Radiative forcing effects of forest fertilization and biomass substitution

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Background

- Forest growth in boreal forests with mineral soil is often limited by nitrogen availability
- Fertilization can more than double biomass productivity in some stands (Bergh et al. 1999)
- Previous research using static (i.e. non-time-dependent) methods shows that the net GHG balance of forest fertilization is positive, i.e. avoided emissions due to increased substitution and C-stock are greater than additional emissions due to fertilization (Sathre et al. 2010)

Question

- Fertilization occurs first and substitution and C-stock increase occur later, so:

- Does fertilization of boreal forests reduce radiative forcing?

Analytical approach

- We compare production and use of biomass from a hectare of fertilized and non-fertilized forest land in northern Sweden
- We calculate annual net emissions of CO_2, N_2O and CH_4 for each system, over a 150-year period with 1-year time steps
- We calculate annual atmospheric concentration decay of each emission, and calculate resulting radiative forcing change for each year

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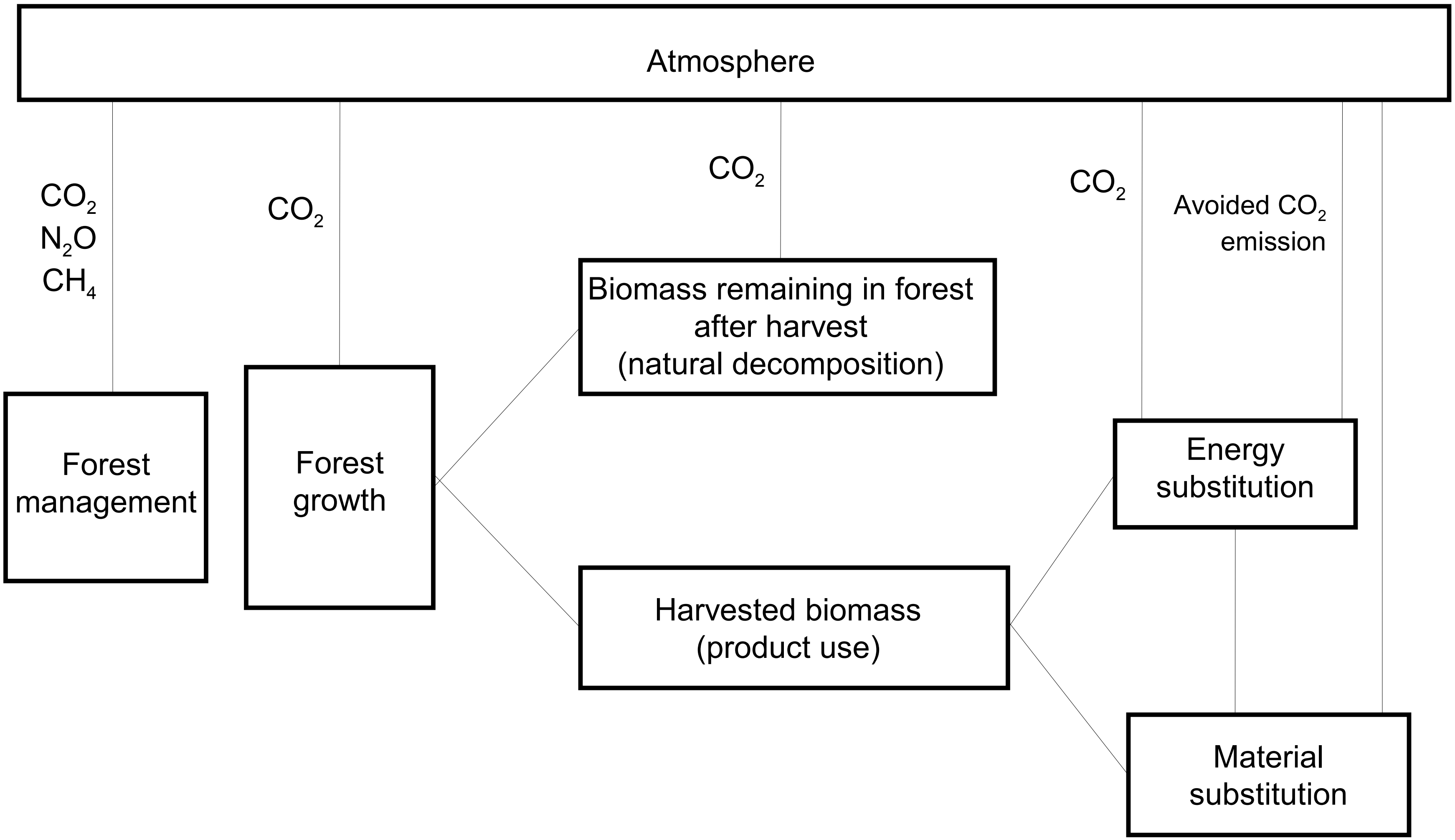
GHG flows and C stock changes considered

- CO_2, N_2O and CH_4 from production and application of fertilizer
- N_2O emission from fertilized soil
- Soil C stock change due to fertilization
- CO_2 from fossil fuels used for biomass harvest and transport
- Avoided CO_2 emissions from using biomass to substitute for materials and fuels
- C-stock change in living trees
- C-stock change in wood products
- C-stock change in soil and decaying biomass

Tracking of GHG stocks and flows



- Dynamics of stocks and flows assessed in 1-year time steps
- Avoided emissions are treated at negative emissions

Forest management and growth

- Unit hectare stands of Norway spruce located in northern Sweden*
- Forest growth modelled with DT model (Sathre et al. 2010)
- Fossil energy used for forest operations (establishment, thinning, harvest, and transport) (Berg and Lindholm 2005)
- Fossil energy used for recovery and transport of forest residues (Eriksson et al. 2007)
- Fossil emissions occur during year of forest operation

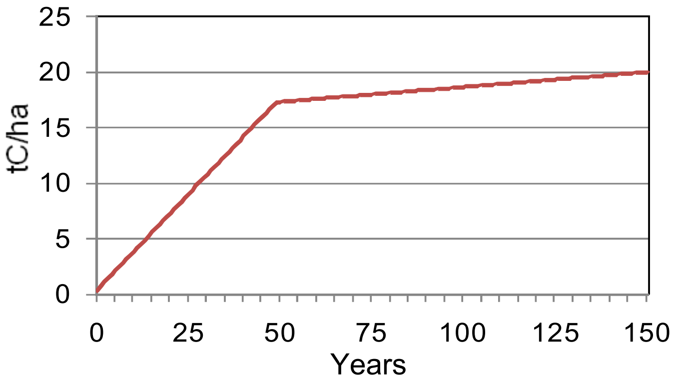
* Effect of fertilization will be less significant in central and southern Sweden

Fertilization (1)

- Fertilized stand receives small, frequent N or NPK doses based on tree needle analyses of nutrient requirements
- We assume 10 applications of 125 kg N during rotation
  (at years 11,13,15,17,19,21,23,33,43,53 of 69-year rotation)
- CO_2, N_2O and CH_4 emission from production of fertilizer (Davis and Haglund 1999)
- CO_2 emission from helicopter application of fertilizer (Mead and Pimentel 2006)

Fertilization (2)

- We assume 1% of the applied N is released as N_2O, during year of application (Nordin et al. 2009)
- We do not consider potential CH_4 oxidation changes in soil
- We assume soil C-stock increase due to fertilization is rapid during first 50 years, then slows (Eriksson et al. 2007)



Harvested biomass:

Large-diameter stemwood used for material substitution

- Used for production of wood construction material to substitute reinforced concrete construction (Gustavsson et al. 2006)
- Avoided material production energy emissions occur at year of harvest
- Residues from wood processing (net after internal use) and construction site used as bioenergy at year of harvest
- Avoided cement process CO_2 emissions occur at different times:
  - Calcination emission at year of harvest
  - Slow carbonation uptake (18%) during 50-year service life
  - Rapid carbonation uptake (20%) when concrete is crushed
  - (Dodoo et al. 2009)
- C-stock in wood building materials during 50-year building life span
- Demolition wood used as bioenergy at end of building life

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Harvested biomass:

Energy substitution to replace fossil fuels

- Slash from thinnings and final harvest: 75% of branches and 25% of needles
- Stumps: 50% of recoverable stumps and coarse roots
- Small-diameter stemwood ("pulpwood"): 100%
  (might also be used for pulp or wood products)
- This biomass substitutes either coal or fossil gas, taking into account relative conversion efficiencies and full fuel-cycle emissions (Gustavsson et al. 2006)
- Combustion emissions return to the atmosphere as CO_2

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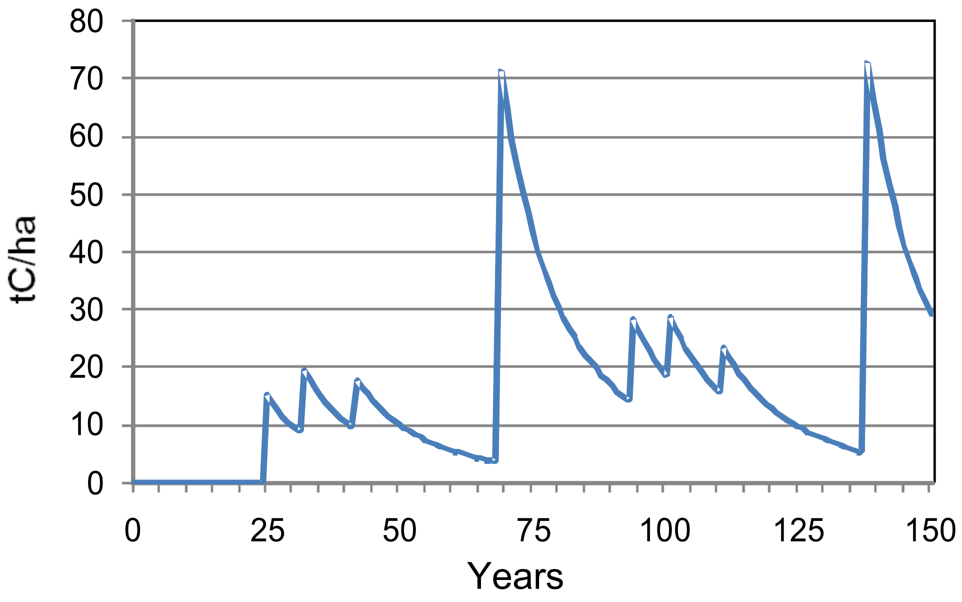
Decay of biomass left in forest

- We assume decay into CO_2 at a negative exponential rate
- Decay constants of:

-0.046 for stumps (Melin et al. 2009)

-0.074 for branches (Palviainen et al. 2004)

-0.170 for needles (Palviainen et al. 2004)



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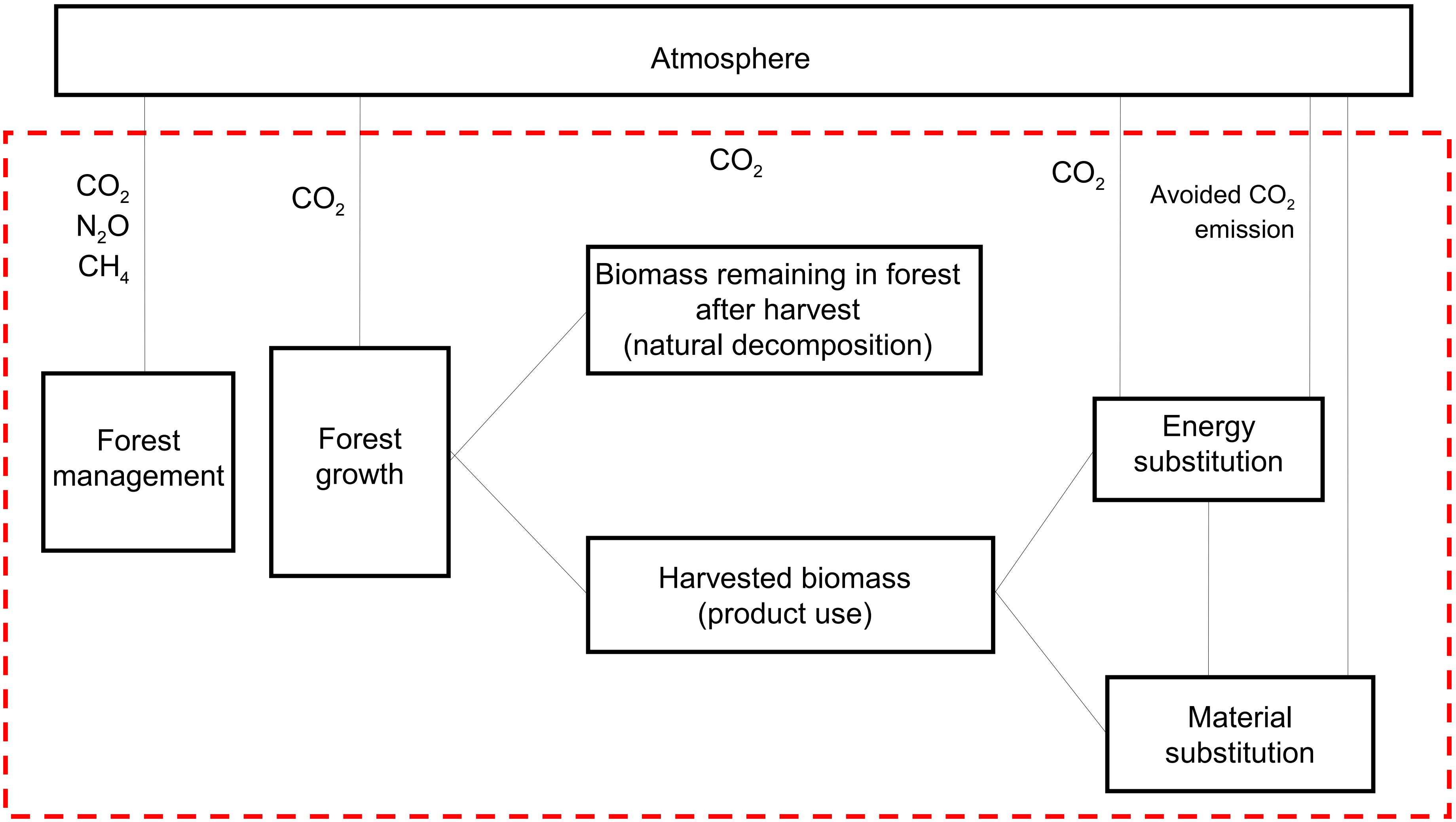
Flows of CO_2, N_2O and CH_4

- Annual net emission of each GHG is treated as a pulse emission



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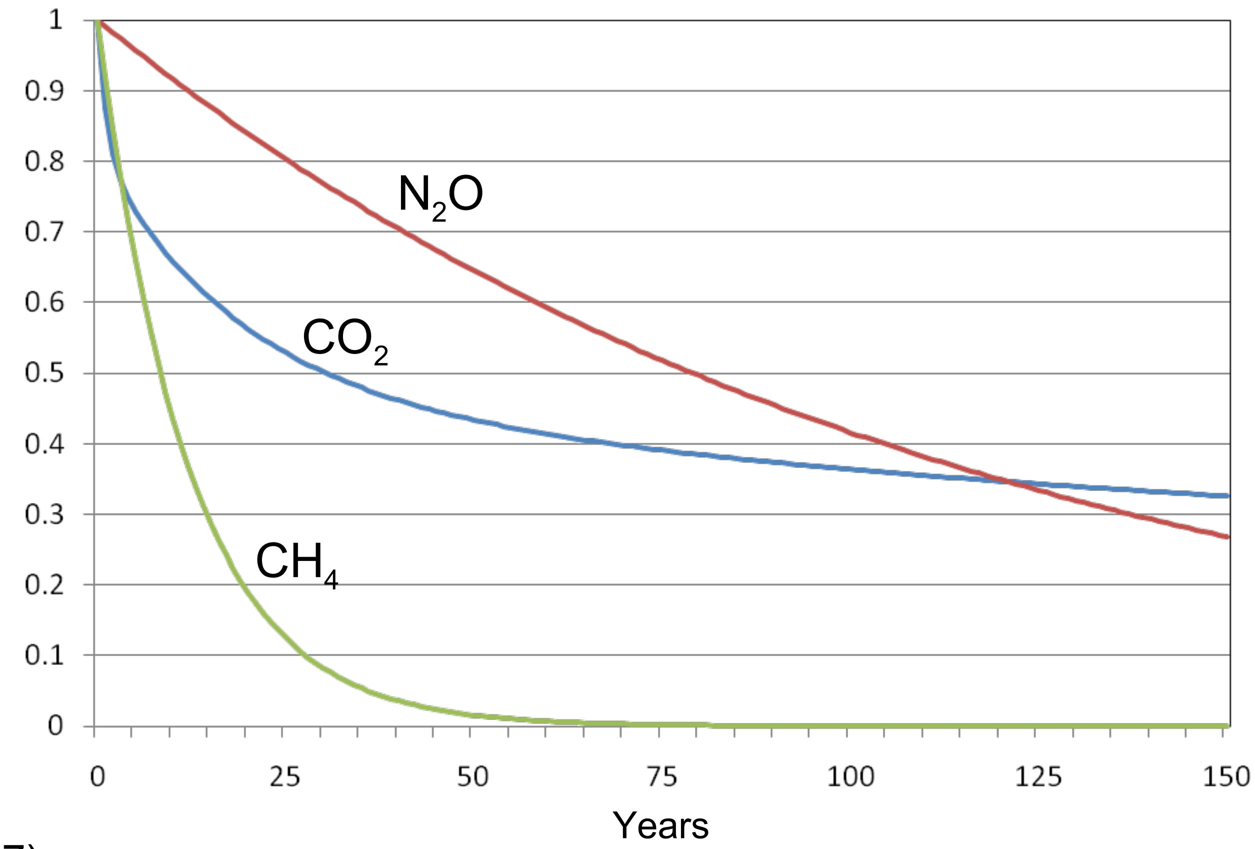
Atmospheric decay of unit pulses of GHGs

$$(CO_2)_t = 0.217 + 0.259e^{\frac{-t}{172.9}} + 0.338e^{\frac{-t}{18.51}} + 0.186e^{\frac{-t}{1.186}}$$

$$(N_2O)_t = e^{\frac{-t}{114}}$$

$$(CH_4)_t = e^{\frac{-t}{12}}$$



(IPCC 1997, 2001, 2007)

Radiative forcing (W/m²) due to GHG concentration change

$$F_{CO_2} = \frac{3.7}{\ln(2)} \times \ln\left\{1 + \frac{\Delta CO_2}{CO_{2ref}}\right\}$$

$$F_{N_2O} = 0.12 \times \left(\sqrt{\Delta N_2O + N_2O_{ref}} - \sqrt{N_2O_{ref}}\right)$$

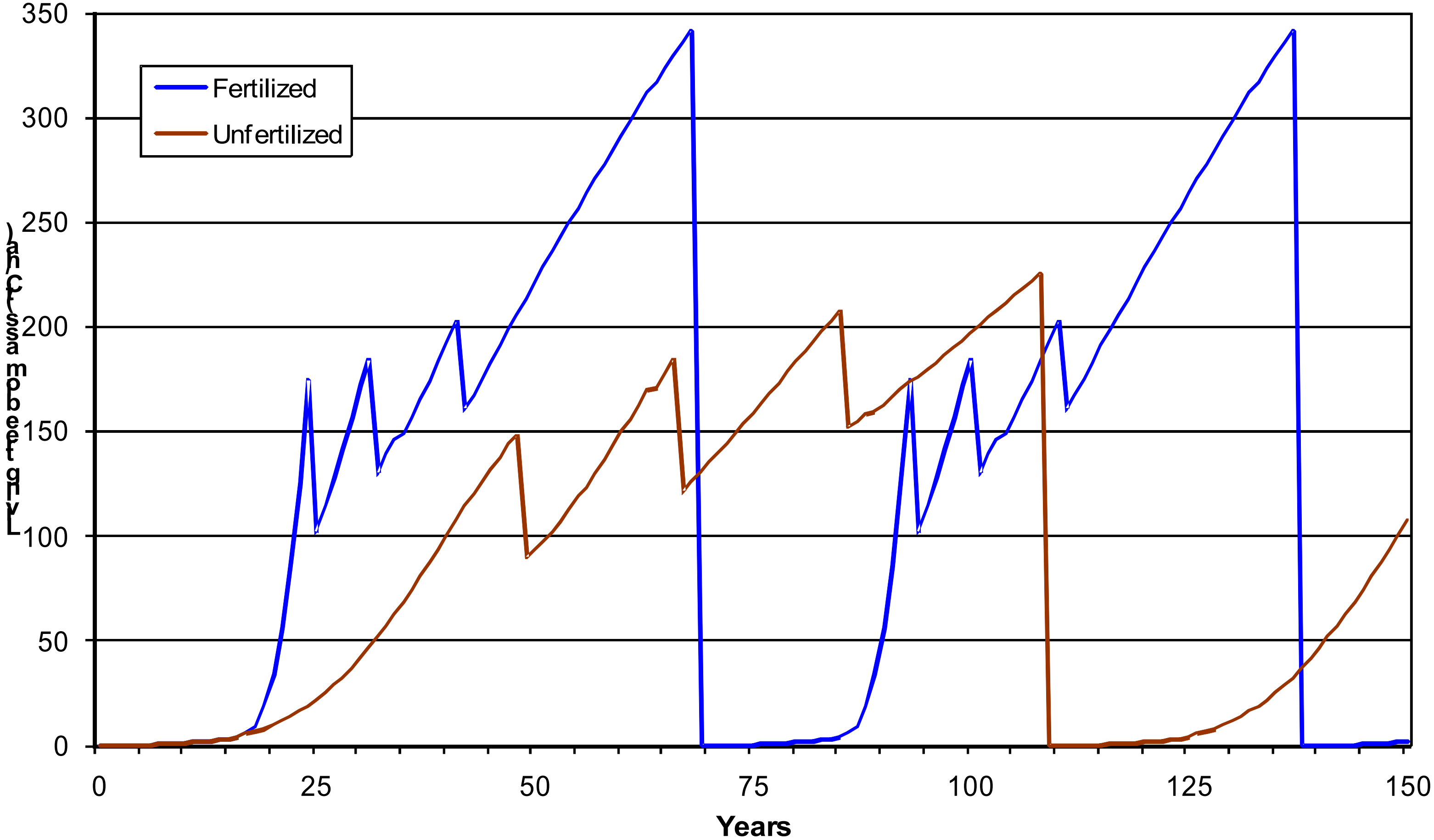
$$F_{CH_4} = 0.036 \times \left(\sqrt{\Delta CH_4 + CH_{4ref}} - \sqrt{CH_{4ref}}\right)$$

where CO_{2ref} = 383ppmv, N_2O_{ref} = 319ppbv, CH_{4ref} = 1774ppbv

- Assumes relatively minor marginal changes in GHG concentrations
- Spectral overlap between N_2O and CH_4 is not considered
- Radiative forcing not related to GHGs (e.g. albedo change) is not considered

(IPCC 1997, 2001, 2007)

Tree biomass production



- Average production rate is about doubled by fertilization
- Large-diameter stemwood is 38% of total biomass

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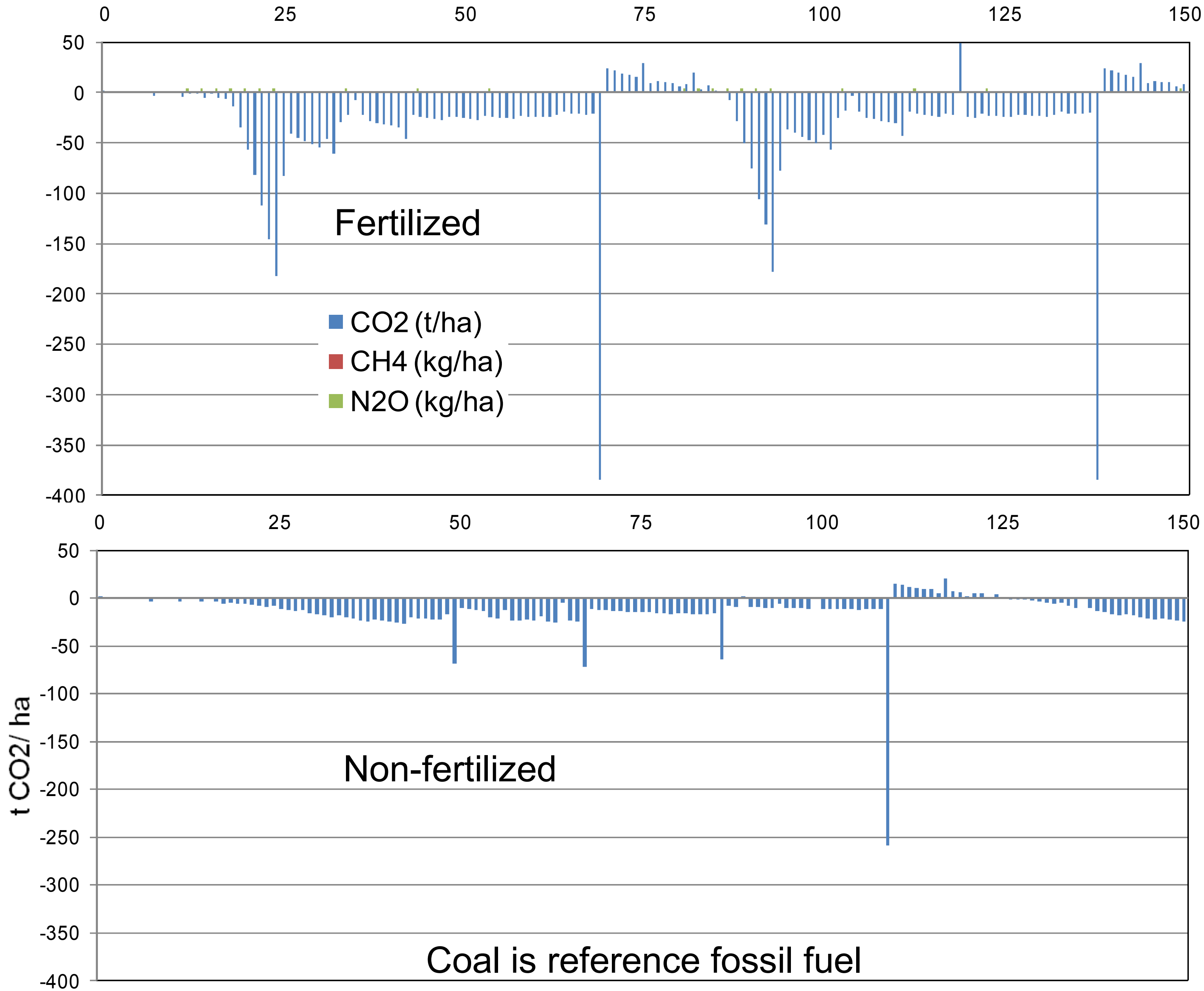
Annual net emissions



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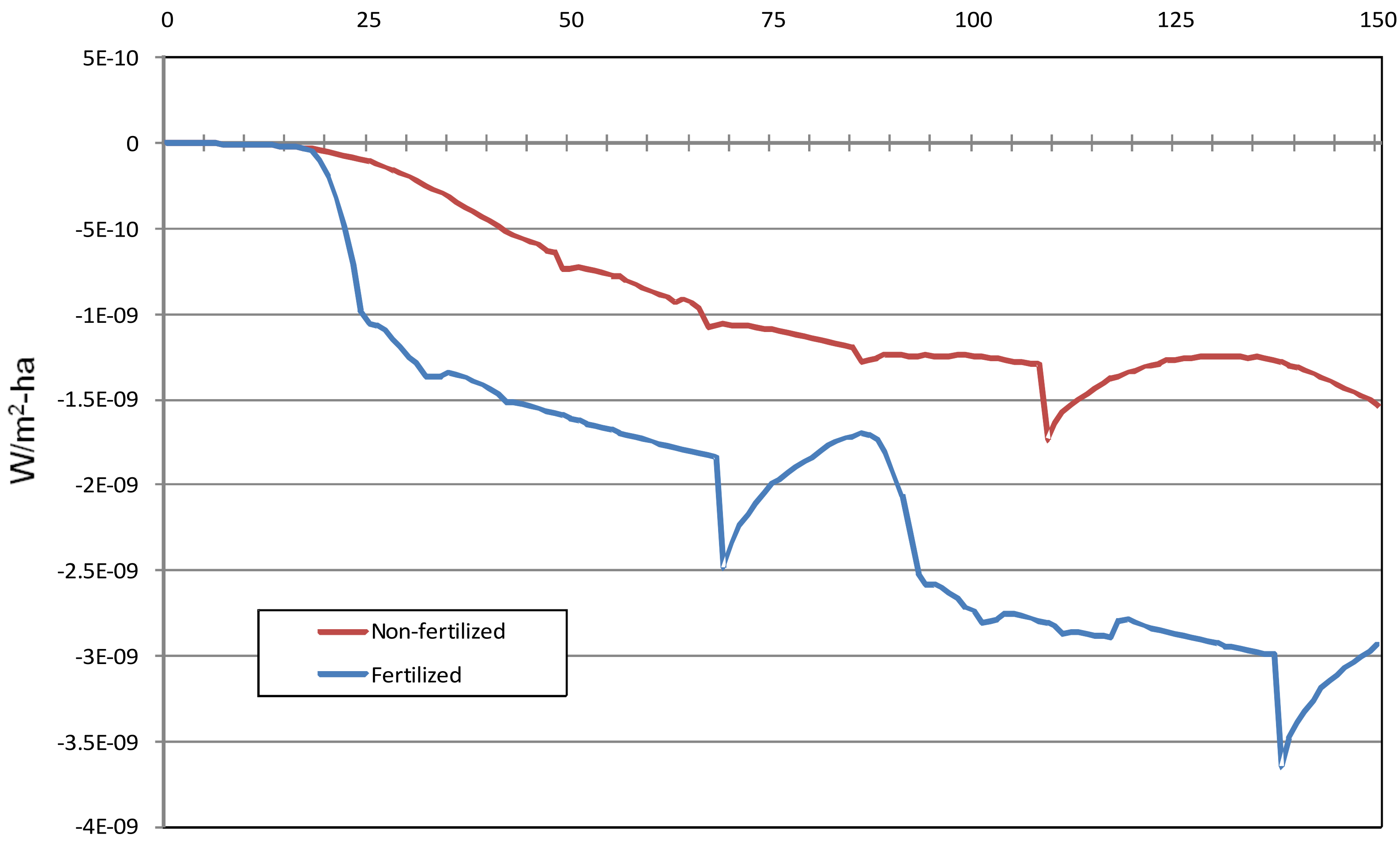
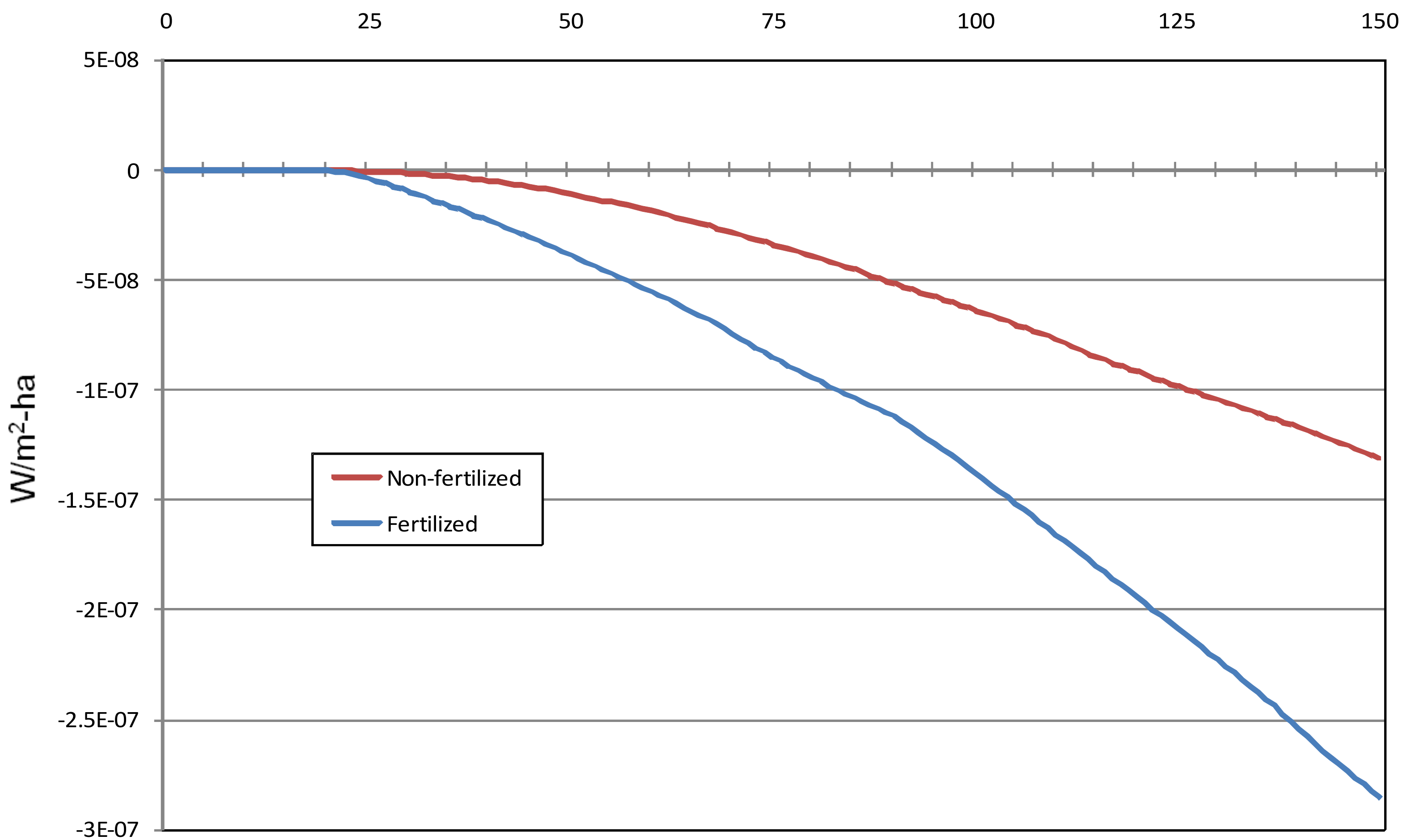
Annual radiative forcing



- Coal is reference fossil fuel

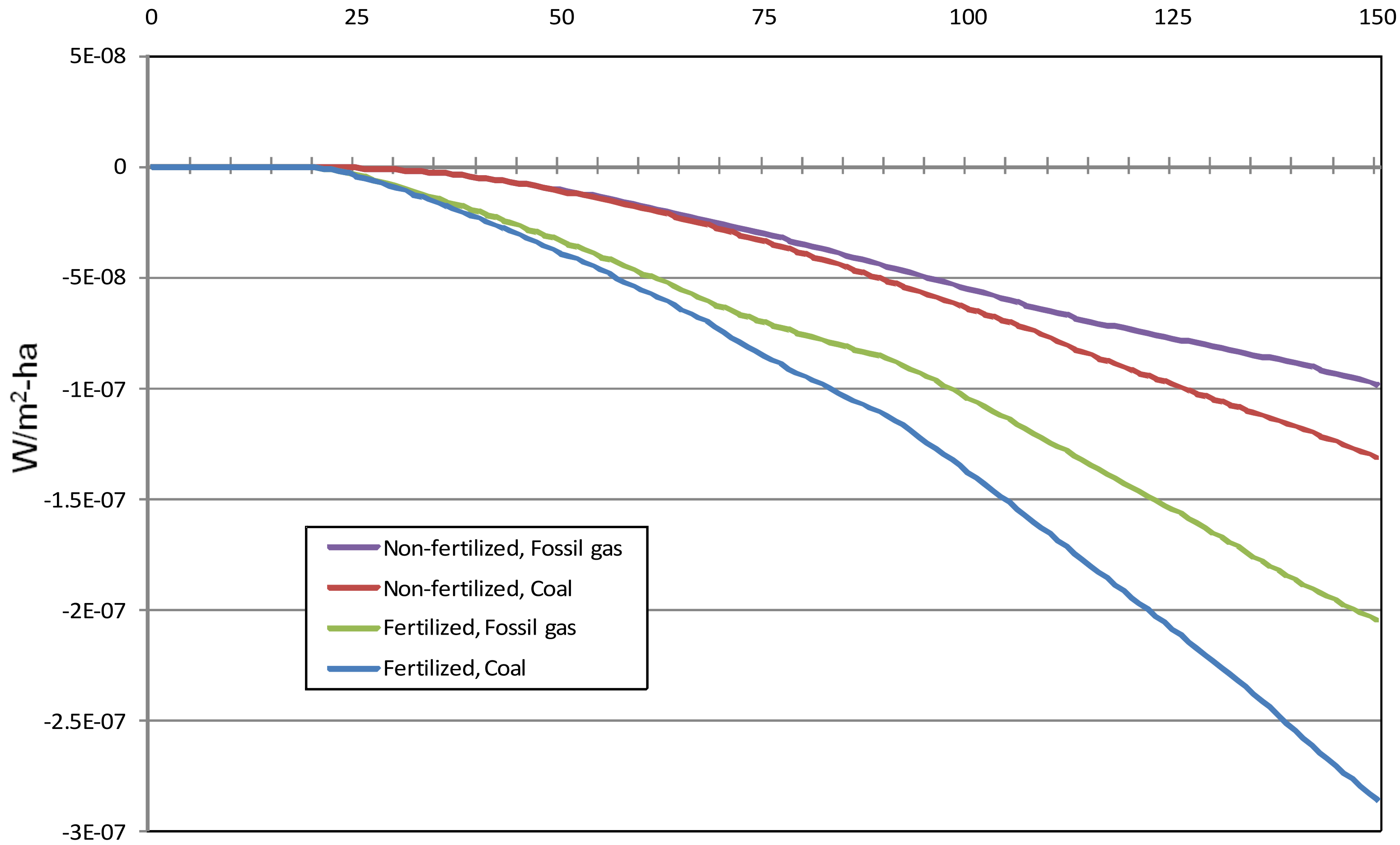
Cumulative radiative forcing



- Coal is reference fossil fuel

Cumulative radiative forcing:

Coal or fossil gas is reference fossil fuel



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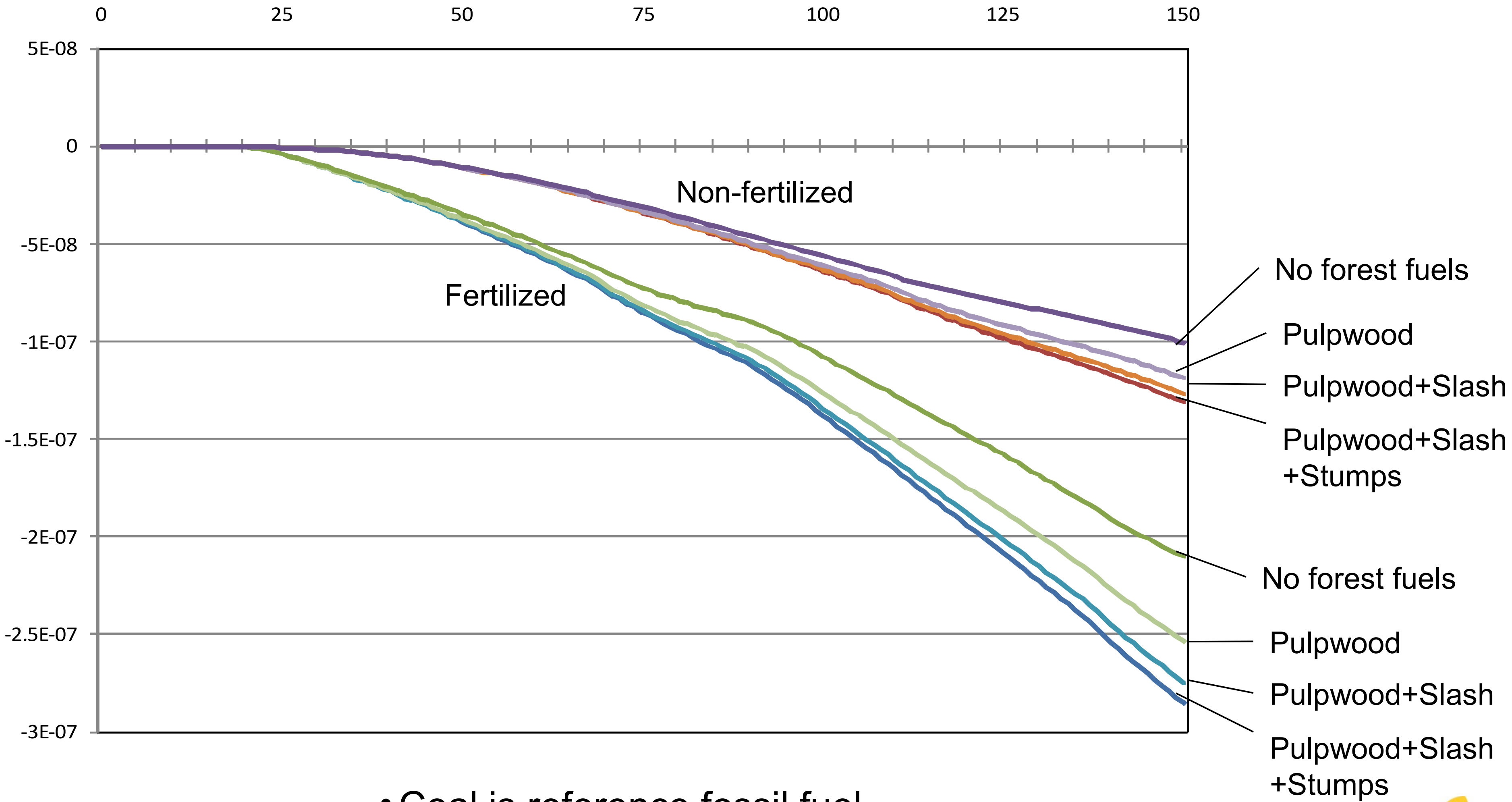
Cumulative radiative forcing:

Different forest fuel recovery amounts



- Coal is reference fossil fuel

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Conclusions

- Forest fertilization can significantly increase biomass production
- Material and energy substitution potentials increase when fertilization is used
- Average C stock in tree biomass, forest soils and wood products increase when fertilization is used
- Additional GHG emissions due to fertilization are small compared to increases in substitution benefits and C-stock
- Annual and cumulative radiative forcing is consistently lower for the fertilized forest system

Thank you

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