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Climate impacts of forest bioenergy: issues of scale

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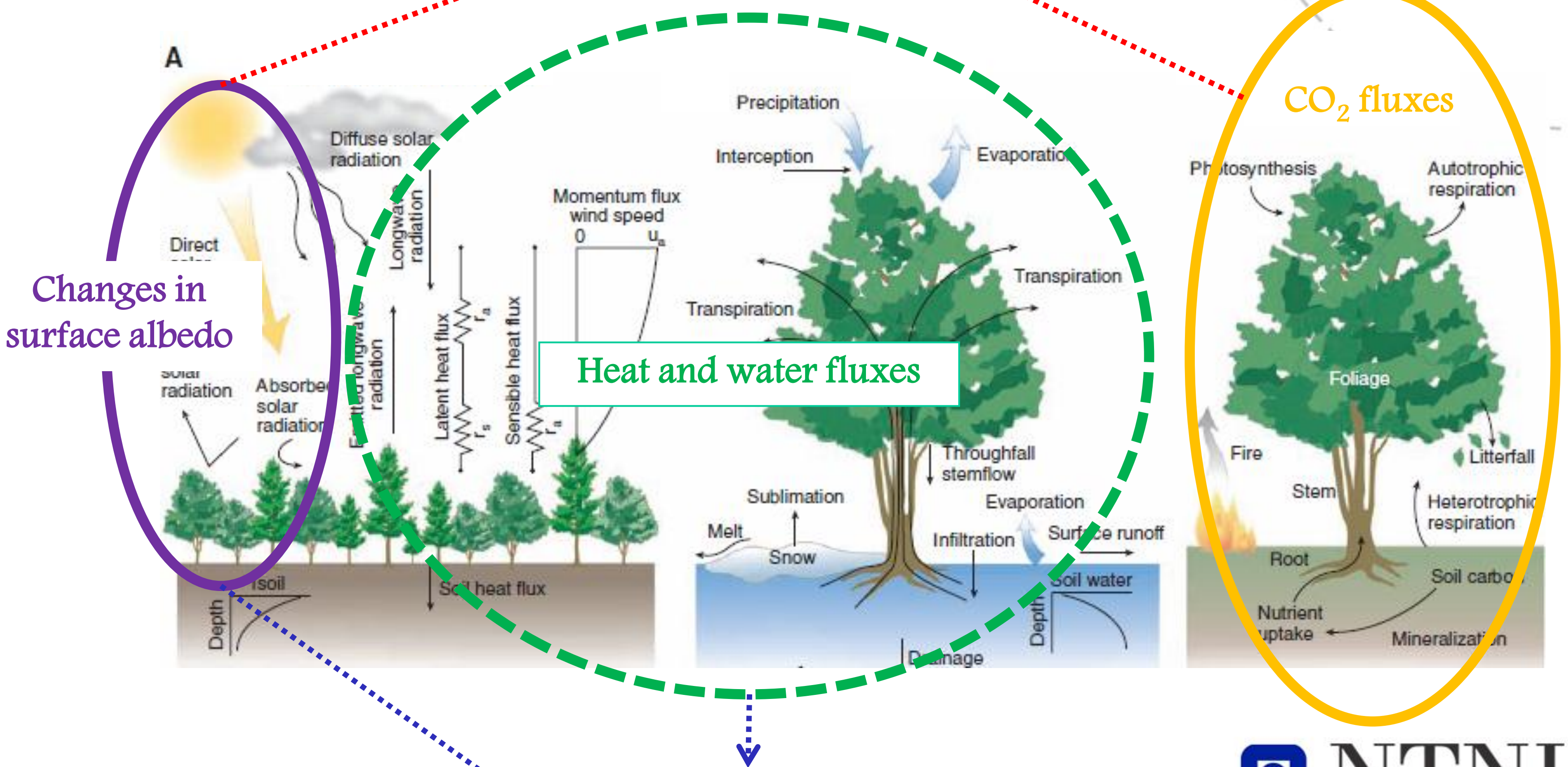
Forests and climate

Global impact



Local impact
(indirectly global)

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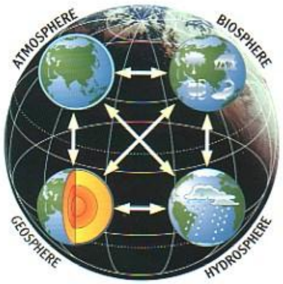
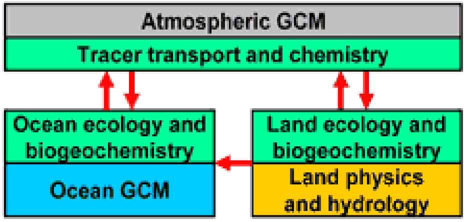
How can we measure effects on climate of forest harvest events?

Earth system models (inclusive of land, biosphere, atmosphere and ocean components)

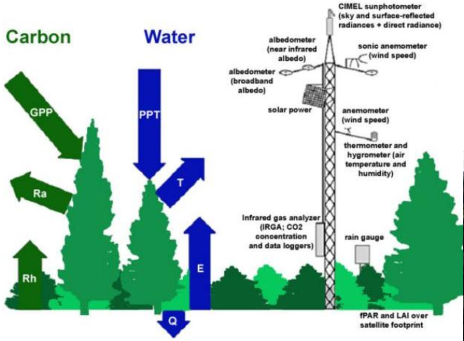
- Low resolution (grid: 100x100 km^2), but point simulations are possible
- High complexity
- Cooperation with climate scientists needed





Empyrical measurements

- Directly on site: flux towers, through eddy covariance techniques
- Remote: satellite observations
- We can take advantage of published chronosequence
- High site-specific resolution



CO_2 fluxes on site after harvest

Chronosequences of Net Ecosystem Productivity (NEP)

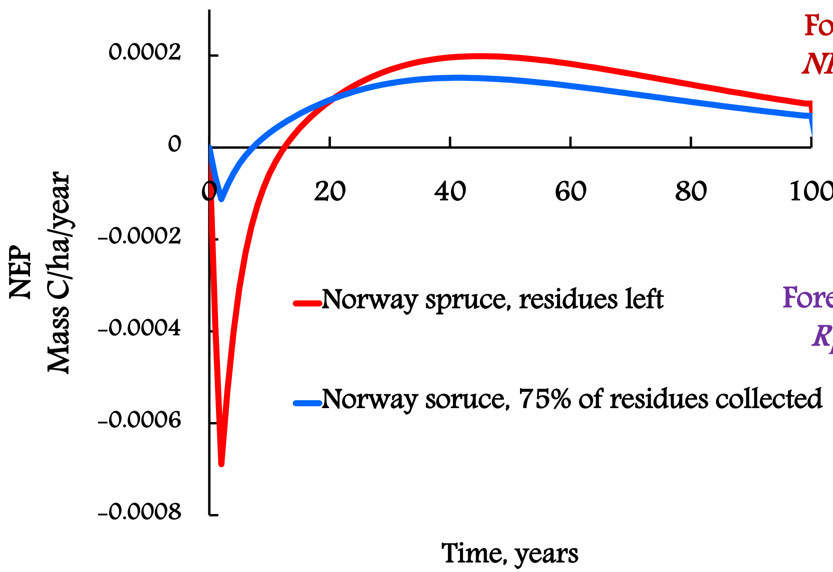
$$NEP = NPP - R_h$$

NPP = Net Primary Productivity

R_h = heterothrophic respiration, e.g. CO_2 from oxidation of dead organic materials

1. Directly measured on site (chronosequence)

2. Indirectly modeled



NEP > 0
Forest is C sink
NPP dominates

NEP < 0
Forest is C source
R_h dominates

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Biogenic CO_2 and Impulse Response Functions (IRF)

- Biogenic CO_2 fluxes can be embedded in IRFs
- IRFs are widely used in climate science and in LCA for characterization of impacts
- IRFs for biogenic CO_2 emission pulses are biomass-specific (depend on the NEP chronosequence)
- IRFs are the basis for physical metrics, both absolute (radiative forcing, surface temperature, etc.) and normalized (GWP, GTP, iGTP)
- Thanks to IRFs, biogenic CO_2 emissions can be treated as the other GHGs in LCA:
  - Emissions: listed as inventory items in LCI
  - Removals: not in LCI, because they are embedded in the characterization factor (e.g. GWP)

Atmospheric response to a pulse emission

Impule Response Functions (IRFs)

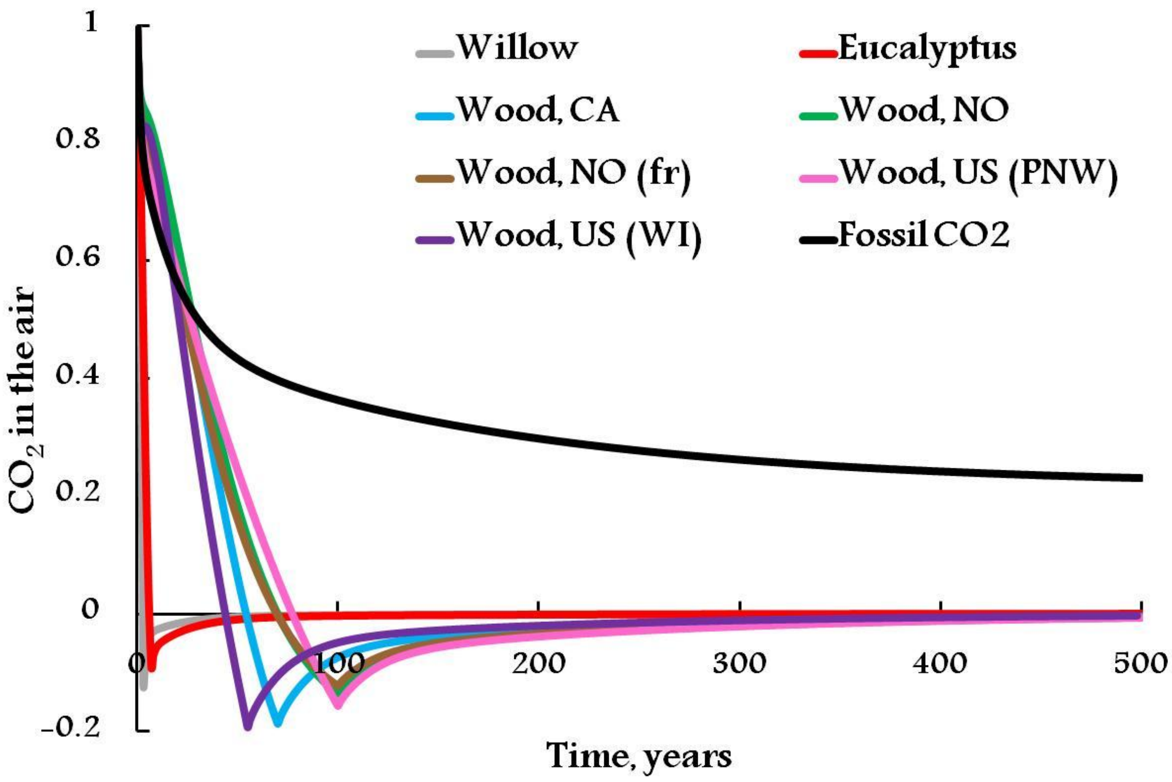
CO_2 from fossils/Deforestation

About 22% always remains in the atmosphere

CO_2 from regenerative biomass

Completely reabsorbed in few decades

Biomass-specific



	GWP		
	20	100	500
CO_2	1.00	1.00	1.00
CH_4	96.3	34.5	10.6
N_2O	336	348	179
NO: Bio CO_2	1.25	0.62	0.11
NO (fr): Bio CO_2	1.07	0.51	0.09
US PNW: Bio CO_2	1.04	0.58	0.10
US WI: Bio CO_2	1.08	0.32	0.06
CA: Bio CO_2	1.13	0.42	0.08
Eucalyptus: Bio CO_2	0.17	0.03	0.01
Willow: Bio CO_2	0.09	0.02	0.00

NO: Norway, Norwegian spruce, rotation period 100 years
NO (fr): as above, but with collection of 75% forest residues
US PNW: Mixed forest in PNW, rotation period 100 years
US WI: Aspen forest in Wisconsin, rotation period 55 years
CA: jack pine forest in Canada, rotation period 70 years
Eucalyptus: plantation in Brazil, rotation period 7 years
Willow: plantation in EU/US, rotation period 3 years

Cherubini et al. (2012). "Site-specific global warming potentials of biogenic CO 2 for bioenergy: contributions from carbon fluxes and albedo dynamics." Environmental Research Letters 7(4): 045902.

Global surface temperature response to a pulse emission

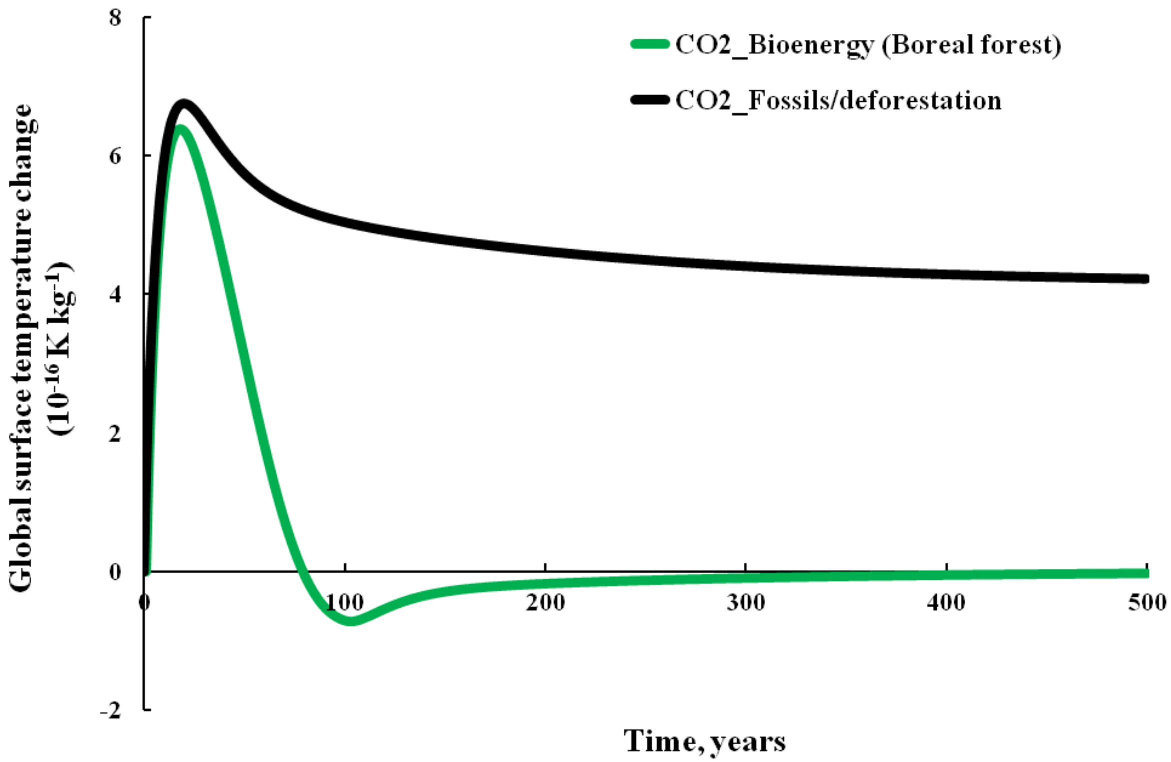
CO_2 from fossils/Deforestation

Warms the climate for millennia

CO_2 from regenerative biomass

Warms the climate temporarily

Cools the climate at some times



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Bright et al. (2012). "A comment to “Large-scale bioenergy from additional harvest of forest biomass is neither sustainable nor greenhouse gas neutral”: Important insights beyond greenhouse gas accounting." GCB Bioenergy 4(6): 617-619.

Stand scale: Forest fire in Alaska caused a net cooling effect

REPORTS

Science AAAS

The Impact of Boreal Forest Fire on Climate Warming

J. T. Randerson,[1*] H. Liu,[2] M. G. Flanner,[1] S. D. Chambers,[3] Y. Jin,[1] P. G. Hess,[4] G. Pfister,[4] M. C. Mack,[5] K. K. Treseder,[1] L. R. Welp,[6] F. S. Chapin,[7] J. W. Harden,[8] M. L. Goulden,[1] E. Lyons,[1] J. C. Neff[9] E. A. G. Schuur,[5] C. S. Zender[1]

Table 1. Radiative forcing associated with the Donnelly Flats fire.

Forcing agent	Radiative forcing* [W (m^2 burned)$^{-1}$]	
	Year 1	Years 0 to 80 (mean)
Long-lived greenhouse gases (CH_4 and CO_2)	8 ± 3	1.6 ± 0.8
Ozone	6 ± 4	0.1 ± 0.1
Black carbon deposition on snow	3 ± 3	0.0 ± 0.0
Black carbon deposition on sea ice	5 ± 4	0.1 ± 0.1
Aerosols (direct radiative forcing)†	17 ± 30	0.2 ± 0.4
Impact at the surface: −90 W ± 35 m^{-2}		
Changes in post-fire surface albedo	−5 ± 2	−4.2 ± 2.0
Total‡	34 ± 31	−2.3 ± 2.2

Warming from biogenic CO_2 emissions

Cooling from albedo

Net effect

Combined climate and carbon-cycle effects of large-scale deforestation

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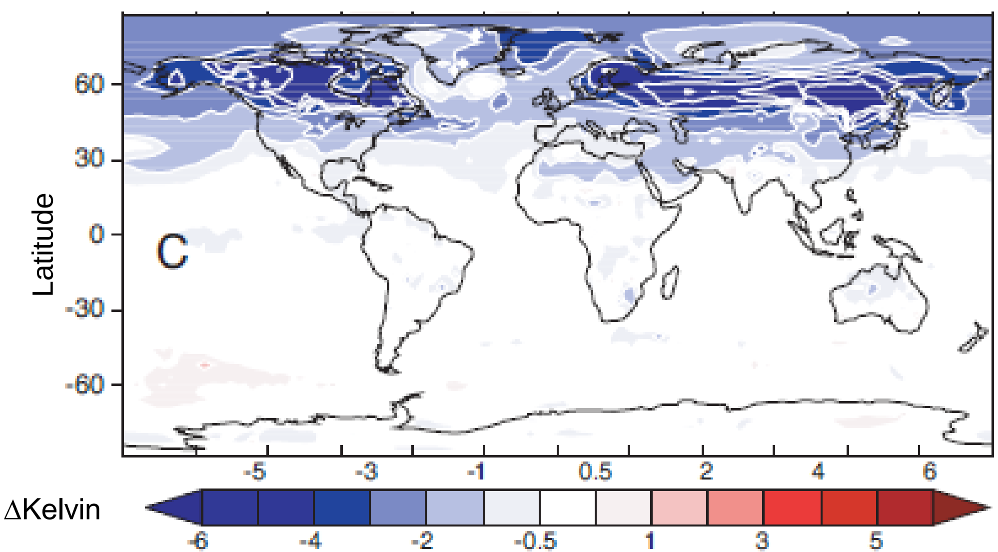
The prevention of deforestation and promotion of afforestation have often been cited as strategies to slow global warming. transpiration rates and increase sensible heat f regionally decreased precipitation and increa

Large scale deforestation in northern latitudes

↓

Net strong cooling effect on climate (albedo cooling dominates over CO_2 warming)



- Bala et al., *PNAS*, (2007)

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Other biogeophysical factors

Changes in surface albedo, evapotranspiration, longwave radiation fluxes, etc.

They can be measured:

1. Through flux towers located on site
2. Through satellite observations

We need to link changes in these factors with climate impacts

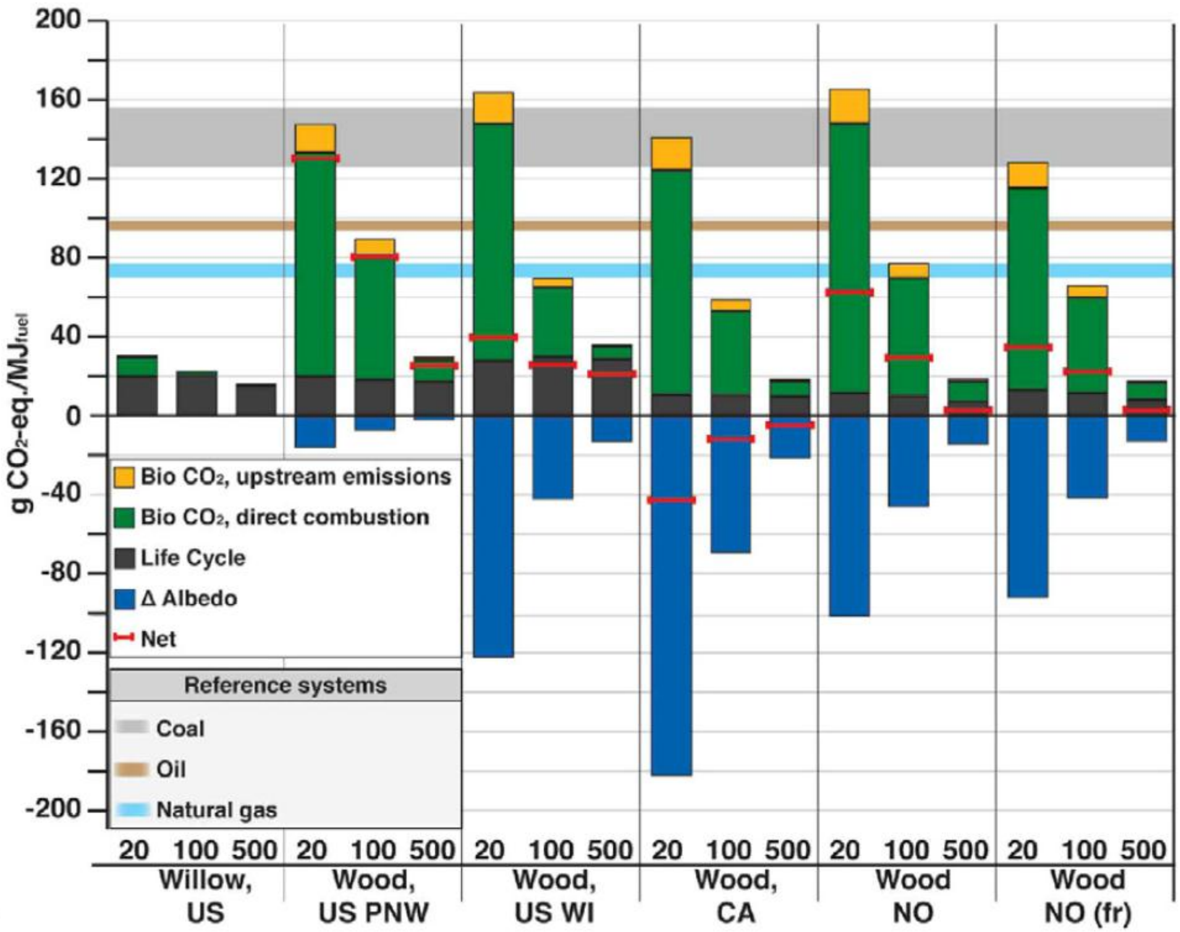
Discern global and local climate impacts

Global impacts: through radiative forcing

Local impacts: local effects on, e.g., surface temperature

Indirect effects of local impacts on global climate: limited

LCA of Heat production: Biomass vs. Fossils
Direct contributions to global warming



Under the default C neutrality assumption
&
Neglection of albedo contributions

The impact covered is only that in black bars!

The risk of mis-quantifying the direct climate impact of bioenergy would be high

NO: Norway, Norwegian spruce, rotation period 100 years
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Investigation of the issues of scale

Conversion of a fully grown forest (FGF) to a managed forest (MF)
Example: boreal forest in Southern Norway

- Single stand
  - Unit pulse emission from one single harvest event
- Landscape level analysis
  - Continuous series of pulse emissions
  - Forest divided in multiple stands (100), one stand harvested per year

Benchmark:

- *Single stand*: unit pulse emission
- *Landscape level*: continuous series of pulse emissions

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Summary

- The new normative framework for bioenergy should be rooted in physics and not in conventions or default assumptions
- Global climate impacts beyond CO_2 (e.g., albedo) cannot be neglected
- Bioenergy and Climate: no "one size fits all" rhetoric
- Direct climate impact from forest bioenergy is lower than that from fossil energy:
  - In the long term
    - Always
  - In the short and medium term
    - If cooling contributions from albedo are strong
    - If temperature is taken as metric

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NTNU research on bioenergy and climate

- IRFs and GWPs of biogenic CO_2 for bioenergy
  - Cherubini, F., G. P. Peters, T. Berntsen, A. H. Strømman and E. Hertwich (2011). "CO2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming." GCB Bioenergy 3(5): 413-426.
  - Cherubini, F., A. H. Strømman and E. Hertwich (2011). "Effects of boreal forest management practices on the climate impact of CO2 emissions from bioenergy." Ecological Modelling 223(1): 59-66.
- IRFs and GWPs of biogenic CO_2 for biomaterials (HWP)
  - Cherubini, F., G. Guest and A. H. Strømman (2012). "Application of probability distributions to the modeling of biogenic CO2 fluxes in life cycle assessment." GCB Bioenergy 4(6): 784-798.
  - Guest, G., F. Cherubini and A. H. Strømman (2012). "Global Warming Potential of Carbon Dioxide Emissions from Biomass Stored in the Anthroposphere and Used for Bioenergy at End of Life." Journal of Industrial Ecology: In press.
- Influence of forest residues on GWPs and IRFs for biogenic CO_2
  - Guest, G., F. Cherubini and A. H. Strømman (2013). "The role of forest residues in the accounting for the global warming potential of bioenergy." GCB Bioenergy In press.
  - Guest, G., F. Cherubini, and A. H. Strømman (2013) "Climate impact potential of utilizing forest residues for bioenergy in Norway." Mitigation and Adaptation Strategies for Global Change: In press.
- Combination of impacts from biogenic CO_2 and albedo
  - Cherubini, F., R. M. Bright and A. H. Strømman (2013). "Site-specific global warming potentials of biogenic CO2 for bioenergy: contributions from carbon fluxes and albedo dynamics." Environmental Research Letters In press.
  - Bright, R. M., A. H. Strømman, G. Peters (2011). "Radiative Forcing Impacts of Boreal Forest Biofuels: A Scenario Study for Norway in Light of Albedo." Environmental Science & Technology 45(17): 7570-7580.
- Bioenergy and biodiversity
  - Michelsen, O., F. Cherubini, A. H. Strømman. (2012). "Impact Assessment of Biodiversity and Carbon Pools from Land Use and Land Use Changes in Life Cycle Assessment, Exemplified with Forestry Operations in Norway." Journal of Industrial Ecology 16(2): 231-242.

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