Carbon Dioxide Removal, Planetary Waste Management & Carbon Pricing: A Public Economics Perspective

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Prof. Dr. Ottmar Edenhofer

Director, Potsdam Institute for Climate Impact Research (PIK)
Director, Mercator Research Institute on Global Commons and Climate Change (MCC)
TU Berlin, Chair of The Economics of Climate Change
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Climate targets and carbon dioxide removals
Window to 1.5°C rapidly closing. “Overshoot” very likely while very risky

Markedly different emission pathways fulfill same carbon budget

Overshoot = Zero by 2050 and Negative emissions thereafter

Source: Bauer et al. (2023, in revision)
No mitigation strategy meets the Paris temperature goal without carbon dioxide removal (CDR)

Source: Smith, Geden, Nemet et al. (2023). *The State of Carbon Dioxide Removal*
The first half of the 21st century is dominated by GHG emission reductions

Source: Smith, Geden, Nemet et al. (2023). The State of Carbon Dioxide Removal
The second half of the 21st century is dominated by CDR

Source: Smith, Geden, Nemet et al. (2023). *The State of Carbon Dioxide Removal*
Huge gap between proposed levels of CDR and actual needs

Carbon dioxide removal (GtCO2/yr), proposed levels compared to three Paris-relevant scenarios in 2030 and 2050

Closing the gap requires scaling up carbon dioxide removal, particularly rapidly in the next decade

Source: Smith, Geden, Nemet et al. (2023). The State of Carbon Dioxide Removal
There is no CDR silver bullet. Portfolios have multiple benefits

- Higher CDR availability can lead to lower levels of net emissions and hence enable earlier emission neutrality

- Limit contribution of each options, thus reducing risks and tradeoffs

- Portfolios balance regional CDR deployment

Source: Strefler et al. (2021). Carbon dioxide removal technologies are not born equal
Optimal Carbon Pricing
Carbon dioxide removal needs good governance
To infinity and beyond? Storage times of CDR methods vary significantly

<table>
<thead>
<tr>
<th>Technology</th>
<th>Potentials (Gt CO₂ yr⁻¹)</th>
<th>Costs ($)</th>
<th>Storage duration (half-life)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afforestation/reforestation</td>
<td>0.5-3.6</td>
<td>0-50</td>
<td>Decades to centuries</td>
</tr>
<tr>
<td>BECCS</td>
<td>0.5-5</td>
<td>100-200</td>
<td>Millenia</td>
</tr>
<tr>
<td>Ocean alkalinisation</td>
<td>0.1-10</td>
<td>14-500</td>
<td>Centuries</td>
</tr>
<tr>
<td>Enhanced weathering</td>
<td>2-4</td>
<td>50-200</td>
<td>Centuries</td>
</tr>
<tr>
<td>Biochar</td>
<td>0.5-2</td>
<td>30-120</td>
<td>Centuries</td>
</tr>
<tr>
<td>Modified patterns of agriculture</td>
<td>2-5</td>
<td>0-100</td>
<td>Years to decades</td>
</tr>
<tr>
<td>DACCS</td>
<td>0.5-5</td>
<td>100-300</td>
<td>Millennia</td>
</tr>
</tbody>
</table>

Source: Kalkuhl et al. (2023). *Pigou’s Advice and Sisyphus’ Warning: Carbon Pricing with Non-Permanent Carbon-Dioxide Removal*
Non-permanent carbon removal introduces a new social cost of carbon metric: the social cost of carbon removal

› The conventional **social cost of carbon emissions (SCC-E)** is a measure of the marginal climate change damages from one ton of carbon emitted into the atmosphere

› The new metric **social costs of carbon removal (SCC-R)** is a measure of climate change damages resulting from releasing emissions from storage

› The SCC-E and SCC-R metrics are **central concepts for the design of tax and subsidy policies**
Planetary waste management will become core task in the 21st century

1) **Downstream pricing**
   - Price all removals and all occurring leakage/releases at the same carbon price

2) **Downstream pricing**
   - Carbon tax on emissions from economic activity and a subsidy adjusted for the social cost of carbon removal

3) **Storage stock subsidy**
   - Annual subsidy on carbon reservoir

4) **Pricing of carbon stock in atmosphere**
   - Taxation of cumulative net CO₂ emissions / 'carbon shares'
Optimal pricing for carbon dioxide removal depends on inter-regional leakage

Under inter-regional carbon leakage, the optimal CDR subsidy should exceed the price for carbon (reducing emissions by a ton of CO₂ domestically causes more inter-regional leakage than removing a ton).

This wedge may be exacerbated or reversed, depending on the resource trade balance of a country.

A net exporter of fossil resources increases the price differential to increase rents of their carbon resource producers.

A net importer sets a carbon tax above the CDR subsidy to appropriate the resource rents from resource exporters.
Separate quantity targets for residual emissions and CDR lead to diverging prices

Hotelling price paths to reach respective abatement and CDR target in 2050 at net CO2 neutrality

Carbon price or CDR subsidy in [$/t CO2]

<table>
<thead>
<tr>
<th>CO2 price</th>
<th>CDR subsidy</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 GtCO2/y</td>
<td>2 GtCO2/y</td>
</tr>
<tr>
<td>4 GtCO2/y</td>
<td>4 GtCO2/y</td>
</tr>
<tr>
<td>6 GtCO2/y</td>
<td>6 GtCO2/y</td>
</tr>
<tr>
<td>Optimum (6.7 GtCO2/y)</td>
<td>Optimum (6.7 GtCO2/y)</td>
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<tr>
<td>7 GtCO2/y</td>
<td>7 GtCO2/y</td>
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<tr>
<td>8 GtCO2/y</td>
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</tr>
<tr>
<td>10 GtCO2/y</td>
<td>10 GtCO2/y</td>
</tr>
</tbody>
</table>

Source: Merfort & Strefler, in prep.

Decreasing residual emissions and reliance on CDR at net-zero
Governing CDR in the European Union
Climate neutrality implies that residual emissions are balanced by carbon dioxide removals

Residual Greenhouse Gas Emissions in EU Green Deal Scenario

Source: Rodrigues, Pietzcker et al., in prep
“Fit for 55” revision: The EU ETS endgame could start in 2039 already

› Increasingly scarce allowance supply will heavily alter price formation and the functioning of the market

› “Endgame” characterized by transition from positive to negative supply equilibrium (ie. balancing of rest emission via CO₂ removals)

› This raises the question whether the ETS is fit for climate neutrality and how governance must be adjusted to account for the changes

Source: Pahle et al. (2023). The Emerging Endgame: The EU ETS on the Road Towards Climate Neutrality
Managing the ETS cap: emissions from non-permanent removal need to be compensated by further removals

- Initial removal of C non-permanent units (1) creates additional ETS certificates (2)
- Released emissions from reservoir have to be compensated by additional removals (3)
- This goes on in perpetuity (4, 5, ..)

Source: Edenhofer et al. (2023). *On the Governance of Carbon Dioxide Removal – A Public Economics Perspective*
Released emissions can also be compensated by regular ETS certificate

- Non-permanent removal (1) is compensated by a regular ETS certificate (2)
- Perpetual renewal of removals becomes a financial liability in the ETS

Source: Edenhofer et al. (2023). *On the Governance of Carbon Dioxide Removal – A Public Economics Perspective*
The carbon debt from non-permanent removal activities might be very large or even infinite

<table>
<thead>
<tr>
<th>$\gamma_R$</th>
<th>$r$</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>50</th>
<th>100</th>
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<td>1.2</td>
<td>0.3</td>
<td>0.1</td>
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<tr>
<td>5%</td>
<td>3.6</td>
<td>1.6</td>
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<td>0.1</td>
<td>0.0</td>
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<tr>
<td>1%</td>
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<td>∞</td>
<td>∞</td>
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<td>∞</td>
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<tr>
<td>2%</td>
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<tr>
<td>3%</td>
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<td>3.0</td>
<td>1.3</td>
<td>0.3</td>
<td>0.1</td>
<td></td>
</tr>
</tbody>
</table>

$\gamma_R =$ growth rate of marginal removal costs

$r =$ discount rate

Source: Edenhofer et al. (2023). On the Governance of Carbon Dioxide Removal – A Public Economics Perspective
A way forward: A governance proposal for CDR in the EU

- Carbon Removal Certification Authority
- European Carbon Central Bank
- Green Leap Innovation Authority
Key takeaways

› **Climate targets cannot be met without CDR.** Sustainably managing the carbon cycle is a core challenge of climate action in the 21st century ("planetary waste management system").

› The **CDR gap needs to be addressed swiftly.** Early years of technology deployment are decisive for upscaling and successfully meeting demand in the coming decades.

› Without **good governance**, the CDR gap won’t close and mitigation efforts might be jeopardized. Deployment at scale requires a consistent policy framework and solid incentive schemes.

› A **governance framework for carbon dioxide removal and a mandate for a European Carbon Central Bank** should find its way into EU legislation.
Thank you

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