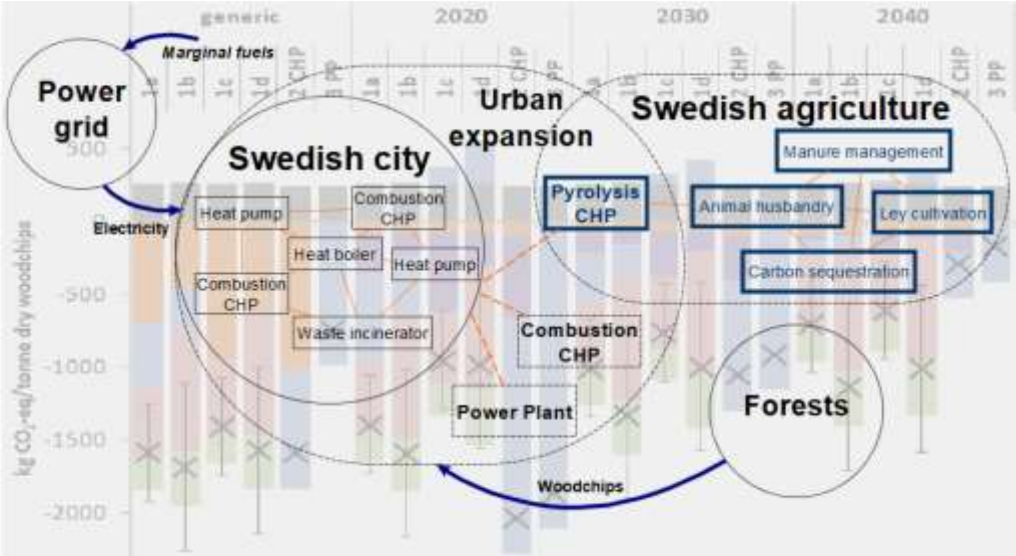
Large-scale biochar production and use in Stockholm

A prospective life cycle assessment



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Prospective Life Cycle Assessment of Large-Scale Biochar Production and Use for Negative Emissions in Stockholm

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Supporting Information

ABSTRACT: Several cities in Sweden are aiming for climate neutrality within a few decades and for negative emissions thereafter. Combined biochar, heat, and power production is an option to achieve carbon sequestration for cities relying on biomass-fuelled district heating, while biochar use could mitigate environmental pollution and greenhouse gas emissions from the agricultural sector. By using prospective life cycle assessment, the climate impact of the pyrolysis of woodchips in Stockholm is compared with two reference scenarios based on woodchip combustion. The pyrolysis of woodchips produces heat and power for the city of Stockholm, and biochar whose potential use as a feed and manure additive on Swedish dairy farms is explored. The climate change mitigation trade-off between bioenergy production and biochar carbon sequestration in Stockholm's context is dominated by the fate of marginal power. If decarbonisation of power is achieved, building a new pyrolysis plant becomes a better climate option than conventional combustion. Effects of cascading biochar use in animal husbandry are uncertain but could provide 10−20% more mitigation than direct biochar soil incorporation. These results help design regional biochar systems that combine negative carbon dioxide emissions with increased methane and nitrous oxide mitigation efforts and can also guide the development of minimum performance criteria for biochar products.

250 000 tons/year woodchips
~60 000 tons/year biochar
~ 7 tons/hour biochar

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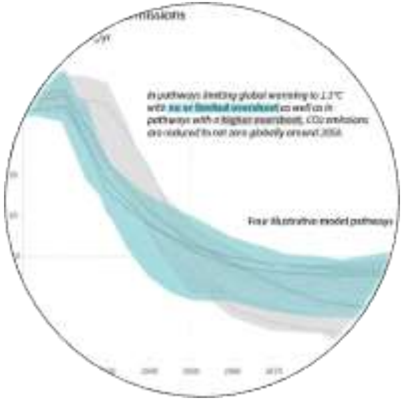
Stockholm’s context

Among fastests growing cities in Europe

Biomass-fuelled district heating network, phased out most fossil fuels in past decades



Ambitious climate goals set by municipalities

What kind of district heating plant should we build next?
What would be the most *’climate efficient’* use of biomass in Stockholm’s district heating network?
Would a biochar plant be ’*better*’ than today’s state-of-the-art?

Trade-offs: biochar or bioenergy

Energy

Carbon sequestration

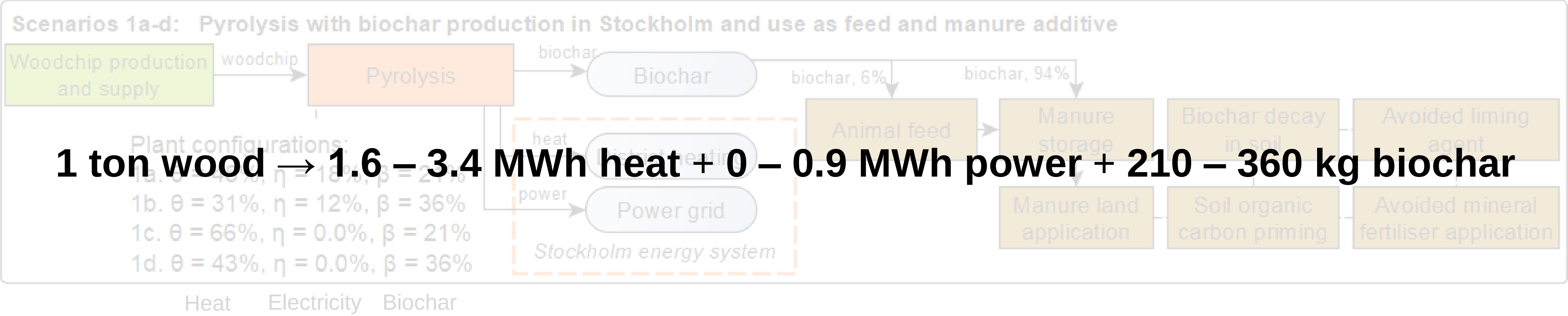
Food

Materials

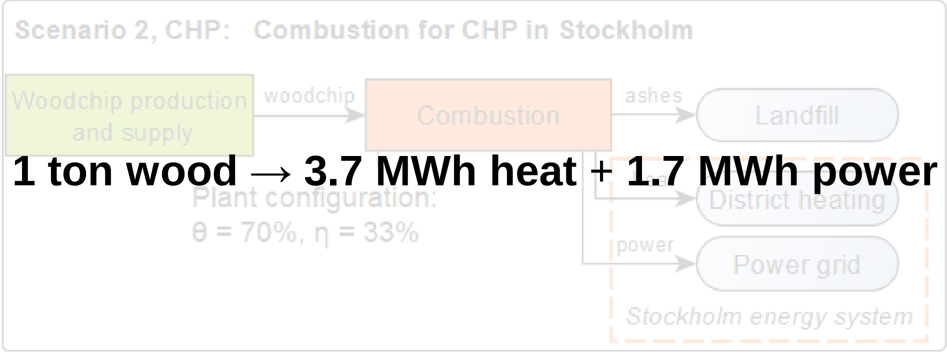
Ecosystem services

1. Life-cycle approach
2. Specific study

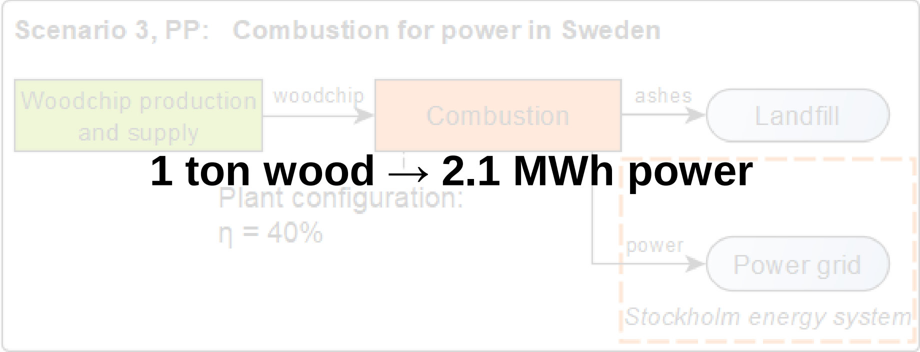
Six scenarios



1 ton wood → 1.6 – 3.4 MWh heat + 0 – 0.9 MWh power + 210 – 360 kg biochar



1 ton wood → 3.7 MWh heat + 1.7 MWh power



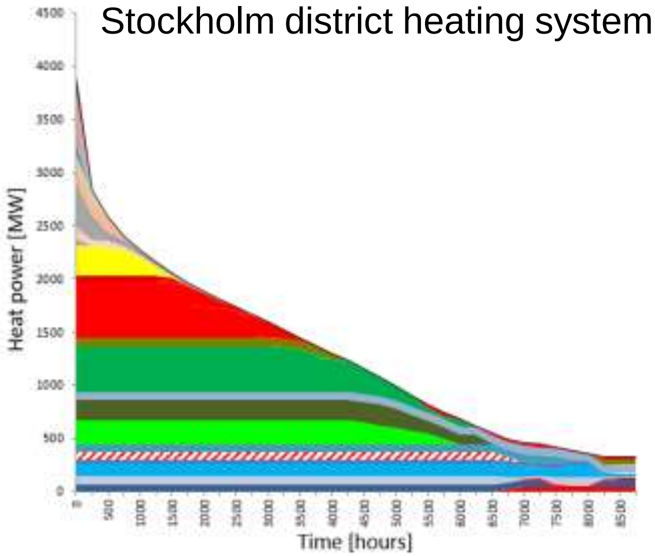
1 ton wood → 2.1 MWh power

Some pictures…

Woodchip production and supply

Some more pictures…

Pyrolysis / Combustion



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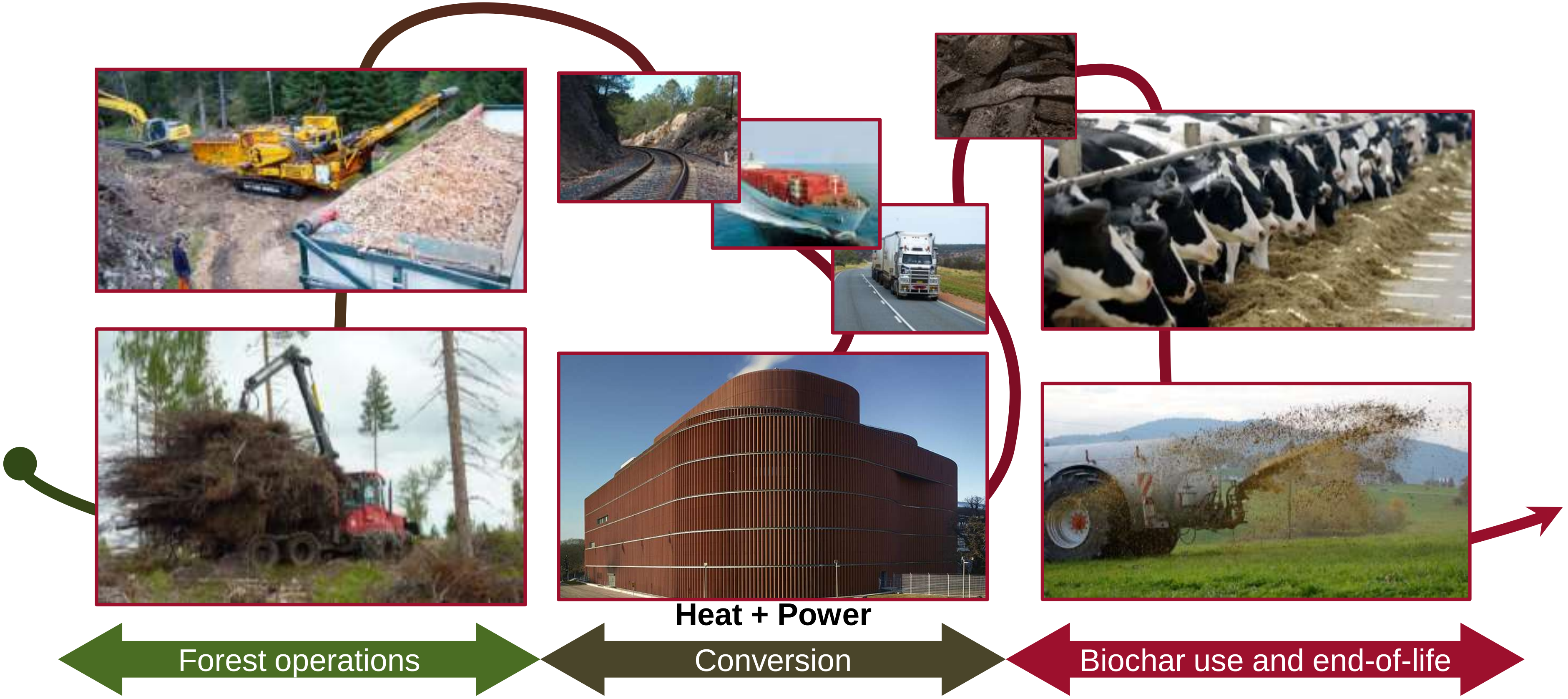
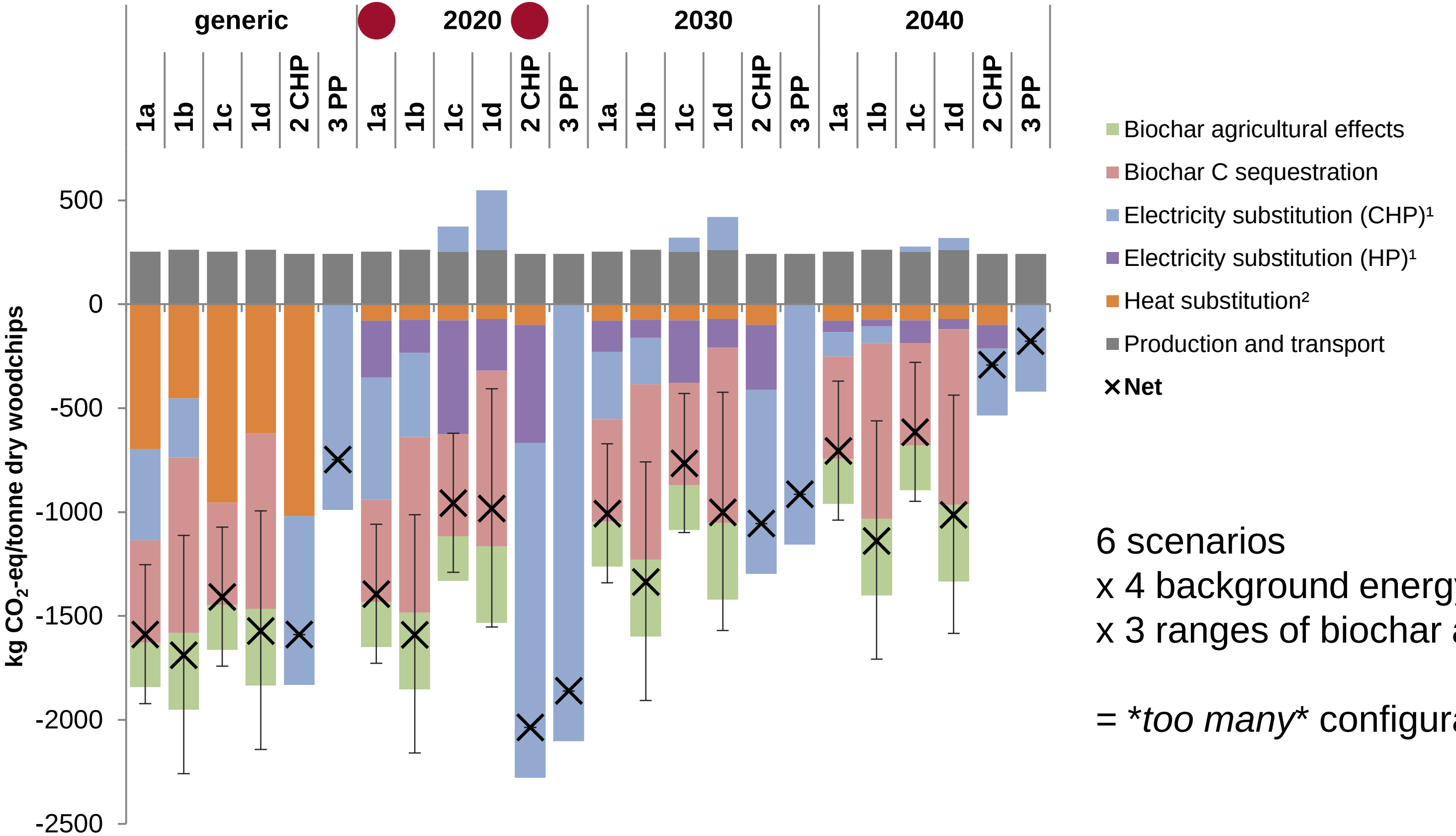
Some more pictures (bis)…

Biochar use

Everything together… a life-cycle !



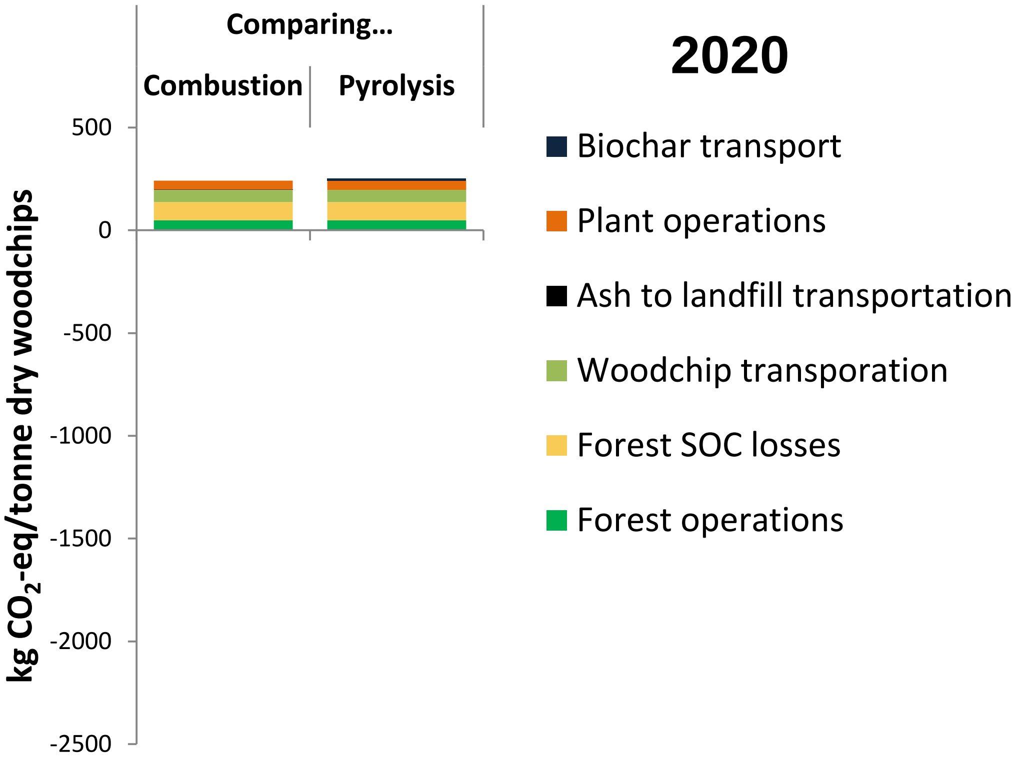
Climate impact *of many configurations*

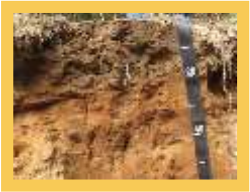


6 scenarios
x 4 background energy systems
x 3 ranges of biochar agricultural effects

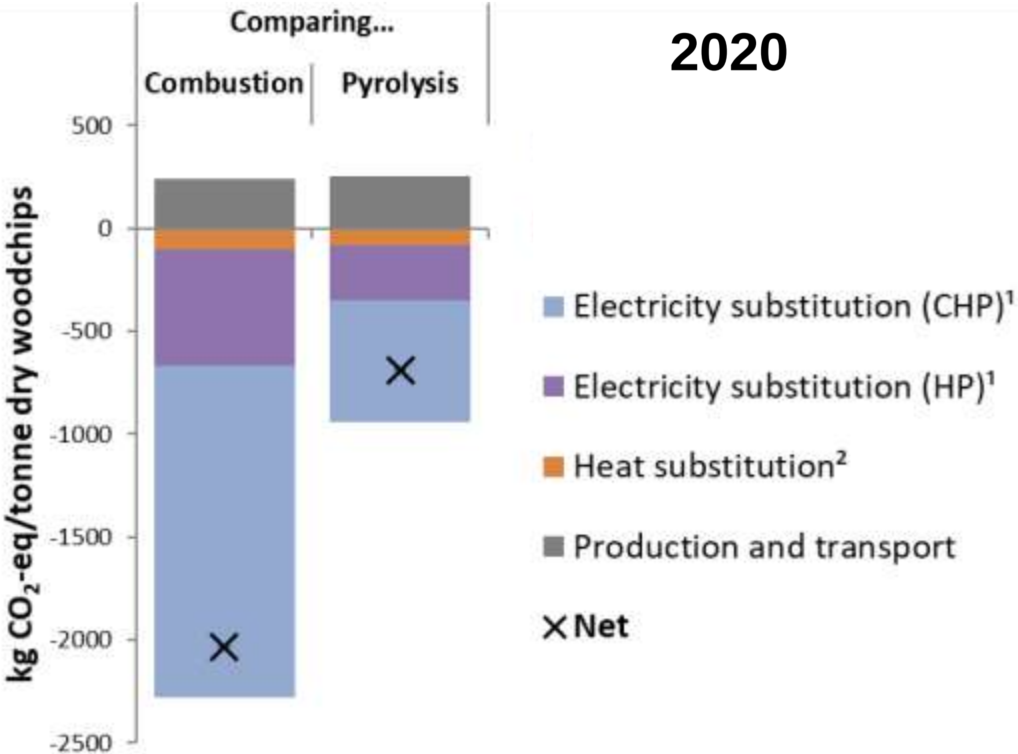
= **too many** configurations for today!

Climate impact *at production*

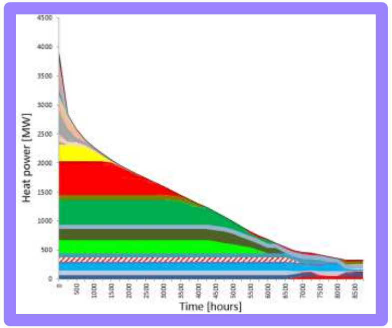




Climate impact *after energy use*



2020



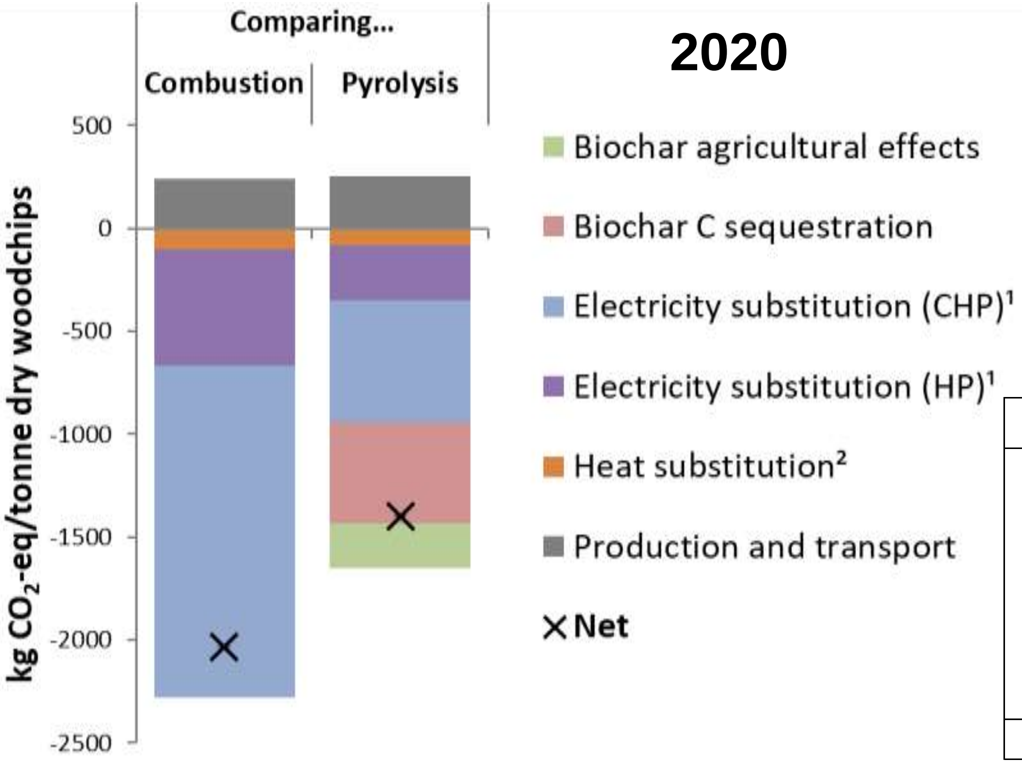
Marginal electricity 2020 from IVL, EF = 277 kg/GWh el

Fuels (GWh)	Scenarios		
	BAU	2	1a
Woodchip-eq	5398	4942	**5021**
Waste	4183	4183	4183
El. for HP	739	*610*	*677*
El. for CHP	36	93	63
Other fuels	541	*457*	*503*
Electricity output	1574	*1998*	1735

Fuels & outputs at the city-scale after introduction of a new plant

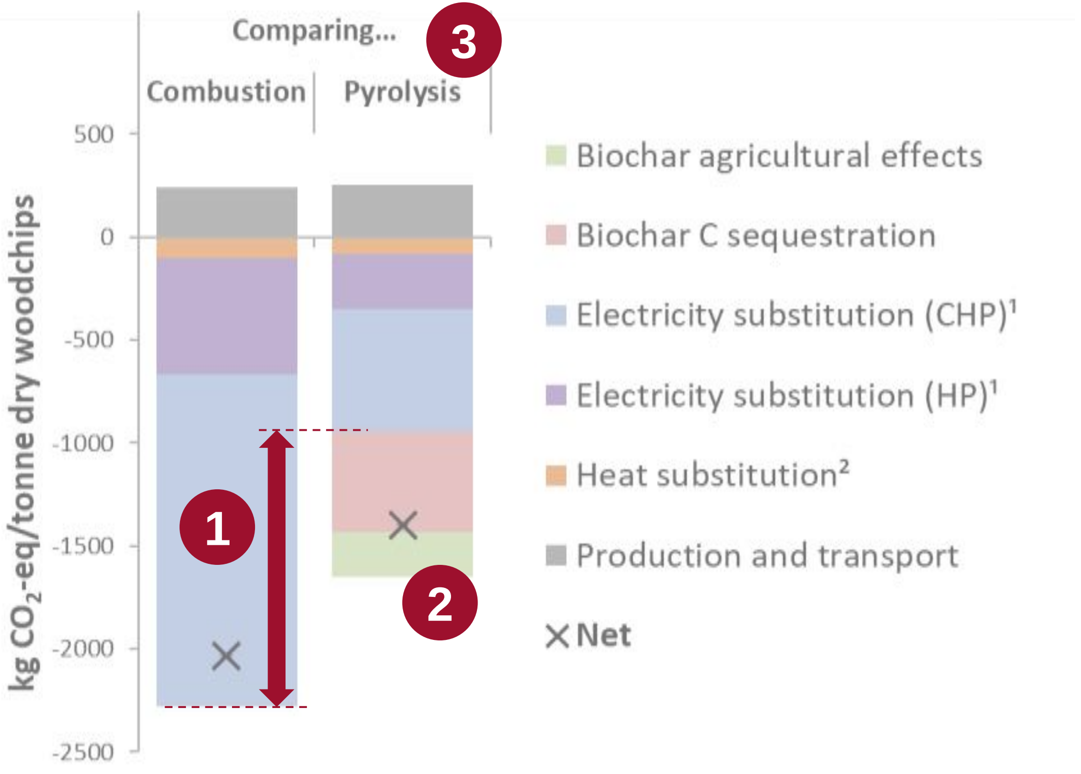
Climate impact *after biochar use*

2020



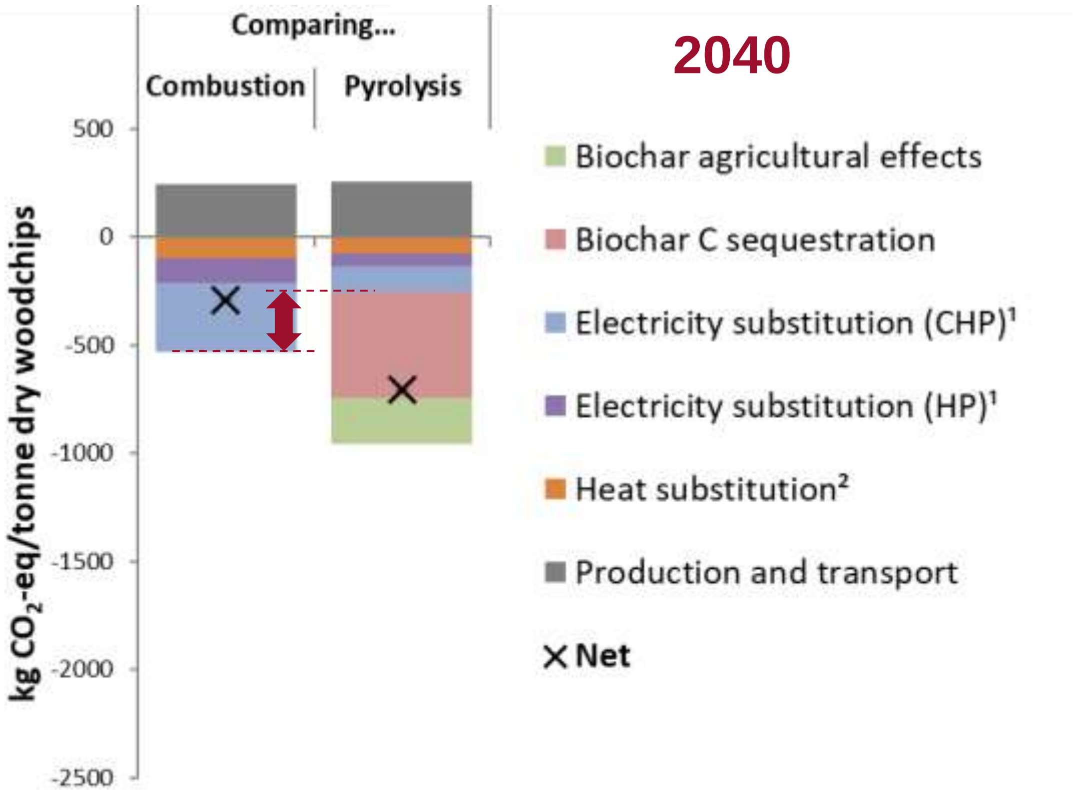
Step	Avoided climate impact (kg CO_2-eq/ton woodchips)		CH_4	d-N_2O	i-N_2O	CO_2-f	CO_2-bio	CO_2-py
Enteric fermentation	32	4,6%	100%	-	-	-	-	-
Manure storage	58	8,2%	95%	4%	2%	-	-	-
Manure application	38	5,3%	-	68%	32%	-	-	-
Mineral fertiliser application	53	7,4%	-	87%	13%	-	-	-
Mineral fertiliser production	9,2	1,3%	-	-	-	100%	-	-
Avoided liming production	2,2	0,3%				100%		
Soil methane sink	-7,9	-1,1%	100%	-	-	-	-	-
Slurry transport and spreading	-1,2	-0,2%	-	-	-	100%	-	-
Sub total: agricultural effects	***183***	***26%***	*43%*	*40%*	*11%*	*4%*	-	-
Field SOC increase	**32**	**4,6%**	-	-	-	-	100%	-
Biochar C sequestration	**493**	**70%**	-	-	-	-	-	100%
Total	***708***		**11%**	**10%**	**2,8%**	**1,4%**	**4,6%**	**70%**

Disappointing? Life cycle *interpretation* needed!



1. **Energy penalty**
   What changes and emission factors?
2. **Biochar use phase**
   How certain are the biochar effects?
3. **Parameter sensitivity**
   What if yields/efficiencies are changed?

Energy penalty

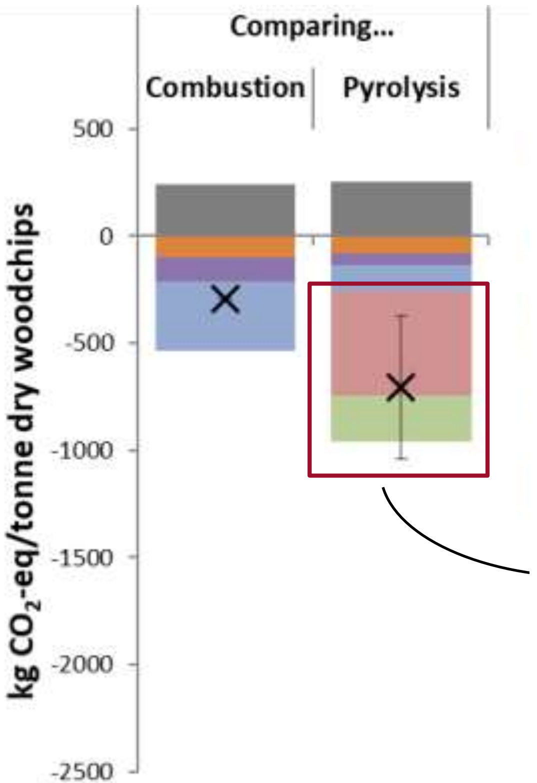


Long-term marginal electricity, Sweden (IVL, 2017)

Timeframe	gCO_2-eq kWh^{-1}	gCO_2-eq GJ^{-1}	
2020	1000	277	Coal & natural gas
2030	550	153	Natural gas
2040	200	56	Efficient natural gas & other

Biochar effects: explorative modelling

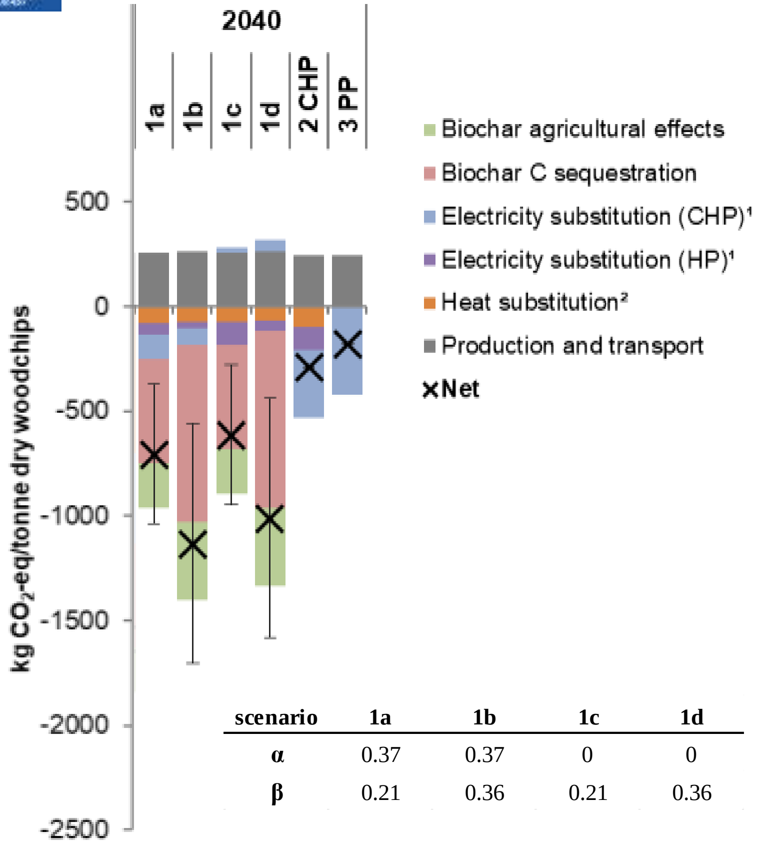
2



Step	Gas	Worst, **Average**, Best	Source
Enteric fermentation	CH_4	0%, **2.5%**, 5.0%	In-vitro experiments highlighted no increase in emissions, and probably a small decrease could be expected[52].
Indoor storage	CH_4-C	0%, **12.5%**, 25%	*Assumed effects on manure storage. No negative effects were reported in one experiment[53].*
	NH_3-N	0%, **12.5%**, 25%	
	d-N_2O-N	0%, **12.5%**, 25%	
Slurry application	NH_3-N	0%, **20%**, 40%	*Assumed reduced ammonia loss by biochar adsorption.*
	NO_3-N	5.7%, **26%**, 41%	Meta-analysis[54]. Value for longer studies, with widest 95% confidence interval.
	d-N_2O-N	-10%, **16%**, 42%	Meta-analysis[9]. Value for small application rates.
Mineral fertiliser application	NH_3-N	0%, **20%**, 40%	*Assumed reduced ammonia loss by biochar adsorption.*
	NO_3-N	5.7%, **26%**, 41%	Meta-analysis[54]. Value for longer studies, with widest 95% confidence interval.
	d-N_2O-N	-10%, **16%**, 42%	Meta-analysis[9]. Value for small application rates.
Soil methane sink	CH_4	0%, **-25%**, -50%	In upland soils, the strength of the methane sink may slightly be reduced[55–57]. Increased emissions.
Parameter	**Unit**	Worst, **Average**, Best	**Source**
Biochar liming effect	% $CaCO_3$	1.0%, **10%**, 20%	Assumed liming effect based on liming classes from[58].
SOC decay rate change	-	-0.80%, **3.8%**, 8.1%	Meta-analysis[12]. Grand mean and 95% confidence interval.
Biochar carbon recalcitrance	%C	70%, **80%**, 90%	Higher value supported by meta-analysis, for woody biomass[12]. Lower value suggested as in[14].

Parameter sensitivity

3



scenario	1a	1b	1c	1d
α	0.37	0.37	0	0
β	0.21	0.36	0.21	0.36

If electricity is already decarbonised,

- Trade-off is in favour of biochar production
- Investing in a costly turbine is not necessary

Final word

At the large-scale envisioned in this study, where woodchips are sourced on the global market, **the suitability of biochar systems in Stockholm is subject to the decarbonisation of the electricity market and other carbon-intensive sectors**. If this decarbonisation is achieved by 2040, biochar solutions would represent a suitable expansion for the district heating network, thereby providing a sound option for carbon dioxide removal. **If agricultural effects of biochar are optimised, through cascading use in animal husbandry, manure management and fertiliser management, the climate benefits of biochar could at best be doubled**. Such a prospective development requires research efforts, in both upscaling of pyrolysis technologies and mechanistic understanding of biochar agricultural effects. **When developing new biochar products, the life cycle perspective is useful to assess trade-offs and the relative importance of various potential effects**.

*The **climate suitability** of "using woodchips for biochar" is function of*

(i) Developments in background energy system

(ii) Performance of biochar in the field

In this study,

(i) Energy penalty was dominated by the fate of power production

(ii) Biochar effects in the field were exploratory rather than predictive, require manure-related experiments and long-term carbon monitoring

Keywords:
Industrial ecology
Life cycle assessment
Energy and agriculture

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Time for feedback & questions

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Summer Nights, Eugene Jansson, 1898