Climate effects of forestry and substitution of carbon-intensive materials and fossil fuels – a country level study for Sweden[1]

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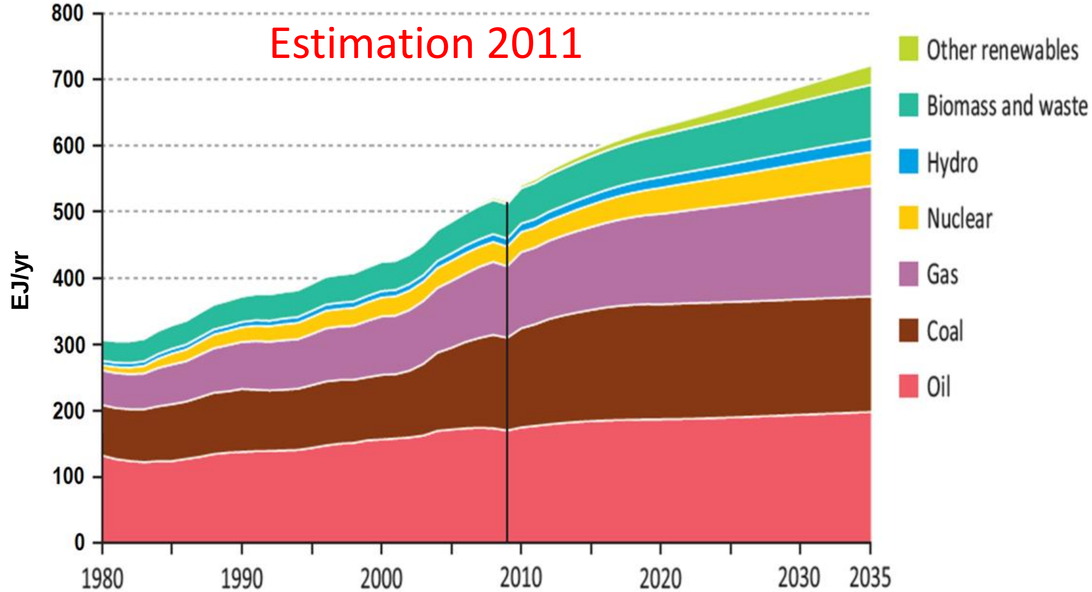
Forests and the climate
Manage for maximum wood production or leave the forest as a carbon sink?
Mars 12-13, 2018
Royal Swedish Academy of Agriculture and Forestry, Drottninggatan 95 B, Stockholm, Sweden

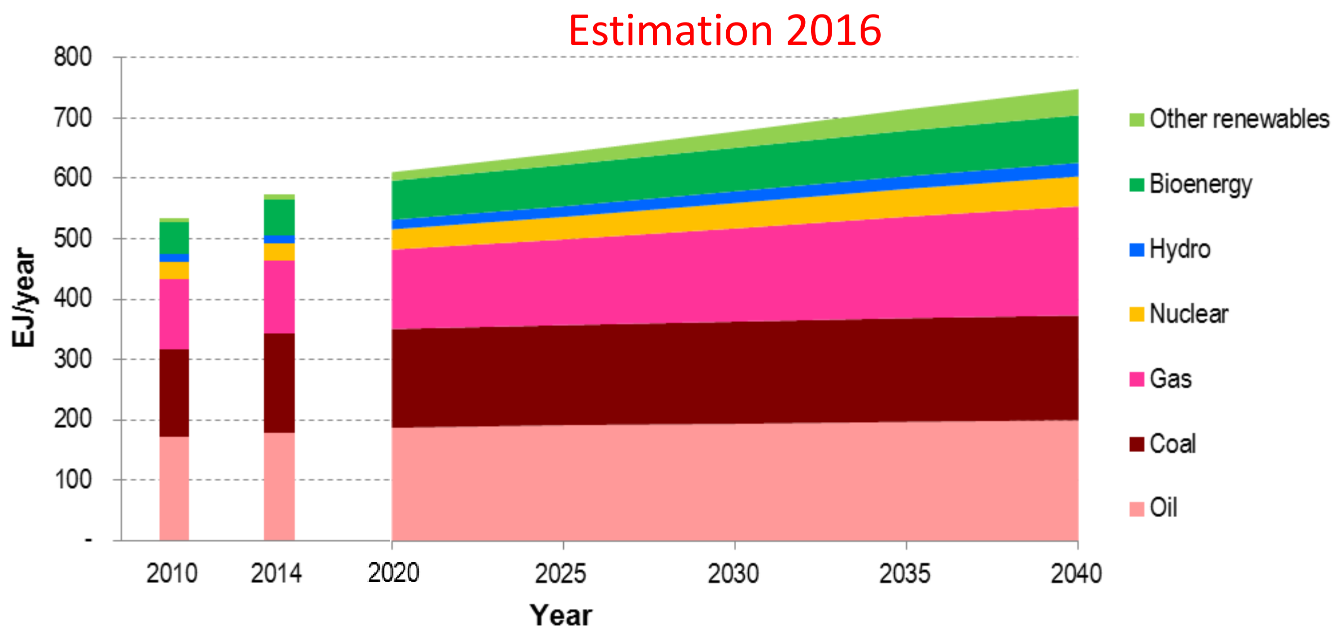
Organiser: The Royal Swedish Academy of Agriculture and Forestry, The Royal Swedish Academy of Sciences, and The Royal Swedish Academy of Engineering Sciences

[1] See also a summary by Leif Gustavsson, Roger Sathre, Ambrose Dodoo, Mattias Lundblad, UnibenTettey and Nguyen Le Truong.

Annual global primary energy use and trends (IEA)



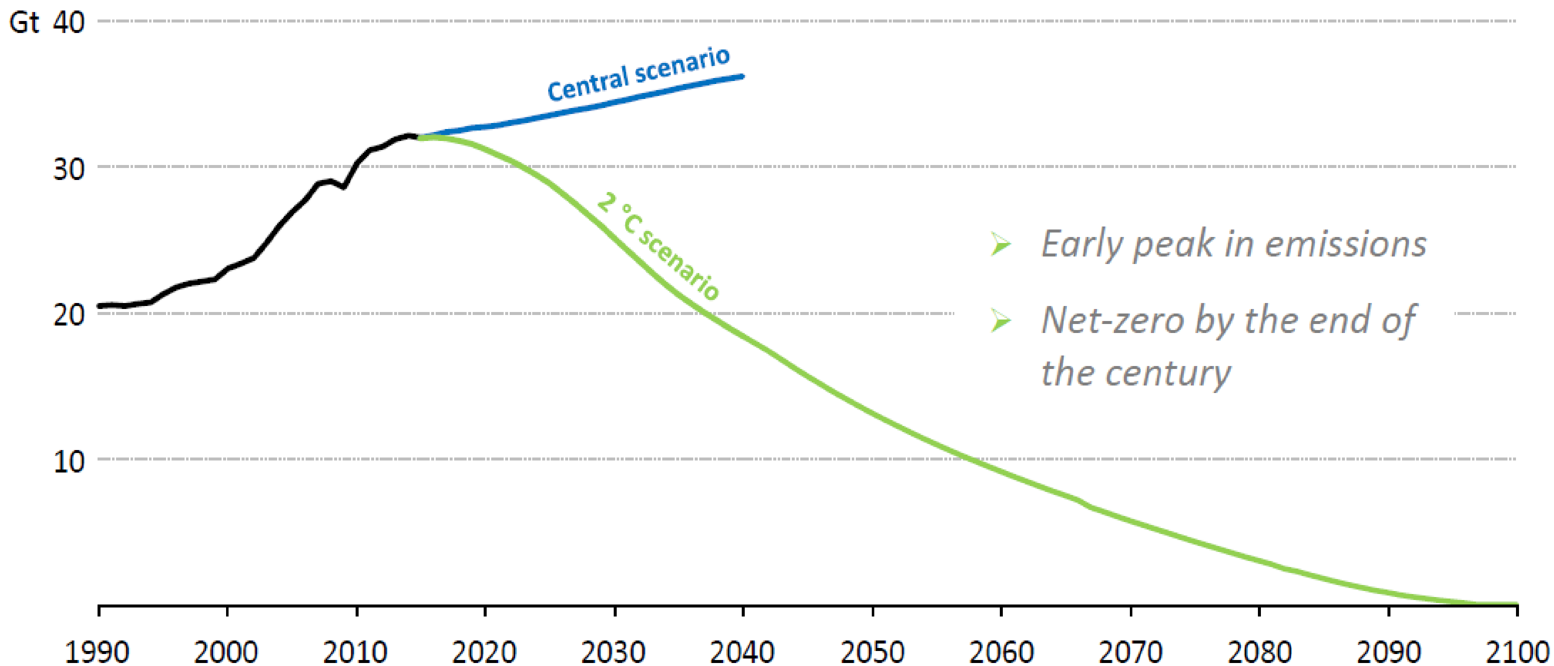
Year	2010	2014
Total (EJ)	**533**	**573**
	Distribution	**(%)**
Oil	32.4	31.2
Coal	27.3	28.7
Gas	21.4	21.1
Total fossil	**81.1**	**81.0**
Bioenergy	10.0	10.4
Nuclear	5.7	4.8
Other	3.2	3.8



Source: International Energy Agency (IE.
2011. World Energy Outlook 2011
IEA, 2013. World Energy Outlook 2013;
IEA, 2012. *Key World Energy Statistics*
IEA, 2016. *World Energy Outlook 2016*

Emission of CO_2 from the energy sector - IEA 2016

Paris agreement, article 2a: "Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels"



Current pledges fall short of limiting the temperature increase to below 2 °C; raising ambition to 1.5 °C is uncharted territory

Source: IEA 2016. World Energy Outlook 2016

Do we need bioenergy in renewable energy systems?

- The shares of fossil fuels and renewable energy in European Union in 2014 were 72% and 14%, respectively (bioenergy: 9.1%; hydro: 2.0%: others: 2.6%).
- Bioenergy assists the integration of wind and solar in renewable energy systems.

We analyse climate change effects of varied forest management and construction of wood buildings and use of bioenergy

In all scenarios

- The same forest land area is included
- The same energy and housing services are provided
- The same amount of pulp wood is provided

- The scenario with least pulpwood steers the amount of pulpwood in other scenarios, and surplus of pulpwood in other scenarios is used for energy
- The maximum harvest of timber steers the maximum potential for wood buildings, and in scenarios with less timber, more concrete buildings are constructed to give the same amount of housing service

We analyse climate change effects of varied forest management and construction of wood buildings and use of bioenergy

- We consider all significant annual net CO_2 emissions in a life-cycle perspective
- We calculate cumulative radiative forcing based on net CO_2 emissions each year
- Important parts:
  - Forest management
  - Building materials and construction
  - End-of-life implications
  - By-products
- Forward looking analysis, modeled to year 2109

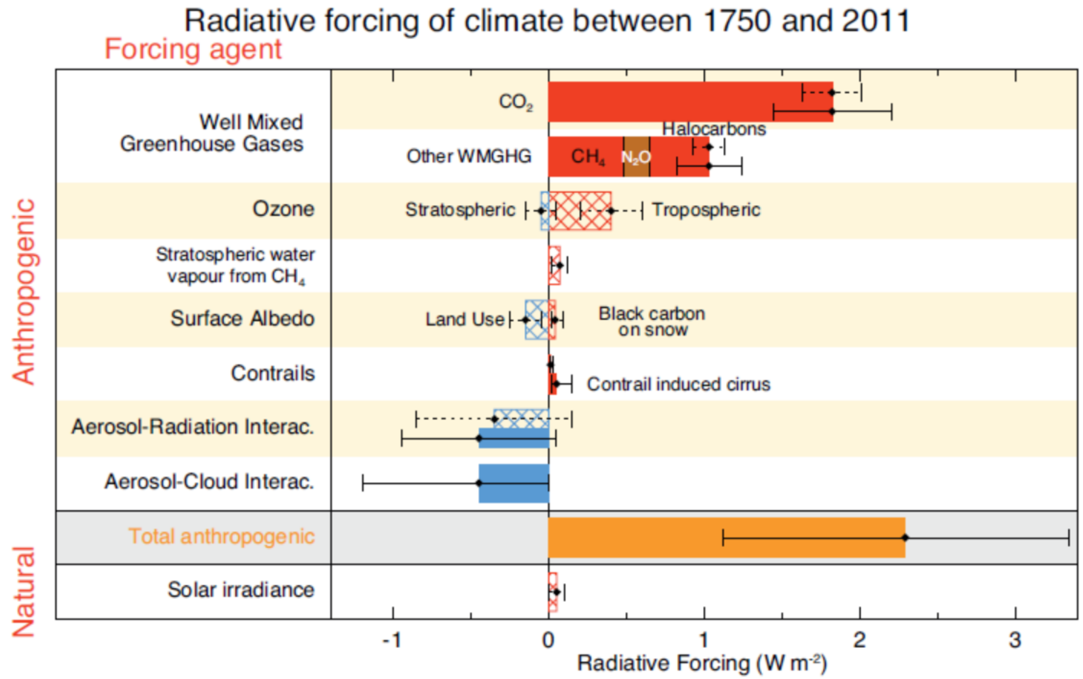
Human activities

- GHG(CO_2) emissions
- Albedo change
- Aerosols
- Ozone

Radiative forcing

Mean temperature change

Physical, ecological, and social disturbances



(IPCC 2013)

Anthropogenic climate change: Chain of events

Some methodological comments

- Many different wood products but here the focus is on buildings
- Long time span and technological development
- Full lifecycle energy and material chains
- Annual net CO_2 emissions over 100 years

Forest management scenarios

1. **BAU (business as usual):** as today (reference)
2. **Set aside land**: protected forest area doubled (from 17% to 33%)
3. **Production**: max amount area treated with fertilizer (within economical and environmental restrictions), increased use of fast growing tree species

In all scenarios:

Climate change is based on RCP 4,5

Annual harvest of forest residues for energy

Reference BAU scenario with current harvest of 8 TWh slash: **BAU (8TWh)**

BAU scenario:

1. 80% of slash and 50% of thinnings: **BAU (80/50)**
2. 80% of slash, 50% of thinnings and stumps: **BAU (80/50/50)**

Set aside land scenario

1. 8 TWh slash: **Set-aside (8TWh)**
2. 80% of slash and 50% of thinnings: **Set-aside (80/50)**

Production scenario:

1. 8 TWh slash: **Production (8TWh)**
2. 80% of slash and 50% of thinnings: **Production (80/50)**
3. 80% of slash, 50% of thinnings and stumps: **Production (80/50/50)**

Extraction is only allowed in coniferous forests and only on mineral soils

Heureka system

The Heureka software for forestry planning and analysis has been used to simulate:

- Forest development
- Harvest of pulpwood, timber, thinnings, slash and stumps
- Input for soil carbon calculations

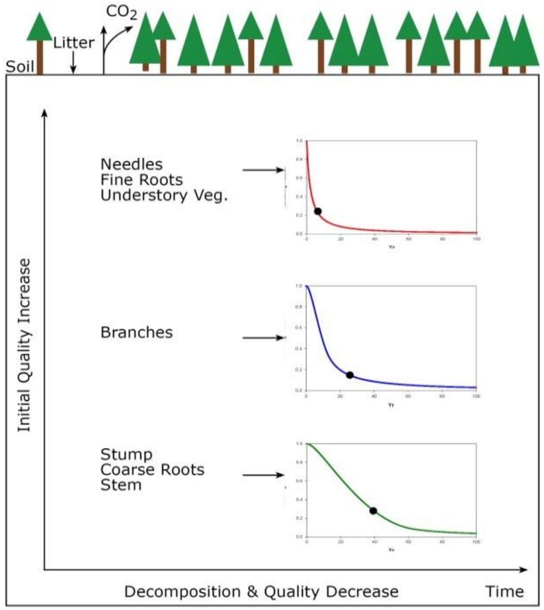
Forecasts based on 30 000 National Forest Inventory plots

Heureka simulates production forests (≈ 23 M ha)
For other forest land (≈ 5 M ha) net removals is assumed to be constant over time in all scenarios

Soil carbon calculations is based on the Q-model

- Q-model is a decomposition model based on continuous quality theory
- Decomposes fractions of material with specific initial quality during time
- Requires annual litter production and temperature input

Rolff, C., Agren, G.I., 1999. Ecological Modelling 118, 193-211



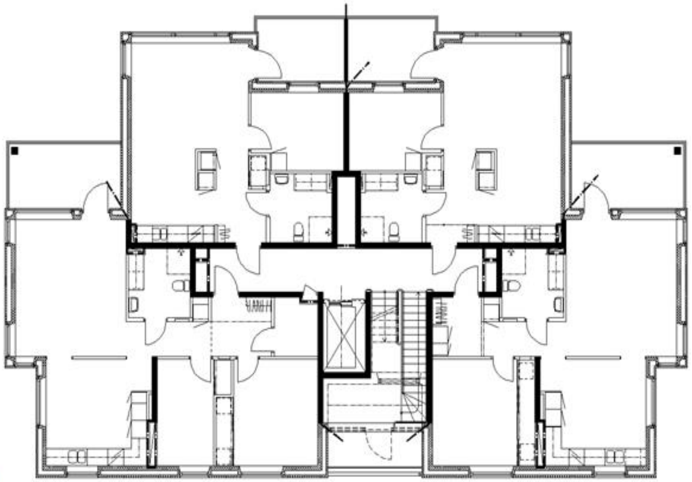
Ortiz et al. 2011. Ecological Modelling 222, 3020-3032

Assumptions and data input

- Input in form of annual litter fall and litter from harvests based on Heureka results
- Biomass is converted in annual litter input for different species (based on turnover rates and harvested biomass) and tree fractions with varying litter initial qualities
- Temperature gradient based on climate change data for RCP 4.5 scenario →reflects the different decomposition rates depending on climate
- Parameter uncertainty is included based on a set of feasible parameters from earlier calibration studies
- We use the version where annual climate and decomposer invasion rates are allowed

Studied building (Täppan) with different structural frames

(a) 

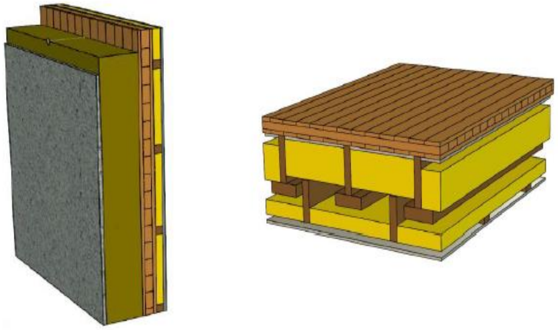
(b) 

- Built in 2014 in Växjö
- Concrete frame
- 6 storeys
- 24 apartments
- 1686 m^2 living area
- Redesigned to meet Passive house criteria

The analysis is based on building versions with concrete-frame, modular timber-frame or cross laminated timber-frame designed to Swedish passive house criteria

Prefabricated concrete frame

Modular timber-frame



Cross laminated timber-frame

The buildings are designed to have the same energy use for operation

CO_2 emission associated with the production of the buildings is based on

- Total material mass inputs for the buildings including losses during production and construction
- Specific end-use energy for material production based on Björklund & Tillman (1997), Fossdal (1995), and Worrell et al (1994).
- Steel is assumed to be produced from 50% ore and 50% scrap steel

End-of-life management of buildings

Building service life is 80 years

Steel is recycled as scrap for production of new steel

Concrete is crushed into aggregate, exposed to the atmosphere to increase carbonation during four months and then used for below-ground filling

Wood is recovered and used to replace fossil energy

Calculation of CO_2 emission

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

Cement reaction emission is calculated as net of emission from calcination and uptake from 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 biomass used for bioenergy international transport of 1000 km is included

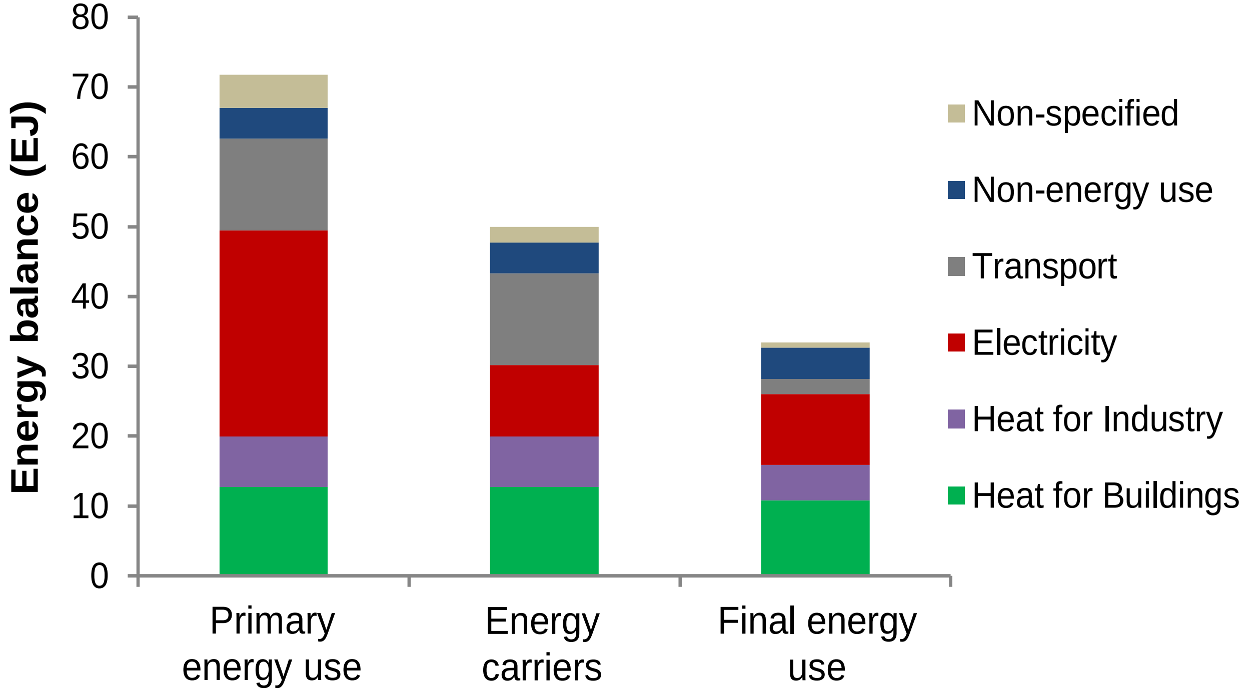
Fossil energy and bioenergy systems

CHP plant with steam turbine fossil coal technology *or*
steam turbine biomass technology

CHP plant with combined cycle fossil gas technology *or*
steam turbine biomass technology

Fossil motorfuels (diesel) *or*
biomotor fuels (DME) - emerging technologies

From primary to final energy use for the EU27 in 2010
How to improve the system efficiency?



Almost 50% of final energy use in the EU is heat for residential, service or industrial purposes

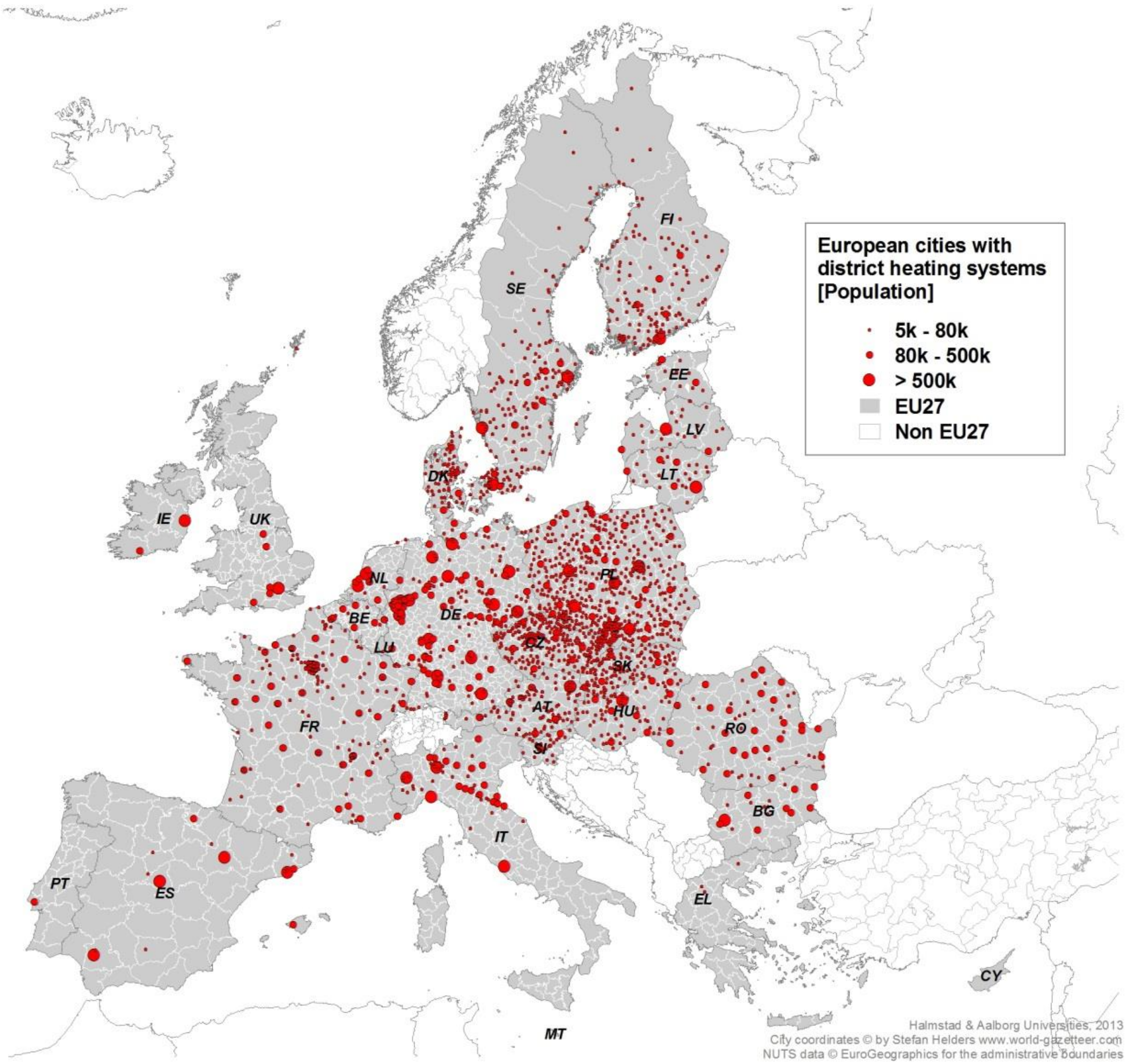
Heat has a high conversion efficiency compared to electricity and transportation

Improved system efficiency by cogeneration of electricity and heat and using electric transport*

*Leif Gustavsson and Nguyen Le Truong. Bioenergy pathways for cars: Effects on primary energy use, CO_2 emission and energy system integration Energy 115 (2016) 1779-1789.

Source: Connolly et al., 2013, Heat Roadmap Europe 2050 - Second Pre-study for the EU27. Department of Development and Planning. Aalborg University, Denmark.

District heating systems in the EU27



- About 6000 systems already exist
- District heating accounted for approximately 13% of total heat supply in the residential and service sector
- Expansion potentials of up to 30% in 2030 and 50% in 2050.

Source: Connolly et al., 2013. Heat Roadmap Europe 2050

Increased use of fossil gas in EU?

“The European Investment Bank yesterday (6 February) approved its largest ever single loan to an energy project: the Trans-Adriatic Pipeline (TAP). The €1.5 billion credit will be used to transport gas from the Caspian Sea to the Mediterranean.”

…

“The EIB board agreed on financing of energy and transport projects worth €6.5 billion"

…

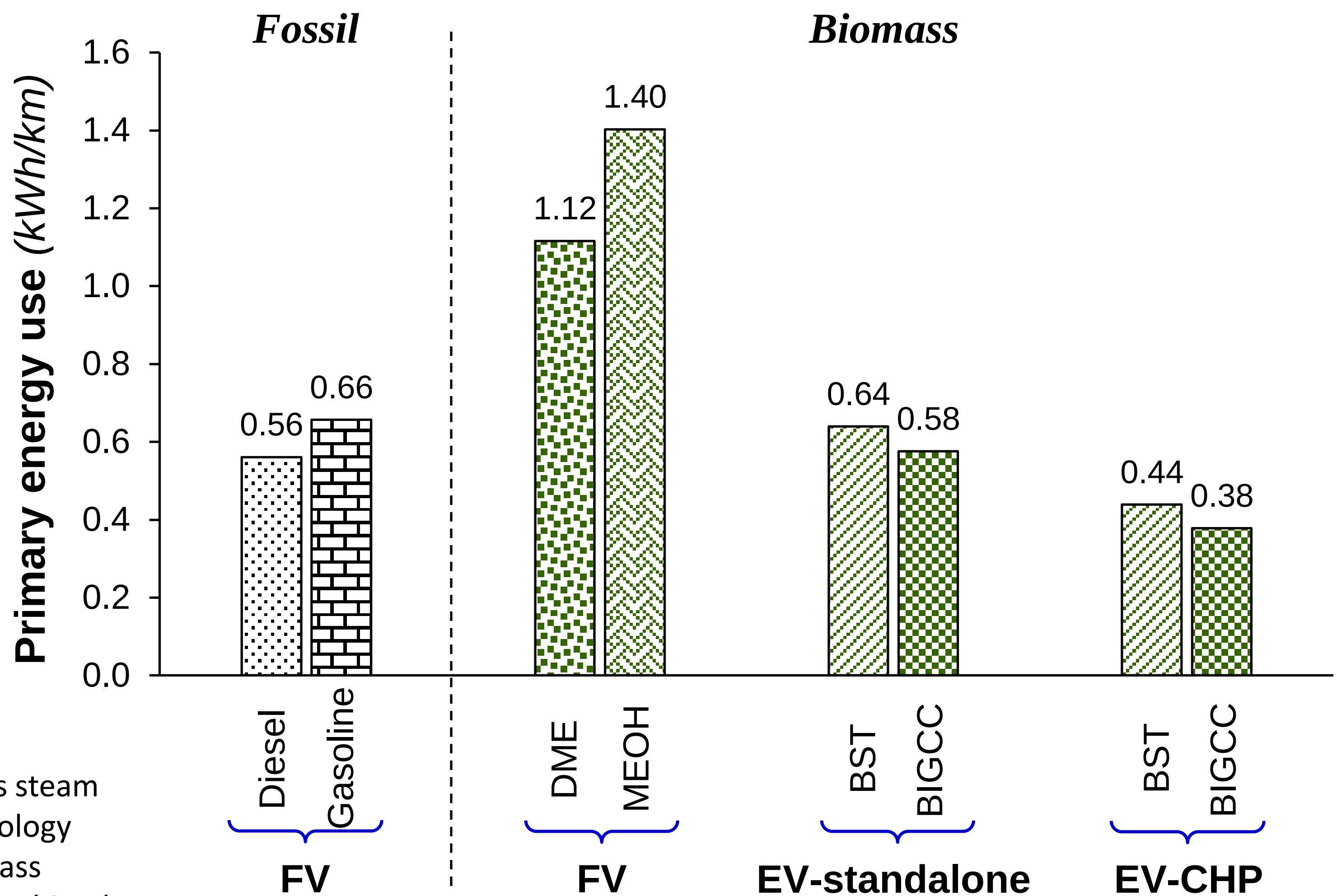
“TAP will form the European leg of the Southern Gas Corridor, a large-scale fossil fuel infrastructure project that will cross the Anatolian plain from Azerbaijan, before cutting through northern Greece, Albania and making land in southern Italy.”

….

“Opposition to the project has been fierce, as activists have highlighted the impact construction work is already having on local communities, as well as the pipeline’s alleged incompatibility with the targets of the Paris climate deal.”

Source: EU bank approves largest ever energy loan for TAP pipeline, by Sam Morgan | EURACTIV.com, 7 Feb 2018

Primary energy use for Mercedes Benz B-type



BST = Biomass steam turbine technology

BIGCC = Biomass gasification combined cycle technology

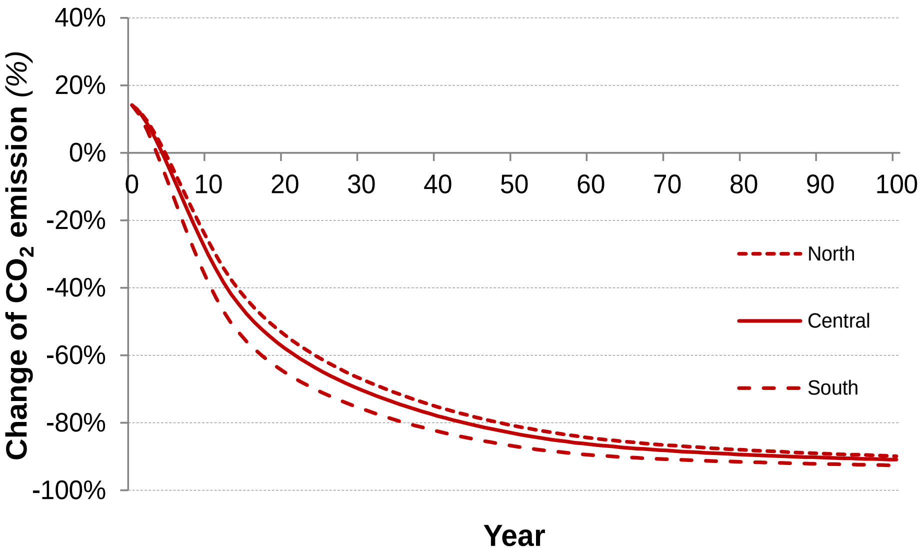
FV = fuel vehicles **EV = electric vehicles**

Based on Gustavsson, L. and Truong, N.L. Bioenergy pathways for cars: Effects on primary energy use, CO_2 emission and energy system integration. Energy 115 (2016) 1779-1789.

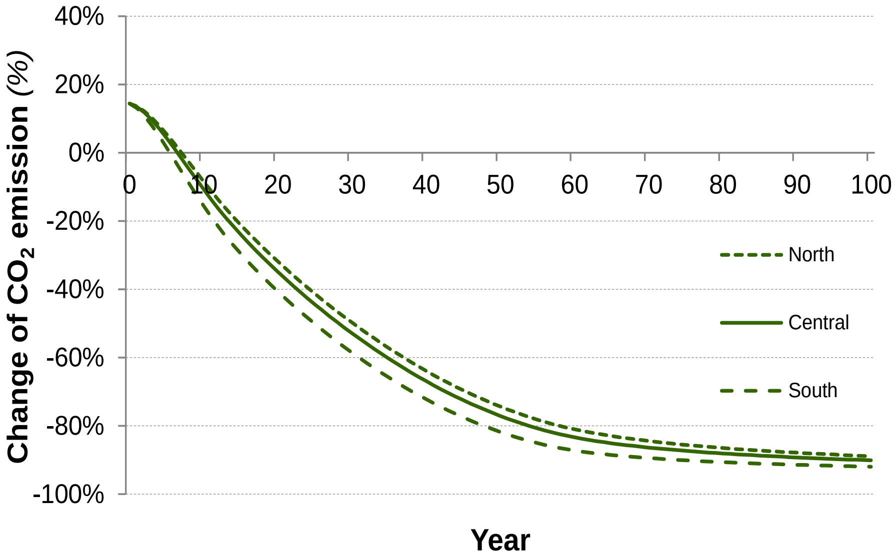
Relative change of CO_2 emissions if slash and thinnings from central Sweden is used instead of fossil coal to produce electricity at year 0

Dashed lines shows if forest biomass is from north (slower) or south (faster decay) of Sweden

Slash



Thinnings



The relative change of net CO_2 emission if slash and thinnings are used instead of fossil energy can be calculated as:

$$\frac{CO_{2bioenergy} - (CO_{2fossil} + CO_{2biodecay})}{CO_{2fossil}}$$

$CO_{2bioenergy}$ is CO_2 emission in the bioenergy pathway

$CO_{2fossil}$ is CO_2 emission in the fossil energy pathway

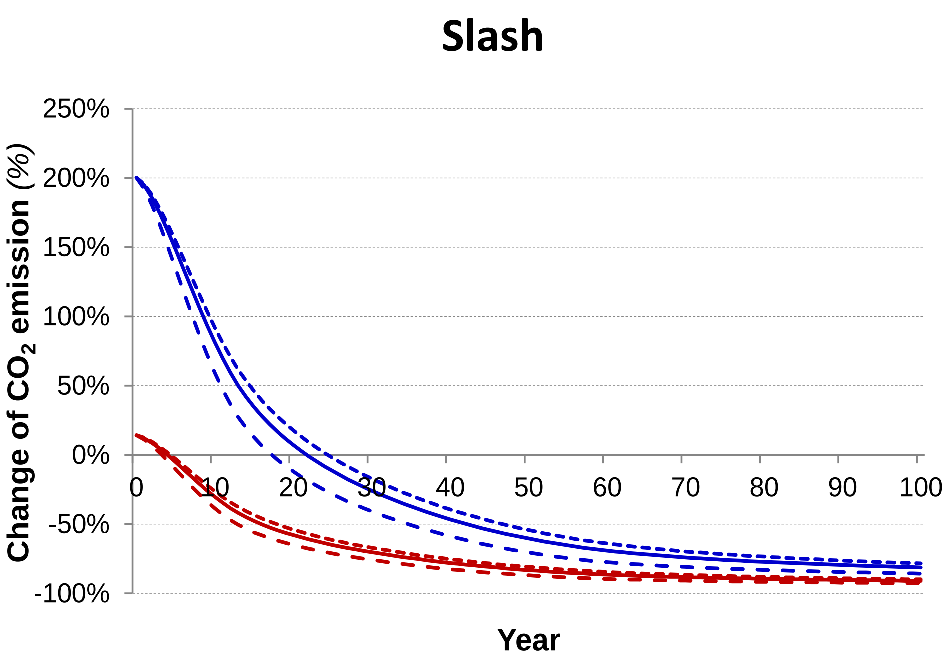
$CO_{2biodecay}$ is CO_2 emission from the decay of forest residues

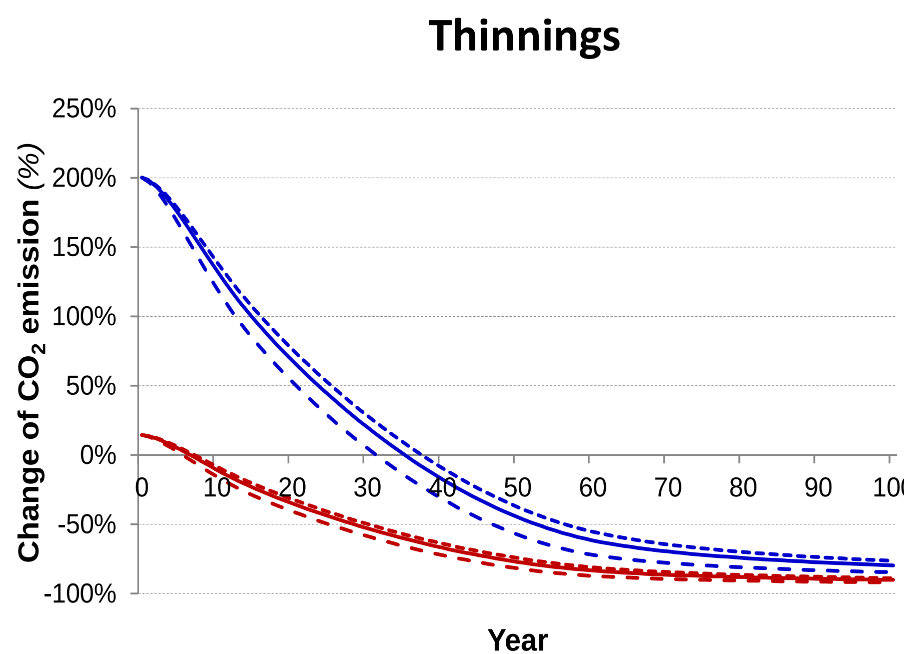
Based on: Sathre, R., Gustavsson, L., and Truong, N.L. Climate change effects of electricity production fuelled by coal, forest slash and municipal solid waste with and without carbon capture. Energy 122 (2017) 711-723.

Relative change of CO_2 emissions if slash and thinnings from central Sweden is used instead of fossil energy at year 0

Red: biomass replaces coal for electricity production
Blue: DME from biomass replaces diesel oil for transportation

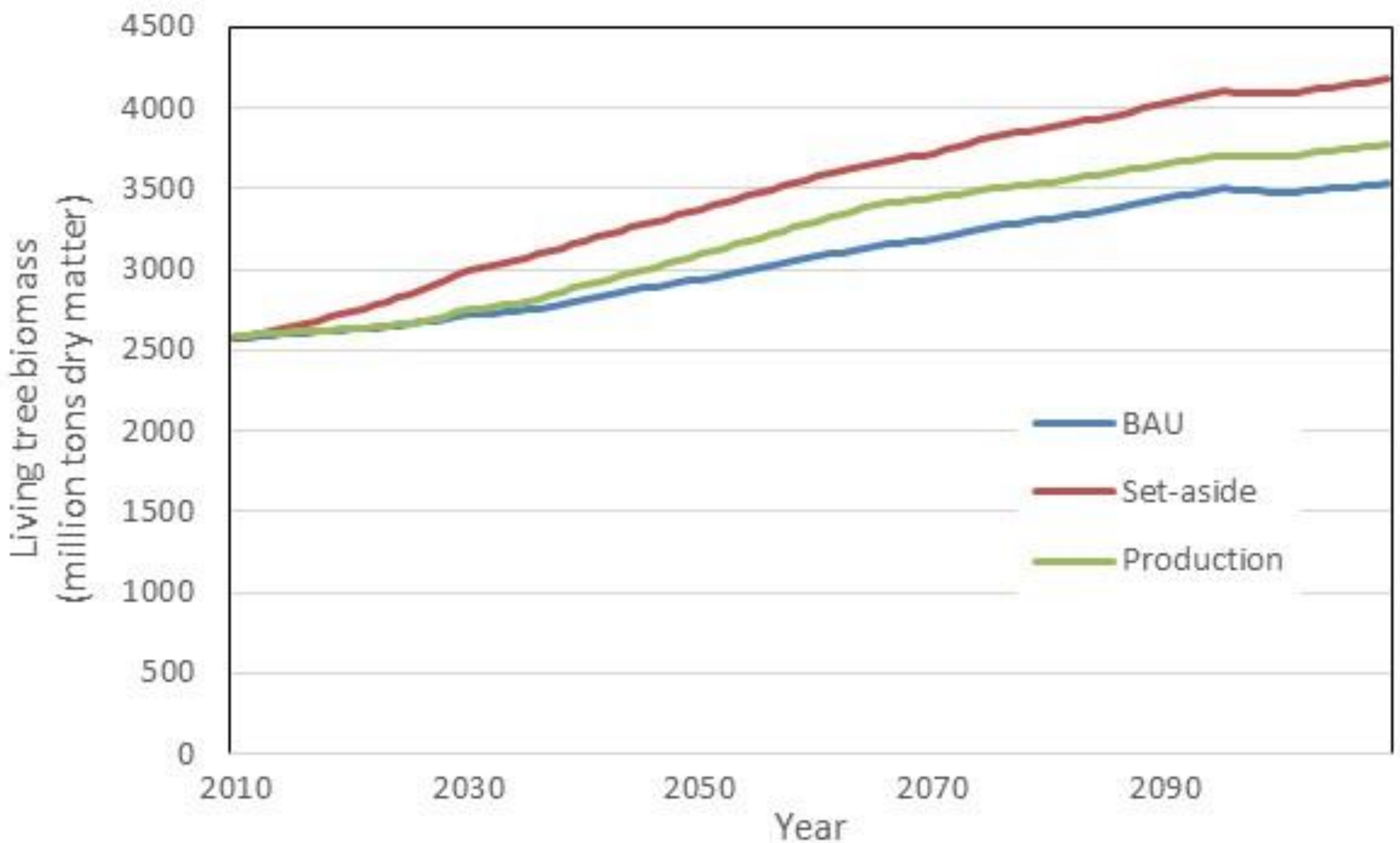
Dashed lines shows if forest biomass is from north (slower) or south (faster decay) of Sweden





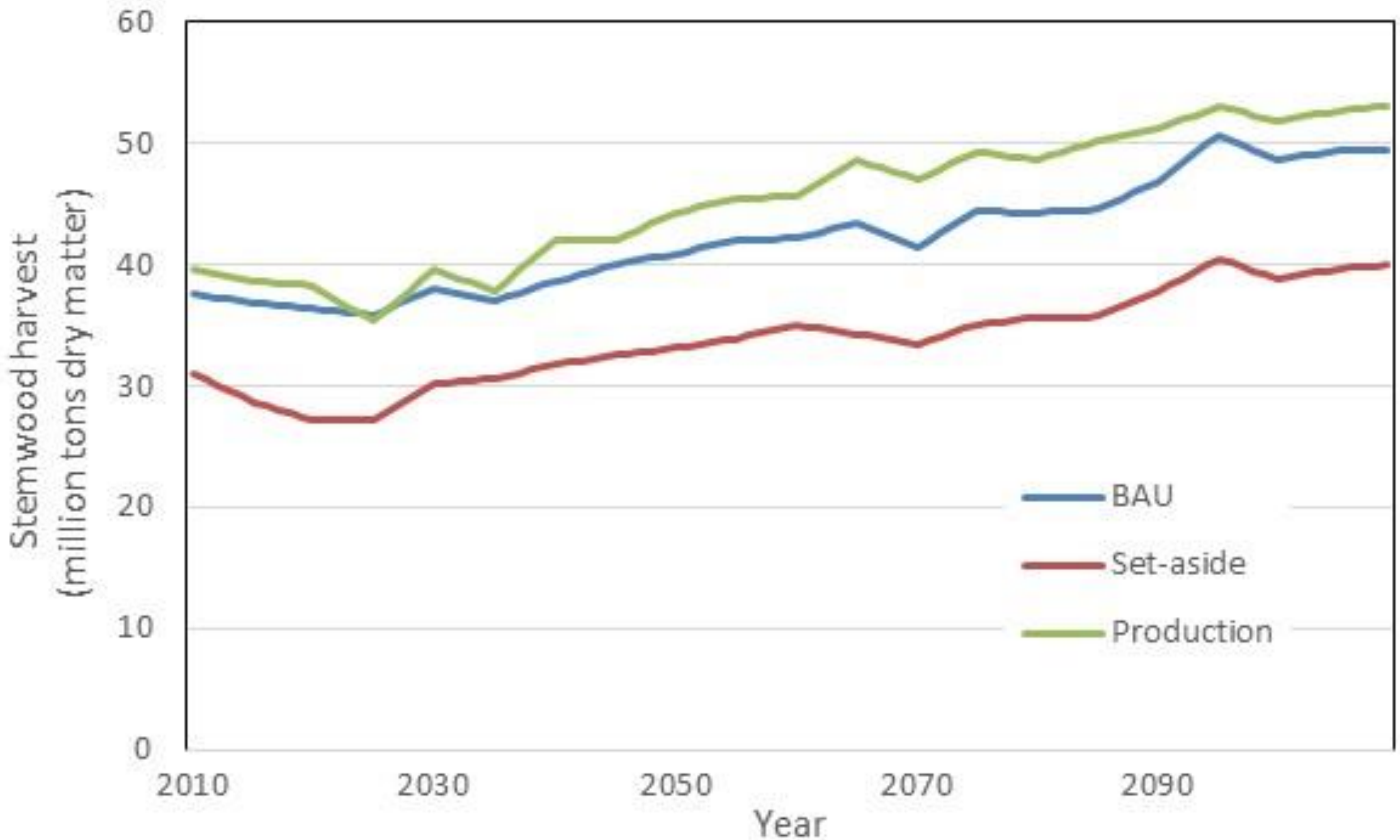
Based on: Sathre, R., Gustavsson, L., and Truong, N.L. Climate change effects of electricity production fuelled by coal, forest slash and municipal solid waste with and without carbon capture. Energy 122 (2017) 711-723.

Living tree biomass (million tons of dry matter) in Swedish forests under three scenarios



Gustavsson, L., Haus, S., Lundblad, M., Lundström, A., Ortiz, C.A., et al. Climate change effects of forestry and substitution of carbon-intensive materials and fossil fuels. Renewable & sustainable energy reviews 67 (2017) 612-624.

Stemwood harvest (million tons of dry matter per year) from Swedish forests under three scenarios



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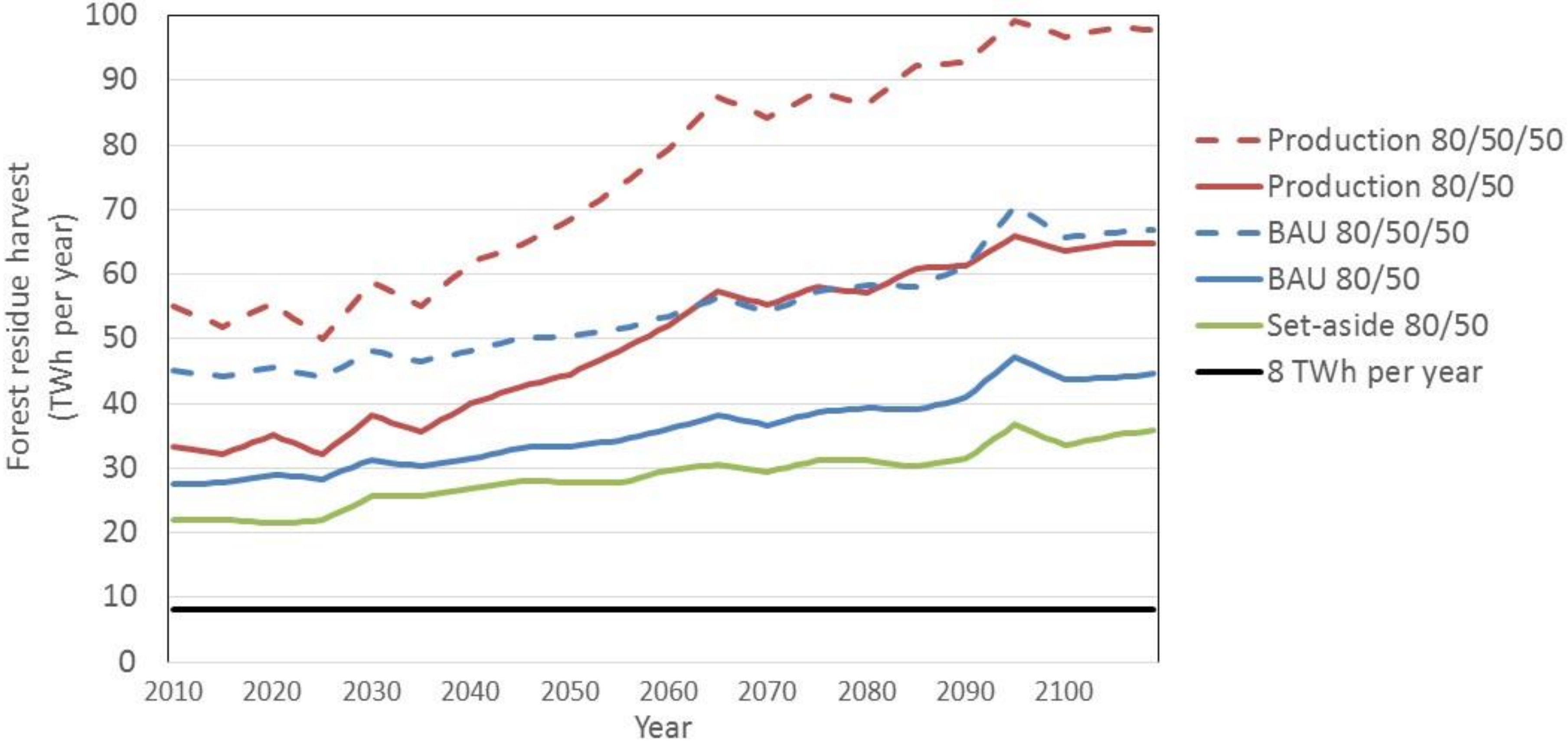
Harvest (TWh per year) of slash, thinnings and stumps



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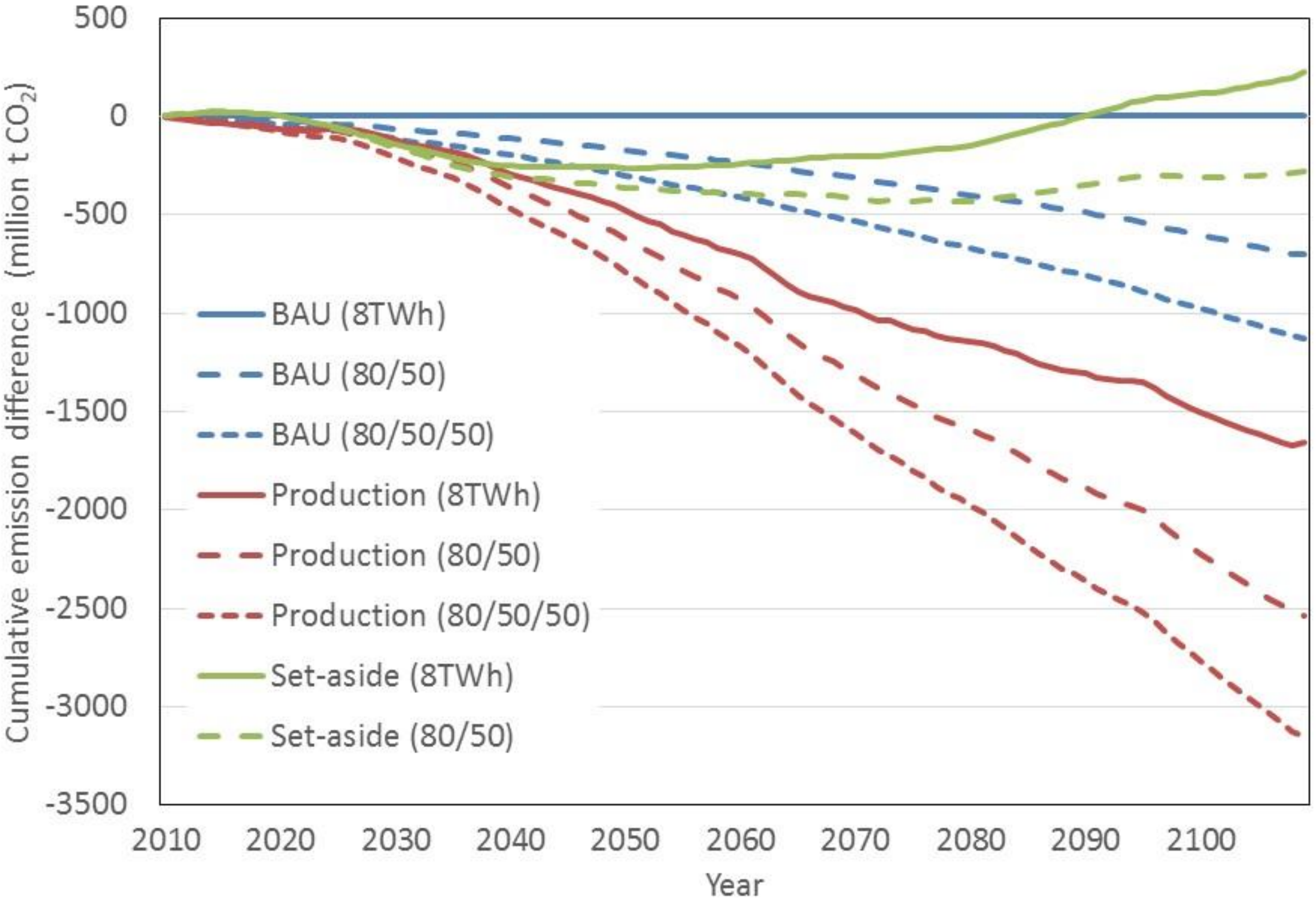
Difference in cumulative CO_2 emission compared to the reference BAU (8TWh) scenario (zero line)

Modular timber building replace concrete building and bioenergy replaces fossil coal



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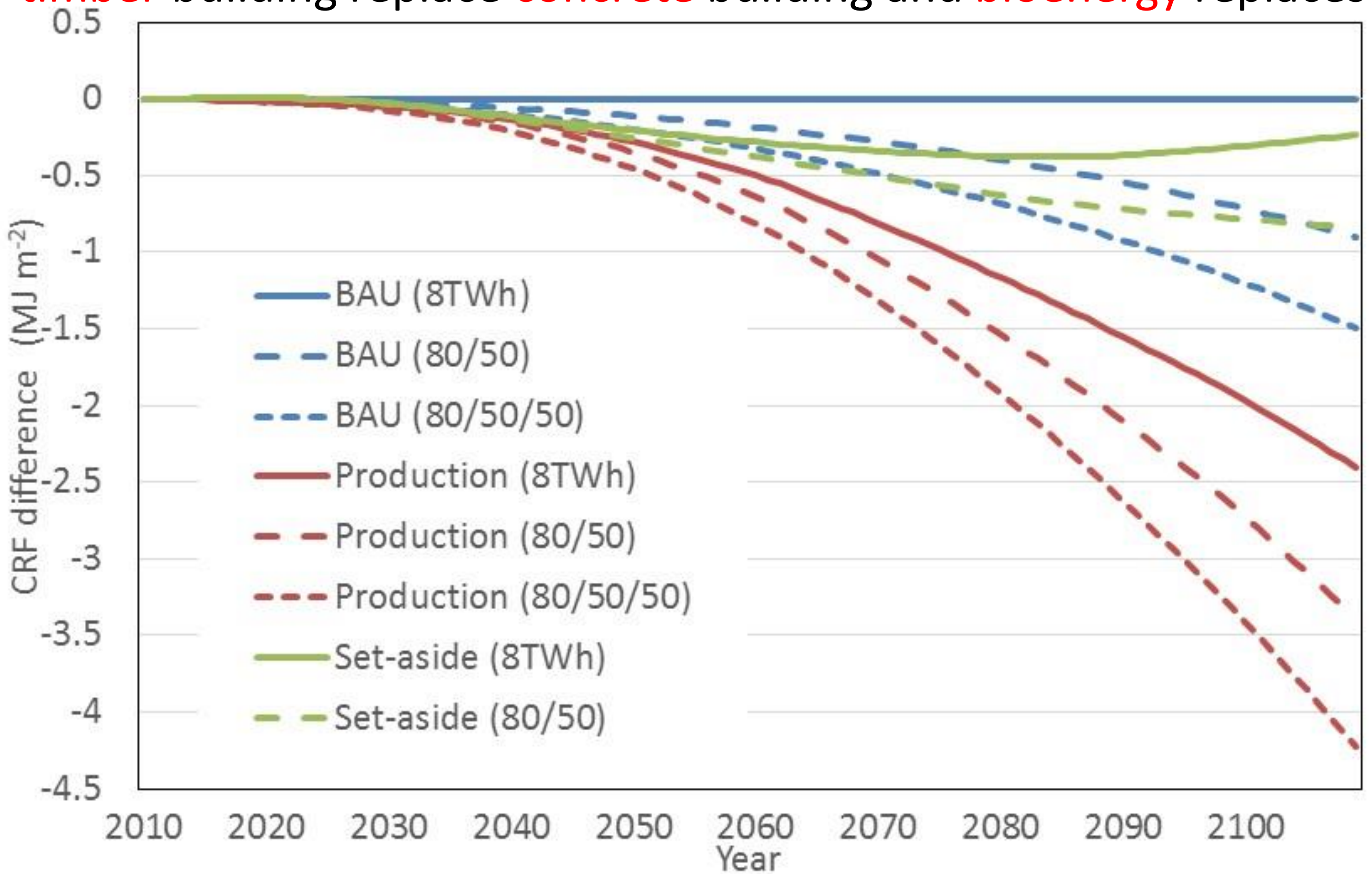
Difference in cumulative radiative forcing compared to the reference BAU (8TWh) scenario (zero line)

Modular timber building replace concrete building and bioenergy replaces fossil coal



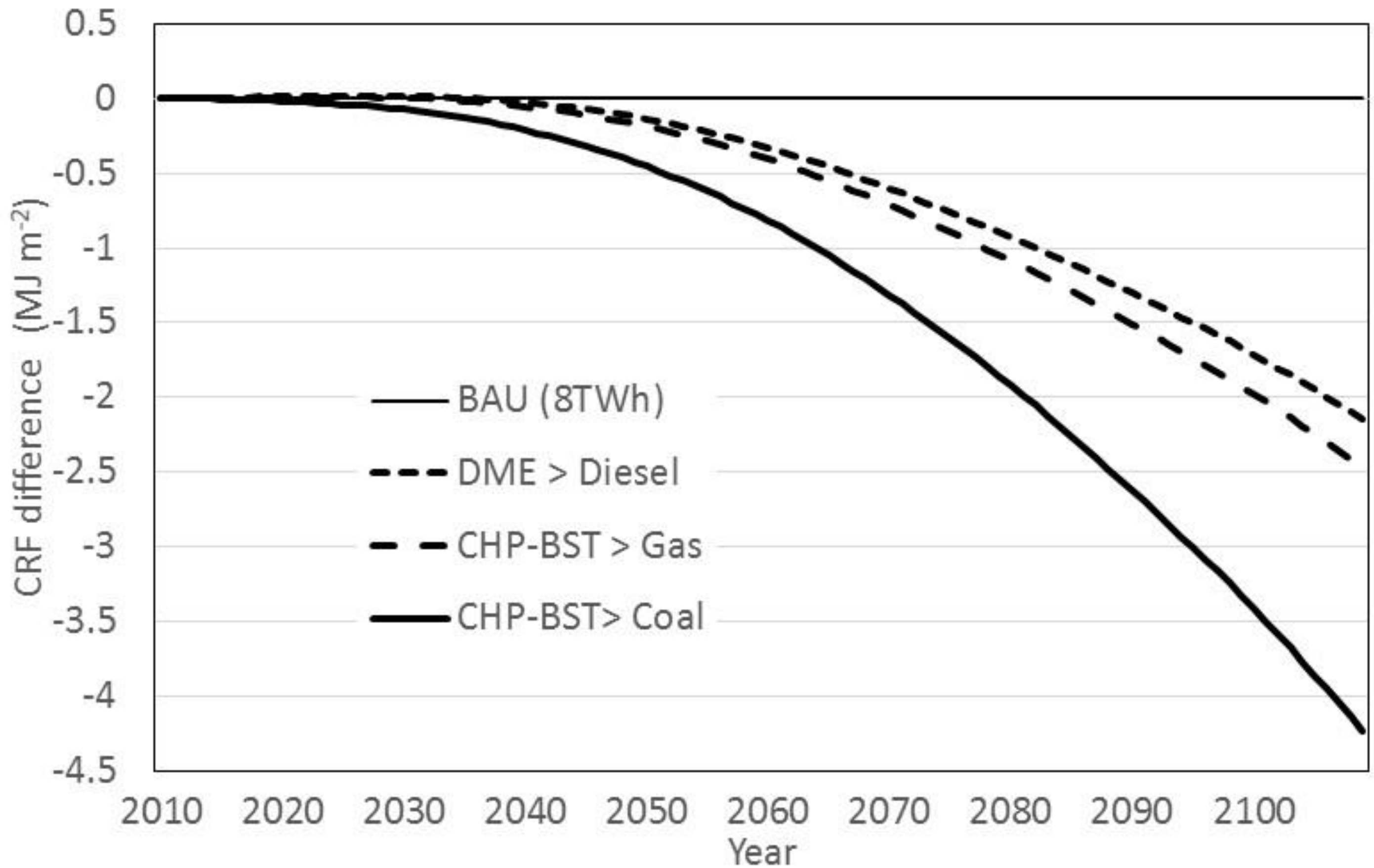
To calculate total heat trapped in the earth system, the CRF per m^2 would be multiplied by the surface area of the troposphere, 5.12 x 10^14 m^2. This is based on earth radius of 6371000 m, plus height to tropopause of 12000 m.

Based on Gustavsson, L., Haus, S., Lundblad, M., Lundström, A., Ortiz, C.A., et al. Climate change effects of forestry and substitution of carbon-intensive materials and fossil fuels. Renewable & sustainable energy reviews 67 (2017) 612-624. Tettey U. Y.A., Dodoo A. and Gustavsson L. Effect of different frame materials on the primary energy use of a multi-storey residential building in a life cycle perspective (manuscript). Ongoing work by Dodoo A., Gustavsson L., Sahtre R., Tettey U. Y.A. and Truong, N.L.

Difference in cumulative radiative forcing compared to the reference BAU (8TWh) scenario (zero line) for different energy systems

Modular timber building replace concrete building

Production forest scenario with harvest of slash, thinnings and stumps



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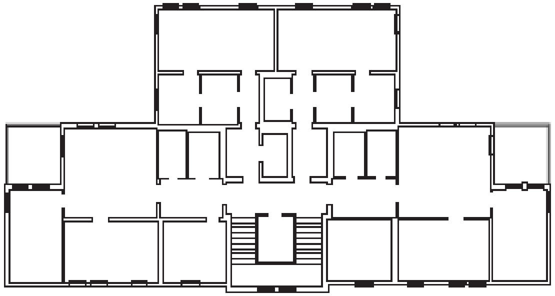
Also studied a 4-storey building (Wälludden) with different structural frames

Building with 16 apartments and 1190 m^2 living area

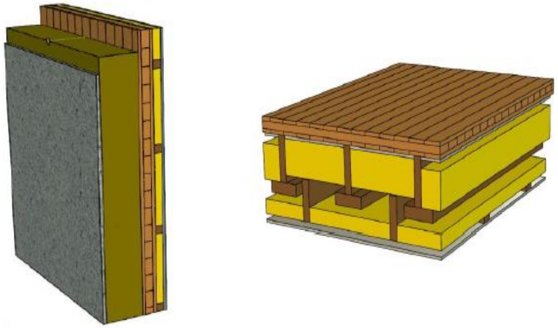


Built in Växjö, Sweden, in 1994

The analysis is based on building versions with concrete-frame, modular timber-frame or cross laminated timber-frame designed to Swedish passive house criteria

Concrete -frame

Modular timber-frame



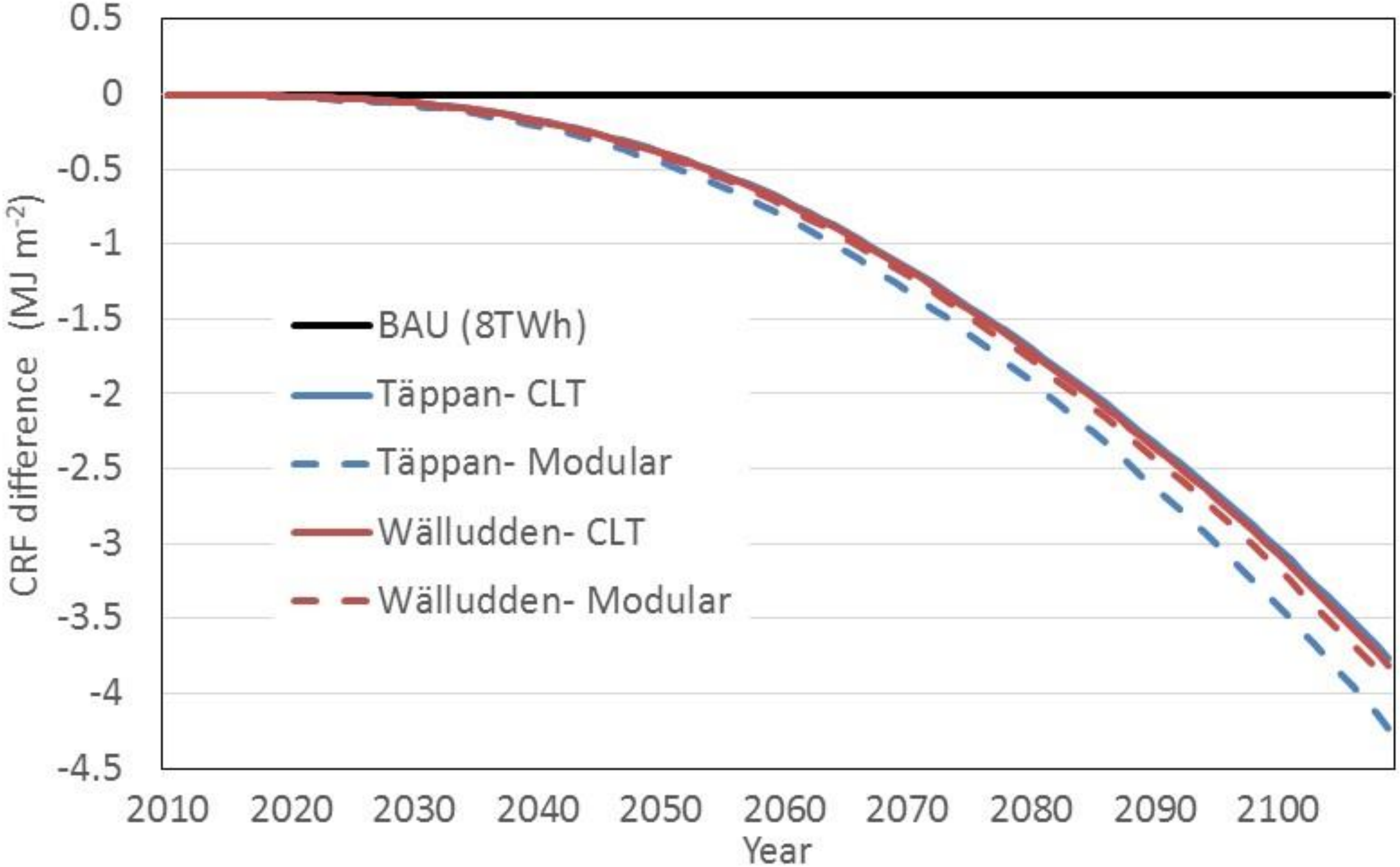
Cross laminated timber (CLT)-frame

The buildings are designed to give the same energy use for operation

Difference in cumulative radiative forcing compared to the reference BAU (8TWh) scenario (zero line) for different building types and frames

Wood frame buildings replace concrete frame buildings and bioenergy replace coal

Production forest scenario with harvest of slash, thinnings and stumps



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Key factors steering the results

- Forest management
- Harvest of forest biomass
- Use of forest biomass including residues
- Replaced non-wood products
- End-of-life management of the building
- Timespan of the analysis of 100 years

Strength and weakness

- Climate implications of bioenergy and wood construction are considered in a holistic life-cycle system perspective
- Complicated analyses
- Forward looking analysis considering imposed changes
- Detail description of forest system
- Detail description of technical systems
- A landscape perspective is used to consider forest dynamics
- All annual significant flows of CO_2 emission to and from the atmosphere are considered but not other climate effects as albedo
- The cumulative radiative forcing is calculated based on annual net CO_2 emissions to the atmosphere
- Technological development may change the results
- Mainly one forest rotation period is considered

Climate effects

- A small difference between the scenarios in the first 20-40 years of the analysis if bioenergy replaces fossil coal
- But then a clear and over time increasing difference if bioenergy replaces fossil coal
- The climate benefit is significantly reduced if bioenergy replaces fossil gas
- The climate benefit is even less if bioenergy replaces diesel oil for transportation
- A strategy for climate benefits may include
  - High forest production and harvest
  - High residue recovery rate
  - Efficient utilization of harvested biomass
  - Replacement of carbon-intensive non-wood products and fuels

Thank you for your attention!

Questions and comments?