Integrated biomaterial and bioenergy implications of balanced forest fertilization in Sweden

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Background

Forest biomass can be used as biofuel (energy) and biomaterial, to reduce GHG emission.

Nitrogen availability often limits forest growth in boreal forests with mineral soil.

We analyzed the energy and GHG implications of using balanced fertilization on 10% of Swedish forest land.

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We consider energy flows from:

- Fossil fuels used for biomass production and logistics
- Manufacture and application of fertilizer
- Biomass recovered for use as biofuel
- Energy use reduction due to material substitution

The baseline is the current forestry practice.

Thus, we quantify *changes from the current system*.

We consider GHG flows and stock changes from:

- Production and application of fertilizer
- N_2O emission from fertilized soil
- Soil C stock change due to fertilization
- Soil C stock change due to biomass residue removal
- Fossil fuels used for biomass harvest and transport
- Avoided emissions from using biomass to substitute for materials and fuels
- C stock changes in living trees
- C stock changes in wood products

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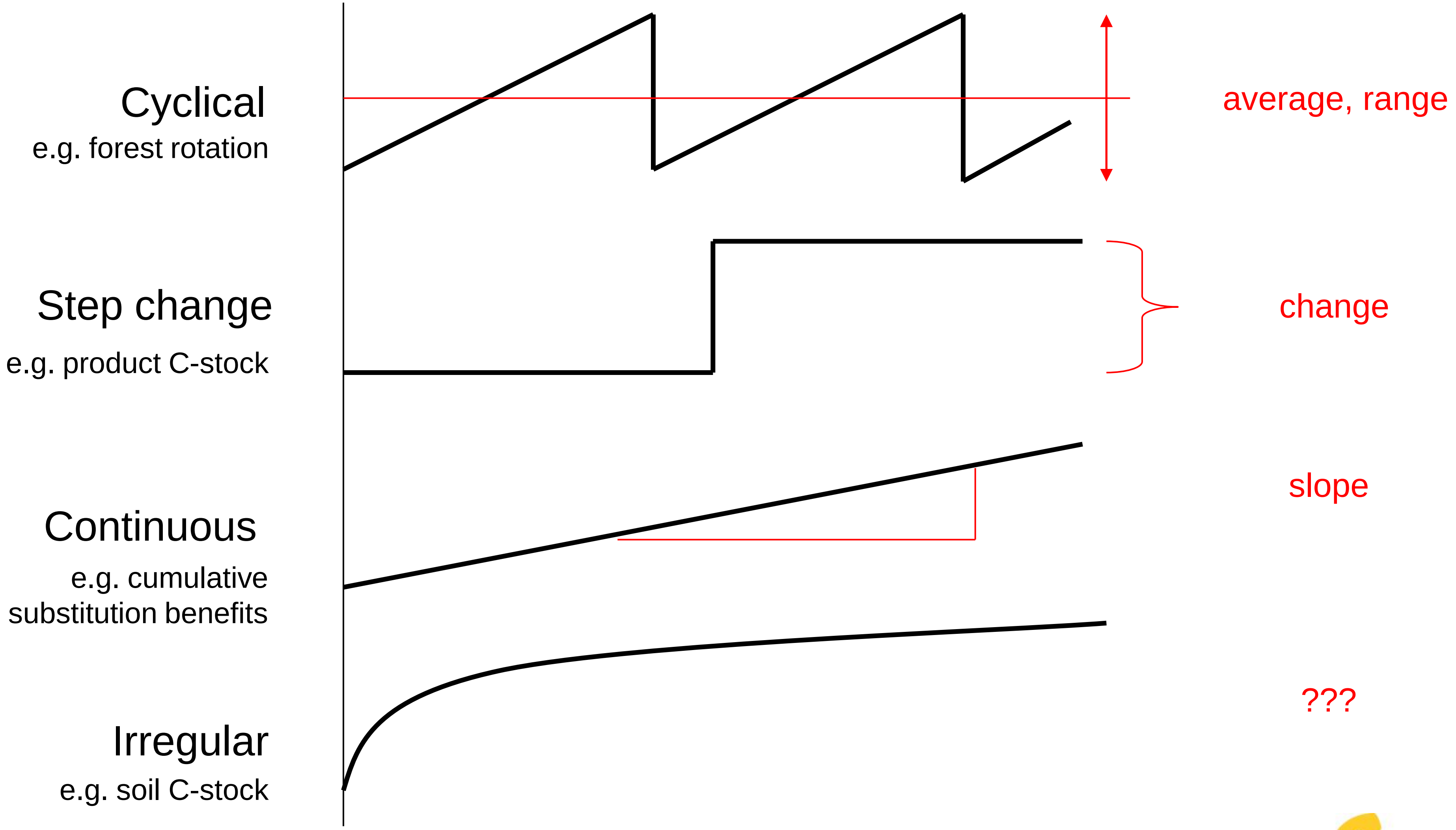
Time dynamics of GHG flows



We use **0% discount rate** (no preference toward present or future)

Fertilization and biomass production

- Norway spuce stands, modelled with DT model
- N and NPK applied 5-10 times during rotation, based on needle analysis of nutrient requirement
- 800-1500 kg N / ha applied during rotation

Annual N fertilizer applied and increased annual biomass production

Amount of applied nitrogen (10^3 ton N)	48.7
Increased stemwood volume (10^3 m^3)	12632
Increased stemwood biomass (10^3 oven-dry ton)	5076
Increased branch biomass (10^3 oven-dry ton)	1721
Increased needle biomass (10^3 oven-dry ton)	597
Increased root biomass (10^3 oven-dry ton)	1785
Increased total biomass (10^3 oven-dry ton)	9179

N-use efficiency is 3.9 kg N per m^3 additional stemwood

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Biomass assortment

- Large-diameter stemwood: 100% used for production of wood construction material (replaces concrete).
- Small-diameter stemwood: 100% used either for biofuel or for pulp.
- Thinning residues: 75% of branches and 25% of needles, used for biofuel.
- Final harvest residues: 75% of branches and 25% of needles, used for biofuel.
- Stumps: 100% of recoverable stumps and roots, not including fine roots, used for biofuel.

Biofuels replace either coal or fossil gas.

Annual energy and GHG flows

	Energy	GHG	
	PJ/year	10^3 tC_{eq}/year	
		Coal	Fossil Gas
Forest management			
establishment, thinning, harvest	0.93	20.9	20.2
Fertilization			
production and application	2.29	127.1	127.1
N_2O emission from soil	0	62.2	62.2
soil C stock change	0	-183.2	-183.2
Large-diameter stemwood			
transport	0.73	16.9	15.4
material substitution (fossil fuel)	-35.31	-851.9	-655.0
material substitution (cement process)	0	-871.9	-871.9
fuel substitution (processing residue)	-24.48	-736.7	-421.8
fuel substitution (construction residue)	-2.54	-76.4	-43.8
fuel substitution (demolition residue)	-22.70	-682.7	-391.1
Small-diameter stemwood			
transport	0.49	11.3	10.3
fuel substitution	-31.14	-934.1	-538.1
Thinning residue (branches/foliage)			
recovery/transport	0.40	8.8	8.8
soil C stock change	0	27.7	27.7
fuel substitution	-7.96	-238.7	-137.5
Harvest residue (branches/foliage)			
recovery/transport	0.71	15.5	15.5
soil C stock change	0	49.2	49.2
fuel substitution	-14.12	-423.7	-244.0
Stumps			
recovery/transport	2.74	60.2	60.2
soil C stock change	0	113.4	113.4
fuel substitution	-27.38	-821.4	-473.1
Total	**-157**	**-5307**	**-3450**

positive numbers = used energy GHG emissions
negative numbers = available energy avoided emissions

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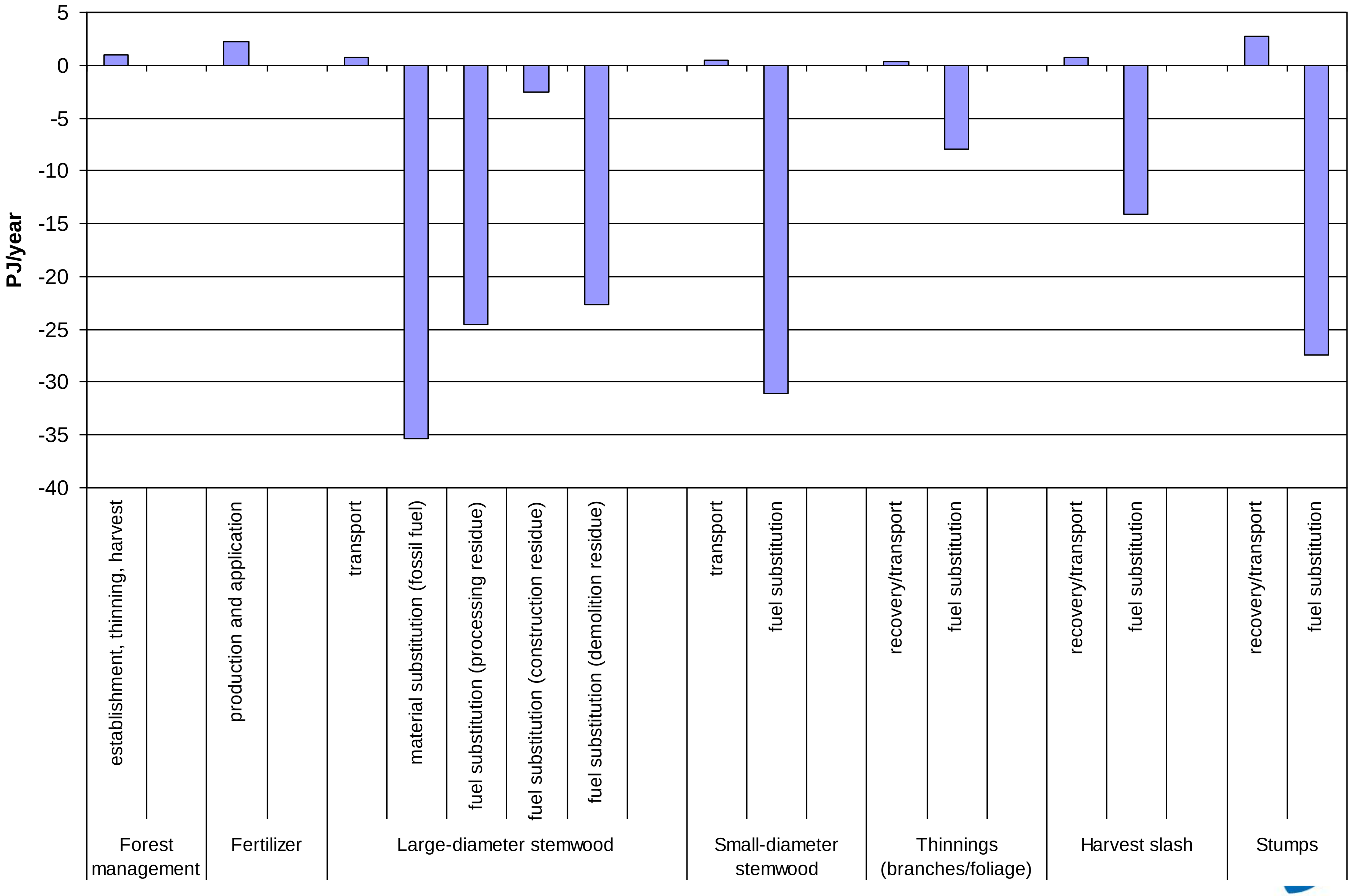
Annual energy flows *(PJ/year)*



Swedish energy use in 2006 = 2240 PJ

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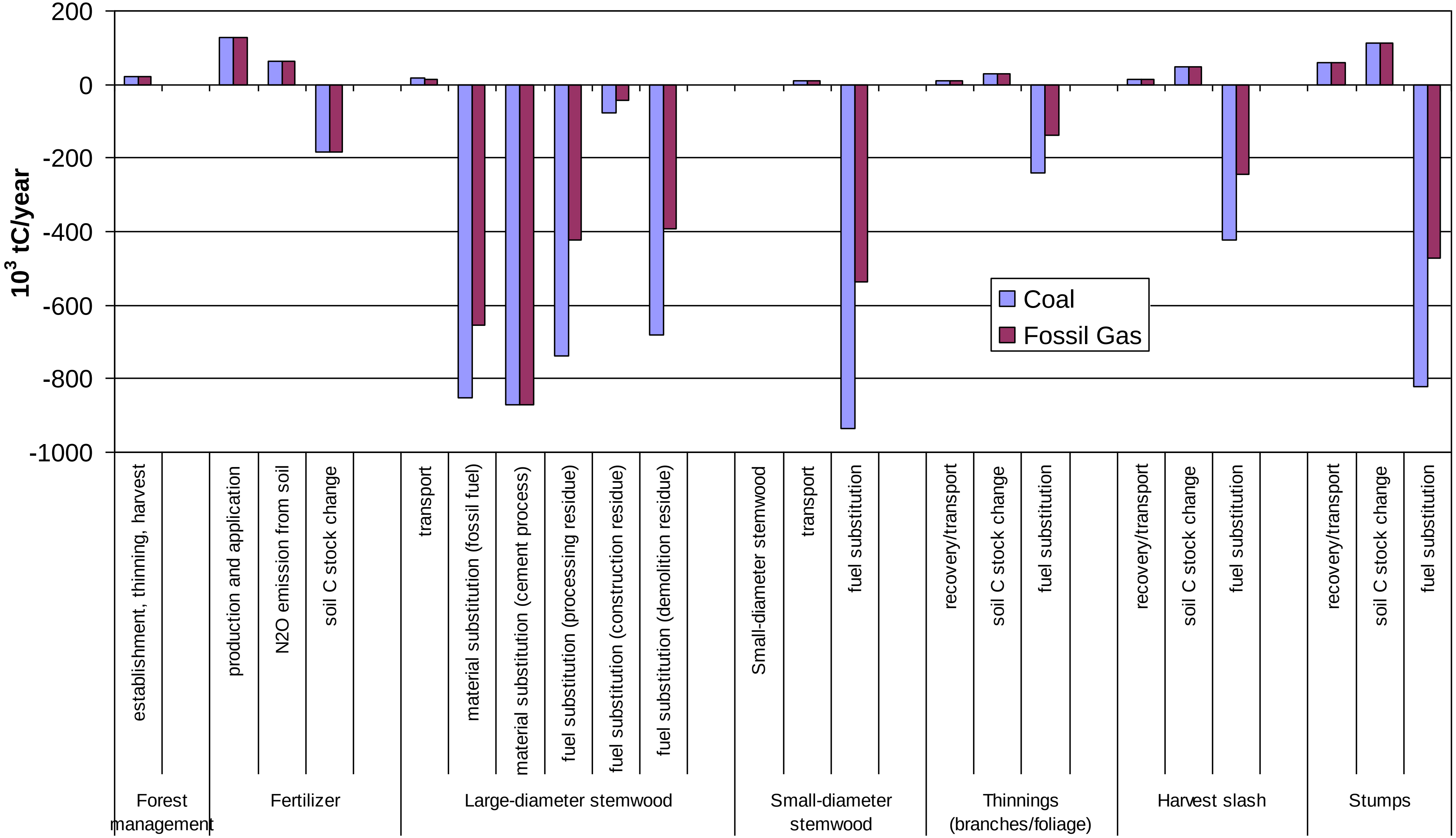
Annual GHG flows *(10^3 tC_{eq}/year)*



Swedish GHG emissions in 2006 = 17.9 million tC_{eq}

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Carbon stock changes

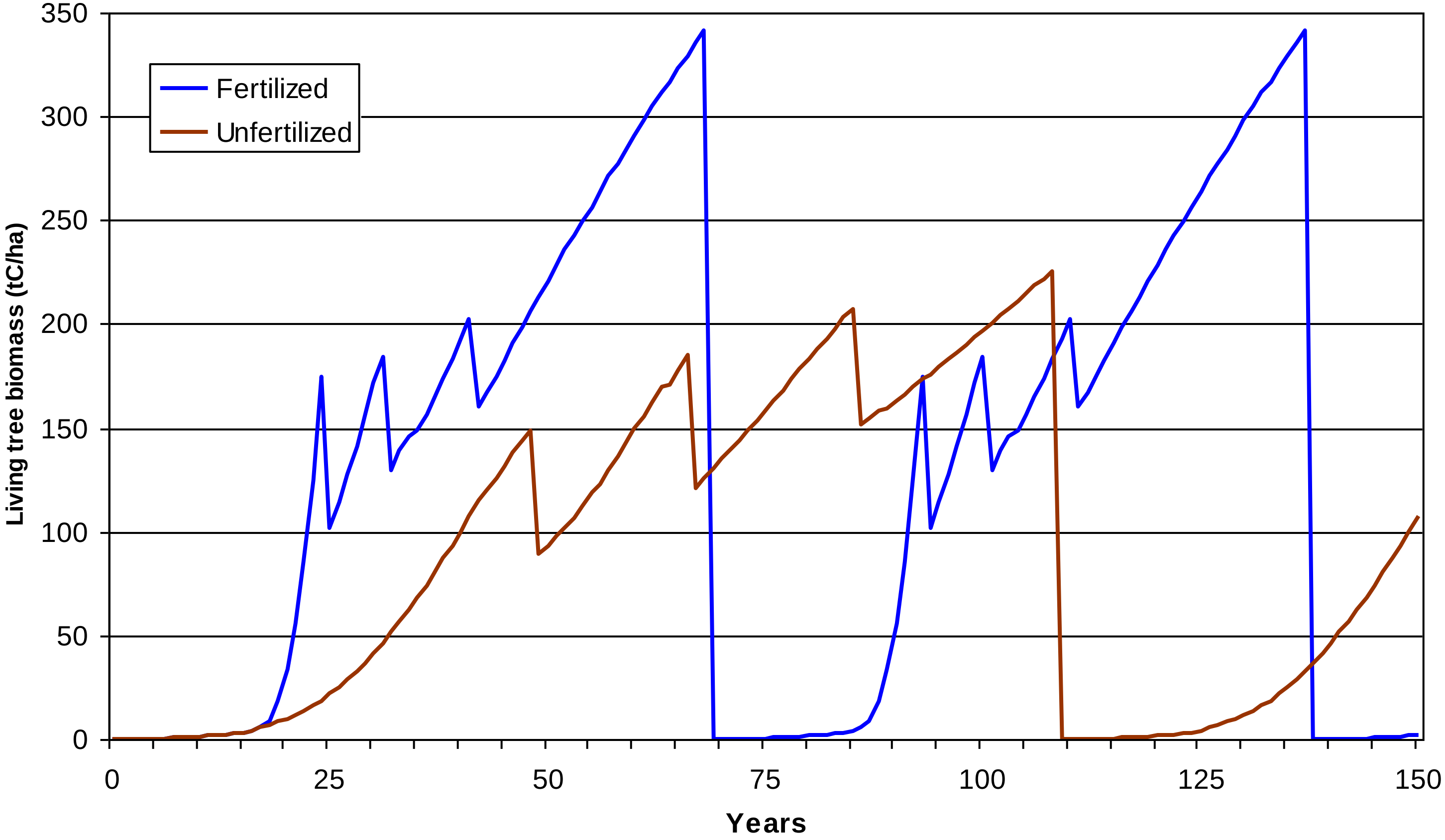
	10^3 tC
Temporary C stock increase in wood products (per year)	813
One-time C stock increase in wood products [a]	40,650
One-time C stock increase in tree biomass [b]	53,900

[a] Assuming a 50-year life span for wood products, and continued replacement of demolished buildings with new buildings of equivalent wood content.
[b] Assuming continuation of fertilized management and sustainable yield.

Average tree biomass (averaged over full rotation period)

Region	Without fertilization (t dry matter / ha)	With fertilization (t dry matter / ha)	Increase (t dry matter / ha)	Increase (%)
N. Norrland	189	230	41	22
S. Norrland	199	251	52	26
Svealand	209	267	58	28
Götaland	251	280	29	12

Carbon stock in living tree biomass over a 150-year period



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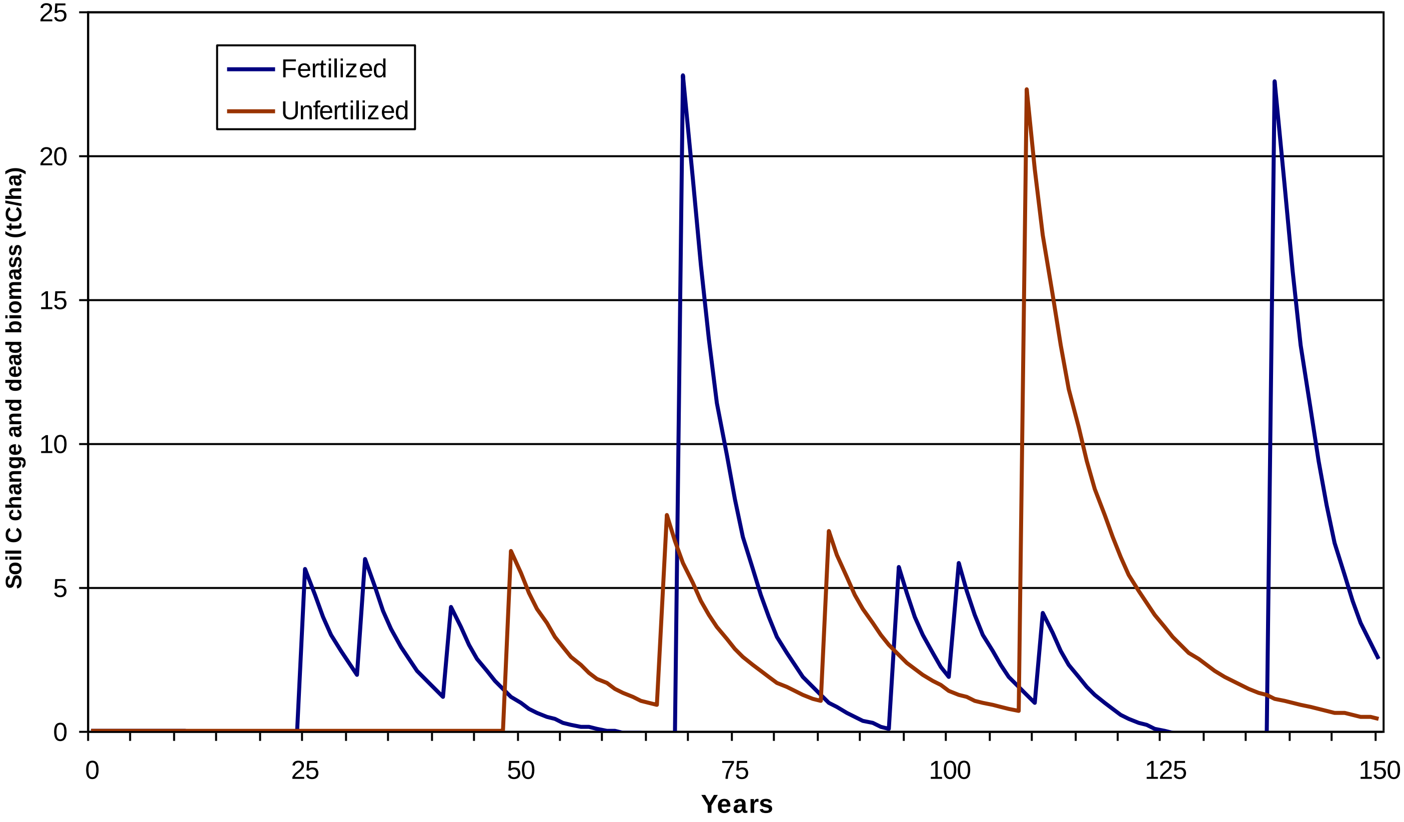
Carbon stock changes in soil and decaying biomass over a 150-year period



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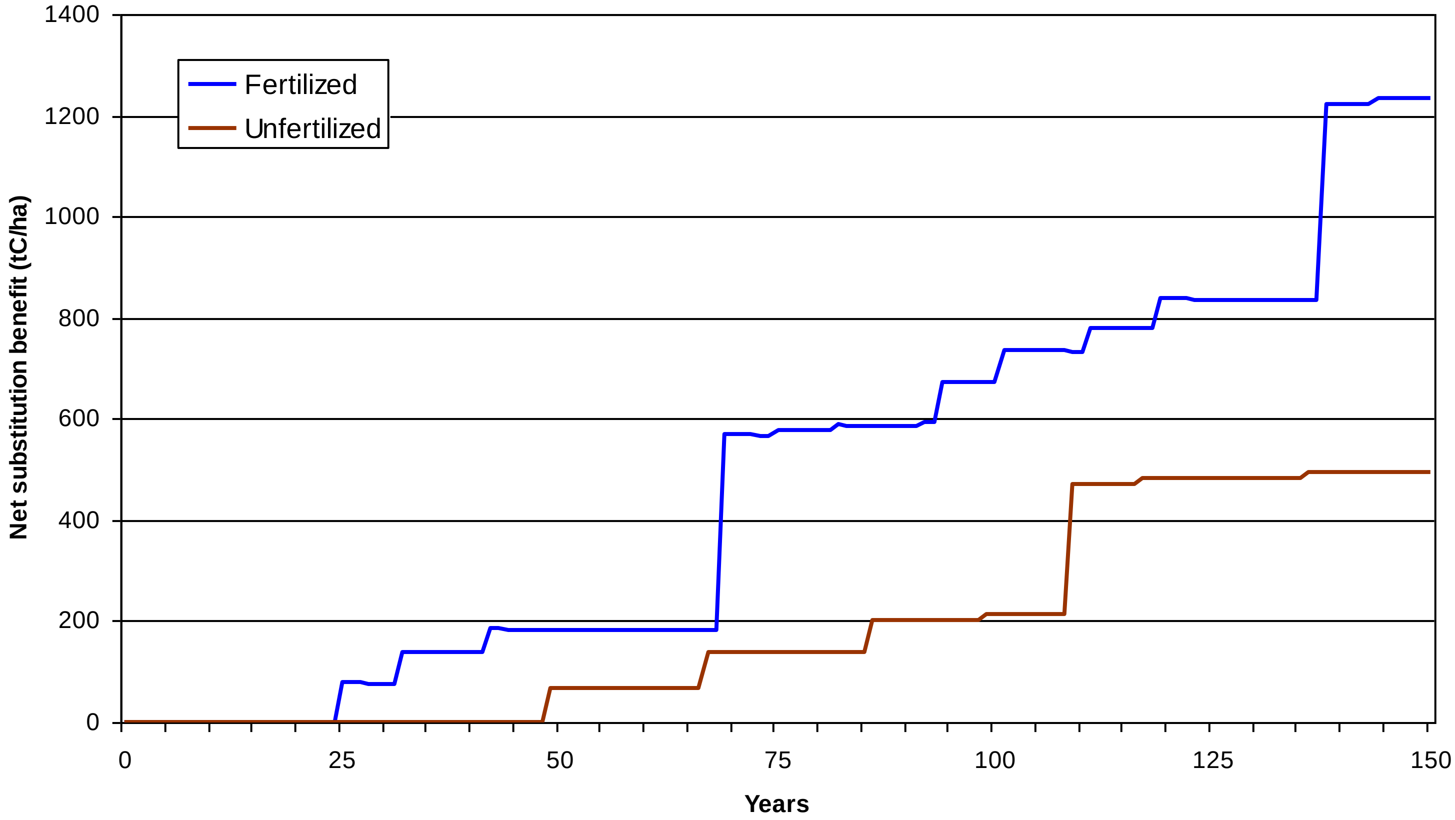
Net substitution benefits of wood product and biofuel use over a 150-year period



Conclusions

- Fertilization of 10% of Swedish forest land can increase the annual production of usable biomass by 8.3 million dry tons.
- This increased production could cover about 7% of Sweden’s energy supply, through material and fuel substitution.
- Of the energy benefit, 22% is decreased energy use due to material substitution, 20% is biofuel from small-diameter stemwood, 17% from wood processing and construction residues, 17% from stumps, and 14% from building demolition residues.
- Net GHG emission could be reduced by 3.4 million or 5.3 million tons C_{eq} if the reference fossil fuel is fossil gas or coal, respectively.
- This annual emission reduction corresponds to 19% or 30%, respectively, of the total Swedish GHG emission in 2006.
- An additional one-time carbon stock increase of 41 and 54 million tons C occurs in wood products and forest trees, respectively.
- Forest fertilization appears to be an attractive option for increasing energy security and reducing net GHG emission.

Thank you

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