Climate change effects of wood products and bioenergy

Leif Gustavsson, Sylvia Haus, Seppo Kellomäki, Roger Sathre

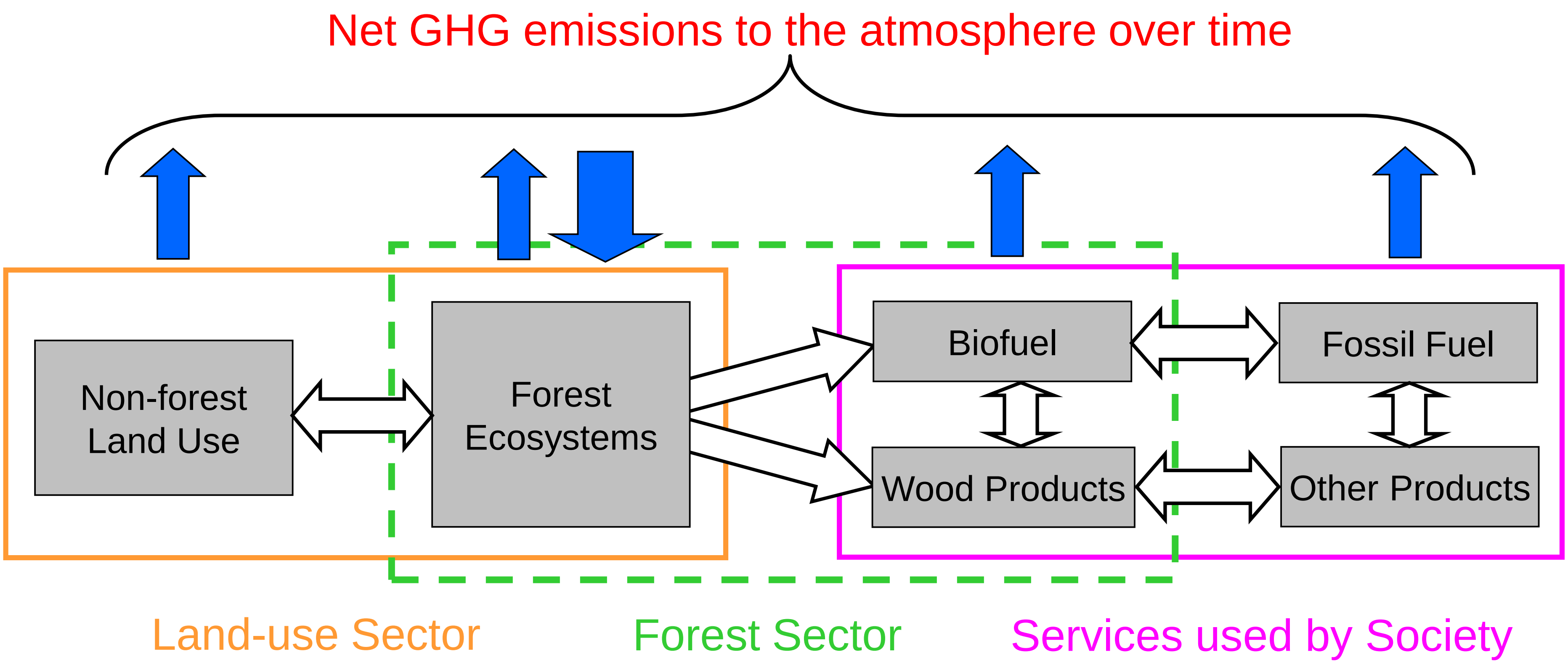
Wood based energy systems from Nordic and Baltic Forests

ENERWOODS International Conference 27th August, 2015,

KSLA, Drottninggatan 95, Stockholm

How can the forest sector contribute to mitigating climate change?

A holistic understanding is required



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Wood construction, bioenergy and climate change mitigation

Consider all significant net greenhouse gases in a life-cycle perspective of wood construction and non-wood alternatives

Important parts:

- Forest management
- Building materials and construction
- End-of-life implications
- Woody residues

Forward looking analysis— not historical average values

Sources of biomass residues from building life-cycle

Forest residues

Wood processing residues

Construction residues

Demolition residues

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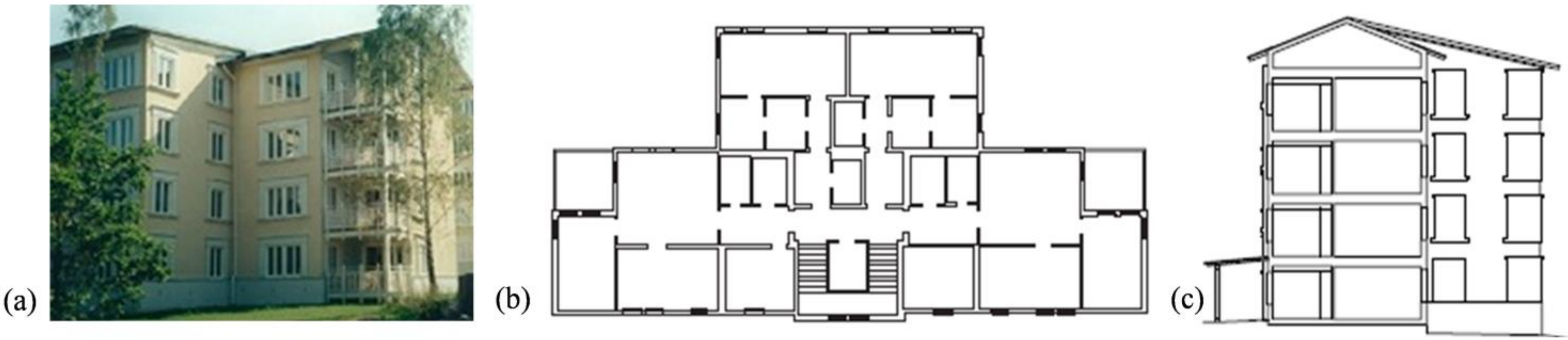
Case-study building

- Four-storey building
- Total usable floor area of 1190 m^2
- 16 apartments



We compare **concrete-frame and wood-frame versions**

- Same size and function
- Both comply with the energy regulations of the 2014 Swedish building code (BBR 2014)

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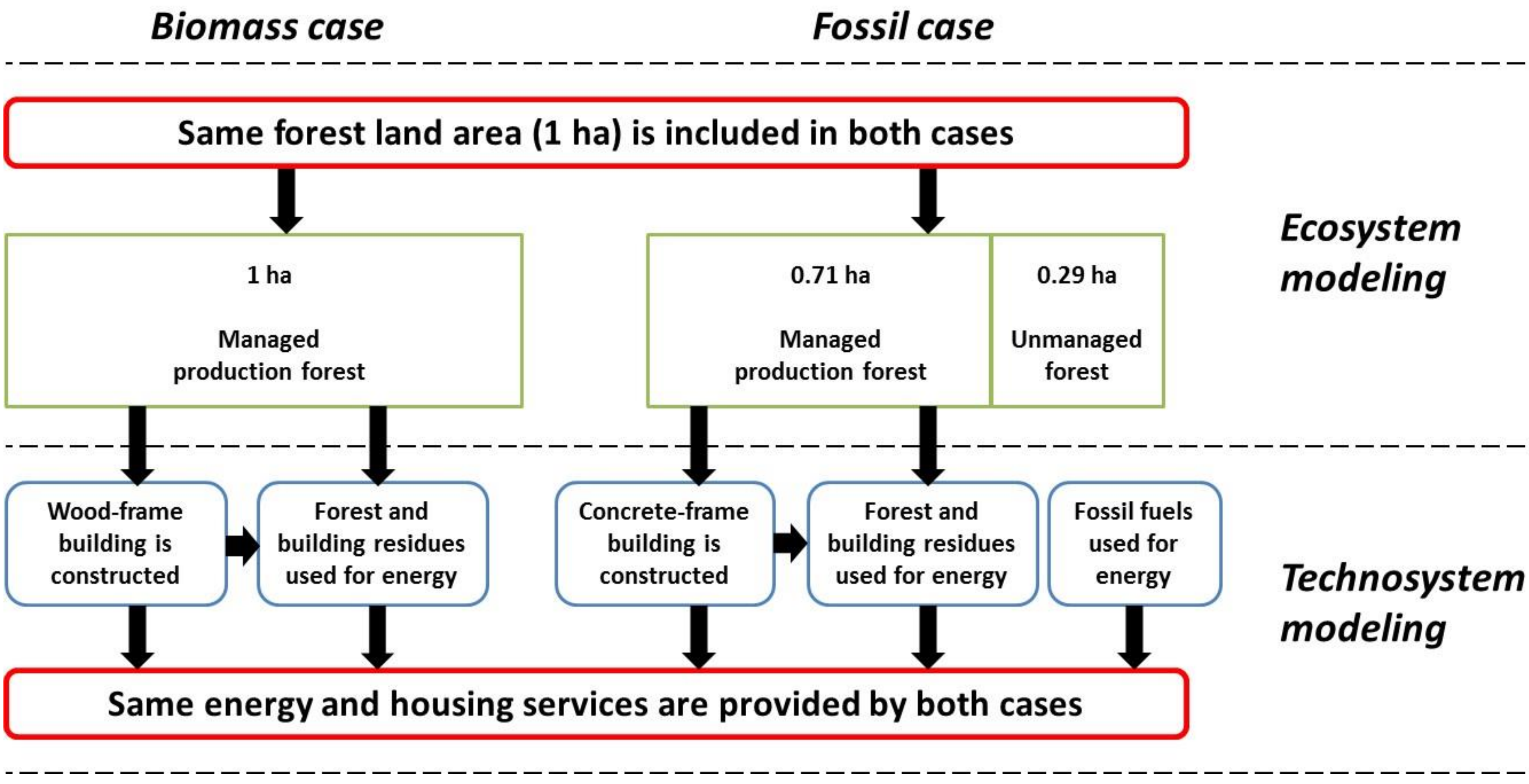
Equivalent functional units for Biomass and Fossil cases



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Forest modeling

- Unit hectare of Norway spruce (*Picea abies*) forest
- Medium fertility site index 27 (H_{100})
- Mean temperature is 2.2 °C
- Annual precipitation is 630 mm

2 forestry regimes: Unmanaged and Managed

Unmanaged forest stand is left unharvested

- Natural processes and disturbance regimes determine carbon flows

Managed forest is clear-cut harvested on 80-year rotation period

- Commercial thinnings at 35 and 60 years
- 3 management practices for final harvest residues:
    - no removal
    - slash removal
    - slash and stump removal

Calculation of CO_2 emission in technical systems

Carbon emission includes emission from extraction, processing, manufacture and transport of building materials

Cement reaction emission is calculated as net of emissions from calcination and carbonation

Woody residues from wood processing and end-of-life of building are used to substitute fossil energy

Full fuel cycle CO_2 emissions are considered

For woody biomass international transport of 1000 km is included

Biomass residues used for bioenergy

Residues from:

- Forest thinning
- Forest harvest
- Wood processing
- Building construction
- Building demolition

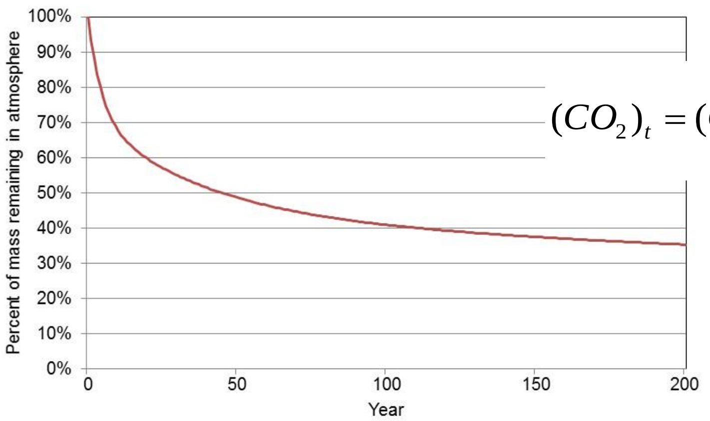
	Fossil fuel use (MJ per dry ton)		
	Stemwood	**Slash**	**Stumps**
Recovery (felling, lifting, forwarding)	116	189	569
Roadside comminution	0	77	96
Truck transport	227	145	145
Train transport	0	19	19
Ship transport	0	56	56
Total	**343**	**486**	**885**

6 different bioenergy pathways using modern large-scale high-efficiency biomass conversion plants

Bioenergy system							**Corresponding fossil system**							
Fuel use (MJ)	Conversion technology	Main product		Coproduct		CO_{2eq} emission (g)	Fossil fuel	Conversion technology	Main product		Coproduct		Fossil fuel use (MJ)	CO_{2eq} emission (g)
		Type	MJ	Type	MJ				Type	MJ	Type	MJ		
Existing technologies														
1.0	BST	Electricity	0.45	-	-	109	Coal	CST	Electricity	0.45	-	-	0.98	104
1.0	BST	Electricity	0.45	-	-	109	Gas	FGCC	Electricity	0.45	-	-	0.78	53.5
1.0	CHP-BST	Heat	0.80	Electricity	0.30	109	Coal	CHP-CST	Heat	0.80	Electricity	0.41	1.12	120
Emerging technologies														
1.0	CHP-BIGCC	Heat	0.47	Electricity	0.43	109	Coal	CHP-CST	Heat	0.47	Electricity	0.24	1.21	130
1.0	CHP-BIGCC	Heat	0.47	Electricity	0.43	109	Gas	CHP-FGCC	Heat	0.47	Electricity	0.50	0.97	66.8
1.0	DME	DME	0.50	-	-	109	Oil	Diesel	Diesel	0.50	-	-	0.50	39.8

Climate forcing due to net CO_2 emissions

Atmospheric decay of unit pulse of CO_2



$$(CO_2)_t = (CO_2)_0 \times \left[0.217 + 0.224 e^{\frac{-t}{394.4}} + 0.282 e^{\frac{-t}{36.54}} + 0.276 e^{\frac{-t}{4.304}} \right]$$

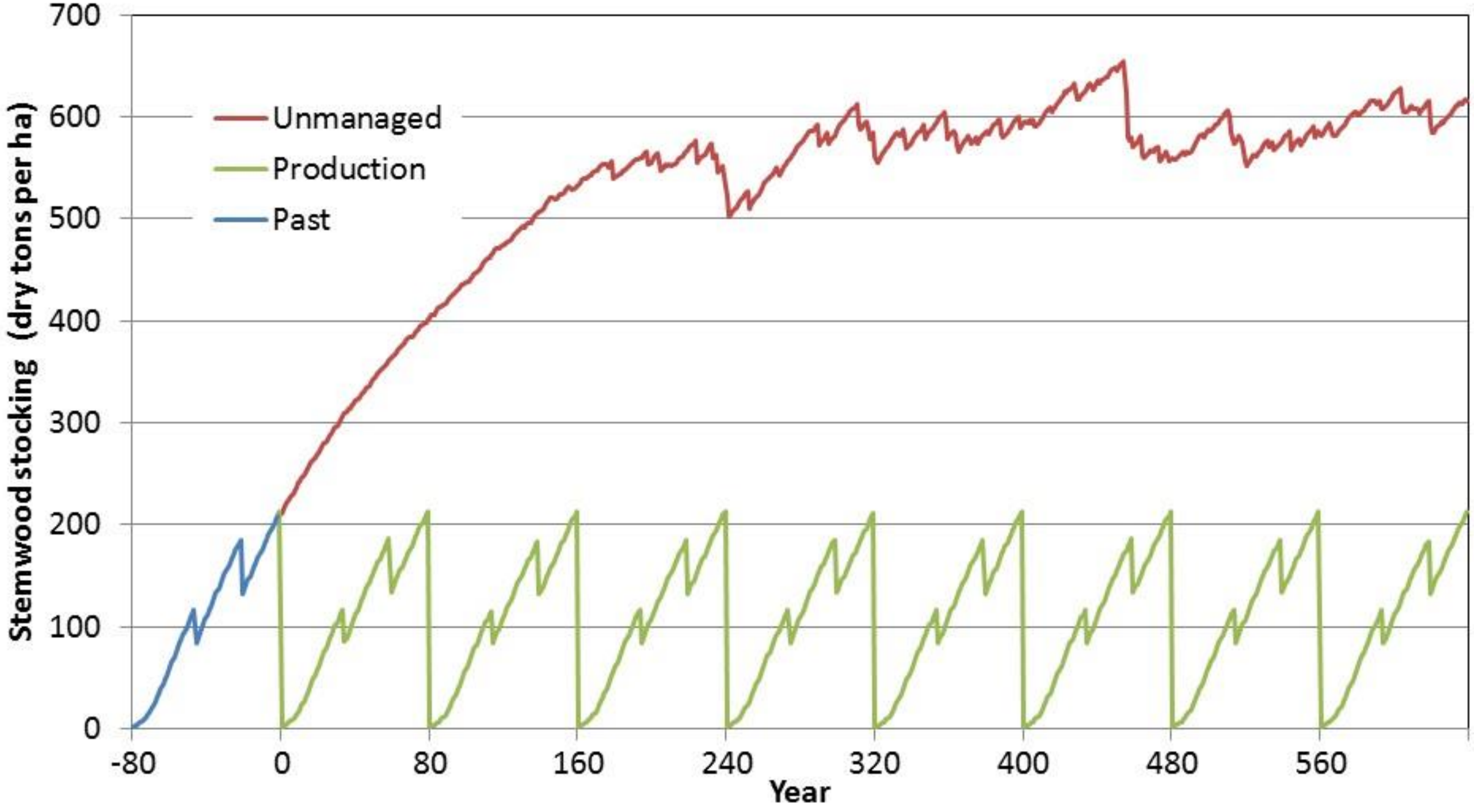
Radiative forcing (W/m²) due to CO_2 concentration change

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

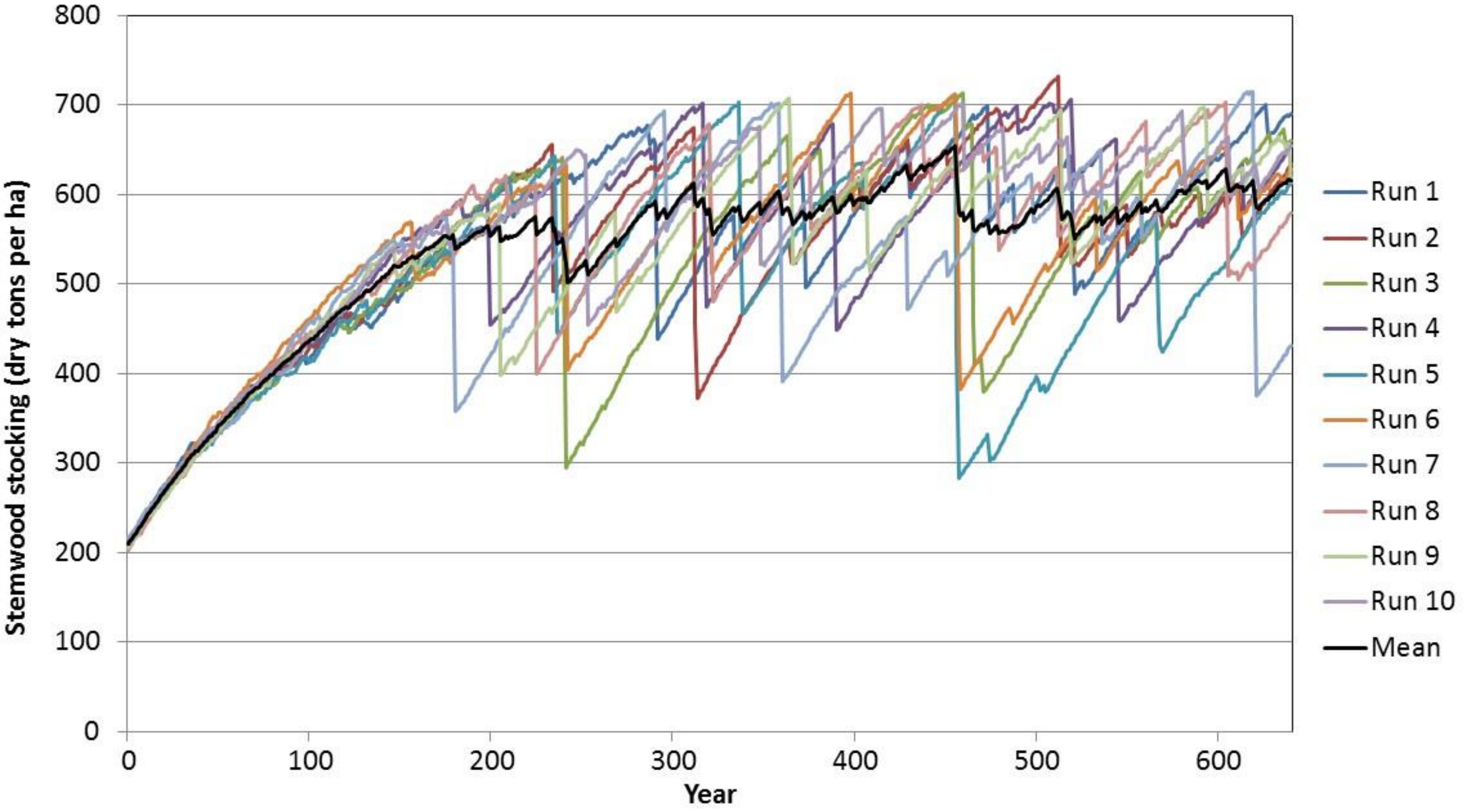
where CO_{2ref} = 400 ppmv

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

Stemwood biomass in unmanaged and managed stands



Stemwood biomass in unmanaged stand
10 different model runs



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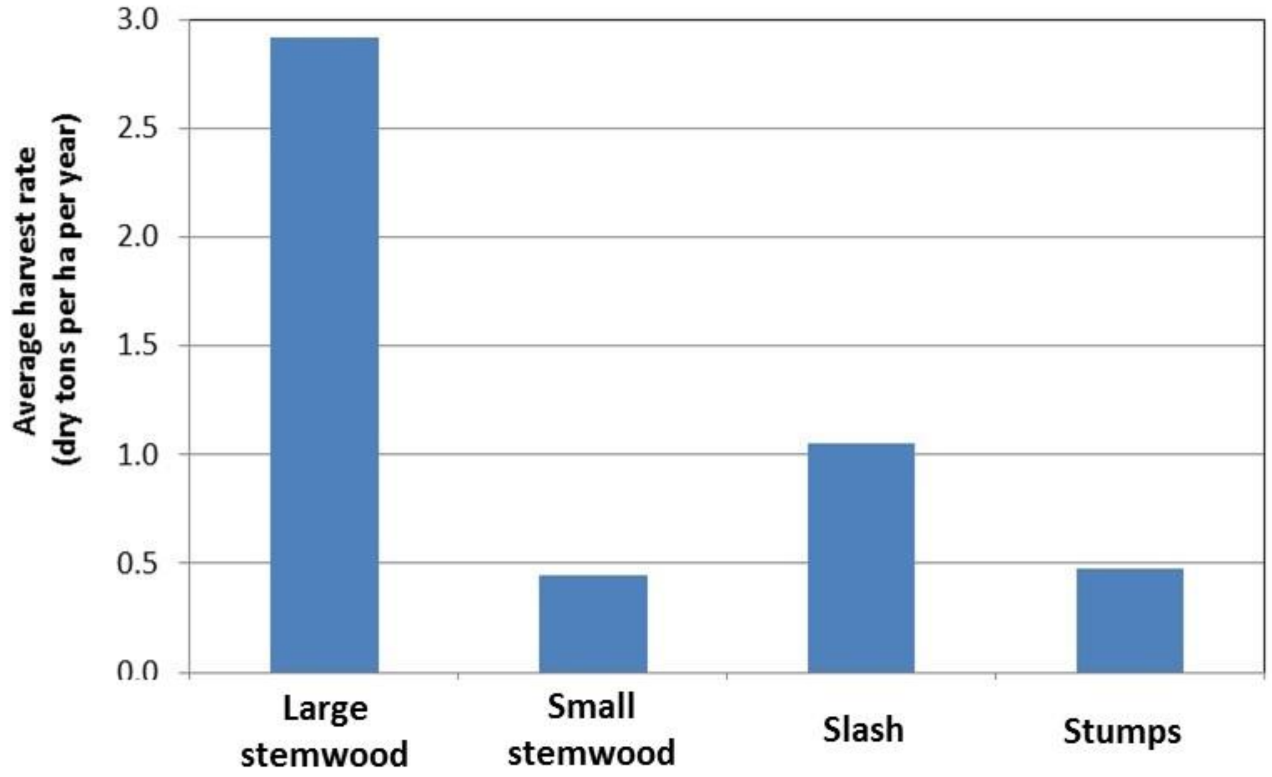
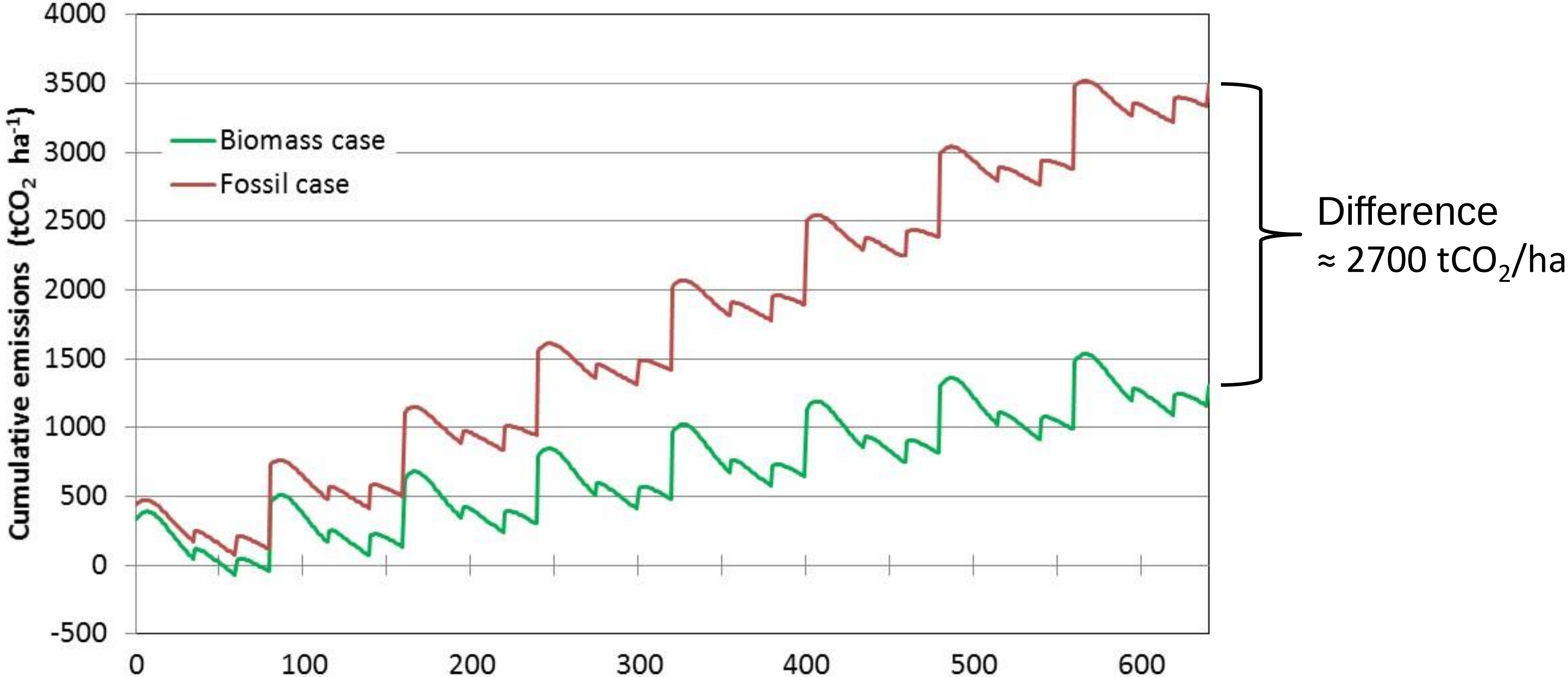
Average annual harvest rates from managed forest stand



Cumulative net emissions of Biomass case and Fossil case



Base-case conditions:

- Harvest of stemwood, slash and stumps
- Bioenergy displaces coal-fired CHP-BST heat and electricity production
- Average net ecosystem exchange (NEE) of unmanaged forest

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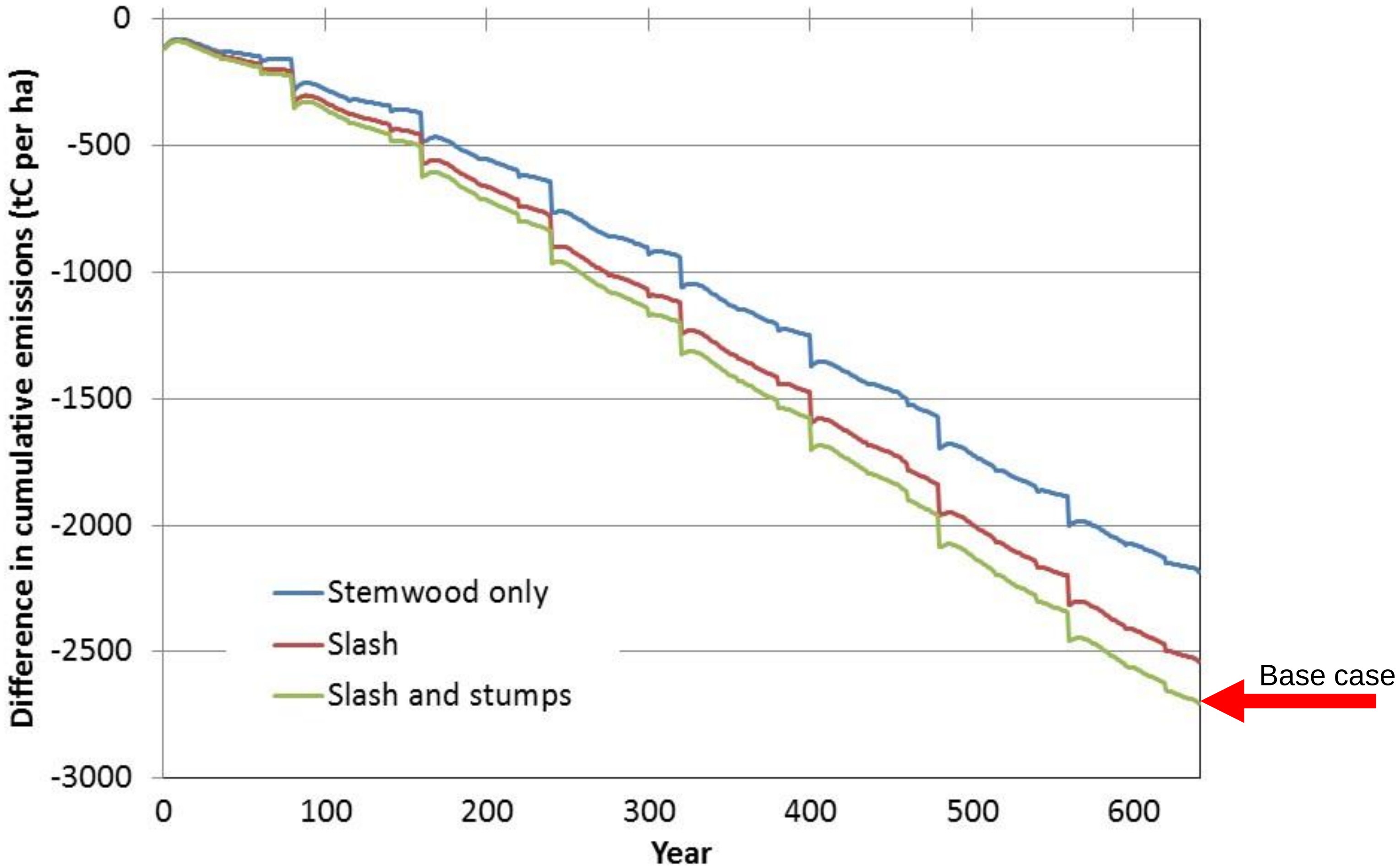
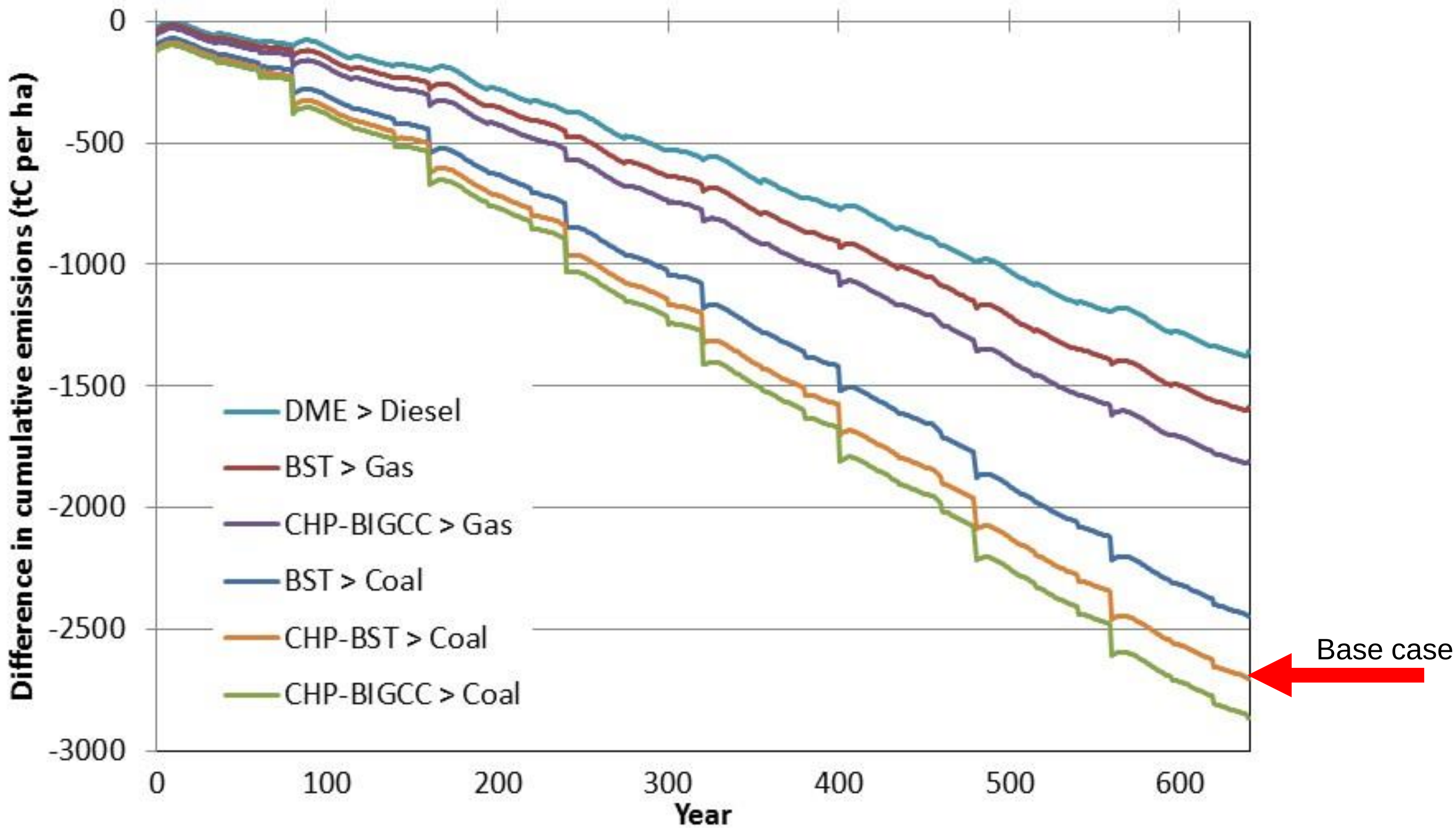
Difference in cumulative net emissions
Varying level of harvest residue collection



- Bioenergy displaces coal-fired CHP-BST heat and electricity production
- Average NEE of unmanaged forest

Difference in cumulative net emissions
Varying bioenergy and fossil energy systems



- Harvest of stemwood, slash and stumps
- Average NEE of unmanaged forest

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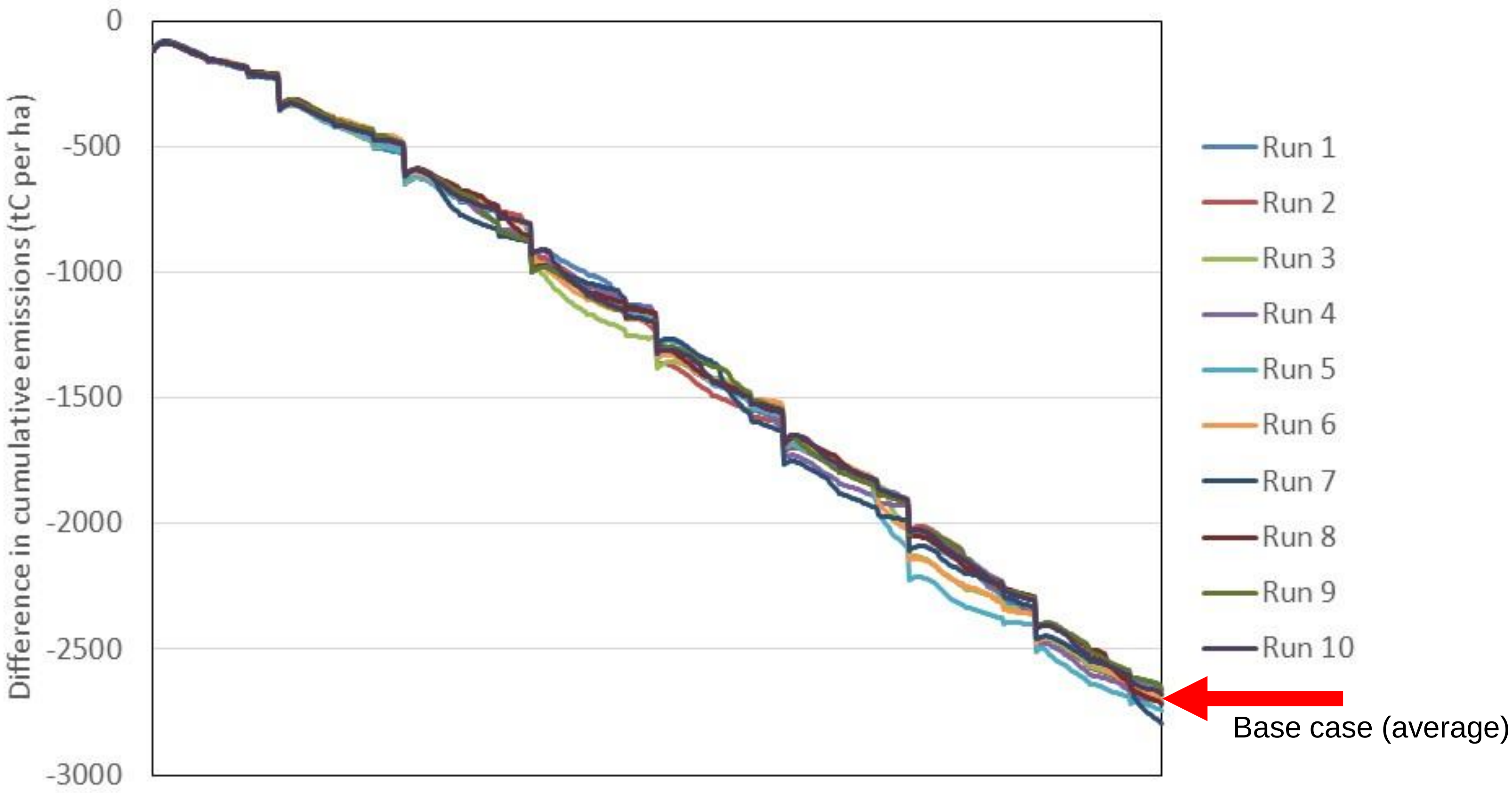
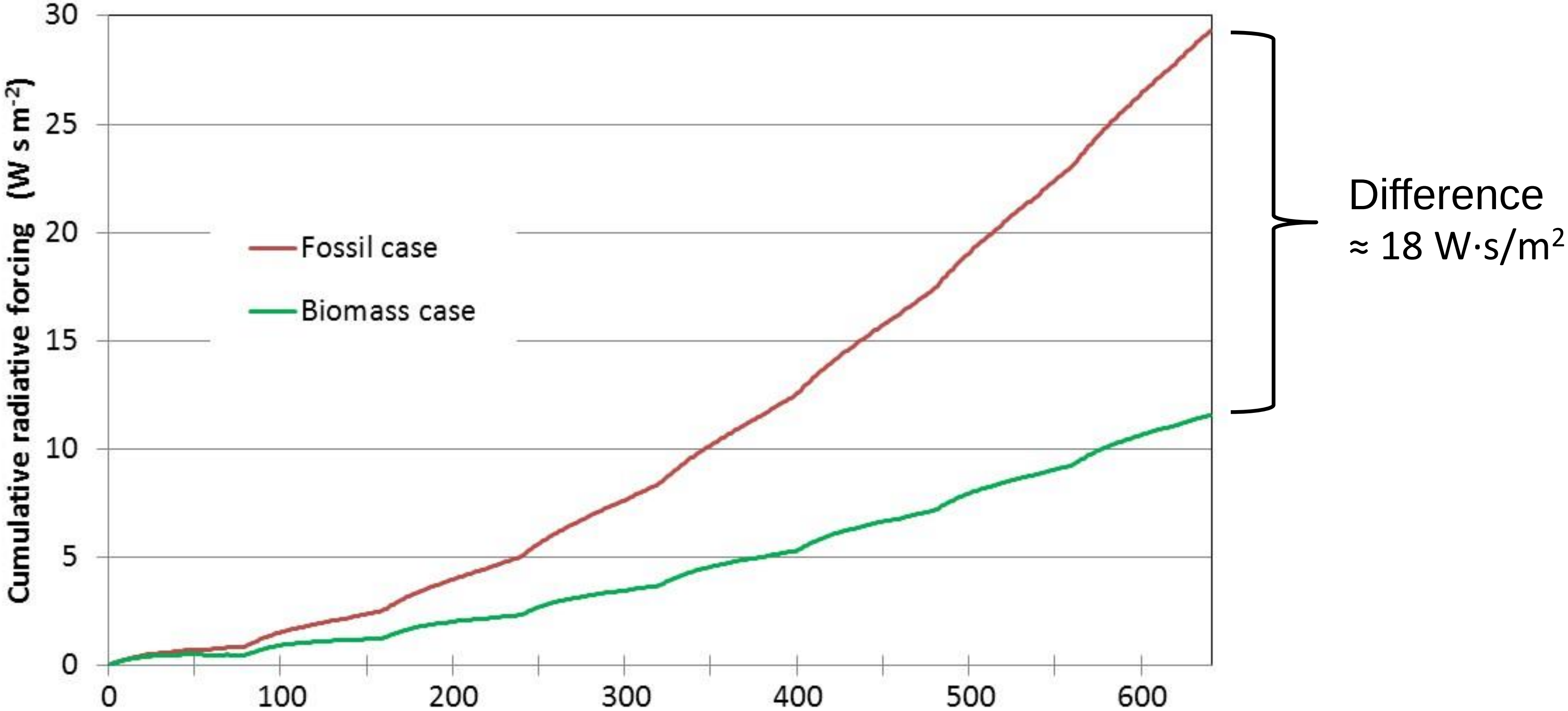
Difference in cumulative net emissions
Varying of net ecosystem exchange of unmanaged forest



- Harvest of stemwood, slash and stumps
- Bioenergy displaces coal-fired CHP-BST heat and electricity production

Cumulative radiative forcing of Biomass and Fossil case



Base-case conditions:

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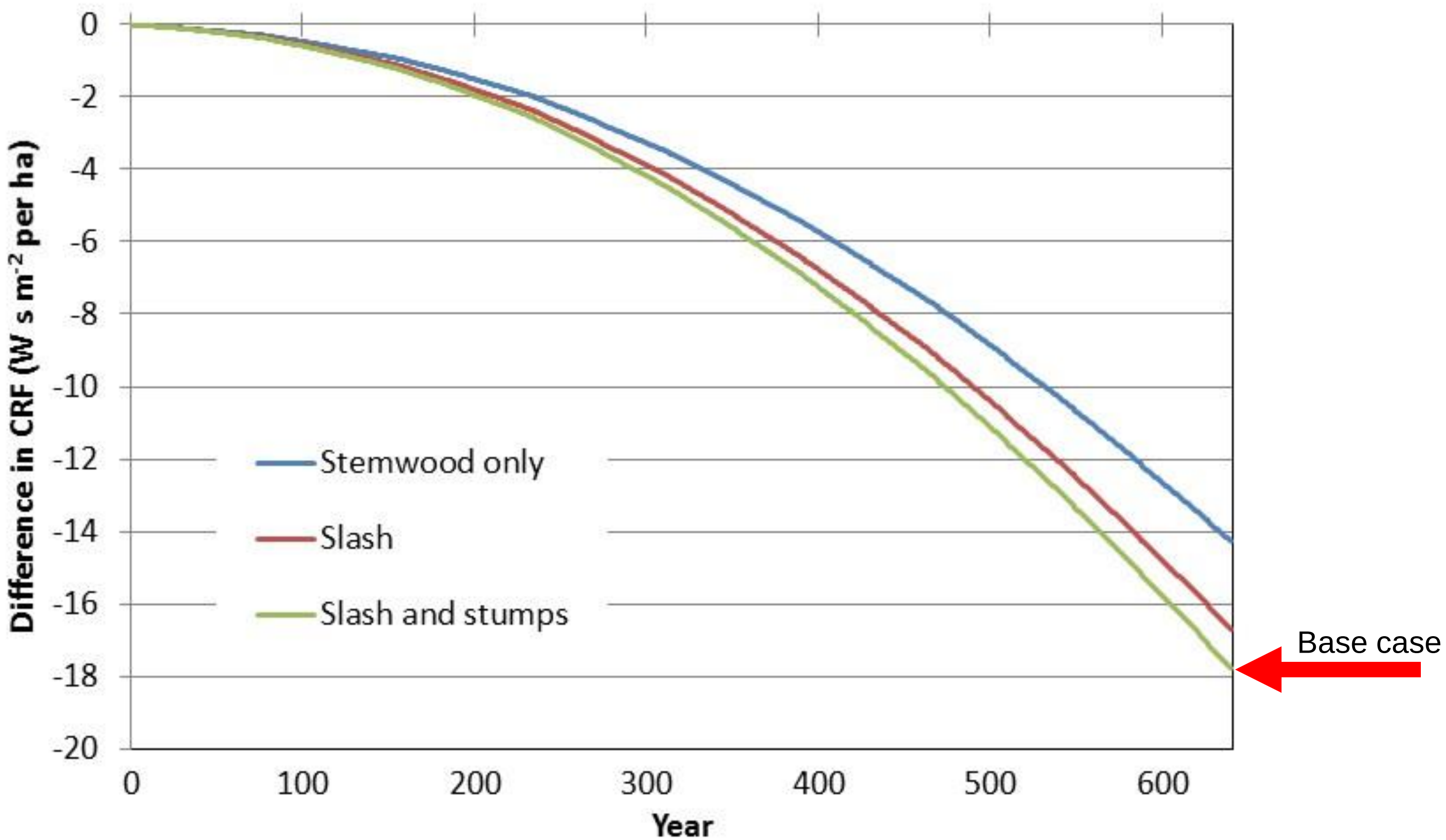
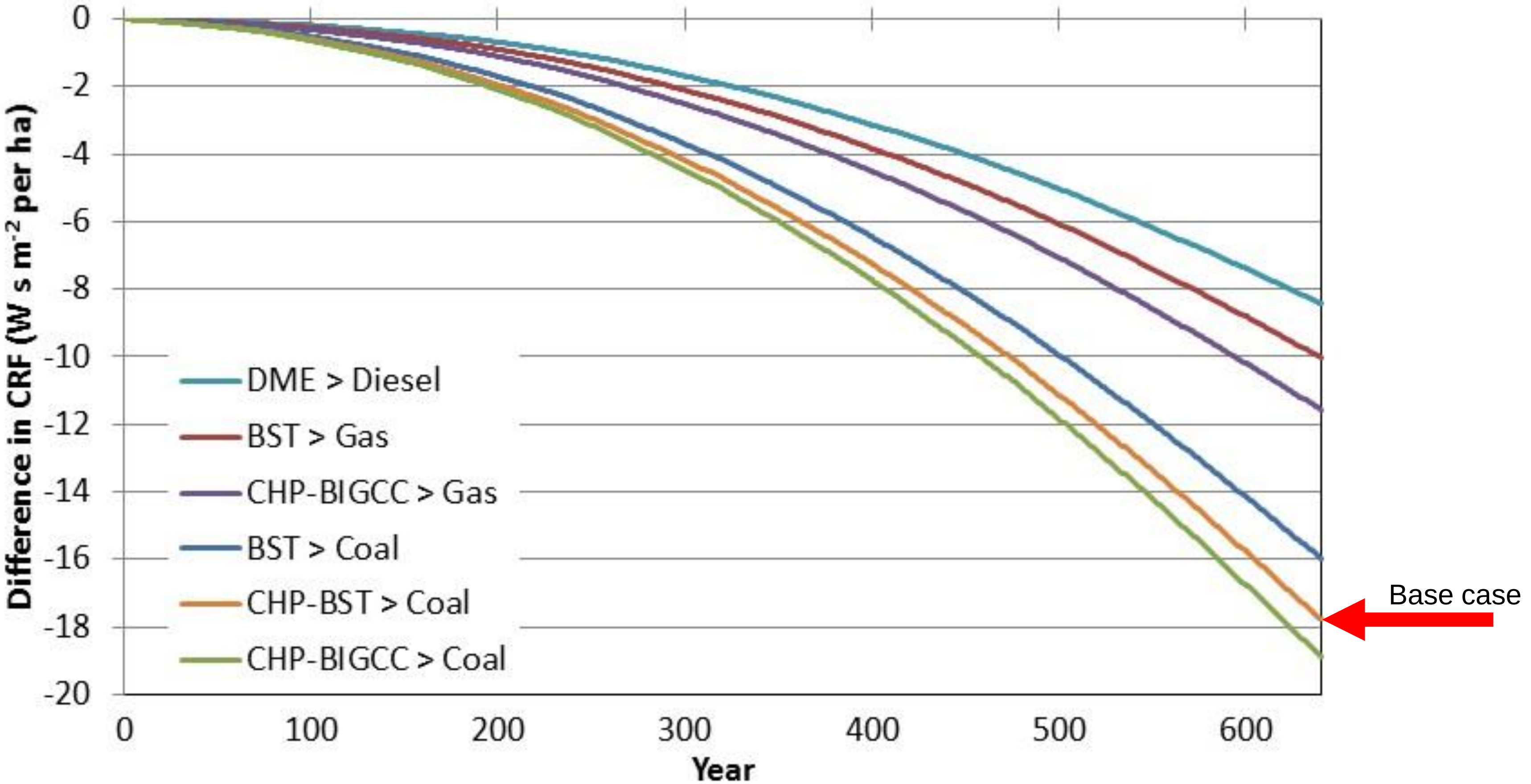
Difference in cumulative radiative forcing
Varying level of harvest residue collection



- Bioenergy displaces coal-fired CHP-BST heat and electricity production
- Average NEE of unmanaged forest

Difference in cumulative radiative forcing
Varying bioenergy and fossil energy systems



- Harvest of stemwood, slash and stumps
- Average NEE of unmanaged forest

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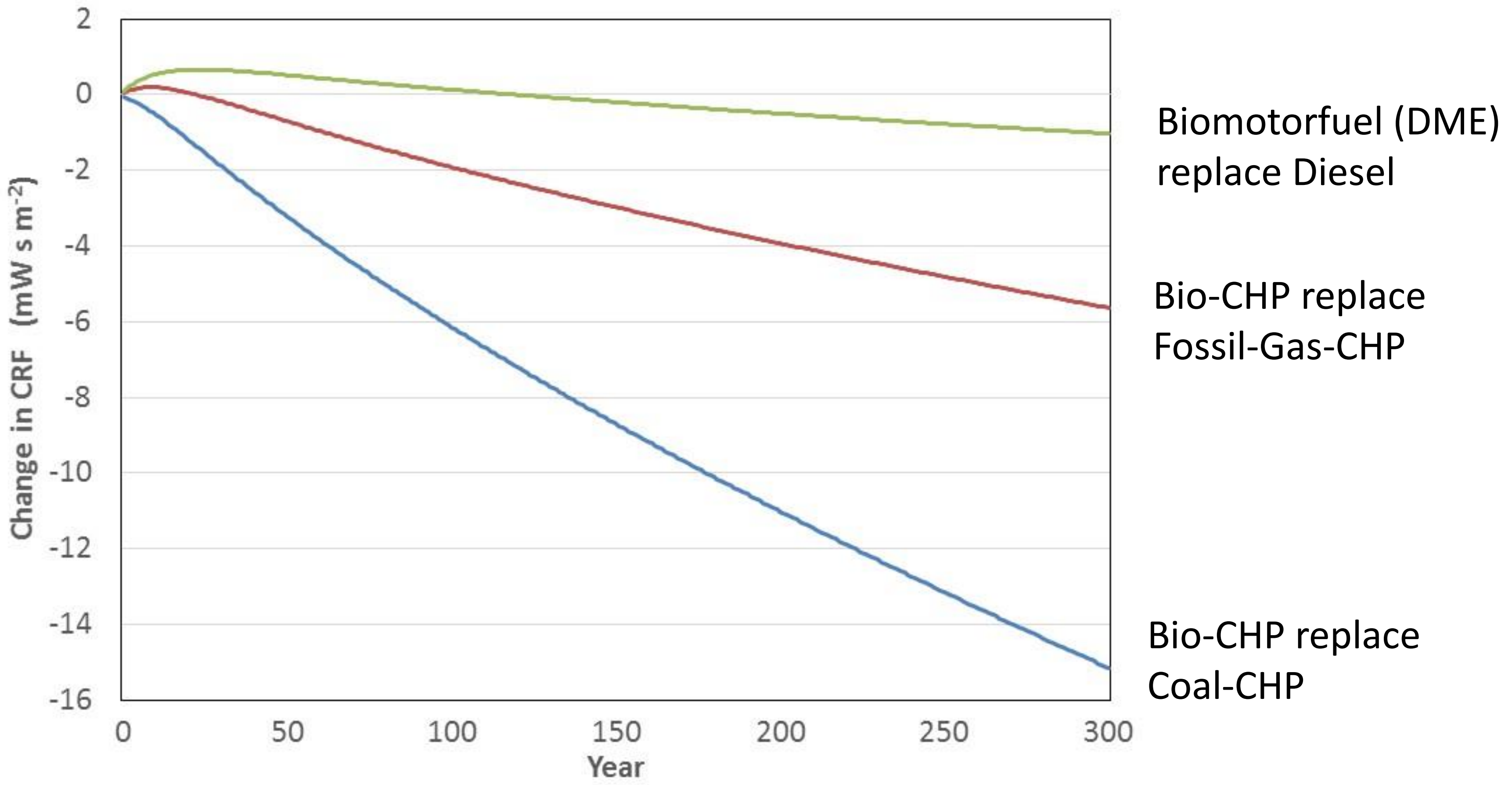
Changed CRF when one ton of dry woody biomass of logging residues replace fossil energy



Slash, internationell transport, central Sverige, Q-decay model

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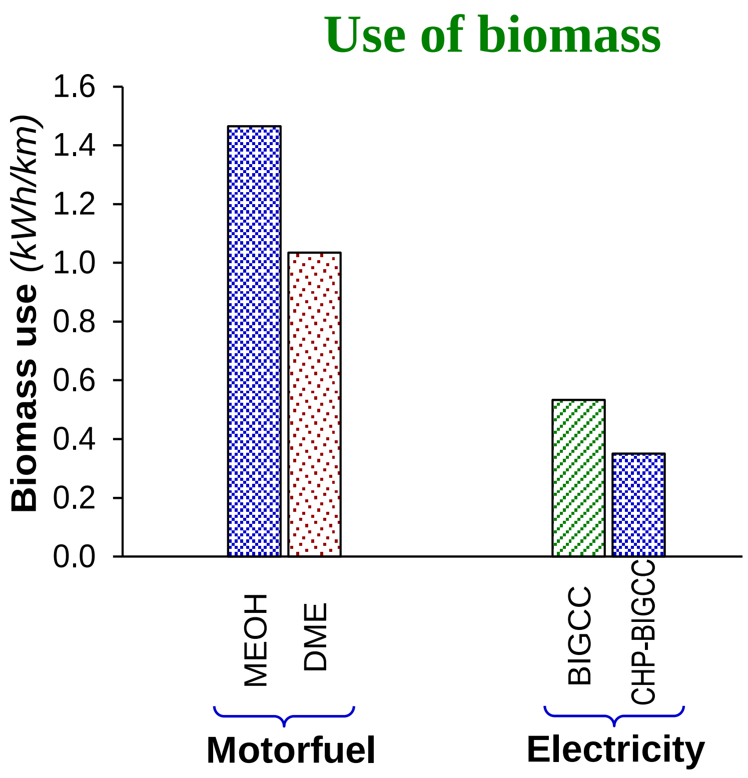
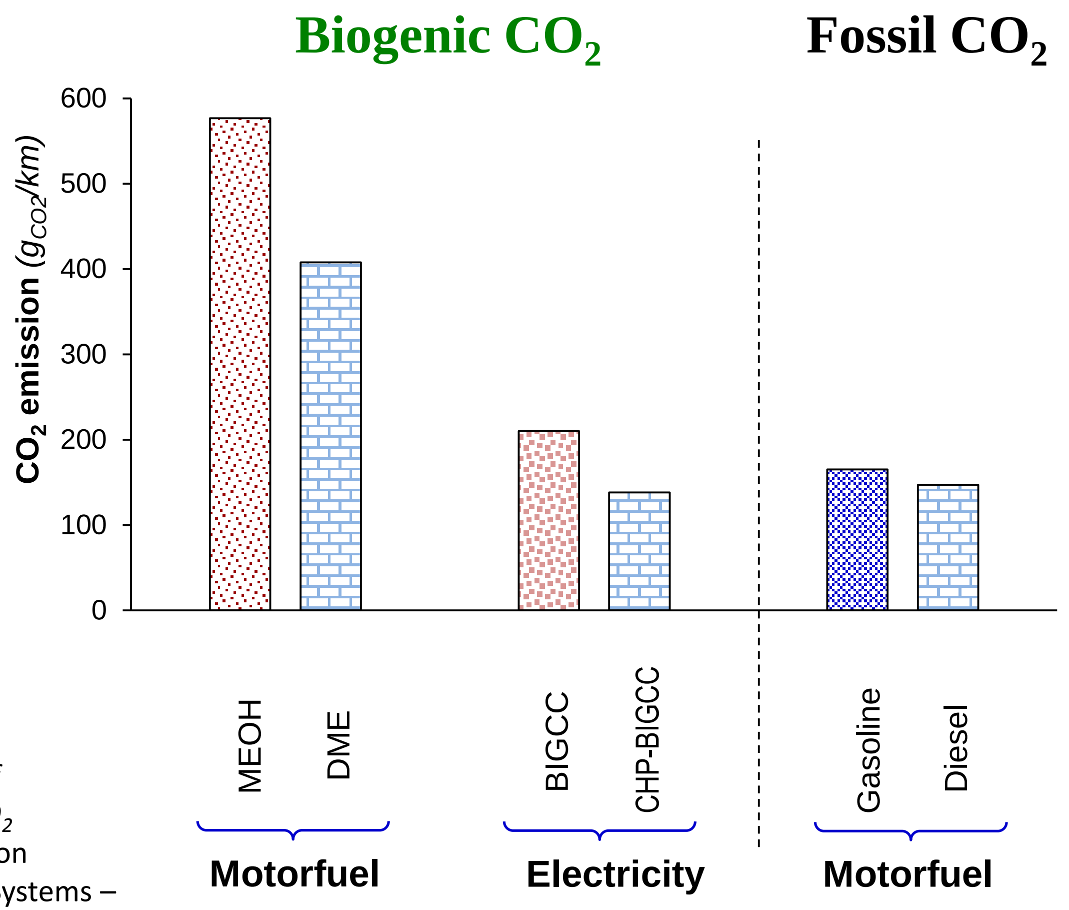
Adapted from Gustavsson, L. et al. (2015) Climate effects of bioenergy from forest residues in comparison to fossil energy. *Applied Energy* 138,pp. 36-50

Mercedes-Benz B-Class - Use of biomass and emission of CO_2 per km driving distance





Adopted from Gustavsson L. and Truong N.L. (2015). *Effects of different bioenergy pathways on primary energy efficiency, CO_2 emission and energy system integration.* The 10th Conference on Sustainable Development of Energy, Water and Environment Systems – SDEWES 2015 (Accepted manuscript).

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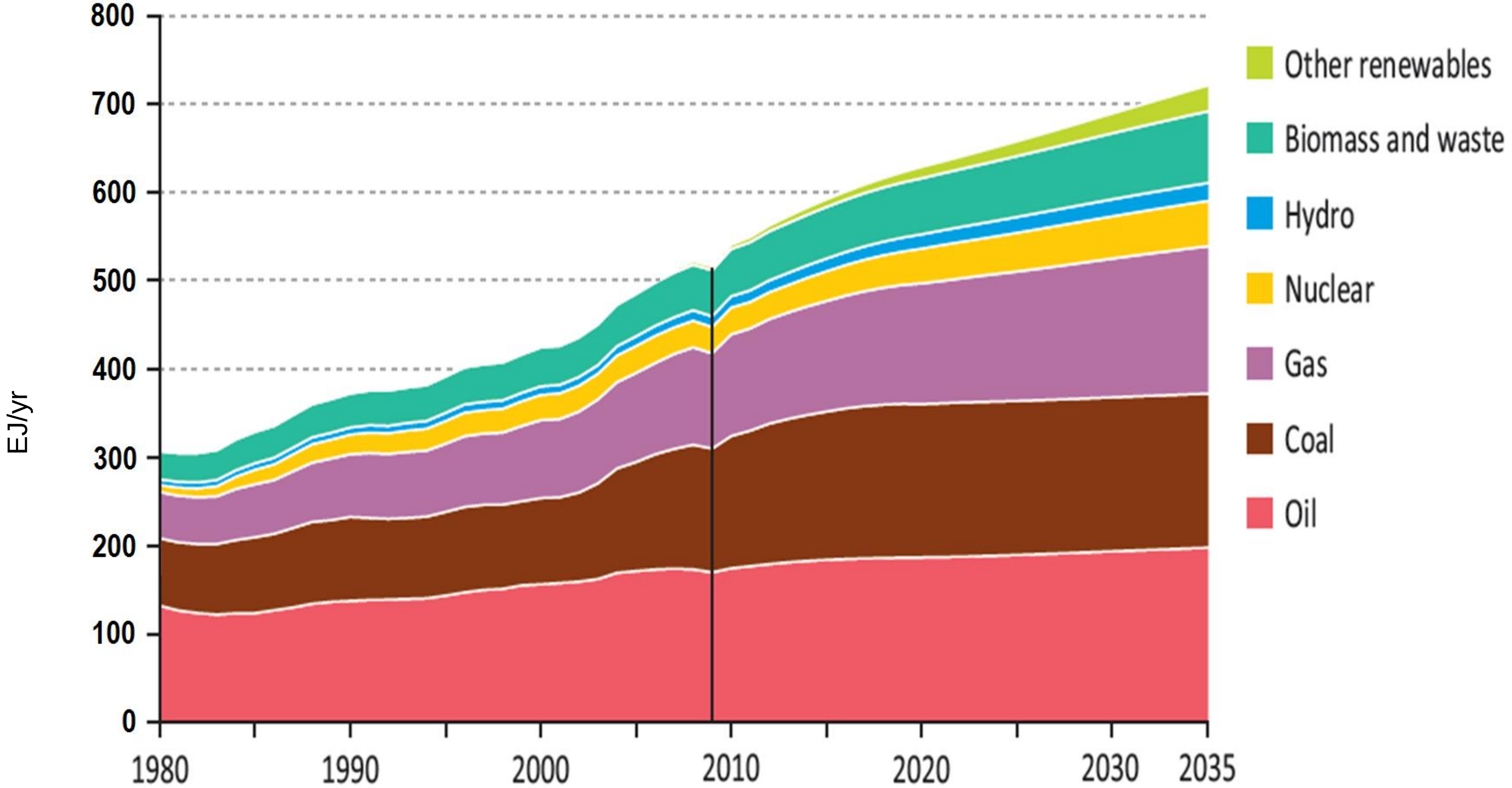
Conclusions/discussion

- Climate implications of bioenergy and wood construction should be considered in a holistic life-cycle system perspective
- Important parts are forest management, building production and end-of-life management as well as biomass residues
- Forward looking analysis (not historical average values) considering imposed changes
- Good description of current and potential forest systems
- Good description of current and potential technical systems
- A landscape perspective is needed to consider forest dynamics
- Renewable-based district-heat production with cogeneration of electricity is cost- and primary energy-efficient system if environmental and social costs are considered

Primary energy use in IEA "New Policies" scenario



The new policy scenarios include expanded activities in countries to reduce emission of greenhouse gases compared to the current situation

Source: International Energy Agency, 2011. World Energy Outlook 2011.