4th Generation District Heating – Second Conference

Combined heat and power plants – now and in the future

How to get most out of forest biomass?

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Sustainable Built Environment Research
www.lnu.se/SBER

Global primary energy use in 2010 (≈500 Exajoule)

Oil	32.4%
Coal	27.3%
Gas	21.4%
Total fossil	**81.1%**
Bioenergy	10.0%
Nuclear	5.7%
Other	3.2%

Exa = 10^{18}

Source: International Energy Agency, 2012. *Key World Energy Statistics*

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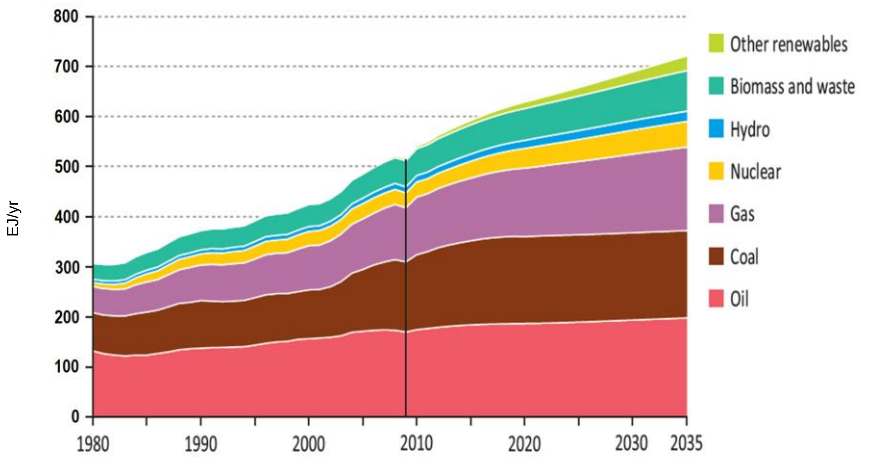
Primary energy use in IEA "New Policies" scenario



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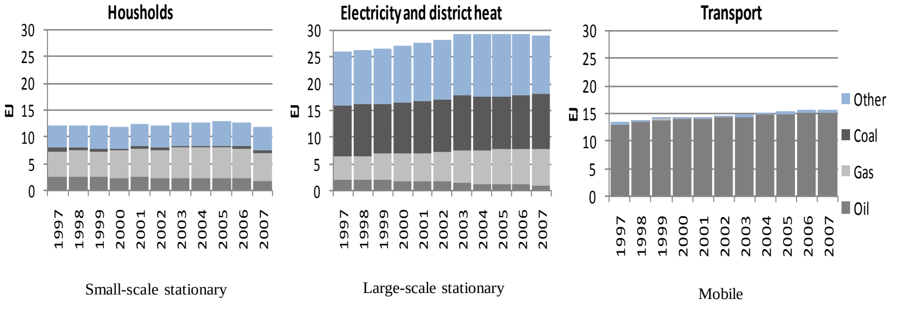
Source: International Energy Agency, 2011.
World Energy Outlook 2011.

Energy use in the EU - Three typical applications



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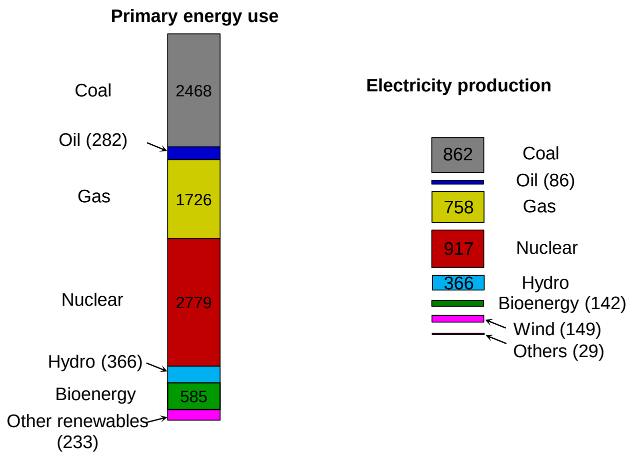
Source: Eurostat data, 2011

Primary energy use in EU27 for electricity production in 2010 (TWh)



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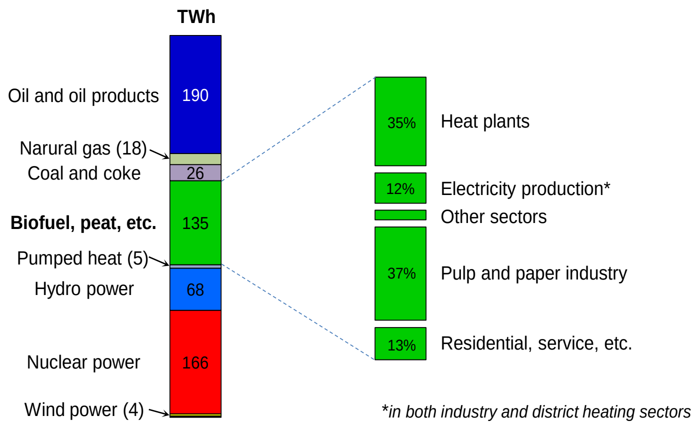
Source: World Energy Outlook 2012.

Primary energy use in Sweden 2010



*in both industry and district heating sectors

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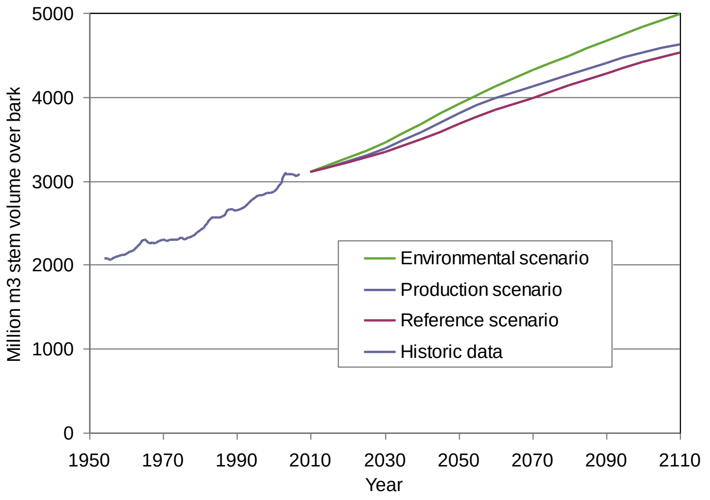
Source: Energy in Sweden 2012, Swedish Energy Agency

Standing stem volume on Swedish productive forest land and scenarios for 2010 - 2110



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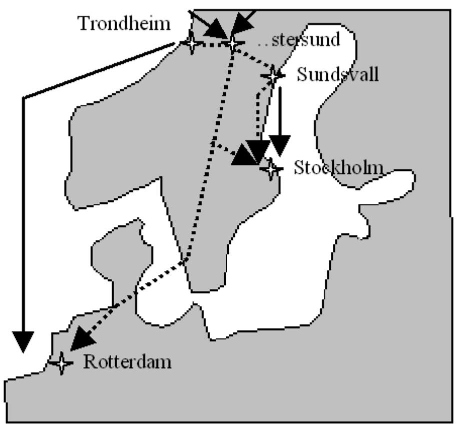
Source: Skogsstyrelsen, Skogliga konsekvensanalyser och virkesbalanser 2008

Example: Forest residues (slash) substitute different fossil fuels in stationary plants at different locations



A system analysis from forest area to local (80km), national (600km) and international (1100km) large end-users

Functional unit is 1 MWh of delivered wood chips at the local, national and international large end-users

Data on forest residues based on experience in central Sweden

Fuel cycle fossil emissions are considered

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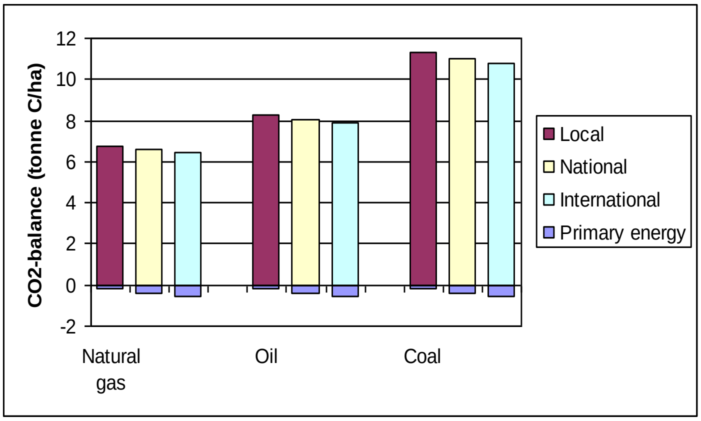
Reduced fossil CO_2 emission if slash substitutes fossil fuels in stationary plants at different locations



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Source: Gustavsson L, Eriksson L, Sathre R. 2011. Costs and CO_2 benefits of recovering, refining and transporting logging residues for fossil fuel replacement. *Applied Energy* 88(1): 192-197.

Example: Forest residues substitute fossil fuels

Fossil system

1. Fossil fuels are used for energy
2. Forest harvest residues are left in forest and gradually decay

Bioenergy system

1. Fossil fuels are used for biomass harvest and logistics
2. Forest residues are used for energy, releasing biological carbon emission

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Decay of biomass left in forest

- We assume decay into CO_2 at a negative exponential rate
- Decay constants of:

-0.033 for small-diameter logs	(Næsset 1999)
-0.046 for stumps and coarse roots	(Melin et al. 2009)
-0.074 for branches and tops	(Palviainen et al. 2004)
-0.129 for fine roots	(Palviainen et al. 2004)
-0.170 for needles	(Palviainen et al. 2004)

Several uncertainties

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Emissions time profile influence the climate impact

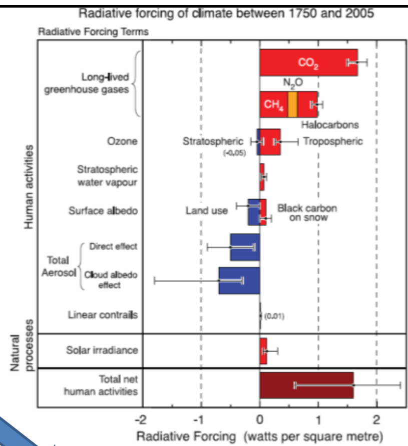
Human activities

- GHG emissions
- Albedo change
- Aerosols
- Ozone

Radiative forcing

Mean temperature change

Physical, ecological, and social disturbances



(IPCC 2007)

Anthropogenic climate change: Chain of events

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Greenhouse gases cause an imbalance between incoming and outgoing radiation - "radiative forcing" heat is trapped

- Integrated over time, **cumulative radiative forcing (CRF)** is W-s/m^2, i.e. trapped energy per area – **a proxy for temperature increase**
- The longer a GHG is in the atmosphere the more energy is trapped and the more climate change occurs

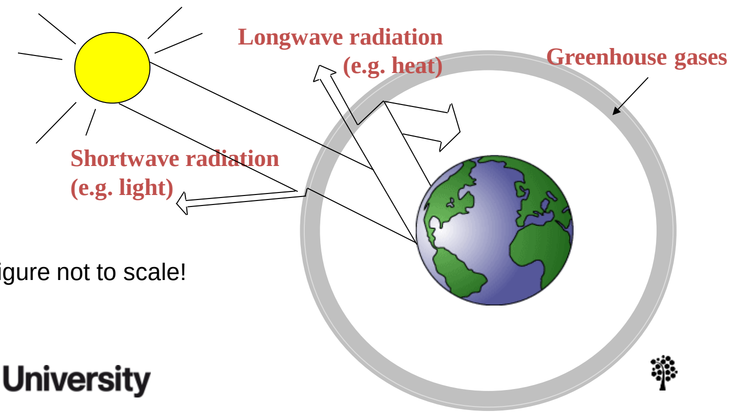

Figure not to scale!

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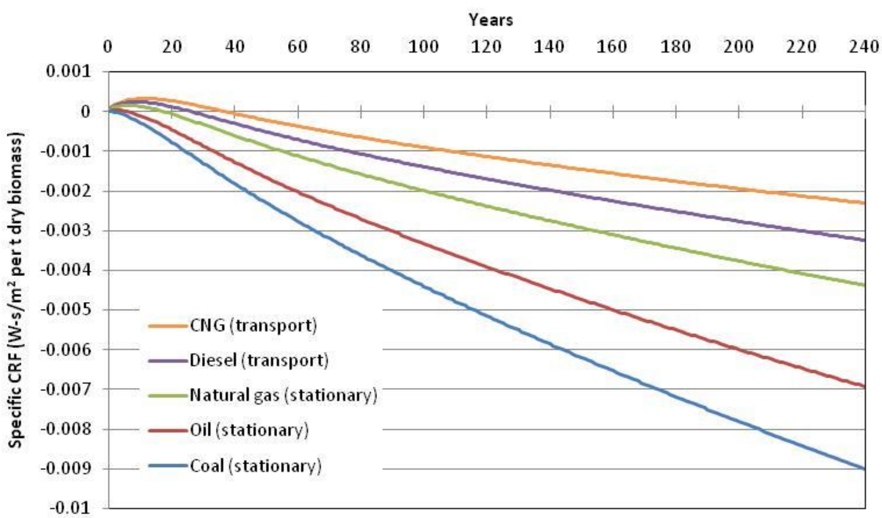
Changed cumulative radiative forcing (trapped heat) per ton of dry biomass when slash substitute fossil fuels



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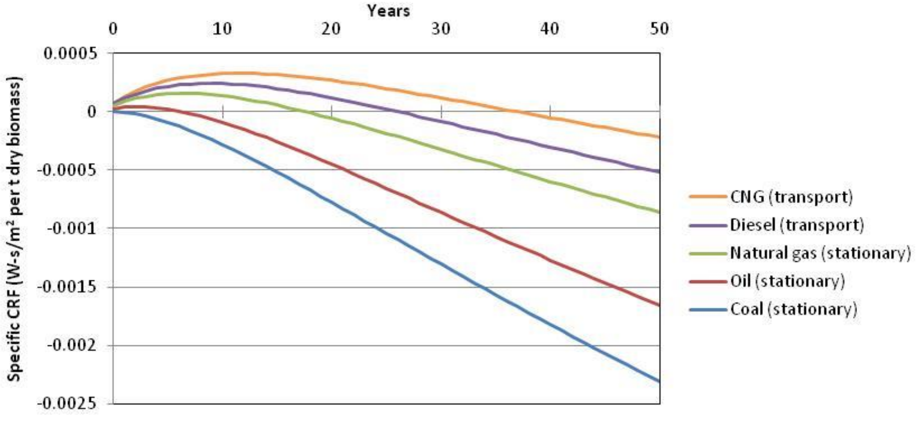
Adapted from: Sathre R. and Gustavsson L. 2011. Time-dependent climate benefits of using forest residues to substitute fossil fuels. *Biomass and Bioenergy* 35(7): 2506-2516.

Changed cumulative radiative forcing (trapped heat) per ton of dry biomass when slash substitute fossil fuels



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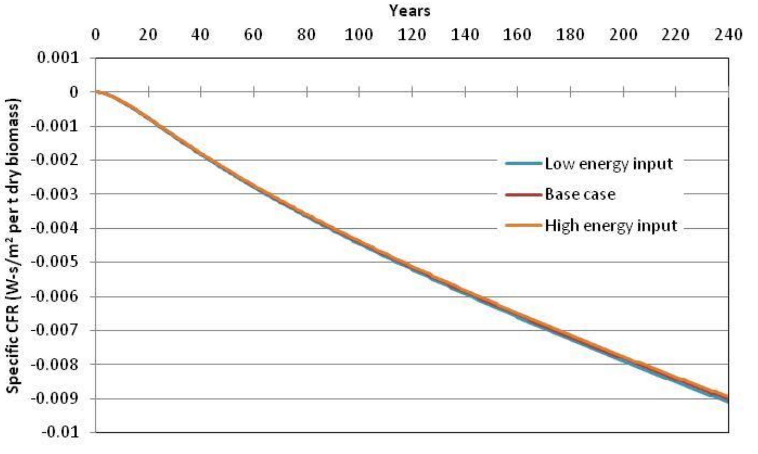
Adapted from: Sathre R. and Gustavsson L. 2011. Time-dependent climate benefits of using forest residues to substitute fossil fuels. *Biomass and Bioenergy* 35(7): 2506-2516.

Changed cumulative radiative forcing when slash substitute fossil coal – sensitivity analysis of energy input for harvest and transport



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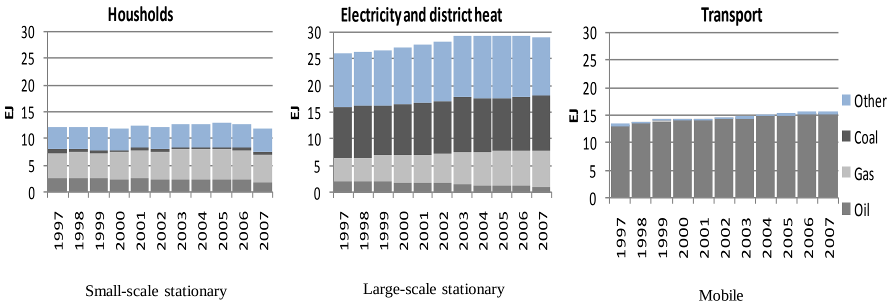
Fossil energy use in the EU - Three typical applications



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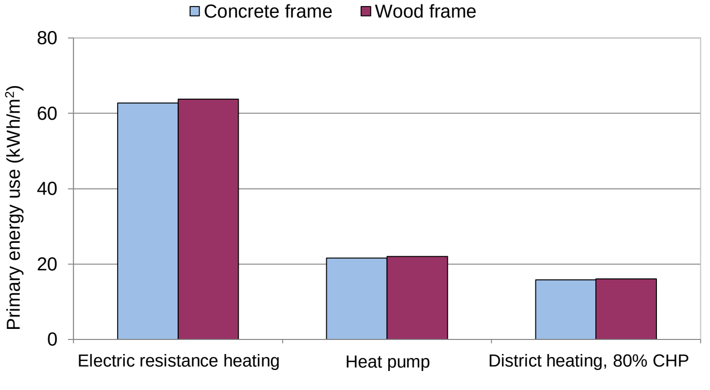
Source: Eurostat data, 2011

Annual primary energy use for space heating of houses with different heating systems



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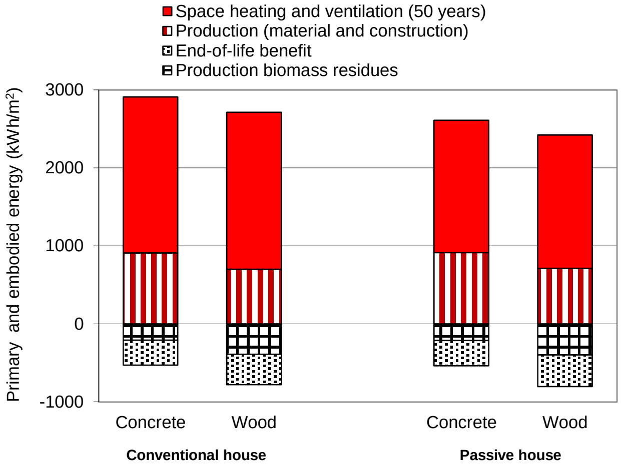
Adapted from: Dodoo A, Gustavsson L, Sathre R. 2012. Effect of thermal mass on primary energy balances of a concrete and a wood-frame building. *Applied Energy* 92: 462-472.

Primary energy use for production, space heating and ventilation, and end-of-life of a district-heated house



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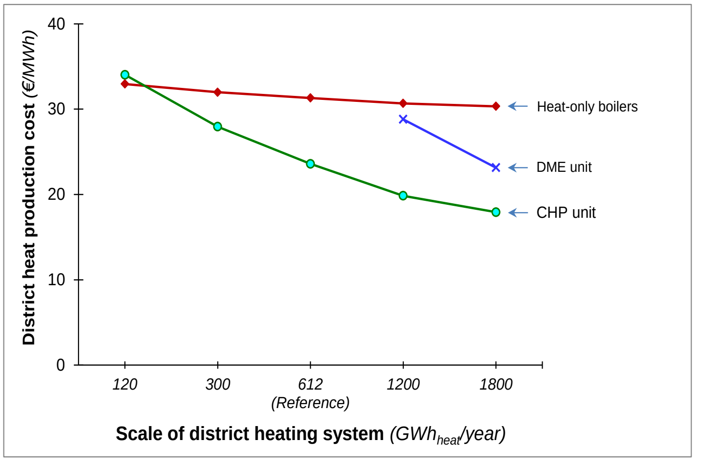
Adapted from: Dodoo A, Gustavsson L, Sathre R. 2012. Effect of thermal mass on primary energy balances of a concrete and a wood-frame building. *Applied Energy* 92: 462-472.

The cost efficiency of biomass-based district heat production units for different scale and technologies



Adapted from: Truong N.L. and Gustavsson L. 2013. Integrated biomass-based production of district heat, electricity, motor fuels and pellets of different scales. *Applied Energy* 104:623-632

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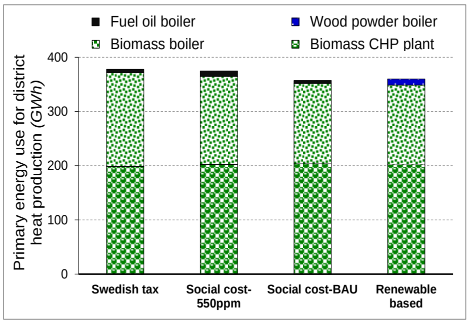
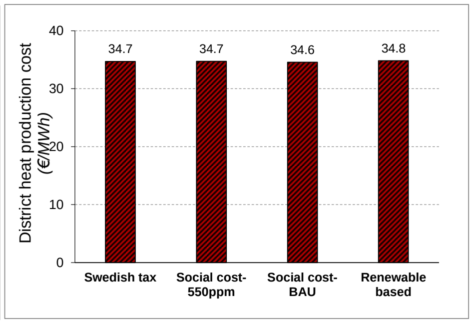
District heat production cost and fuel use - different taxation scenarios





Heat production of about 600 GWh/year.
The cogenerated electricity is credit based on power production in a minimum cost stand-alone plant.

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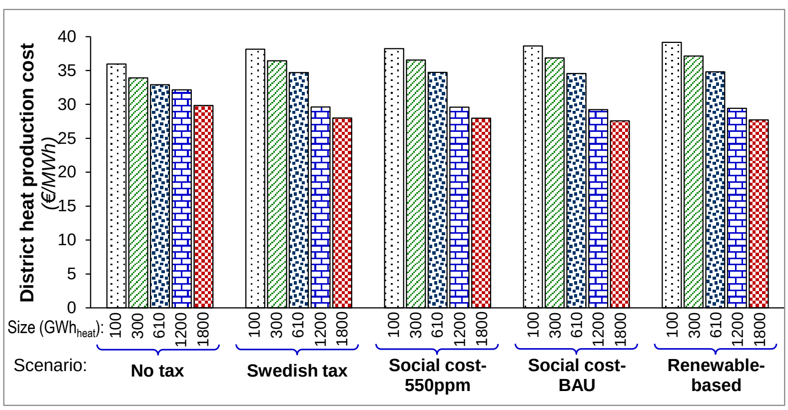
Adapted from: Truong N.L. and Gustavsson L. 2013. Integrated biomass-based production of district heat, electricity, motor fuels and pellets of different scales. *Applied Energy* 104:623-632

Cost of fuel-based district heat production for different scales and taxation scenarios



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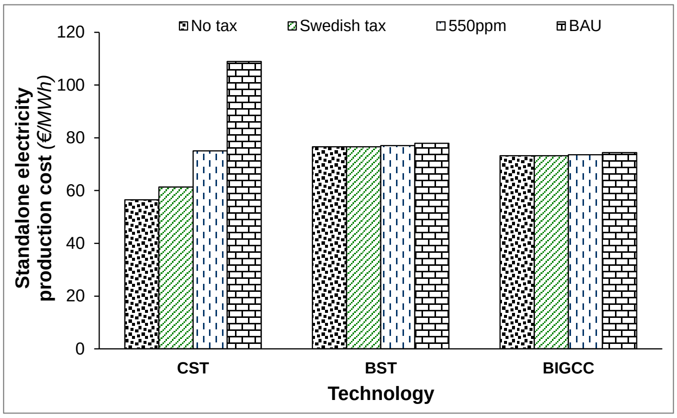
Electricity production cost of fuel-based standalone plants



CST coal steam turbine
BST biomass steam turbine
BIGCC biomass-integrated gasification combined cycle

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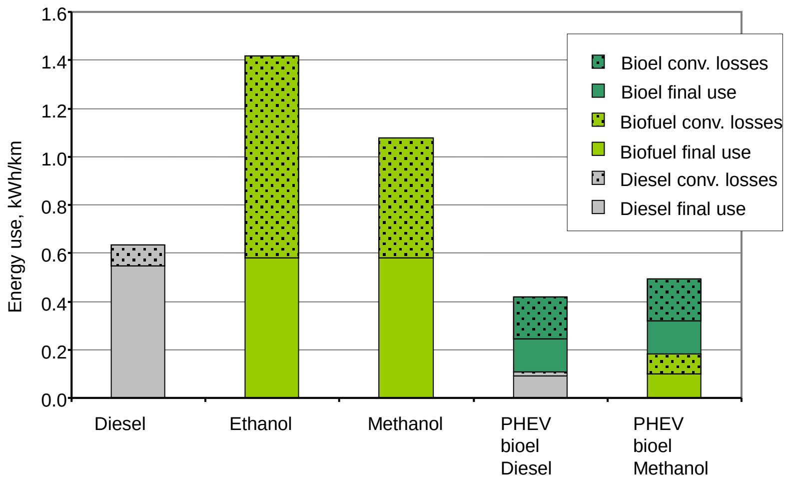
Adapted from: Truong N.L. and Gustavsson L. 2013. Integrated biomass-based production of district heat, electricity, motor fuels and pellets of different scales. *Applied Energy* 104:623-632

Primary energy use in compact cars



PHEV = Plug-in hybrid vehicles

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Adapted from: Joelsson J. M. and Gustavsson L. 2010. Reduction of CO_2 emission and oil dependency with biomass-based polygeneration. *Biomass and Bioenergy* 34 (7):967-984..

Conclusions

Climate benefits of forest residue use depends strongly on the fossil energy system that is substituted

Substituting coal in stationary plants consistently results in large climate benefits

Substituting transportation fuels results in initial climate impacts, followed by modest long-term climate benefits

Long-distance transport of forest residues has a minor impact on climate benefits

CPH-plants are typically a primary energy efficient supply system (further improved if gasification technology is used)

Scale of district heating influence the production system

District heating need to be combined with a much more energy efficient built environment

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Conclusions/discussion

Energy efficient systems from the natural resources to the delivered services and use of renewable resources

- Energy efficient built environment
  - Existing buildings to be deeply energy renovated
  - New energy-efficient wood-frame buildings
- District heating with biocogeneration
- District heating combined with solar energy, geothermal energy
- Plug-in hybrid vehicles and electric cars
- Solar and wind power, hydrogen (methanol) and fuel cells for transportation
- Etc.
- Etc.

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