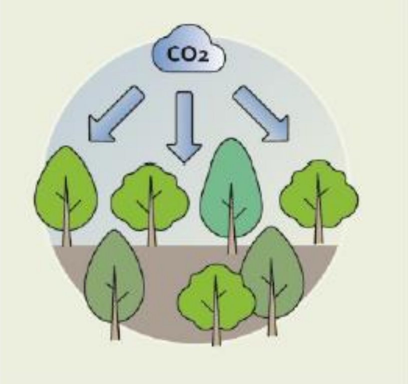
Christian Bauer :: Laboratory for Energy Systems Analysis (LEA) :: Paul Scherrer Institut

LCA of Negative Emission Technologies/Carbon Dioxide Removal: Current state and recommendations

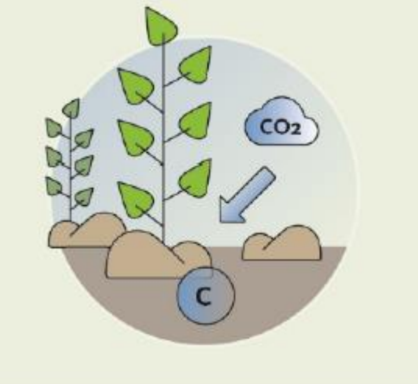
80th LCA discussion forum, 9.6.2022

Carbon Dioxide Removal / Negative Emission Technologies

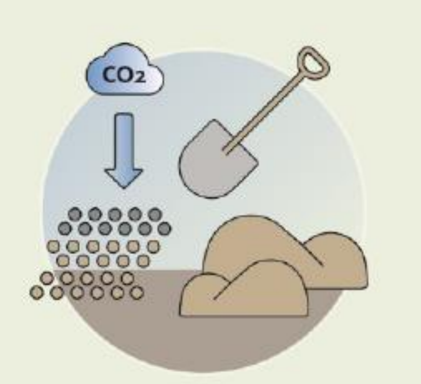
Afforestation, Reforestation



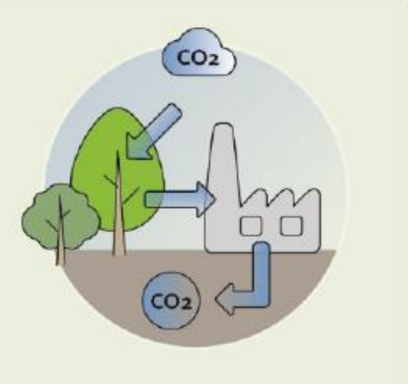
Soil management and biochar



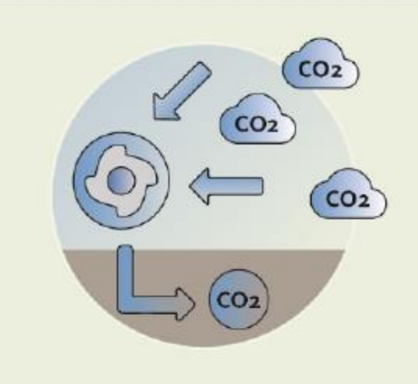
Enhanced Weathering



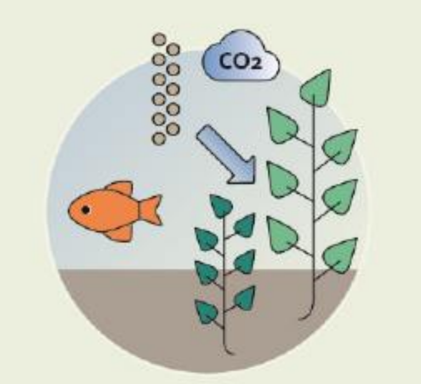
Bioenergy with Carbon Capture & Storage



Direct Air Carbon Capture and Storage



Ocean Fertilization



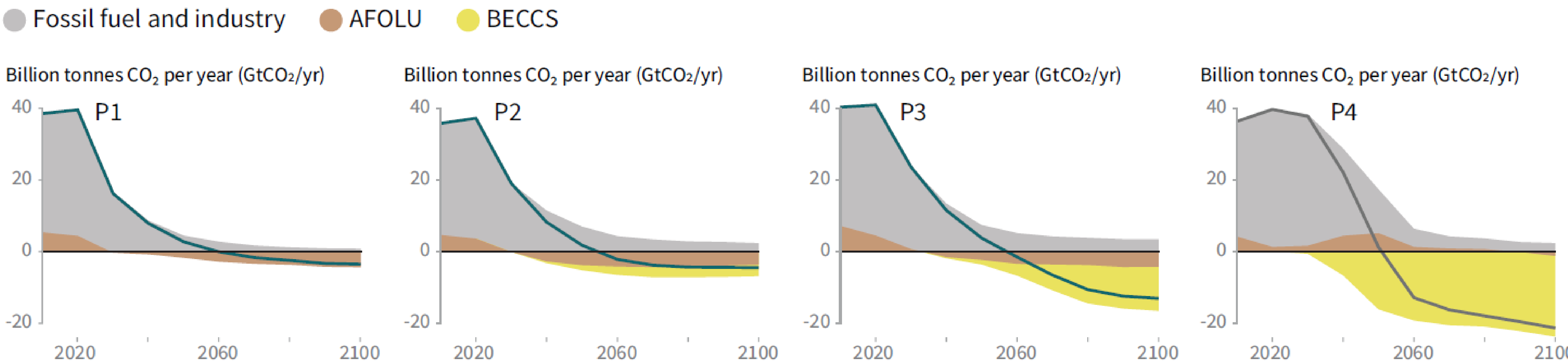
Key feature: Permanent ("very long-term") removal of CO_2 (GHG) from the atmosphere

"CDR refers to **anthropogenic activities removing CO_2 from the atmosphere** and **durably storing it** in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological, geochemical or chemical CO_2 sinks, but excludes natural CO_2 uptake not directly caused by human activities. Carbon Capture and Storage (**CCS**) and Carbon Capture and Utilisation (**CCU**) **applied to fossil CO_2 do not count as removal technologies**. CCS and CCU can only be part of CDR methods if the CO_2 is biogenic or directly captured from ambient air, and stored durably in geological reservoirs or products."

BAFU 2020 | IPCC 2022

CDR as enabler of IPCC's 1.5°C scenarios

Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways



P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

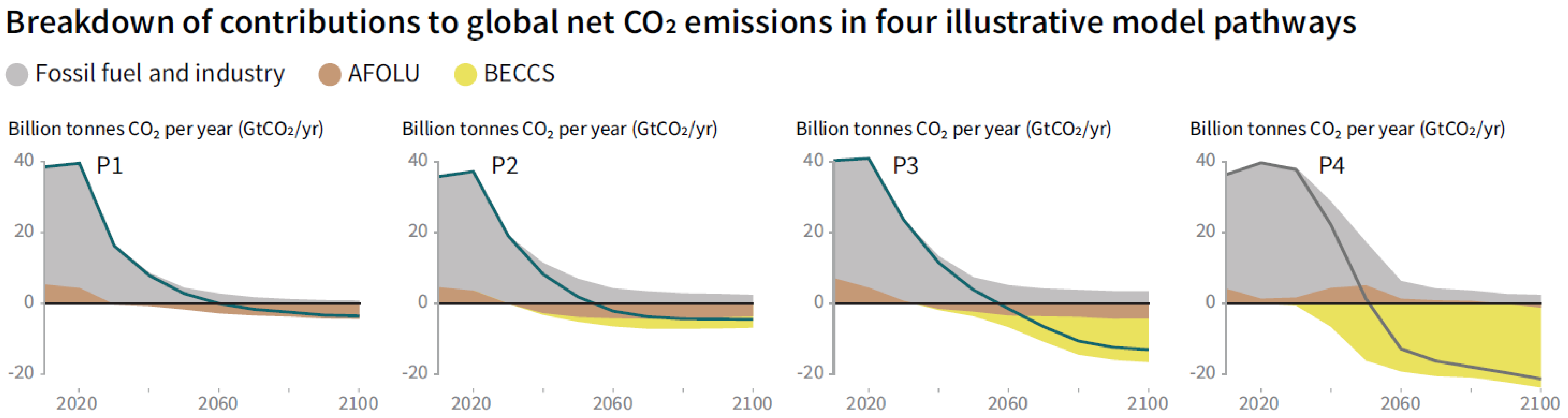
P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

IPCC 2018

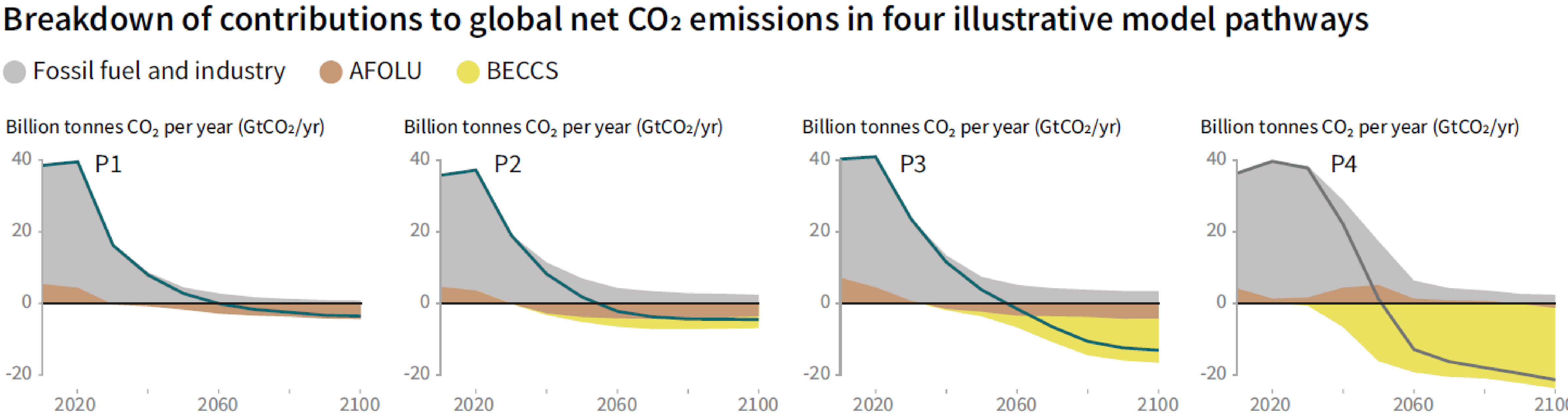
CDR as enabler of IPCC's 1.5°C scenarios



- Expected future emissions from **existing fossil fuel infrastructure** ("locked in emissions") already exceeds the remaining carbon budget for 1.5°C global warming
- Even if fossil fuel emissions were immediately halted, current trends in **global food systems** would prevent the achievement of the 1.5°C target and threaten the achievement of the 2°C target

IPCC 2018 | IPCC 2022 | Clark et al. (2020), https://www.science.org/doi/10.1126/science.aba7357

CDR as enabler of IPCC’s 1.5°C scenarios

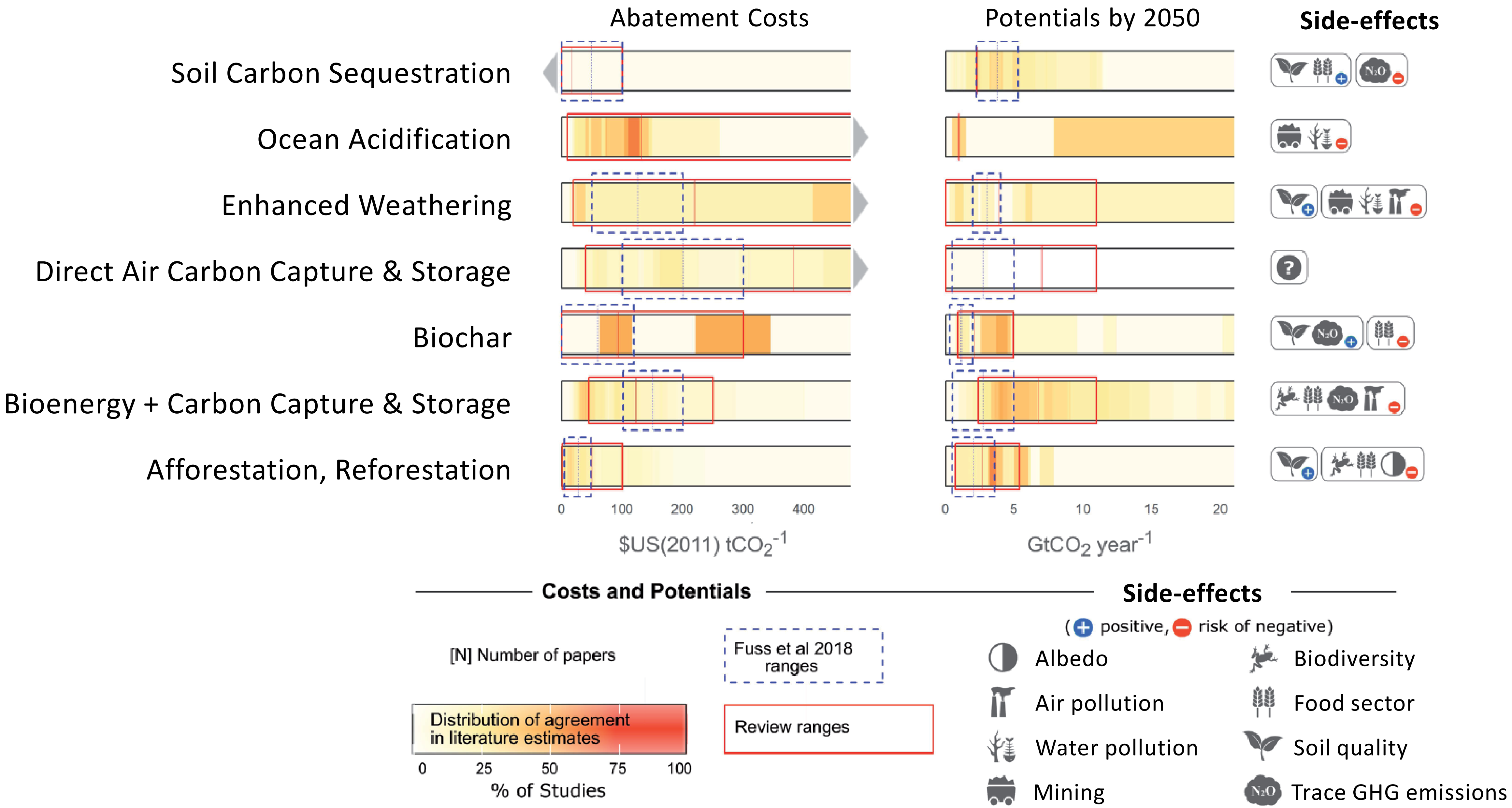


Roles of CDR

1) Near-term: **Reducing net CO_2 or GHG emissions**
2) Mid-term: **Counterbalancing “hard-to-abate” residual emissions** – CO_2 from industrial activities, CH_4 from agriculture
3) Long-term: **Achieving net negative CO_2 or GHG emissions** to remove the accumulated stock of atmospheric CO_2 from human activities in the past

IPCC 2022

CDR / NET – Sustainability concerns



Role of LCA in the evaluation of CDR / NET

- Quantifying the "net-effectiveness" of CO_2 removal
  - ✓ Indirect GHG emissions
  - ✓ Addressing temporal aspects – permanence of CO_2 removal
- Quantifying adverse human-health/ecosystem/resource-related side effects

Issues

- Partially low maturity of CDR options
- Small-scale vs. large-scale application (consequential LCA)
- Location-specific aspects (regionalized LCA)

Urgent need for reliable LCA

- «Carbon removal markets»
- Mitigation pathways/scenarios (IPCC,…)

Current status regarding LCA of CDR / NET

Energy & Environmental Science

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REVIEW

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Life cycle assessment of carbon dioxide removal technologies: a critical review†

Tom Terlouw, *[ab] Christian Bauer, [a] Lorenzo Rosa [b] and Marco Mazzotti [b]

A large number of prospective climate scenarios rely on Carbon Dioxide Removal (CDR) technologies to limit global warming below 2 °C. To date, however, a comprehensive understanding of the overall life-cycle environmental impacts of CDR technologies is missing. We present a critical review on conducted Life Cycle Assessments (LCAs) of a comprehensive set of CDR technologies: afforestation and reforestation, biochar, soil carbon sequestration, enhanced weathering, ocean fertilisation, bioenergy with carbon capture and storage, and direct air carbon capture and storage. One of the key observations is that emissions avoided due to substitution of certain processes (due to system expansion in LCA) can be easily misinterpreted as negative emissions, *i.e.* as carbon removal from the atmosphere. Based on the observed inconsistencies and shortcomings, we recommend to interpret available CDR LCA results with caution. To improve the understanding of environmental implications of CDR deployment, we recommend (1) to conduct LCAs with multiple environmental impact categories, (2) to consider the temporal aspect of emissions in biomass-related CDR technologies, (3) to focus on so far overlooked CDR technologies, (4) to be as transparent as possible regarding methodological choices, (5) to capture environmental side-effects, and (6) to distinguish between 'avoided emissions' and 'negative emissions' – only negative emissions correspond to permanent removal from the atmosphere. We conclude that more comprehensive and rigorous LCAs are needed to help inform the design of CDR technology portfolios and to aid in anticipatory governance.

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rsc.li/ees

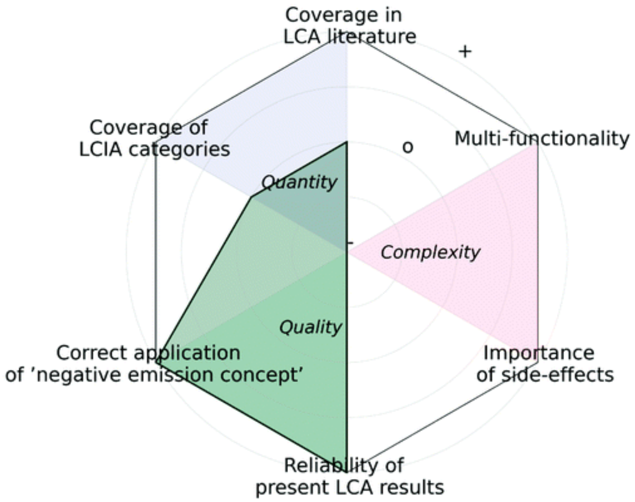
Terlouw et al. 2021a, https://pubs.rsc.org/en/content/articlehtml/2021/ee/d0ee03757e

Current status regarding LCA of CDR / NET

Evaluation criteria applied to all CDR options

- **Quantity**
  - ✓ Number of LCA studies published
  - ✓ LCIA midpoint categories addressed
- **Complexity**
  - ✓ Multi-functionality
  - ✓ Importance of side-effects
- **Quality**
  - ✓ Correct application of “negative emission concept”
  - ✓ Reliability of present LCA results

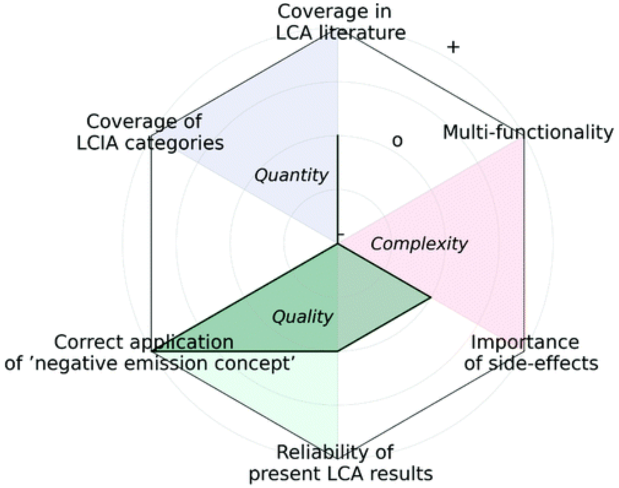
Direct Air Carbon Capture & Storage



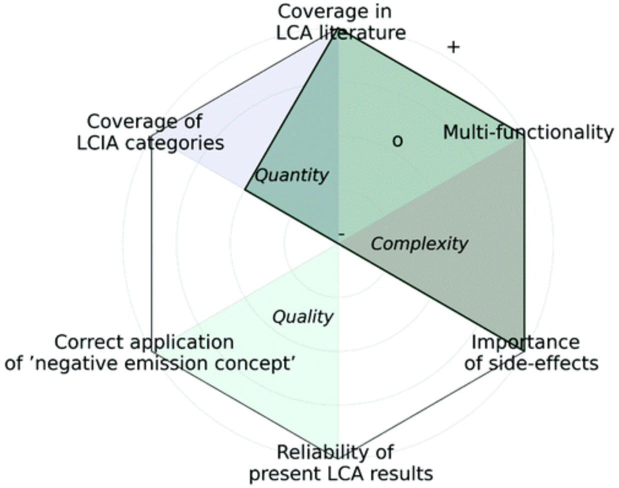
Symbol/abb.	Meaning
Quality	Quality of LCAs
Quantity	Quantity of LCAs
Complexity	Complexity of LCAs
[1]	Source
n.a.	Not Applicable

Current status regarding LCA of CDR / NET

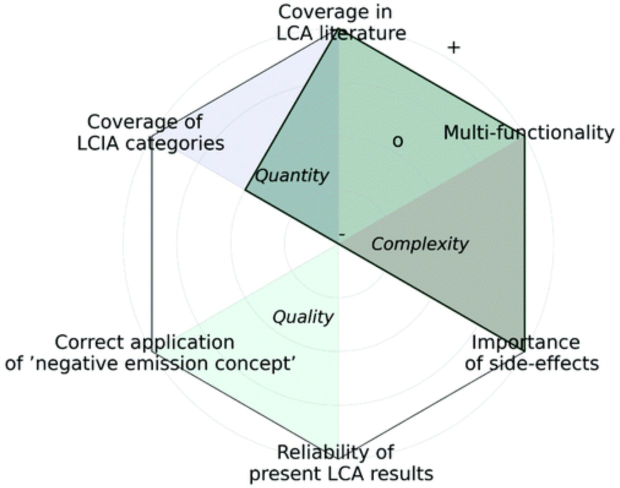
Afforestation & Reforestation



Biochar



Soil Carbon Sequestration



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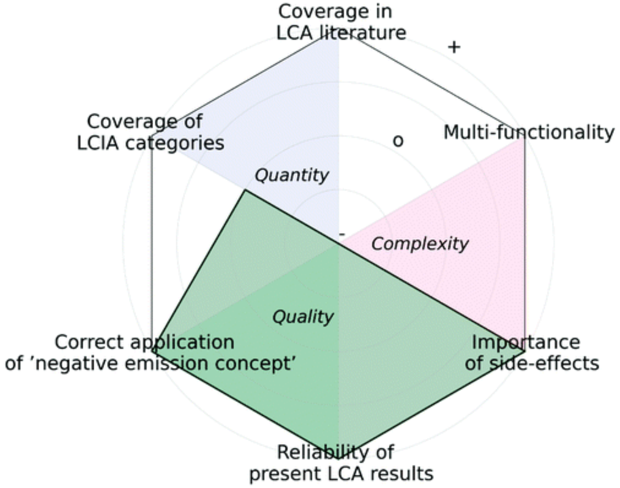

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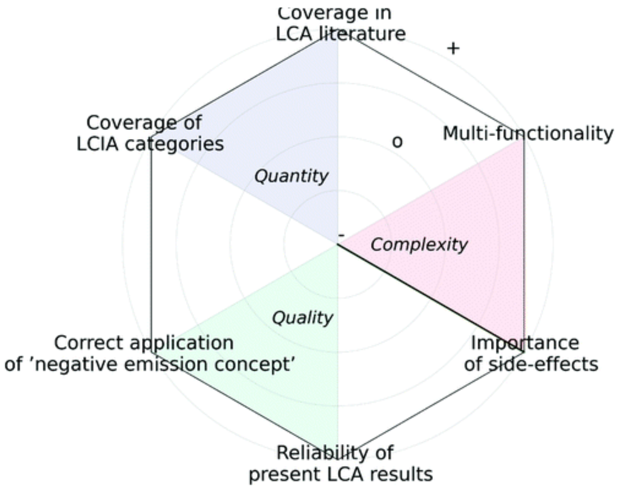
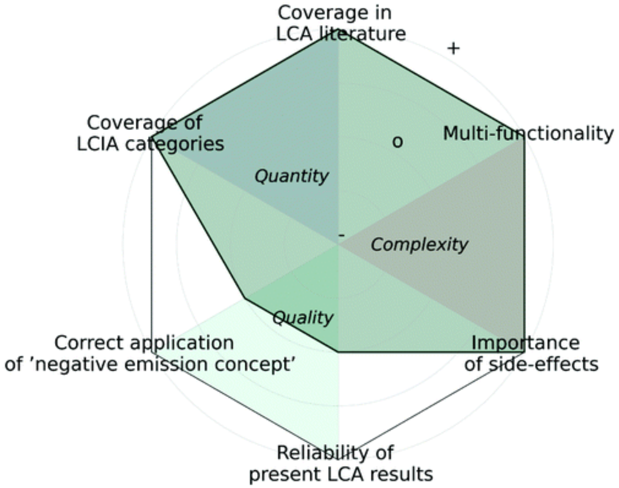
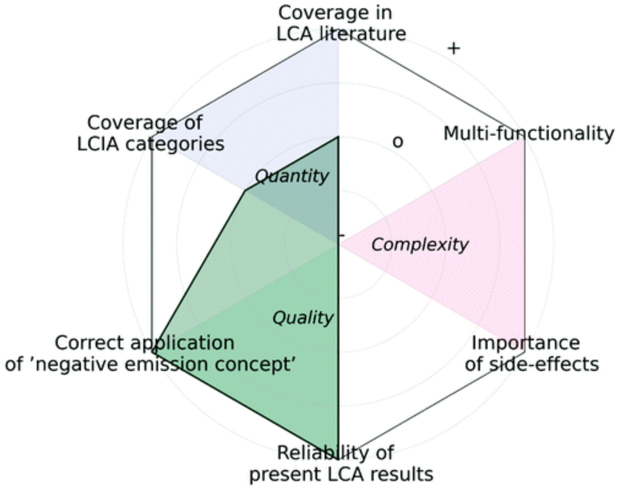


Bioenergy with Carbon Capture & Storage



Direct Air Carbon Capture & Storage



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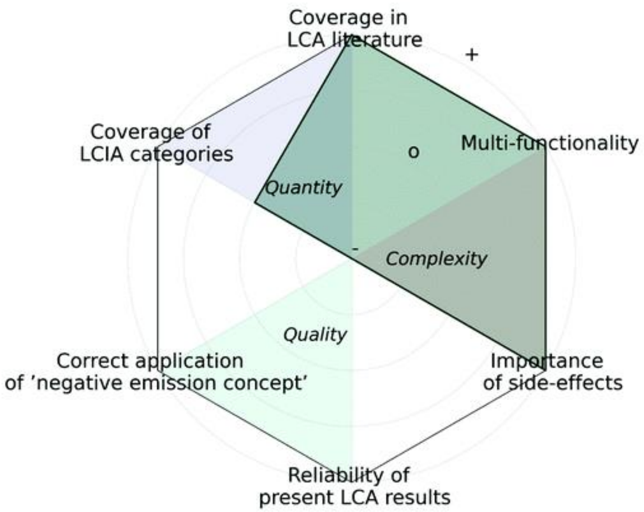
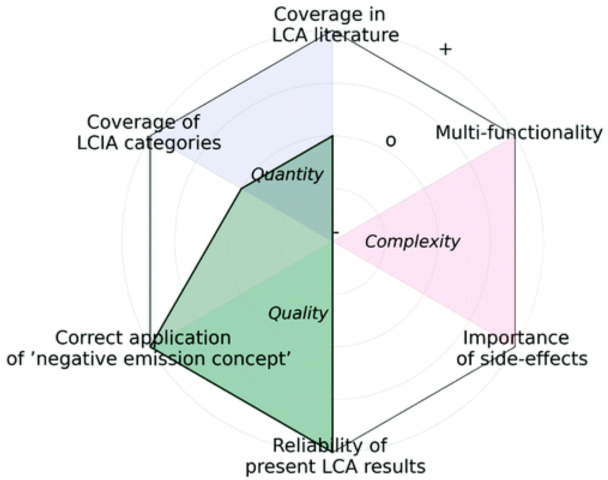
Current status regarding LCA of CDR / NET

Biochar



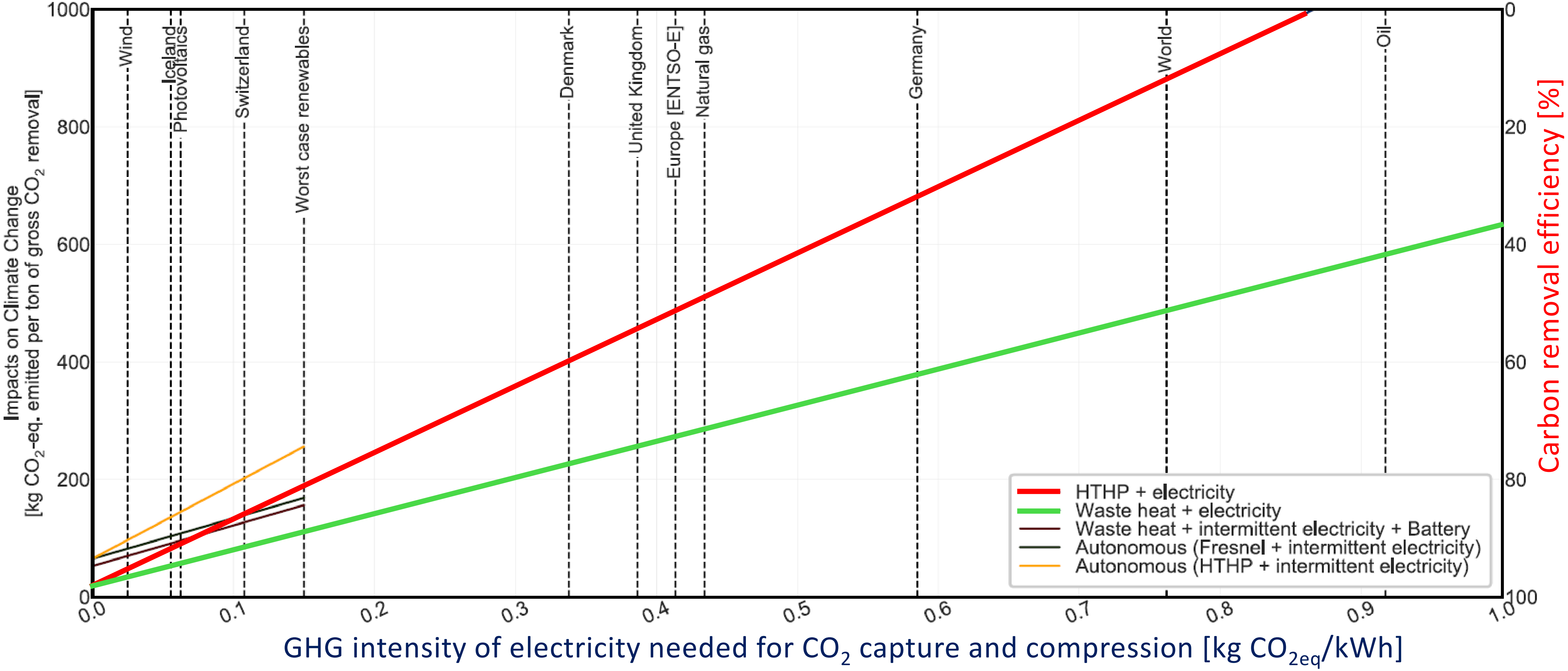
- Numerous, "mixed-quality" LCA studies of biochar published over the years
- Quantifying selected impact categories beyond impacts on climate change
- Multi-functionality: in biomass supply and biochar production
- Side-effects: soil quality change, albedo change, land use change
- "Negative emissions" NOT correctly applied: often CO_2 removals and emission reductions are simply added
- Low level of transparency
- Inconsistent and unreliable results

Direct Air Carbon Capture & Storage



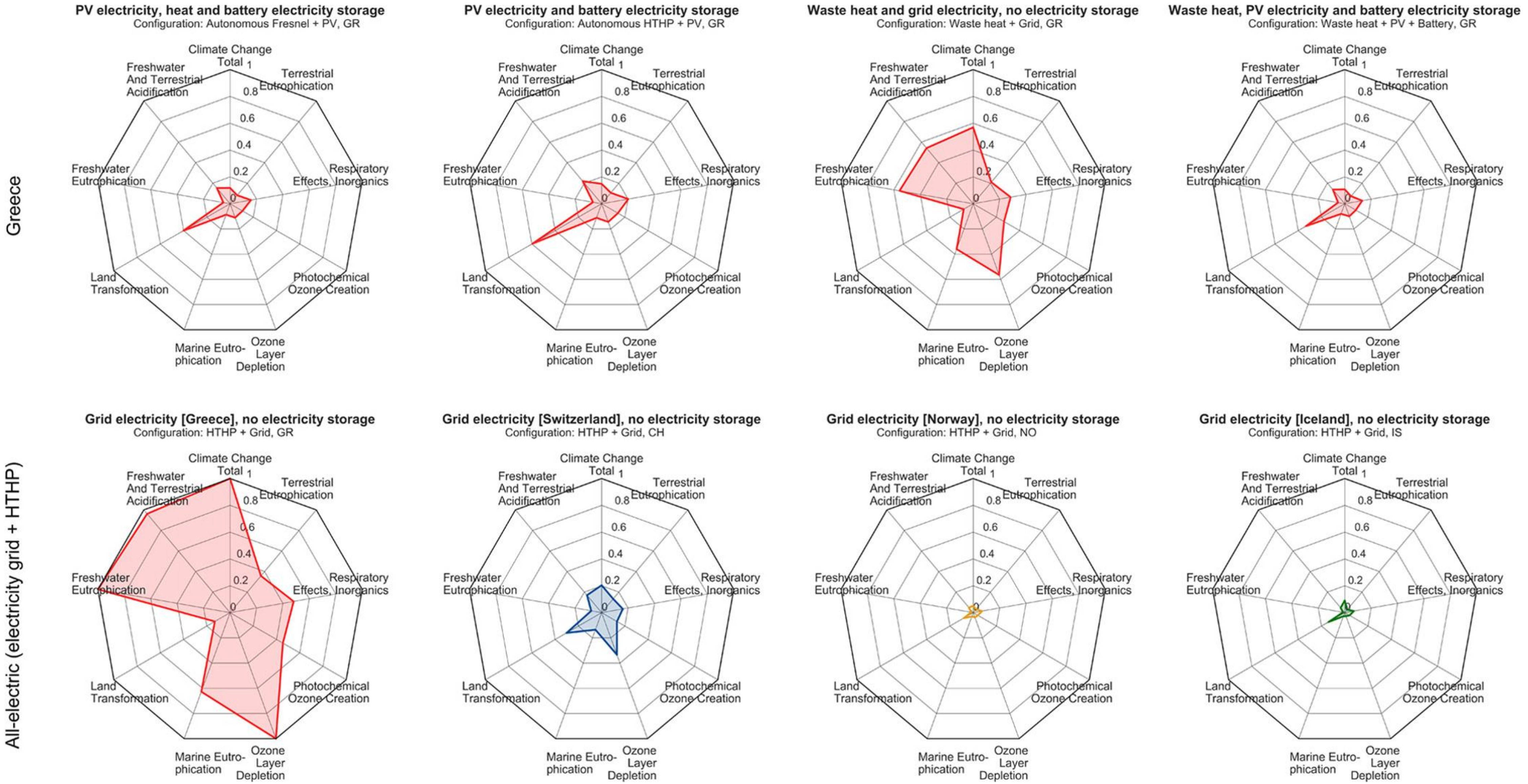
- Few original, high-quality LCA of DACCS recently published
- Quantifying selected impact categories / burdens beyond impacts on climate change
- No multi-functionality: CO_2 removal as only purpose
- No important side effects identified (at small-scale application)
- "Negative emissions" correctly applied
- High level of transparency (extensive ESI)
- Consistent and reliable results

LCA results – example of low-temperature DACCS



Terlouw et al. 2021b, https://pubs.acs.org/doi/10.1021/acs.est.1c03263

LCA results – example of low-temperature DACCS



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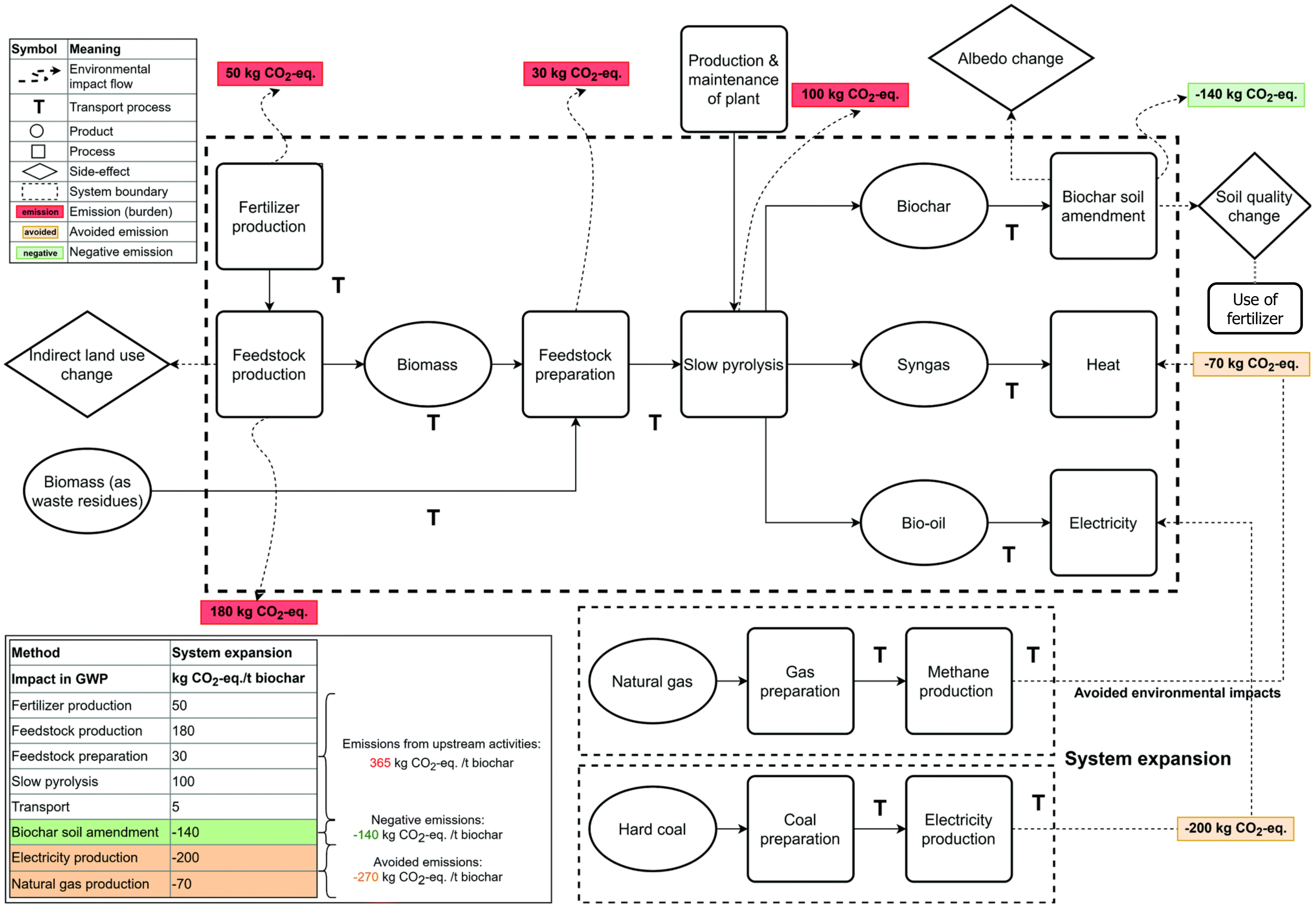
LCA of biochar – complex value chain



Method	System expansion
Impact in GWP	kg CO_2-eq./t biochar
Fertilizer production	50
Feedstock production	180
Feedstock preparation	30
Slow pyrolysis	100
Transport	5
Biochar soil amendment	-140
Electricity production	-200
Natural gas production	-70

Issues identified:

- Sum of CO_2 permanently removed and avoided emissions are reported as "negative emissions"
- Lack of transparency
  - ✓ System boundaries
  - ✓ Approach for multi-functionality
  - ✓ Addressing temporal dynamics of CO_2 in soil
- Lack of sensitivity analysis

Terlouw et al. 2021a, https://pubs.rsc.org/en/content/articlehtml/2021/ee/d0ee03757e

Summary and recommendations

- CDR is indispensable to limit global warming at 1.5-2 degrees
- Quantifying net-effectiveness, environmental co-benefits and trade-offs calls for LCA
- **Current status of LCA of CDR: room for improvement!**

Recommendations for practitioners, reviewers and editors

1) Be transparent: methodological choices, LCI
2) Distinguish between “avoided emissions” and “negative emissions” (permanent CO_2 removal)
3) Consider temporal aspects regarding CO_2 removal and storage
4) Do not limit analysis to climate impacts and put other burdens in context
5) If feasible, address system perspective & consequential effects of large-scale implementation
6) Acknowledge potential limitations

Sources

- Terlouw, T., Bauer, C., Rosa, L. and Mazzotti, M. (2021a) Life cycle assessment of carbon dioxide removal technologies: a critical review. Energy & Environmental Science, https://pubs.rsc.org/en/content/articlelanding/2021/EE/D0EE03757E
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Wir schaffen Wissen – heute für morgen

Thanks to:

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https://www.psi.ch/ta/