Unraveling the Knot of CO_2 Emissions from Bioenergy and Climate Change

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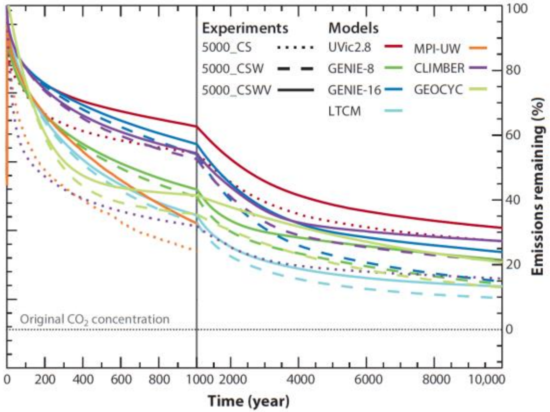
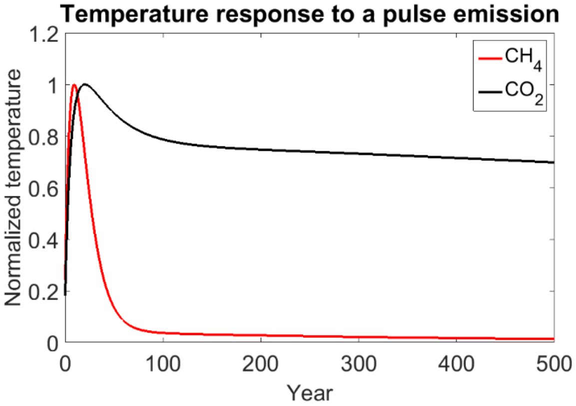
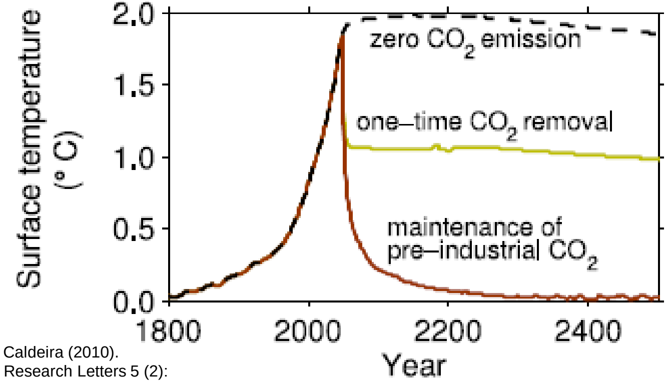
CO_2 emissions and climate

A pulse of CO_2 in the air at year 0

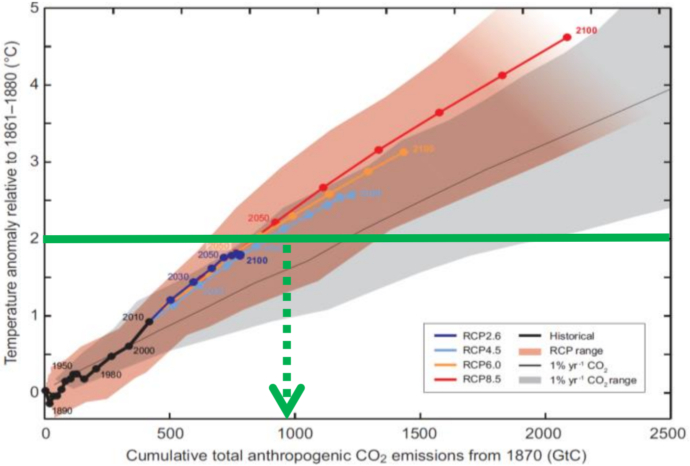


Archer, D., et al. (2009). "Atmospheric Lifetime of Fossil Fuel Carbon Dioxide." Annual Review of Earth and Planetary Sciences 37: 117-134.





Cao, L. and K. Caldeira (2010). Environmental Research Letters 5 (2): 024011.



IPCC. 2013. Summary for policymakers. IPCC WG I

CO_2-budget for 2°C

is limited

1000 GtC

CO_2-budget for 2°C

is limited

800 GtC

CO_2-budget for 2°C

we have already spent 2/3 of it

~250 GtC remain

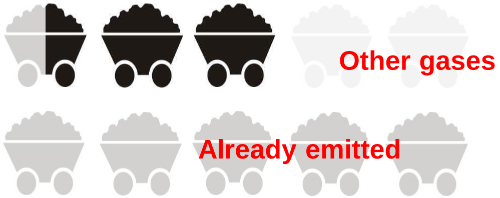
Note:

Annual emission rates are about 10 GtC/year

In case of no emission reductions the budget will be over within 15 or 20 years

Available fossil C far outweight the remaing C budget

Remaining C budget



~250 of 1 000 GtC remaining

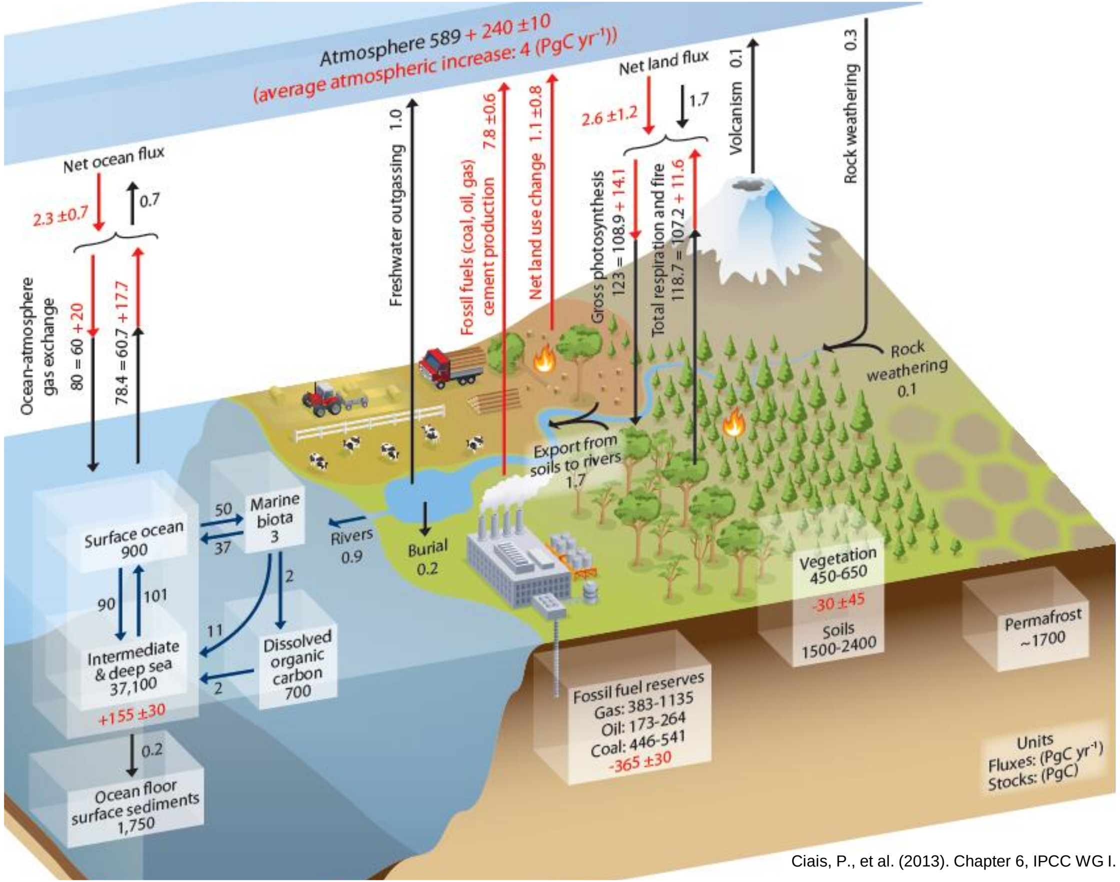
Available fossil fuel resources

	Reserves [Gt C]
Oil	170-250
Gas	380-1150
Coal	450-550
Total	**1 000- 1 950**

IPCC. 2014. Summary for policymakers. In *Climate Change 2014: Working Group III, Mitigation of climate change*

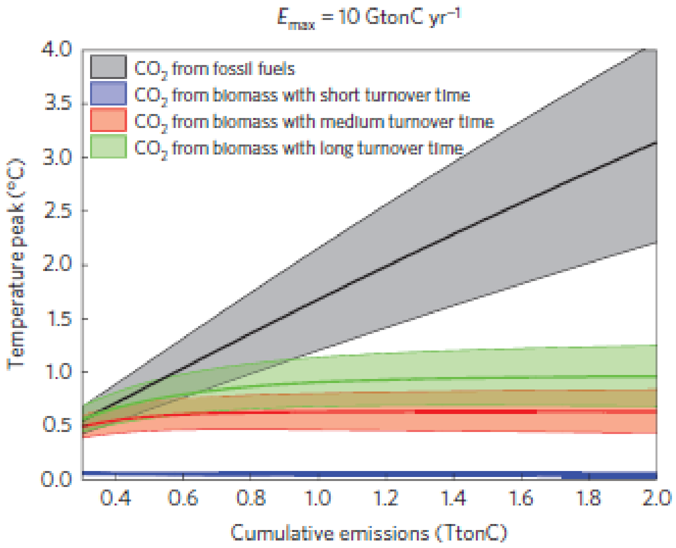
Climate change mitigation through C storage in vegetation

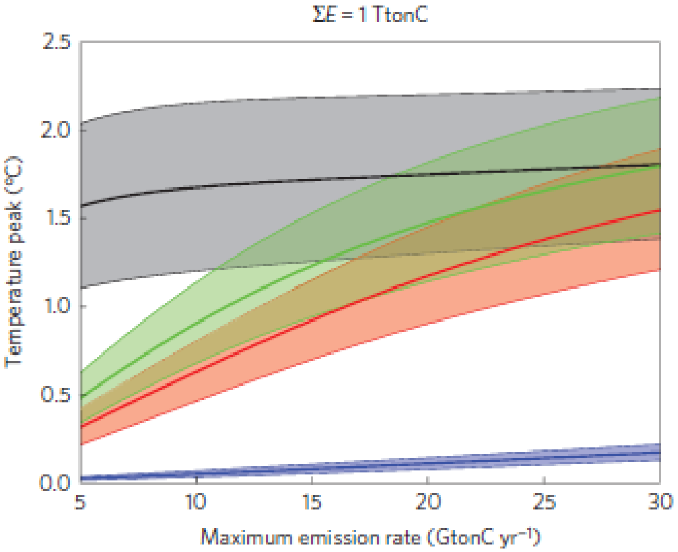
The replenishment of all pre-industrial vegetation C pools can capture less than 10% of global historical fossil C emissions



Ciais, P., et al. (2013). Chapter 6, IPCC WG I.

Is CO_2 from bioenergy to be accounted for in the Carbon budget?





Method. These results are obtained after integration of a global carbon-cycle climate model (OSCAR) and empirical observations of biosphere/atmosphere exchanges of CO_2 following harvest disturbance. We created two independent groups of 500 idealized emission trajectories (with a ten-year peak phase occurring between 2030 and 2160, followed by a post-peak phase with a decline to zero within a maximum of 100 years) to study the sensitivity of ΔT_{peak} to cumulative emissions ($\sum E$) or max emission rates (E_{max}). In the experiment aiming at testing the sensitivity of ΔT_{peak} to $\sum E$ (Fig. left), emission trajectories are constrained to E_{max} = 10 GtonC yr^{-1} and result in $\sum E$ ranging between 0.3 and 2 TtonC. The dependency on E_{max} (Fig. right) is studied over emission trajectories of $5 < E_{max} < 30$GtC yr^{-1} and resulting in the same amount of cumulative emissions ($\sum E = 1$ TtonC). CO2 emissions from bioenergy are sourced from biomass resources with short (6 years), medium (55 years) and long (103 years) turnover times.

Cherubini, F., et al. (2014). Nature Clim. Change **4**: 983–987.

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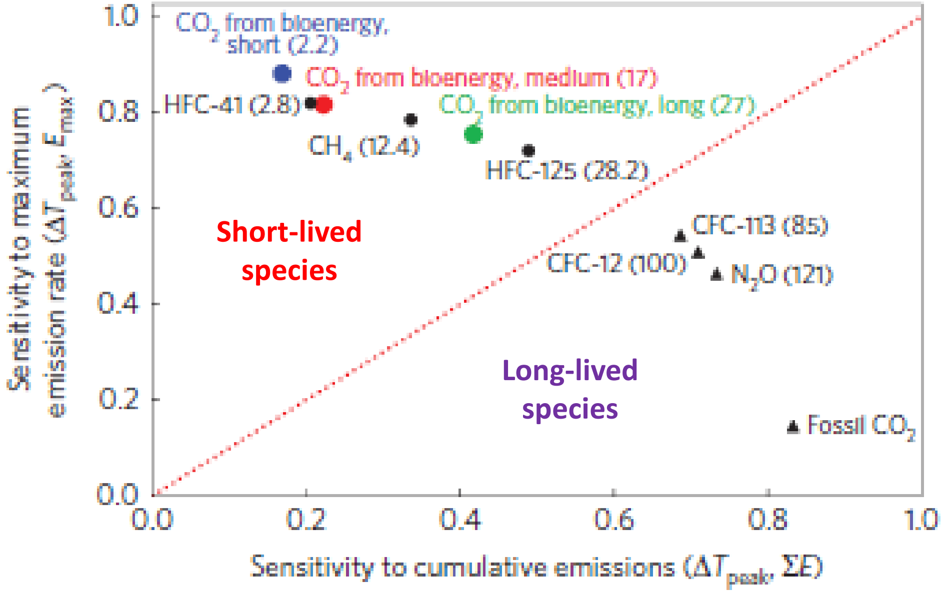
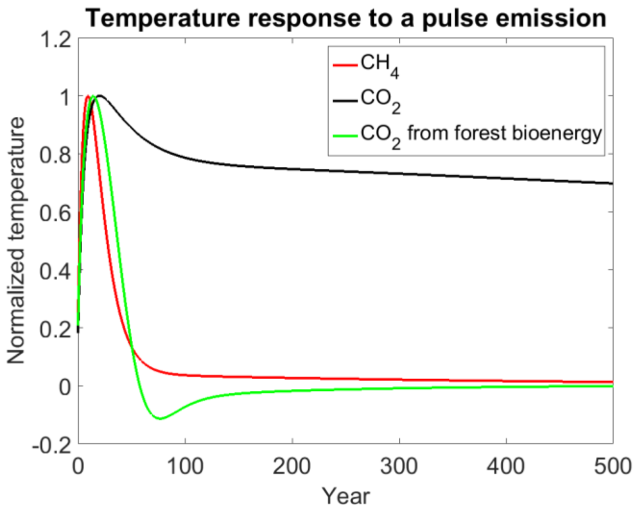
Climate response to CO_2 emissions from bioenergy resembles the one to short-lived GHGs

Short-lived: temporary perturbation, mostly contribute to the rate of climate change

Long-lived: nearly irreversible warming, contribute to both near- and long-term warming

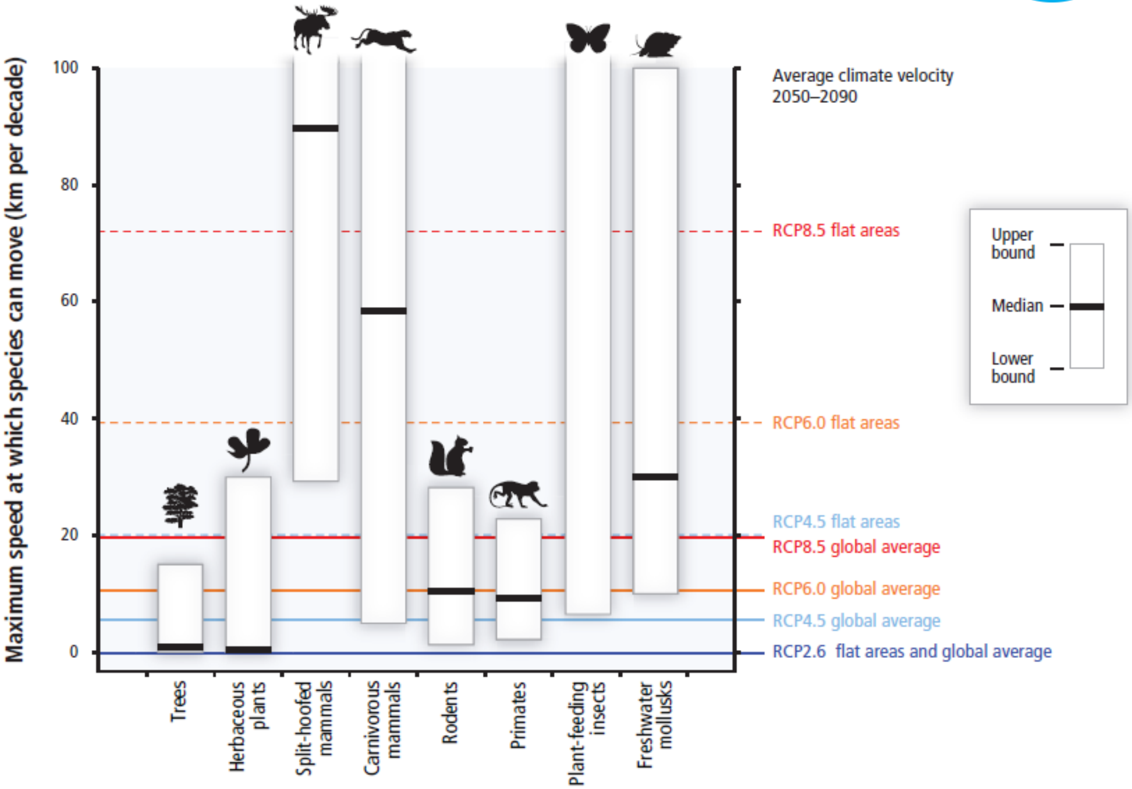




Cherubini, F., et al. (2014). Nature Clim. Change **4**: 983–987.

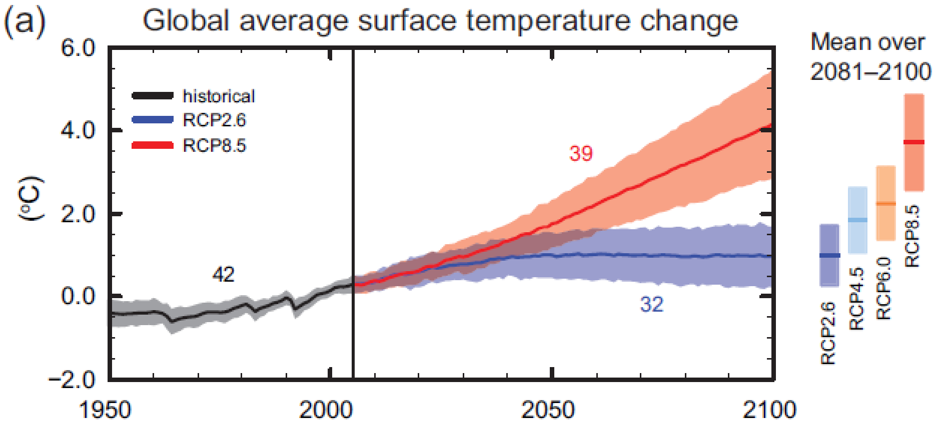
Rate of climate change: key for ecosystems adaptation via migration

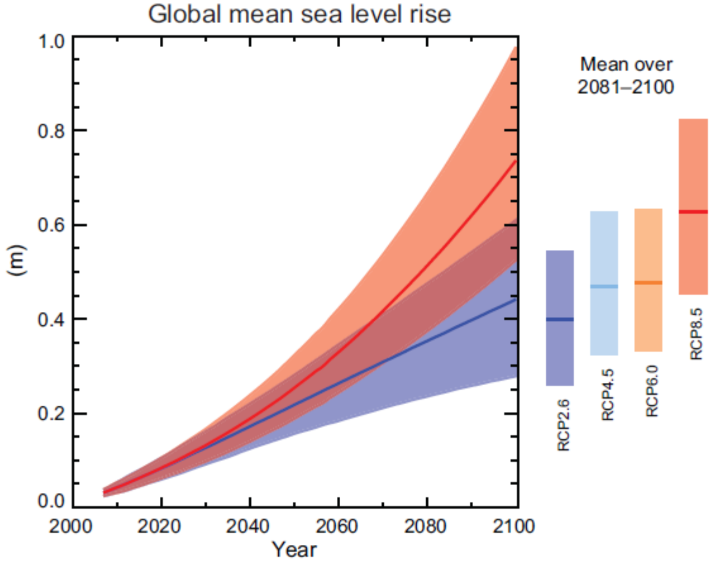
- Extinction risks increase at higher warming rates
- Some species will adapt to new climates.
- Those that cannot adapt sufficiently fast will decrease in abundance or go extinct in part or all of their ranges.



IPCC. 2014. Summary for policymakers. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*

Long-term climate change: temperature stabilization, sea level rise ...

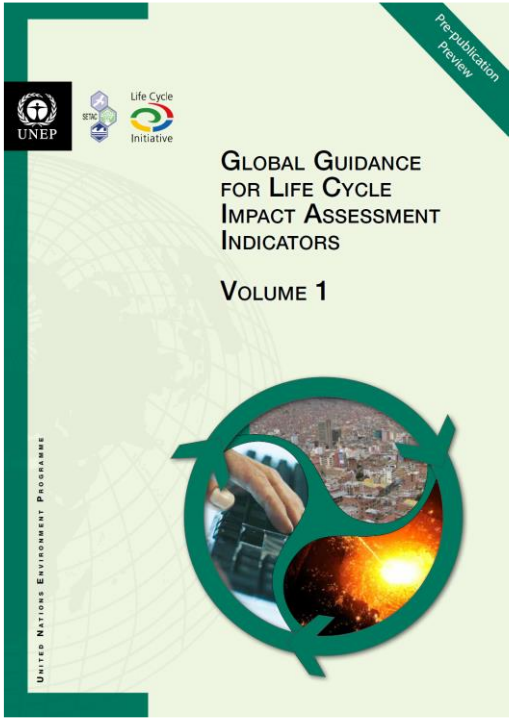




IPCC. 2013. Summary for policymakers. In *Climate Change 2014: Working Group I, The physical science basis*

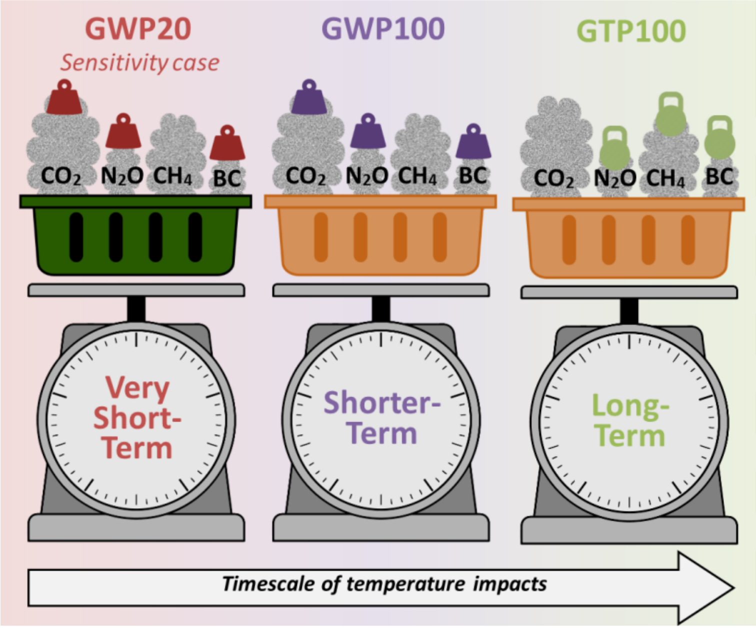
UNEP-SETAC Guidelines for LCIA methodology – Two complementary impact categories for climate change

	Shorter-term climate change	Long-term climate change
Metric	GWP100	GTP100
Unit	CO_2-equivalents (short)	CO_2-equivalents (long)
Timescale of temperature impacts	~ 40 years	100 years
Targeted impacts	Rate of climate change, short-term warming	Temperature stabilization, long-term warming
Sensitivity analysis	With NTCFs and GWP20	With NTCFs



Levasseur, A., de Schryver, A., Hauschild, M., Kabe, Y., Sahnoune, A., Tanaka, K., Cherubini, F. (2017). **Greenhouse gas emissions and climate change impacts. Global Guidance for Life Cycle Impact Assessment Indicators -** Volume 1. Ed.: R. Frischknecht and O. Jolliet, *UNEP/SETAC Life Cycle Initiative*. Chapter 3: 59-75. Available at http://www.lifecycleinitiative.org/training-resources/global-guidance-lcia-indicators-v-1/.

CH_4-equivalents for shorter-term impacts?



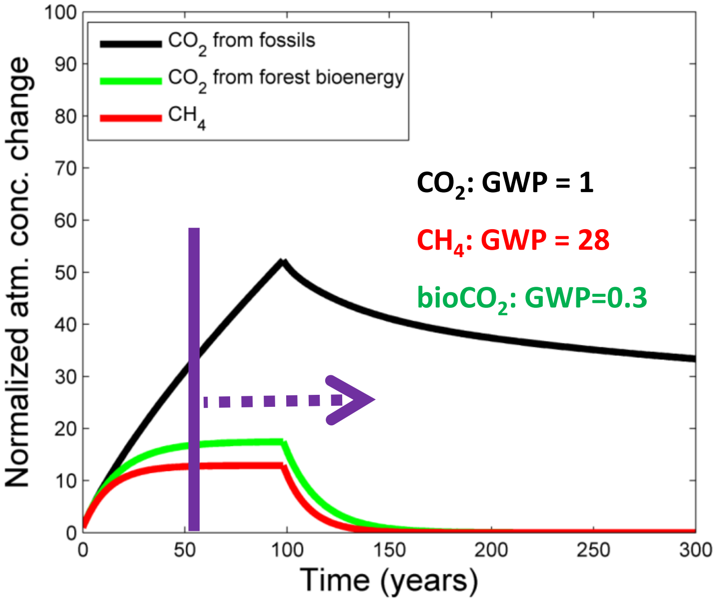
Forcing agent	*GWP20 (CH_4-equiv.)*	*GWP100 (CH_4-equiv.)*	*GTP100 (CO_2-equiv.)*
CO_2	0.011	0.028	1
CH_4	1	1	11
HCFC-122a	11	9	101
HFC-134a	44	46	530
CFC-11	82	157	3 490
N_2O	3	8	297
SF_6	204	725	33 631
CF_4	58	216	9 560
BC	37 ± 34	28 ± 25	56 ± 25
OC	-1.84 ± 1.2	-1.4 ± 0.9	-7.3 ± 2.1
SO_x	-1.62	-1.3	-5.3
NO_x	-1.24 ± 0.4	-1 ± 0.3	-2.2 ± 2.1
CO	0.09 ± 0.02	0.07 ± 0.02	-0.26 ± 0.11
VOC	0.21 ± 0.08	0.2 ± 0.1	0.9 ± 0.5

Cherubini F., and Tanaka K. (2016), Amending the Inadequacy of a Single Indicator for Climate Impact Analyses, Environmental Science and Technology, 50(23): 12530–12531.

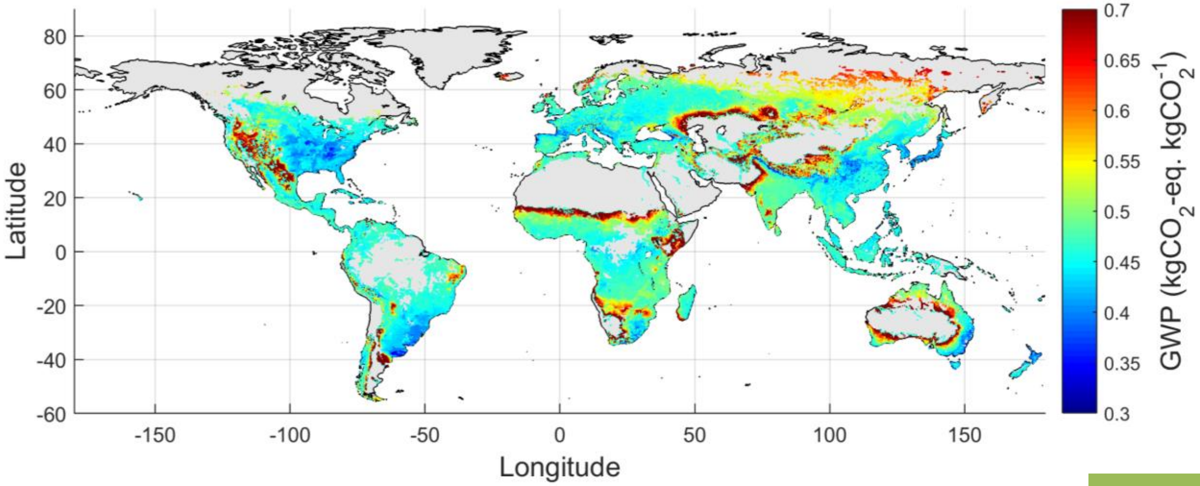
Is forest bioenergy climate neutral (GWP=0) if we assume that CO_2 emissions are offset by sequestration in other stands?

Hypothesis: CO_2 emitted from wood harvested in one stand is offset by the sequestration in other stands

Continuous pulse emissions



GWP100 for CO_2 emissions from (secondary) forest bioenergy at 0.25° resolution



	0% Residue extraction rate	50% Residue extraction rate	100% Residue extraction rate
Equation	GWP = 0.0073·R	GWP = 0.0055·R	GWP = 0.0046·R
R^2	0.738	0.835	0.863
RMSE	0.0073	0.030	0.022

Global average: 0.49 ± 0.03 $kgCO_2$-eq./$kgCO_2$ (mean ± σ)

		GWP 100		
		50%	All res.	No res.
COUNTRY	Grids	Mean	Mean	Mean
Afghanistan	854	0.54	0.46	0.72
Albania	42	0.43	0.36	0.56
Algeria	342	0.47	0.40	0.61
Andorra	1	0.46	0.39	0.59
Angola	1521	0.48	0.39	0.65
Argentina	4020	0.49	0.41	0.64
Armenia	46	0.45	0.39	0.59
Australia	7151	0.53	0.44	0.72
Austria	151	0.46	0.40	0.59
…				

Cherubini F., M. Huijbregts, G. Kindermann, R. Van Zelm, M. Van Der Velde, K. Stadler, A.H. Strømman, Global spatially explicit CO_2 emission metrics for forest bioenergy, Nature Scientific Reports **6**: 20186.

Land management and land use changes involve interactions with the climate system through many complex mechanisms

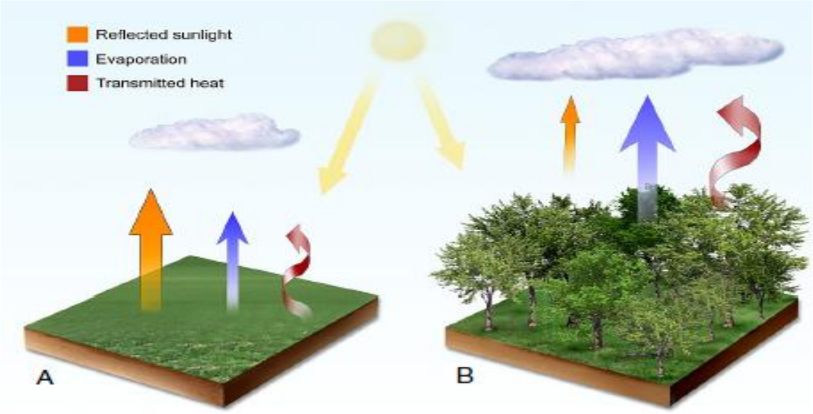


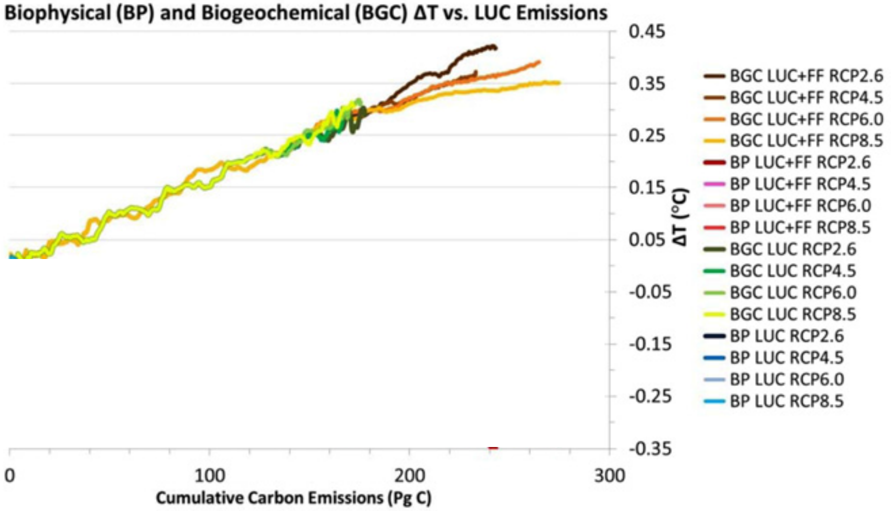
Figure from: Jackson et al., *Env. Res. Lett.*, (2008)

Biochemical effects:
- CO_2 and other GHGs
- Biogenic VOCs

Biophysical effects:
- Surface albedo
- Evapotranspiration
- Surface roughness

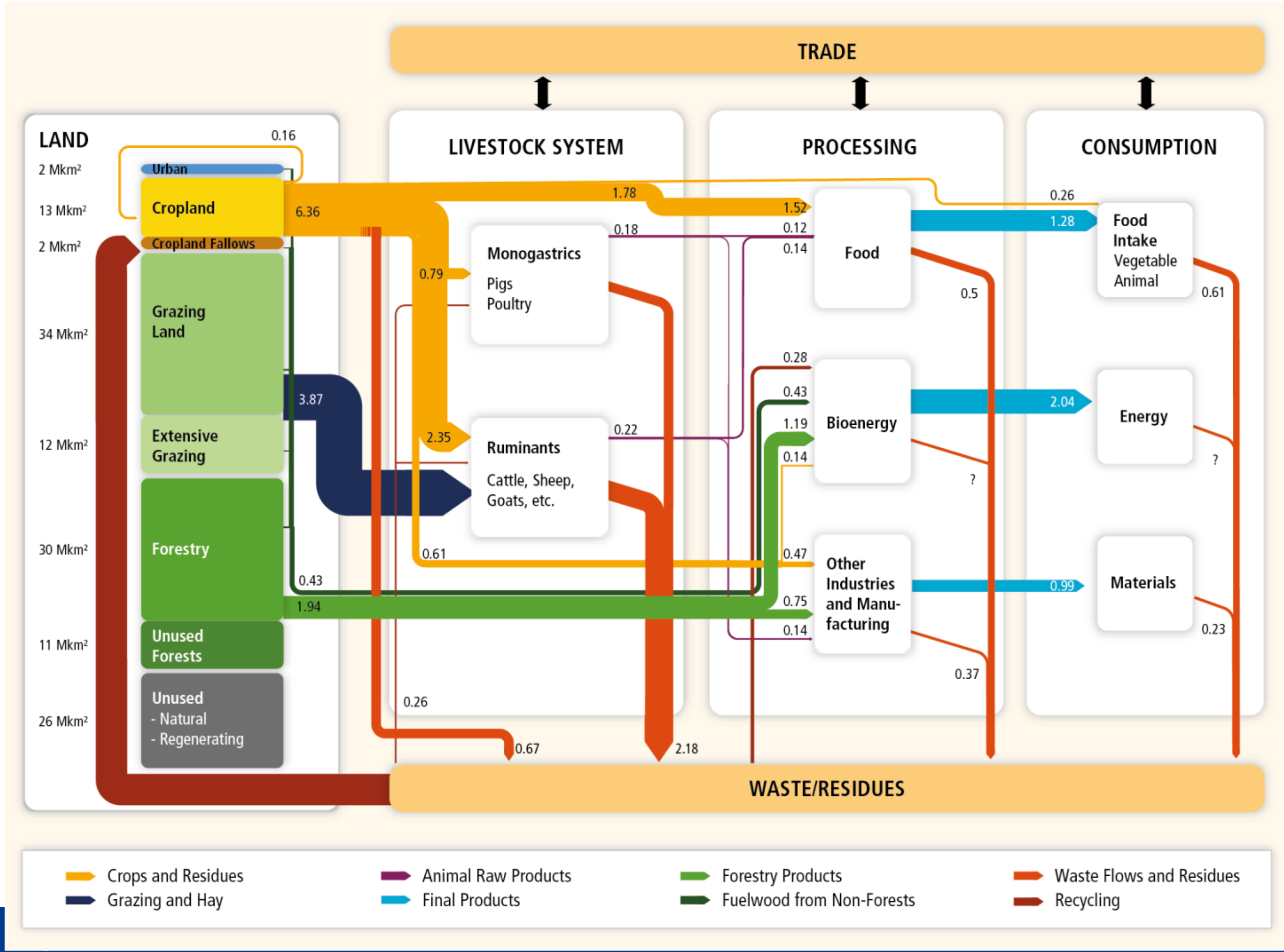
"The feedbacks between terrestrial ecosystems and climate include, among other mechanisms, changes in surface albedo, evapotranspiration and greenhouse gas emissions and uptake. The physical effects on the climate can be opposite in direction to the greenhouse gas effects, and can materially alter the net outcome of the ecosystem change on the global climate (*high confidence*)." (IPCC 2014, Chapter 4, WG II)

Linearity between temperature and historical LUC: CO_2 (BGC) + biophysics (BP)



Consideration of both CO_2 (BGC) and biophysical (BP) forcings leads to a temperature response to historical LUC that is nearly climate neutral

Simmons, C. T. and H. D. Matthews (2016). Environmental Research Letters 11(3): 035001.



By 2100 in RCP2.6, Bioenergy crops are projected to occupy approximately 4 million km^2, approximately 7% of global cultivated land (WGII 4.4.4)

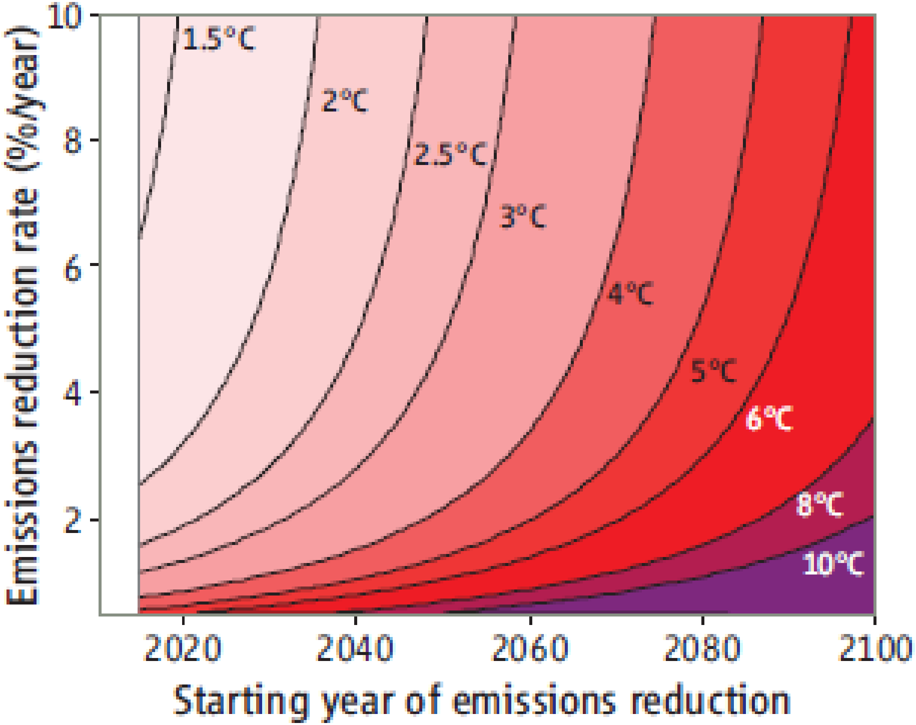
Figure 11.9. Global land use and biomass flows arising from human economic activity in 2000 from the cradle to the grave. Values in Gt dry matter biomass/yr. Source: IPCC WGIII, Chapter 11

CLIMATE CHANGE

The Closing Door of Climate Targets

Thomas F. Stocker

The linear relationship between cumulative carbon emissions and global climate warming implies that as mitigation is delayed, climate targets become unachievable.



Thank you!

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Different climate response from different timing of emission reductions and lifetime of the gas

The mitigation of short-lived species would temporarily reduce the rate of warming and it is less relevant to the risk of passing warming thresholds, because as long as the concentration of CO_2 grows the reaching of them is only temporally postponed

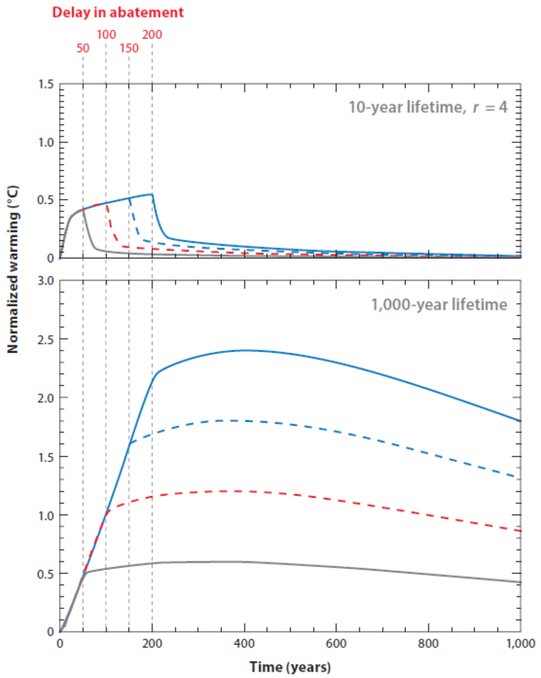

Figure 6

Consequences of delay in mitigation of a decadal- versus millennial-lifetime gas. Normalization is as for Figure 5. Calculations are done with $r = 4$.

Pierrehumbert, R. T. (2014). "Short-Lived Climate Pollution." Annual Review of Earth and Planetary Sciences **42**(1): 341-379.

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GWP100 ~ GTP40

GHG	GWP20	GWP100	GTP20	GTP40	GTP100
CO_2	1	1	1	1	1
CH_4	84	28	67	26	4
N_2O	264	265	277	285	234
HFC-134a	3710	1300	3050	1173	201

Allen, M. R., et al. (2016). "New use of global warming potentials to compare cumulative and short-lived climate pollutants." Nature Climate Change 6(8): 773-776.

The choice between GWP100 and GTP100 can thus be seen as a preference to reduce climate change over the next few decades (GWP100) or in a longer period (GTP100)

SPECIAL C4MIP COLLECTION

Twenty-First-Century Compatible CO_2 Emissions and Airborne Fraction Simulated by CMIP5 Earth System Models under Four Representative Concentration Pathways

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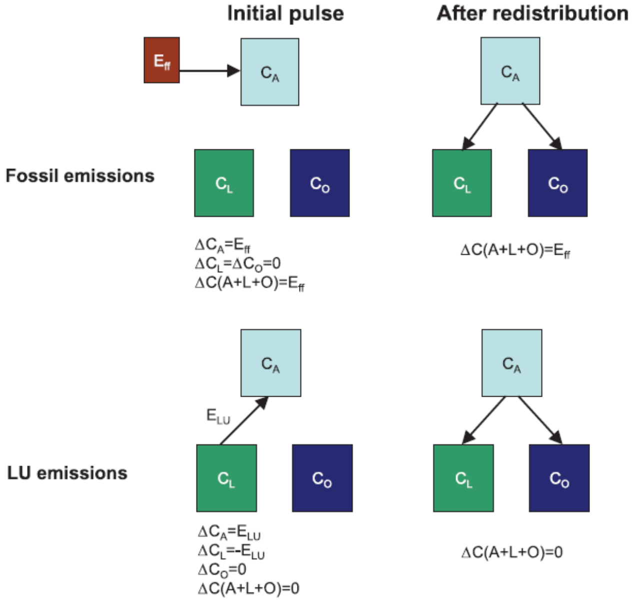

"Land-use emissions of CO_2 are fundamentally different from fossil-fuel emissions, which add a new supply of CO_2 to the atmosphere–land–oceans, whereas land-use emissions merely relocate carbon from one component to another within this system."

"Fast domain vs. Slow domain of the C cycle"

IPCC 5AR WGI Chapter 6