NEGEM

Developing a portfolio of NETs for EU member states in line with the Paris Agreement

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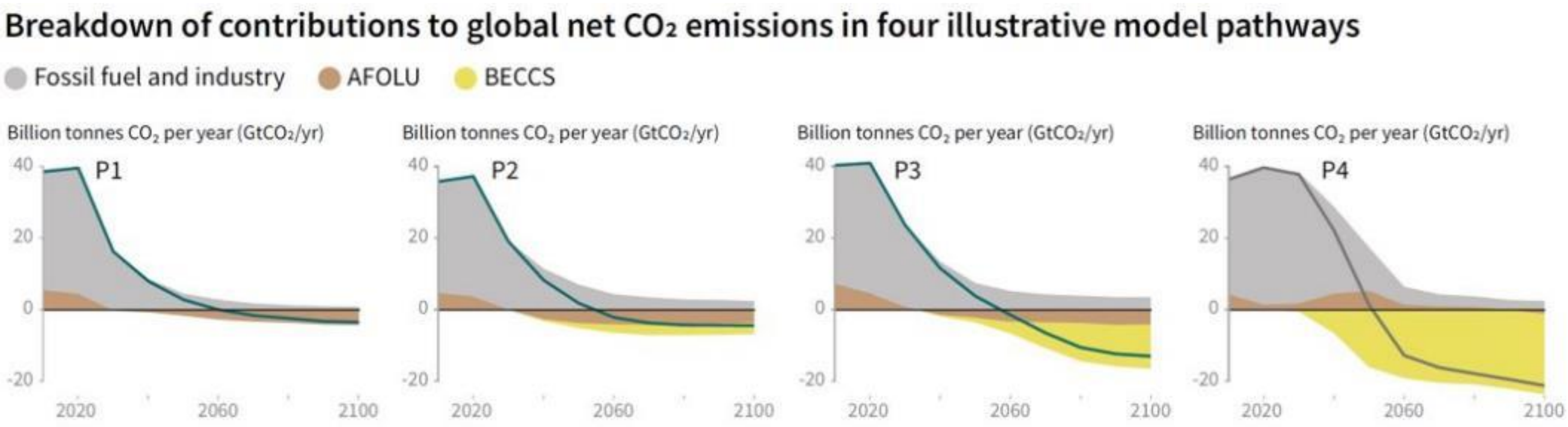
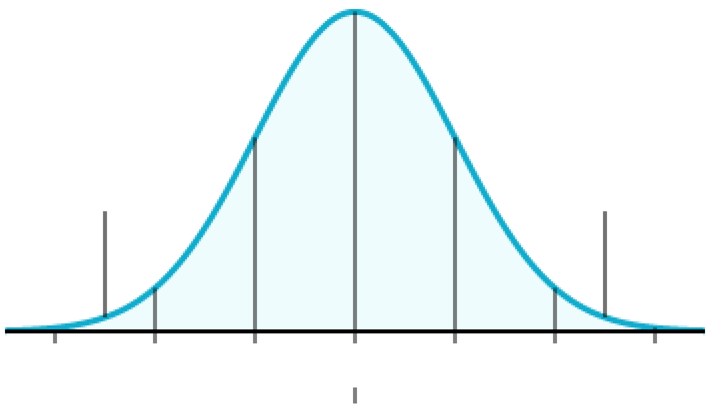
NEGEM WP4 – Key Objectives

- Quantify the capacity for different EU member states to deploy negative emissions.
- Identify investment targets for negative emissions in the EU in line with the Paris Agreement.
- Establish if the EU member states can meet their demand for negative emissions using indigenous supply at both a member-state, and continental level.
- Develop a cost-optimal portfolio of NETs for the EU member states, while noting impacts on other key KPIs.

Demand is unknown - cumulative negative emissions requirement by 2100



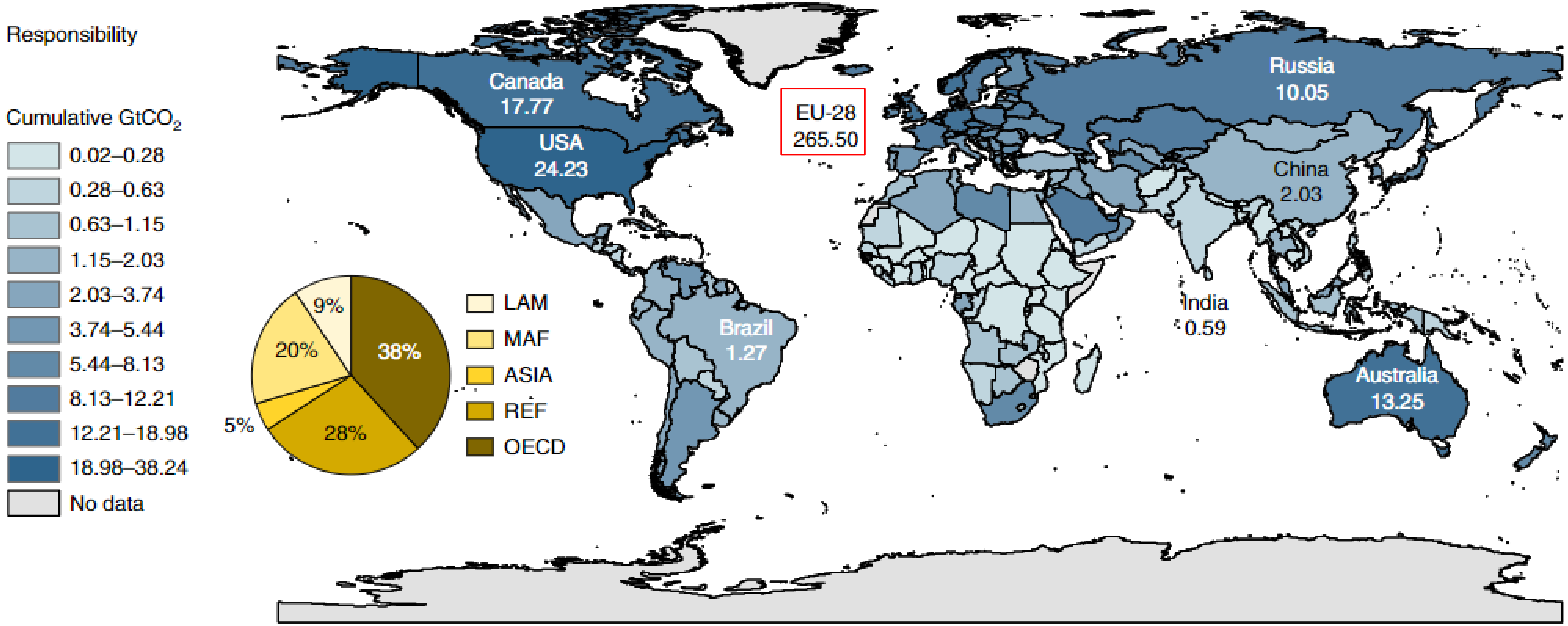
	P1: Lower energy demand	P2: Sustainability focus	P3: Middle-of-the-road (historical patterns)	P4: Resource and energy intensive (high demand)
Cumulative until 2100 $GtCO_2$	0	348	687	1218



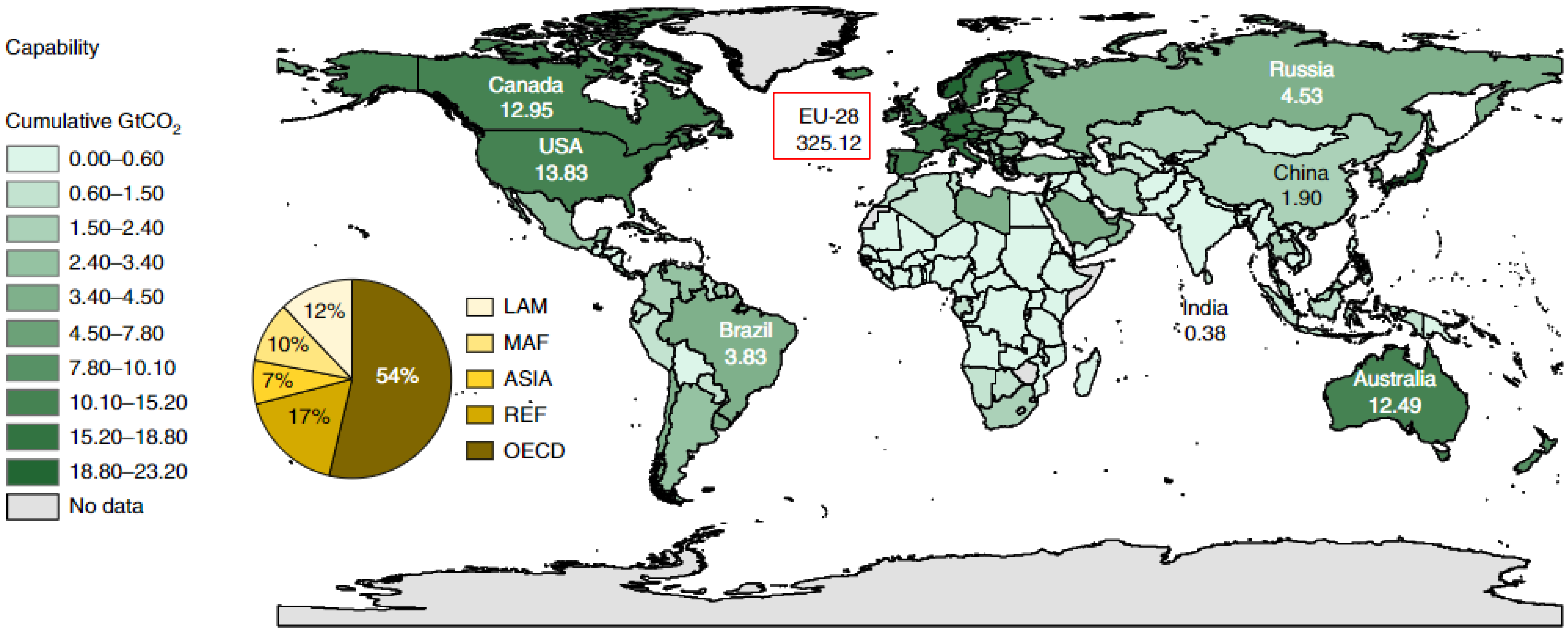
What is each member state responsible for?

- The use of widely accepted principles for allocating quotas for negative emissions is a potential option, and such approaches have been used elsewhere.
- They provide an internally consistent method to address each member state’s contribution to the total CDR deployment in EU.
- However, achieving agreements across member states is a deeply political process.
- Here, a handful of principles are highlighted to explore a range of deployment trajectories.

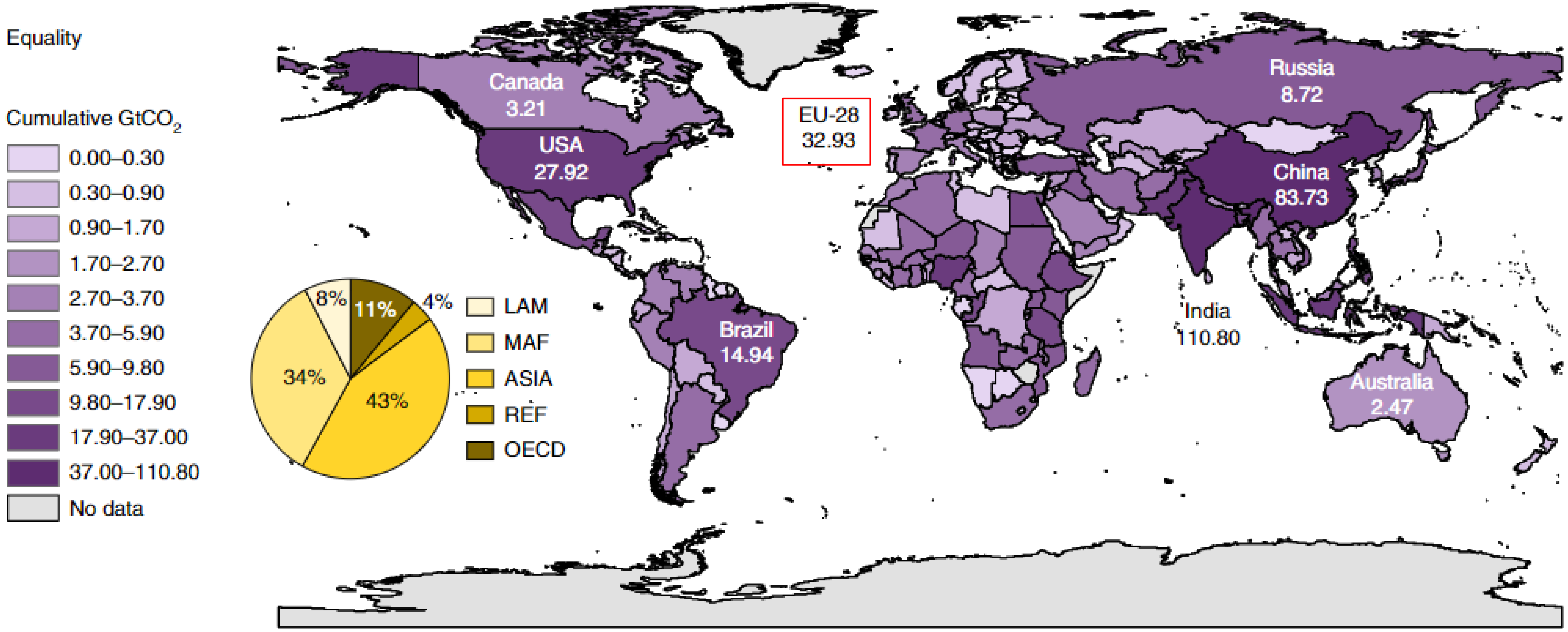
The Responsibility Principle – Pozo et al., 2020



The Capacity Principle – Pozo et al., 2020



The Equality Principle – Pozo et al., 2020



What about the supply of negative emissions in the EU?

- Regional endowment of resources dictate the domestic potential to generate negative emissions.

- Understanding the technical potential to deliver CO_2 removal based on indigenous resources is necessary to support policy development.

- Closing the gap between supply and demand with a competitive local market will insulate the EU from external pressures.

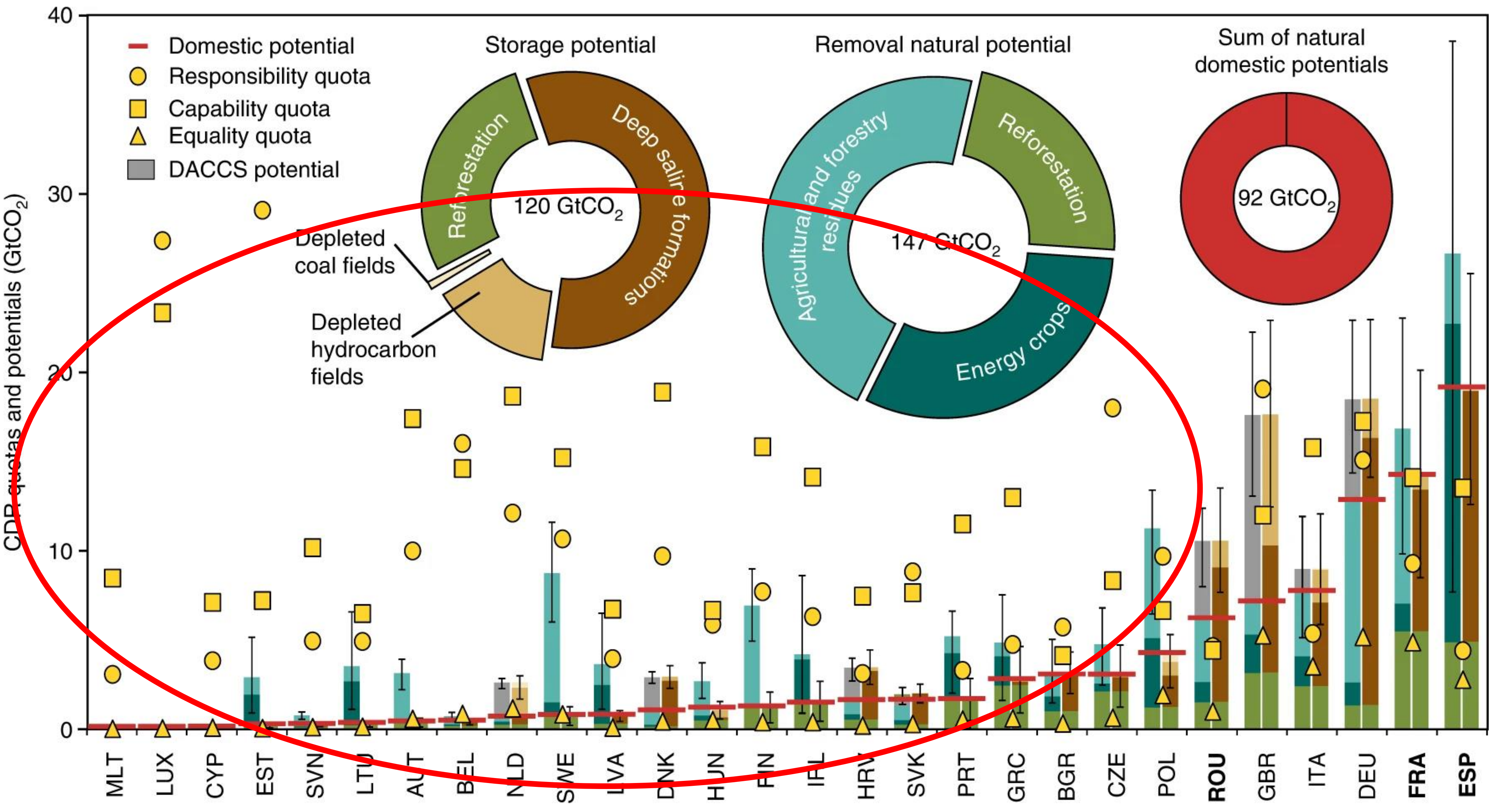
NETs supply and demand in the EU member states

- Pozo et al., 2020, assessed the following: removal potential from agricultural and forestry residues, reforestation, dedicated energy crops, and the overall permanent geological sequestration capacity.

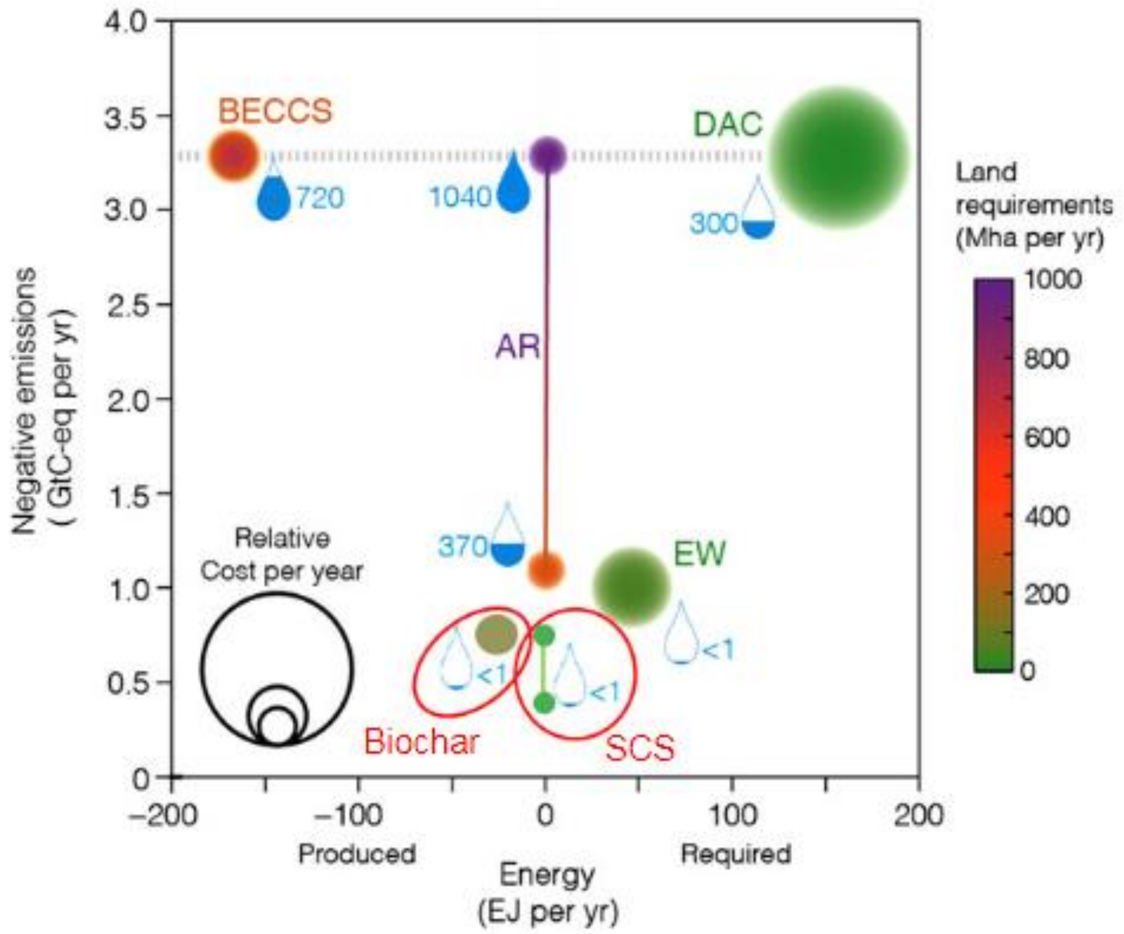
- They note a greater share of biomass availability through residues than via dedicated energy crops. DACCS is combined with BECCS and afforestation in their assessments.

- Only 3 – 6 EU member states can meet their respective quotas as allocated by burden-sharing principles. These states have the potential to become leading suppliers of NETs in Europe.

Availability of resources is the primary constraint to scaling up at a member state-level – Pozo et al., 2020



Smith, 2015, on soil carbon sequestration and biochar application



- Global estimates of negative emissions by soil carbon sequestration and biochar application by Smith shows less than 1 Gt C_{eq}/yr, or 3.7 Gt $CO_{2,eq}$/yr each. What does this translate to at the EU level?

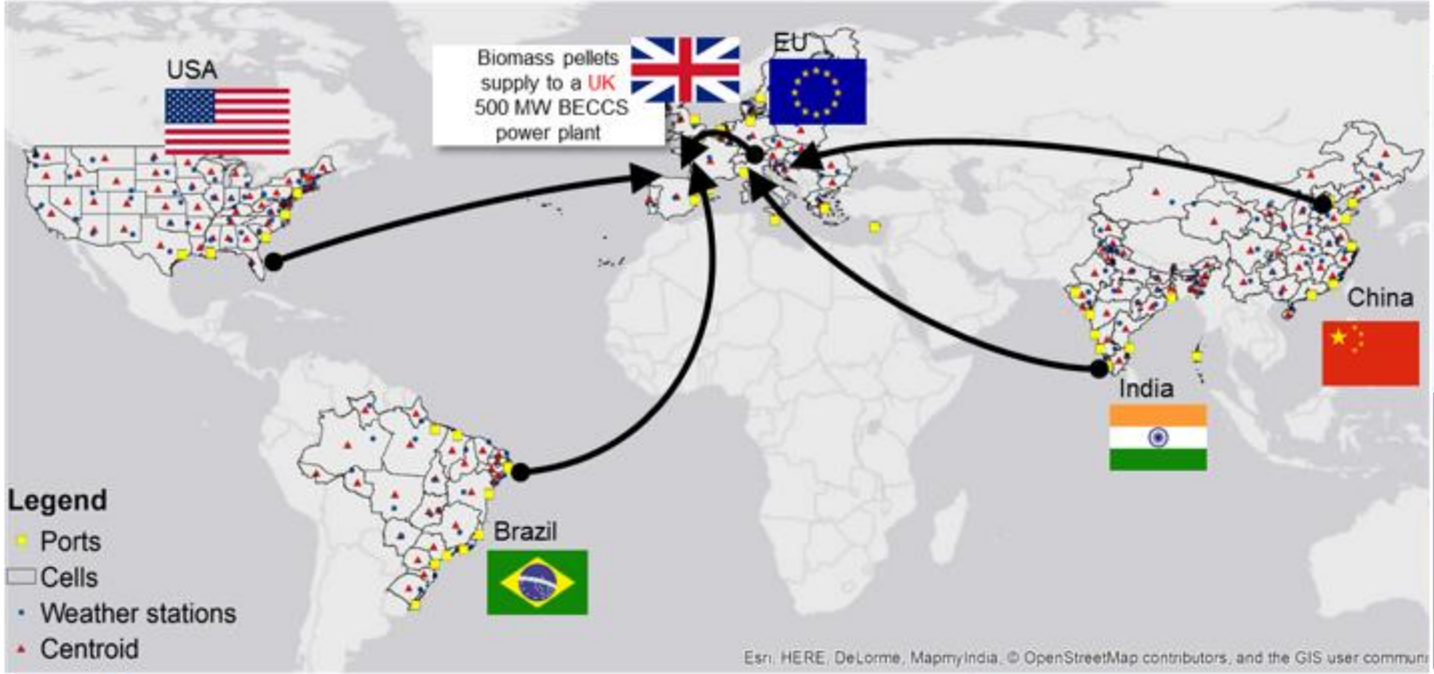
Smith et al. , 2015, on the scale of removal potential of enhanced weathering against other technologies

Table 1 | Global impacts of NETs for the average needed global C removals per year in 2100 in 2 °C-consistent scenarios (430–480 ppm scenario category; Supplementary Table 3).

NET	Global C removal (Gt Ceq yr^{-1} in 2100)	Mean (max.) land requirement (Mha in 2100)	Estimated energy requirement (EJ yr^{-1} in 2100)	Mean (max.) water requirement (km^3 yr^{-1} in 2100)	Nutrient impact (kt N yr^{-1} in 2100)	Albedo impact in 2100	Investment needs (BECCS for electricity/ biofuel; US$ yr^{-1} in 2050)
BECCS	3.3	380–700	−170	720	Variable	Variable	138 billion /123 billion
DAC	3.3	Very low (unless solar PV is used for energy)	156	10–300	None	None	>>BECCS
EW*	0.2 (1.0)	2 (10)	46	0.3 (1.5)	None	None	>BECCS
AR*	1.1 (3.3)	320 (970)	Very low	370 (1,040)	2.2 (16.8)	Negative, or reduced GHG benefit where not negative	<<BECCS

*NETs with lower maximum potential than the BECCS emission requirement of 3.3 Gt Ceq per year in 2100; their mean (and maximum) potential is given along with their impacts (see Supplementary Methods). Wide ranges exist for most impacts, but for simplicity and to allow comparison between NETs (sign and order of magnitude), mean values are presented. See main text and Supplementary Methods for full details. PV, photovoltaic.

Our methodological framework for estimating the supply-side potential



Supply chain model

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

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

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

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

$yr = 1..50$

$WaterUse(sr, b)$
$LandUse(sr, b, l, p)$
$CO_2Removed(sr, b, l, p)$
$NetEnergy(sr, b, l, p)$
$CO_2BET(sr, b, l, p)$
$EnergyBET(sr, b, l, p)$

Optimisation program

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

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

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

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

Subject to:

$$\sum_{sr,b,l,p} CO_2removed(sr, b, l, p) > CO_2RemovalTarget$$

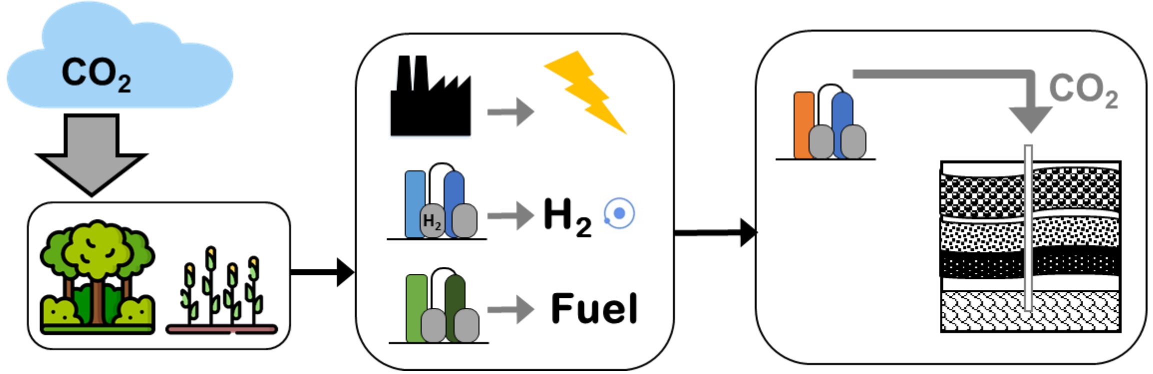
$$LandUse(sr, b, l, p) < AvailableLandDensity(sr, l) \times Area(sr)$$

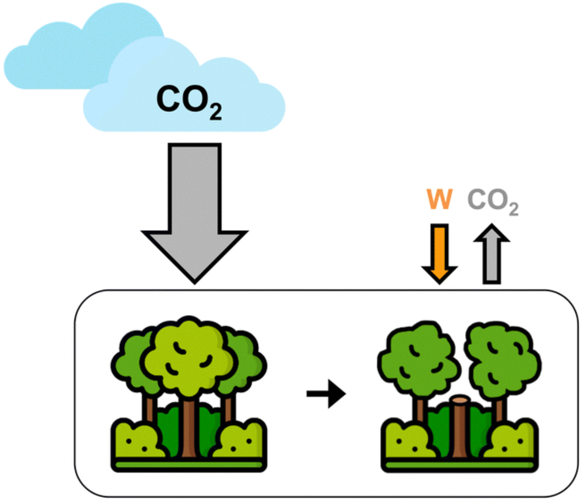
$$CO_2removed(sr, b, l, p) > 0$$

- Under which conditions, and **when**, is BECCS carbon negative?
- Is BECCS a sustainable and resource efficient technology?
- Does BECCS deployment contribute to the energy system?
- What are the trade-offs between BECCS KPIs?

NETs with natural limits on the level of deployment

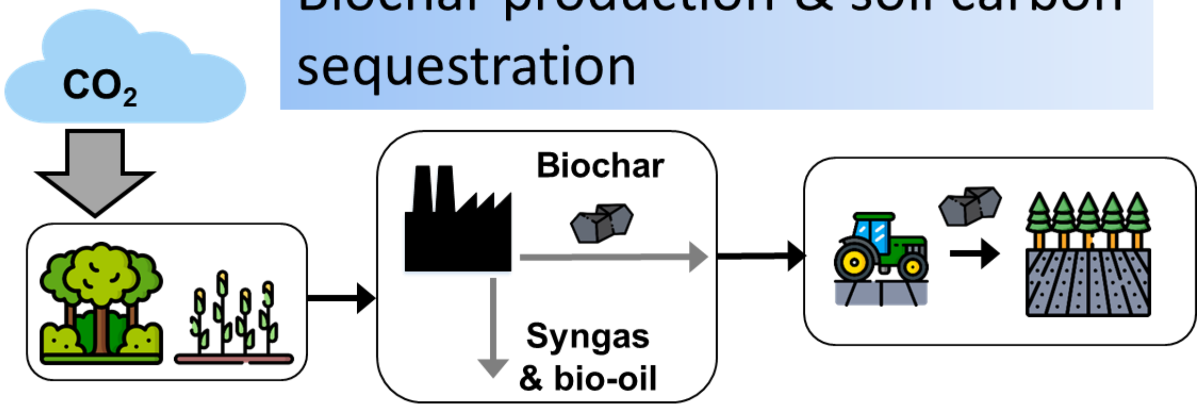
Bioenergy with carbon capture & storage (BECCS)



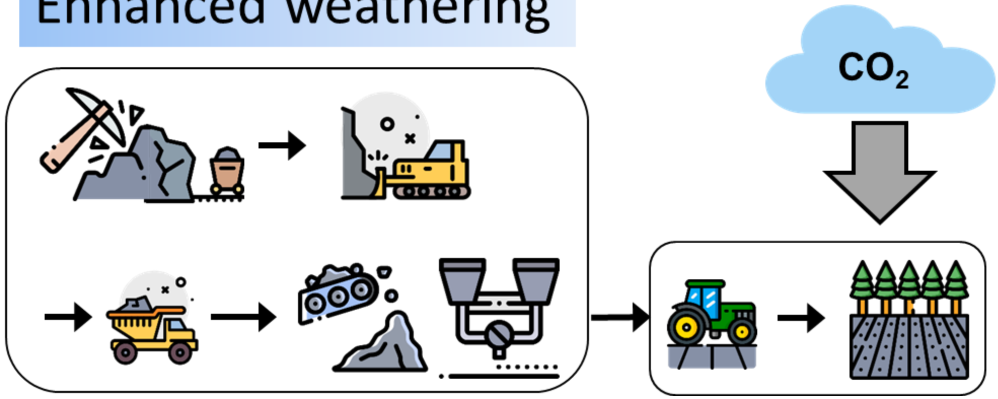


Afforestation/Reforestation

Biochar production & soil carbon sequestration



Enhanced weathering



Bui, M. & Mac Dowell, N., 2022. Greenhouse Gas Removal Technologies, The Royal Society of Chemistry, UK. https://doi.org/10.1039/9781839165245

Factors which influence the domestic supply potential

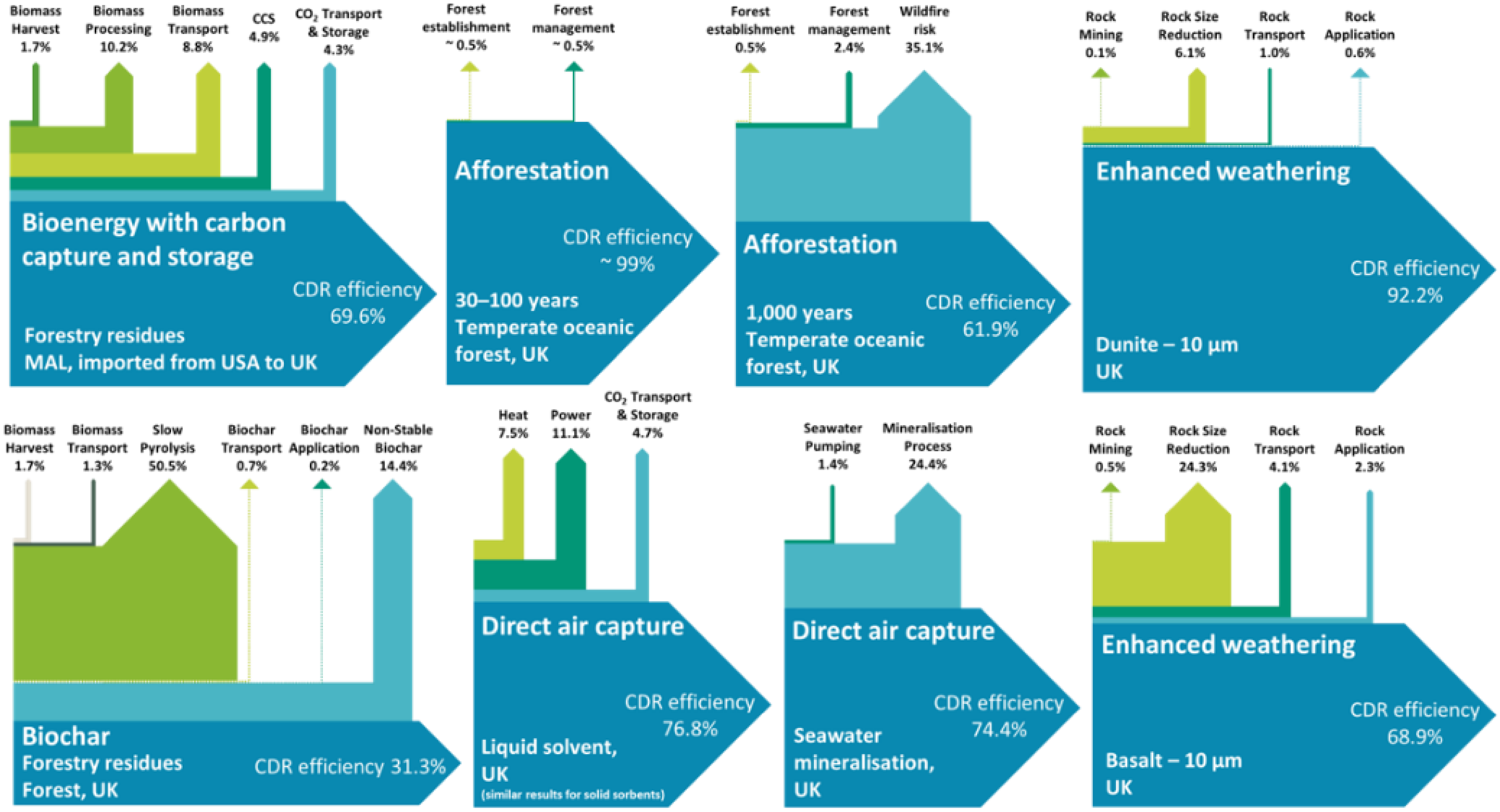
- BECCS – types of biomass feedstocks and their availabilities. Technology archetypes and the CO_2 capture rates. Emissions from processing in the supply chain. CO_2 sequestration potential.

- Biochar – very similar to the list for BECCS. Scale- and output-dependent constraints and highly variable based on method of production. Soil and environment conditions.

- Afforestation – forest management, the type of land used – new land or land with reforestation potential? Indirect emissions from energy and supply chain.

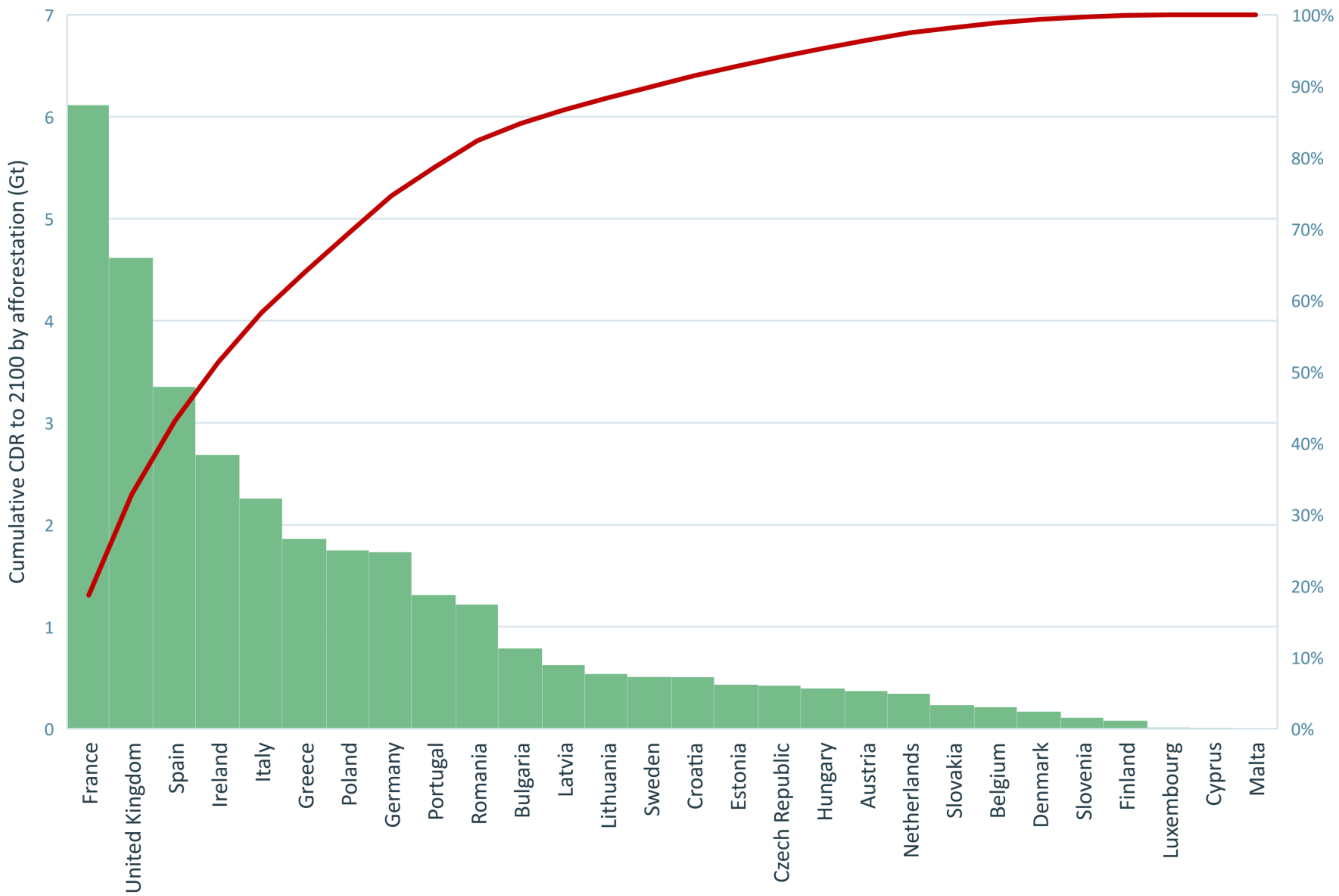
- Enhanced weathering – availability of basic rock formations. Indirect emissions from energy and equipment. Particle size and weathering rates. Soil characteristics.

Carbon removal potential is a function of supply chain decisions

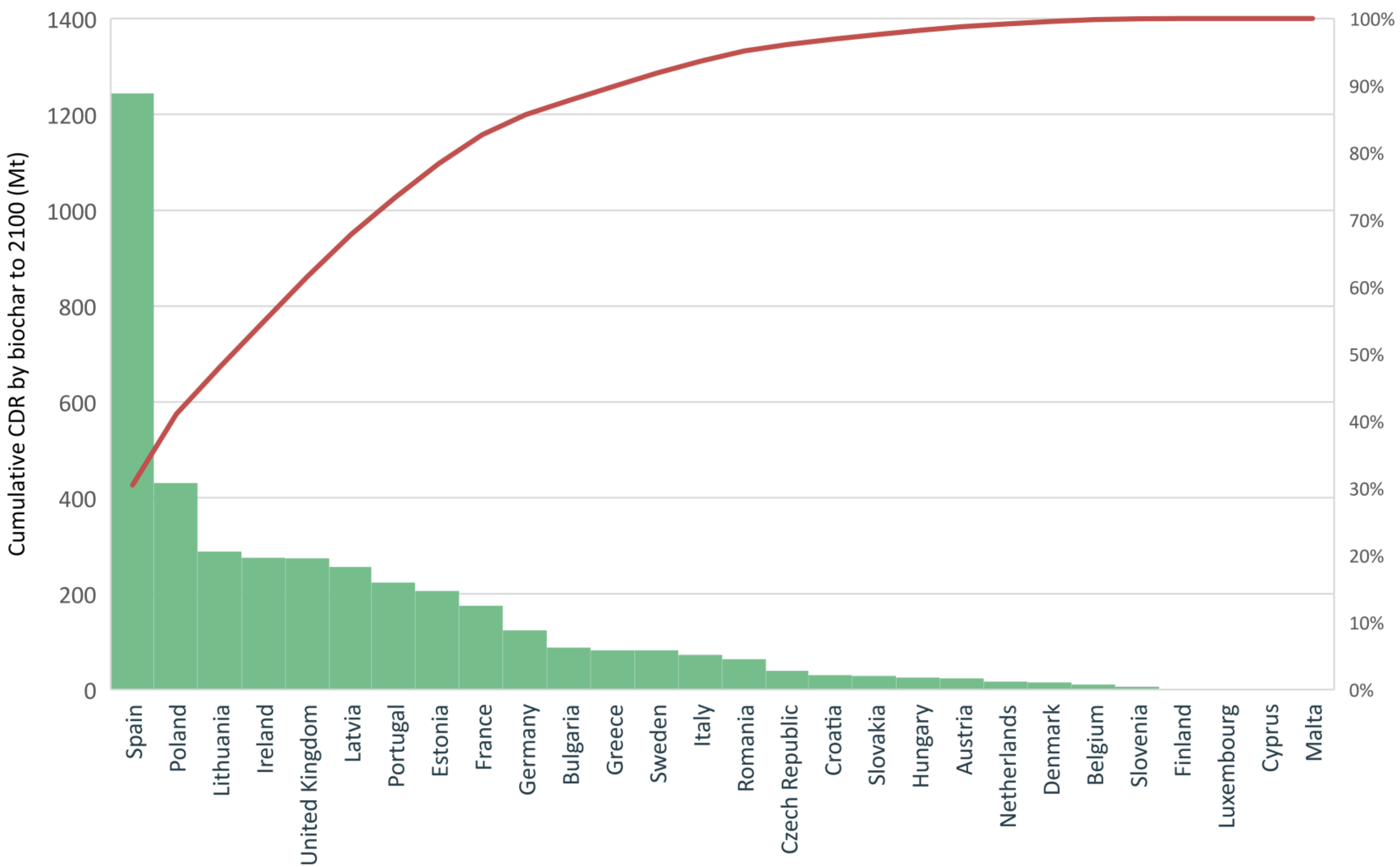


Chiquier, S., Patrizio, P., Bui, M., Sunny N., Mac Dowell, N. (2022). A comparative analysis of the efficiency, timing, and permanence of CO_2 removal pathways. https://doi.org/10.1039/D2EE01021F

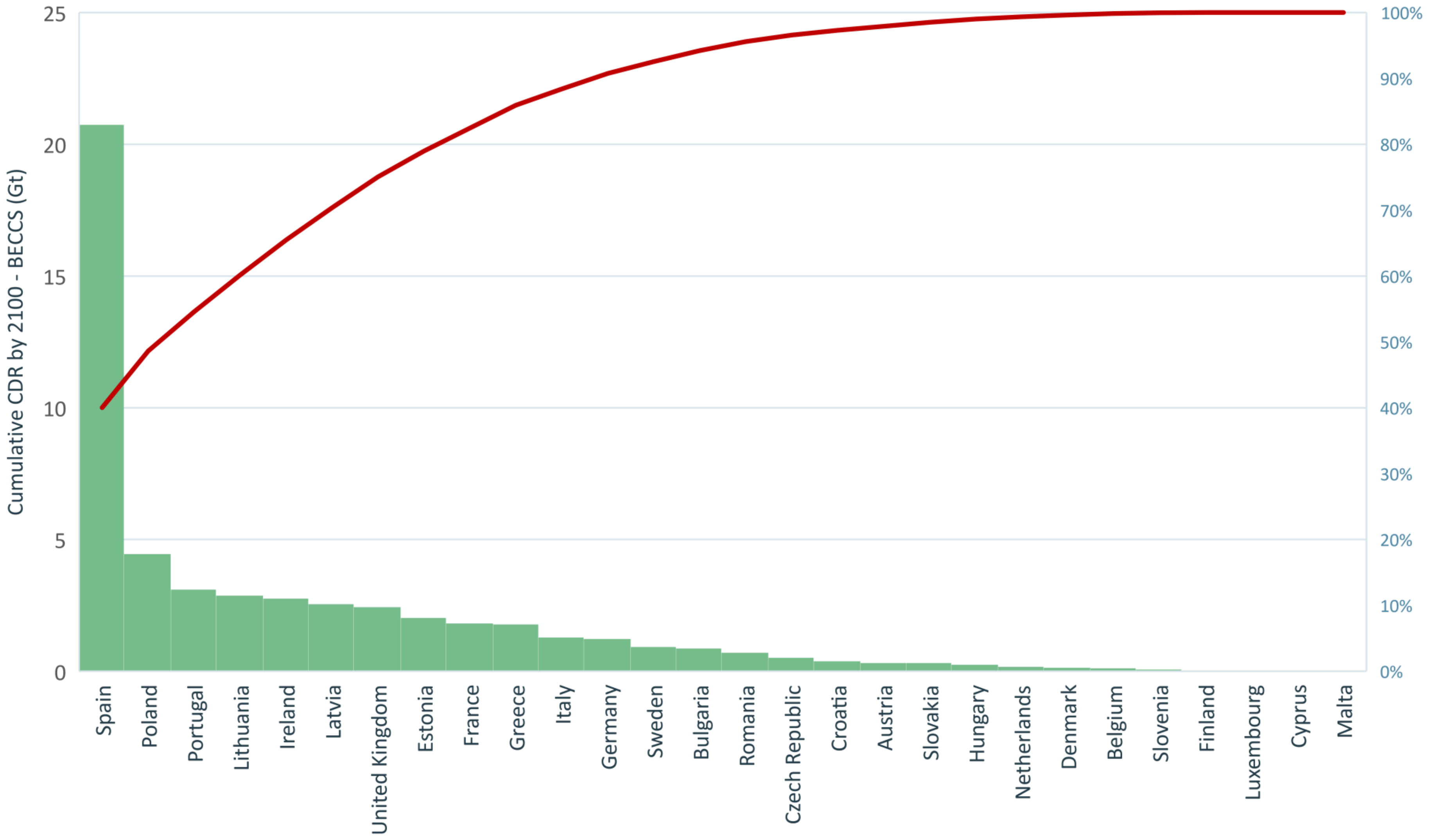
Afforestation – 33 Gt cumulative CO_2 removal potential by 2100



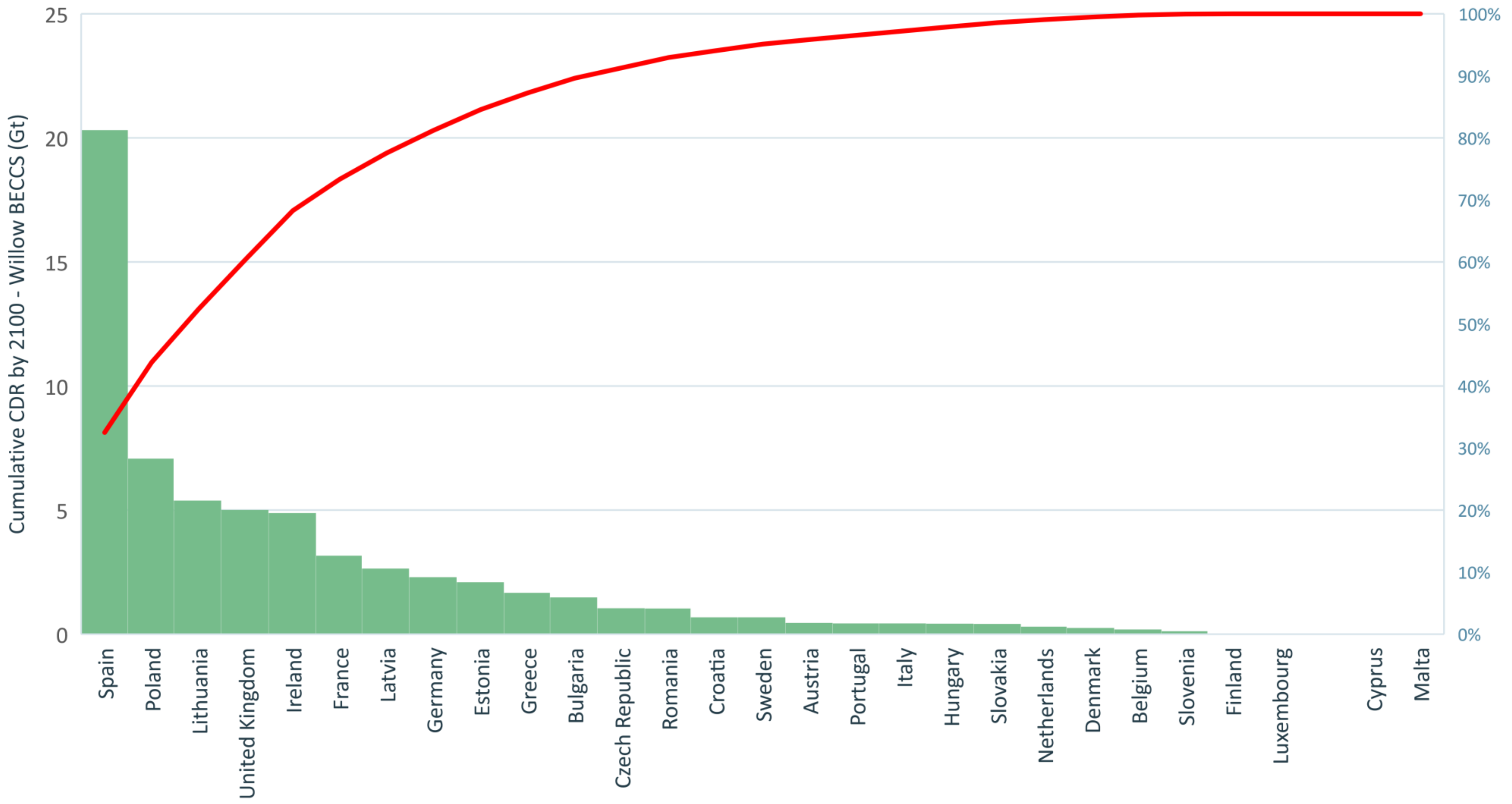
Biochar with miscanthus on marginal agricultural land – 4.8 Gt cumulative CO_2 removal potential by 2100



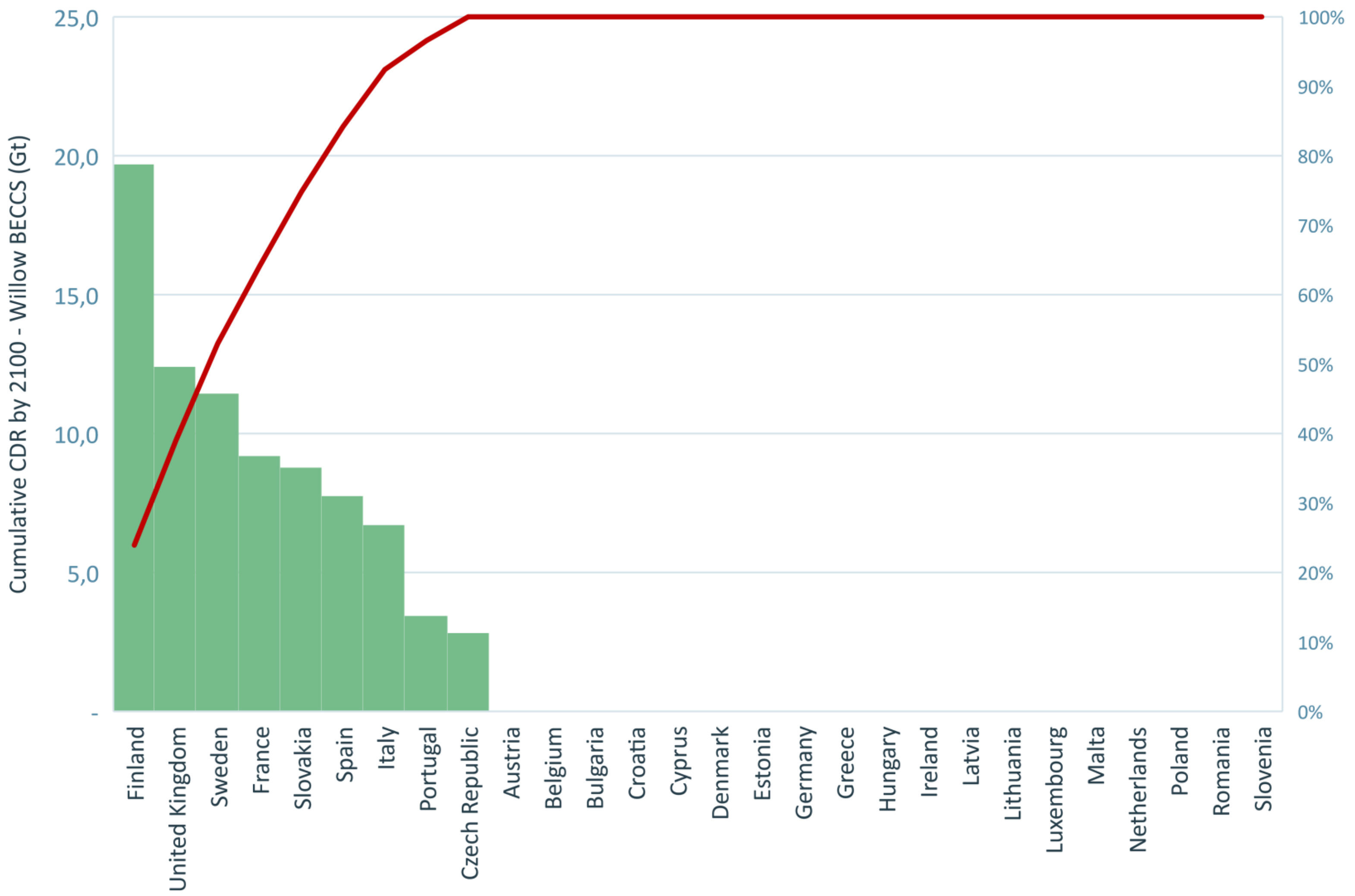
BECCS with miscanthus on marginal agricultural land – 52 Gt cumulative CO_2 removal potential by 2100



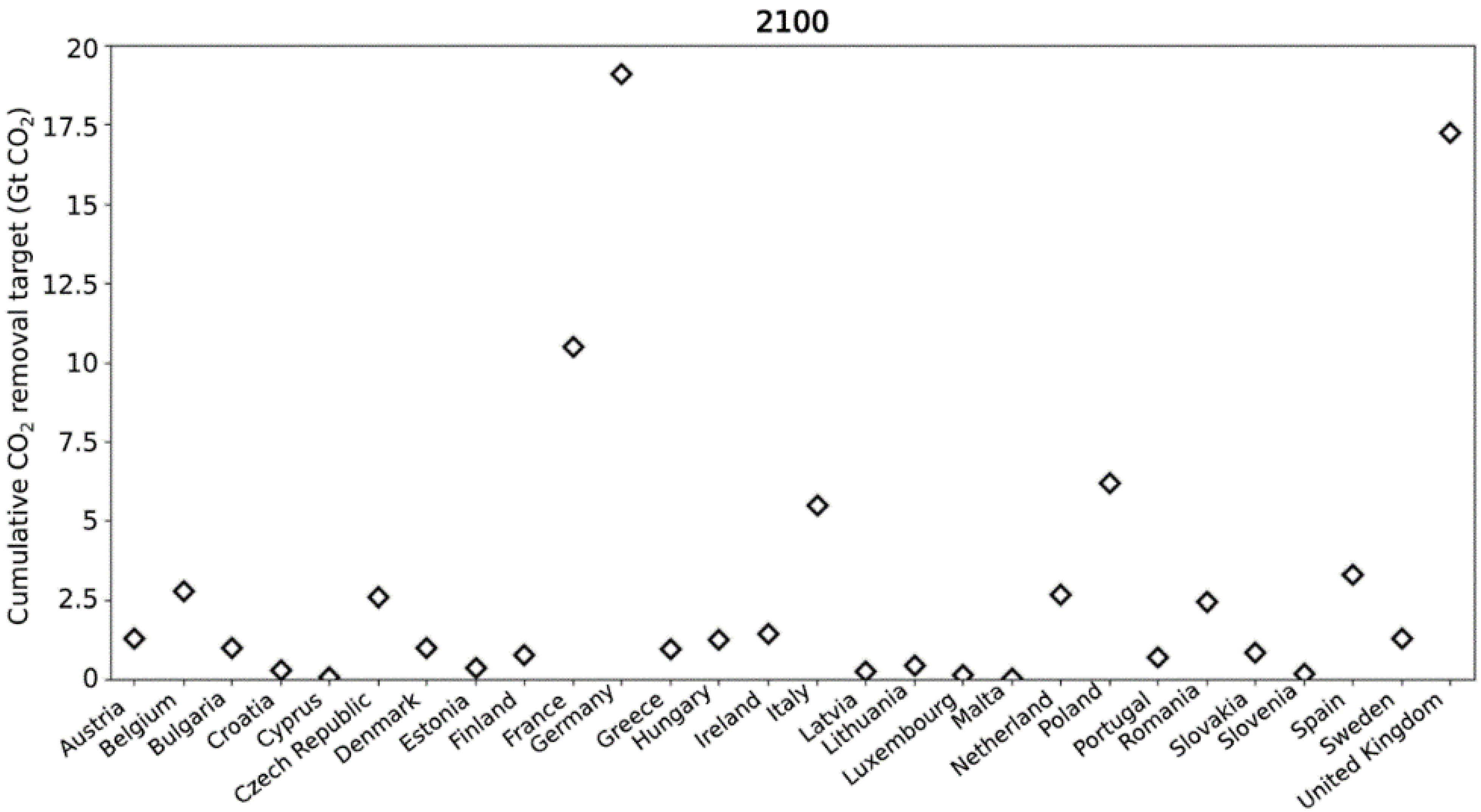
BECCS with willow on marginal agricultural land – 63 Gt cumulative CO_2 removal potential by 2100



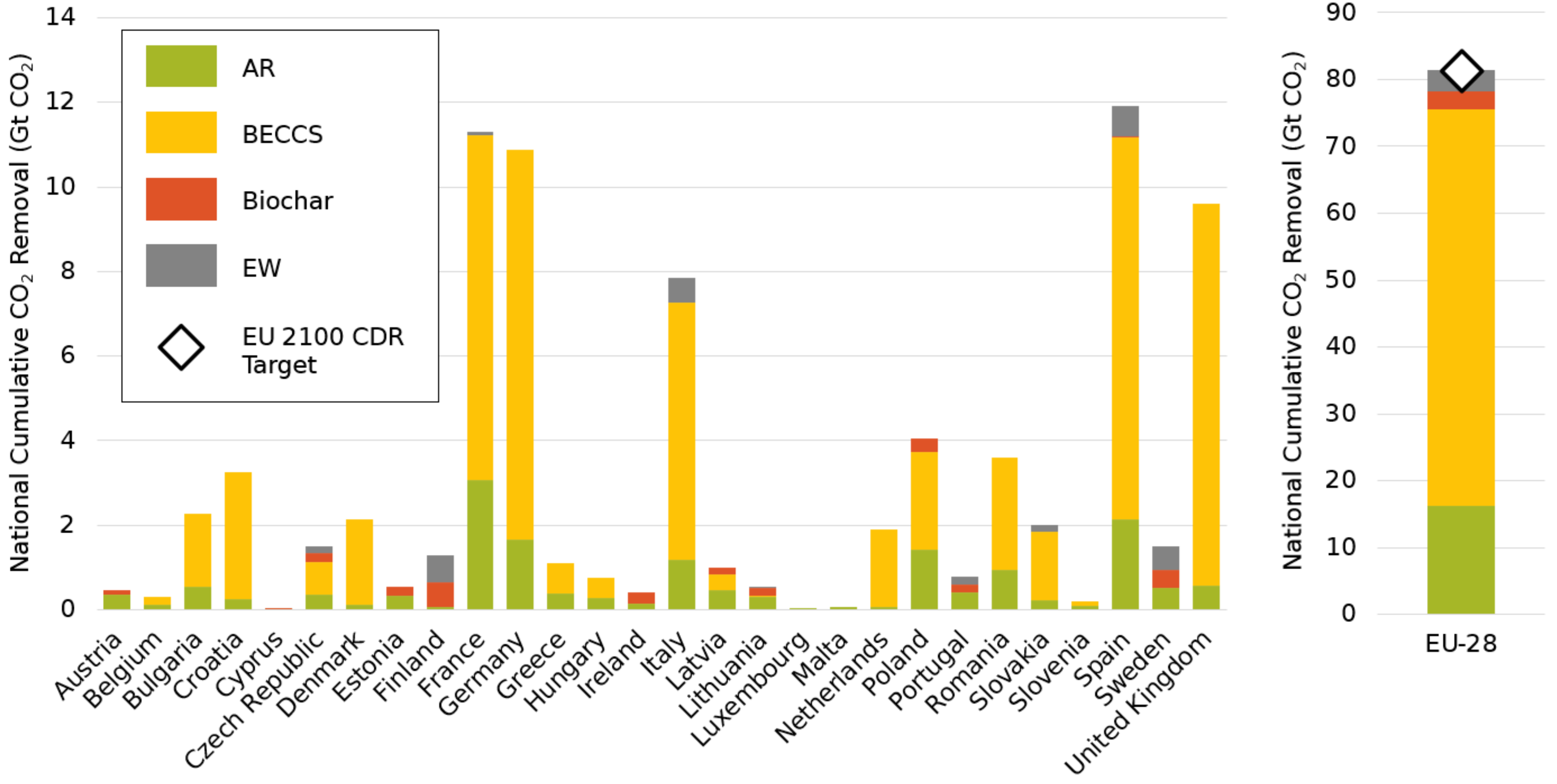
Enhanced weathering with basalt without land application limits – 82 Gt of highly uncertain cumulative CO_2 removal potential by 2100



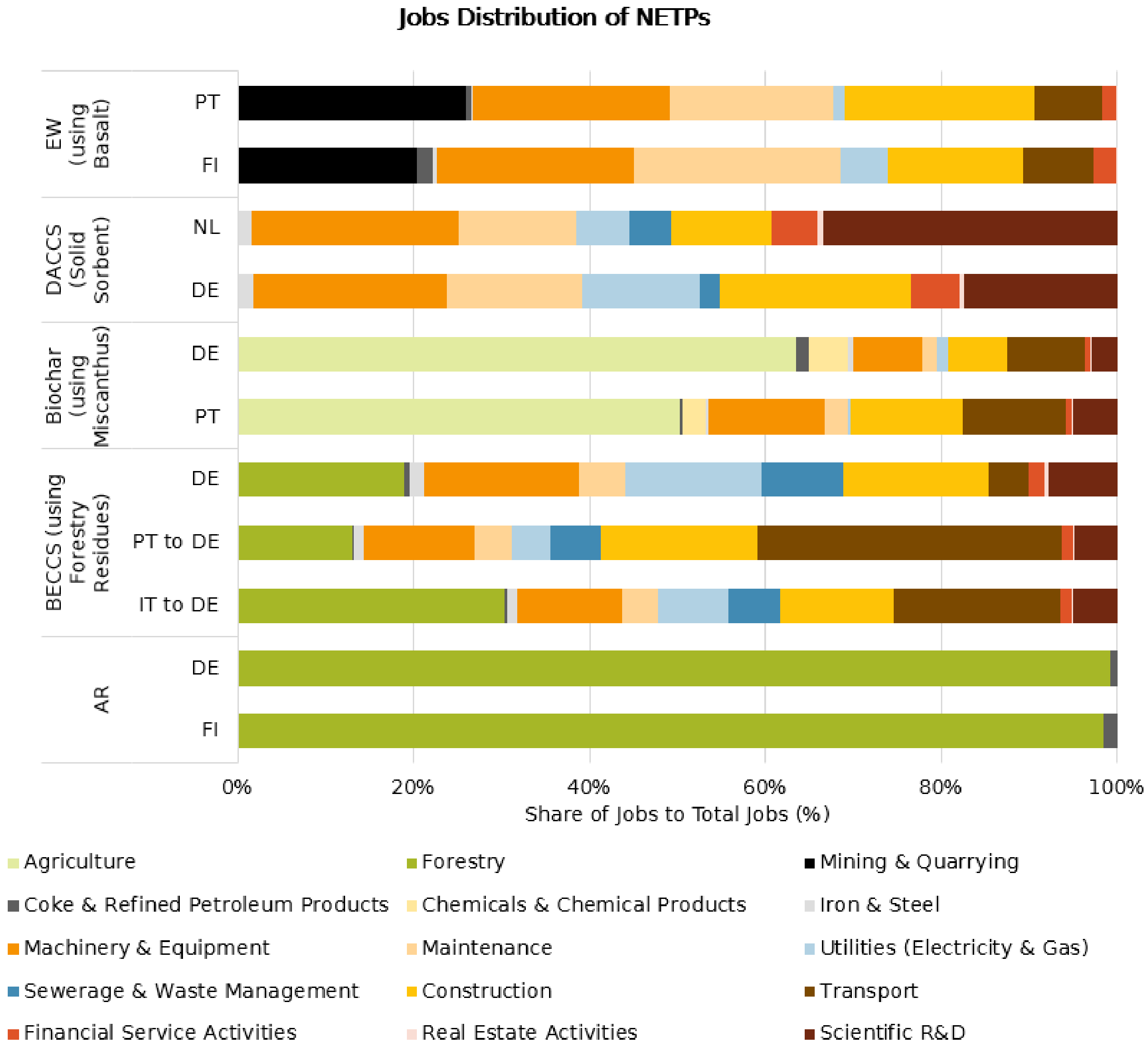
Demand for NETs in the EU member states + UK – a deterministic scenario



Cost-optimal portfolio of NETs for the EU member states + UK – a deterministic outcome



Macro-economic impacts and job distribution?



Insights from the analysis

- P1 and P2 scenarios may be supported with domestic potential for negative emissions in the EU member states.

- Higher levels of CDR deployment will need significant levels of DACCS which will be constrained by the availability of CO_2 storage in Europe.

- At a member-state level, the EU does not have enough “high-certainty” NETs to match or exceed P3 country-level targets based on historical responsibility. Moving beyond 100 Gt CO_2 of removal will be highly challenging.

- Uncertainty analysis is critical to understand the cost profile and achievable amount of negative emissions under limiting assumptions of demand and supply.

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Questions?

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