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Synergies and trade-offs between energy systems and negative emission technologies

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nature climate change

Biophysical and economic limits to negative CO_2 emissions

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To have a >50% chance of limiting warming below 2 °C, most recent scenarios from integrated assessment models (IAMs) require large-scale deployment of negative emissions technologies (NETs). These are technologies that result in the net removal of greenhouse gases from the atmosphere. We quantify potential global impacts of the different NETs on various factors (such as land, greenhouse gas emissions, water, albedo, nutrients and energy) to determine the biophysical limits to, and economic costs of, their widespread application. Resource implications vary between technologies and need to be satisfactorily addressed if NETs are to have a significant role in achieving climate goals.

Despite two decades of effort to curb emissions of CO_2 and other greenhouse gases (GHGs), emissions grew faster during the 2000s than in the 1990s[1], and by 2010 had reached ~50 Gt CO_2 equivalent (CO_2eq) yr^{-1} (refs 2,3). The continuing rise in emissions is a growing challenge for meeting the international options, to be able to decide which pathways are most desirable for dealing with climate change.

There are distinct classes of NETs, such as: (1) bioenergy with carbon capture and storage (BECCS)[11,12]; (2) direct air capture of CO_2 from ambient air by engineered chemical reactions (DAC)[13,14];

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Soil carbon sequestration and biochar as negative emission technologies

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Abstract

Despite 20 years of effort to curb emissions, greenhouse gas (GHG) emissions grew faster during the 2000s than in the 1990s, which presents a major challenge for meeting the international goal of limiting warming to <2 °C relative to the preindustrial era. Most recent scenarios from integrated assessment models require large-scale deployment of negative emissions technologies (NETs) to reach the 2 °C target. A recent analysis of NETs, including direct air capture, enhanced weathering, bioenergy with carbon capture and storage and afforestation/deforestation, showed that all NETs have significant limits to implementation, including economic cost, energy requirements, land use, and water use. In this paper, I assess the potential for negative emissions from soil carbon sequestration and biochar addition to land, and also the potential global impacts on land use, water, nutrients, albedo, energy and cost. Results indicate that soil carbon sequestration and biochar have useful negative emission potential (each 0.7 GtCeq. yr^{-1}) and that they potentially have lower impact on land, water use, nutrients, albedo, energy requirement and cost, so have fewer disadvantages than many NETs. Limitations of soil carbon sequestration as a NET centre around issues of sink saturation and reversibility. Biochar could be implemented in combination with bioenergy with carbon capture and storage. Current integrated assessment models do not represent soil carbon sequestration or biochar. Given the negative emission potential of SCS and biochar and their potential advantages compared to other NETs, efforts should be made to include these options within IAMs, so that their potential can be explored further in comparison with other NETs for climate stabilization.

Keywords: biochar, carbon, negative emission technology, sequestration, soil

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Collaborators – Global Carbon Project NETs meeting

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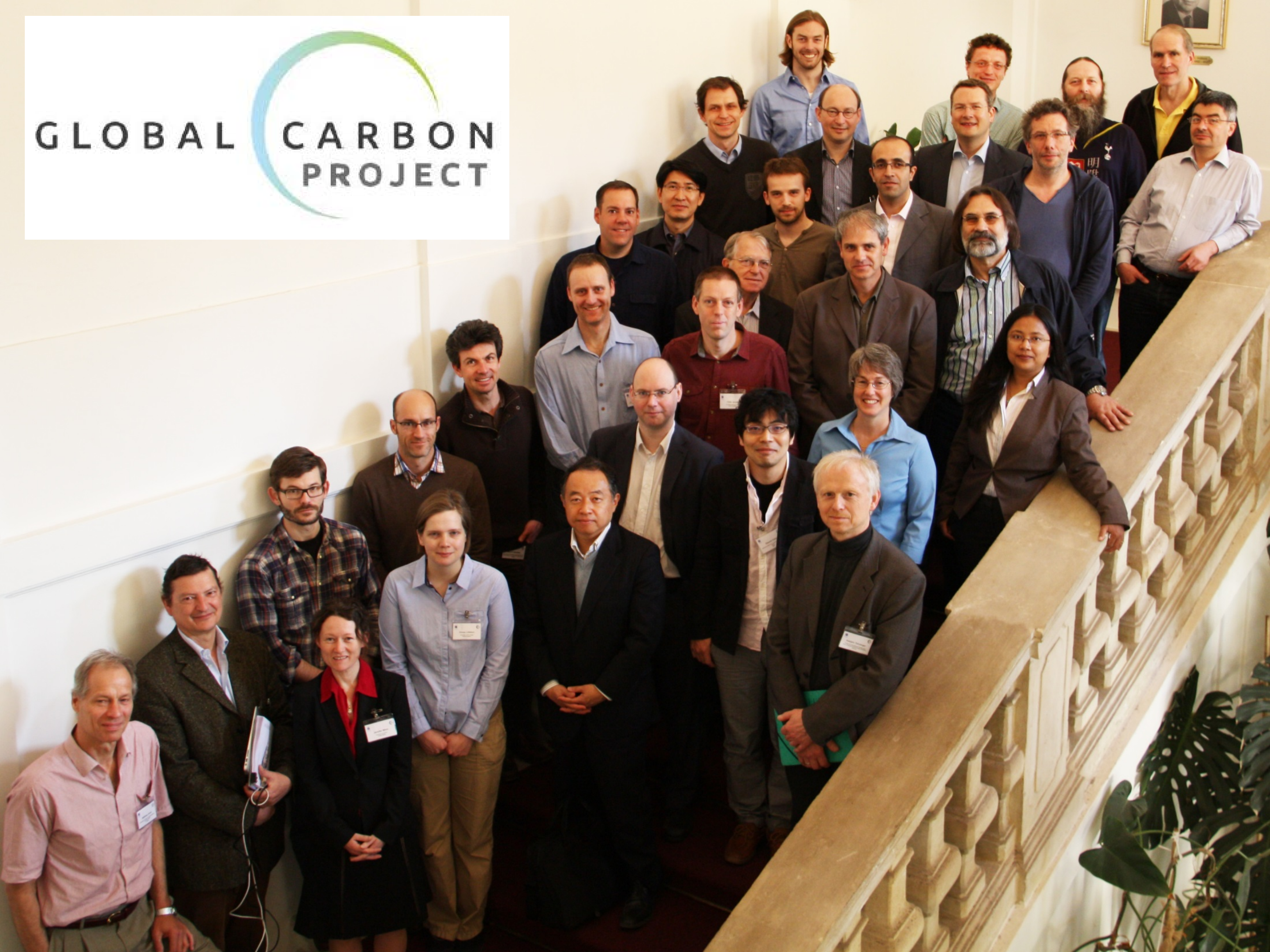
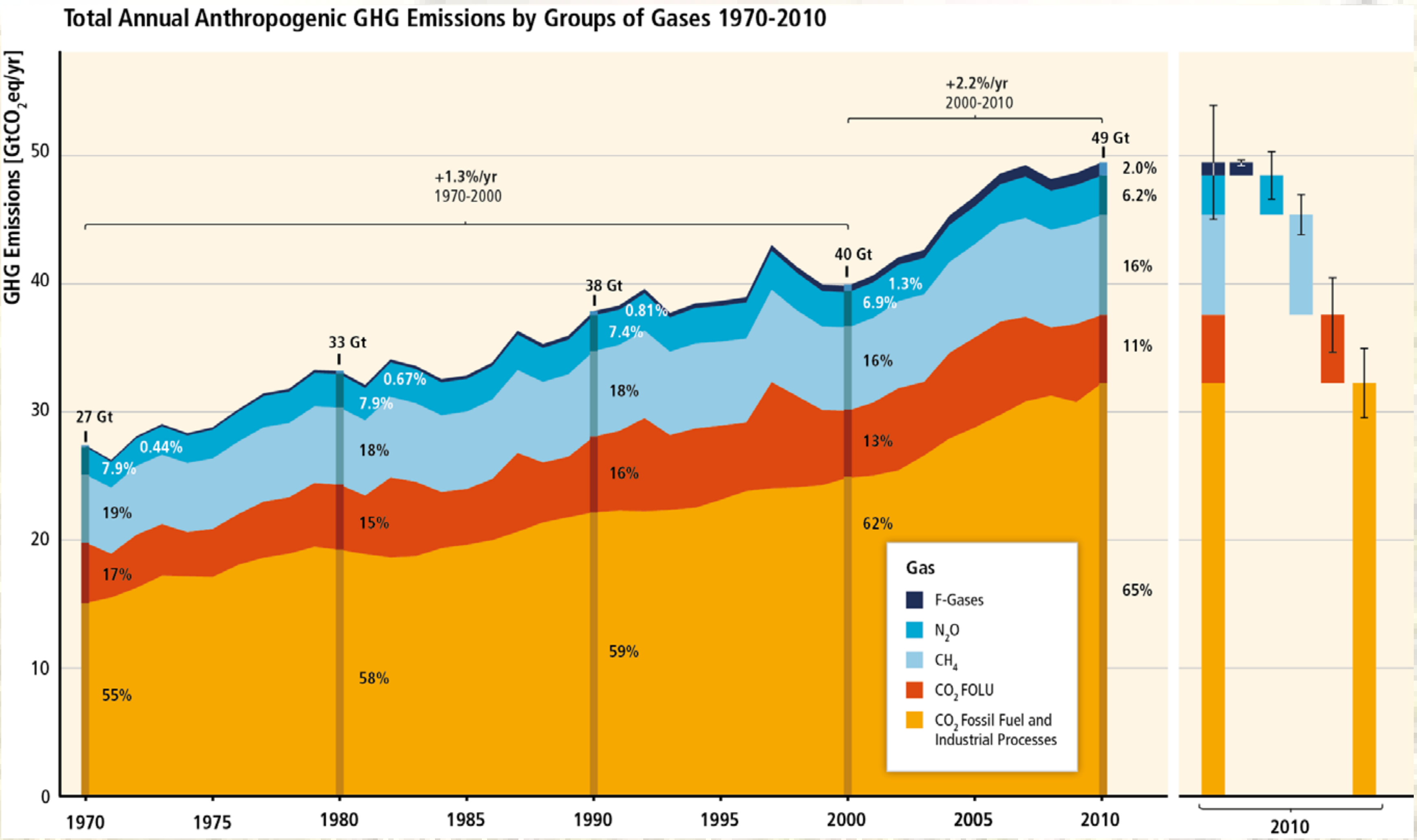

GLOBAL CARBON
PROJECT

GHG emissions accelerate despite reduction efforts. Most emission growth is CO_2 from fossil fuel combustion and industrial processes.

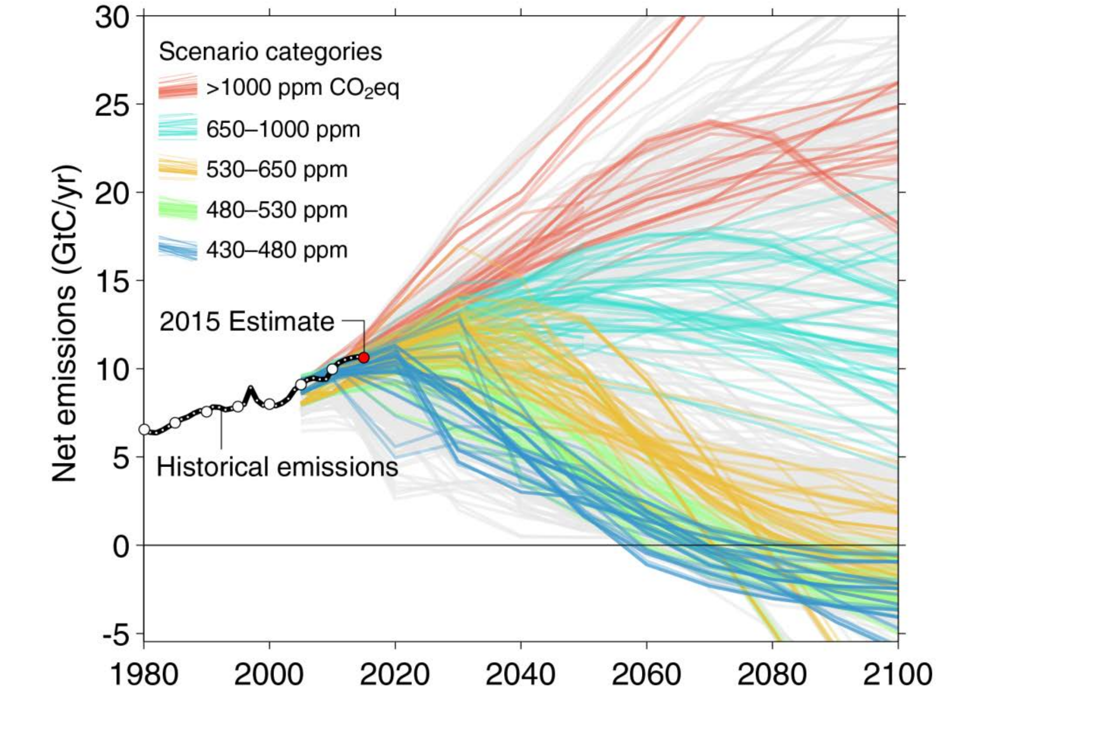


Edenhofer *et al.* (2014)

The Paris Agreement (COP21) was a game changer…

- The **Paris Agreement** commits the **190+ signatories** of the United Nations Framework Convention on Climate Change (UNFCCC) to keeping the increase in **global average temperature to well below 2°C above pre-industrial levels**, with an aim to limit the increase to **1.5°C**.
- It is necessary that global **emissions peak as soon as possible**, recognizing that this will take longer for developing countries, and that rapid reductions occur thereafter.
- In order to be consistent with a 2°C target, emissions across all sectors need to **decrease by over 80% by 2050**, with **even greater reductions required for a 1.5°C target**.

Negative Emissions Technologies (NETs)



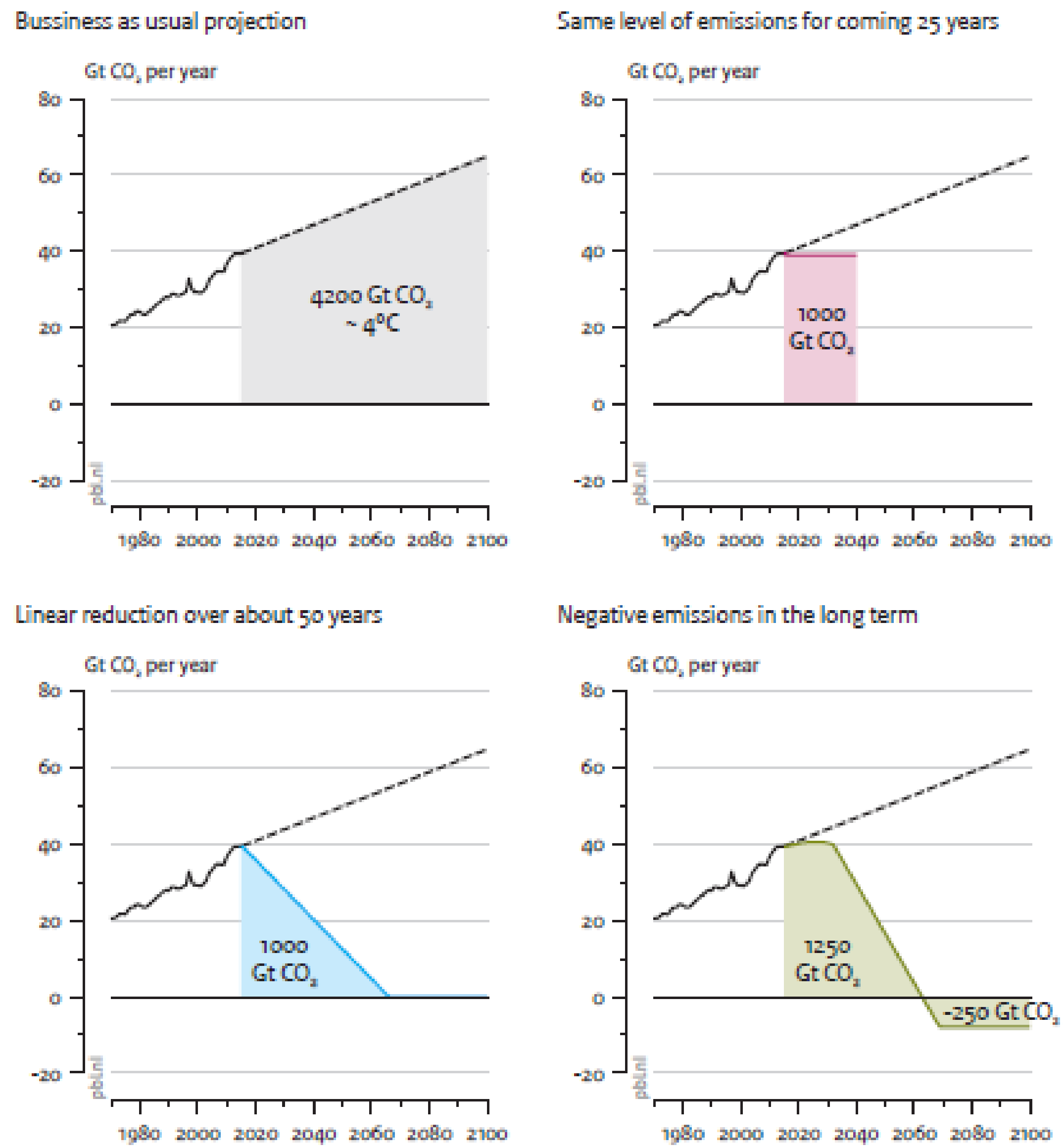
Of the 116 scenarios consistent with limiting warming below 2°C, 101 (87%) apply global NETs in the second half of this century, as do many scenarios that allow CO_2 concentrations to grow between 480 and 720 ppm CO_2-eq. by 2100 (501/653 apply BECCS; with 235/653 [36%] delivering net negative emissions globally.

Fuss *et al.* (2014); Smith *et al.* (2016)

Why do IAMs get this result?

<2^{o}C target is very stringent!

Rio+20, 15 May 2012



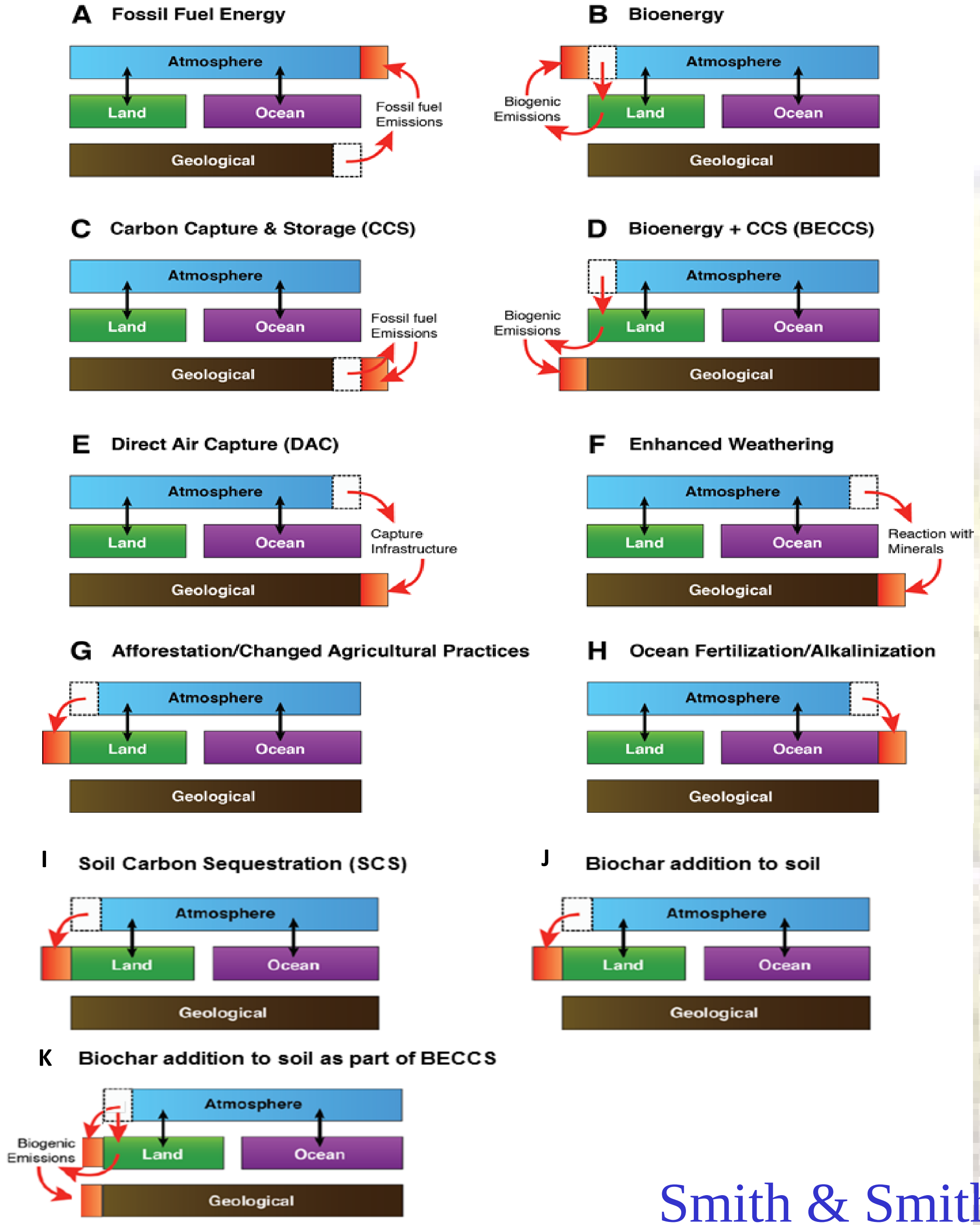
Slide courtesy of Detlef van Vuuren, PBL

Negative Emissions Technologies (NETs)

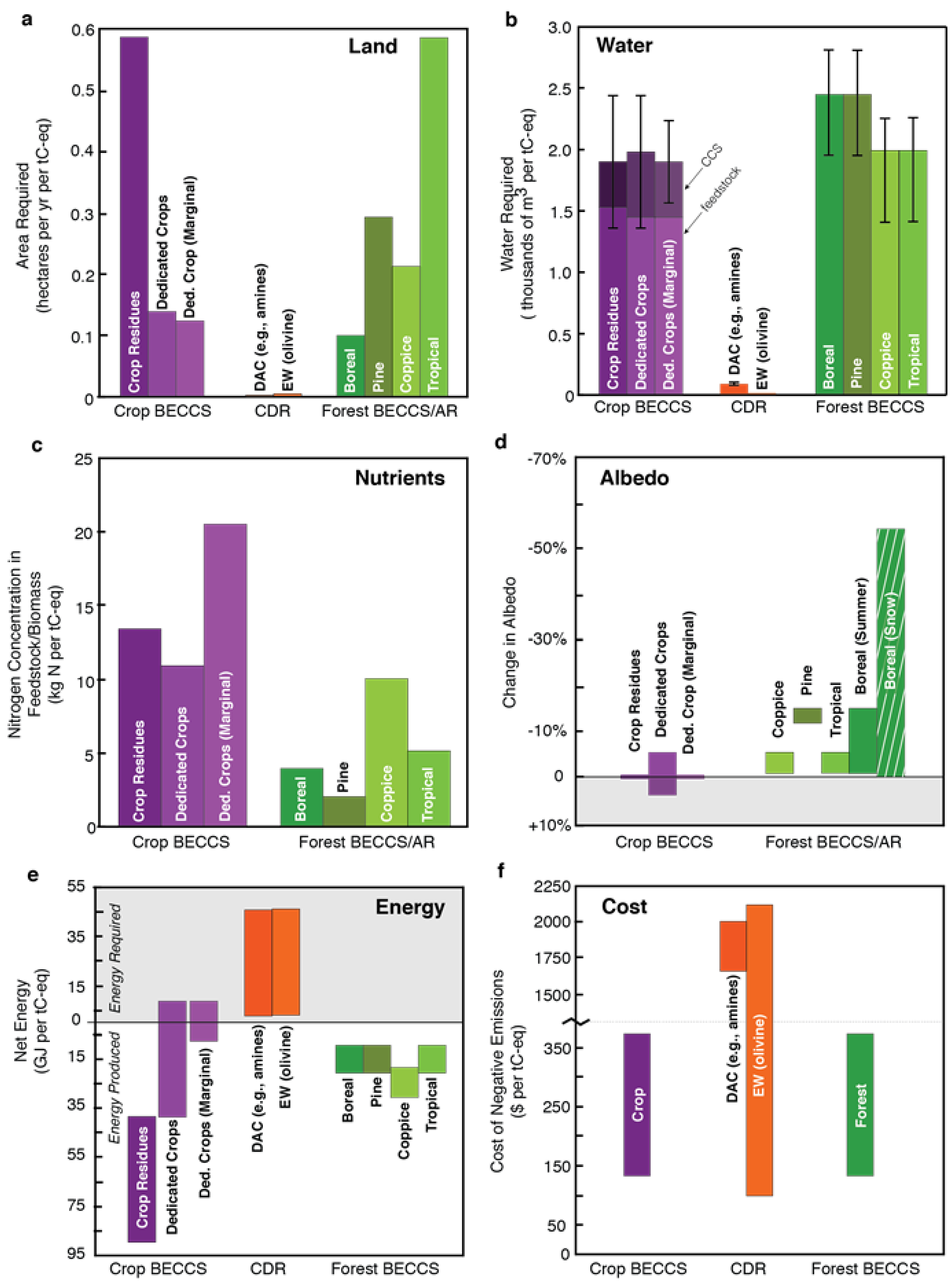
The ones I will focus on today….

- Direct Air Capture (DAC)
- Enhanced weathering of minerals (EW)
- Afforestation
- Bioenergy with carbon capture and storage (BECCS)
- Soil carbon sequestration
- Biochar

Summary of the carbon cycle impacts of different NETs



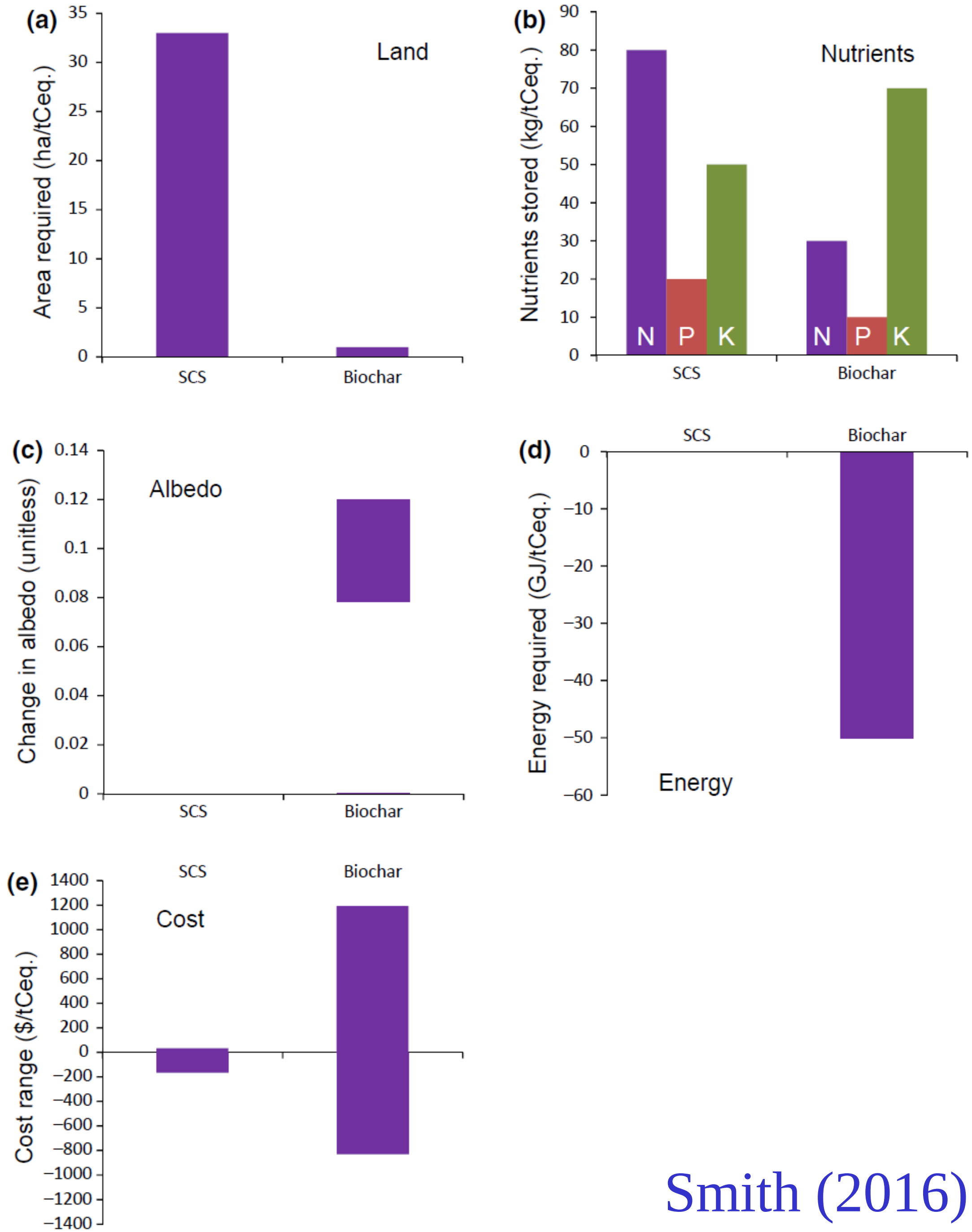
Smith & Smith (2016)



Impact of BECCS, DAC, EW, AR on land, water, nutrients, albedo, energy and cost – all expressed on a per-t-C basis

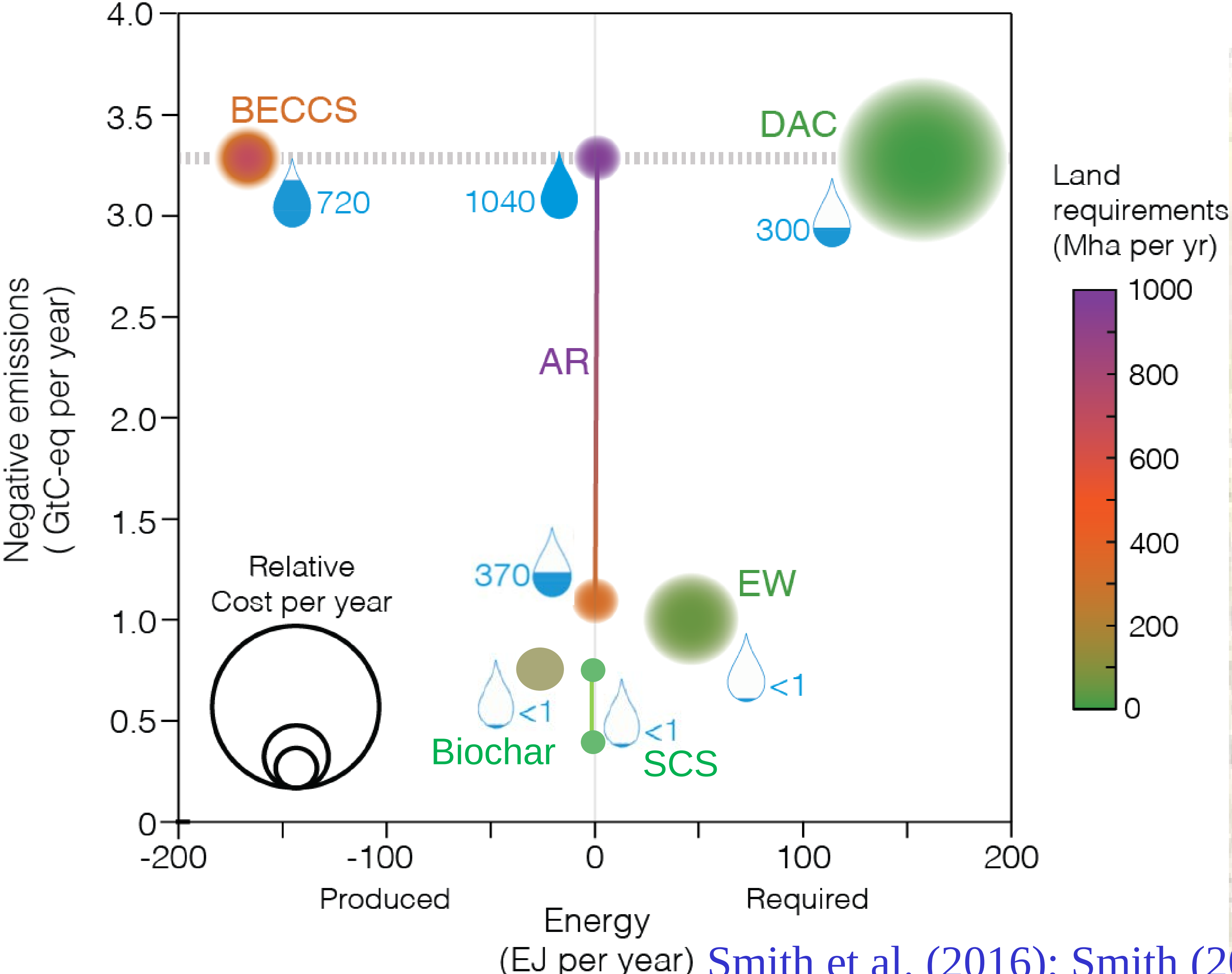
Smith *et al.* (2016)

Impact of SCS, biochar and biochar as part of BECCS on land, nutrients, albedo, energy and cost – all expressed on a per-t-C basis



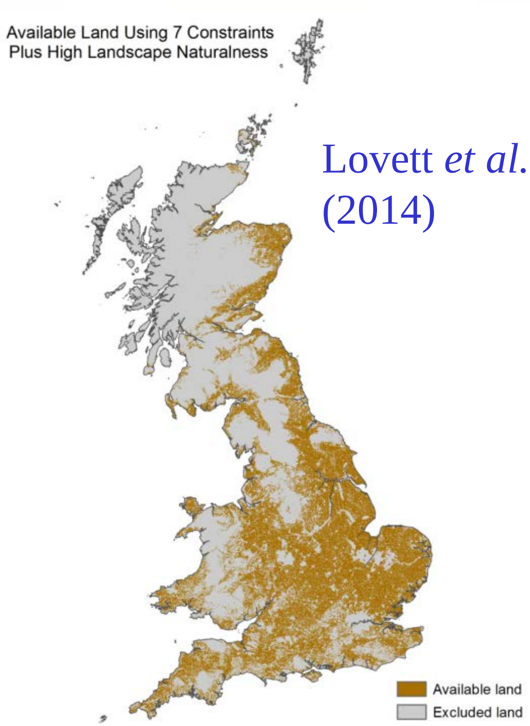
Smith (2016)

Impact / limit summary for NETS



Smith et al. (2016); Smith (2016)

NETS in the UK



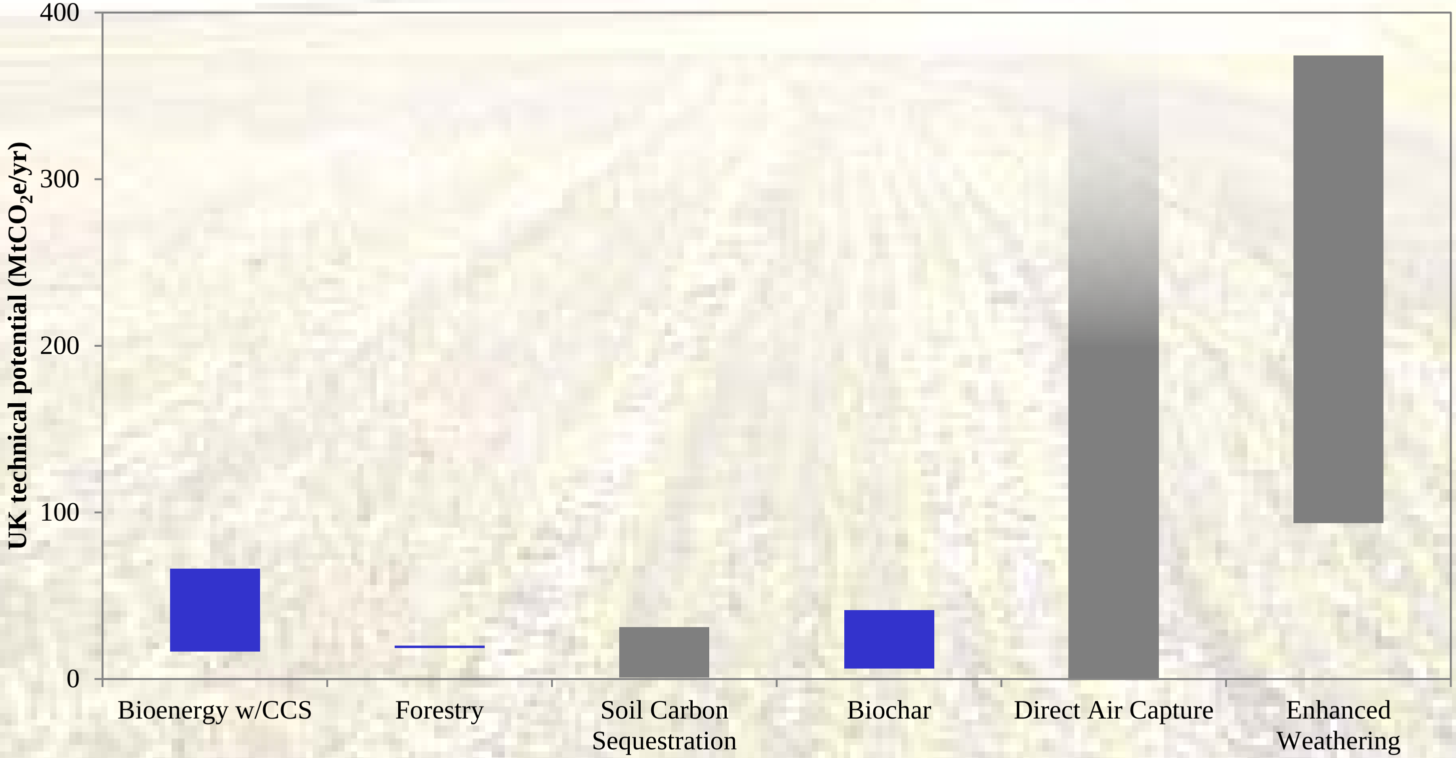
Lovett *et al.* (2014)

All UKERC constraints including naturalness score	8.5	Mha
All UKERC contraints plus exclude Grade 1-2 land	6.4	Mha
All UKERC contraints plus exclude Grade 1-3 land	1.5	Mha

Smith & Smith (2016)

	Area applied	Negative Emission Potential		Water use		Energy required		Nitrogen		Phosphorus		Potassium		Albedo		Cost	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Technology	Mha	Mt Ceq./yr	Mt Ceq./yr	km^3/yr	km^3/yr	PJ/yr	PJ/yr	ktN/yr	ktN/yr	ktP/yr	ktP/yr	ktK/yr	ktK/yr	unitless	unitless	B$US/yr	B$US/yr
BECCS	1.5	4.5	18	9.00	45.00	-173.7	156.6	49.5	360	3.6	360	25.7	396	0	0.04	0.59	2.38
AR	1.5	5.1	5.1	6.02	11.99	0	0	10.2	25.5	20.4	25.5	2.0	15.9	0.002	0.62	0.33	0.55
SCS	8.5	0.255	8.5	0	0	0	0	20.4	680	5.1	170	3.8	127.5	0	0	-0.04	0.34
Biochar	1.5	1.725	11.25	0	0	-86.3	-225	51.8	337.5	17.3	112.5	120.8	787.5	0.08	0.12	-1.43	13.5
DAC		4.5*	18*	0.33	1.98	11.7	824.4	0	0	0	0	0	0	0	0	7.2	37.44
EW	8.5	25.5	102	0.04	0.15	76.5	4712.4	0	0	0	0	0	0	0	0	2.244	216.24

NETS in the UK



- Aggregate technical potential for land-based NETs = 30-130 MtC-eq./yr
- This is 20-80% of current total UK emissions
- Many limitations (as per global study)

Smith & Smith (2016)

Conclusions

- Negative emissions of 3.3 GtC-eq./yr in 2100 are possible globally with BECCS and DAC
- EW, AR, SCS and biochar can provide less negative emissions than this in 2100
- All NETs have limits / downsides and none is a magic bullet
- Need more R&D and pilot projects – then to see if technology is scalable → Most probably will need to look into other NETs to complement BECCS and AR, e.g. DAC, EW, SCS, biochar
- Improve governance to ensure sustainable implementation of NETs. Safe storage needed, in addition to storage from fossil CCS.
- An over-reliance on NETs in the future, if used as a means to allow continued use of fossil fuels in the present, is extremely risky since our ability to stabilise the climate at <2°C declines as cumulative emissions increase (Kriegler et al., 2014, Luderer et al., 2012) – so we must reduce emissions aggressively now.
- Seems impossible to meet Paris targets without NETs
- Aggregate technical potential for land-based NETs in UK = 30-130 MtC-eq./yr (20-80% of current total UK emissions) – but many limitations

Smith *et al.* (2016); Smith (2016); Smith & Smith (2016)

Thank you for your attention

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