UFZ HELMHOLTZ Centre for Environmental Research

CDRterra BioNET

Synergiepotenziale & Risiken

Feasibility assessment of carbon dioxide removal (CDR) in Germany – comprehensive evaluation of selected options

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HELMHOLTZ CLIMATE INITIATIVE

Motivation and aim of the study

German emissions in 2020: 644 Mt CO_2 [1]

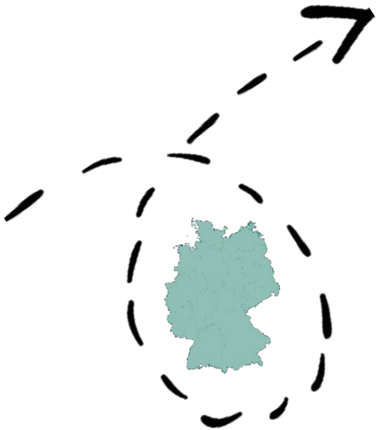
Carbon budget **6.9 Gt CO_2** [2]

Avoid and reduce

Hard-to-abate **~ 60 Mt CO_2/yr** [3]

CDR

Graphics by MCC

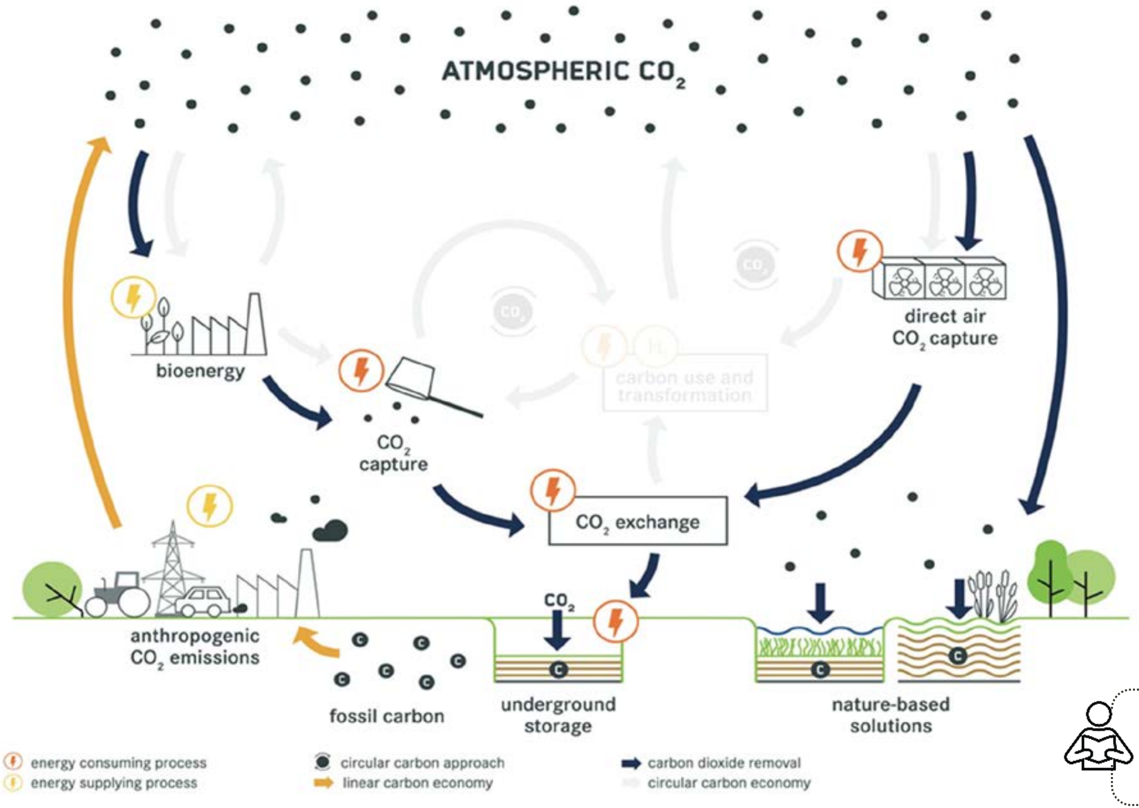


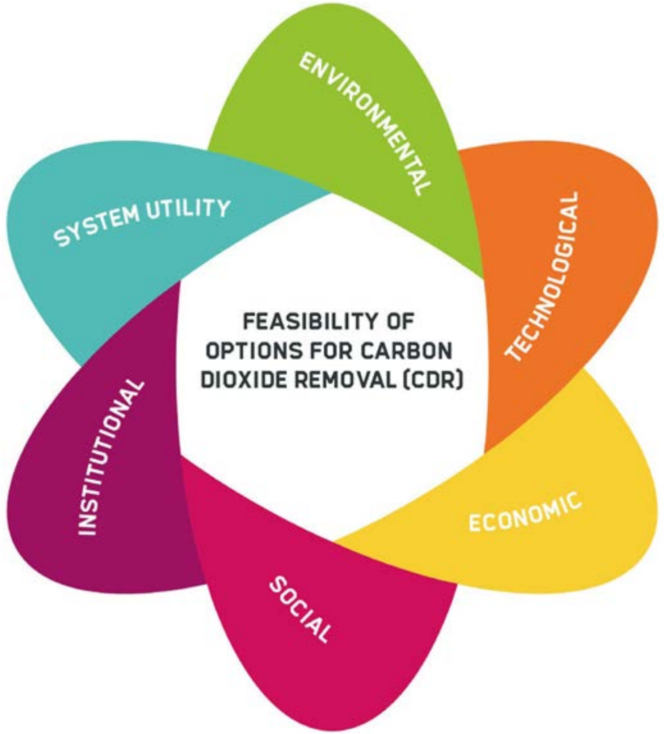
Aim

Multi-dimensional assessment of feasibility of selected CDR options addressing their specific, national context of implementation.

1: UBA, 2021 | 2: Mengis et al., 2021 | 3: Mengis, Kalhori et al., 2022

How can we know CDR is a good idea?





Förster et al. (2022) Framework for Assessing the Feasibility of Carbon Dioxide Removal Options Within the National Context of Germany. Frontiers in Climate 4:758628

Selection of CDR options

Borchers, M. et al. (2022): Scoping carbon dioxide removal options for Germany– What is their potential contribution to Net-Zero CO_2? *Front. Clim.* **4** , art. 810343

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Units of CDR options

Plants

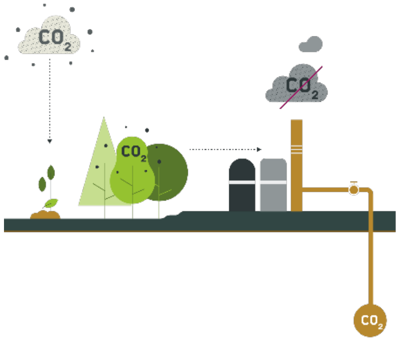
BECCS or DACCS

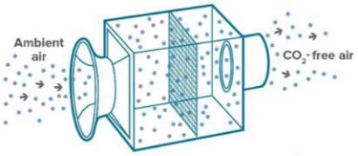
Unit of area

e.g. 1 ha NSE & ERW

Selection criteria

- Maturity level
- Availability of biomass
- Geophysical conditions
- …





- ✓ BECCS: Wood combustion CHP
- ✓ BECCS: Slow pyrolysis for biochar
- ✓ BECCS: Gasification BtL
- ✓ BECCS: Mixed biomass biogas CHP
- ✓ BECCS: Paludiculture biogas CHP
- ✓ BECCS: Macroalgae biogas CHP
- ✓ DACCS: farms (centralized)
- ✓ DACCS: HVAC (decentralized)
- ✓ Enhanced Rock Weathering
- ✓ NSE: afforestation of cropland
- ✓ NSE: SOC - cover crops
- ✓ NSE: peatland rewetting
- ✓ NSE: seagrass meadows restoration
- ✓ Geological CO_2 storage

Assessment framework

Förster et al. (2022) Framework for Assessing the Feasibility of Carbon Dioxide Removal Options Within the National Context of Germany. Frontiers in Climate 4:758628

- 32 interdisciplinary experts
- internal review
- workshop & meetings

HELMHOLTZ CLIMATE INITIATIVE

- 13 CDR options
- 6 dimensions
- 26 criteria
- 68 indicators (6-14 per dimen.)

	OPTION 1	OPTION 2	…
ENVIRONMENTAL			…
TECHNOLOGICAL			…
ECONOMIC			…
SOCIAL			…
INSTITUTIONAL			…
SYSTEM UTILITY			…

EVALUATION SCALE

- traffic light system
- where and what effort for implementation

		Carbon capture mechanism:	hybrid (biological + technological)						chemical				biological				
		CDR option:	BECC (+S)						DACC (+S)		ERW	S					
			WCom	WGas	WPyr	MxBG	PalBG	MABG	Farms	HVAC		GEOSTOR	PReW	agricAFF	agricCC	agricCR	SeaGr
Systemic effects on climate	F1: CDR potential	F1.1 Max. feasible net CO2 emissions removal deployed by 2050	▯ D	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻ ▯	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻ ▯ D
		F1.2 Max. feasible 'near-term' net CO2 emissions removal	☻ ▯ D	☻ D	☻ D	☻ D	☻ ▯ D	☻ ▯ D	☻ D	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻ D	☻ D	☻ D	☻ ▯ D	☻ D
		F1.3 Max. total sequestration potential between 2020 and 2050	☻ ▯ D	☻ ▯ D	☻ D	☻ D	☻ D	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻ D	☻ ▯ D	☻ ▯ D	☻ ▯ D
	F2: CO2 emissions avoidance potential (CirC potential)	F2.1 Max. of CO2 emissions avoided through deployment in 2050	☻ ▯ D	☻ ▯ D	☻ D	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻ D	☻ D	☻ D	☻	☻ ▯ D	☻	☻	☻	☻ D
		F2.2 Max. CO2 emissions avoided in the 'near-term' through deployment	☻ ▯ D	☻ D	☻ D	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻ D	☻ D	☻ D	☻	☻ ▯ D	☻	☻	☻	☻ D
	F3: Permanence	F3.1 Natural persistence of storage	seeGEO-STOR	seeGEO-STOR	☻ ▯ D	seeGEO-STOR	seeGEO-STOR	seeGEO-STOR	seeGEO-STOR	seeGEO-STOR	☻ ▯	☻ ▯	☻ ▯ D	☻	☻ ▯	☻	☻
		F3.2 Risk of carbon loss due to climate change and/or natural disturbances	seeGEO-STOR	seeGEO-STOR	☻	seeGEO-STOR	seeGEO-STOR	seeGEO-STOR	seeGEO-STOR	seeGEO-STOR	☻	☻ ▯ D	☻	☻ ▯	☻	☻	☻ ▯ D
		F3.3 Risk of carbon loss due to antropogenic disturbances	seeGEO-STOR	☻	☻	seeGEO-STOR	seeGEO-STOR	seeGEO-STOR	seeGEO-STOR	seeGEO-STOR	☻	☻	☻	☻	☻	☻	☻ ▯ D
	F4: Verifiability	F4.1 Ability to confirm the amount of CO2 captured/avoided	☻ D	☻ D	☻	☻ D	☻ D	☻	☻	☻	☻ ▯	☻	☻	☻	☻	☻	☻
		F4.2 Ability to confirm the amount of CO2 stored	seeGEO-STOR	☻	☻	seeGEO-STOR	seeGEO-STOR	seeGEO-STOR	seeGEO-STOR	seeGEO-STOR	☻ ▯	☻ ▯	☻	☻ ▯	☻ ▯	☻ ▯	☻
		F4.3 Uncertainty of estimates for CO2 removal/avoidance	☻	☻	☻	☻	☻	☻	☻	☻	☻ ▯ D	☻	☻	☻	☻	☻ D	☻ ▯
Environmental	A1: Impact on air/atmosphere	A 1.1 Outdoor air quality (with an impact on human health)	☻ ▯	☻ D	☻ D	☻	☻	☻	☻	☻	☻	☻ ▯	☻ ▯ D	☻	☻	☻	☻
		A 1.2 GHG emissions related to land/sea use change	☻ ▯	☻ D	☻ D	☻ ▯	☻ ▯ D	☻	☻	☻	☻ ▯	☻	☻ ▯ D	☻	☻	☻	☻
		A 1.3 Net biophysical effect on local climate (different scales)	☻ ▯	☻ D	☻ D	☻	☻ ▯ D	☻	☻	☻	☻	☻	☻ ▯ D	☻ ▯ D	☻	☻	☻
		A 1.4 Net effects of audible noise on humans and ecosystems	☻ ▯	☻ D	☻ D	☻	☻	☻	☻	☻	☻	☻	☻	☻	☻	☻	☻
	A2: Impact on land and sea area (from land-use / sea-use changes)	A 2.1: Area demand and competition for other area uses (land and/or sea)	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻ ▯ D	☻	☻ ▯	☻ ▯	☻ ▯	☻	☻	☻	☻	☻	☻
		A 2.2: Biodiversity (ecosystems, species, genes)	☻ ▯	☻ ▯ D	☻ ▯ D	☻ ▯	☻ ▯ D	☻ ▯	☻	☻	☻ ▯	☻ ▯	☻ ▯ D	☻	☻	☻	☻
		A. 2.3 Soils (chemical and physical quality)	☻ ▯	☻ D	☻ ▯ D	☻ ▯	☻ ▯ D	☻	☻	☻	☻ ▯	☻ ▯	☻ ▯ D	☻	☻ ▯	☻	☻
	A3: Impact on water	A 3.1 Ground water quality	☻ D	☻ D	☻ D	☻ ▯ D	☻ ▯ D	☻	☻	☻	☻	☻ ▯	☻ ▯ D	☻	☻ ▯	☻	☻
		A 3.2 Water demand / local water availability	☻ ▯ D	☻ D	☻ D	☻ ▯ D	☻ ▯ D	☻	☻	☻	☻	☻ ▯	☻ ▯ D	☻	☻	☻	☻
		A 3.3 Surface water quality	☻ D	☻ D	☻ D	☻ ▯ D	☻ ▯ D	☻	☻	☻	☻ ▯	☻ ▯	☻ ▯ D	☻	☻ ▯	☻	☻
		A 3.4 Marine water quality	☻ D	☻ D	☻ D	☻ ▯ D	☻ ▯ D	☻ ▯	☻	☻	☻ ▯	☻ ▯	☻ ▯ D	☻	☻ ▯	☻	☻

Abbreviations:

BECC-	WCom	woody biomass feedstock for combustion with CHP	ERW	terr. enhanced rock weathering on agriculture soils
	WGas	woody biomass feedstock for gasification for BtL production	GEOSTOR	geological storage solutions
	WPyr	woody biomass feedstock for pyrolosis for biochar production	PReW	rewetting of peatlands/organic soils
	MxBG	mixed biomass feedstock for biogas with CHP	agricAFF	afforestation of croplands
	PalBG	paludiculture feedstock for biogas with CHP	agricCC	cover crops on agricultural soils
	MABG	macroalgae feedstock for biogas with CHP	agricCR	crop rotation on arable soils
DACC	Farms	Direct Air Carbon Capture Farms	SeaGr	seagrass meadow restoration
	HVAC	DACC installed in heat, ventilation, air-conditioning (HVAC) systems		

(dark green)	no/low hurdles
(light green)	
(yellow)	medium hurdles
(orange)	
(red)	high hurdles
(grey)	Not applicable
(white)	No data
☻	expert assessment
▯	literature-based
D	specific for Germany

Borchers et al. accepted (Earth's Future)

Selected observations

Borchers et al. accepted (Earth's Future)

Systemic feasibility of CDR options:

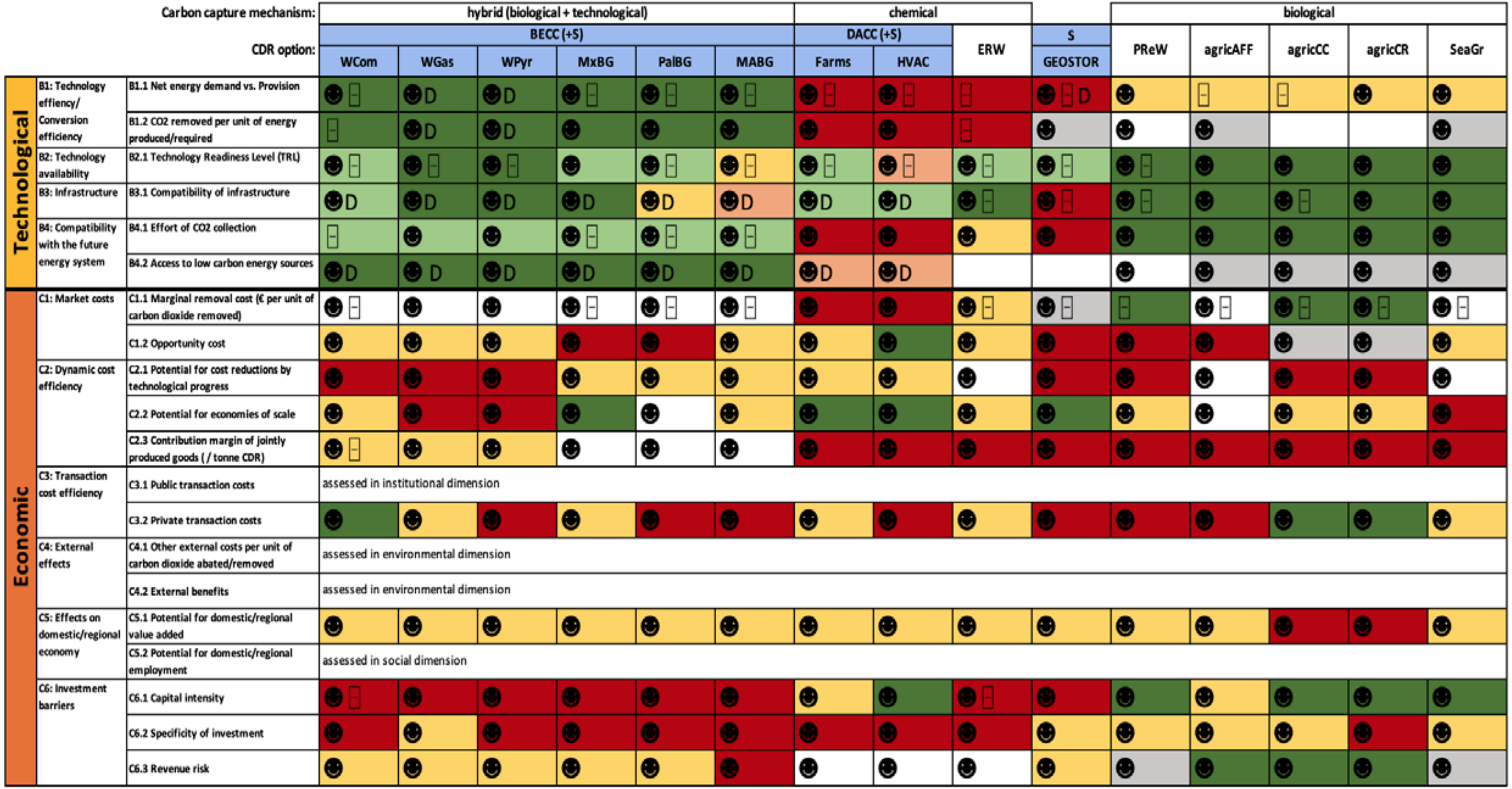
- Options involving carbon capture (S) could technically have a significant contribution to carbon removal (BECCS 0.5-29.9 Mt CO_2/year and DACCS 15-16 Mt CO_2/year)
  *But: CCS is currently not allowed in Germany

- Options of natural sink enhancements (ecosystem restoration, cover crops, etc.) are expected to have smaller contributions to carbon removal (1.7-6.3 Mt CO_2/year)
  *But: potential for mitigating carbon emissions can be high (e.g. peatland restoration)

Environmental feasibility of CDR options:

- BECCS with high demand for biomass can drive land-use change & negative effects

- Natural sink enhancement (ecosystem-based options) mainly beneficial for environment when assuming biodiversity safeguards & best management practices



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Technological feasibility of CDR options:

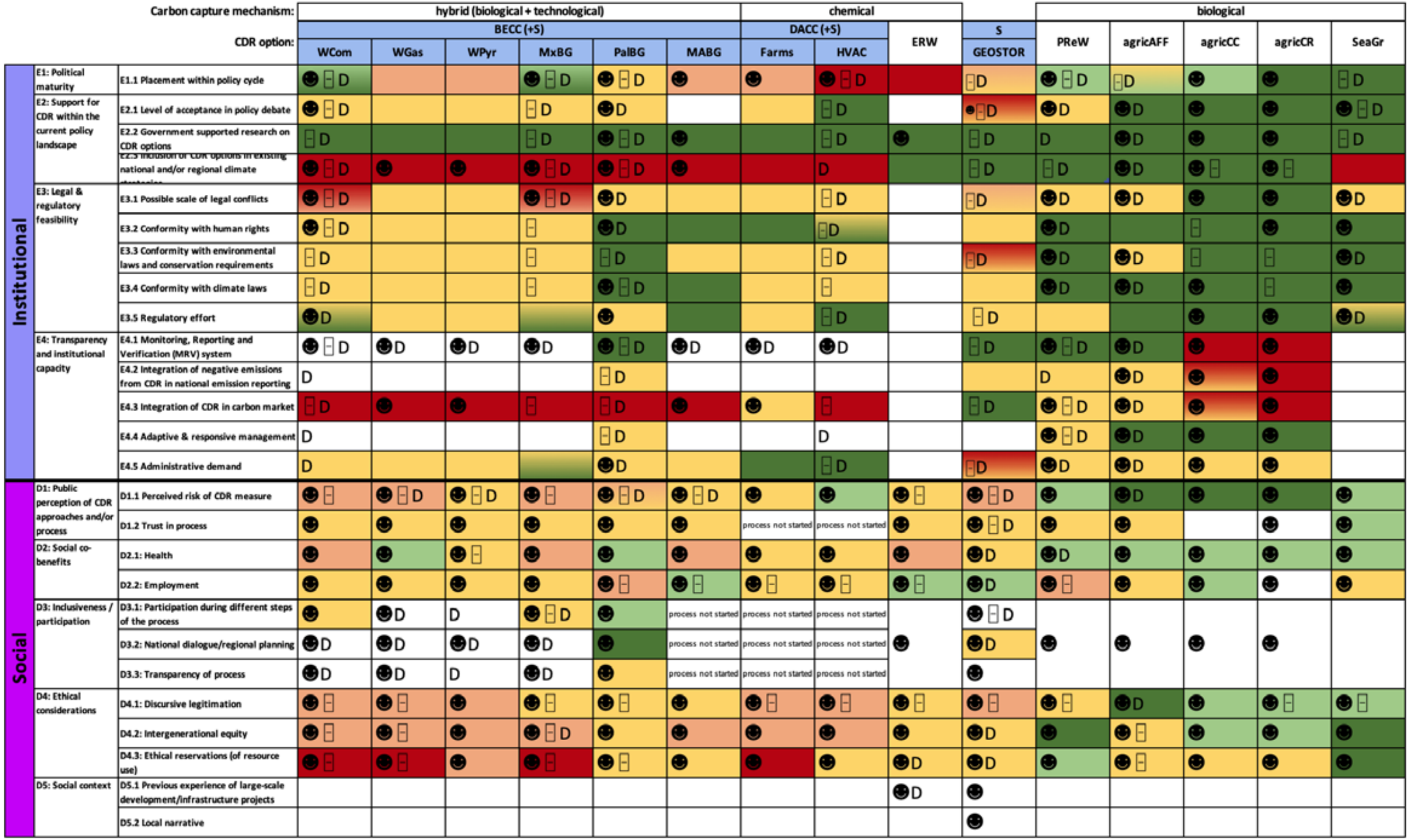
- Most CDR options are feasible from a pure technological perspective; largest technology gaps in DACC-technologies;

- High energy demand is major obstacle in particular for DACC(S) options
  → competition for renewable energy sources

Economic feasibility of CDR options:

- High investment barriers in particular for BECCS & DACCS;
  cost for DACCS may reduce when considering scaling effects

- Natural sink enhancements (ecosystem-based options) have lower investment barriers & lower marginal removal costs but potentially high opportunity costs



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high hurdles
Not applicable
No data
☻ expert assessment
literature-based
D specific for Germany

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Selected observations

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Institutional feasibility of CDR options:

- Technical options with CCS (BECCS & DACCS) limited by carbon storage ban in Germany
- Natural sink enhancements (ecosystem-based options) can be implemented within the existing insitutions & regulations

Social feasibility of CDR options:

- CCS with underground carbon storage perceived to have a rather high risk;
- Natural sink enhancements (ecosystem-based options) generally more accepted but competition for land has potential for conflict

Summary

Selected CDR options for Germany:

- Description of CDR options based on criteria for implementation (factsheets)

Borchers, M. et al. (2022): Scoping carbon dioxide removal options for Germany– What is their potential contribution to Net-Zero CO_2? *Front. Clim.* **4** , art. 810343

Assessment of CDR options for Germany:

- Identifies barriers but also „low-hanging fruits“
- Further assessments needed for including **regional & local** perspectives

Borchers, M., et al. (accepted) Comprehensive Assessment of Carbon Dioxide Removal Options for Germany. Earth's Future.

Förster et al. (2022) Framework for Assessing the Feasibility of Carbon Dioxide Removal Options Within the National Context of Germany. Frontiers in Climate 4:758628

Summary

Borchers et al. accepted (Earth's Future)

- CDR options with higher removal potentials (BECCS & DACCS) face institutional, economic, technological and societal hurdles in particular linked to geological carbon storage (S)
- Ecosystem-based CDR options have lower implementation hurdles but show relatively small CO_2 removal potentials
- More context-specific assessments of CDR options are needed to guide national net-zero decision making

References

- Borchers, M., Thrän, D., Chi, Y., Dahmen, N., Dittmeyer, R., Dolch, T., Dold, C., Förster, J., Herbst, M., Heß, D., Kalhori, A., Koop-Jakobsen, K., Li, Z., Mengis, N., Reusch, T.B., Rhoden, I., Sachs, T., Schmidt-Hattenberger, C., Stevenson, A., Thoni, T., Wu, J., Yeates, C. (2022): Scoping carbon dioxide removal options for Germany–What is their potential contribution to Net-Zero CO_2? *Front. Clim.* **4** , art. 810343
- Borchers, M., Förster, J., Thrän, D., Beck,S., Thoni, T., Korte, K., Gawel, E., Markus, T., Schaller, R., Rhoden, I., Chi, Y., Dahmen, N., Dittmeyer,R., Dolch,T., Dold,C., Herbst,M., Heß,D., Kalhori,A., Koop-Jakobsen, K., Li, Z., Oschlies,A., Reusch, T.B.H., Sachs,T., Schmidt-Hattenberger, C., Stevenson,A., Wu,J., Yeates,C., Mengis, N. (accepted) Comprehensive Assessment of Carbon Dioxide Removal Options for Germany. Earth's Future.
- Förster, J., Beck, S., Borchers, M., Gawel, E., Korte, K., Markus, T., Mengis, N., Oschlies, A., Schaller, R., Stevenson, A., Thoni, T. and Thrän, D. (2022) Framework for Assessing the Feasibility of Carbon Dioxide Removal Options Within the National Context of Germany. Front. Clim. 4:758628. doi: 10.3389/fclim.2022.758628
- Mengis, N., Simon, S., Thoni, T., Stevenson, A., Goerl, K., Steuri, B., et al. (2021) Net-Zero-2050 Cluster: Definig the German carbon budget. Project briefing #2, ver. 2, October 2021. Available online at: https://www.netto-null.org/imperia/md/assets/net_zero/dokumente/2_carbonbudget_2021_10_web.pdf
- Mengis, N., Kalhori, A., Simon, S., Harpprecht, C., Baetcke, L., Prats- Salvado, E., et al. (2022) Net-zero CO2 Germany—A retrospect from the year 2050. Earth's Future 10. https://doi.org/10.1029/2021EF002324
- UBA (2021). Previous year's estimate of German greenhouse gas emissions for 2020. Umweltbundesamt (UBA) Dessau, 15.03.2021. Available online at: https://www.umweltbundesamt.de/sites/default/files/medien/361/dokumente/2021_03_10_trendtabellen_thg_nach_sektoren_v1.0.xlsx

Thank you for your attention!

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