GGR and 1.5^{o}C

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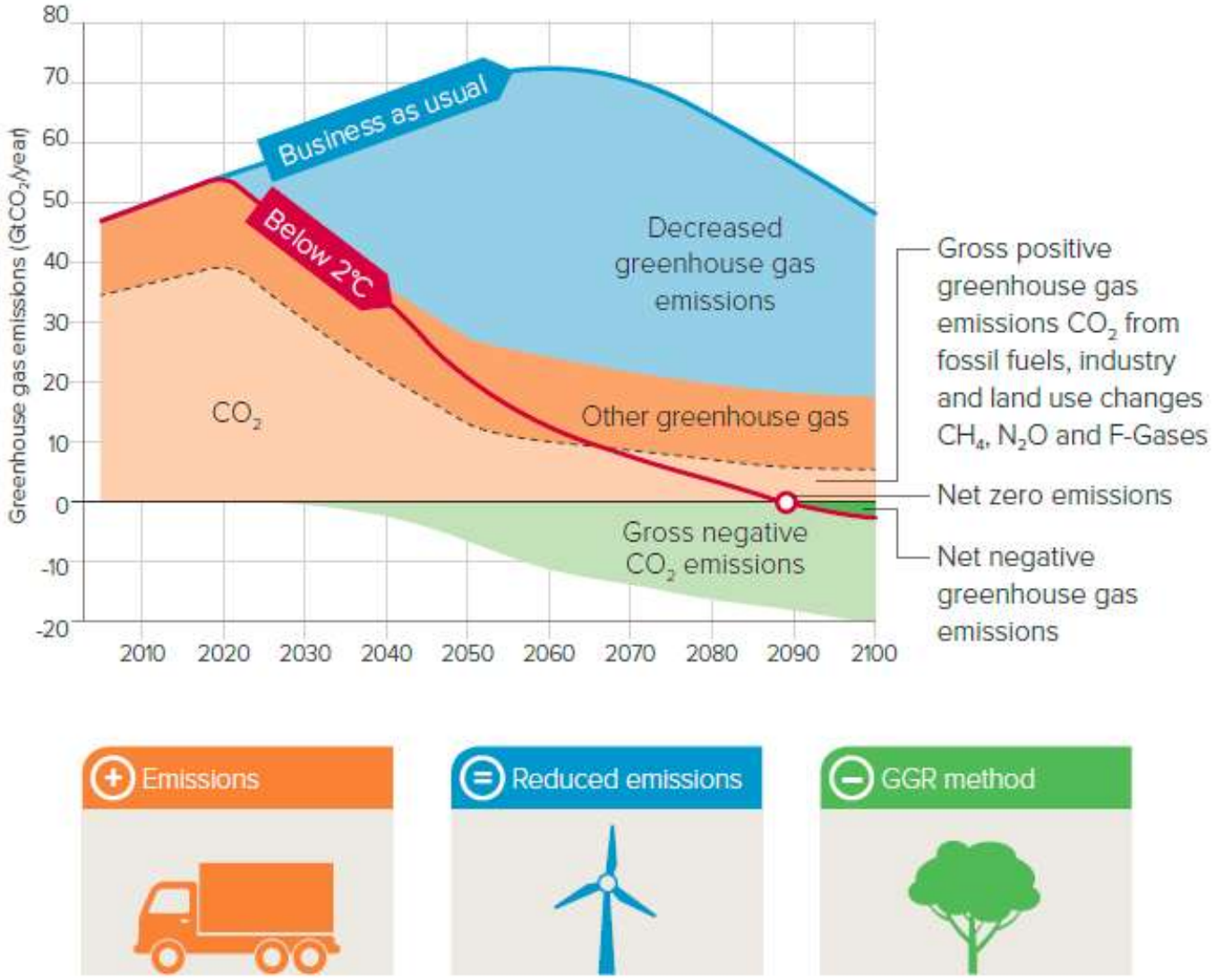
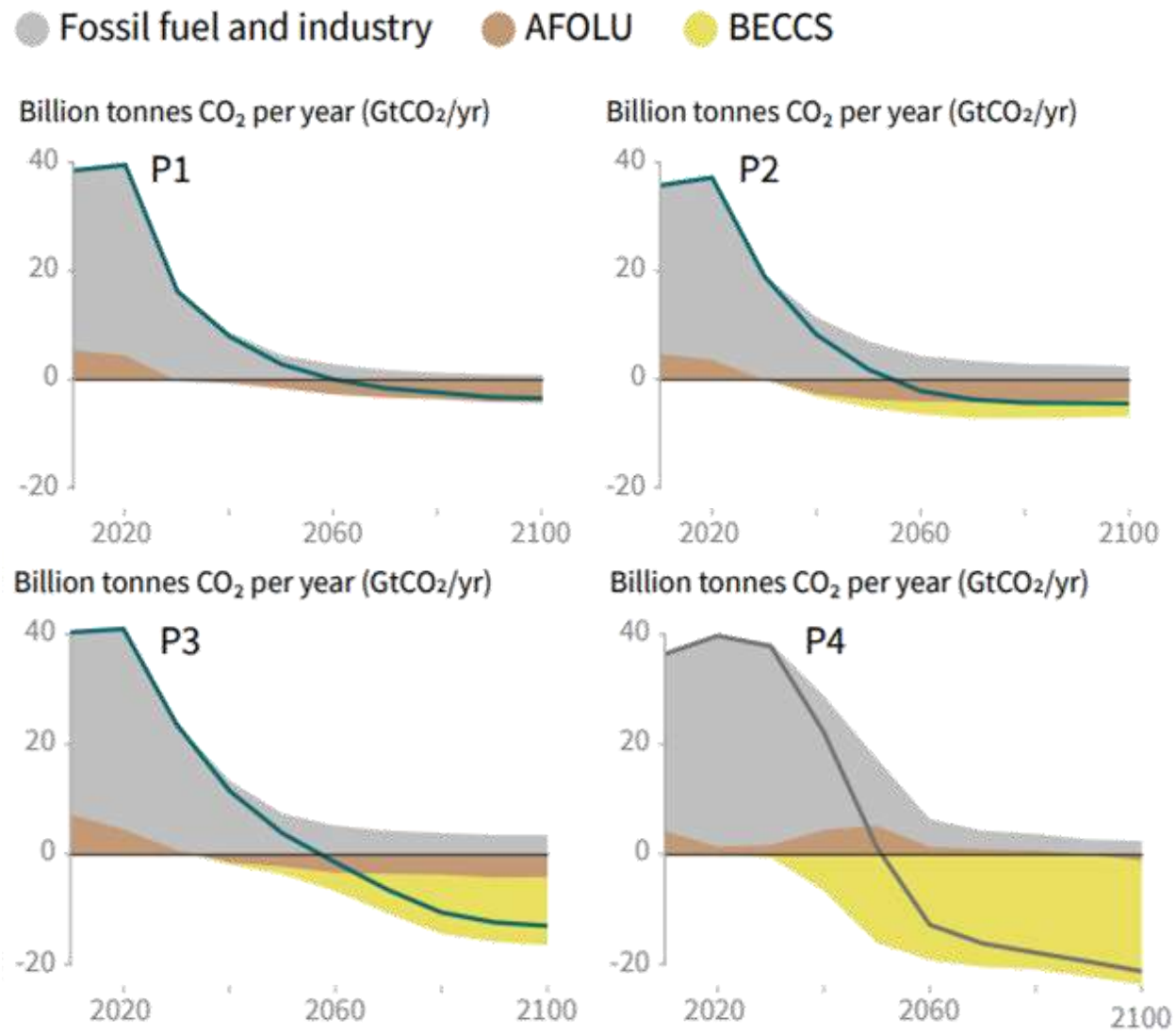
Paris changed everything…



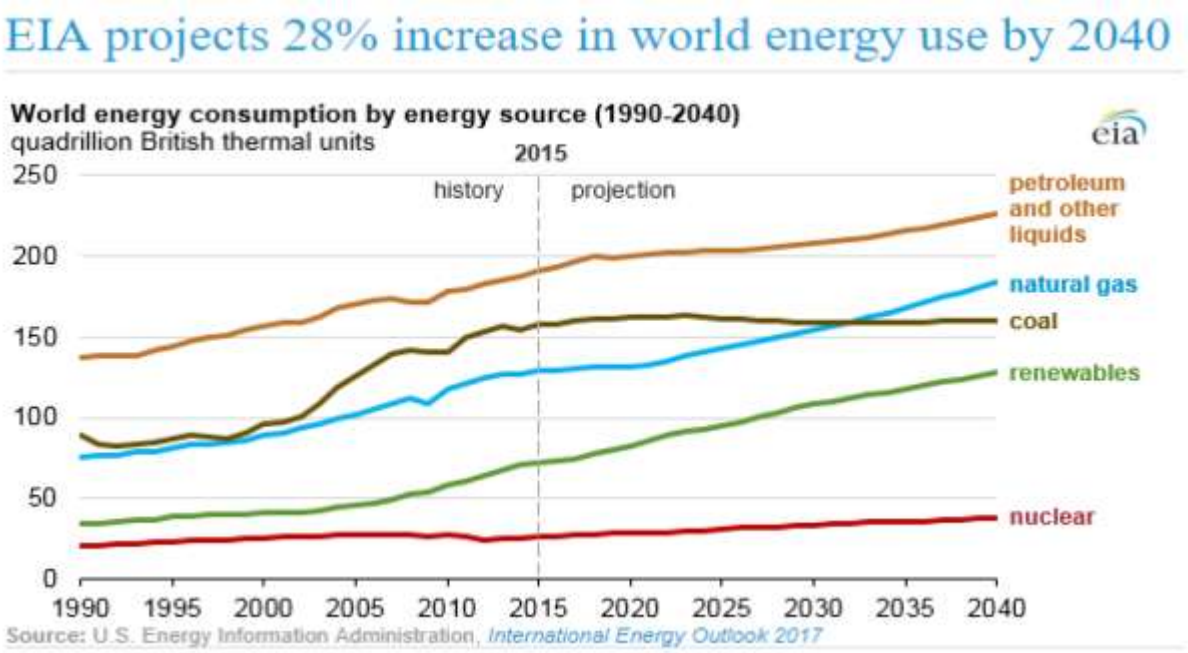
Source: RS & RAEng GGR Report, 2018

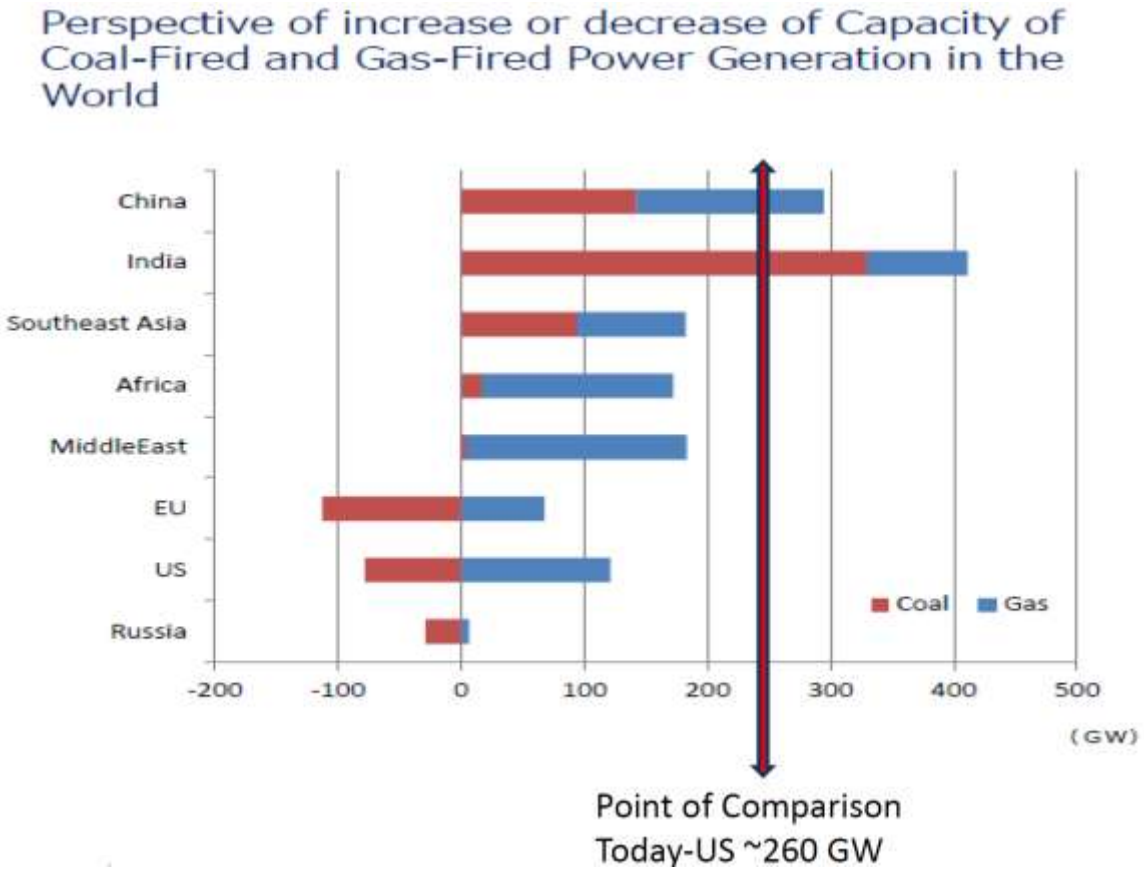
Many paths to 1.5°C…



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

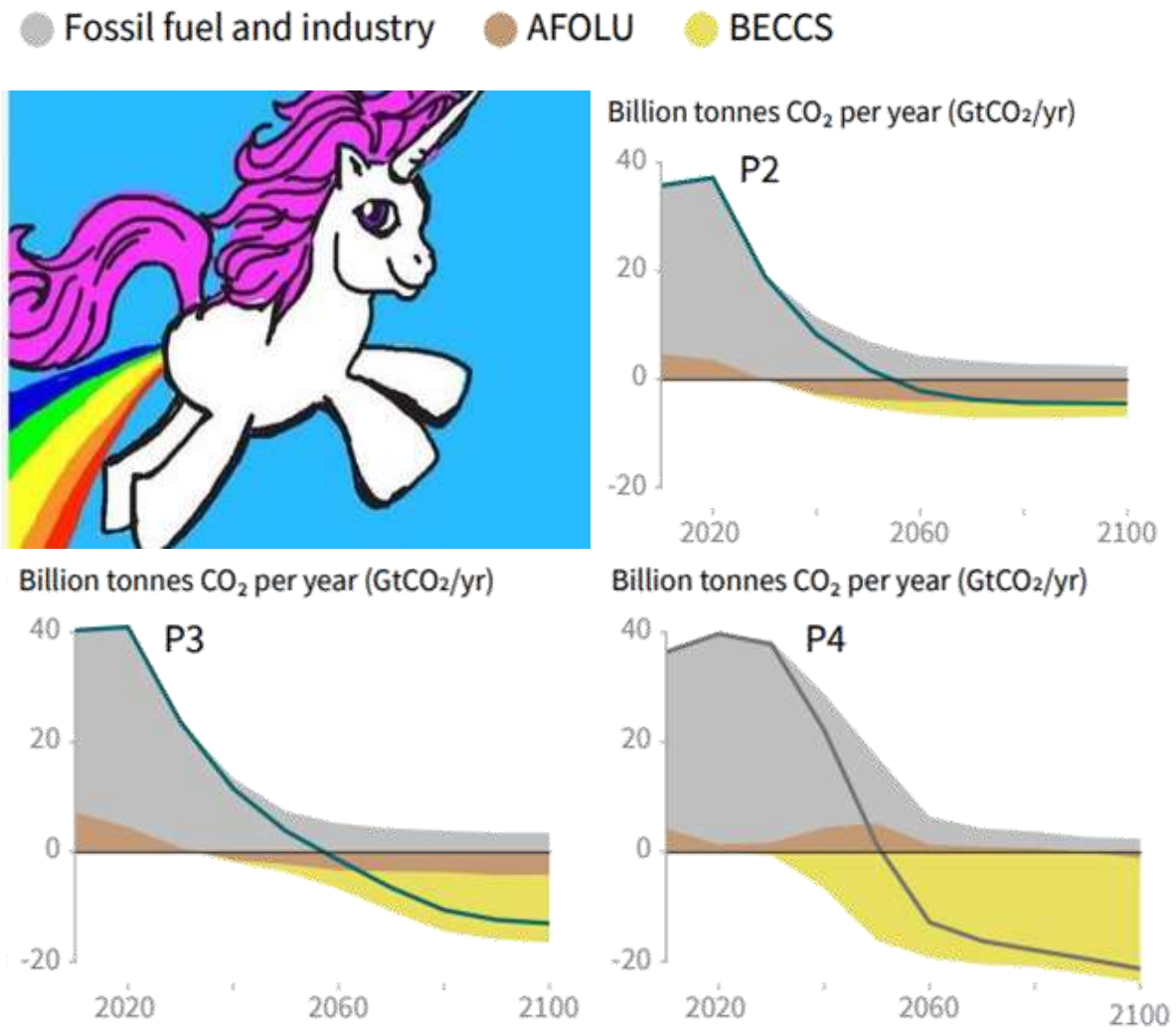
Where will we get our energy?





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

Likely paths to 1.5ºC…



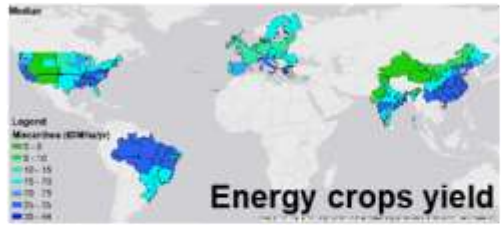
Source: IPCC, 2018, Global warming of 1.5°C

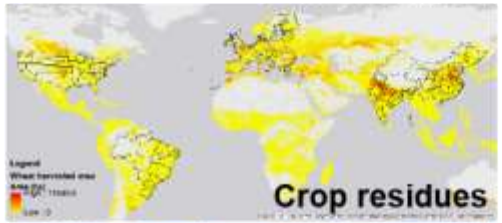
CCS and GGR are integral to the 1.5C target

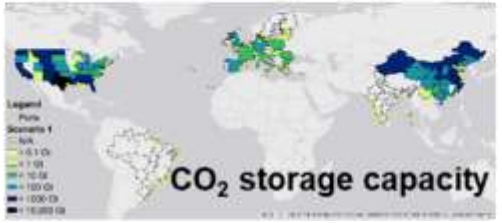
- Some key questions on BECCS
  - Does it “work”?
  - What does it “do”?
  - Who has to do what?
  - Can we go it alone?

The MONET framework

Input data



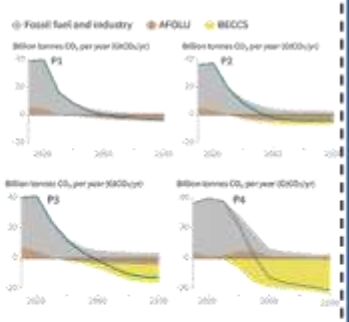




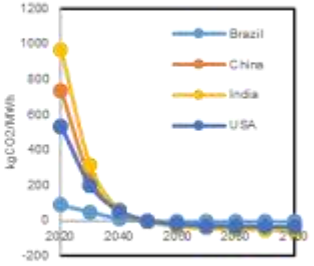
...

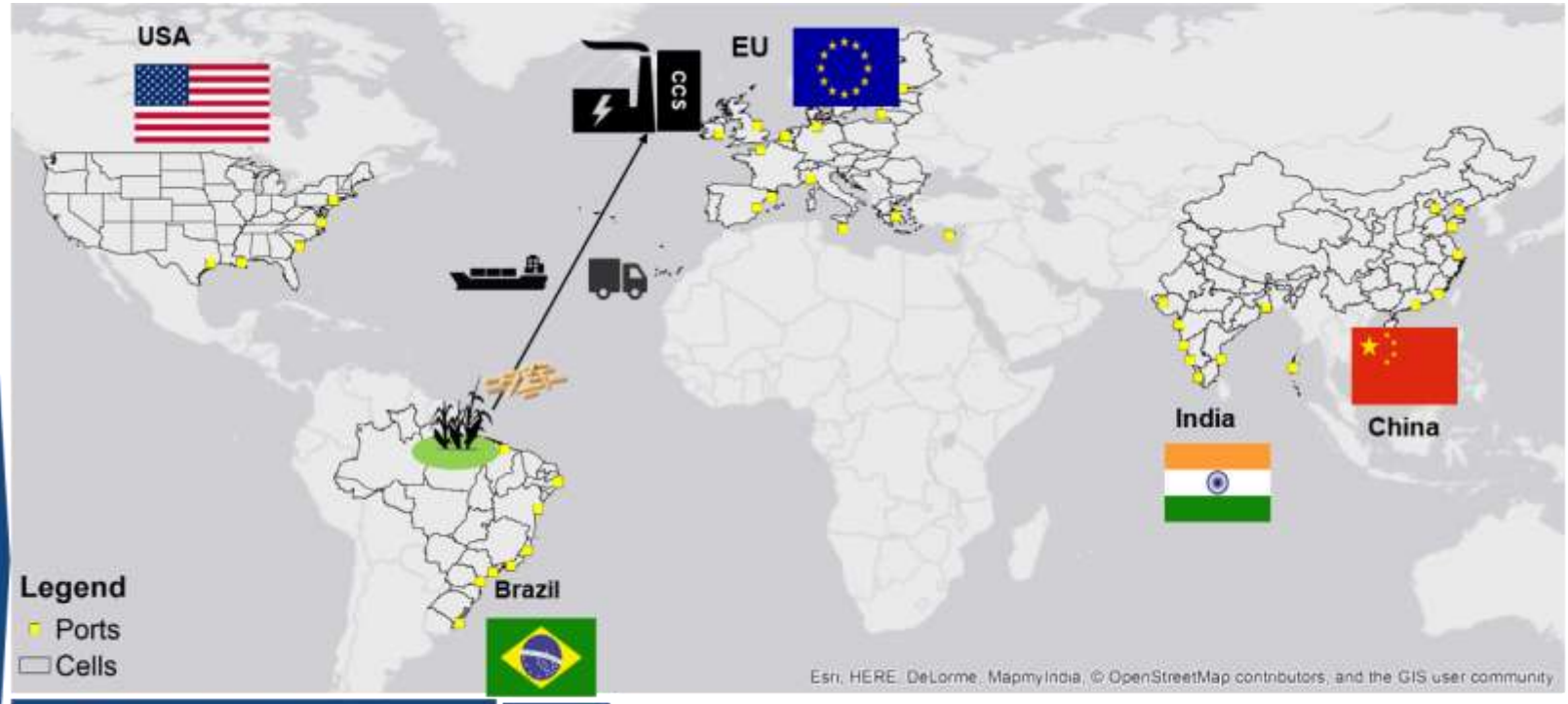
[2030, 2040,.. 2100]

CO_2 removal target



Carbon intensity of electricity and fuels





Supply chain model

$sr \in \{UK, Illinois, Sao\ Paulo \ldots\}$

$b \in \{Miscanthus, Switchgrass, Willow, Wheat\ straw\}$

$l \in \{Cropland, Marginal\ land, Grassland, Forest\}$

$p \in \{Hull, New\ York, Sao\ Paulo \ldots\}$

$sr\_ \in \{UK, USA, China, Brazil\}$

$yr = 1..50$

Optimisation program

Objective: $\min \sum_{sr,sr_b,time} WaterUse(sr,sr',b,time)$

Or $\min \sum_{sr,sr_b,l,p,time} LandUse(sr,sr',b,l,time)$

Or $\max \sum_{sr,sr_b,l,p,time} CO_2efficiency(sr,sr',b,l,time)$

Or $\max \sum_{sr,sr_b,l,p,time} NetEnergy(sr,sr',b,l,time)$

Or $\min \sum_{sr,sr_b,l,p,time} Cost(sr,sr',b,l,time)$

Subject to:

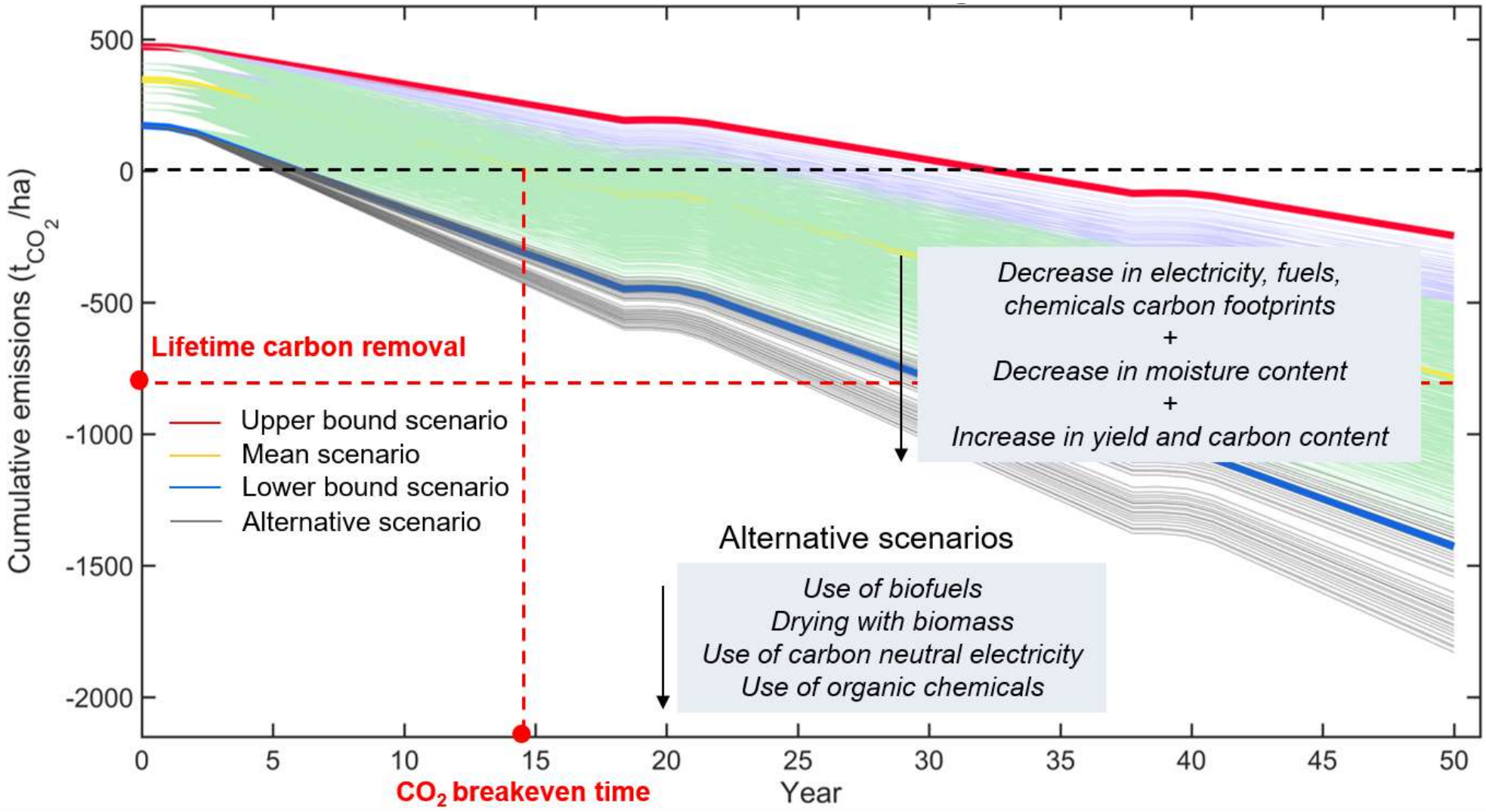
$\sum_{sr,sr',b,l,time} CO_2removed(sr,sr',b,l,p,time) > \sum_{sr'} CO_2Target(sr',time)$

$LandUse(sr,sr\_,b,l,p) < AvailableLandDensity(sr,l) \times Area(sr)$

$CO_2removed(sr,sr_b,l,p,time) > 0$

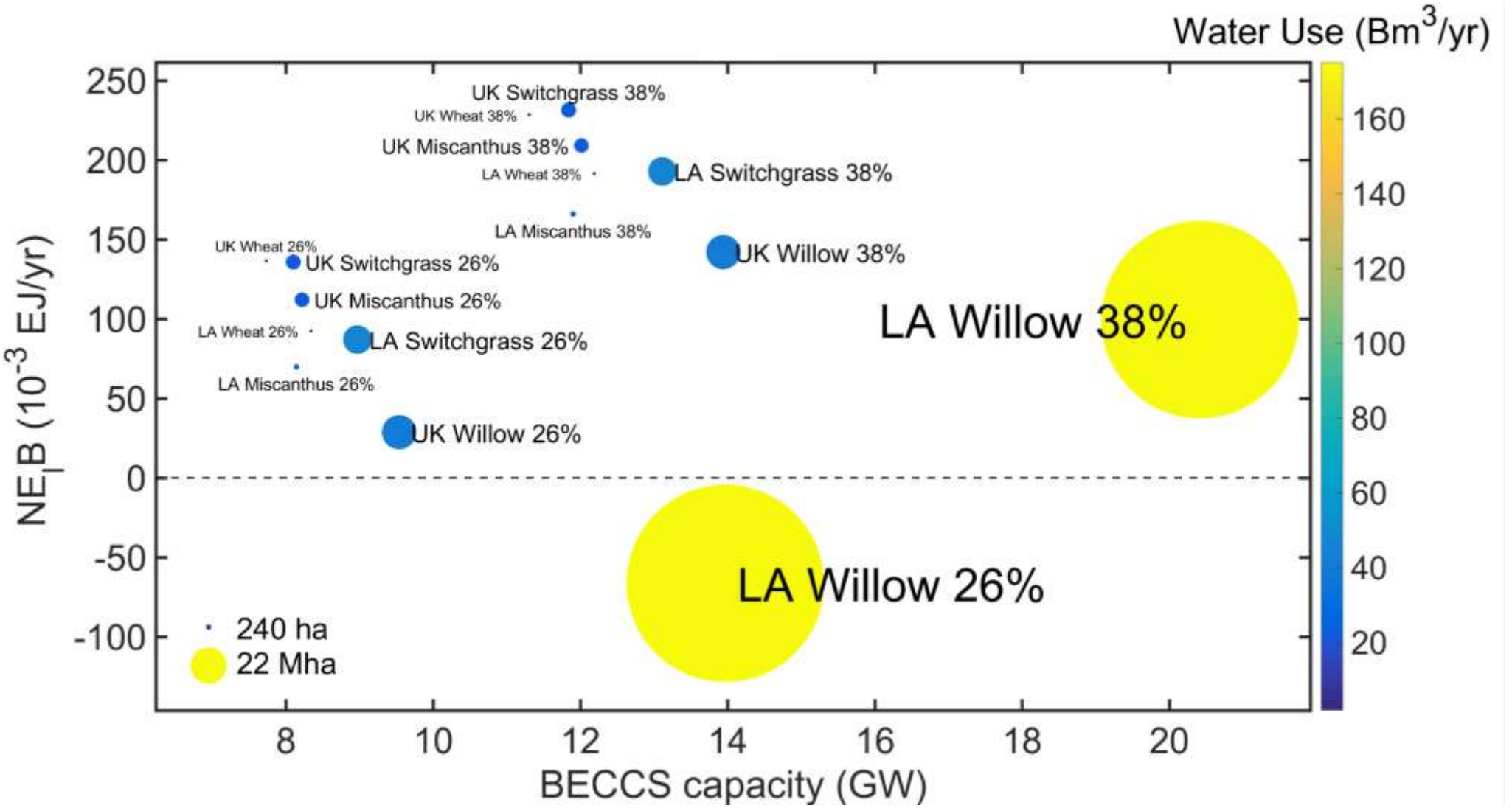
Source: Fajardy and Mac Dowell, Energy and Environ. Sci., 2017

Does BECCS work?



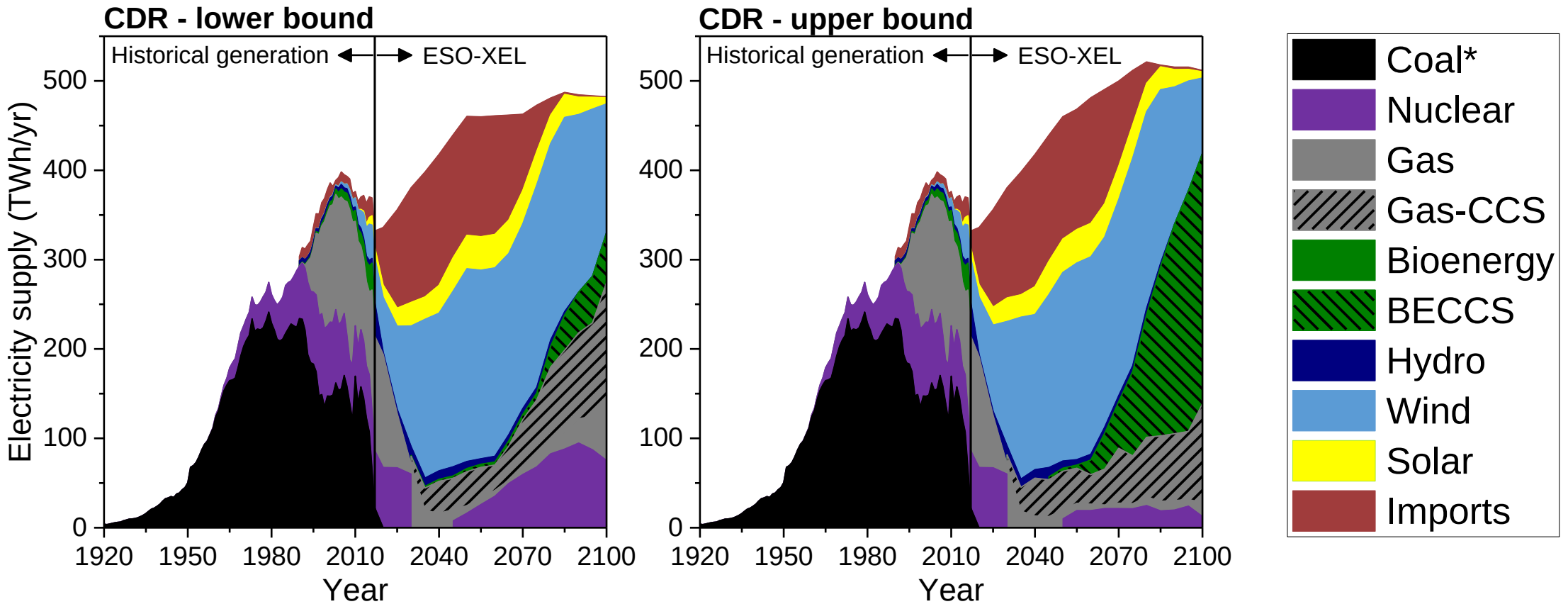
Sources: Fajardy M. and Mac Dowell N., Energy and Environmental Science (2017); Fajardy M. and Mac Dowell N., Energy and Environmental Science (2018)

Does BECCS generate power?



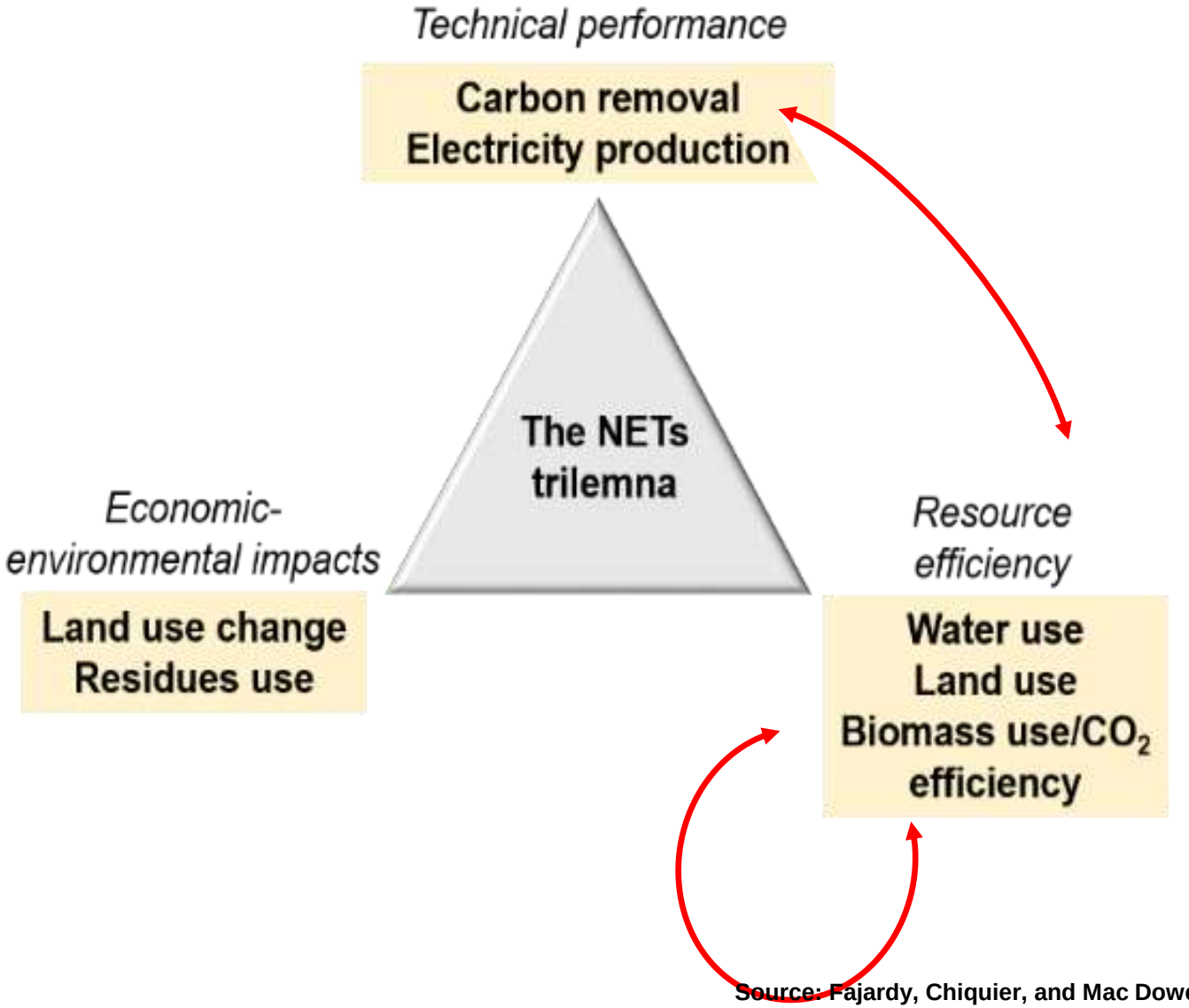
Source: Fajardy and Mac Dowell, Energy and Environmental Science, 2017

Low carbon vs. carbon negative energy systems



Source: Daggash and Mac Dowell, Joule, 2019

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

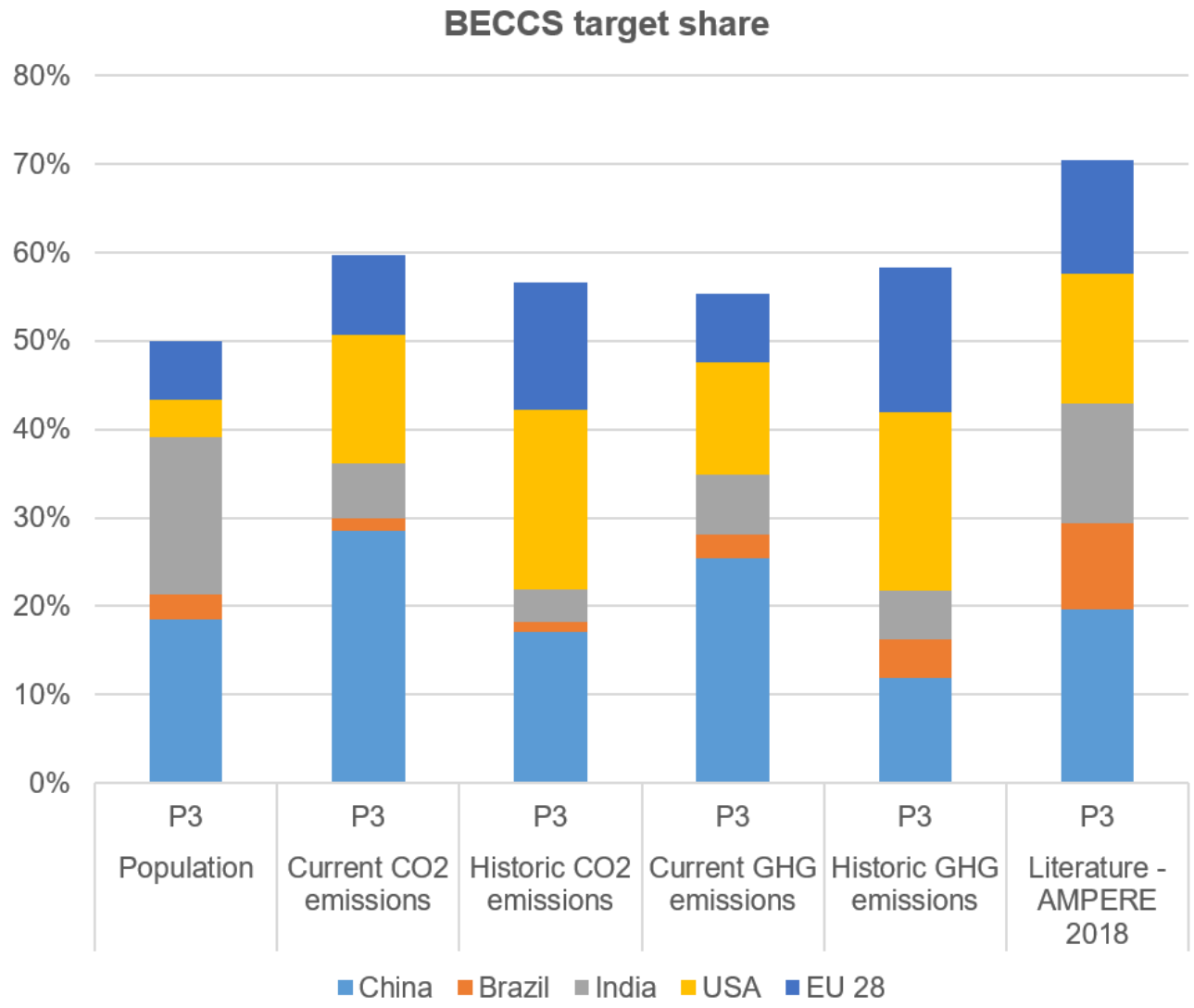


Source: Fajardy, Chiquier, and Mac Dowell, Energy and Environmental Science, 2018

Who has to do what..?

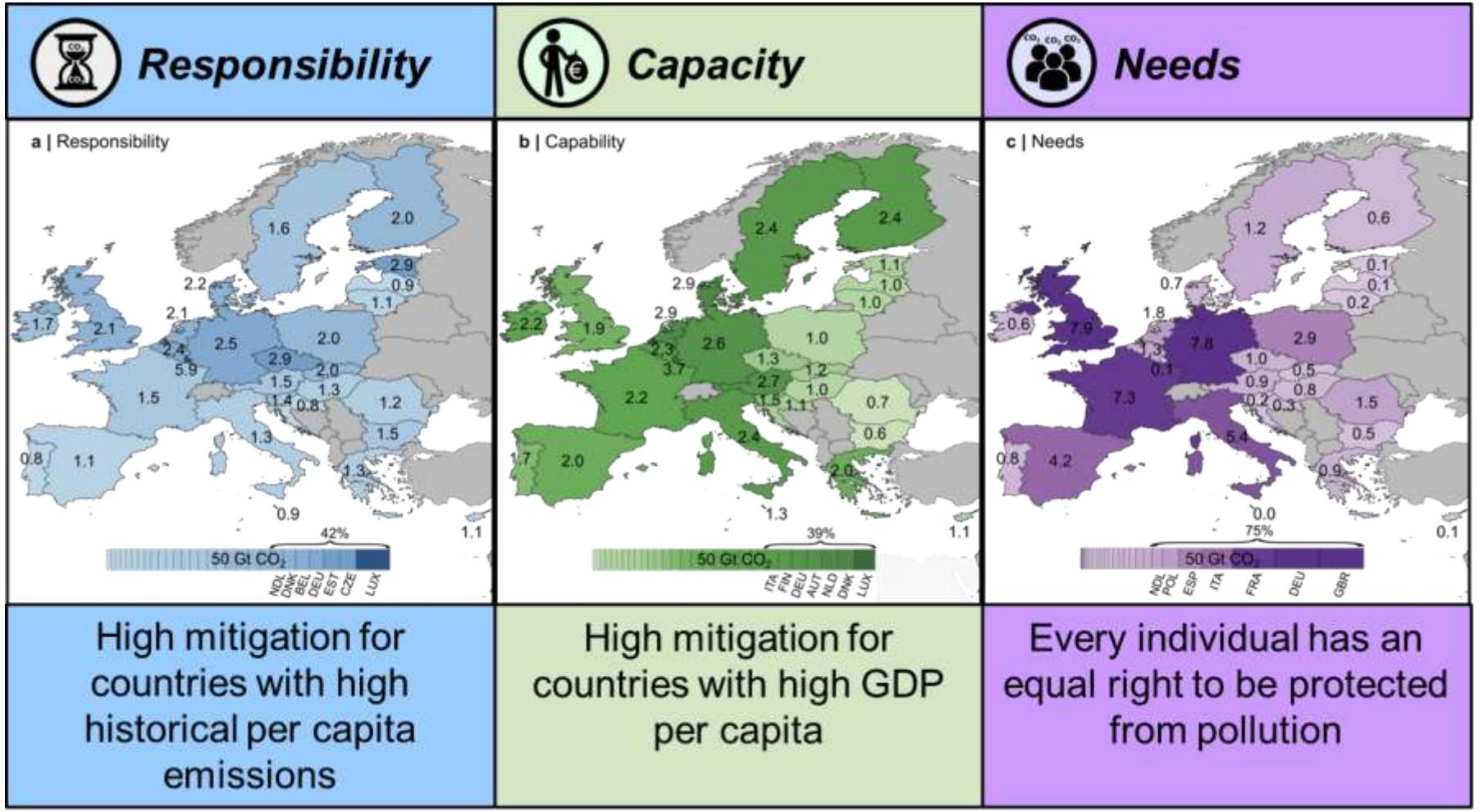
$$target(i) = Gtarget.\frac{x(i)}{\sum_{world} x(i)}$$

- **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

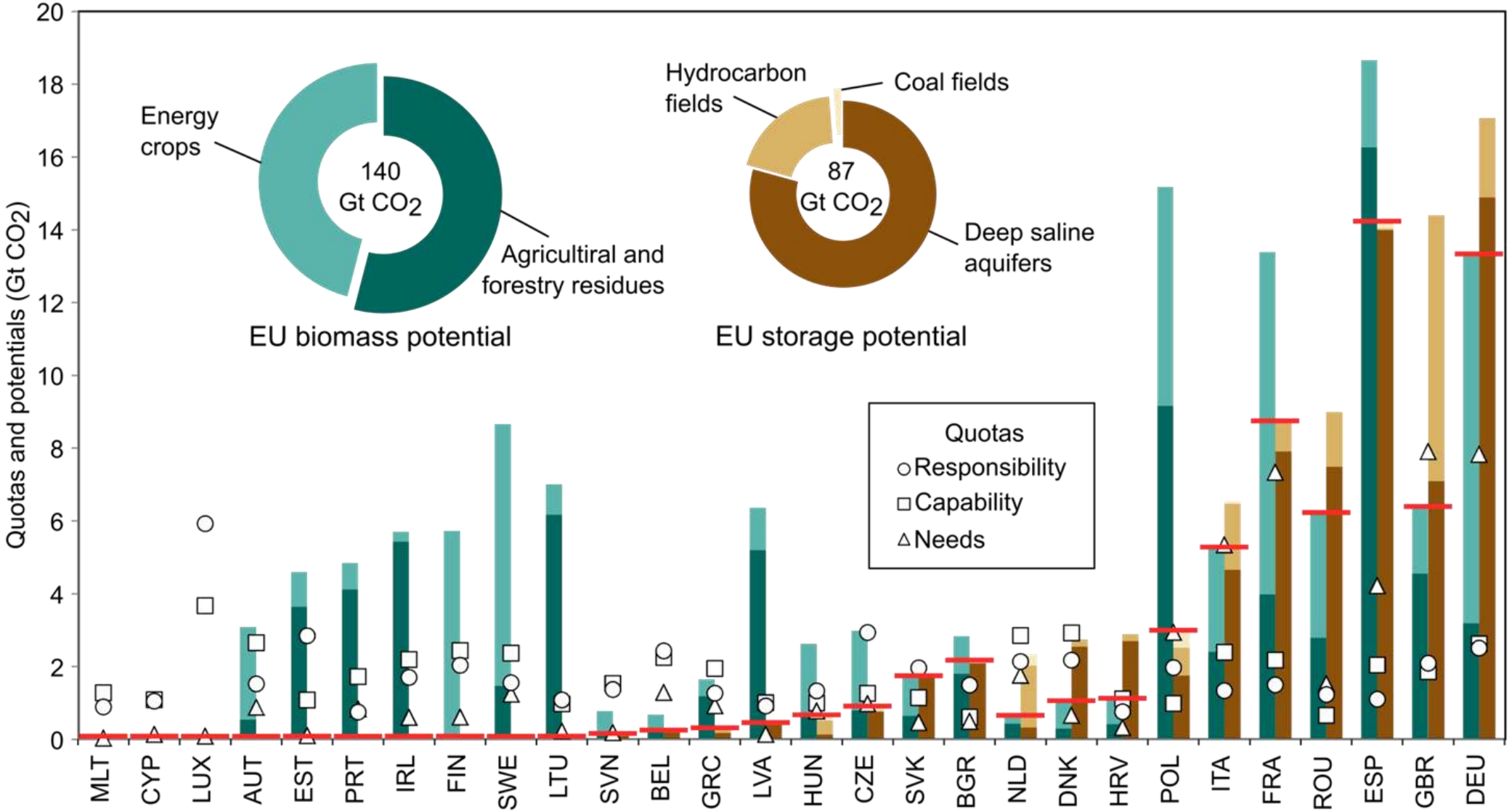


What might this look like at the national level?

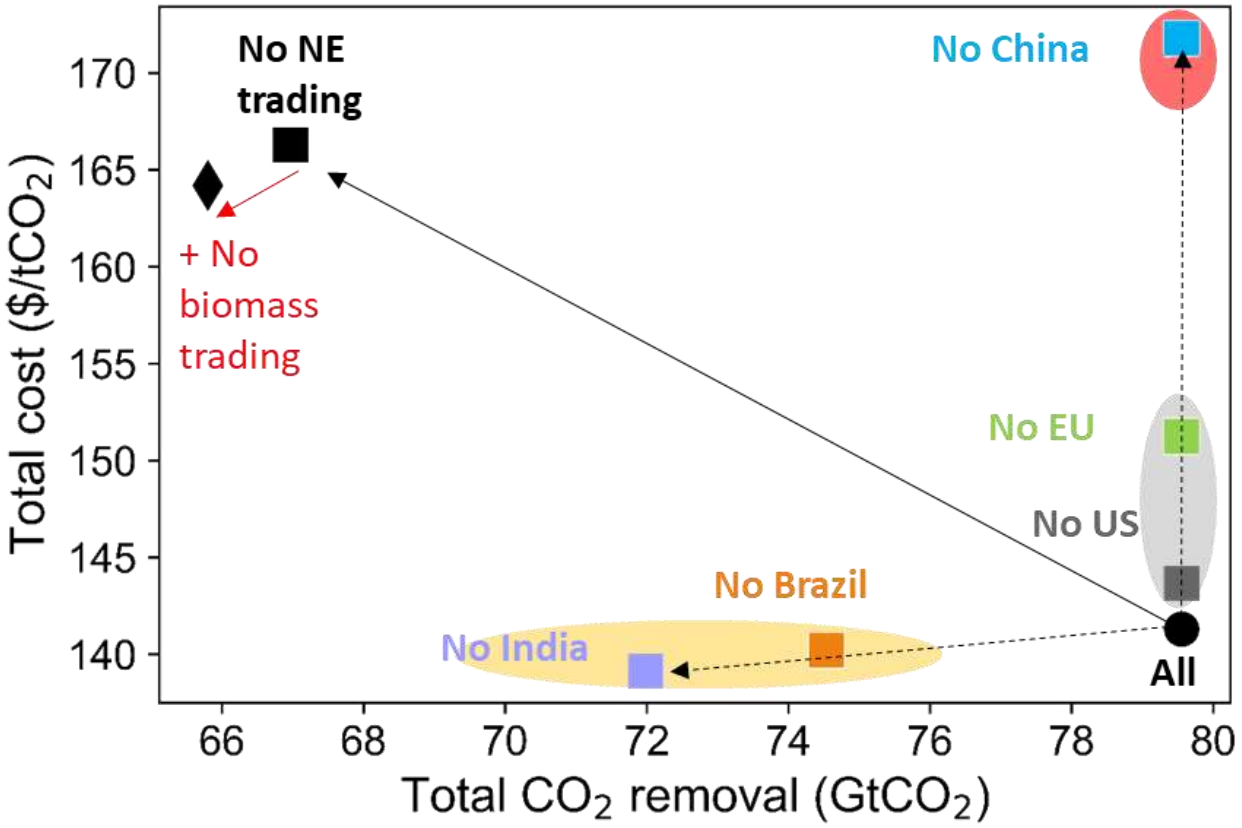
- Responsibility: per-capita historical (1960-2017) CO_2 emissions
- Capacity: per-capita GDP
- Needs: country population



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

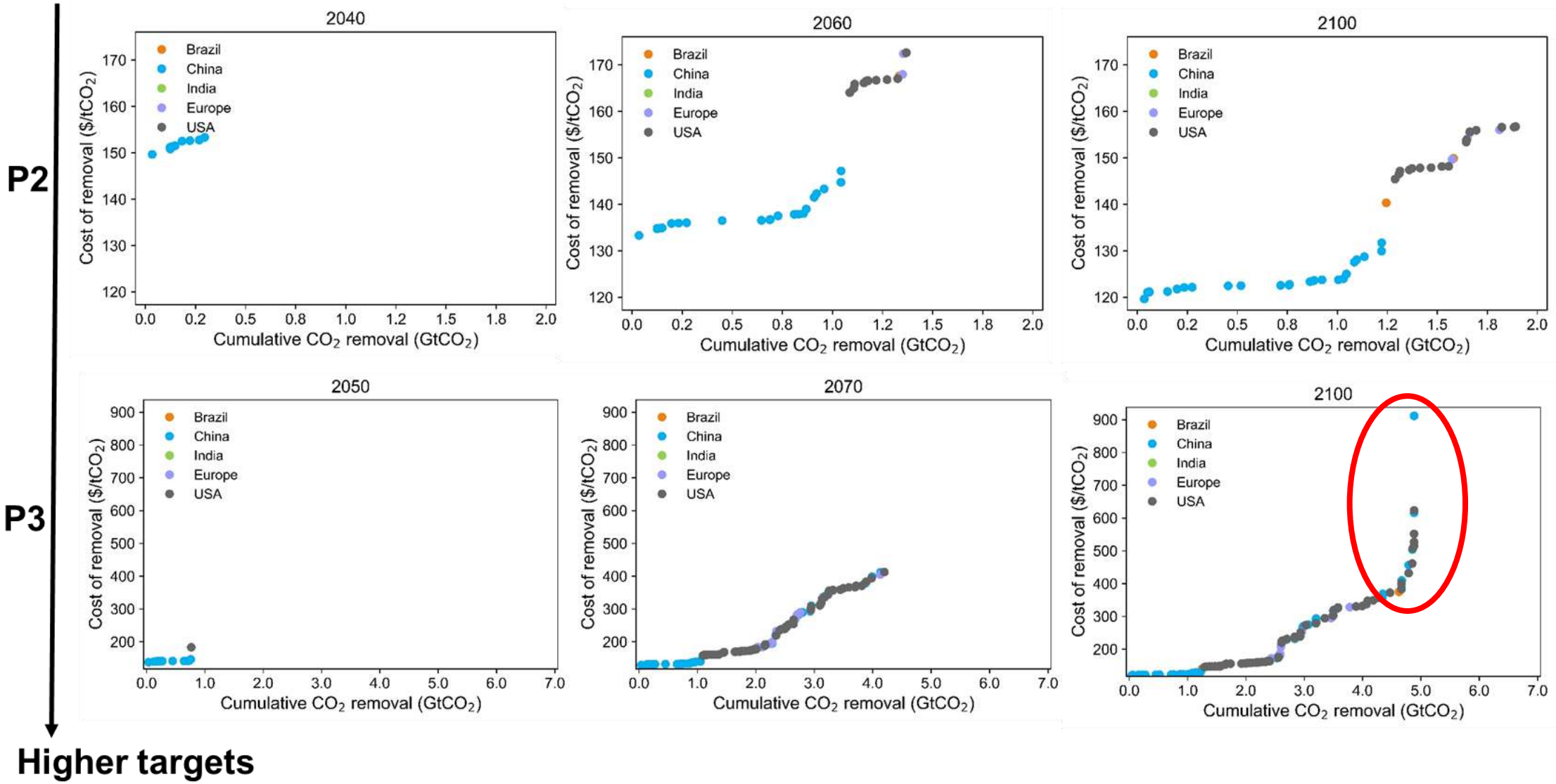
BECCS deployment under P2

- Biomass tends to be used near CO_2 storage sites because of the high cost of transport
- At low targets, China, eastern US and are the main BECCS regions
- BECCS in the EU is limited by higher cost and low marginal land availability
- BECCS deployment in Brazil is limited by CO_2 storage availability

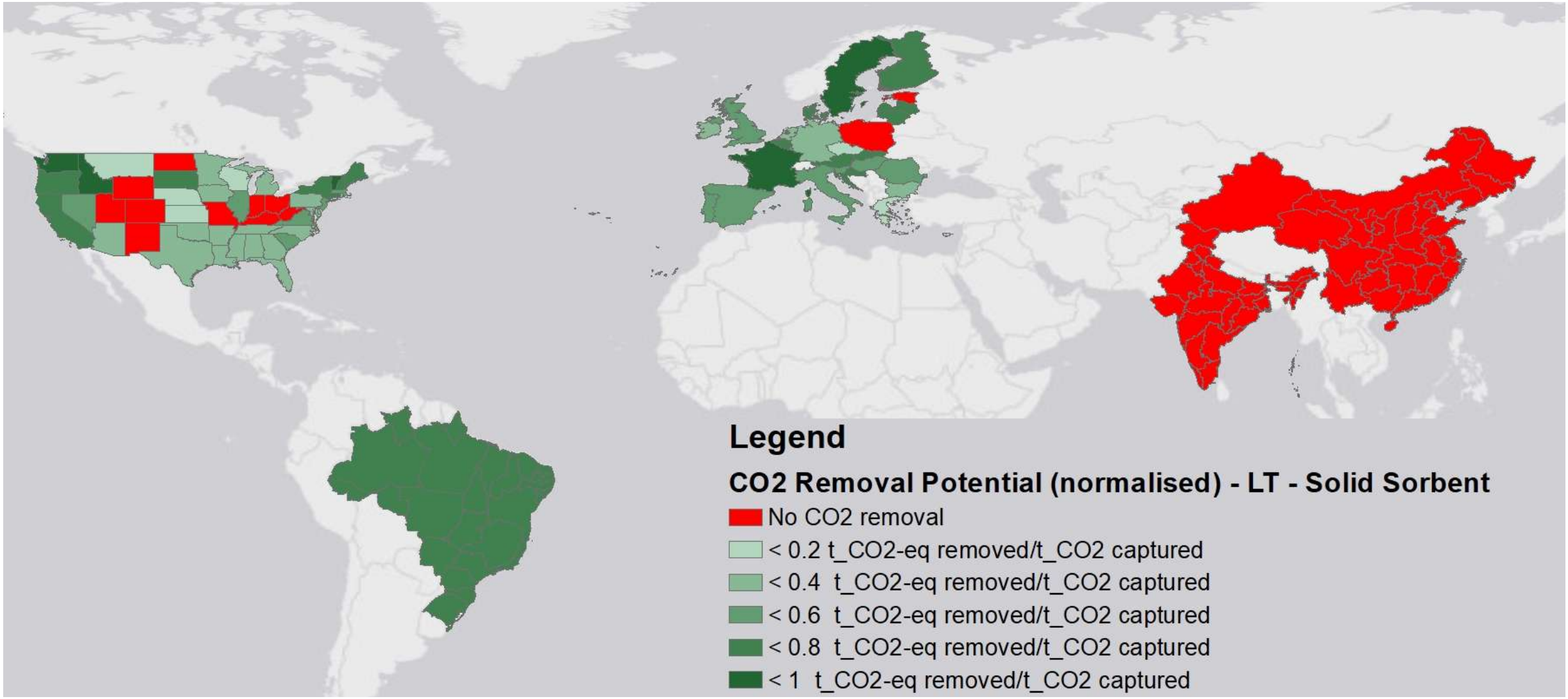
BECCS deployment under P3

- At higher targets, biomass from regions with no/less CO_2 storage is shipped to other regions (Brazil, India)
- The target cannot be met only using energy crops on marginal land

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	

Some conclusions

- Does BECCS actually work?
  - Maybe. It relies upon making astute choices across the supply chain.
  - Exclusive focus on carbon and power may lead to unsustainable outcomes.
- What does BECCS do?
  - There are significant energy system impacts.
  - “Carbon negative” is fundamentally different to “low carbon”.
- Who has to do what?
  - Agreeing burden sharing is likely to be controversial, but important.
- International cooperation is vital to meeting global
  - Mitigation is likely something that can be done on a national basis.
  - GGR is inherently an international challenge.
  - A portfolio of GGR technologies will be required.