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GWPs of biogenic CO_2 from bioenergy: contributions from timing of CO_2 fluxes and albedo.

Applications to selected bioenergy systems (heat, biofuels, forest residues and delayed emissions)

Francesco Cherubini, Ryan Bright, Geoffrey Guest, Anders H. Strømman

Department of Energy and Process Engineering,
Norwegian University of Science and Technology (NTNU), Trondheim – Norway

francesco.cherubini@ntnu.no

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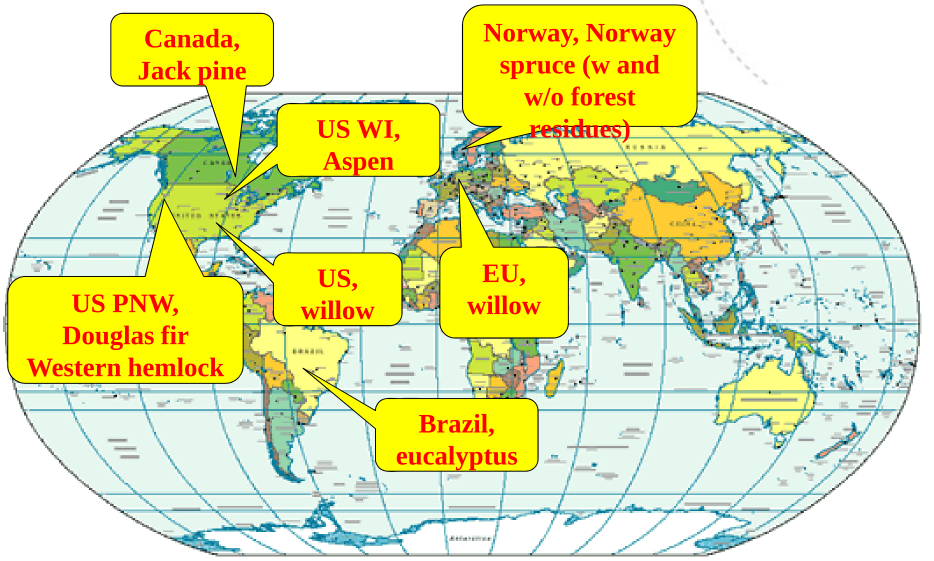
Biomass feedstocks



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Bioenergy case studies

- Impacts from biomass lands under management for bioenergy (e.g., existing plantations and forests)
  - No DLUC and ILUC
- Contributions to global warming (using IPCC metrics) from:
  - Direct life cycle GHG emissions
  - Biogenic CO_2 fluxes: Temporary changes in atmospheric CO_2
  - Temporary changes in (snow) albedo
- Heat from stationary applications
  - Benchmark: heat from fossil fuels (natural gas, oil and coal)
- Transportation biofuels (bioethanol and FT-Diesel)
  - Benchmark: gasoline, diesel, 1st generation bioethanol (from corn in the US and sugarcane in Brazil), 1st generation biodiesel (from rapeseed and waste oil in the EU)
- Results
  - Absolute metrics: effective forcing (Wm^{-2})/MJ combusted
  - Normalized metrics: g CO_2-eq./MJ combusted

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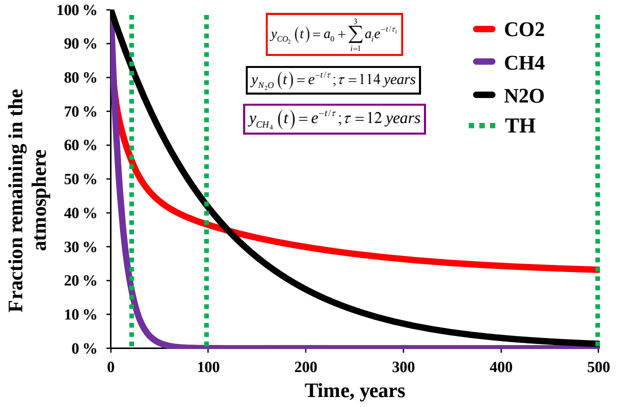
GHG emissions and their atmospheric decay



The climate impact of the different GHG emissions is assessed with the GWP metric

$$GWP = \frac{CRF_{gas}}{CRF_{CO_2}} = \frac{C_0 \int_0^{TH} \alpha_{gas} \cdot y_{gas}(t)dt}{C_0 \int_0^{TH} \alpha_{CO_2} \cdot y_{CO_2}(t)dt}$$

C_0 = pulse emission
α = radiative efficiency of the gas
y_i = function describing the atmospheric decay of the gas

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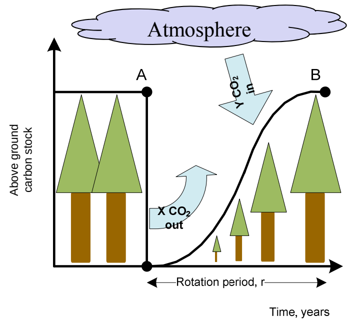
How to include timing of biogenic CO_2 fluxes in LCA



- CO_2 fluxes are modeled with appropriate functions
- These functions are convoluted with the Bern CO_2 decay (this integrates the biomass system with the global C cycle)
- Computation of absolute metrics, i.e. change in atmospheric CO_2 concentration, radiative forcing, temperature
- Computation of normalized metrics (GWP, GTP)

1. Identification of the bioenergy system and its biogenic CO_2 flows (stand/landscape level)

2. Elaboration of the functions to model biogenic CO_2 fluxes
- 2.1 Dynamic of CO_2 sequestration from growing vegetation
- 2.2 Dynamic of CO_2 emissions from combustion or oxidation of HWP

3. Computing the net change in atmospheric CO_2 concentration

$$f(t)=\int_0^t\left[C_0\delta(t')-C_0^{*}g(t')\right]\cdot y(t-t')dt'$$

4. Calculation of the climate impact with an appropriate metric:
- Radiative forcing
- GWP
- GTP

5. Combination with other climate aspects or accounting rules
- Changes in albedo
- Life-cycle auxiliary inputs
- Theoretical substitution of fossil CO_2

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CO_2 fluxes from the site after harvest

- Chronosequences of Net Ecosystem Productivity (NEP)
  - Directly measured in the field through eddy covariance technique
  - OR
  - Indirectly modeled with C dynamic models

$$NEP = NPP - R_h$$

NPP = Net Primary Productivity (GPP – R_a)

R_h = heterothrophic respiration, CO_2 emissions from oxidation of dead organic materials

- NEP > 0, the ecosystem is a C sink
- NEP < 0, the ecosystem is a C source

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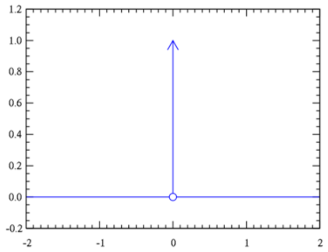
Timing of biogenic CO_2 fluxes

- In the bioenergy system, we have two types of CO_2 fluxes:
  1. Emissions from combustion
  2. Fluxes on the site after harvest

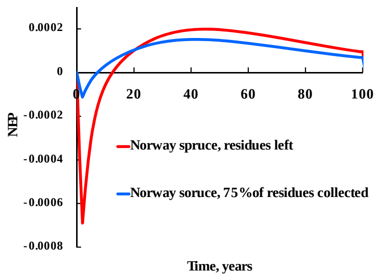
Emissions from combustion are modeled using a delta function

$$\delta(t)=\begin{cases}+\infty & t=0\\ 0 & t\neq 0\end{cases} \quad with \int_{-\infty}^{+\infty}\delta(t)\,dt=1$$



Fluxes on the site after harvest are modeled with chronosequences of NEP

$$NEP = NPP - R_h$$



Integration with the global C cycle

$$f(t)=\int_0^t\left[\delta(t')-NEP(t')\right]\cdot y(t-t')\,dt'$$

Time evolution of the change caused in atmospheric CO_2 concentration (decay)

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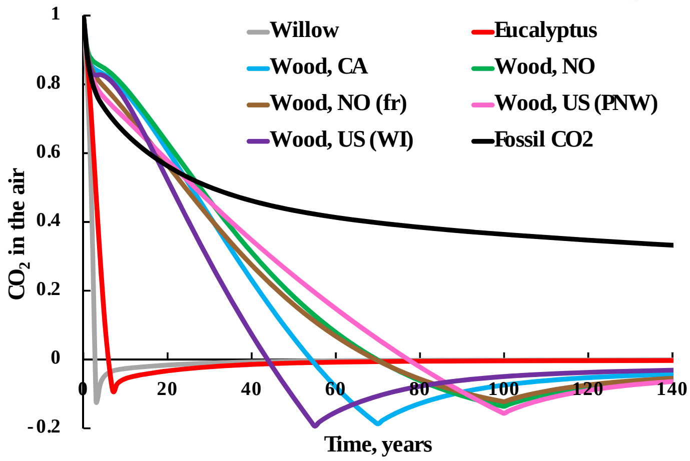
Bio CO_2 decay



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Changes in albedo from bioenergy

- Forested areas reflect less incoming shortwave radiation than open land areas, especially in regions affected by seasonal snow cover
  - Open land (before afforestation): $\alpha \approx 0.78$
  - Forested land: $\alpha \approx 0.26$
- Bioenergy from managed forests causes *temporary* changes in albedo, which are significant when snow is present:
  - From «forested land» to «open land» → global cooling
  - From «open land» to «forest land» → global warming

$$GWP_{Albedo} = \gamma^{-1} \frac{\int_0^{TH} E_{albedo} \Delta RF_{\alpha}(t) \mathrm{d}t}{\int_0^{TH} E_{CO_2} \Delta RF_{CO_2}(t) \mathrm{d}t}$$

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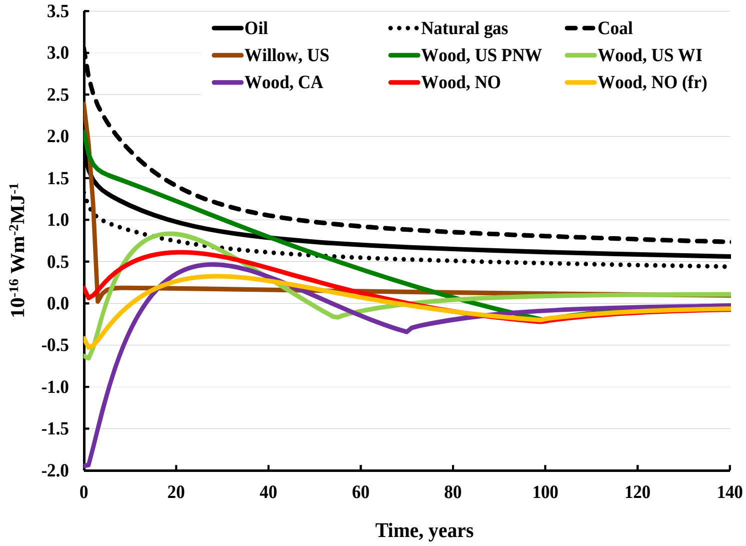
Effective forcing
Heat



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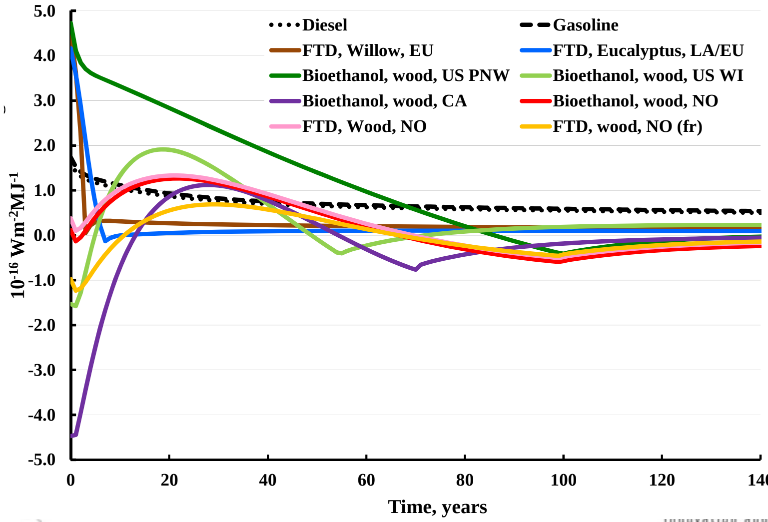
Effective forcing
Transportation biofuels



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Normalized metrics:
GWP, GTP and iGTP

	GWP			GTP			iGTP		
	20	**100**	**500**	**20**	**100**	**500**	**20**	**100**	**500**
CO_2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CH_4	96.3	34.5	10.6	45.0	0.10	0.0	96.3	34.5	10.6
N_2O	336	348	179	374	287	13.5	336	348	179
Bio CO_2, NO	1.25	0.62	0.11	1.12	-0.37	-0.03	1.14	0.56	0.10
Albedo, NO	-0.94	-0.42	-0.13	-0.66	0.00	0.00	-0.94	-0.42	-0.13
Net, NO	0.32	0.20	-0.02	0.46	-0.37	-0.03	0.21	0.13	-0.03
Bio CO_2, NO (fr)	1.07	0.51	0.09	1.01	-0.34	-0.03	1.06	0.51	0.09
Albedo, NO (fr)	-1.22	-0.55	-0.17	-0.86	0.00	0.00	-1.22	-0.55	-0.17
Net, NO (fr)	-0.16	-0.05	-0.08	0.14	-0.34	-0.03	-0.16	-0.05	-0.08
Bio CO_2, US PNW	1.04	0.58	0.10	1.03	-0.43	-0.03	1.04	0.58	0.10
Albedo, US PNW	-0.14	-0.07	-0.02	-0.10	0.00	0.00	-0.14	-0.07	-0.02
Net, US PNW	0.90	0.51	0.08	0.93	-0.43	-0.03	0.90	0.51	0.08
Bio CO_2, US WI	1.08	0.32	0.06	0.93	-0.14	-0.02	1.07	0.32	0.06
Albedo, US WI	-1.10	-0.38	-0.12	-0.47	0.00	0.00	-1.10	-0.38	-0.12
Net, US WI	-0.02	-0.06	-0.06	0.46	-0.14	-0.02	-0.03	-0.06	-0.06
Bio CO_2, CA	1.13	0.42	0.08	1.08	-0.20	-0.02	1.12	0.43	0.08
Albedo, CA	-1.60	-0.61	-0.19	-0.87	0.00	0.00	-1.60	-0.61	-0.19
Net, CA	-0.47	-0.18	-0.11	0.21	-0.20	-0.02	-0.48	-0.18	-0.11
Bio CO_2, eucalyptus	0.17	0.03	0.01	-0.06	-0.01	0.00	0.19	0.04	0.01
Bio CO_2, willow	0.09	0.02	0.00	-0.03	0.00	0.00	0.11	0.03	0.01
Bio CO_2, an. crops	0.02	0.00	0.00	0.01	0.02	0.01	0.09	0.04	0.02

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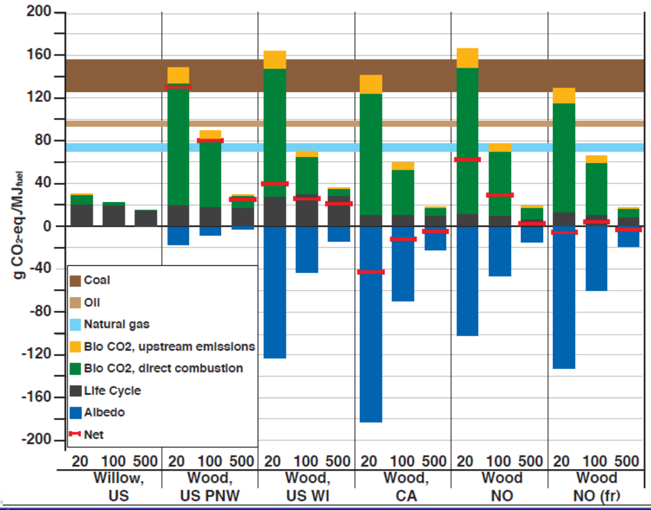
Contributions to global warming Heat



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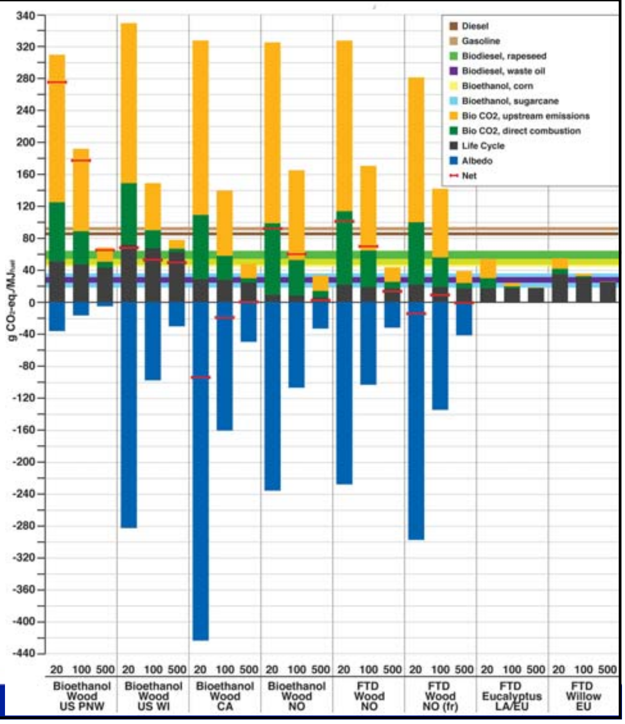
Contributions to global warming Transportation biofuels



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Conclusions

- Inclusion of timing of biogenic CO_2 fluxes in LCA using appropriate functions
- Albedo contributions can be the dominating direct climate change effect
- Quantification of GWP of biogenic CO_2 is far more complex than an issue of 0 or 1 accounting
- Equivalency factors of biogenic CO_2 are case-specific: they require high spatial and temporal modeling resolution
- Discussion on metrics and role of TH:
  - Absolute metrics or normalized metrics?
  - Instantaneous or integrated?
  - RF-based or temperature?

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