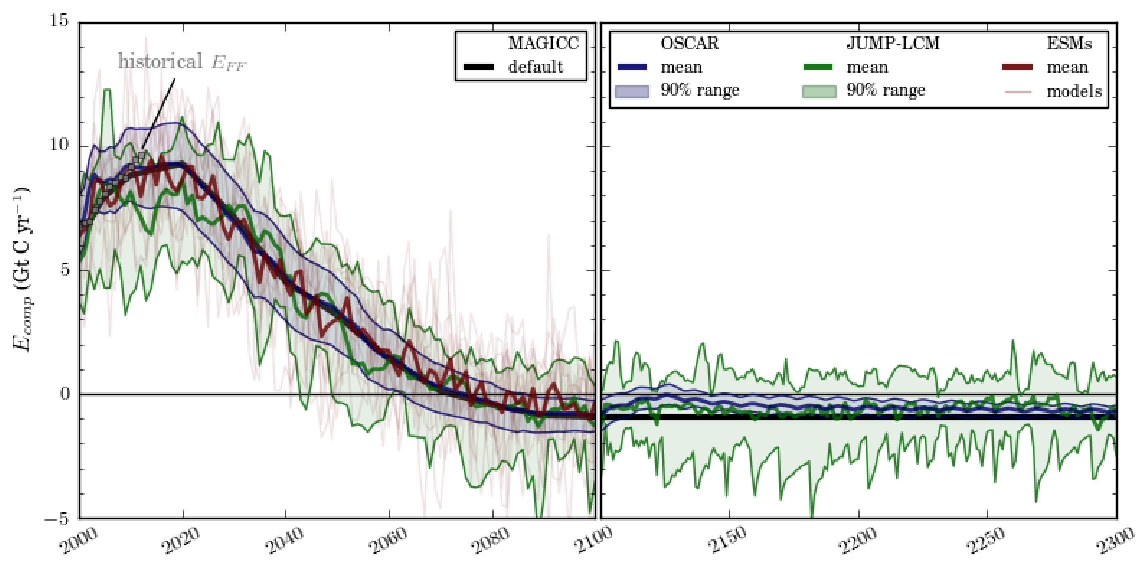


- Net effect over different periods:



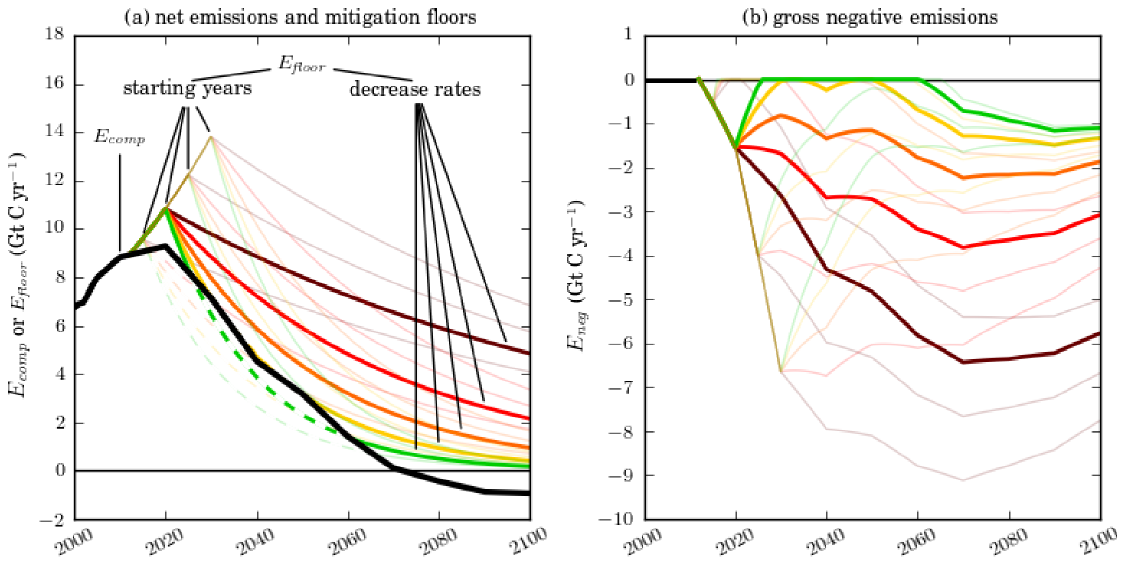
[Jones et al., 2017; *Simulating the Earth system response to negative emissions*]

How much negative emissions? (Physically based)



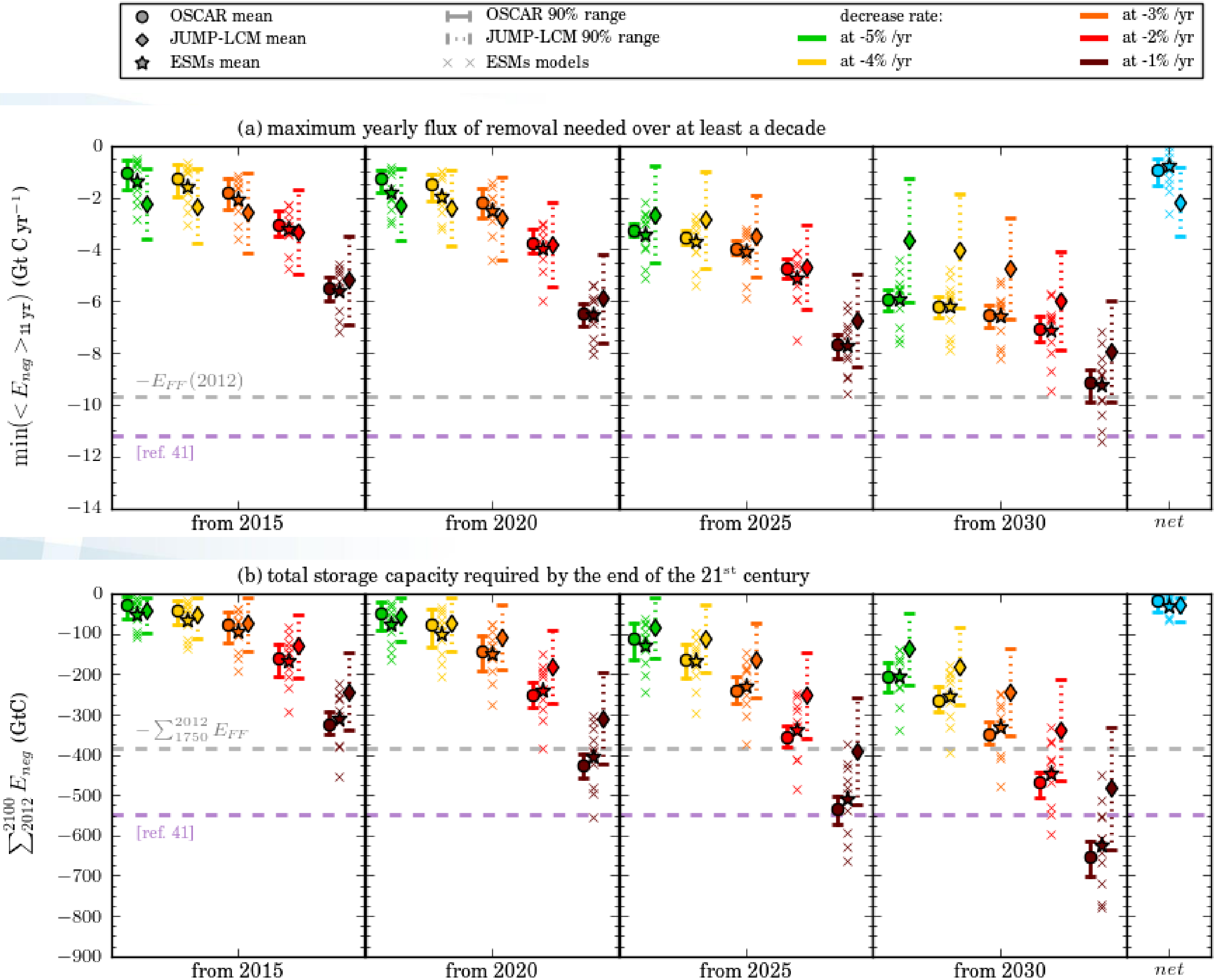
➢ Compatible emissions estimated by carbon-climate models of various complexities (JUMP-LCM is an EMIC, OSCAR is a compact model):

➢ Assumptions about the gross positive flux (mitigation floors) are made, and the gross negative flux is deduced by mass conservation:



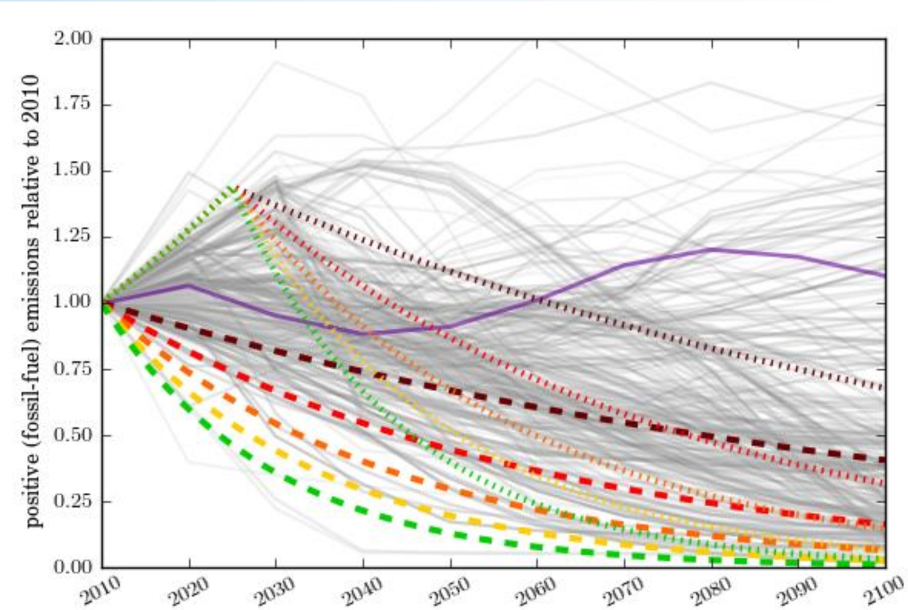
[Gasser et al., 2015; *Negative emissions physically needed to keep global warming below 2°C*]

How much negative emissions? (Physically based)



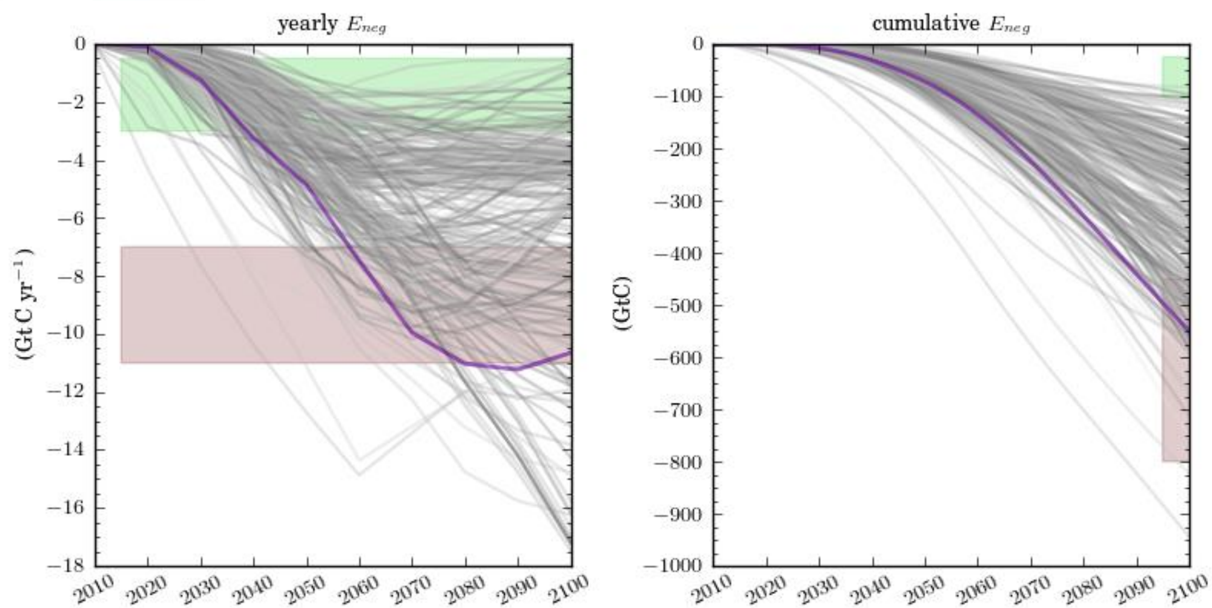
[Gasser et al., 2015; *Negative emissions physically needed to keep global warming below 2°C*]

How much negative emissions? (in IAMs)



- ➢ Positive emissions

- ➢ Negative emissions



[Gasser et al., 2015; *Negative emissions physically needed to keep global warming below 2°C*]