GHG IMPACTS RELATED TO FOREST BIOENERGY: CASE JOUTSENO

BEST WP4.4 2014: Final results

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1. Terminology

- **bio-SNG**: Synthetic natural gas (>95% methane) made from woody biomass
- **GHGs**: Greenhouse gases that trap heat energy in the atmosphere, such as CO_2, CH_4, N_2O, H_2O, CFCs etc.
- **EU Renewable Energy Directive (RED):** Directive 2009/28/EC on Promotion of use of energy from renewable sources. Includes sustainability requirements, such as minimum GHG emission savings requirements for (transport) biofuels and bioliquids

1. Terminology (2)

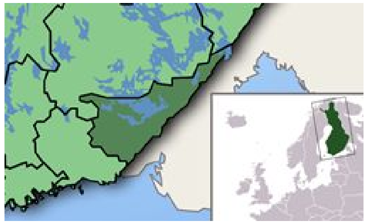
- **Biogenic carbon**: Carbon that has been sequestered to, emitted from, or stored in biomass. Combustion and decay of biomass releases biogenic CO_2 to the atmosphere.
- **Carbon deficit, debt or investment**: A difference in terrestrial carbon stocks over time attributable to an activity, such as an industrial project. Here the difference in forest carbon stocks with and without the studied investment (i.e. relative to business-as-usual).
- **Radiative forcing**: An measure of energy added to (→warming) or reduced from (→cooling) the climate system by an activity through influencing the concentration of GHGs in the atmosphere or the reflectivity of the earth (i.e. albedo).

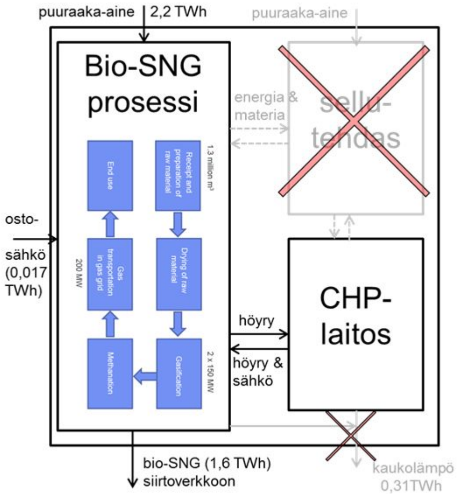
1. Terminology (3)

- **Global warming potential (GWP):** An index of the total energy added to the climate system by an activity relative to that added by fossil CO_2. GWP of fossil CO_2 is 1.
- **Allocation**: Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems. i.e. sharing the environmental burden in between several co-products (here industrial wood, pre-commercial thinning wood, and harvest residues)

2. Case study: Synthetic natural gas from forest biomass

- A study on potential **climate impacts** of a future large investment in forest bioenergy
- Synthetic natural gas production from forest biomass in **South-East Finland**
    - 1.3 Mm^3/yr woody raw material
    - 1.6 TWh/yr bio-SNG production
- Special focus on the future **forest carbon stocks** in the region



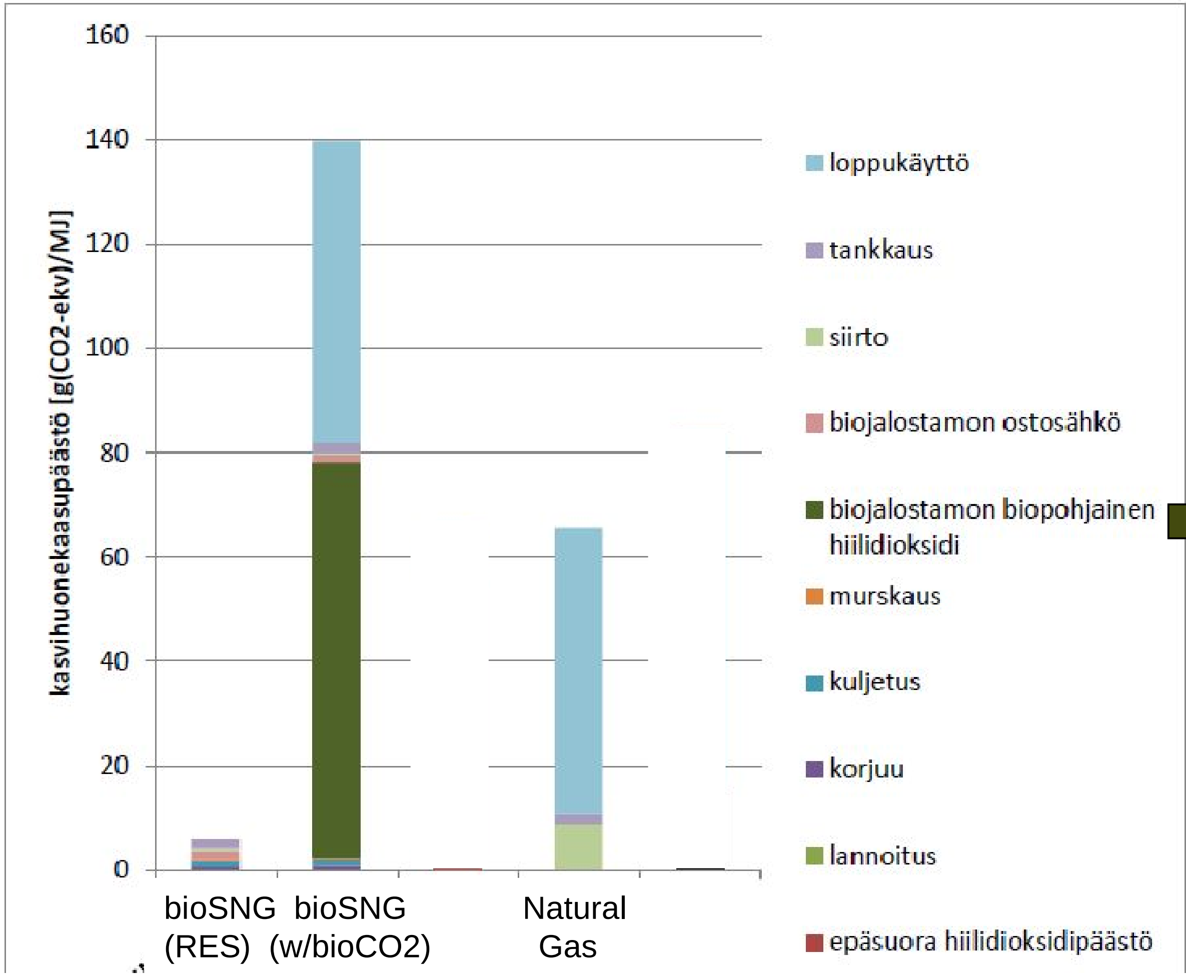


3. Motivation for the study

Background

- **EU Renewable Energy Directive (RED)** and GHG savings calculations
  - GHG reduction accounting rules for biofuels
  - Changes in biogenic carbon included only if a change in land use type (e.g. from forest to agriculture)
- Discussion on climate impact assessment of bioenergy in recent **scientific literature**
  - Energy use of e.g. stumps influences forest carbon stocks
  - Inclusion of the impacts on forest carbon stocks?

3. Motivation: Previous assessment on bio-SNG



Bio-SNG delivers significant GHG emission savings in comparison to natural gas with current accounting rules.

What if the rules change?

Modified from: Niskanen T. 2012. Master's Thesis.

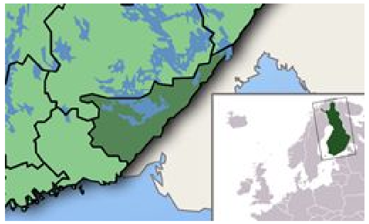
4. Objectives

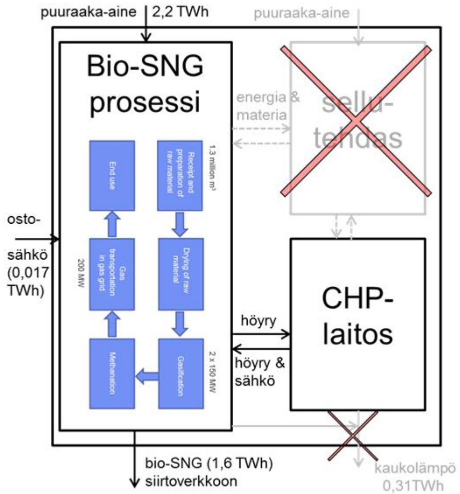
Main question for case-study

- What **risks** (and possibilities) are connected to the investment, if climate impact assessment rules in EU (e.g. RED) would change towards the approaches proposed in scientific literature?
  - Main focus on the treatment of **biogenic carbon in a forest value chain**
  - Relevant question for all forest bioenergy chains, not specific to this case

5. Scope and approach

- Future forest carbon stock modelling, incl. soil (Scenarios; Metla, SYKE)
- Impacts from processing of wood for synthetic natural gas
  (EIA/YVA, Master's thesis; Gasum, MetsäFibre, VTT)
- Climate impact modelling (VTT)





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5. Scope and approach: Studied scenarios for forests

1. Business-as-usual (BAU) scenario

- Harvests of industrial wood and energy wood remain at current levels

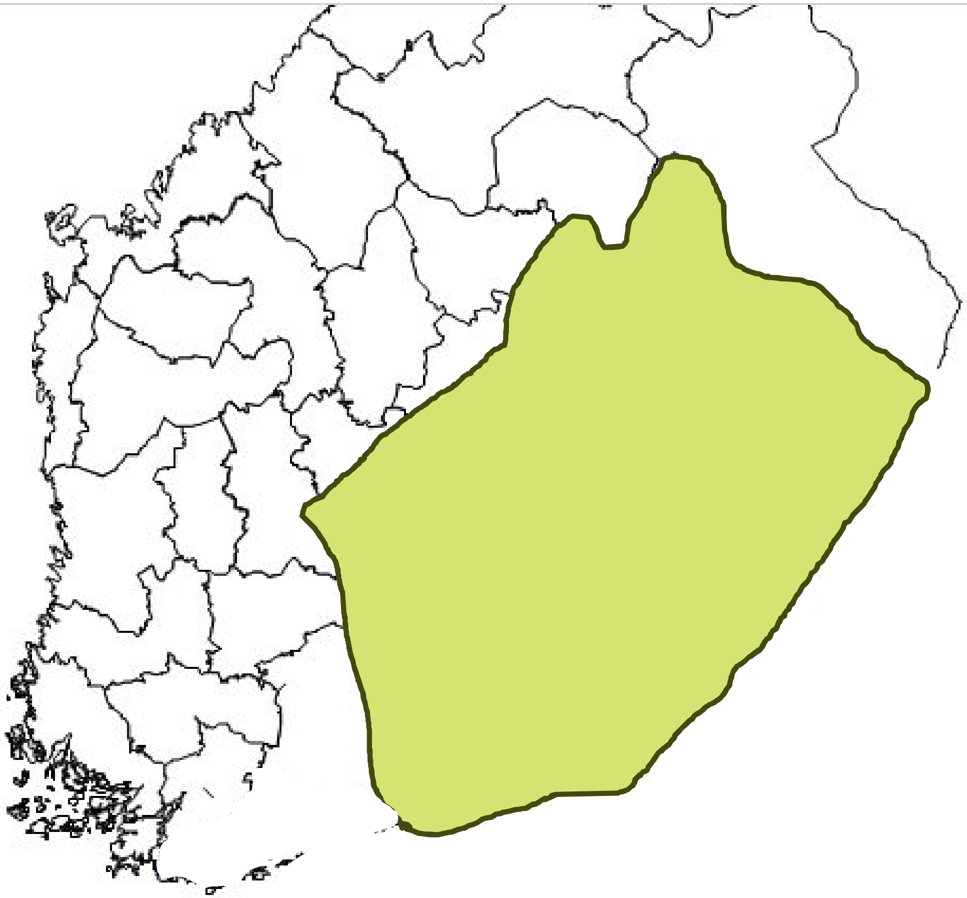
2. Increasing energywood (Energy) scenario

- Additional 0.8 Mm^3/a of energywood needed for bio-SNG process:
  - Forest residues and stumps from final fellings
  - Combined harvesting of energy and industrial wood in thinnings
  - Prerequisite: No industrial wood directly to bio-SNG process

=> Harvests of industrial wood in the area need to increase

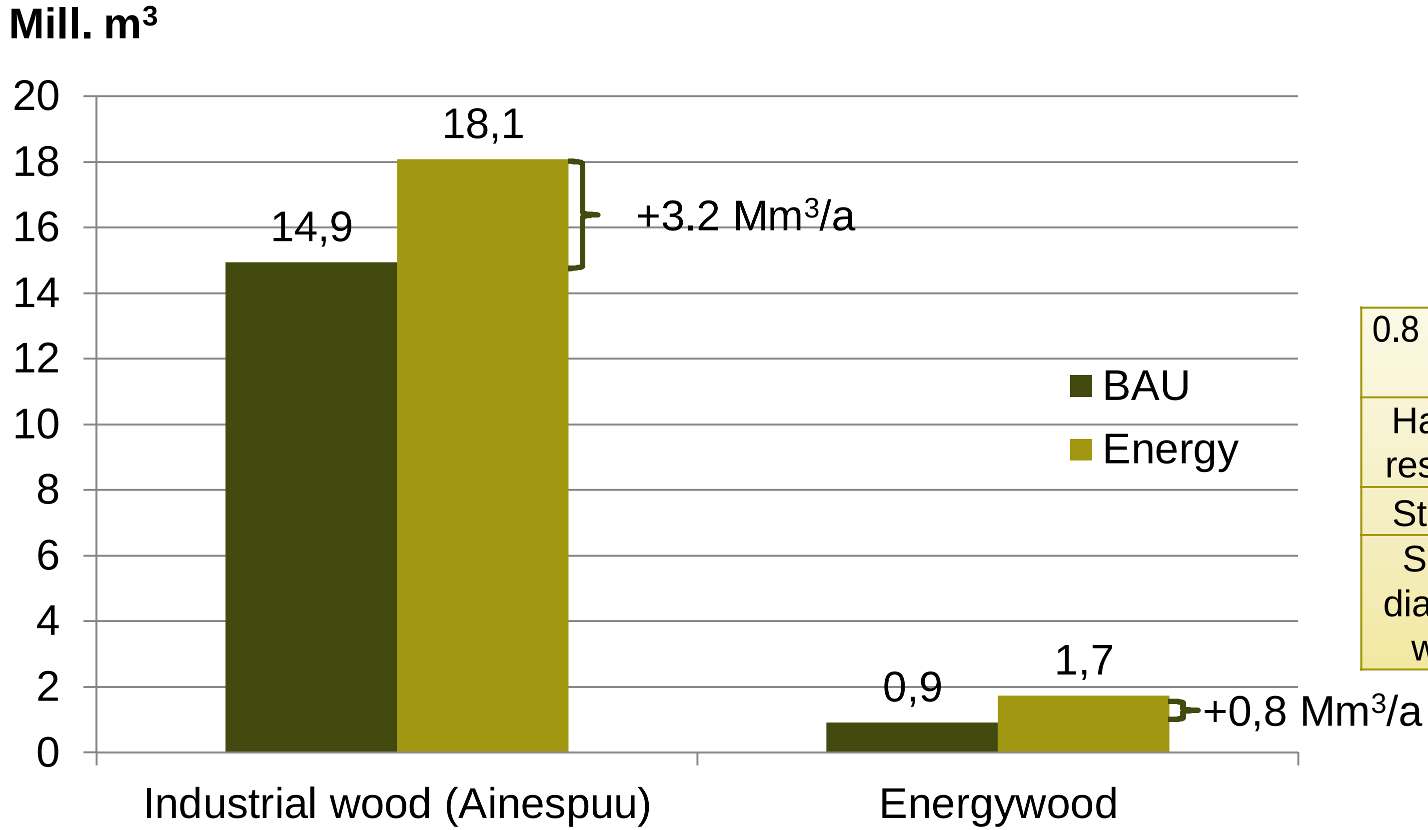
6.1 Results of forest modeling

6.1 Wood-sourcing area



- 3.4 mill.ha of forestland
- Average transport distances 50-260 km

6.1 Annual harvests of industrial and energy wood

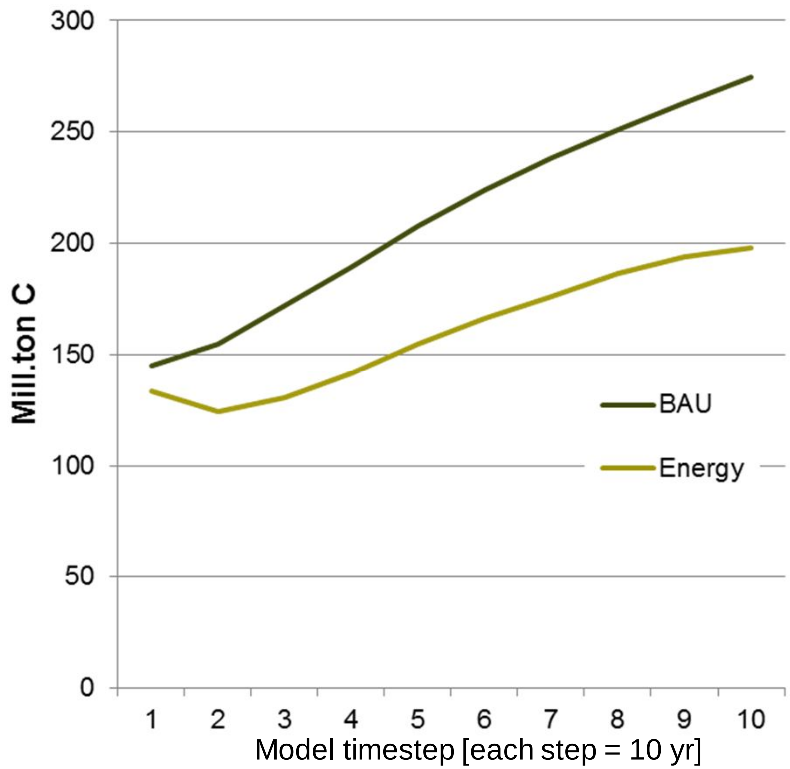


0.8 Mm3 for bio-SNG divided into:	
Harvest residues	58 %
Stumps	22 %
Small-diameter wood	20 %

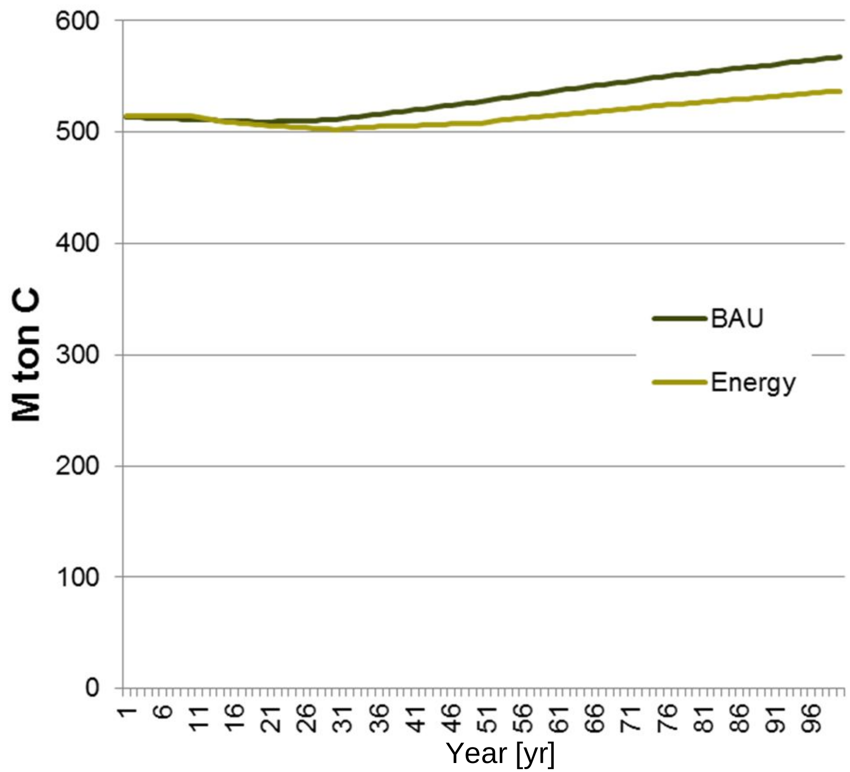
⇒ Harvests of industrial wood need to increase more than the additional harvests of energy wood for bio-SNG

6.1 Forest carbon stocks

- Living forest biomass



- Forest floor and soil



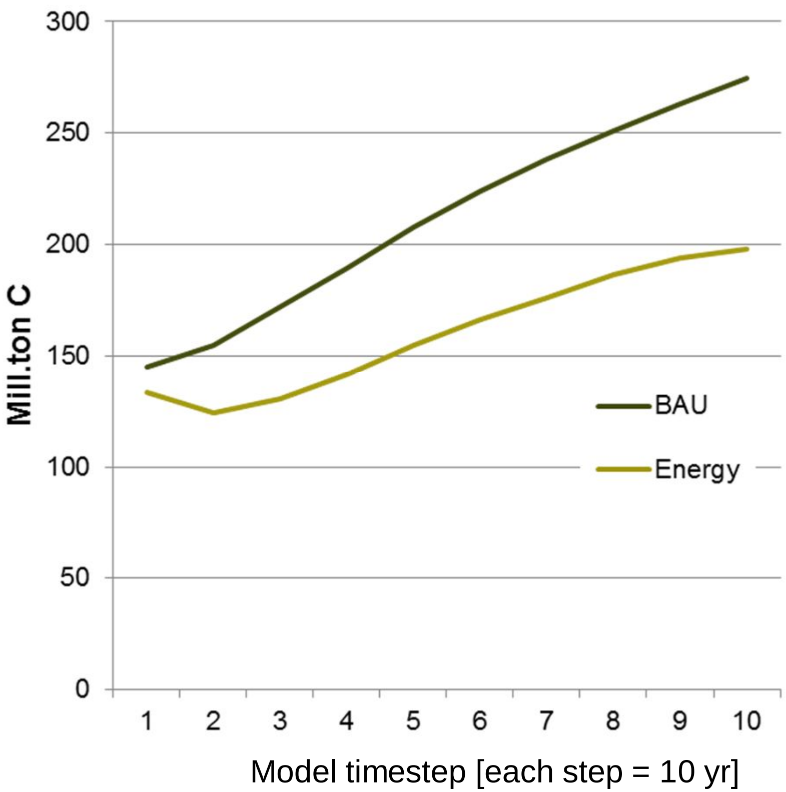
⇒ Increase in harvests leads to lower C stocks in forests than in BAU

⇒ Forest C stocks increase in both scenarios

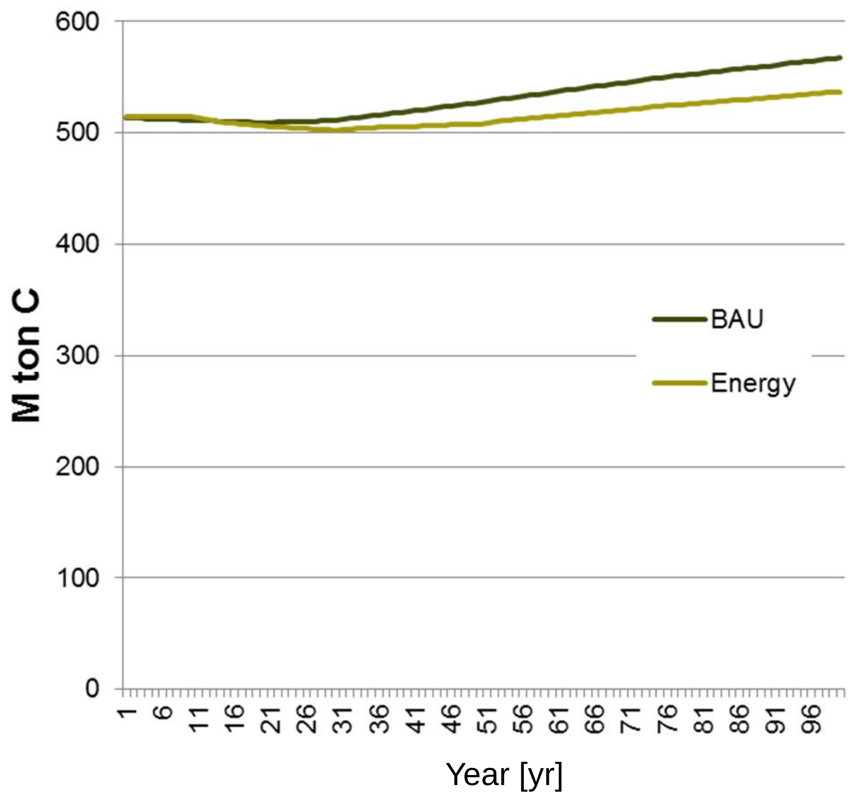
6.2. Results of climate impact assessment

6.2 So where in the figures is the GHG impact of increased harvesting for energy?

- Living forest biomass

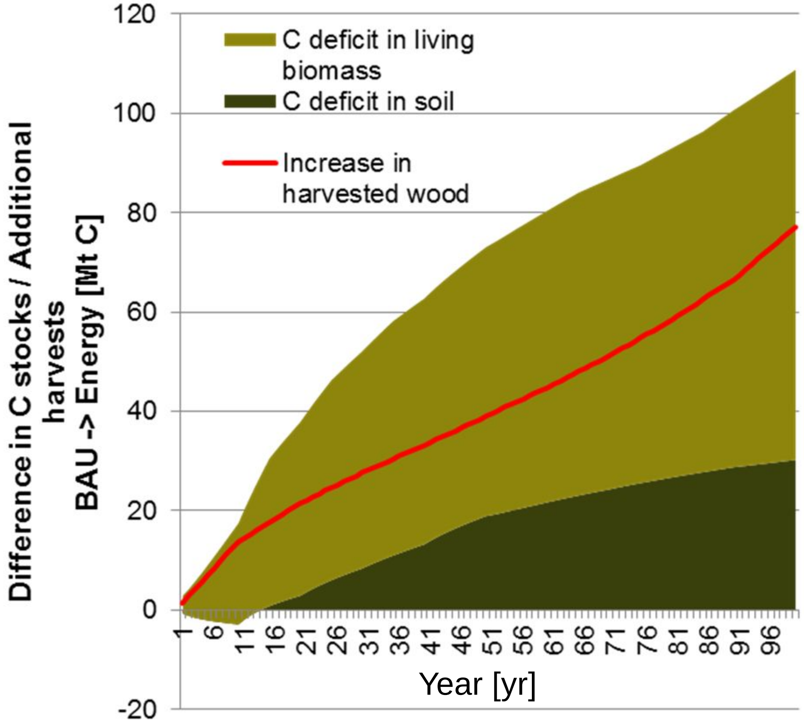


- Forest floor and soil



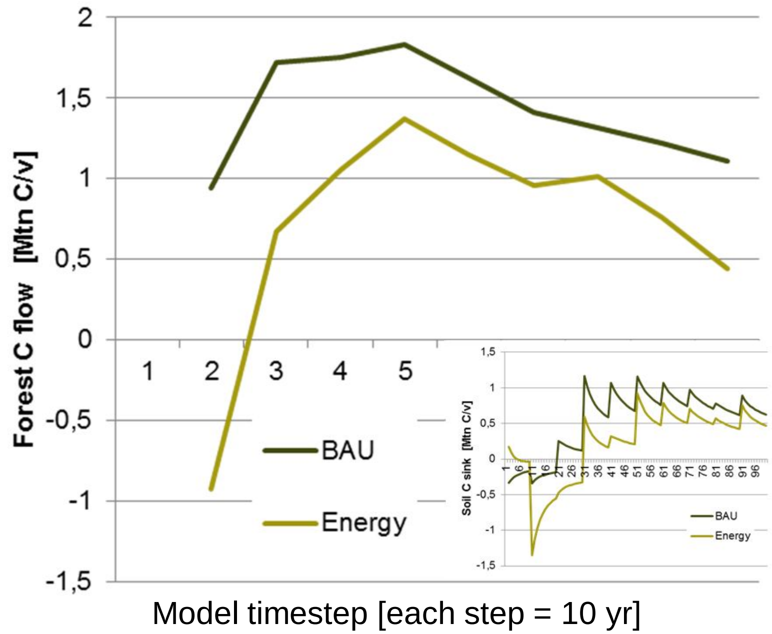
6.2 Two complimentary viewpoints: Atmospheric impacts and regional GHG balances

A. Difference in forest C stocks in two studied scenarios:



"More GHGs in atmosphere in the Energy scenario"
"Forest C deficit > C in raw material"

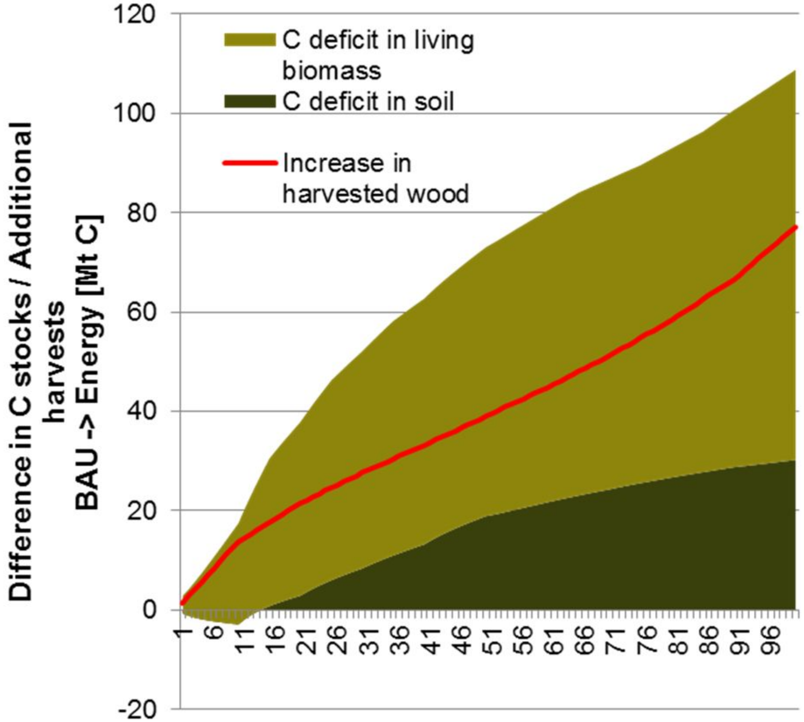
B. Regional GHG balances



"Forests remain as net CO2 sinks in both cases over next 100 years"

6.2 Following the aim of the work, next we model the atmospheric impacts of the activity

Difference in forest C stocks in two studied scenarios:

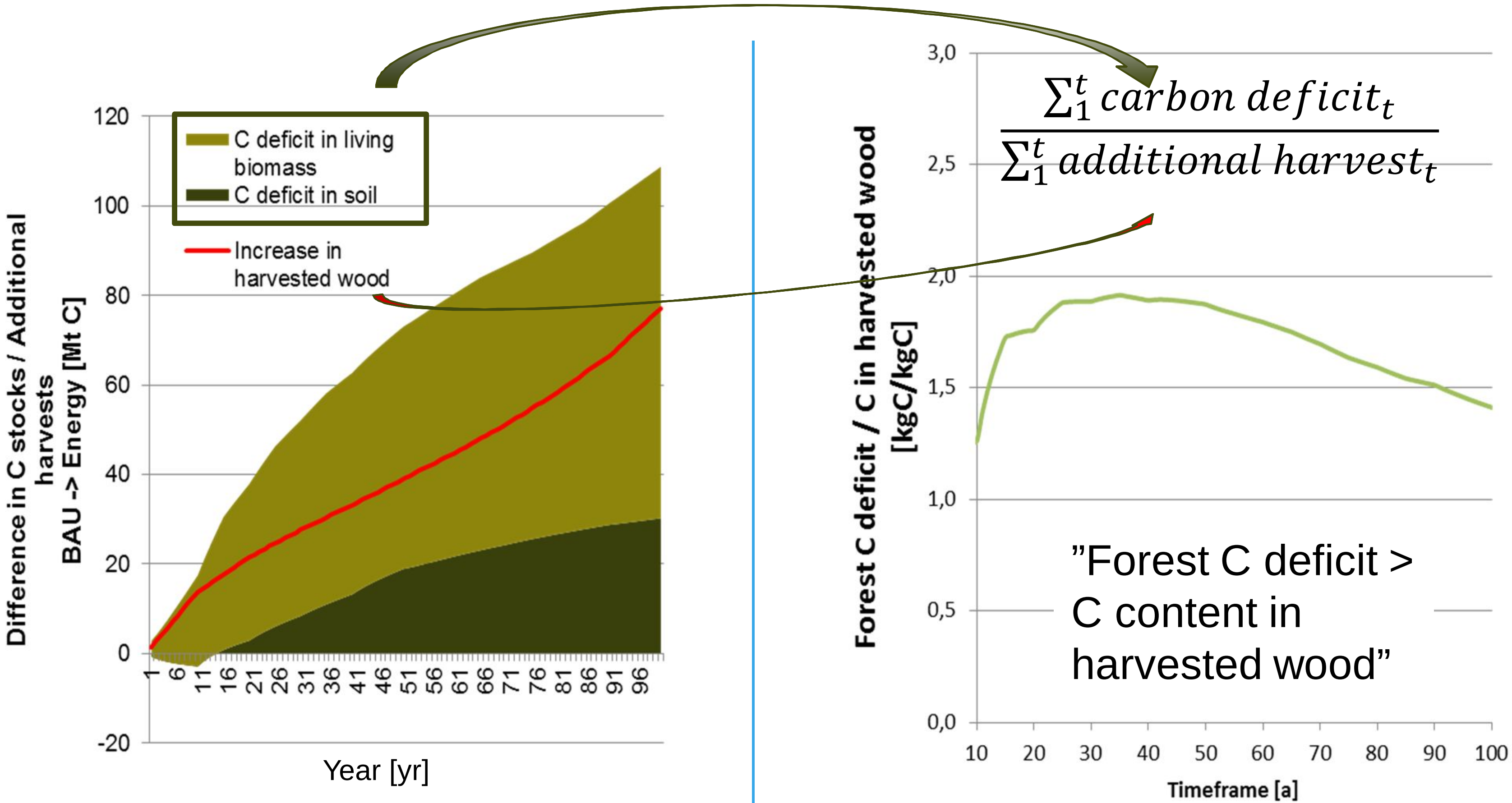


“Main questions for case-study

- What **risks** are connected to the investment, if climate impact assessment rules in EU (e.g. RED) **would change** towards the approaches proposed in scientific literature?”

”More GHGs in the atmosphere in Energy scenario”
”Forest C deficit > C in raw material”

6.2 Carbon deficit and increase in harvests: Absolute cumulative or Relative



NB! Harvests of both industrial wood and energy wood increase in Energy scenario

6.2 Solving multifunctionality:

Harvests of both industrial wood and energy wood increase

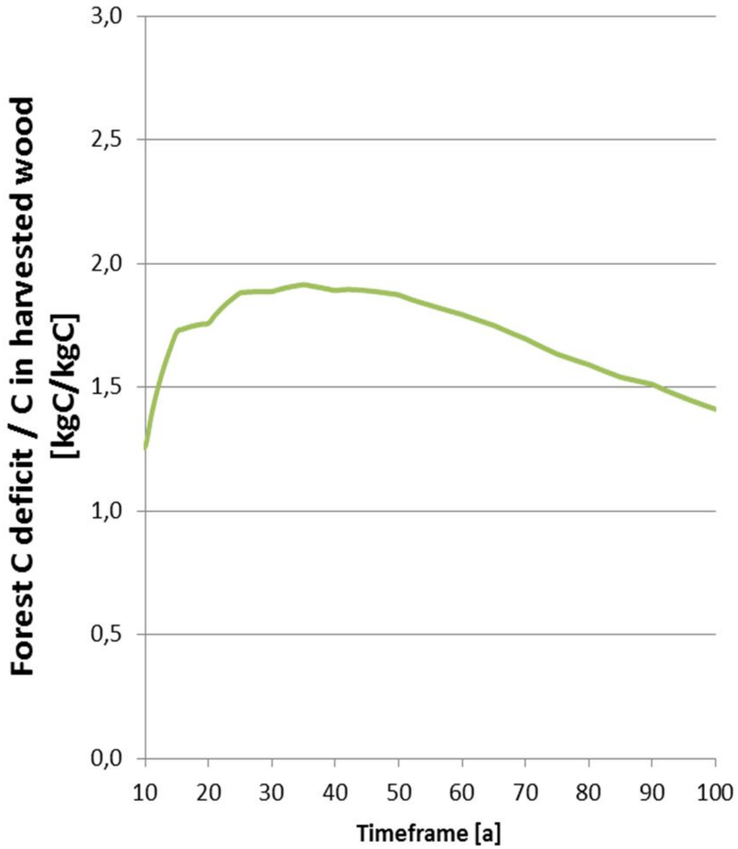
How to differentiate the impact of energy wood harvests for bio-SNG-process from impacts of increased harvests of industrial wood?

6.2 Option 1: Allocation

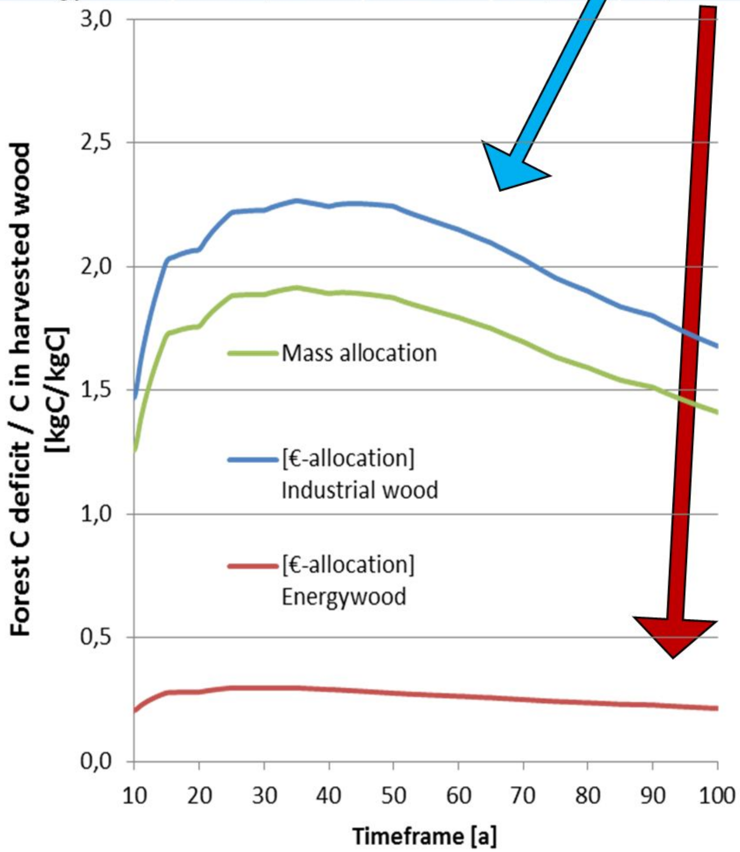
- **1a) Mass-based allocation**
  - Allocation of environmental impacts with **physical basis** (e.g. mass, volume or energy)
- **1b) Economic allocation**
  - Allocation of impacts based on the rationale that **economic value is the driver** for activities and decisions in the market-driven economy
  - The environmental burden to be allocated to fractions of harvested wood based on economic value
  - Here the viewpoint of forest owner as a decision-maker is applied:
    - » Wood prices considered at forest-road (before delivery)
    - » In base-case no subsidies assumed. Additionally a sensitivity analysis with a subsidy of +10 €/m^3 for energywood.

6.2 Allocated results:
1a) Mass-based or 1b) Economic-based

	Volume Mm³	Value M€	%-vol	%-€
Industrywood	313,87	9950	79,5 %	**97,2 %**
Energywood	80,86	283	20,5 %	**2,8 %**



SS3



Assumptions on value at forest road:
Energywood 3,5 €/m3
Fibrewood 17 €/m3
Timberwood 53 €/m3

SS3 "Cumulative Forest C deficit / Cumulative C in harvested wood" kummankin kuvaajan Y-akselille
Soimakallio Sampo; 22.10.2014

6.2 From carbon stock changes to warming impacts

- Step 1: Cumulative additional CO2 in the atmosphere

  ”How much additional C is in the atmosphere because of increased forest harvesting, combustion and sequestration compared to if similar (harvested) amount of fossil C was released?”

- Step 2: Radiative forcings

  ”How much the additional C in the atmosphere warms (W/m^2) instantly in comparison to a same (harvested) amount of fossil C burnt?”

- Step 3: Cumulative radiative forcings (CRF)

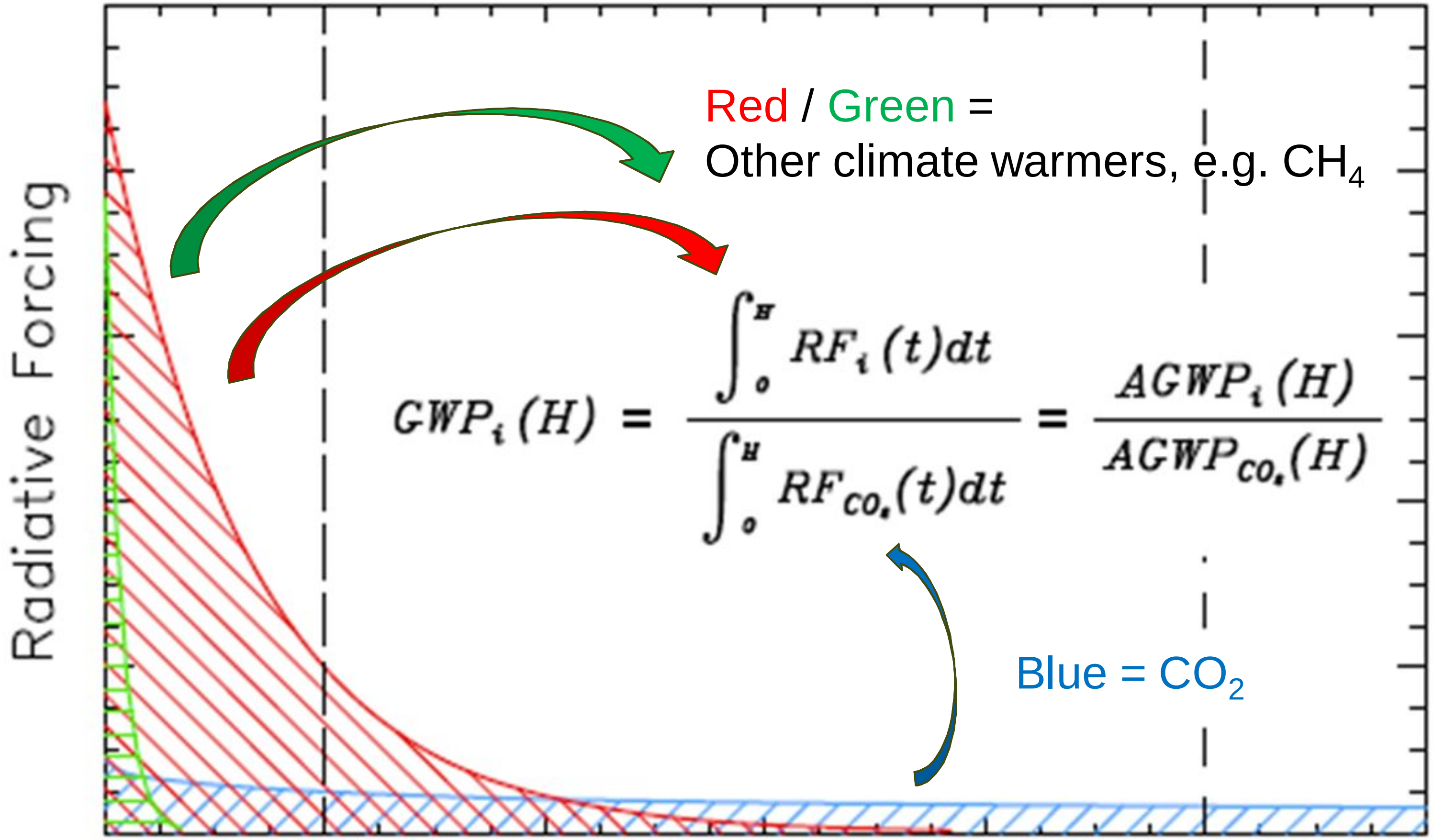
  ”How much the additional C in the atmosphere warms (W/m^2) cumulatively in comparison to a same (harvested) amount of fossil C burnt?”

- Step 4: Present the CRF in relative units, Global Warming Potential

  “GWP > 1: warms the climate more than same amount of fossil CO_2
  GWP < 1: warms the climate less than same amount of fossil CO_2 “

See an example with details in the end of this presentation

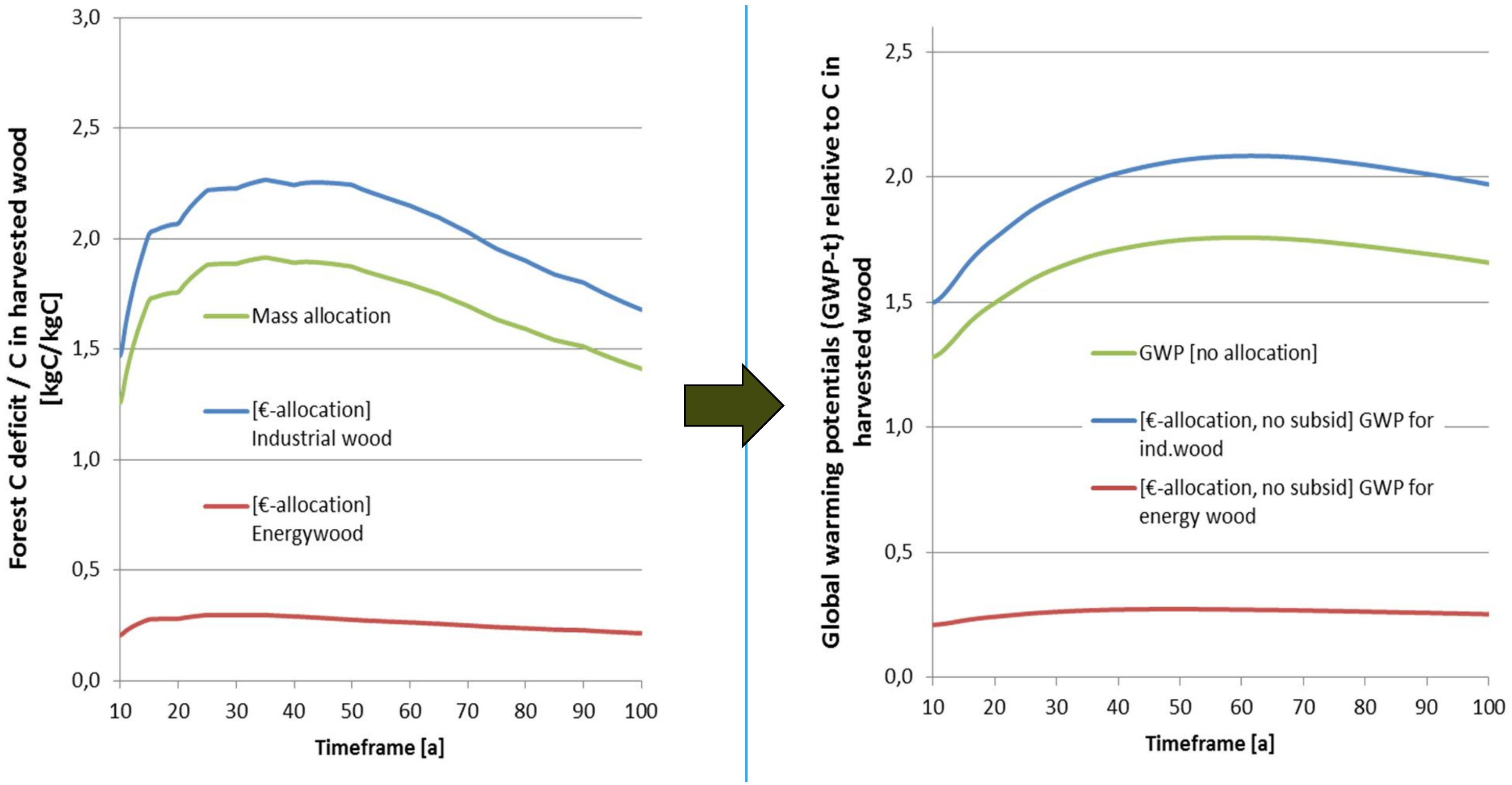
6.2
Global warming potential GWP (IPCC 2013)



$$GWP_i(H) = \frac{\int_0^H RF_i(t)dt}{\int_0^H RF_{CO_2}(t)dt} = \frac{AGWP_i(H)}{AGWP_{CO_2}(H)}$$

Source: Myhre et al. 2013 (AR5 WG1 Ch8)

6.2 From C stock changes to warming impacts (kgC/kgC) → Watts → dimensionless GWP

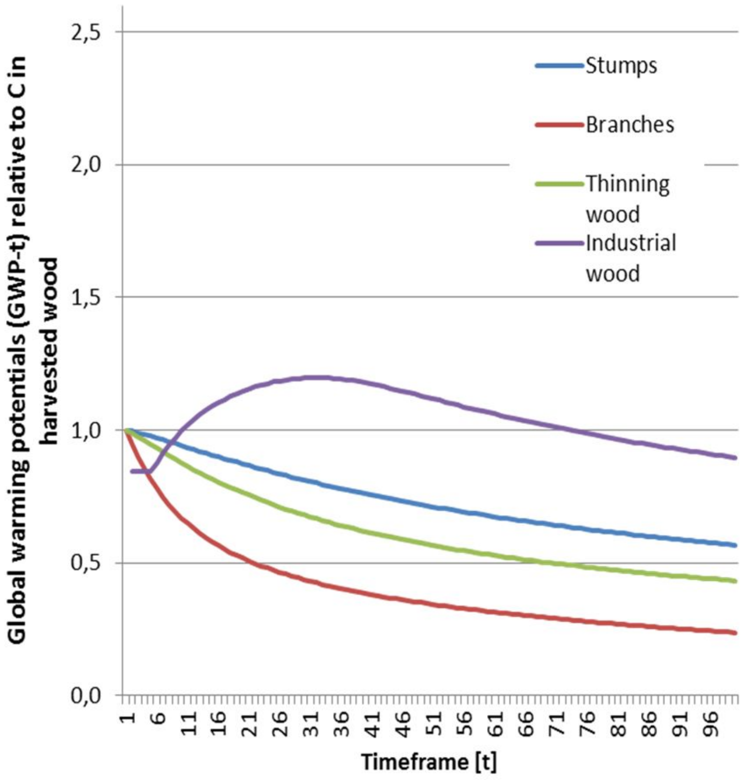


Warming impacts presented as relative Global Warming Potential (GWP):
The GWP of an identical amount of fossil CO_2 released is 1.

6.2 Option 2: Harvesting of energy wood compared to non-harvesting of energy wood

- If harvests of industrial wood take place regardless of energy wood harvesting, it is possible to assess the impacts of energy wood harvesting by confronting them to non-harvesting of energy wood
- In such a case, forest residues would decay and imported industrial wood from Russia would grow in forest

6.2 Option 2: Application of decay curves for distinct fractions from previous literature



- **Stumps, branches & wood from pre-commercial thinnings in Southern-Finland**:
  - Decay curves from Repo et al. (2012)
  - Assumed a continuous activity and run through radiative forcing model (REFUGE)
- **Imported industrial wood from Russia:**
  - Data from EffFibre-project (Hynynen et al. 2014) used as proxy for boreal stemwood
  - Change of management from business-as-usual to intensive in Forest Region 5

Repo et al. (2012) Forest bioenergy climate impact can be improved by allocating forest residue removal. GCB Bioenergy 4, 20
Hynynen et al. (2014) Scenario analysis for the biomass supply potential and the future development of Finnish forest resource
Metlan työraportteja / Working Papers of the Finnish Forest Research Institute 302

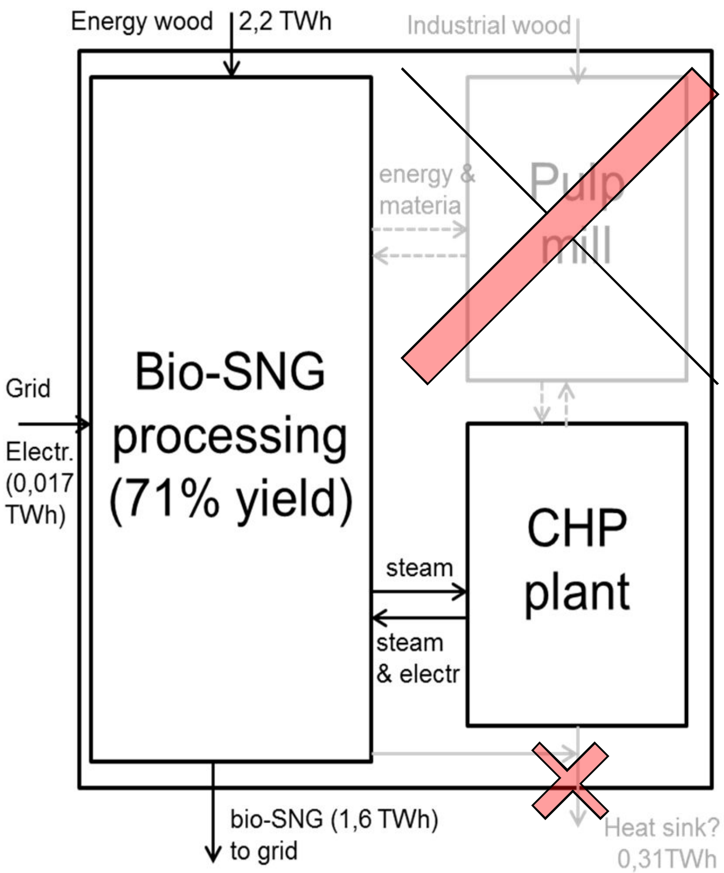
6.2 GWP-50yr and GWP-100yr for distinct wood fractions

	Option 1			Option 2	Option 1			Option 2
	Mass allocation	€-allocation		Literature based	Mass allocation	€-allocation		Literature based
	GWP-50				GWP-100			
		(3,5 €/m³)	(13,5 €/m³)			(3,5 €/m³)	(13,5 €/m³)	
Bark & chips from nearby industry (*)	0	0	0	0	0	0	0	0
Imported stemwood	1,75	2,07	1,92	1,12	1,66	1,97	1,83	0,90
Forest residues:	1,75	0,27	0,97		1,66	0,25	0,90	
- Wood from pre-commecial thinnings	1,75	0,27	0,97	0,57	1,66	0,25	0,90	0,43
- Branches	1,75	0,27	0,97	0,35	1,66	0,25	0,90	0,24
- Stumps	1,75	0,27	0,97	0,72	1,66	0,25	0,90	0,57

$$Climate\ impact, t\ [kgCO_2eq/GJ_{SNG}] = bioGWP, t \times CO_{2,bio}released/GJ_{SNG}$$

(*) Bark and chips are considered as waste streams,
thus no climate burden is considered for that fraction in the following results.

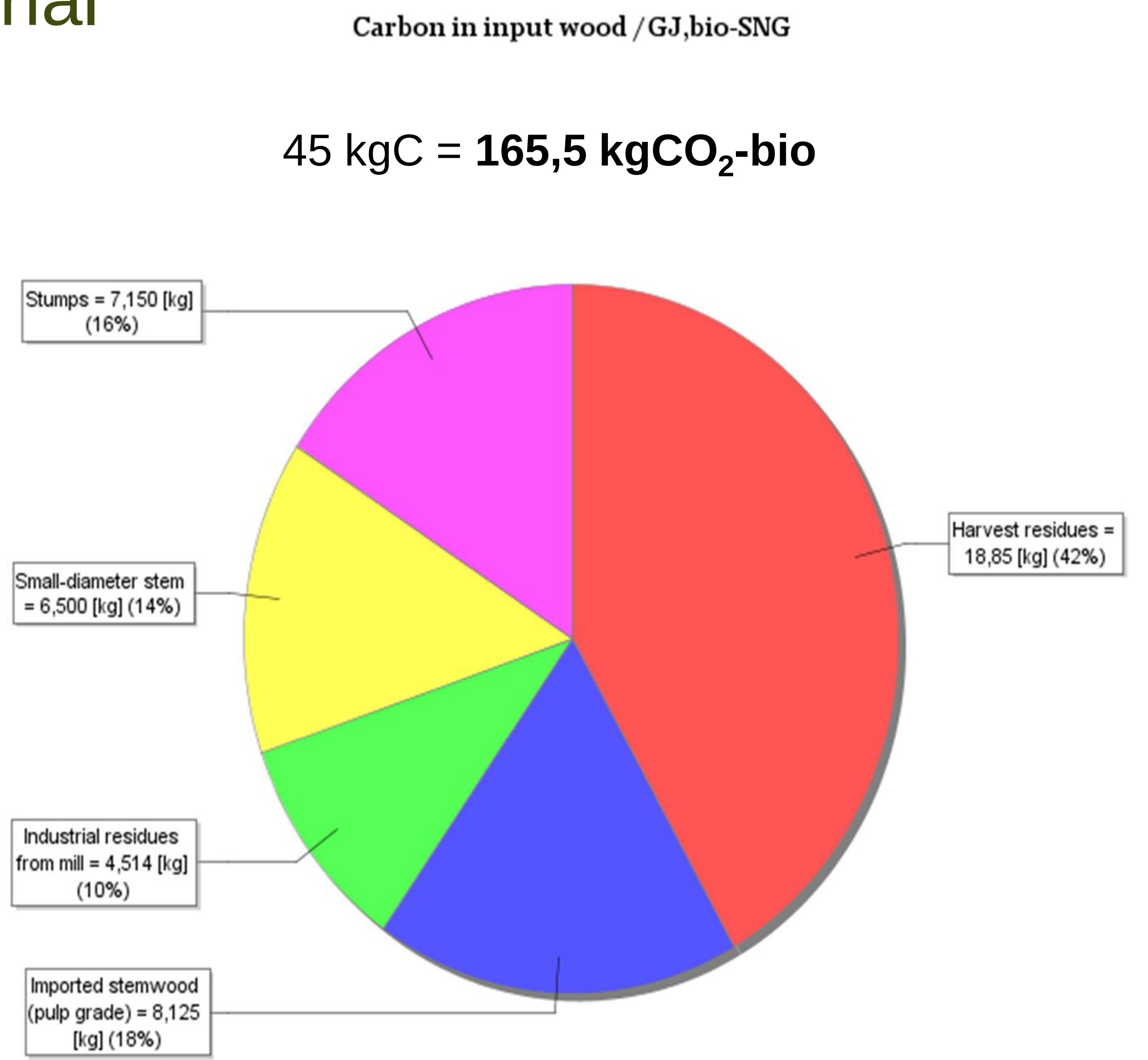
6.2 Next the conversion efficiencies and losses are included in the assessment...



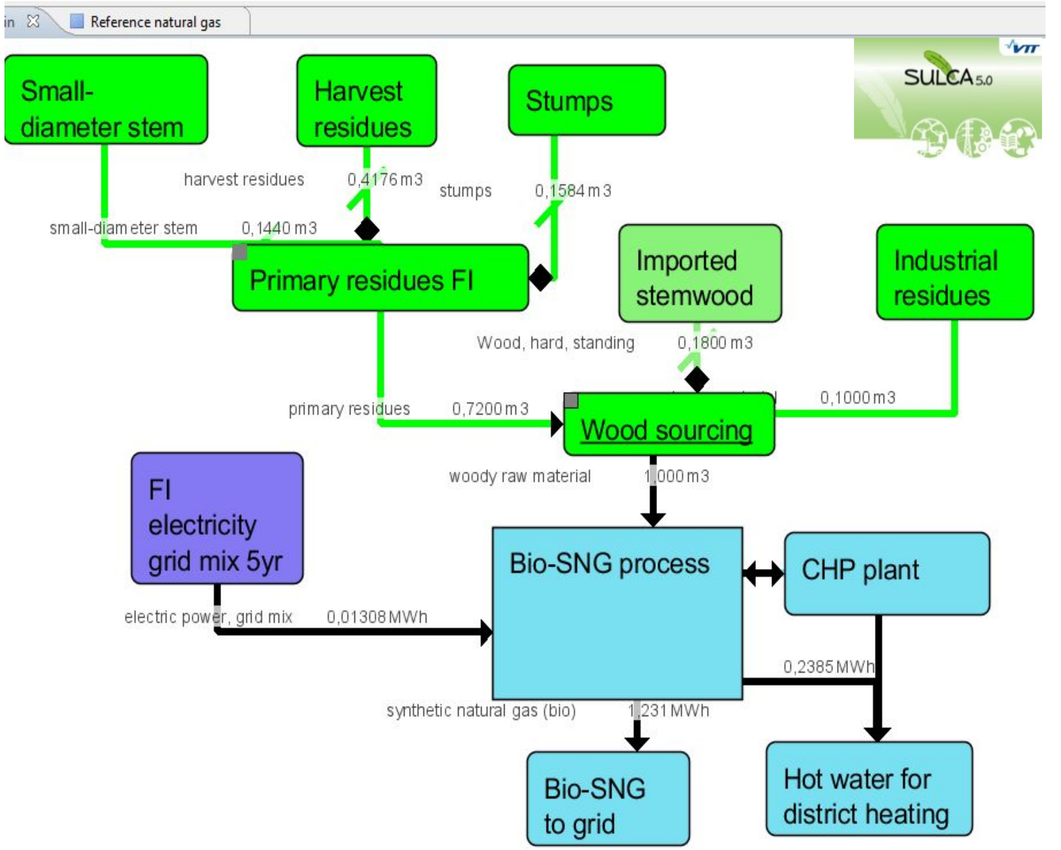
Balance based on published data in Niskanen (2013) and the EIA (YVA) report

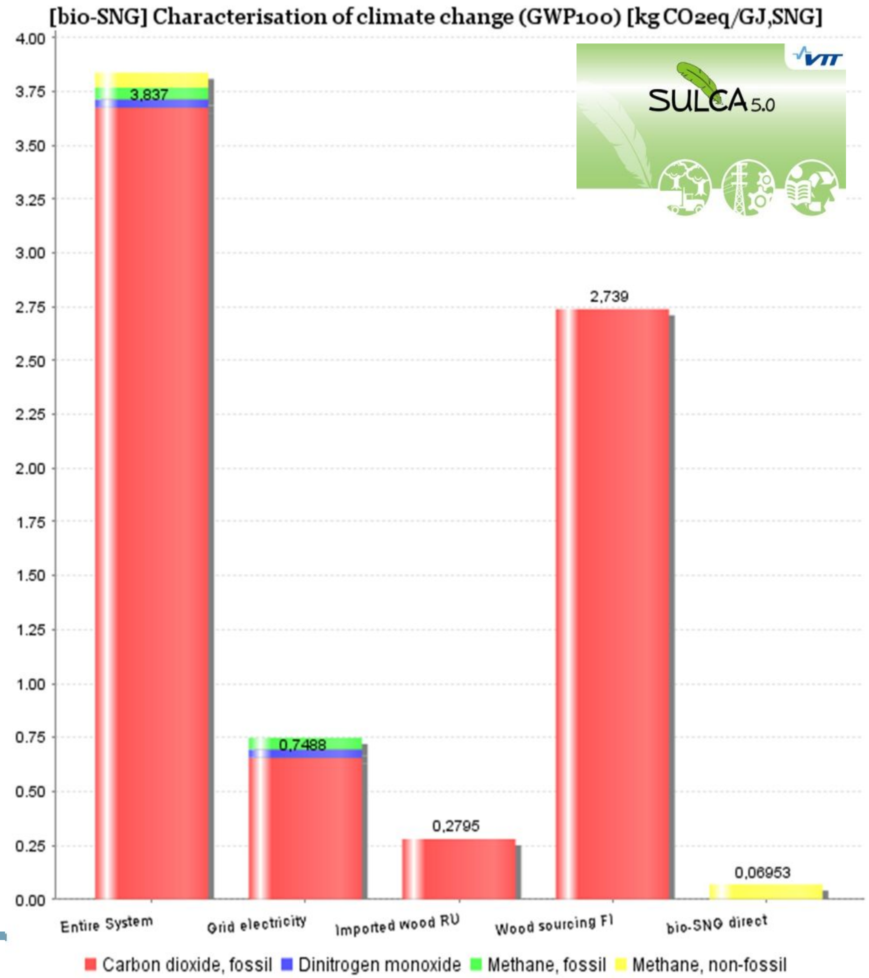
- **Bio-SNG process integrated to CHP-plant** that generates electric power and heat at several pressure levels for the bio-SNG process
  - Condensing turbine: Electric power production maximised
  - System is net importer of electricity
- Assumed that the low-pressure hot water is not utilisable in surrounding mill integrate. Thus **no integration benefits considered for excess heat**
  - *Sensitivity analysis*: insignificant impact on results

…together with raw material pallette (based on YVA) & carbon content in raw material



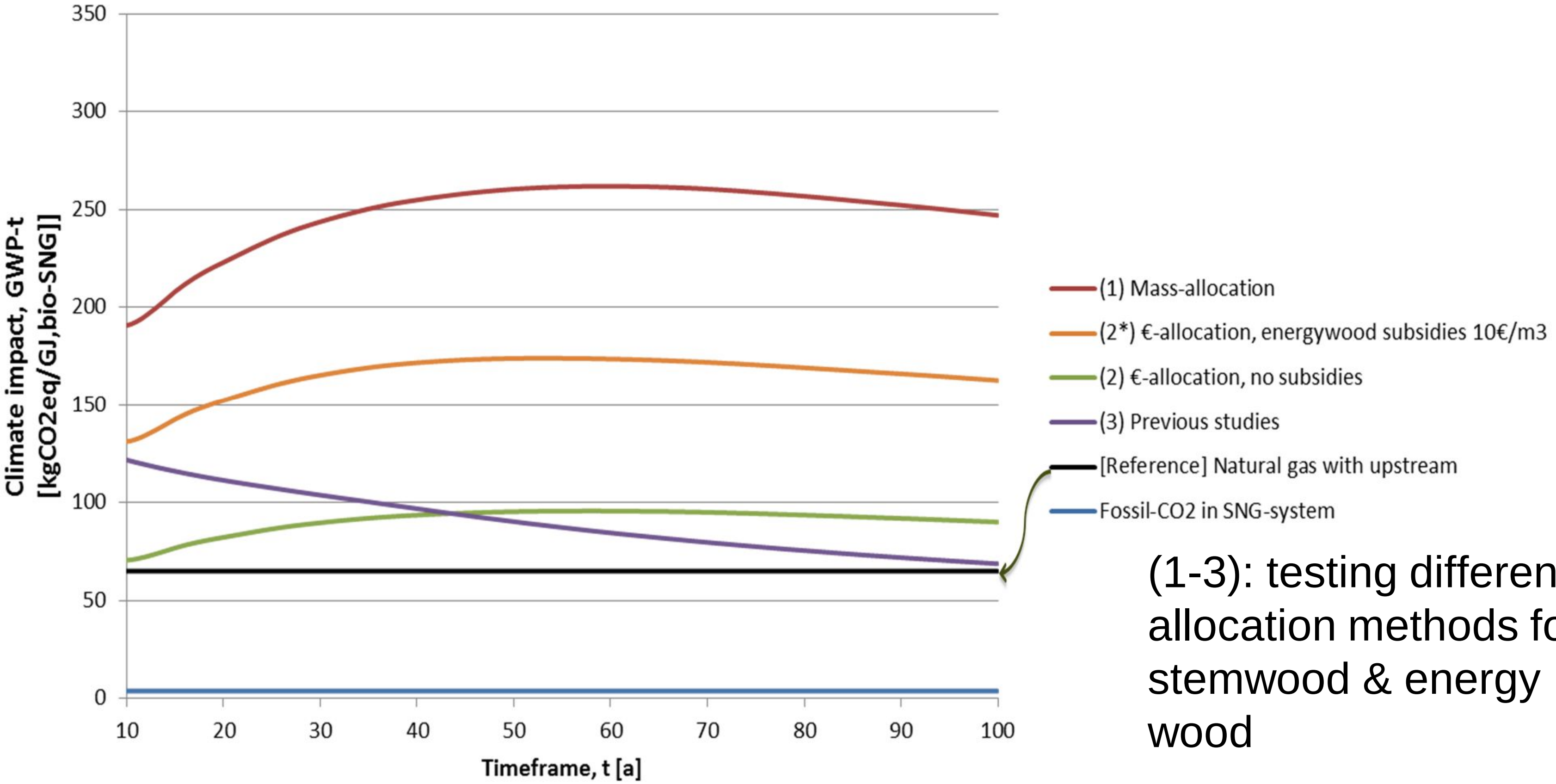
6.2 Fossil GHG emissions in bio-SNG value chain: ca. 4 $kgCO_2eq/GJ,_{SNG}$





7. Findings on climate impact impacts of bio-SNG

7 The key conclusion: Climate impacts of bio-SNG are higher than for natural gas



(1-3): testing different allocation methods for stemwood & energy wood

$$Climate\ impact, t\ [kgCO_2eq/GJ_{SNG}] = bioGWP, t \times CO_{2,bio}released/GJ_{SNG}$$

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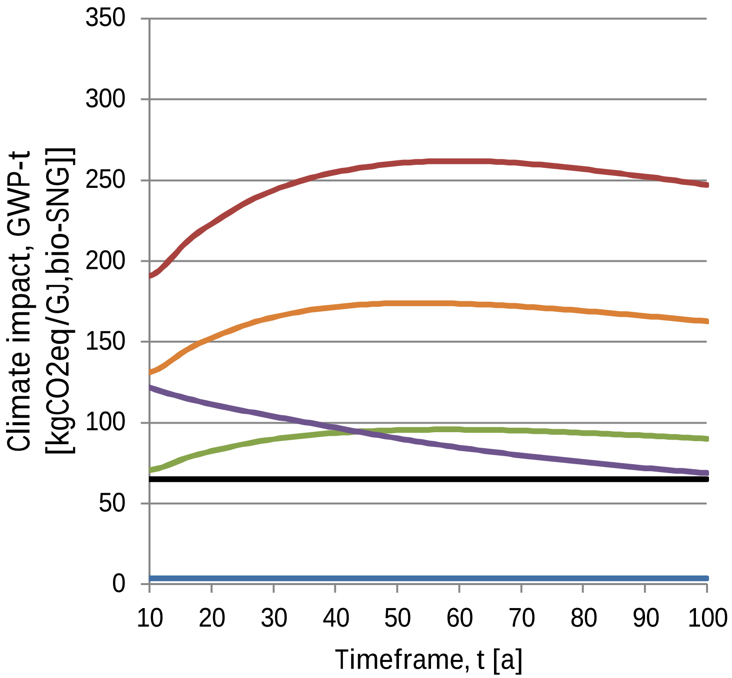
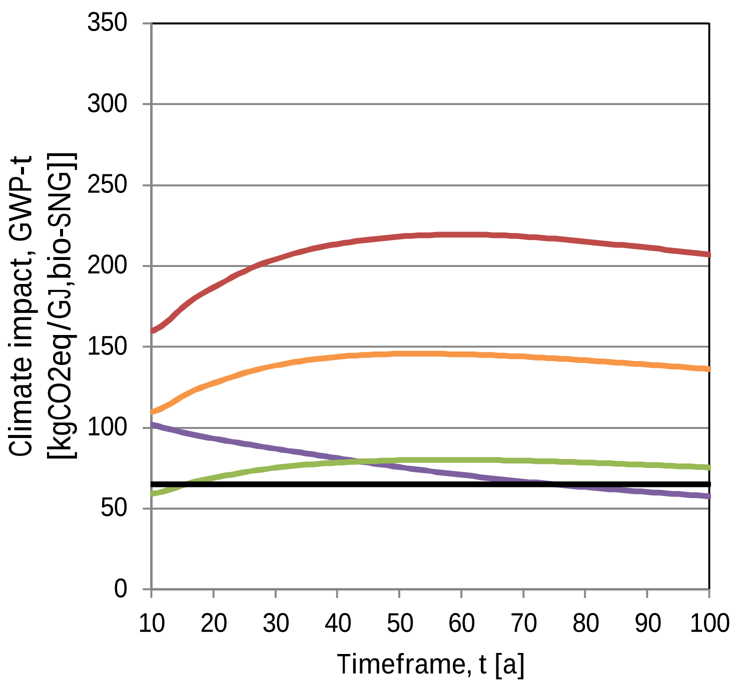
Energy-based allocation to all energy outputs, including hot water for distinct heating has an insignificant impact on the key conclusion

Allocation of all impacts to bio-SNG

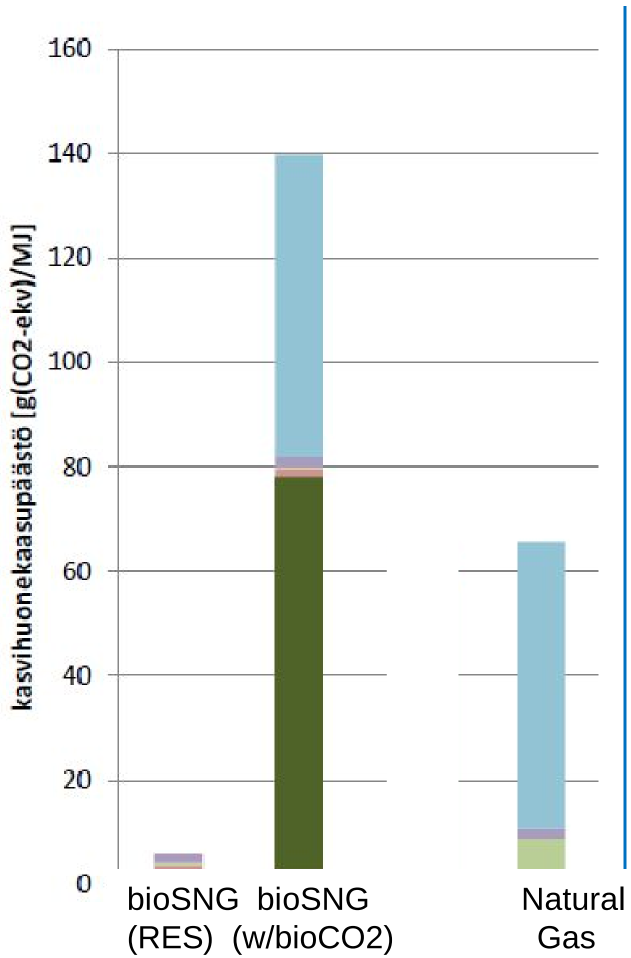


Energy-based allocation:
80% to bio-SNG and 20% to distinct heating



(1) Mass-allocation
(2*) €-allocation, energywood subsidies 10€/m3
(2) €-allocation, no subsidies
(3) Previous studies
[Reference] Natural gas with upstream
Fossil-CO2 in SNG-system

7 Results for bio-SNG depend on raw material mix and the approach for allocation



- High end: Forest model result with mass-allocation

60...250 gCO_2eq/MJ from forest C stocks

- Low end: Decay curves from previous studies

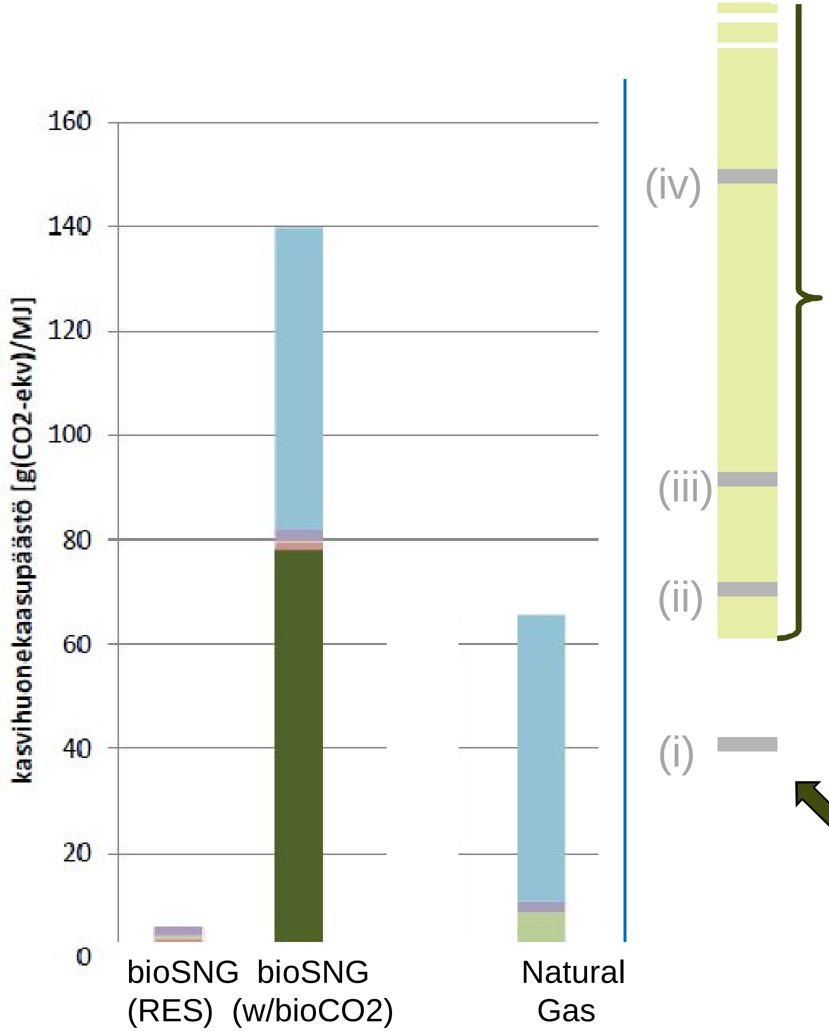
Climate impact of GJ of bio-SNG is not lower than of GJ of natural gas in 100 year perspective (GWP-100)

Left: Niskanen T. 2012.

Right: Analysis in this study

Niskanen T. 2012. Puupohjaisen biokaasun tuotantoketjun energiatehokkuus. Aalto. Master's Thesis.

7 Results for bio-SNG depend on raw material mix and the approach for allocation



- High end: Forest model result with mass-allocation

60...250 gCO_2eq/MJ from forest C stocks

- Low end: Decay curves from previous studies

Theoretical (unrealistic) minumum: 100% of feedstock from fast decaying branches

- Not available in sufficient amounts

Left: Niskanen T. 2012.

Right: Analysis in this study

Niskanen T. 2012. Puupohjaisen biokaasun tuotantoketjun energiatehokkuus. Aalto. Master's Thesis.

7. Findings (1)

- Energy-wood procurement area (transport distances) notably large, when no industrial wood from Finland used as process input
- Harvests of industrial wood had to increase significantly in order to supply enough energy wood to process
- Forest biomass use for bioenergy influenced simulated future forest carbon stocks
  - Regionally forests remained as net carbon sinks;
  - The lowered C stock has an impact on the atmospheric CO_2 concentrations; reduced C sink is analogical to C emission

7. Findings (2)

- More realistic assumption would be market-based wood procurement
  - However, based on the results of the earlier studies (Asikainen et al. 2012, Kallio et al. 2013, Sievänen et al. 2014, Hynynen et al. 2014), the impact on C sink would likely remain in the same order of magnitude
- If difference in forest C stocks is considered, climate impact results for bioSNG are notably high
- There is a significant risk to the investment if approaches from scientific literature were to be adopted in legislation, e.g. EU RED
  - Not specific to this case, but for forest bioenergy in general

7. Further research needs – How to reduce climate impacts?

- The size of the production plant and the wood-sourcing area influence on the availability of various feedstock sources
  - Smaller unit, larger wood-sourcing area → more climate-friendly feedstocks?
- Optimal forest management to boost the growth and to lower the forest C stock reduction
  - Fertilization, energy wood plantations?

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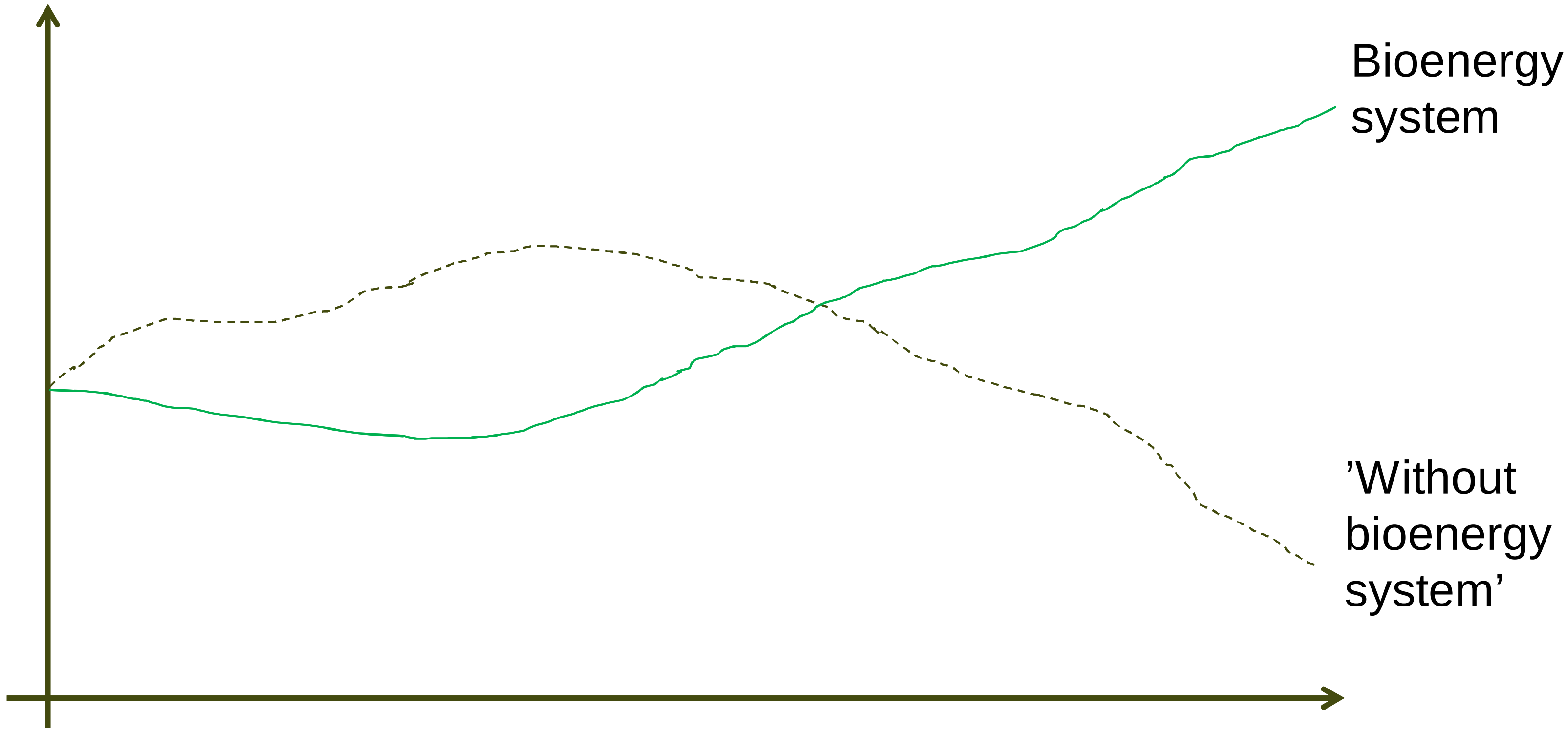
8. Supporting slides:

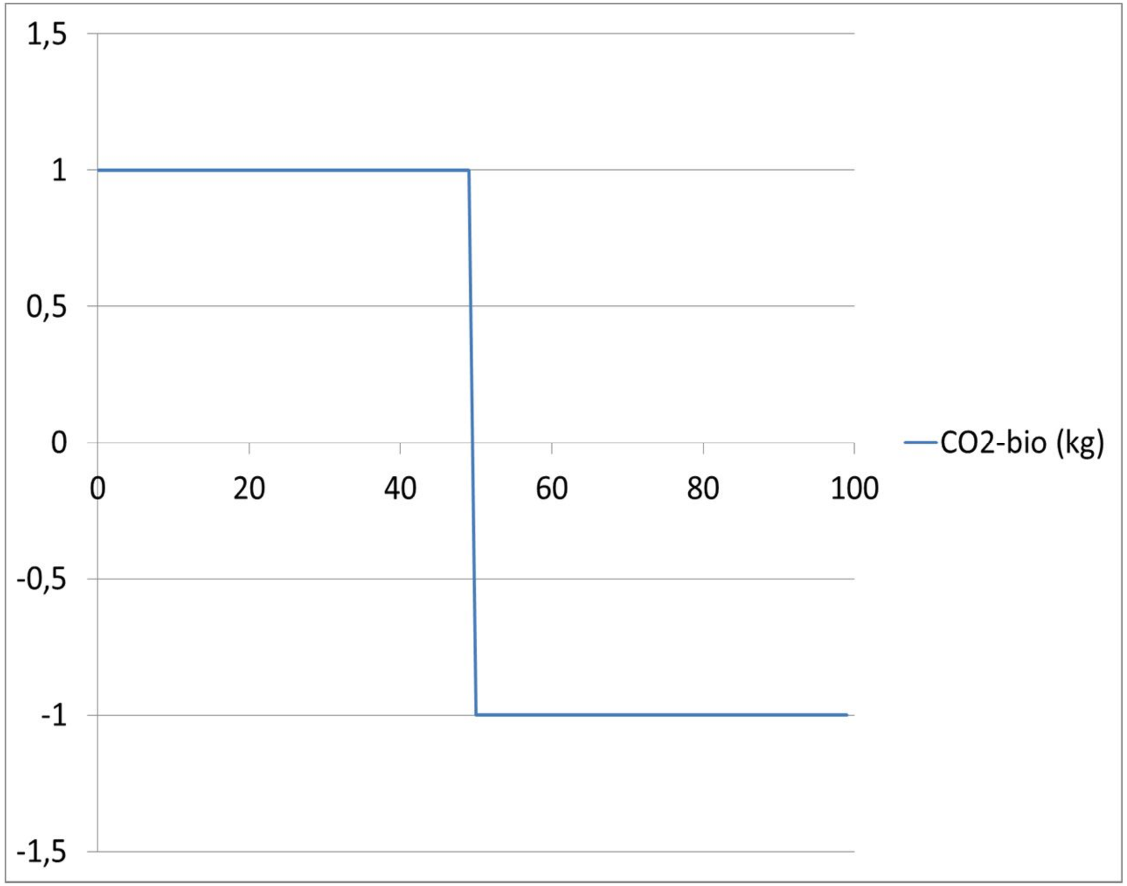
A Step-by-step example from forest carbon stocks to warming impacts and relative global warming potential (GWP) indices

A simplified example…

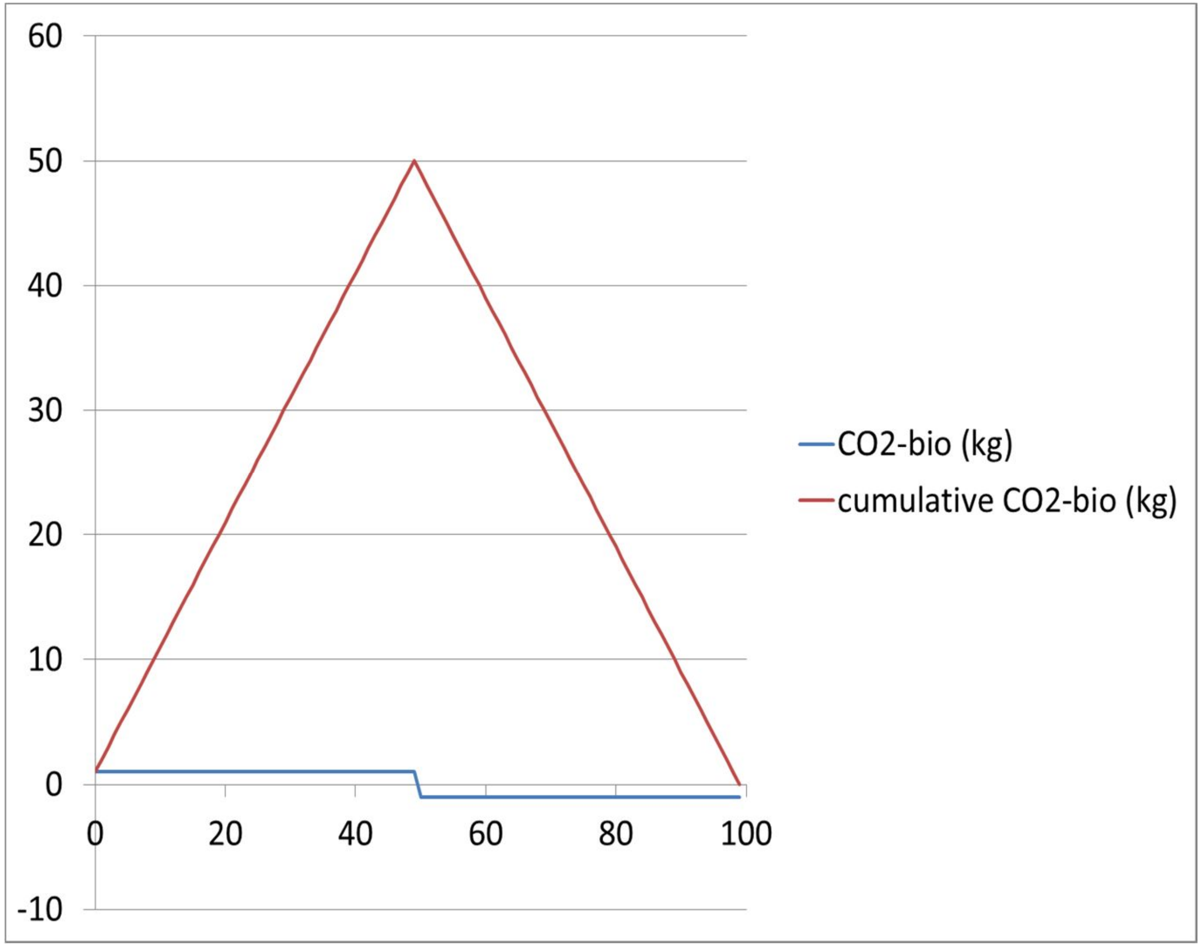
Forest carbon stock with and without continuous biomass harvesting for energy



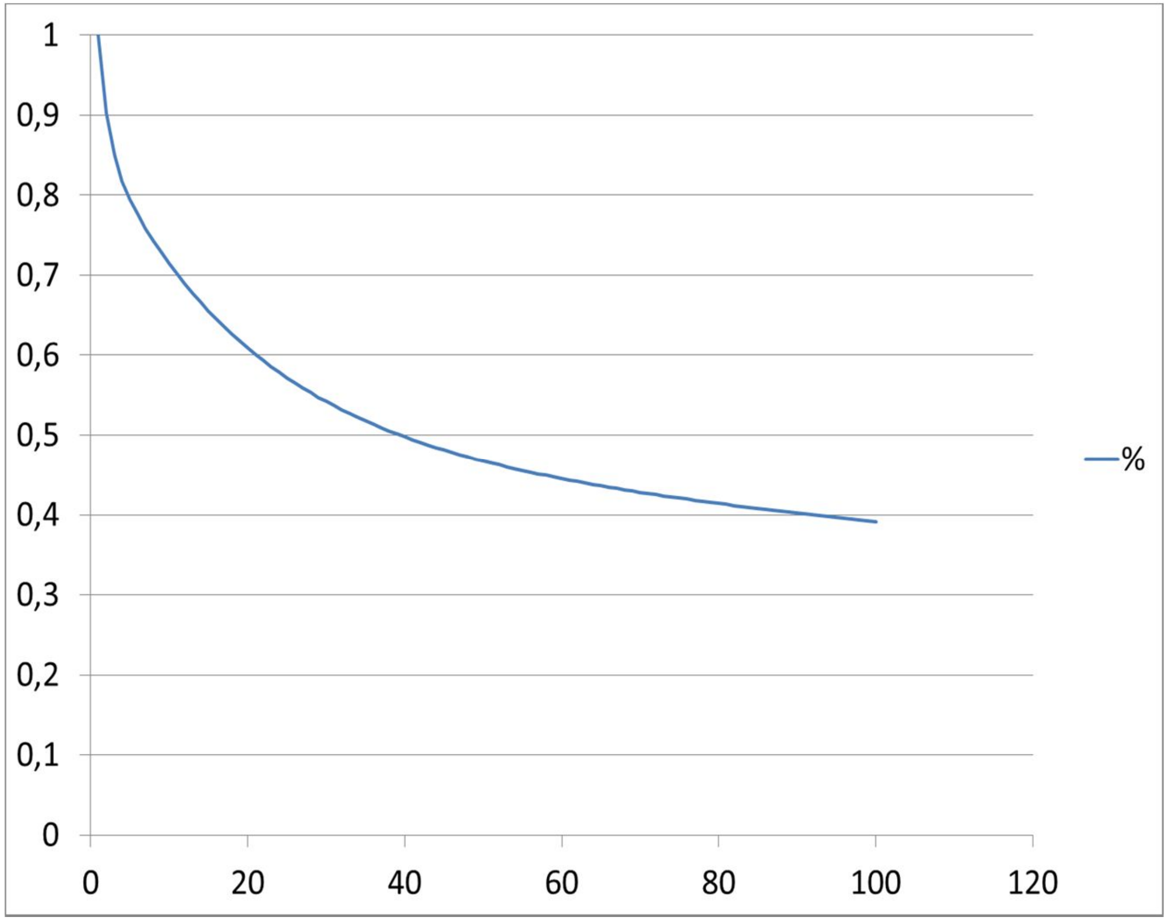
<u>Instant</u> forest carbon stock change between harvest and no harvest scenario when 1 unit of biomass carbon is harvested annually



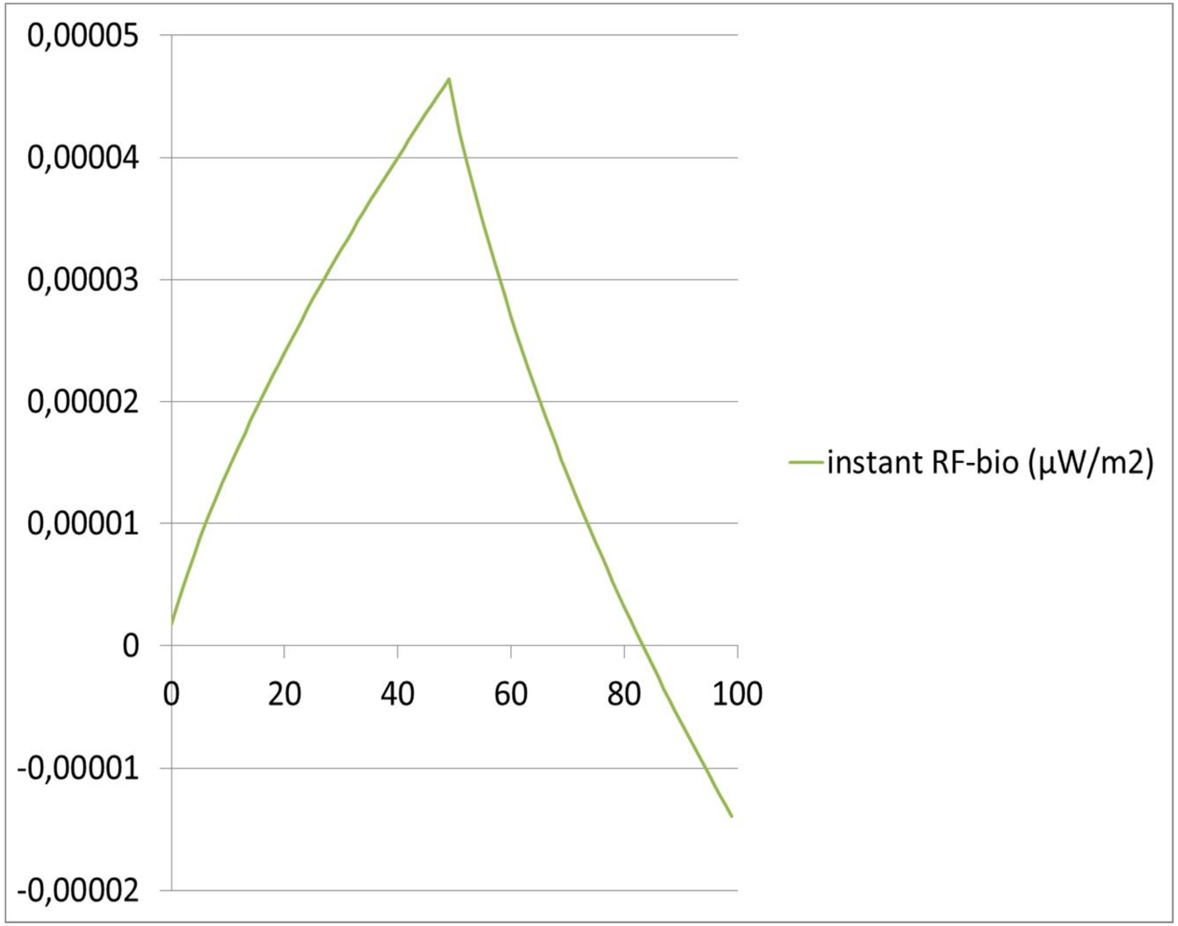
Cumulative forest carbon stock change between harvest and no harvest scenario when 1 unit of biomass carbon is harvested annually



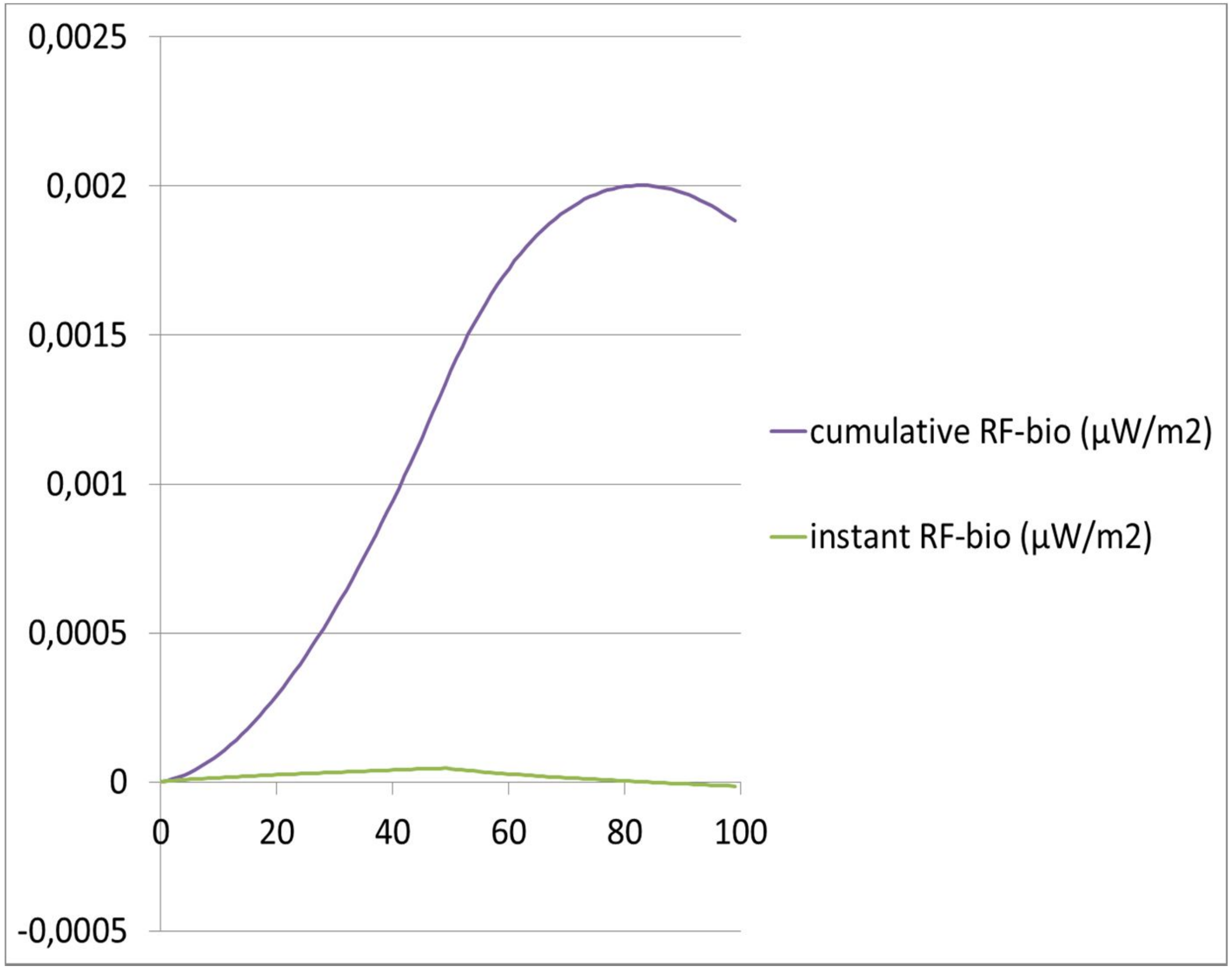
Additional carbon left in the atmosphere due to a single (fossil) pulse unit emission at the time zero



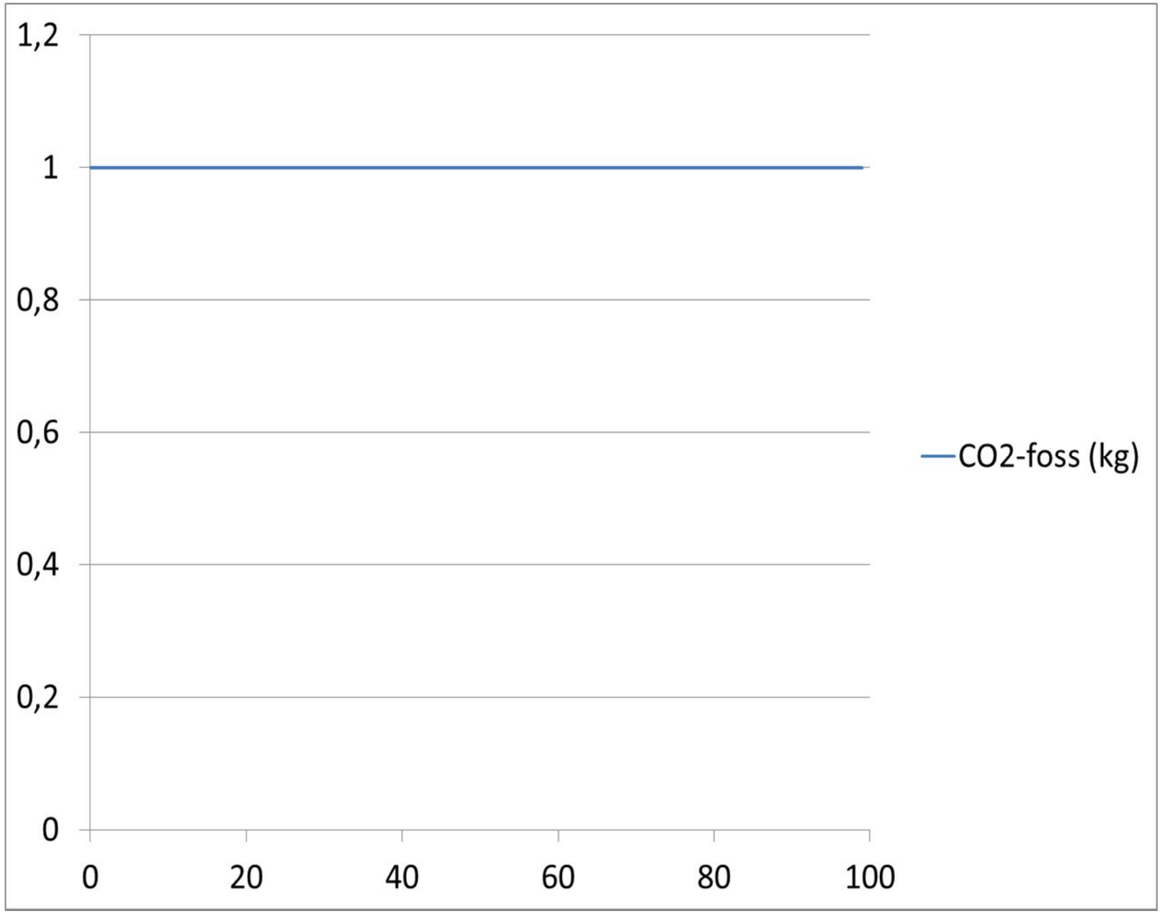
Additional instant radiative forcing due to forest carbon stock change between harvest and no harvest scenario when 1 unit of biomass carbon is harvested annually



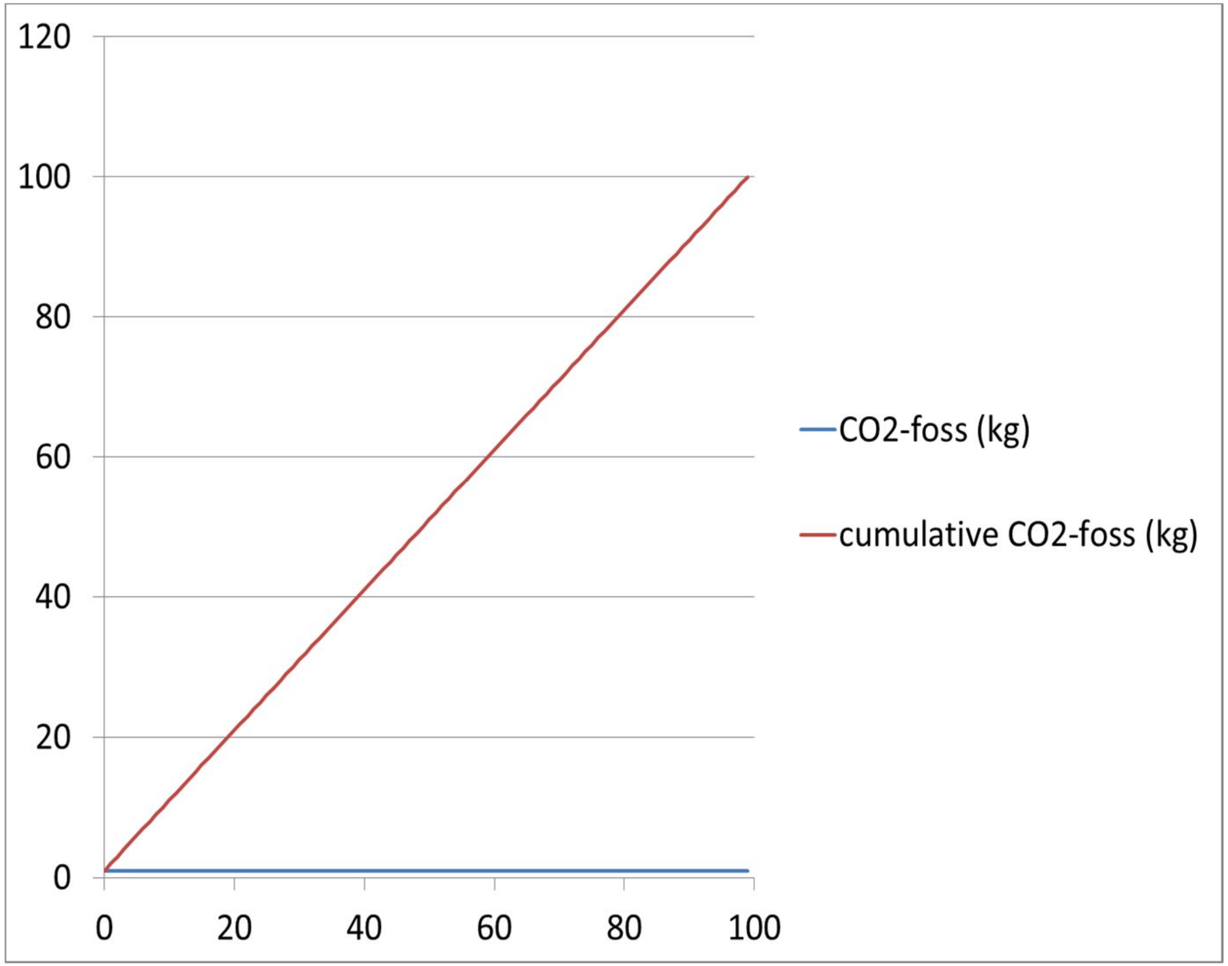
Additional instant and cumulative radiative forcing due to forest carbon stock change between harvest and no harvest scenario when 1 unit of biomass carbon is harvested annually



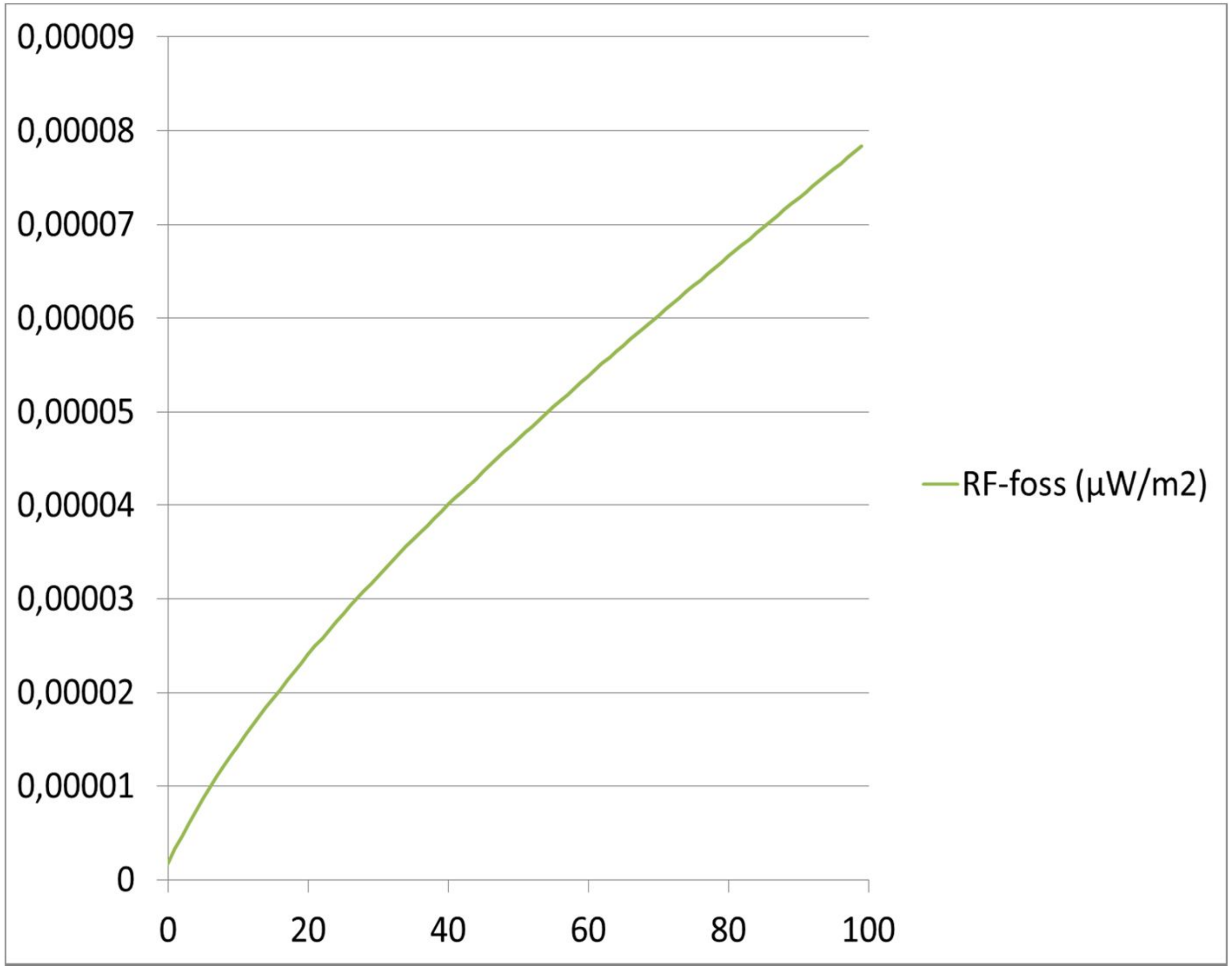
<u>Instant</u> emission due to 1 unit of fossil carbon emitted annually



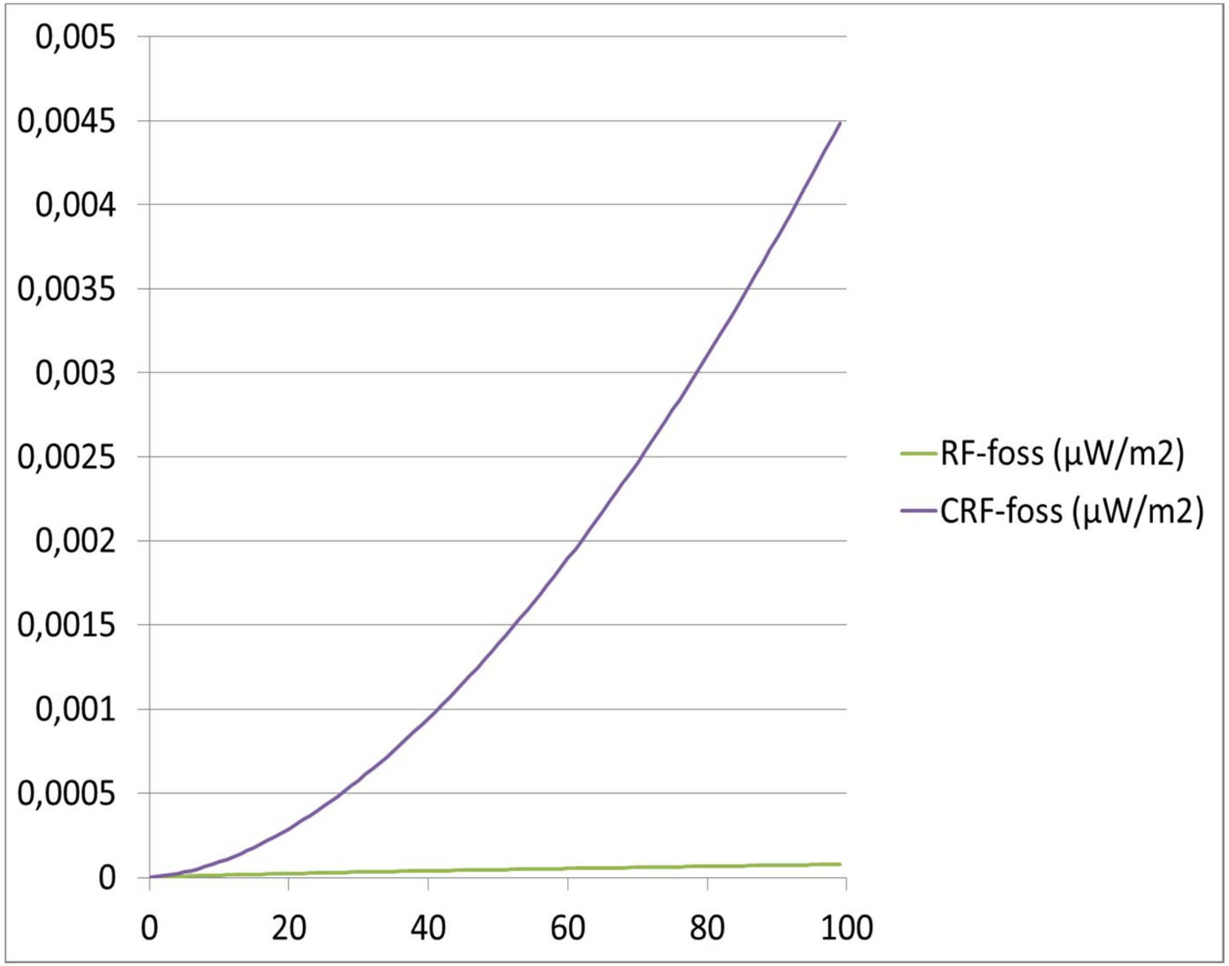
<u>Instant and cumulative</u> emission due to 1 unit of fossil carbon emitted annually



Additional instant radiative forcing due to 1 unit of fossil carbon emitted annually



Additional instant and cumulative radiative forcing due to 1 unit of fossil carbon emitted annually



Cumulative radiative forcing due to 1 unit of carbon emitted annually from bioenergy system compared to that of fossil energy system