Mission Innovation: Greenhouse Gas Removal

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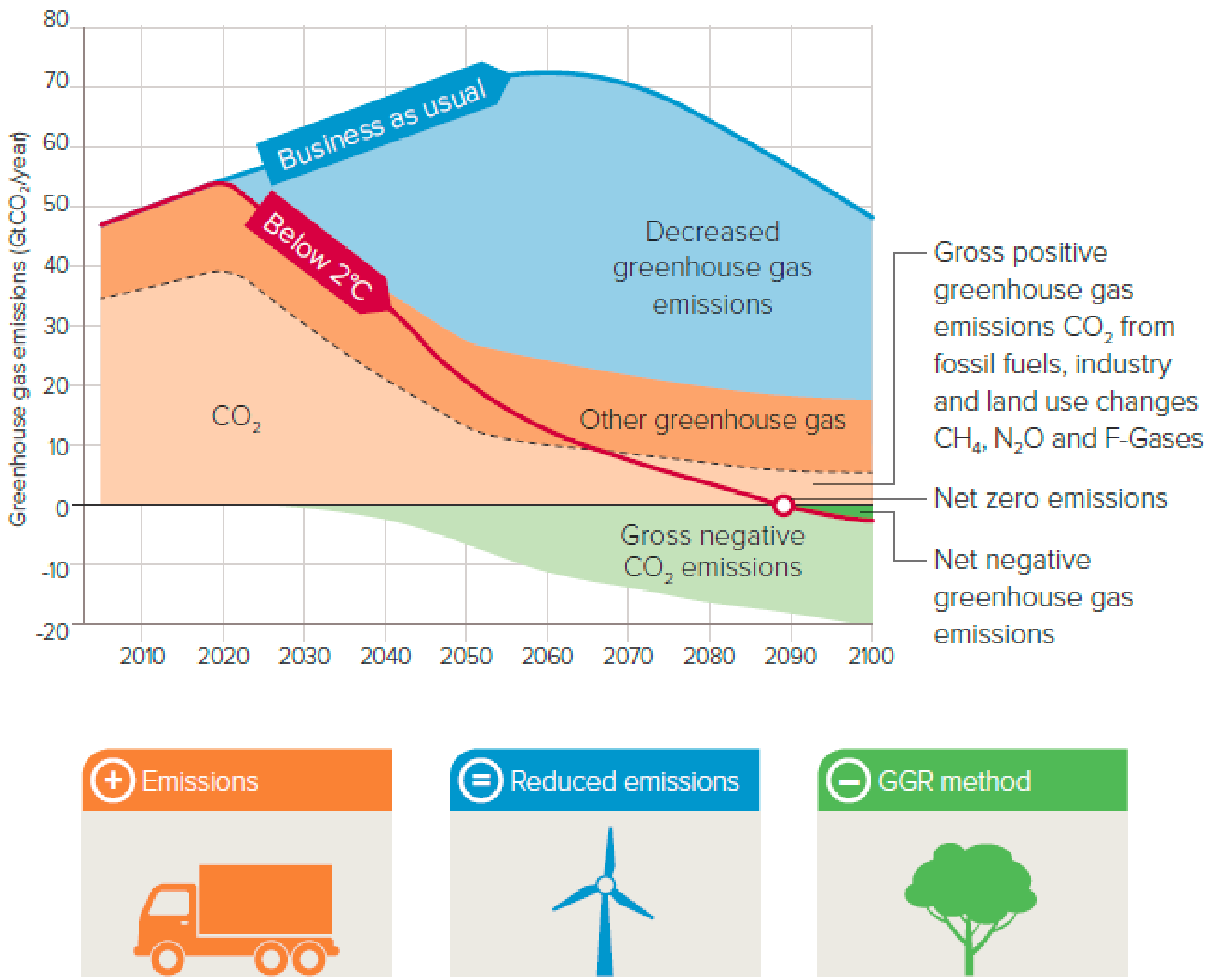
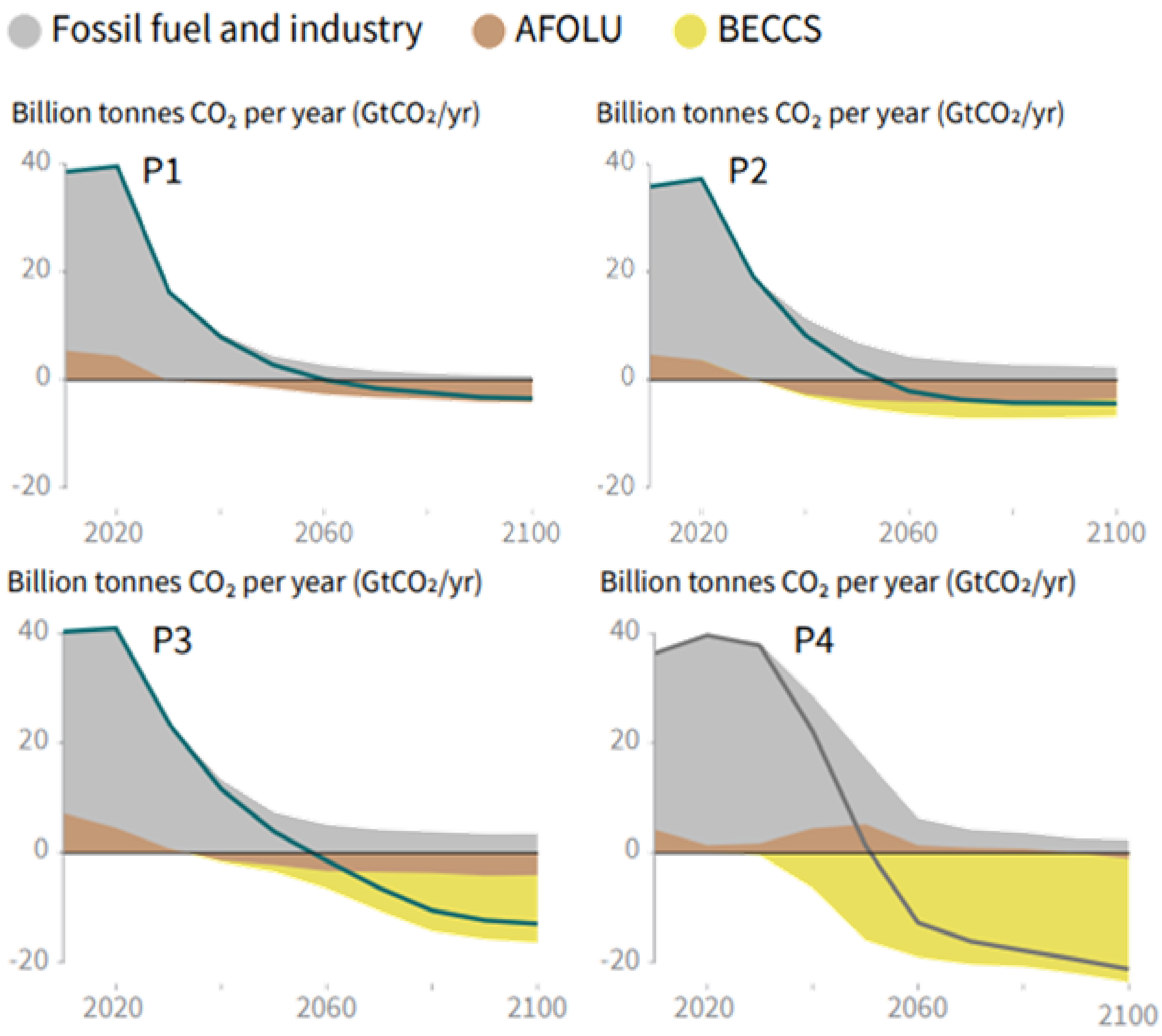
Paris changed everything…



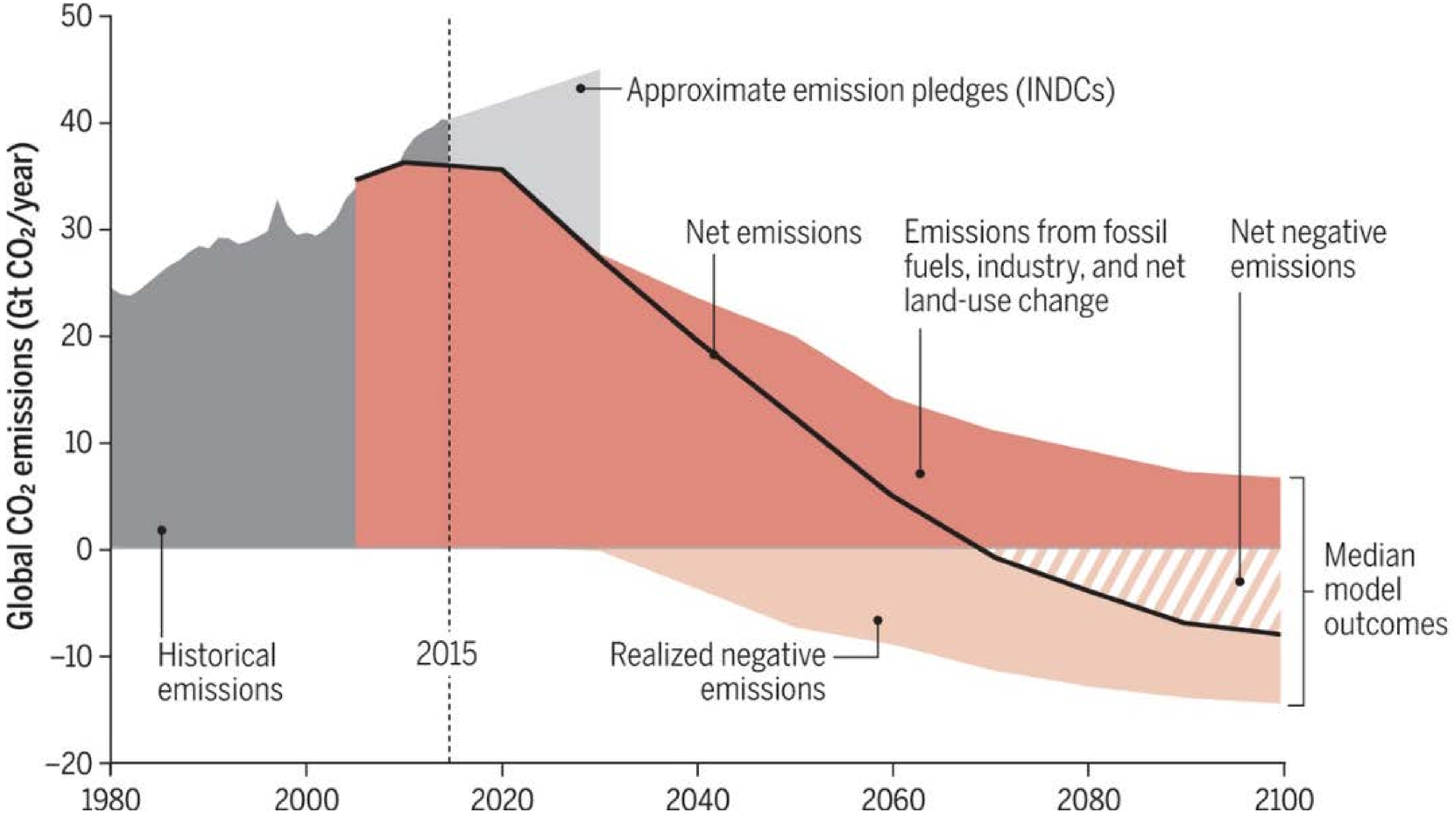
Source: RS & RAEng GGR Report, 2018

Many paths to 1.5°C…



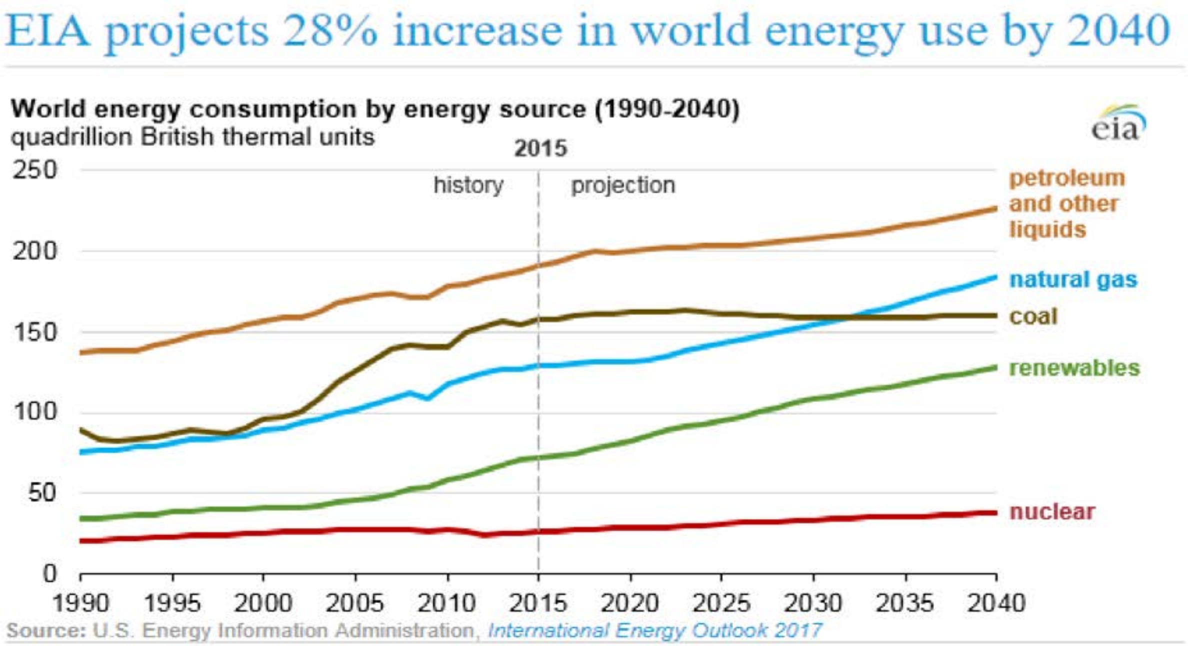
Source: IPCC, 2018, Global warming of 1.5°C

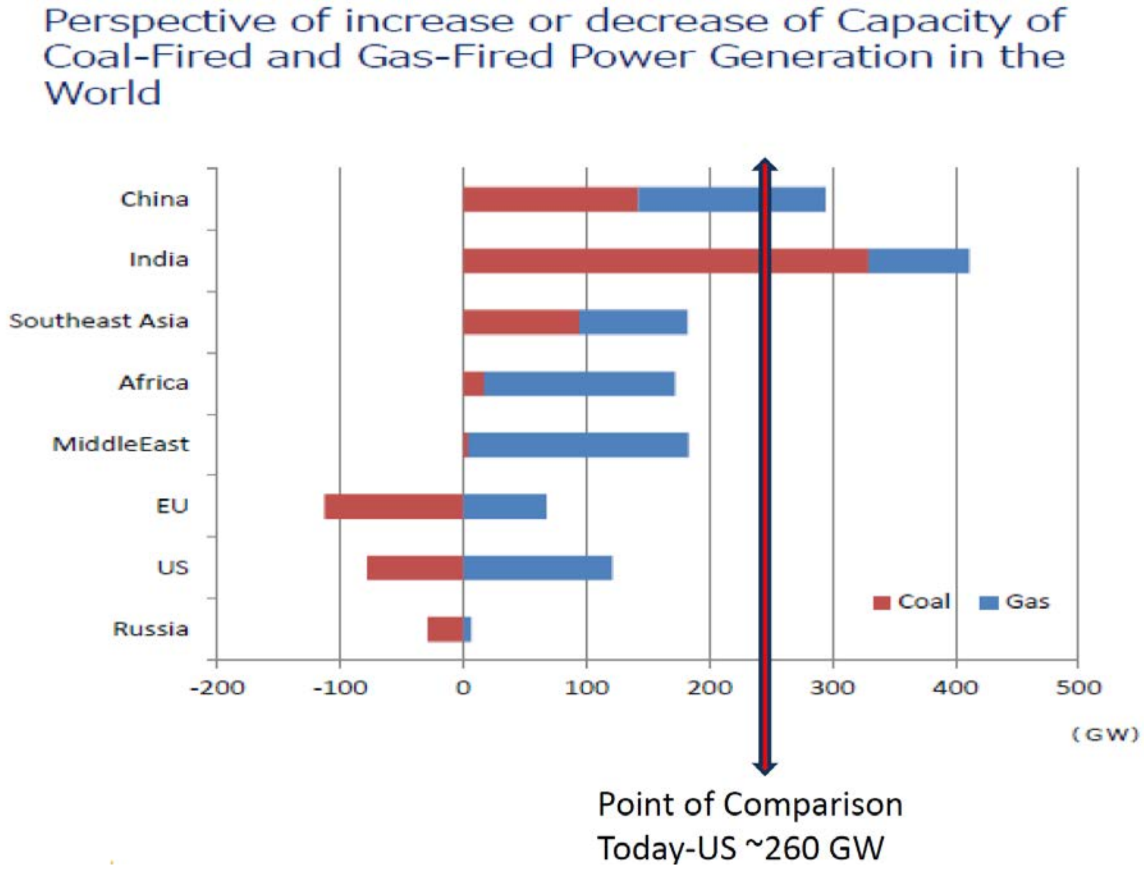
A gap between aspiration and commitment



Anderson and Peters, Science, 2016

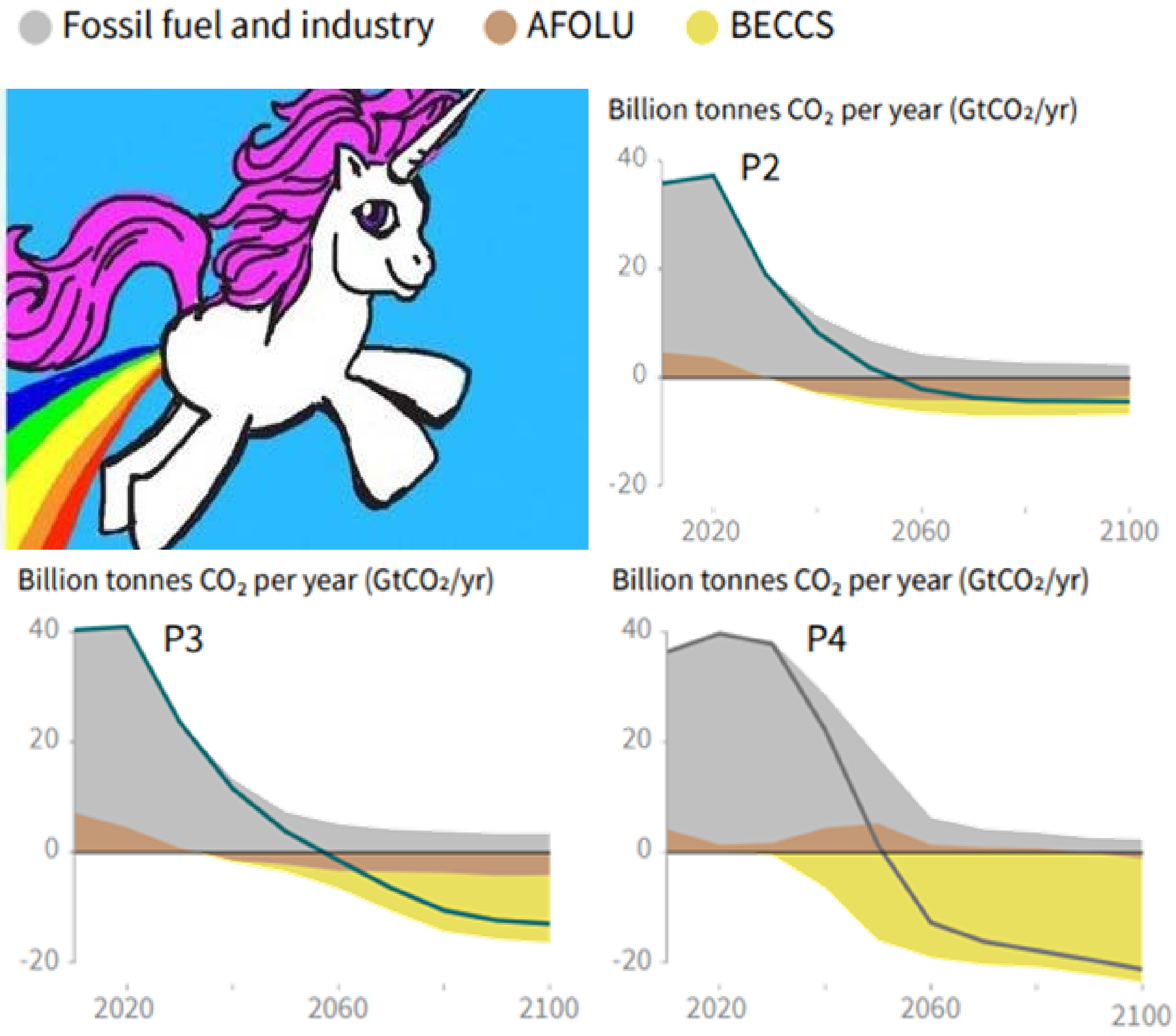
Where will we get our energy?





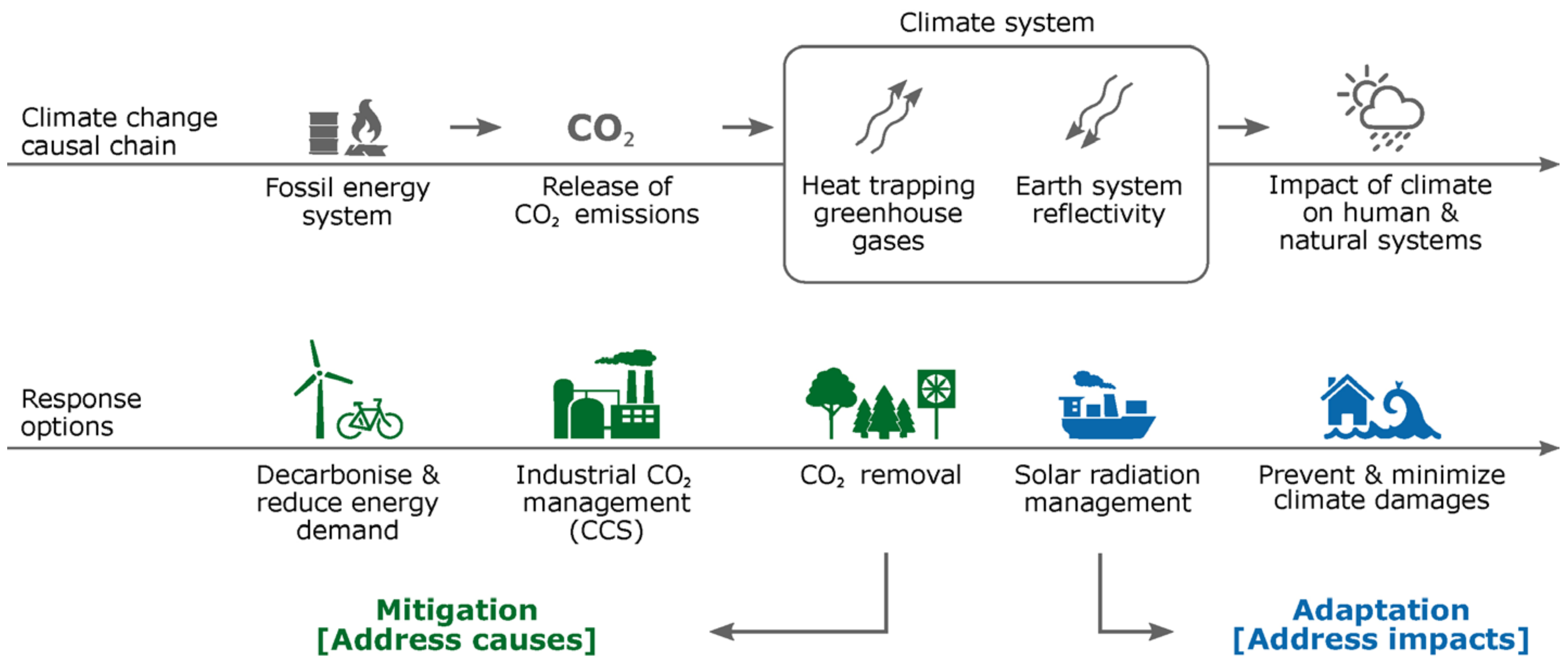
Source: US EIA, IEO, 2017, IEA, WEO, 2017, Lou Hrkman, US DOE, Update on US strategy for coal, 2019

Likely paths to 1.5^{o}C…



Source: IPCC, 2018, Global warming of 1.5°C

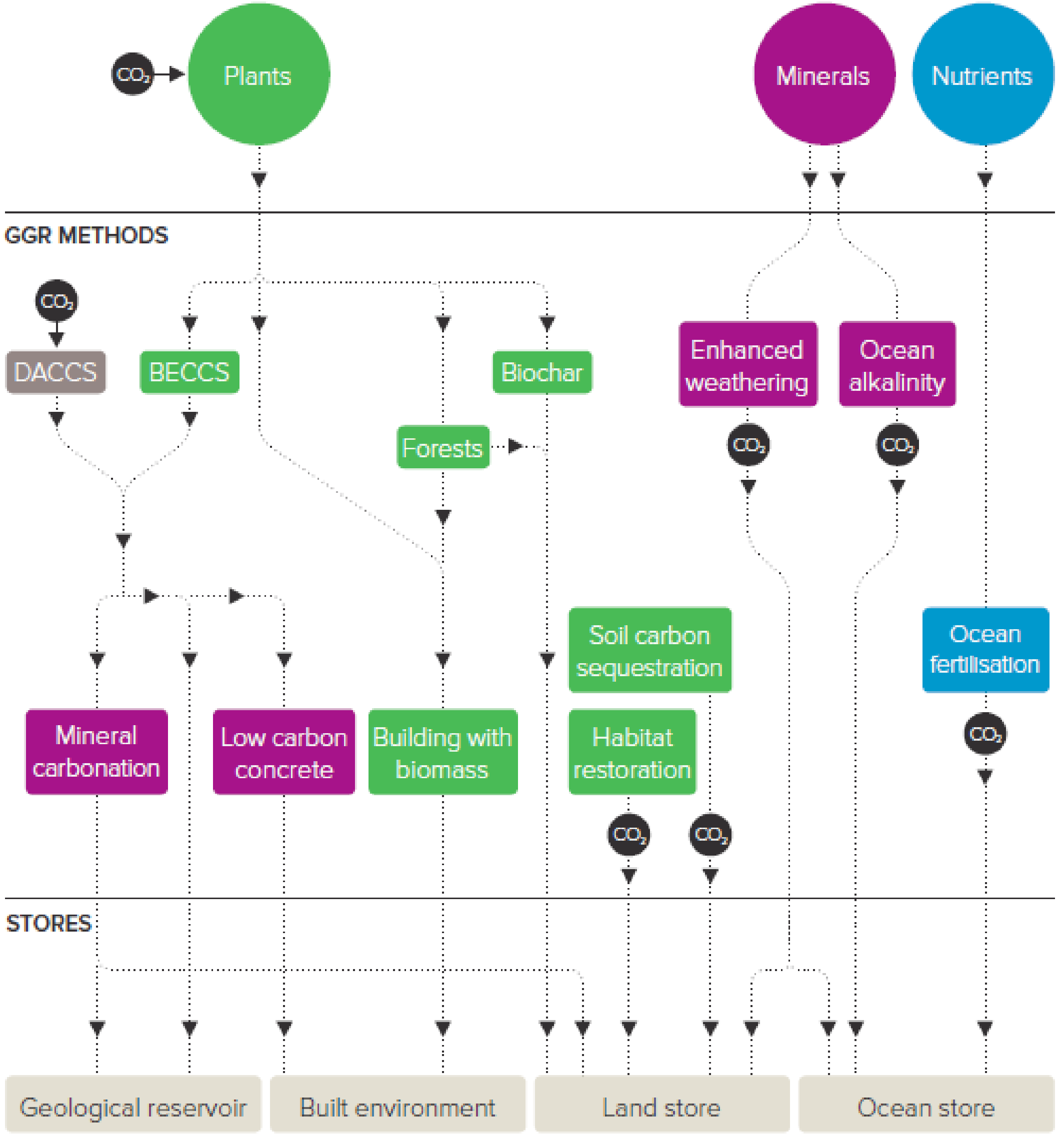
GGR as an alternative to mitigation?



- GGR is part of a portfolio of options, including mitigation and adaptation
- GGR is not an alternative to mitigation

Image from Minx *et al*, Environ. Res. Lett., 2018

A portfolio of GGR options



Source: RS & RAEng GGR Report, 2018

A portfolio of GGR options

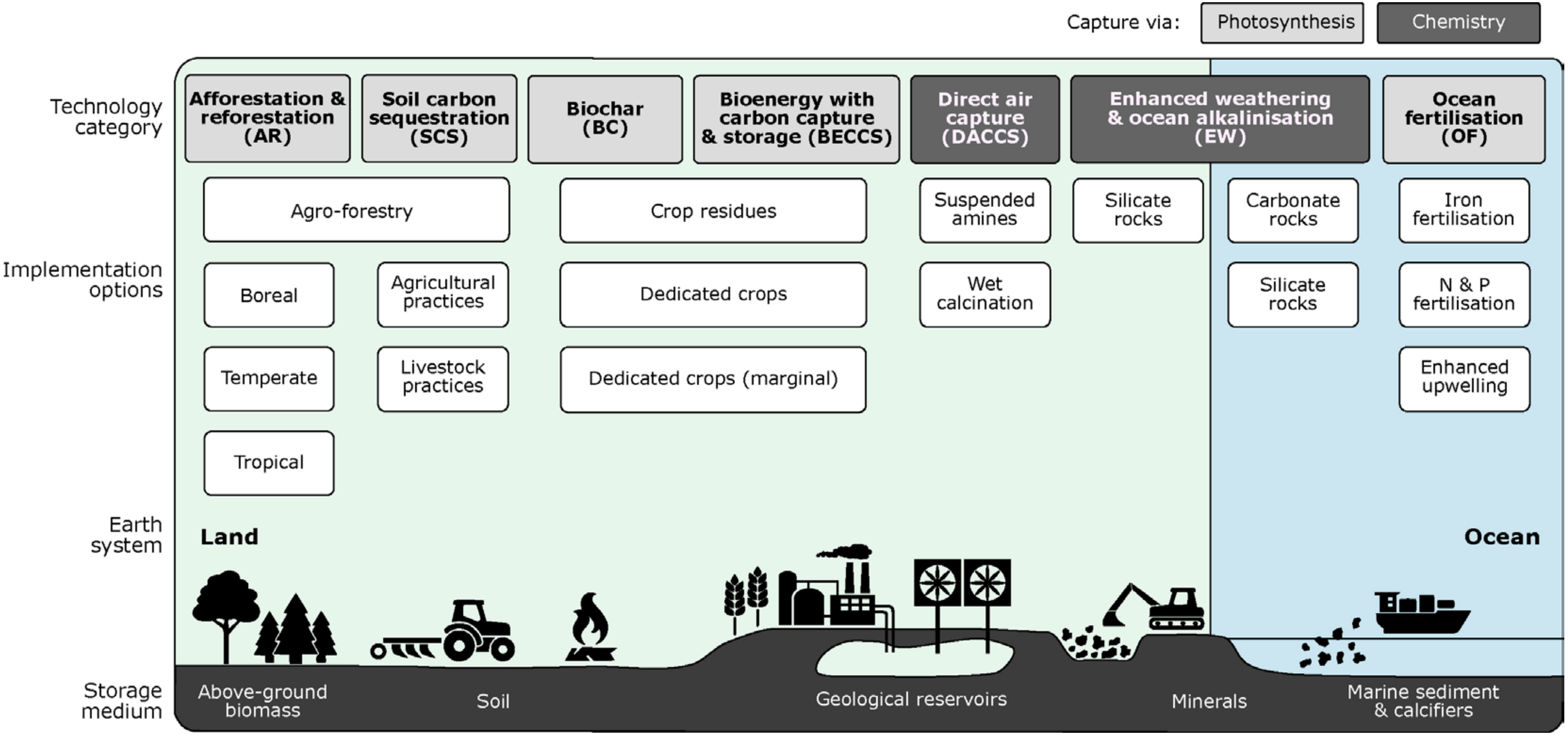
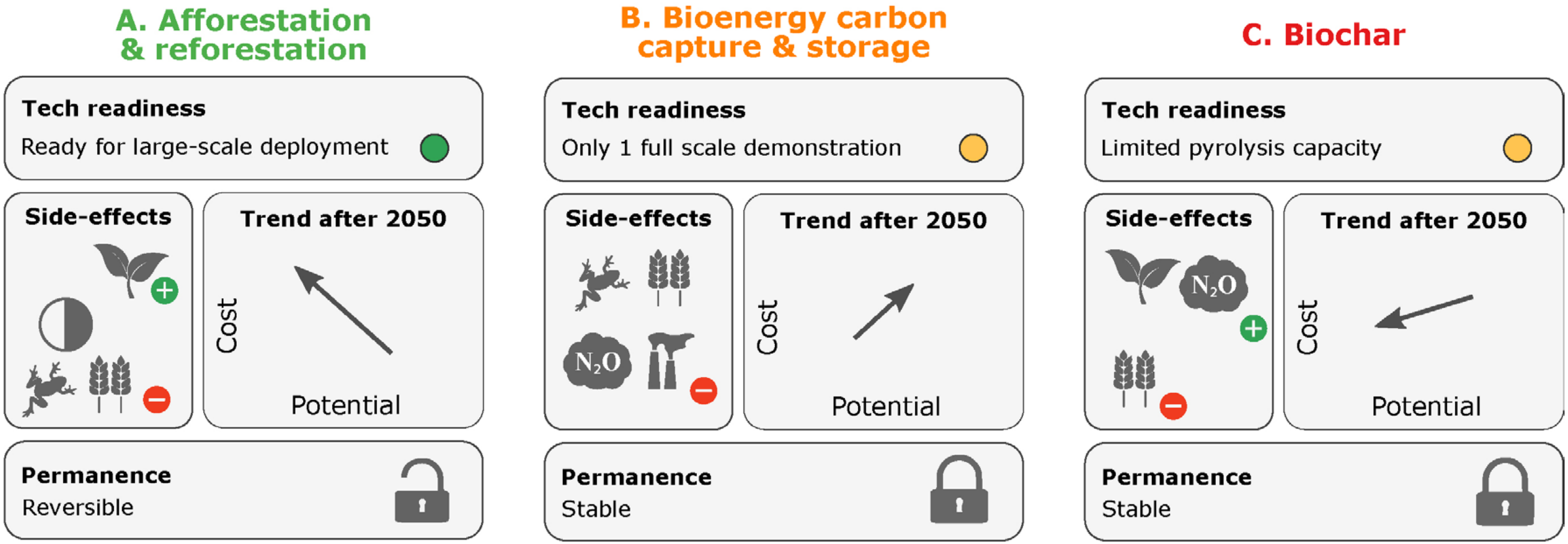


Image from Minx *et al*, Environ. Res. Lett., 2018

A portfolio of GGR options



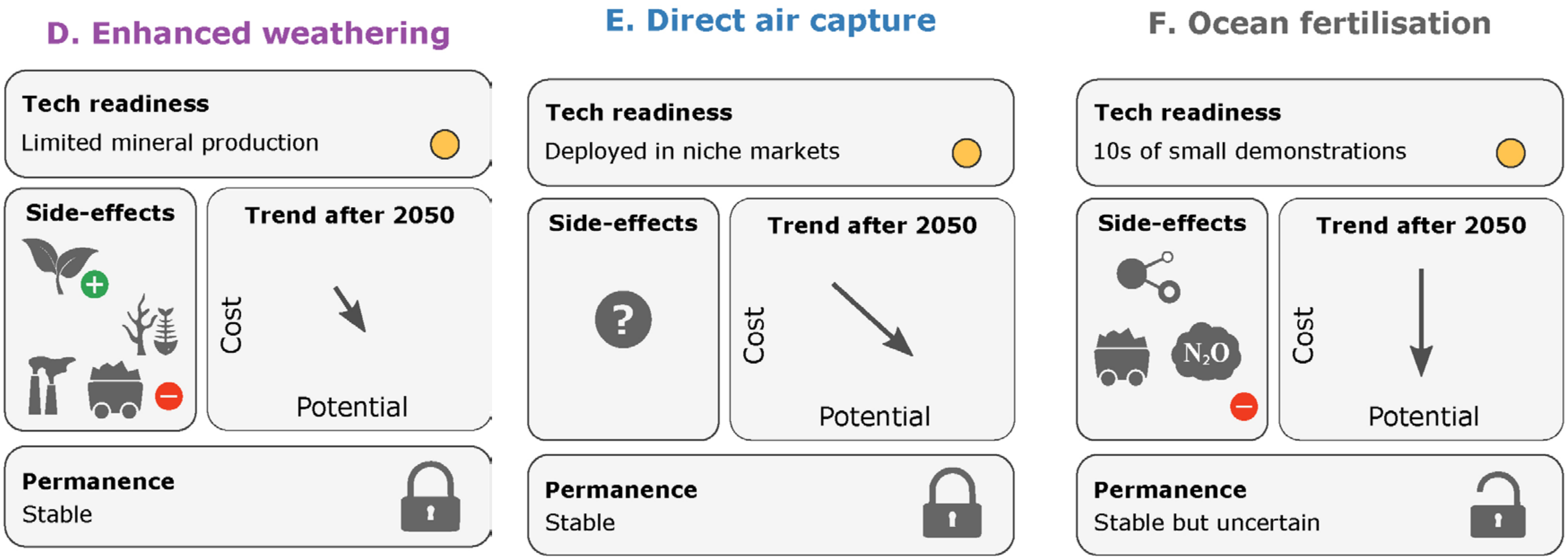
Cost: \$0 – 240/t_{CO2}

Cost: \$15 – 400/t_{CO2}

Cost: \$10 – 345/t_{CO2}

Data from Minx *et al*, Environ. Res. Lett., 2018

Portfolio of NETs



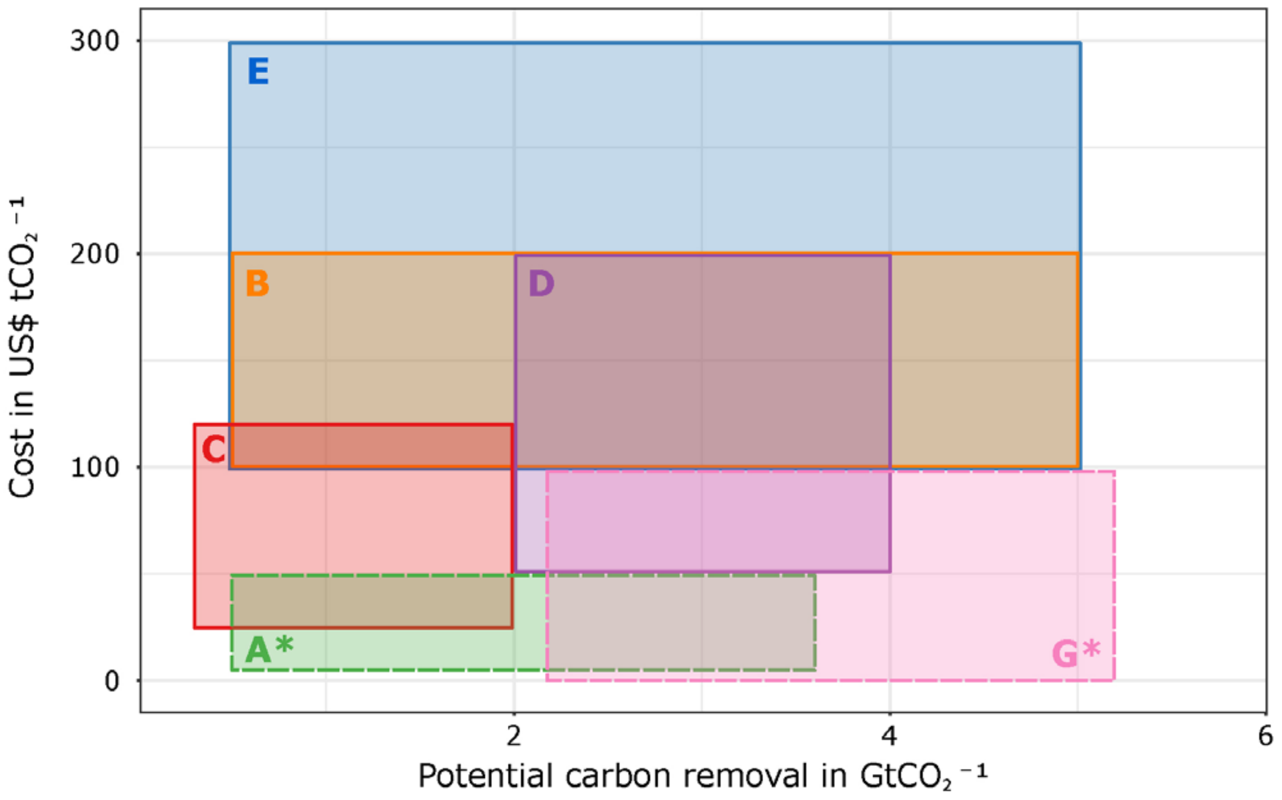
Cost: \$5 – 3460/t_{CO2}

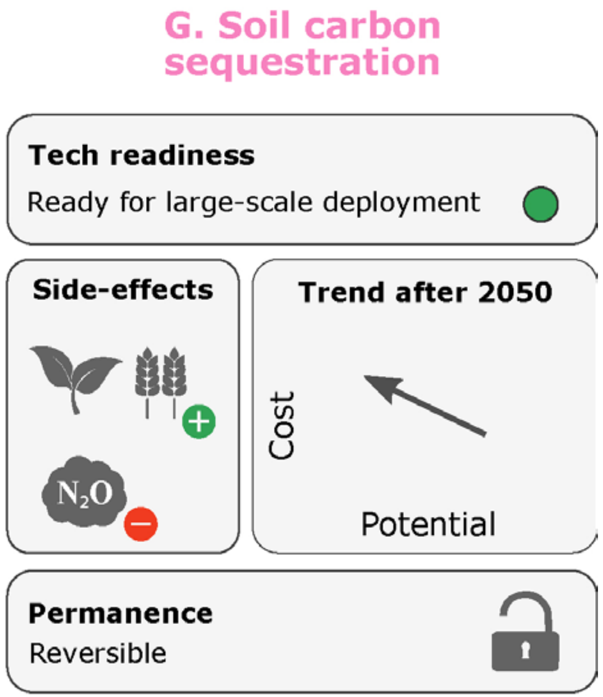
Cost: \$25 – 1,000/t_{CO2}

Cost: \$0 – 460/t_{CO2}

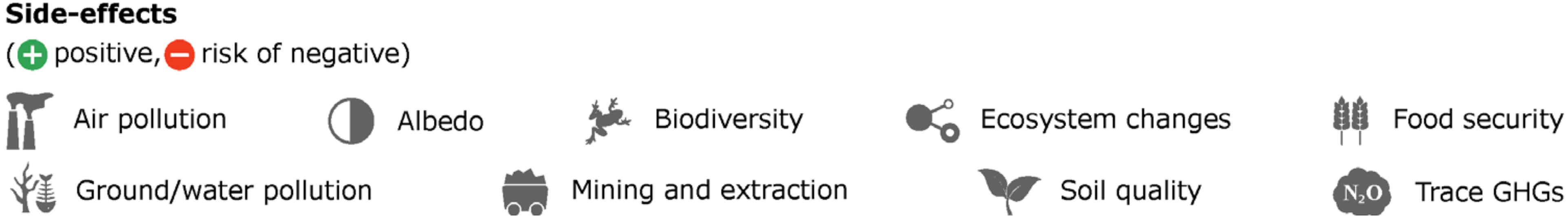
Data from Minx *et al*, Environ. Res. Lett., 2018

Portfolio of NETs



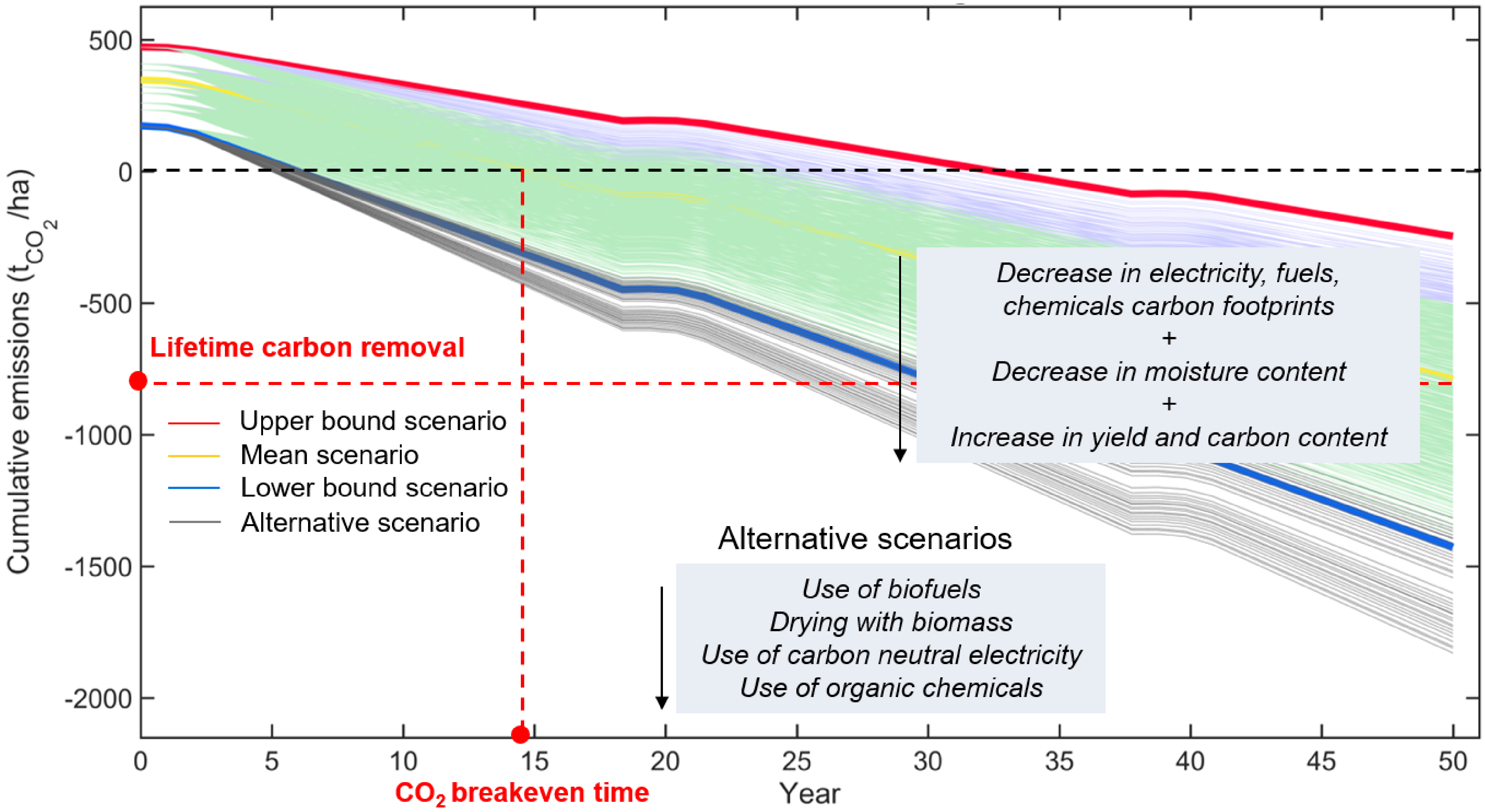


Cost: $-45 – 100/t_{CO2}$



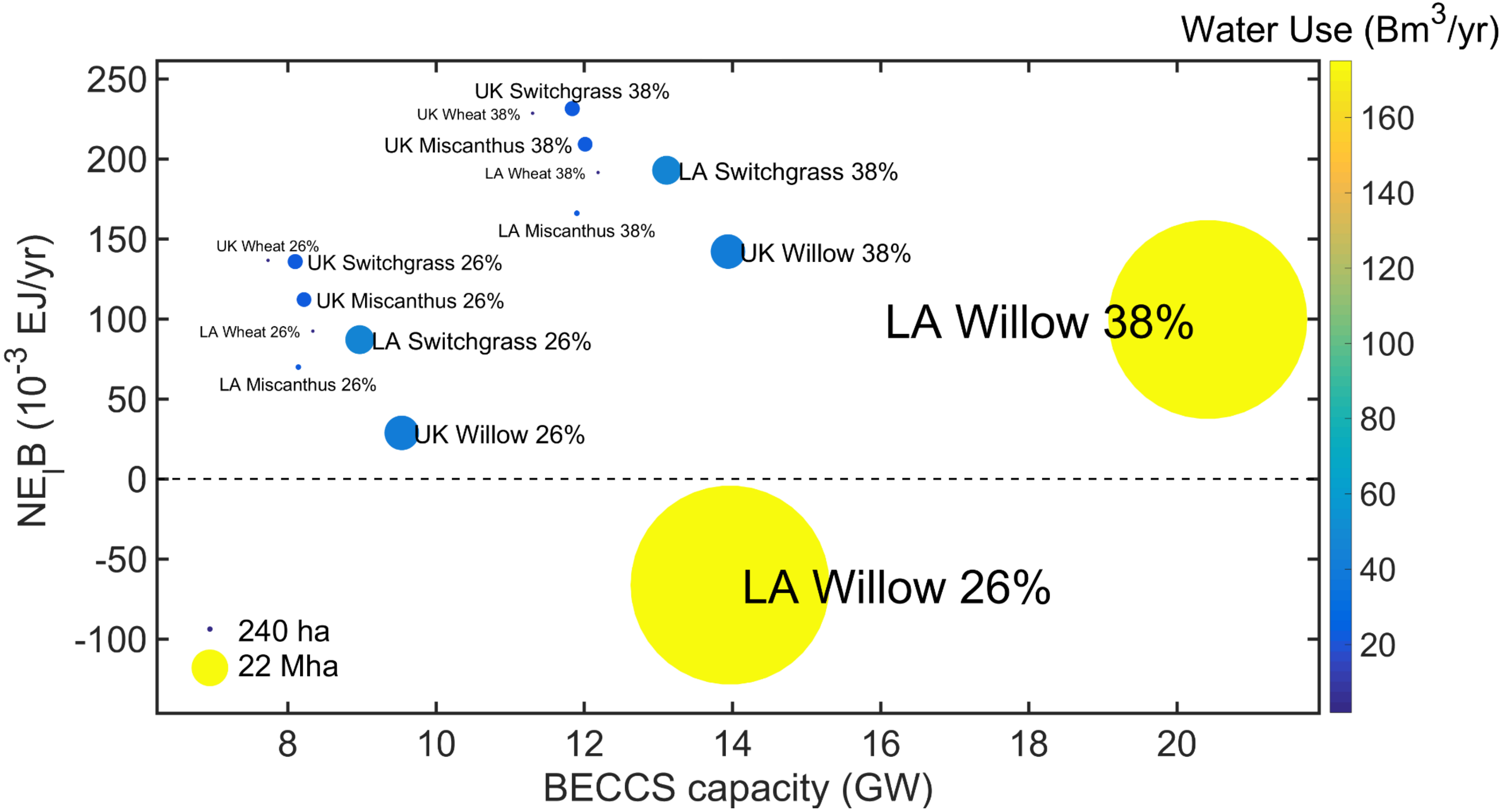
Data from Minx *et al*, Environ. Res. Lett., 2018

Does BECCS work?



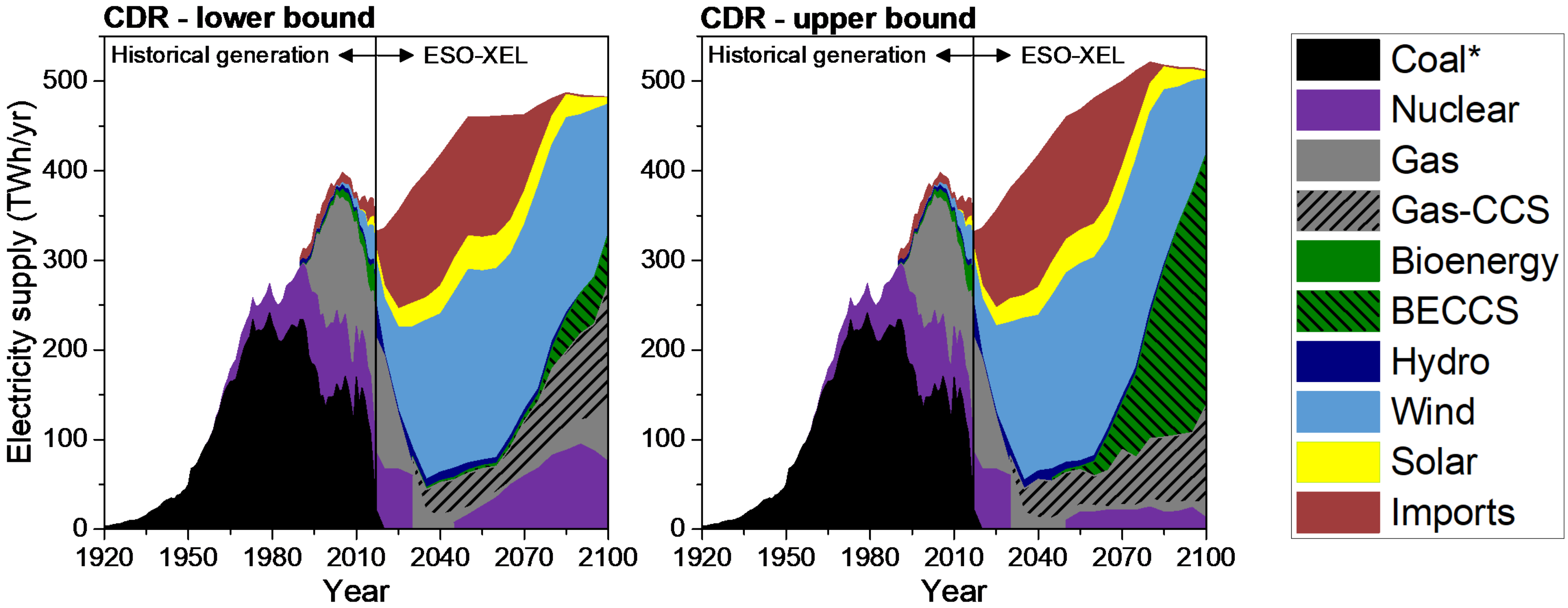
Sources: Fajardy M. and Mac Dowell N., Energy and Environmental Science (2017); Fajardy M. and Mac Dowell N., Energy and Environmental Science (2018)

Does BECCS generate power?



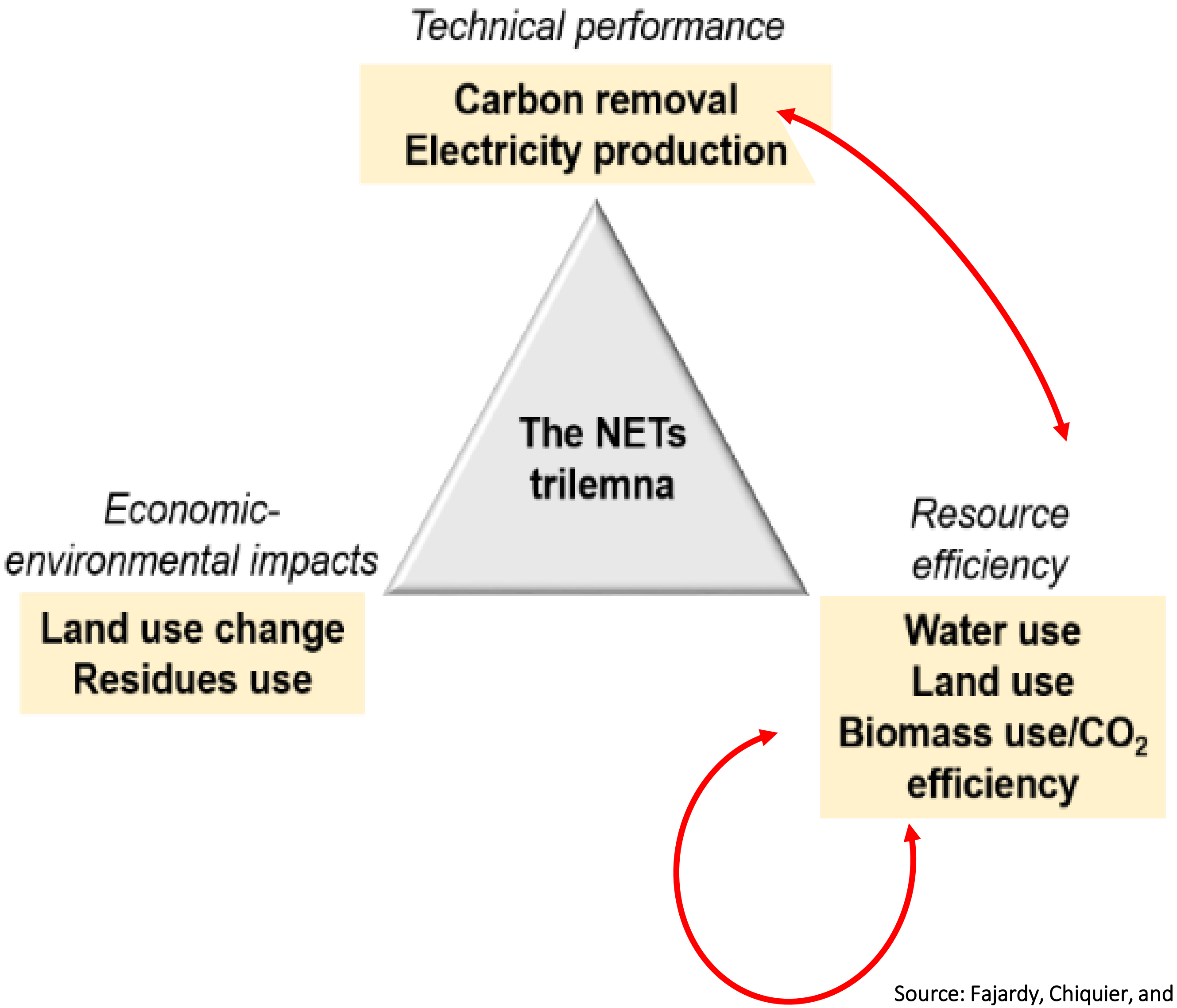
Source: Fajardy and Mac Dowell, Energy and Environmental Science, 2017

Low carbon vs. carbon negative energy systems



Source: Daggash and Mac Dowell, Joule, 2019

Trade-offs within the land-water-carbon-energy nexus

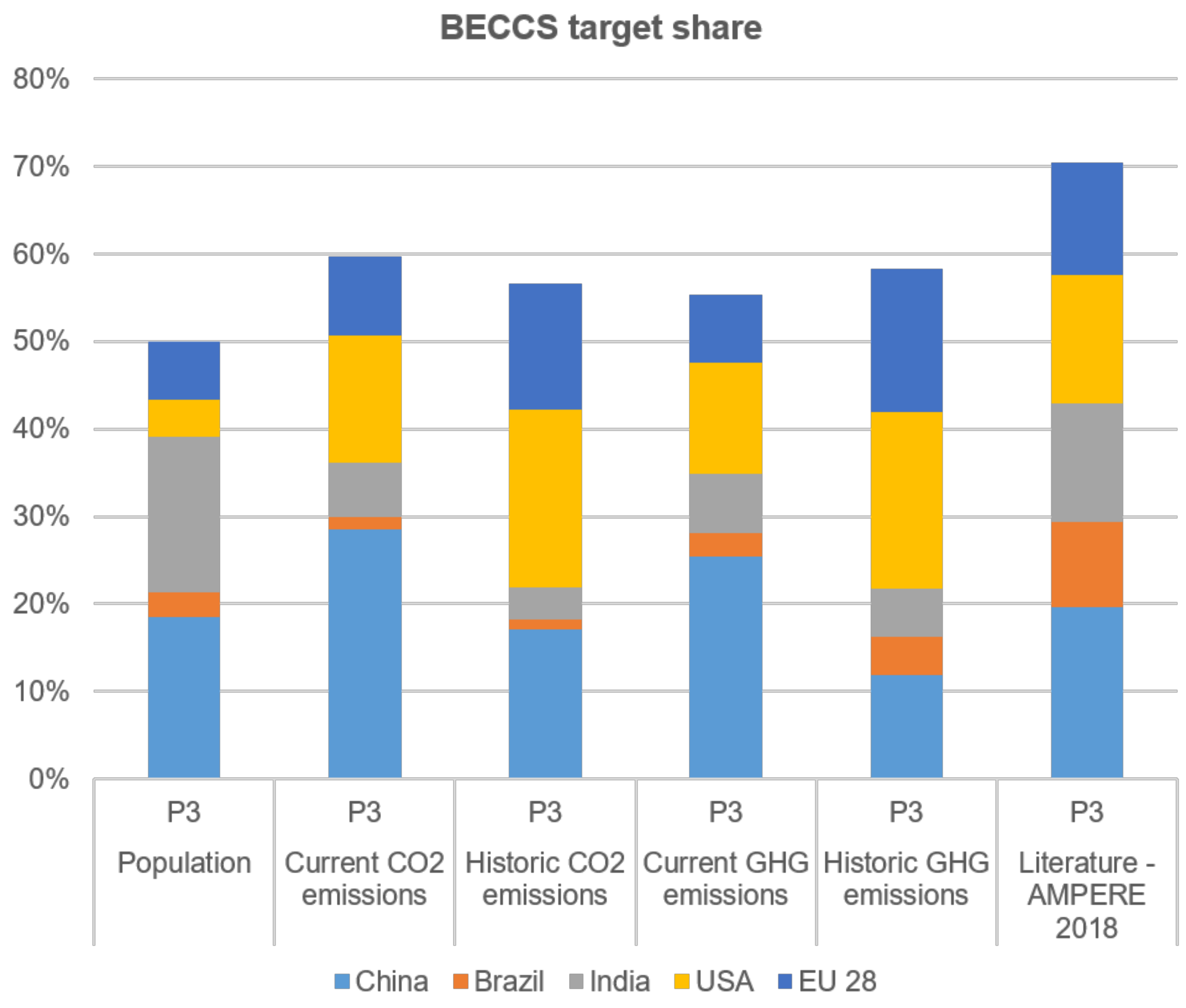


Source: Fajardy, Chiquier, and Mac Dowell, Energy and Environmental Science, 2018

Who has to do what..?

$$target(i) = Gtarget.\frac{x(i)}{\sum_{world} x(i)}$$

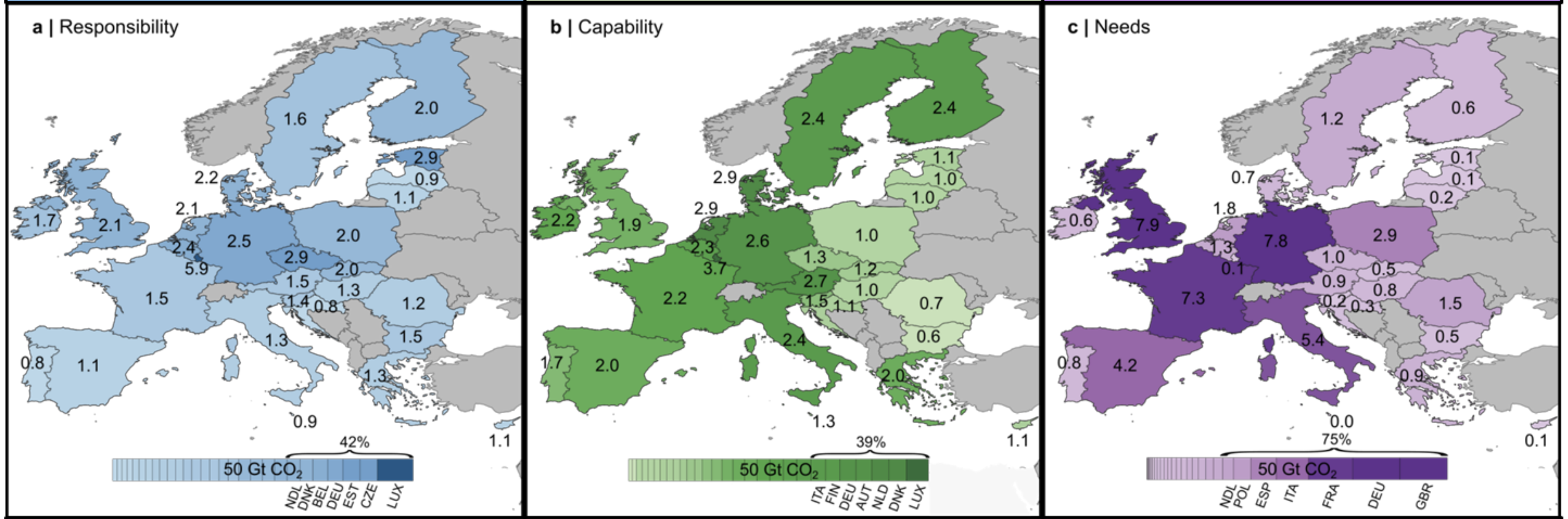
- **Equity**: x(i) = population in 2014
- **Responsibility** – current CO_2 emissions: x(i) = CO_2 emissions in 2014
- **Responsibility** – historical CO_2 emissions: x(i)= cumulative CO_2 emissions 1975-2014
- **Responsibility** – current GHG emissions: x(i) = GHG emissions in 2014
- **Responsibility** – historical GHG emissions: x(i) = cumulative GHG emissions 1850-2014



What might this look like at the national level?

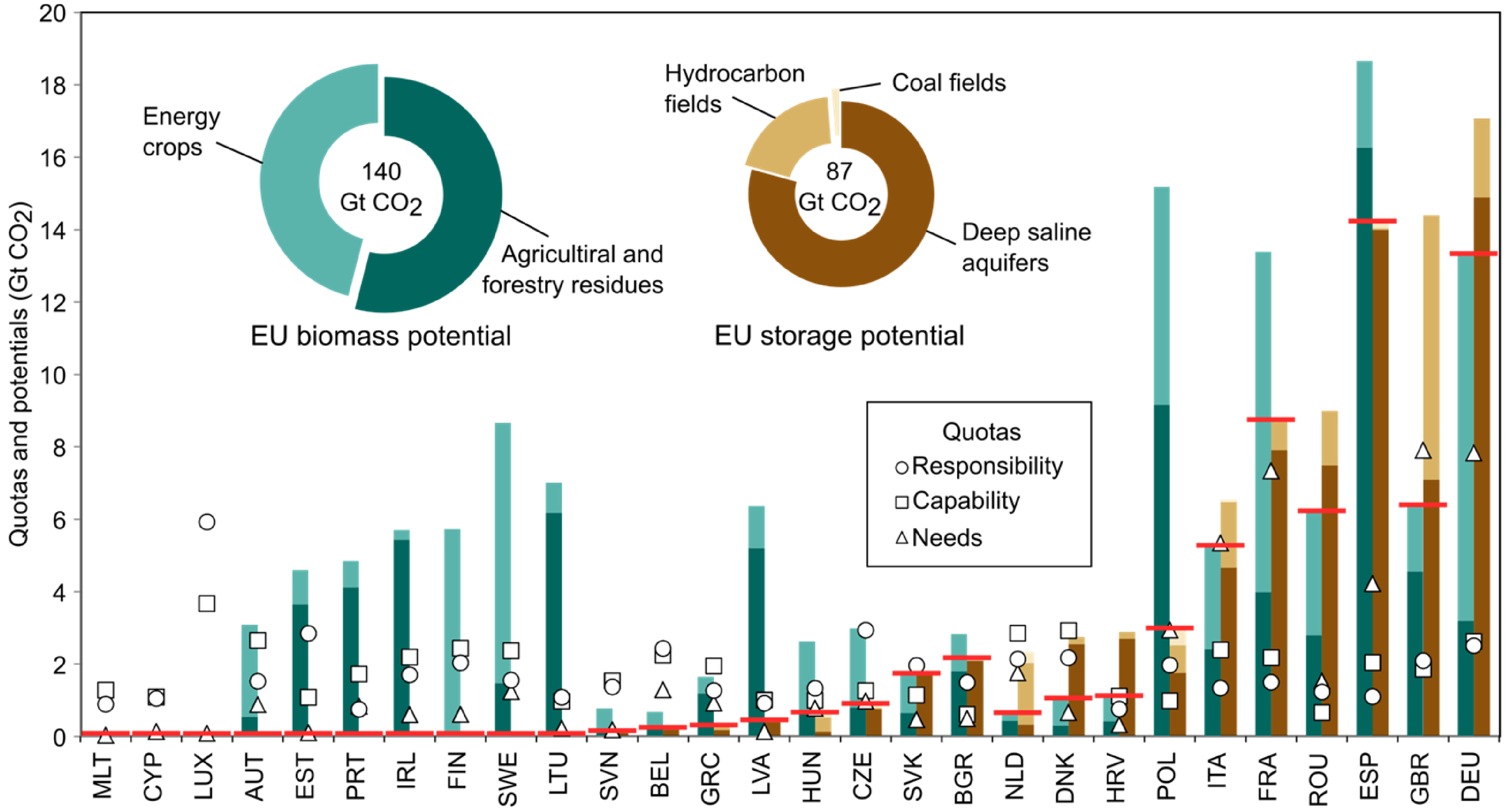
- Responsibility: per-capita historical (1960-2017) CO_2 emissions
- Capacity: per-capita GDP
- Needs: country population

Responsibility	***Capacity***	***Needs***

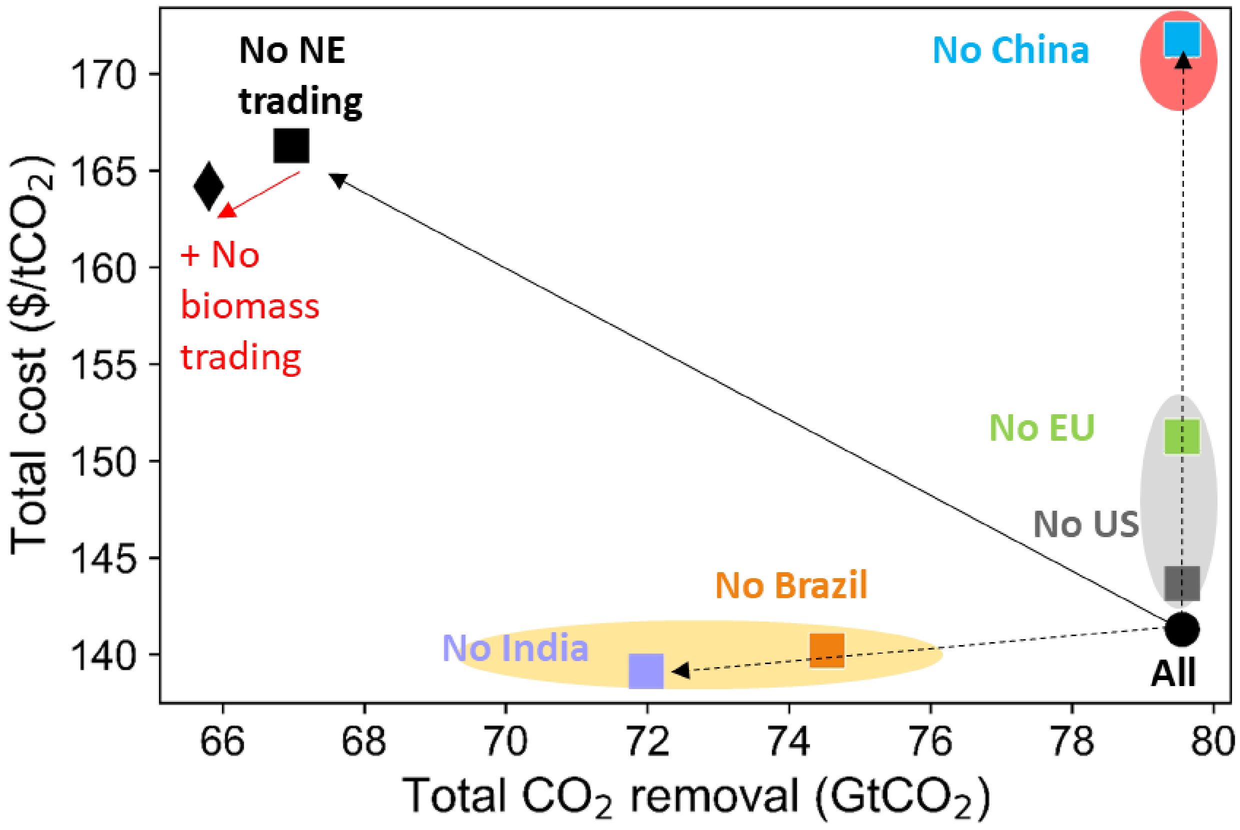


High mitigation for countries with high historical per capita emissions	High mitigation for countries with high GDP per capita	Every individual has an equal right to be protected from pollution

Limited potential for individual action

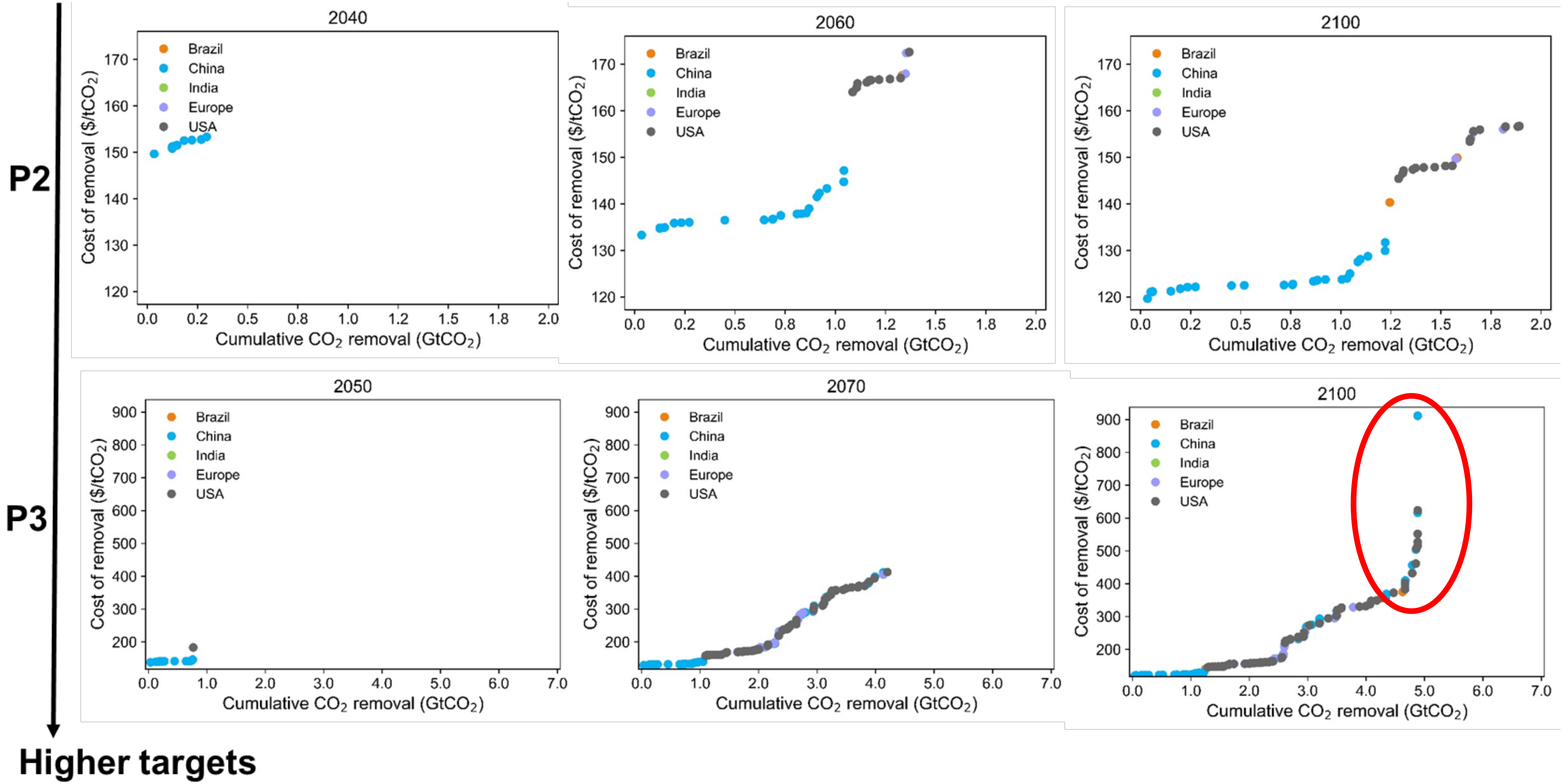


The value of cooperation

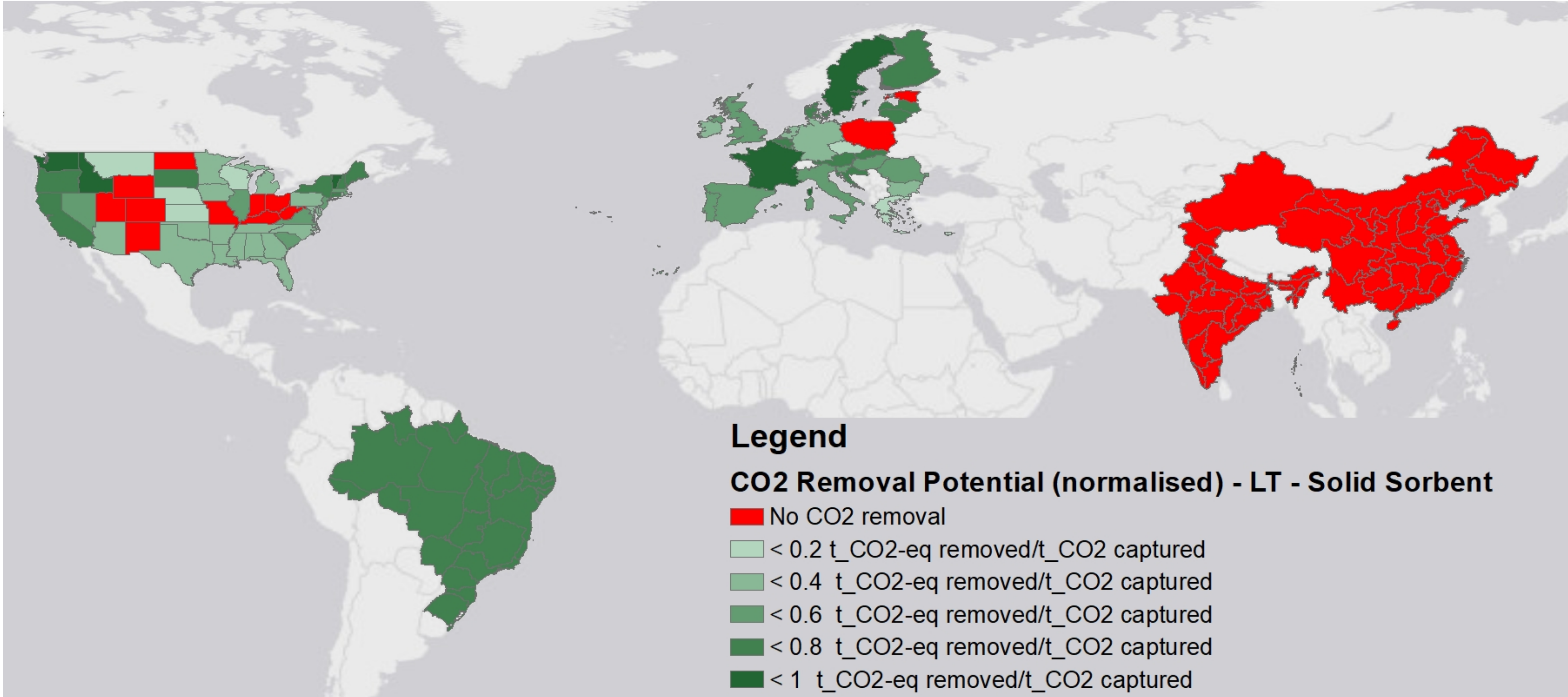


- Different players bring different values :
  - **'Independent providers'** (*e.g*. China): regions with good storage availability, low cost and low carbon biomass close to storage sites >> **much higher cost if excluded** as they can no longer provide surplus for other regions
  - **'Independent beneficiaries'** (*e.g.* EU and US): region with good storage and biomass availability but higher cost >> **higher cost if excluded** as they have to fulfil their own targets
  - **'Dependent beneficiaries'** (*e.g*. Brazil and India) : unable to meet their own targets due to lack of storage >> **unmet CO_2 removal target** if excluded

BECCS supply curve



A role for alternatives: Direct Air Capture (DAC)



Different options, different challenges

	BECCS	DACS	AR/RE	Biochar	EW
Regional constraint(s)	• CO_2 storage capacity • Biomass feedstock • Accessible and available land • Water	• CO_2 storage capacity • Low carbon energy	• Productive and available land • Water • Albedo effect	• Biomass feedstock • Accessible land (may be combined with other uses)	• Accessible land (may be combined with other uses) • Availability of minerals
CO_2 accounting and monitoring	• Cross border supply chain emissions • Delayed CO_2 removal • CO_2 stored permanently	• Immediate CO_2 removal • CO_2 stored permanently	• Immediate CO_2 removal • Permanence subject to monitoring • Sink saturation	• Delayed CO_2 removal • Permanence subject to monitoring • Sink saturation	• Immediate CO_2 removal • Sink saturation
Regional variability of performance	• Yield, water requirement, sustainable biomass availability	• Cost • Carbon footprint of energy	• Growth rate • Risk of releasing CO_2	• CO_2 uptake	

Research and innovation challenges

- NETs and GGR are still nascent
- Many remaining research challenges
  - Technology demonstration and price discovery is a work in progress
  - For BECCS,
    - We need to properly understand the value of the co-products
    - Is bioelectricity the best use of the biomass? Heat? Power? Mobility? H_2?
  - Scalability, permanence of CO_2 removal, and broader sustainability
  - Social license and political economy, in particular, remain unclear
  - How will different countries, and regions, collaborate for optimal deployment?
  - How will NETs/GGR be incentivised, monitored, and regulated?