# GWP factors and warming payback times as climate indicators of forest biomass use cycles

Quantifying and managing land use effects of bioenergy, 19-21 September 2011, Campinas, Brazil

Kim Pingoud, Tommi Ekholm and Ilkka Savolainen

VTT Technical Research Centre of Finland

# Objectives of the study

- The issue: Climate impact of transient emissions and sustainable long-rotation forestry and wood use
- Wood use C neutral over rotation, but temporary C debt in proportion to no-use baseline
- On the other hand: climate benefits in case wood use has an impact on fossil C emissions
- Method: GWP factors both for biomass resource ($GWP_{bio}$) and displacement of fossil C emissions ($GWP_{biouse}$), Warming Payback Time

# Calculation method

Basic assumption: cumulative radiative forcing (absolute global warming potential) appropriate measure for the climate impacts within some prescribed timeframe

# Generalisation of the $GWP_{bio}$ factors to displaced emissions

- Cherubini et al. (2011): C debt due to biomass harvest, $GWP_{bio}$ factor introduced, analogous to the GWP factors defined for non-$CO_2$ GHGs, whose atmospheric dynamics different
- Schlamadinger and Marland(1996, 1997): Displacement of fossil C emissions by biomass, cumulative C balance of biomass and fossil C stocks, displacement factor DF as indicator of efficiency
- **Present study:** Extension of the $GWP_{bio}$ factors. Climate impacts of displacement of fossil fuels and fossil C intensive products by biomass; also consideration of other than instant pulses

Cherubini F, Peters GP, Berntsen T, Strømman AH, Hertwich E (2011) CO2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming. GCB Bioenergy. DOI: 10.1111/j.1757-1707.2011.01102.x.

Marland G, Schlamadinger B (1997) Forests for carbon sequestration or fossil fuel substitution? A sensitivity analysis. Biomass and Bioenergy 13(6): 389-397.

Schlamadinger, B and, Marland, G (1996) The role of forest and bioenergy strategies in the global carbon cycle. Biomass and Bioenergy 10(5/6):275-300.

# Basis of the radiative forcing calculations (1): GWP factors and AGWPs (cumulative radiative forcing)

Cumulative radiative forcing of fossil C pulse emission (irreversible, no flow back to tectonic C stocks):

$$AGWP_{fos}(T) = \int_0^T RF\left(S_{fos}(t)\right) dt \qquad (1)$$

where *RF* is the instant radiative forcing, and *S* the additional atmospheric concentration due to the emission; concentration dynamics calculated by the impulse response model by IPCC.

Cumulative radiative forcing of biogenic C pulse emission due to harvest (reversible, sequestered back to biomass on the same area of land, if forestry on sustainable basis):

$$AGWP_{bio}(T) = \int_0^T RF\left(S_{bio}(t)\right) dt \qquad (2)$$

Note: also other climatic forcers than GHGs (e.g. surface albedo) could be included in AGWP.

# Basis of the radiative forcing calculations (2): GWP factors and AGWPs (cumulative radiative forcing)

Similar integral can be presented for the climate benefits of the harvested biomass use cycle with respect to its fossil alternatives:

$$AGWP_{biouse}(T) = \int_0^T \left(RF\left(S_{displ}(t)\right) + RF\left(S_{seq}(t)\right)\right) dt \qquad (3)$$

where $\boldsymbol{S_{displ}}$ and $\boldsymbol{S_{seq}}$ are the atmospheric concentration changes due to displaced fossil C emissions and to biogenic C sequestered into wood products, respectively.

# Basis of the radiative forcing calculations (3): GWP factors and AGWPs (cumulative radiative forcing)

Relative climate impact of the biogenic C pulse emission (incl regrowth) in proportion an equal fossil C pulse emission (no flow back to tectonic stocks) (Cherubini et al. 2011):

$$GWP_{bio}(T) = \frac{AGWP_{bio}(T)}{AGWP_{fos}(T)} \qquad (4)$$

***GWP*$_{bio}$** factor a dimensionless index, a function of the mitigation timeframe ***T***.

Analogous to definition of GWP factors of non-$CO_2$ GHGs describing their CRF in proportion to $CO_2$; ***T*** = 100 years commonly used.

# Basis of the radiative forcing calculations (4): GWP factors and AGWPs (cumulative radiative forcing)

The GWP index can be generalised to the whole biomass lifecycle, and also to the case where displaced fossil fuel emissions are considered:

$$GWP_{netbio}(T) = \frac{AGWP_{bio}(T) + AGWP_{biouse}(T)}{AGWP_{fos}(T)} \qquad (5)$$

$$= GWP_{bio}(T) + GWP_{biouse}(T) \qquad (6)$$

Where $\boldsymbol{GWP_{netbio}}$ is the GWP of the net climate impact of the biomass harvest and utilisation, and $\boldsymbol{GWP_{biouse}}$ that of the plain use cycle.

# Basis of the radiative forcing calculations (5): GWP factors and AGWPs (cumulative radiative forcing)

Note that in case biomass is used just to bioenergy displacing fossil fuels (no temporary product C stock):

$$GWP_{biouse}(T) = -DF \quad (7)$$

where DF is the displacement factor (Schlamadinger and Marland, 1996 and 1997).

# Results: Case 1

# Bioenergy from forest harvest residues

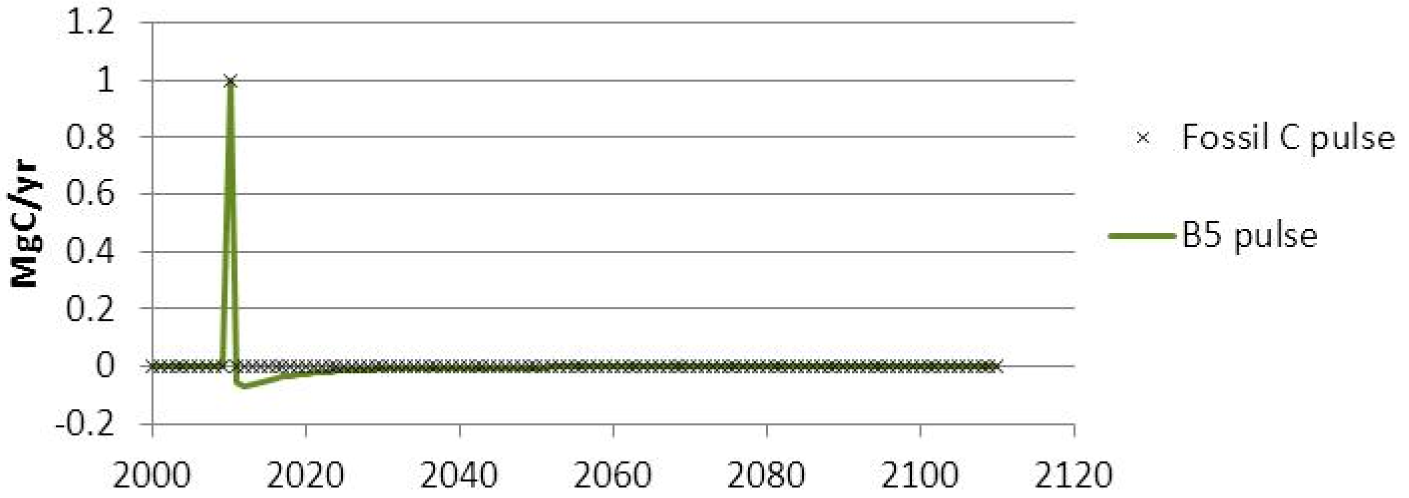
# Case: harvest residues to bioenergy; assumptions:

- Decay of harvest residues or Norway spruce in climate conditions of Southern Finland; from the study of Repo et al.(2010)*.
- Dynamic C debt: Use of residues to bioenergy causes an immediate emission and C debt with respect to no-use baseline where residues decay slowly on site.
- Decay depends on residue diameter. Branches (1 cm, 2 cm, 5 cm) and stumps (10 cm, 20 cm, 26 cm and 35 cm) considered.

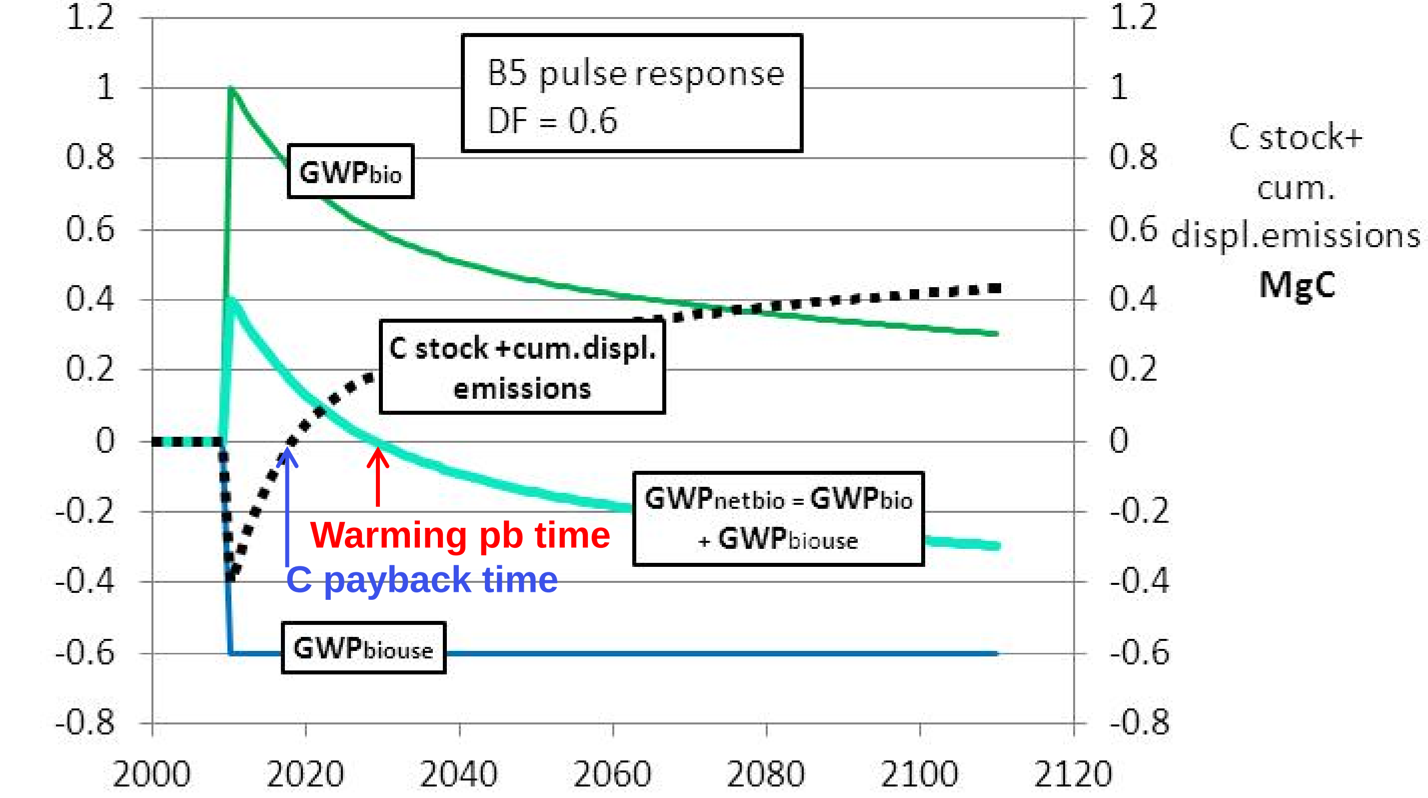
*Repo A, Tuomi M,  Liski J (2010) Indirect carbon dioxide emissions from producing bioenergy from forest harvest residues. GCB Bioenergy. DOI: 10.1111/j.1757-1707.2010.01065.x

Example 1:

- Emission from **pulse use** (1 MgC) of **5 cm branches** vs fossil C pulse at 2010



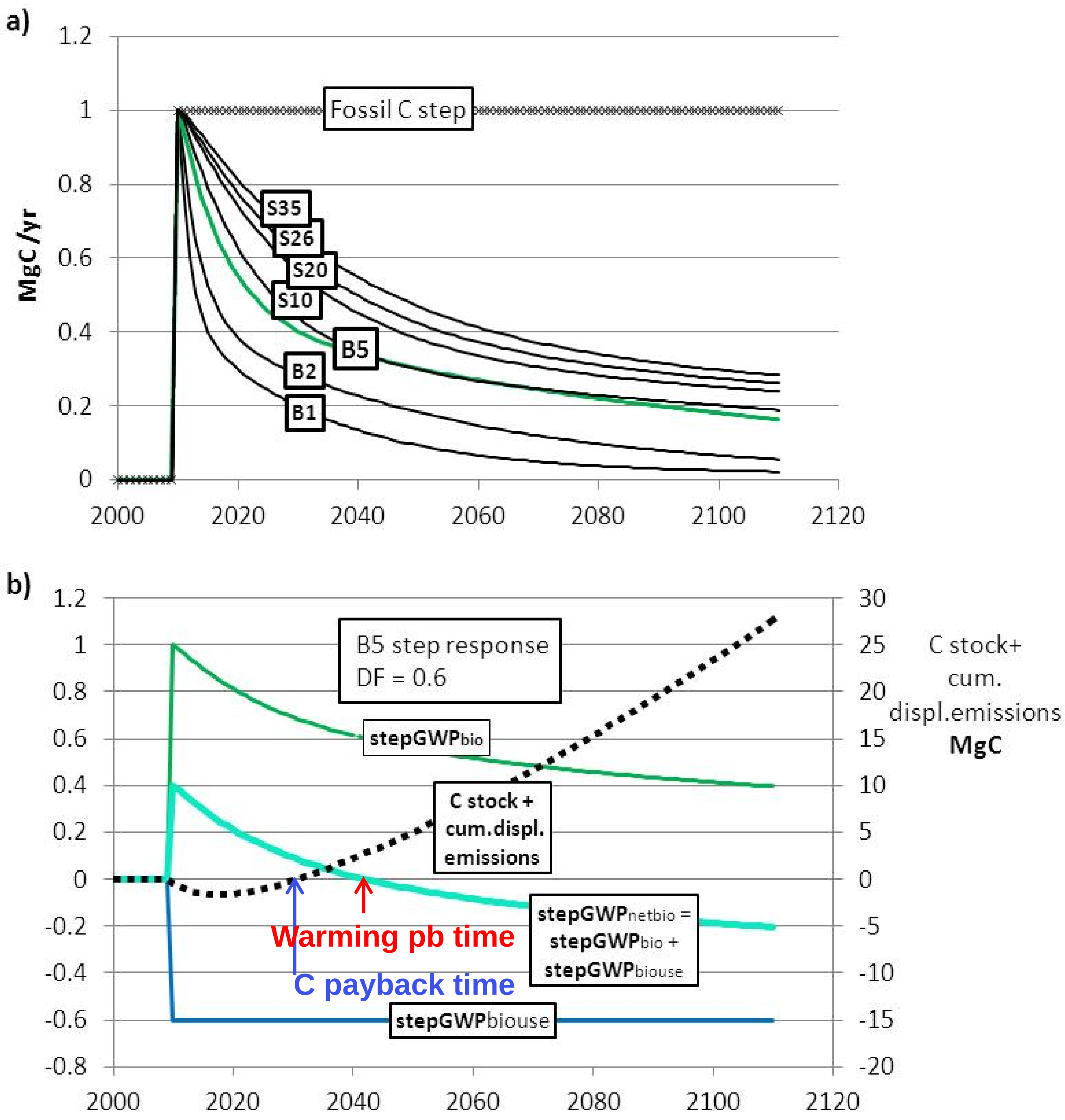

- GWP factors and cumulative C balance of biomass debt and displaced emissions
- Displacement factor DF = 0.6



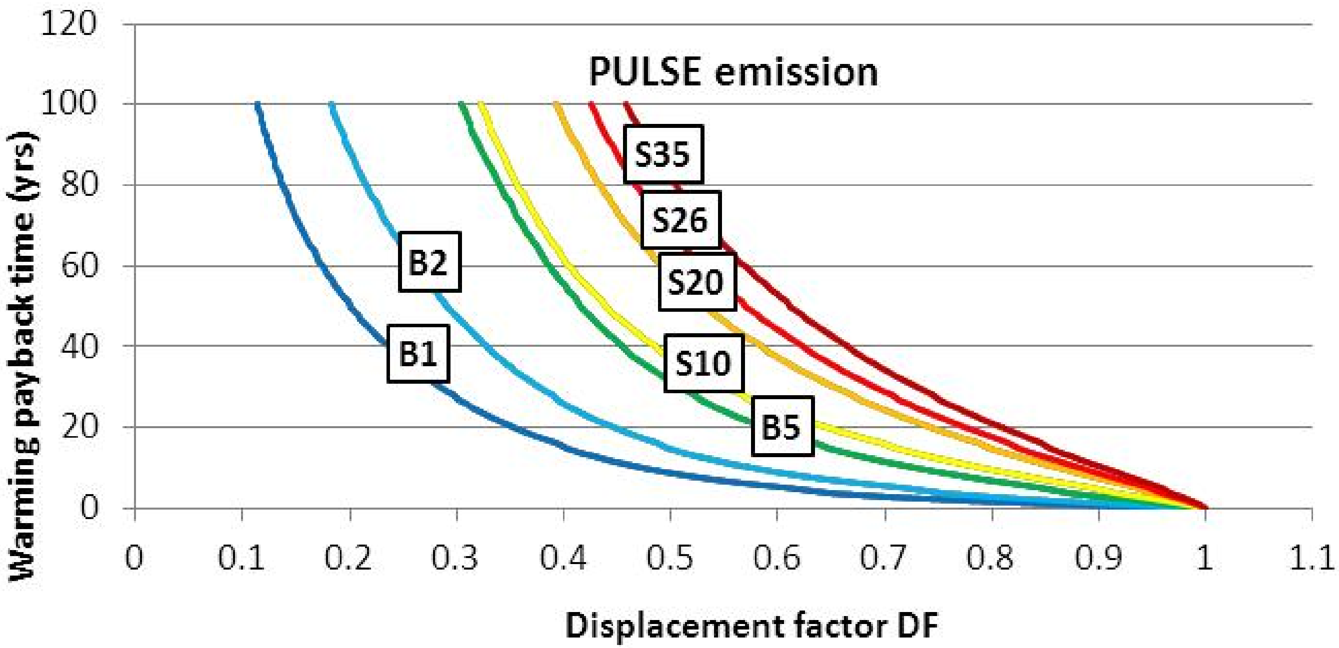
Example 2:

- Emission from **step use** (1 MgC/yr) of **branches and stumps** vs fossil C step at 2010

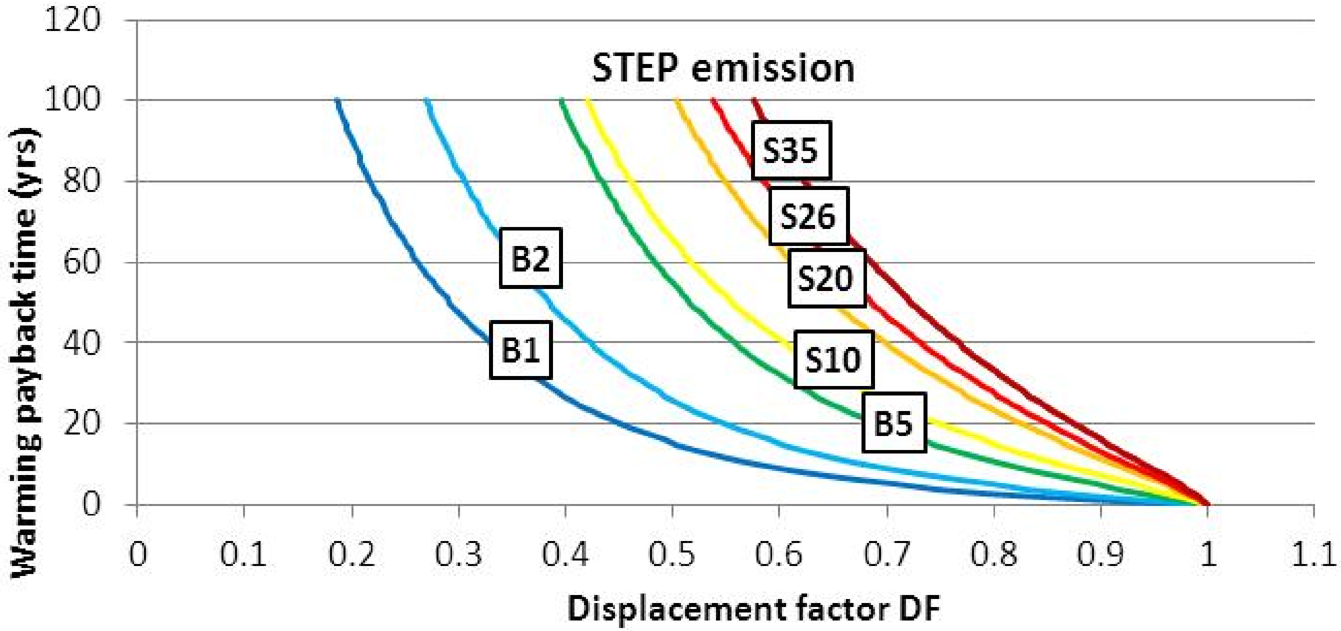
- stepGWP factors (generalisation of the GWP concept) and cumulative C balance of biomass debt and displaced emissions of **bioenergy from 5 cm brances**
- Displacement factor DF = 0.6

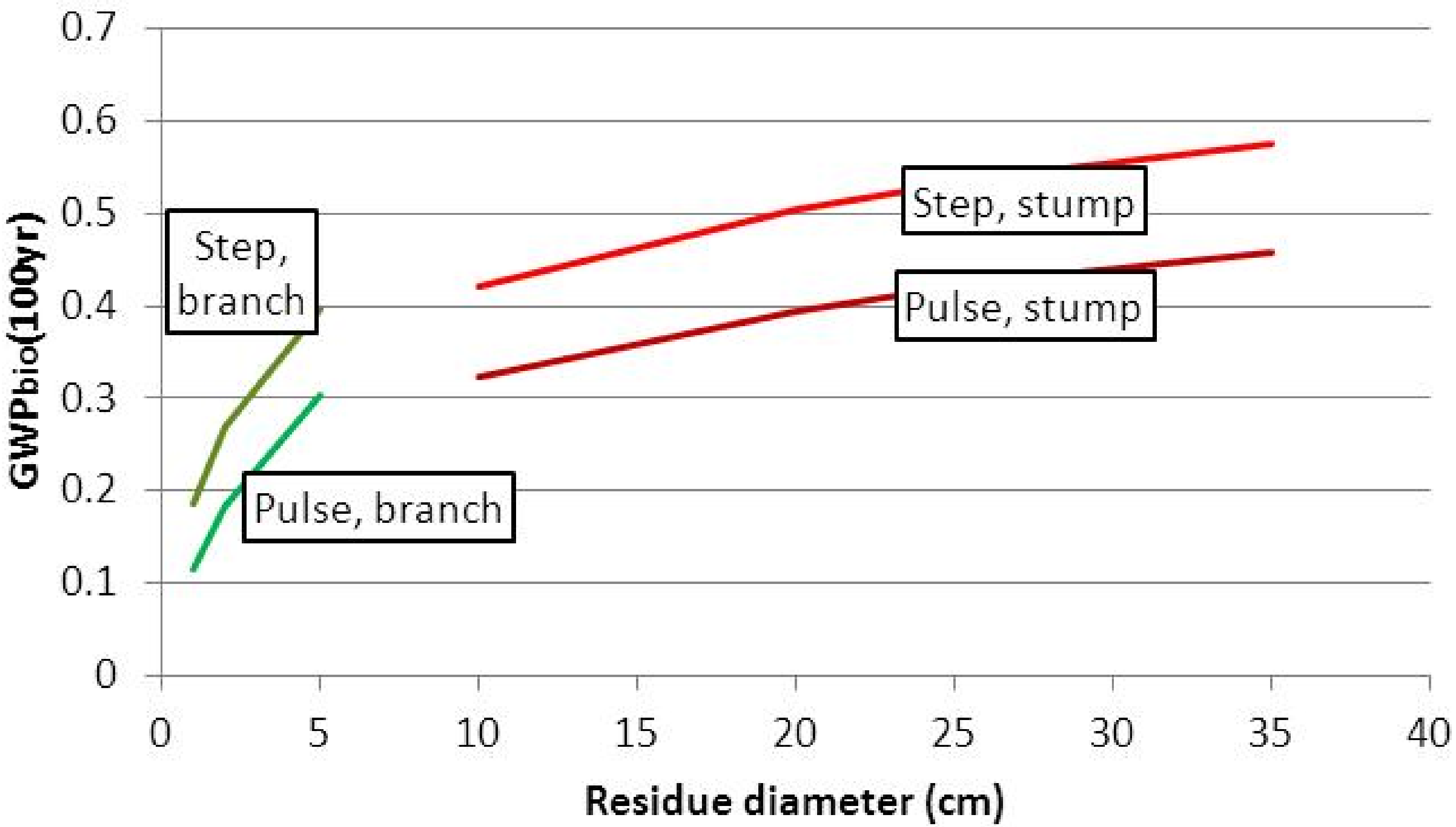


- Warming payback time as a function of DF for **pulse use** of branch and stump harvest residues




- Warming payback time as a function of DF for **step use** of branch and stump harvest residues






$\textit{\textbf{GWP}}_{\textit{\textbf{bio}}}$(100 yrs) of C debt due to harvest residues as a function residue diameter

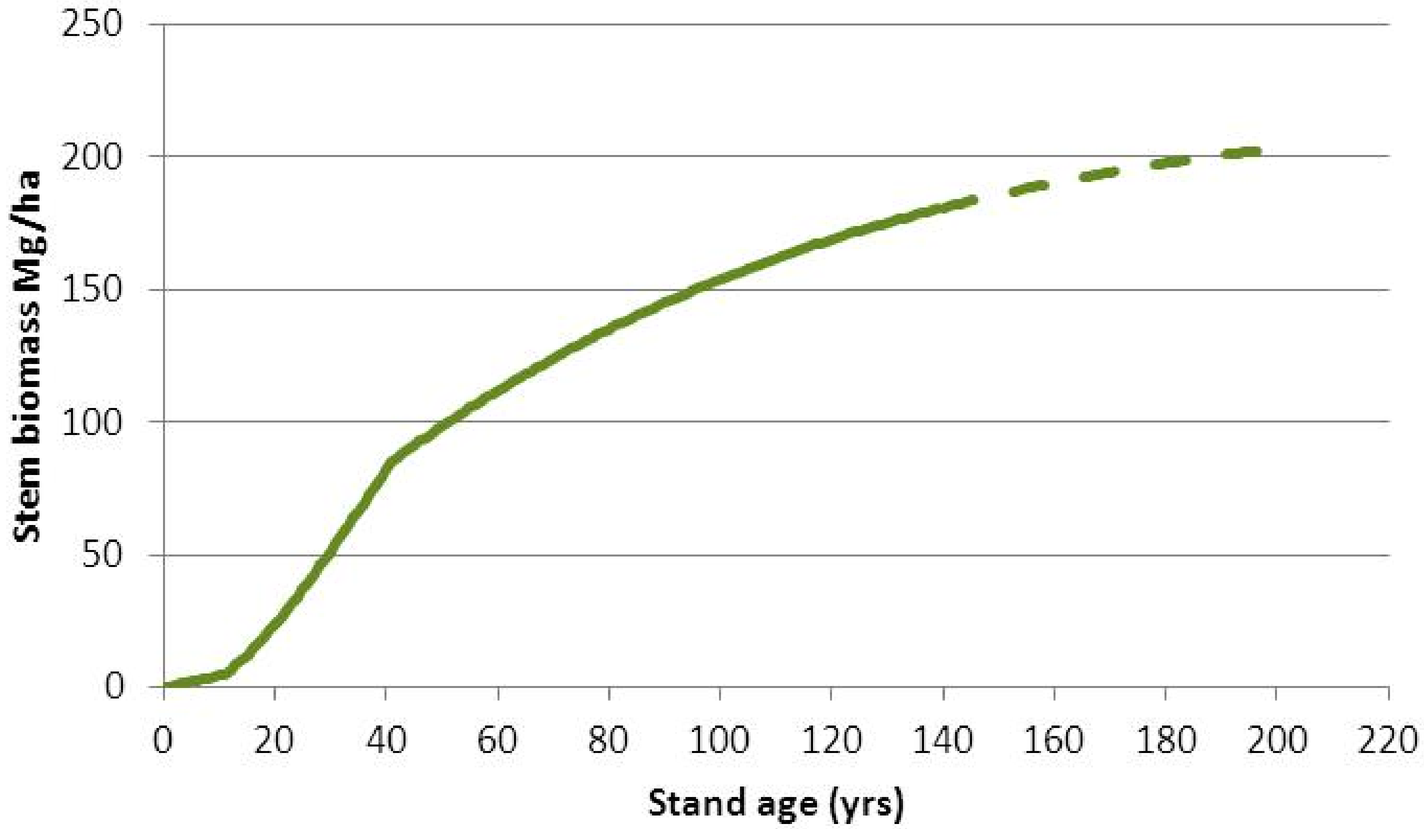
# Case 2

# Material substitution by wood products

# Case: stemwood to long-lived wood products + bioenergy; assumptions:

- GHG emissions of construction a wood office building compared with a conventional concrete one; LCA data from Häkkinen and Wirtanen (2006)*.
- Raw material: stemwood of Scots pine; 40% sequestered to wood pr; by-products used to the renewable energy portion of processing of wood products, excess to displace fossil fuels elsewhere.
- Stemwood growth curve based on representative sample from Finland (MOTTI simulator, Hynynen et al. in Metla)

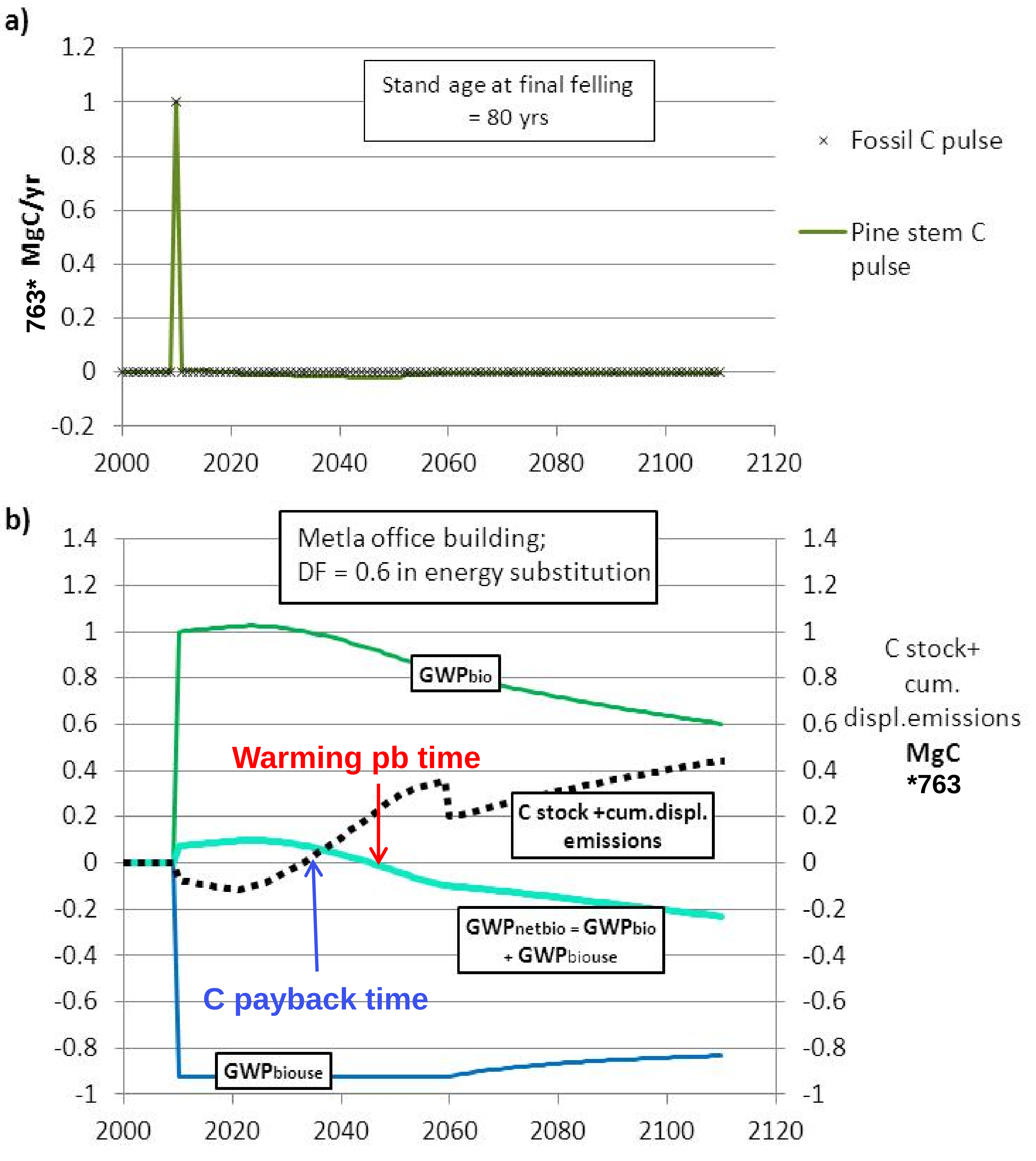
*Häkkinen T, Wirtanen L (2006), Metlan Joensuun tutkimuskeskuksen ympäristö- ja elinkaarinäkökohtien arviointi [Environmental and life cycle assessment of the Finnish Forest Research Institute's (Metla) research centre in Joensuu]. Espoo 2006. VTT Tiedotteita - Research Notes 2342. 29 p.

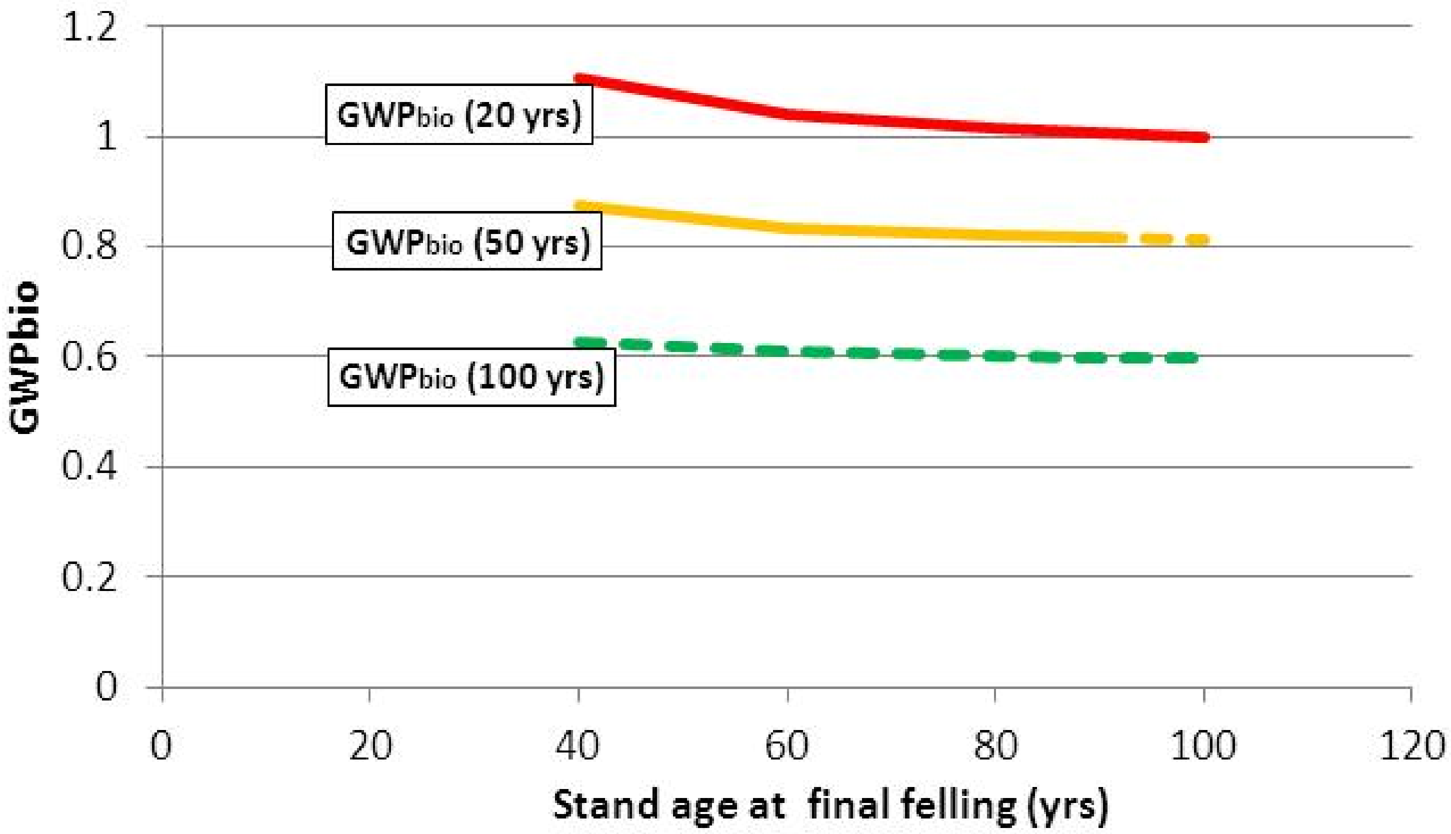



Estimated average development of stemwood biomass (Scots pine, Southern Finland) as a function of stand age. Statistics not representative beyond 140 years (few samples, uncertainties concerning natural disturbances).

Example:

- Emission from **pulse use** of 763 MgC of **stemwood** (=demand for wood building) vs. fossil C pulse at 2010
- Final felling at stand age 80 years
- GWP factors and cumulative C balance of biomass debt and displaced emissions
- Displacement factor DF = 0.6
- Service life of building = 50 years (=underestimate); demolition wood to bioenergy






**GWP$_{bio}$** factors of stemwood (Scots pine) as a function of stand age at final felling (dotted lines denote high uncertainty).

# Discussion and conclusions (1)

- Two dimensionless GWP indicators, one for the biomass resource, the other for the relative impact of the biomass use cycle
- Similar index could be developed for the ”absolute” impact of the use cycle. When mitigation timeframe is fixed GWP could provide a kind of physical discounting factor for LCA by which the impact of future lifecycle emissions of the biomass use cycle could be transformed to a carbon footprint, or an equivalent fossil C (or $CO_2$) emission taking place at present.
- In the short term the use of ”slow” boreal forest biomass appears just to increase the warming impact especially when the efficiency of biomass use is low.
- The true displacement factor DF obviously lower than the theoretical one due to the dynamics of the energy markets. DF a useful parameter that should be varied in the analysis.

# Discussion and conclusions (2)

- The displacement efficiency may even decrease in the future, along with a lowering C intensity of the future energy system (from this point even landfilling of biomass to be considered!).
- The sink or sequestration option is favourable in the short, but the risk of natural disturbances should be considered; stochastic analysis required.
- The forest sink is not a sustainable option in the meaning that it cannot be continued forever due to saturation. Risks of losing the biomass due to disturbances and production capacity of the forest.
- On the other hand: negative(!) emissions required in the second half of the secondary half of the century to avoid critical global warming, C sinks needed.
- Climate change mitigation is management of a transient; temporary means like C sinks must be an option among others.

# Supplementary material: Basis of the radiative forcing calculations (1)

The decay of the $CO_2$ pulse in the atmosphere with time t is given* by

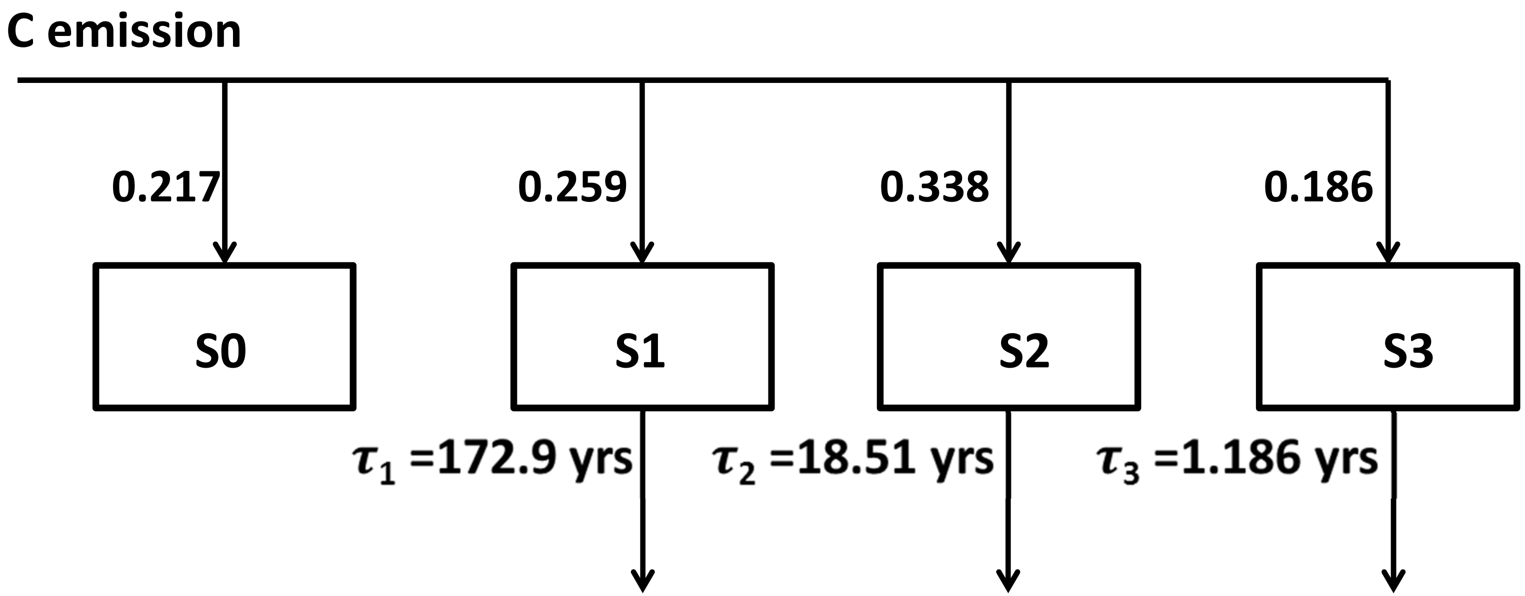
$$a_0 + \sum_{i=1}^{3} a_i \cdot e^{-t/\tau_i}$$

where $a_0 = 0.217$, $a_1 = 0.259$, $a_2 = 0.338$, $a_3 = 0.186$, $\tau_1 = 172.9$ years, $\tau_2 = 18.51$ years, and $\tau_3 = 1.186$ years.

*The $CO_2$ response function is estimated based on the revised version of the Bern Carbon cycle model (Bern2.5CC;Joos et al. 2001) using a background $CO_2$ concentration value of 378 ppm. This approximation is used in IPCC Fourth Assessment Report (AR4), Climate Change 2007: The Physical Science Basis, p. 213.

# Supplementary material: Basis of the radiative forcing calculations (2)

In the calculations a “compartment model” having the above pulse response was used :




**First-order decay, time constants $\tau_1$, $\tau_2$ and $\tau_3$**
**Additional concentration in the atmosphere S = S0 + S1 + S2 + S3**

# Supplementary material:
# Basis of the radiative forcing calculations (3)

The background GHG concentration $CO_2(t)$ in was assumed to develop so that the 2$^o$C stabilisation target 450 $ppm_{eq}$ will be met by 2100.

$$RF(CO_2) = 5.35\ \mathrm{W\ m^{-2}} \left( \ln \frac{CO_2(t)}{CO_2(t_0)} \right)$$

In the study the additive RF due to the emissions was considered.