Earth's Future

Additional Supporting Information

Data Set with supporting information to Figures 1 to 3 from the manuscript:

A Comprehensive Assessment of Carbon Dioxide Removal Options for Germany

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			hybrid (biological + technological)					
			BECC (+S)					
		Traffic light system	WCom	WGas	WPyr	MxBG	PalBG	MABG
Systemic effects on climate – F1: CDR potential	F1.1 Max. feasible net CO2 emissions removal deployed by 2050 Via order of magnitudes in comparison with Order of Magnitude (OoM) of Germany's CDR needed in 2050 (~60 MtCO2/year, see Mengis and Kalhori et al., 2022). Percentage of the CDR need of Germany in 2050 covered by CDR approach:	0-3% 3-10% (i.e. 0.18 - 6 MtCO2) 10-30% (i.e. 6 - 18 Mt CO2) 30-100% (i.e. 18-60 MtCO2) 100%>	30 MtCO2/year Borchers et al., 2022; specific to D	8 Mt CO2 / year Borchers et al., 2022; specific to D	14 Mt CO2/year Borchers et al., 2022; specific to D	12,6 Mt CO2 / year possible Borchers et al., 2022; specific to D	0,5 Mt CO2 / year Borchers et al., 2022; specific to D	0,8 Mt CO2/year Borchers et al., 2022; specific to D
	F1.2 Max. feasible 'near-term' net CO2 emissions removal Via order of magnitudes in comparison with Order of Magnitude (OoM) of Germany's CDR needed in 2030 (assumption: ~30 MtCO2/year). Percentage of the CDR need of Germany in 2030 covered by CDR approach:	<0.1% (i.e. <0.03 Mt CO2) 0.1-1% (i.e. >0.03 Mt CO2) 1-10% (i.e. > 0.3 MtCO2) 10-100% (i.e. >3 MtCO2) 100%>	3 Mt CO2/year (assumption: 10% of capacity installed by 2030; not likely to be implemented before 2025 mainly because of regulations and CDR market); specific to D	0.8 Mt CO2 / year 10% of capacity installed by 2030; not likely to be implemented before 2025 mainly because of regulations and CDR market; specific to D	1,4 Mt CO2/year 10% of capacity installed by 2030; not likely to be implemented before 2025 mainly because of regulations and CDR market; specific to D	1,3 Mt CO2/year 10% of capacity installed by 2030; not likely to be implemented before 2025 mainly because of regulations and CDR market; specific to D	0,05 Mt CO2/year assumption: 10% of capacity installed by 2030; not likely to be implemented before 2025 mainly because of regulations and CDR market; specific to D	0,08 Mt CO2/year assumption: 10% of capacity installed by 2030; not likely to be implemented before 2025 mainly because of regulations and CDR market; specific to D
	F1.3 Max. total sequestration potential between 2020 and 2050 Via order of magnitudes in comparison with Order of Magnitude (OoM) of Germany's remaining carbon budget (~7 GtCO2). Percentage of the remaining carbon budget of Germany covered by CDR approach:	0.1%- 0.1-1% (i.e. >7 Mt CO2) 1-10% (i.e. > 70 MtCO2) 10-100% (i.e. >700 MtCO2) 100%>	360 Mt CO2 assuming linear increase from 3 Mt in 2030 until 30 Mt in 2050; specific to D	112 Mt CO2 assuming in a linear increase from 0.8 Mt in 2030 until 8 Mt in 2045; specific to D	165 Mt CO2 assuming in a linear increase from 1.4 Mt in 2030 until 14 Mt in 2050; specific to D	150 Mt CO2 assuming in a linear increase from 1.3 Mt in 2030 until 12.6 Mt in 2050; specific to D	6 Mt CO2 assuming in a linear increase from 0.08 Mt in 2030 until 0.8 Mt in 2050; specific to D	10 Mt CO2 assuming in a linear increase from 0.08 Mt in 2030 until 0.8 Mt in 2050; specific to D
F2: CO2 emissions avoidance potential (CircC potential)	F2.1 Max. of CO2 emissions avoided through deployment in 2050 Percentage of the Germany's emissions avoided in 2050 by approach	likely causes emissions with high fossil share likely causes emissions 0-30% 30-100% (i.e. 18-60 MtCO2) 100%>	1710 Mt CO2/year Assuming that we replace fossil coal (with an emission factor of 98 tCO2/TJ, source UBA, 2016) by biomass (with an emission factor 30 tCO2 /TJ) of which we also capture 90% and store it, 10 plants with a energy supply of 5000 MWh/year (i.e., 18 TJ/year) would avoid 1710 Mt CO2/year (= (98-3)tCO2/TJ * 18 TJ/year); specific to D	no avoided emission though gasification; possibility of avoided emission through material use of synfuel, but here storage is assumed 7171 t CO2/year: Assuming that we replace fossil/mineral oil (with an emission factor of 3,18 tCO2/TJ, source UBA, 2016) by synthetic fuel (which we assume to have no emissions) of which we supply 2255.154 TJ/year, the approach would avoid 7171 t CO2/year; specific to D	no avoided emission though pyrolosis; possibility of avoided emission through material use of biocoal, but here storage is assumed	821 Mt CO2/year: Assuming that we replace fossil natural gas (with an emission factor of 56 g CO2/MJ, UBA 2016) by biogas (with an emission factor 30 g CO2 / MJ) of which we also capture 90% and store it, 4000 plants with a energy supply of 4300 MWh/year (i.e., 15,48 million MJ/year) would avoid 821 Mt CO2/year.	43 Mt / year 33 t CO2 avoided emissions due to displacement of fossil gas for energy production + 43 Mt CO2/year can be avoided by 100% peatland rewetting (Tanneberger et al., 2021). Towards net zero CO2 in 2050: An emission reduction pathway for organic soils in Germany. Mires and Peat, 27.); specific to D	52 t CO2 avoided emissions due to the displacement of fossil gas for energy production; Borchers et al., 2022; specific to D
	F2.2 Max. CO2 emissions avoided in the 'near-term' through deployment Percentage of the Germany's emissions avoided in 2025 by approach	likely causes emissions with high fossil share likely causes emissions 0-30% 30-100% (i.e. 18-60 MtCO2) 100%>	171 Mt CO2/year Assuming one 500 MWh plant is build by 2030; specific to D	no avoided emission though gasification; possibility of avoided emission through material use of synfuel, but here storage is assumed	no avoided emission through pyrolosis; possibility of avoided emission through material use of biocoal	82 Mt CO2/year Assuming 400 plants are equipped with CC facilities; specific for D	20 Mt CO2 / year Tanneberger et al., 2021; specific to D	5,2 t CO2 / year 10 Mt CO2: assuming in a linear increase from 0.08 Mt in 2030 until 0.8 Mt in 2050
F3: Permanence	F3.1 Natural persistence of storage	Decades Decades to century centuries Centuries to millennia Millennia	see GEO-STOR	see GEO-STOR	Biocoal stability expected for some hundred years; depending on production temperature, only high-temp (500degC) considered here	see GEO-STOR	see GEO-STOR	see GEO-STOR
	F3.2 Risk of carbon loss due to climate change and/or natural disturbances	High risk (ie. high likelyhood and large carbon loss) Medium risk (i.e. low likelihood but high loss, or high likelyhood but low loss) Low risk (ie. low likelyhood and low loss) Uncertain but probably no risk of carbon loss No risk of carbon loss	see GEO-STOR	see GEO-STOR	quality of coal will determine the stability; storage is possible in soil or under-ground; but the long-term effects of the soil need be assesses	see GEO-STOR	see GEO-STOR	see GEO-STOR
	F3.3 Risk of carbon loss due to antropogenic disturbances	High risk (ie. high likelyhood and large carbon loss) Medium risk (i.e. low likelihood but high loss, or high likelyhood but low loss) Low risk (ie. low likelyhood and low loss) Uncertain but probably no risk of carbon loss No risk of carbon loss	see GEO-STOR	high risk of usage of syn. fuels to replace (fossil/char) fuels; and high carbon loss in this case expert assessment (N.M.)	risk of usage of biocoal to replace (fossil/char) coals to displace charcoal products, not coal for combustions!; delayed carbon loss (decades) in this case	see GEO-STOR	see GEO-STOR	see GEO-STOR
F4: Verifiability	F4.1 Ability to confirm the amount of CO2 captured/avoided	Unfeasible and not foreseen to be feasible with new technology Difficult to verify but potentially possible with new technology Moderately difficult/existing systems would need to be adapted Planned observation system feasible Already possible to verify with existing system	Harvesting of biomass and use in bioenergy plant can be monitored and verified; Amount of CO2 separated from the process is measurable on site; Storage sites are monitored. There is a system developed (Uni Greifswald), that accounts for the carbon fluxes.	ORCA measures CO2 fluxes, CO2 captured and transported can be confirmed; current instrument give you flow rates and the purity of CO2 injected that allows for high accurancy; expert assessment (N.D.); specific to D	comercial pyrolysis plants exist; carbon capture plants are highly accurate; and biocoal amount can be measured	Harvesting of biomass and use in bioenergy plant can be monitored and verified; Amount of CO2 separated from the process is measurable on site; Storage sites are monitored. There is a system developed (Uni Greifswald), that accounts for the carbon fluxes.	Harvesting of biomass and use in bioenergy plant can be monitored and verified; Amount of CO2 separated from the process is measurable on site; Storage sites are monitored. There is a system developed (Uni Greifswald), that accounts for the carbon fluxes.	the amount of CO2 captured in the biomass is difficult to verify but potentially possible with new technology; however the CO2 sequestered in geological storage sites is highly accurate
	F4.2 Ability to confirm the amount of CO2 stored	Unfeasible and not foreseen to be feasible with new technology Difficult to verify but potentially possible with new technology Moderately difficult/existing systems would need to be adapted Planned observation system feasible Already possible to verify with existing system	see GEO-STOR	carbon storage by syn. fuels is untested (again long-term effects uncertain); expert assessment (N.D.)	carbon storage by biocoal is untested (again long-term effects uncertain); expert assessment (N.D.)	see GEO-STOR	see GEO-STOR	see GEO-STOR
	F4.3 Uncertainty of estimates for CO2 removal/avoidance	>100% 100-60% 60-30% 30-10% <10%	There is neither uncertainty estimates for capture nor for storage given	high accuracy of gas flux measurement is given (pm 0.25%); faults can cause leakages with high permeability, where CO2 can escape; fault activation can occure if too high pressures are reached; but fault sealing could also be be triggered by high pressure; expert assessment (N.D.)	high CO2 capture accuracy; storage accuracy;	high CO2 capture accuracy; storage accuracy; expert judgement	uncertainties in carbon uptake by paludi-cultures due to growth/saturation	high uncertainty of carbon uptake from macro-algea; depends on the nutrients, tempertaure, other enviromental conditions; also the macro-algea can have diseases that would destroy the yield; but the CO2 captured at the biogas plant can be measured

	chemical			
	DACC (+S)			S
	Farms	HVAC	ERW	GEOSTOR
F1.1	20 Mt CO2/year (Viebahn et al., 2018, DACCS); 70 Mt with DACCU (Borchers et al., 2022) 150 Mt CO2/year (depending on demand and limiting factors)	15+ Mt CO2 / year (max. 100 Mt CO2) Borchers et al., 2022; specific to D	4 Mt CO2/year Borchers et al., 2022; specific to D	using 50 (>5Mt) oil and gas fields (2.5 Gt) and all saline aquifers (deeper than 800m, with sufficient porosity and adequate barrier rock layer, 20Gt) a total storage potential of OoM 25Gt would be available Knopf & May, 2017; BGR 2011 specific for D
F1.2	1 Mt CO2 / year Chile (globalthermostat), Norway, Texas & Scotland (carbon engineering) are planning plants 1M scale (D.H.); not likely to be implemented before 2025 mainly because of regulations and CDR market; specific to D	5 Mt CO2 / year expert assessment (D.H.); specific to D	0,7 Mt CO2/year expert assessment (C.D.), assuming linear increase of areas until 2030; specific to D	4-20 Mt CO2/year assuming 5 depleted oil and gas fields would theoretically be available to be used for CCS (80 Mt CO2 capacity) with an annual injection rate of 4-20 Mt CO2 per site Michael et al., 2011
F1.3	225 Mt CO2 assuming linear increase from 1 Mt in 2030 until 20 Mt in 2050; specific to D	230 Mt CO2 assuming linear increase from 5 Mt in 2030 until 15 Mt in 2050; specific to D	64,5 Mt CO2 expert assessment (C.D.), assuming linear increase of areas until 2050; specific to D	using 50 (>5Mt) oil and gas fields (2.5 Gt) and all saline aquifers (deeper than 800m, with sufficient porosity and adequate barrier rock layer, 20Gt) a total storage potential of OoM 25Gt would be available; specific to D Knopf & May, 2017 BGR 2011
F2.1	energy demand likely causes emissions	energy demand likely causes emissions	energy demand likely causes emissions; expert assessment (N.M.); specific to D	no avoided emissions through carbon storage
F2.2	energy demand likely causes fossil emissions	energy demand likely causes fossil emissions	energy demand likely causes fossil emissions; expert assessment (N.M.); specific to D	no avoided emissions through carbon storage
F3.1	see GEO-STOR	see GEO-STOR	If the CO2 in the atmosphere is neutralised with alkaline substances as in enhanced weathering of minerals then the greenhouse gas is permanently removed from the system. SPP - Climate Engineering - www (https://www.spp-climate-engineering.de/index.php/enhanced-weathering-on-land.html) Löschke and Schröder, 2019	Several 1,000 years of permanent storage Borchers et al., 2022
F3.2	see GEO-STOR	see GEO-STOR	no risk of carbon loss; expert assessment (C.D., N.M.)	large scale earthquakes are named as possible natural disturbances for geological storage, but it is highly uncertain how much CO2 would be released (that also depends on the percentage of mineralisation that has already occurred); Expert judgement - even in case of earthquake very small amounts of CO2 could escape Banks et al., 2021 specific to D
F3.3	see GEO-STOR	see GEO-STOR	no risk of carbon loss; expert assessment (C.D., N.M.)	depleted oil and gas would be easier to recover CO2 after injection; expert assessment (C.Y., N.M.); specific to D
F4.1	ORCA measures CO2 fluxes, CO2 captured and transported can be confirmed; current instrument give you flow rates and the purity of CO2 injected that allows for high accurancy	CO2 captured and transported can be confirmed; current instrument give you flow rates and the purity of CO2 injected that allows for high accurancy	Estimating rock weathering as a function of type of silicate, silicate particle size, application rate, soil ph, soil temperature, soil water content, crop production, type and amount of N fertilizer application (Beerling et al. 2020)	current instrument give you flow rates and the purity of CO2 injected that allows for high accurancy; expert assessment (C.Y.)
F4.2	see GEO-STOR	see GEO-STOR	Measurement of alkalinity and inorganic C in groundwater discharge, creeks, and rivers, and fertilizer application rates (Jones and Schilling 2013)	Several monitoring methods can verify the removal by a proof of CO2 containment in the storage complex: seismic and ERT/EM surveys for mass quantification, PNG logs for saturation estimates, history matched reservoir models which give a prognosis of the plume propagation. Graphimetrics and geophyical measurement. Borchers et al., 2022
F4.3	if storage can be confirmed (i.e. no leakage), high accuracy of gas flux measurement is given (pm 0.25%)	if storage can be confirmed (i.e. no leakage), high accuracy of gas flux measurement is given (pm 0.25%)	uncertainty on ambition (64,5pm23,25 Mt CO2); as well as carbon sequestration saturation Borchers et al., 2022 specific to D	from flux measurements high ; faults can cause leakages with high permeability, where CO2 can escape; fault activation can occure if too high pressures are reached; but fault sealing could also be be triggered by high pressure; expert assessment (C.Y.)

	biological				
	PReW	agricAFF	agricCC	agricCR	SeaGr
F1.1	2,7 Mt CO2/year Mengis and Kalhori et al., 2022; specific to D	2,7 (1,7-3,5) Mt CO2/year Borchers et al., 2022; specific to D	1,7 Mt CO2/year Borchers et al., (2022); specific to D	6,3 Mt CO2/year expert assessment (C.D.), assuming linear increase of areas until 2050, using emission factors and agricultural soil areas; specific to D	0,05 Mt CO2/year Borchers et al., 2022; specific to D
F1.2	It is unclear how much CO2 will be stored in the near-term as it is highly uncertain how much rewetting will occur until 2030, and carbon uptake estimates are highly uncertain	1,6 Mt CO2/year expert assessment (C.D.), assuming linear increase of areas until 2030; specific to D	0,4 Mt CO2 expert assessment (C.D.), assuming linear increase of areas until 2030;	1,9 Mt CO2/year expert assessment (C.D.), assuming linear increase of areas until 2030; specific to D	It is unclear how much CO2 will be stored in the near-term as the carbon fluxes of un-matured seagrass meadows are highly uncertain
F1.3	40 MtCO2 assuming in a linear increase from 0 Mt in 2030 until 2,7 Mt in 2050; specific to D	1,6 Mt CO2/year expert assessment (C.D.), assuming linear increase of areas until 2050; specific to D	36 Mt CO2 expert assessment (C.D.), assuming linear increase of areas until 2050; specific to D	97 Mt CO2 expert assessment (C.D.), assuming linear increase of areas until 2050; specific to D	1,6 Mt CO2 assuming in a linear increase from 0 Mt in 2030 until 0,1 Mt in 2050; specific to D
F2.1	max. 43 Mt CO2/year can be avoided by peatland rewetting (annual fluctuations) Tanneberger et al., 2022; specific to D	no avoided emissions	no avoided emissions	no avoided emissions	no avoided current emissions; restoration of seagrass avoides future emissions from sediments
F2.2	20 Mt CO2 /year Tanneberger et al., 2021; specific to D	no avoided emissions	no avoided emissions	no avoided emissions	no avoided current emissions; restoration of seagrass avoides future emissions from sediments
F3.1	Thousands of years if not drained again Borchers et al., 2022; specific to D	Forest saturation in decades to centuries	steady state (i.e. SOC content does not change) reached after 155 years; residence time depends on cover crop C quality, e.g. fodder radish: 30 years; needs constant management to ensure SOC permanence Poeplau and Don, A., 2015; Mutegi et al., 2013	depends on carbon compounds of the plant material and its resistence to mineralization	multiple centuries to millenial
F3.2	vunerability for changed climatic conditions; but peatlands have a buffer capacity once rewetted IKOS drought study, peatlands mitigation some heat events	changes in climate or sudden disturbances like forest fires or extreme precipitation may alter C permanence; management needed; high carbon loss in case of disturbances Borchers et al. 2021; Poeplau et al., 2011 ?	climate changes pose a risk expert assessment (C.D.)	climate changes pose a risk	Permanence not guaranteed, e.g. the system is sensitive to climate change and could lose a large part of its storage function if their health degrades. The storage capacity of seagrass meadows can generally be explained by factors such as wave exposure and seabed depth. Strong movements stir up the soil and re-suspend the buried carbon, so increased storm events might impact seagrass. Borchers et al., 2022 & Verified Carbon Standard (VCS), 2016 (an updated version under development); specific to D
F3.3	drainage of areas would need to be prevented with policy/regulatory restriction	LUC would need to be prevented by regulatory efforts. There is danger for "Versigelung" and "Versiedelung"	LUC would need to be prevented by regulatory efforts. There is danger for "Versigelung" and "Versiedelung" expert assessment (C.D.)	LUC would need to be prevented by regulatory efforts. There is danger for "Versigelung" and "Versiedelung"	Water quality also has a major influence on CO2 uptake so murky waters (from anthropogenic inputs) allow less sunlight to penetrate to the seafloor where the plants grow. Borchers et al., 2022 & Verified Carbon Standard (VCS), 2016 (an updated version under development); specific to D
F4.1	Depending on the availabilty of monitoring infrastructure on site GHG flux measurements using Eddy Covariance towers and metereological sensors on the rewetted sites is possible but would have to be extended to get the spatial coverages	emission factors for LU categories are available	emission factors for LU categories are available	emission factors for LU categories are available	the method existsis and is applied, but it is expensive and time consuming; expert assessment (A.S.)
F4.2	short cores can be analysied for new accumulation	Soil samples, tree measurements Borchers et al., 2022	Soil carbon stock changes can be monitored; Humus balancing methods, CAP Greening subsidy requirements. Self-verification of growers on environmental impact, e.g., Cool Farm Tool (https://coolfarmtool.org/) https://www.landwirtschaftskammer.de/foerderung/formulare/merkblaetter/mb-sammelantrag-2021-greening.pdf; https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/key_policies/documents/ext-eval-payment-practices-climate-leaflet_2017_en.pdf; Brock et al., 2013	Soil carbon stock changes can be monitored; Humus balancing methods, CAP Greening subsidy requirements. Self-verification of growers on environmental impact, e.g., Cool Farm Tool (https://coolfarmtool.org/) https://www.landwirtschaftskammer.de/foerderung/formulare/merkblaetter/mb-sammelantrag-2021-greening.pdf; https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/key_policies/documents/ext-eval-payment-practices-climate-leaflet_2017_en.pdf; Brock et al., 2013	Health of seagrass is a good indication and through carbon analysis; expert assessment (A.S.)
F4.3	range provided for site variable CO2 uptake amount to about 40% of the average estimate methodological error 10-20% (eddy covariance) on top of that temporal and spatial variability	uncertainty on area assessment (58pm14 Mt CO2) + uncertainty in emissions factors; extracpolated measurements are used to extimate carbon fluxes; depended among others on soil, climate, tree species and age; expert assessment (C.D.)	uncertainty on area assessment (36pm8 Mt CO2) + uncertainty in emissions factors is less than for forests, bc faster growth & adaption; dependent on soil, plant growth expert assessment (C.D.)	uncertainty on area assessment (84pm12 Mt CO2) + uncertainty in emissions factors is less than for forests, bc faster growth & adaption; dependent on soil, plant growth expert assessment (C.D.) specific to D	uncertainty estimates of carbon uptake (37,5pm 12,5 tCO2/year); Borchers et al., 2022; not specific to D

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		

Colour legend: no/low hurdles – medium hurdles – high hurdles; Not applicable; No data

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			Traffic light system	WCom	WGas	WPyr	MxBG	PalBG	MABG	Farms	HVAC	ERW	GEOSTOR	PReW	agricAFF	agricCC	agricCR	SeaGr
				hybrid (biological + technological)						chemical				biological				
				BECC (+S)						DACC (+S)			S					
Environmental	A1: Impact on air/atmosphere	A 1.1 Outdoor air quality (with an impact on human health)	Likely worsens Uncertain, likely worsens Likely no change in impact Uncertain, likely improves Likely improves	Assuming that biomass will replace coal in power plants, additional impacts on air quality expected and emissions will continue to occur: "Because biomass is less energy intensive than fossil fuels, the use of biomass to substitute for fossil fuels will nearly always initially increase emissions to the atmosphere." Birdsey et al., 2018; Own assessment based on the assumption that coal will be replaced with biomass. (J.F.)	No additional impact expected as it is the assumption that no additional biomass will be used. Flue gas from combustion of product gas. Flue gas composition: 80.7 vol.% N2, 1.8 vol.% H2O, 14.5 vol.% CO2.; Own expert assessment (J.F.)	No additional impact expected as it is the assumption that no additional biomass will be used. Flue gas from combustion of product gas. Flue gas composition: 80.7 vol.% N2, 1.8 vol.% H2O, 14.5 vol.% CO2.	Assuming the use of already existing biomass production and biogas plants, no increase in biomass production is assumed and therefore no increase in the impact on air quality is expected. Outdoor air quality could be negatively impacted if biomass production would be increased. Expert judgment (J.F.)	Likely no impact on air quality from paludiculture production itself; Potential impact on air quality from transportation and from biogas CHP plant. Expert judgment (J.F.)	Rather small impacts could include: halocarbons can be released from algae; operation of vessels for managing / operating the farm could have negative impacts	DAC could potentially clean the air because pollutants adhere to the sorbents as well. However, this has not been investigated so far, so a clear statement cannot be made. Expert assessment (J.F., D.H.)	DAC could potentially clean the air because pollutants adhere to the sorbents as well. However, this has not been investigated so far, so a clear statement can't be made. Own assessment; expert judgment	Additional mining of minerals and the application of rock powder could increase aerosol concentrations. Own assessment; expert judgment	The CCS process requires energy and thereby additional fuel is likely to be required compared to processes not using CCS (EEA 2011). In the case of BECCS this can lead to increased use of biomass, leading to more emissions. In the unlikely case of a gas break-out, CO2 would be released into the air. Drilling could impact air quality; small of amounts of pollutants could be released. No combustion processes and no air pollution from the CCS process itself. Dautzenberg & Bruhn, 2013; Own assessment; expert judgment	Less impact on air quality when compared to the previous land use; LM M-V, 2017 Expert judgment; Specific to D	Trees have a positive impact on air quality and can reduce particles (dust, etc.) and emissions from agricultural land. Own assessment; expert judgment	Assuming that there would be other crops as well the impact might not be very different; Own assessment; expert judgment	Change in crop rotation should not impact air quality Own assessment; expert judgment	Likely no impact expected. Expert judgment
		A 1.2 GHG emissions related to land/sea use change	Likely increases Uncertain, likely increases Likely no change in emissions Uncertain, likely reduces Likely reduces	Based on the literature (Babin et al., 2021; Erlach et al., 2019; Bentsen, 2017; Schlesinger, 2018; Birdsey et al., 2018) and the assumption that biomass production will have to be increased; Expert judgment (J.F.)	Assuming sustainable forest management practices with no more biomass being harvested than is regrowing, there are likely no additional emissions. In Germany, there is a law that there should be no reduction in forest area (Bundeswaldschutzgesetz 1975). Short rotation cycles are rather the exception. Possible risks in case more biomass is used for bioenergy than is currently used: Wood is likely to be sourced either 1) from forests with short rotation cycles with low carbon storage or 2) from old forest stands causing the reduction in carbon storage. Only under a long rotation cycle the carbon balance could become positive (Schlesinger, 2018). Hence there is a greater risk of increasing carbon loss from forests to the atmosphere. Assessment methods still involve large uncertainties (Bentsen, 2017). Own expert assessment	Assuming the current use of wood biomass. Assuming sustainable forest management practices with no more biomass being harvested than is regrowing, there are likely no additional emissions. In Germany, there is a law that there should be no reduction in forest area (Bundeswaldschutzgesetz 1975). Short rotation cycles are rather the exception. Possible risks in case more biomass is used for bioenergy than is currently used: Wood is likely to be sourced either 1) from forests with short rotation cycles with low carbon storage or 2) from old forest stands causing the reduction in carbon storage. Only under a long rotation cycle the carbon balance could become positive (Schlesinger, 2018). Hence there is a greater risk of increasing carbon loss from forests to the atmosphere. Assessment methods still involve large uncertainties (Bentsen, 2017).	Assuming the use of already existing biomass production and biogas plants there would be no increase in biomass production and therefore no additional emissions from land use. Emissions can potentially be reduced when changing from conventional energy crops to perennial energy crops. In the case of agricultural production on drained wetlands, shifting to paludiculture for biomass production can significantly reduce he emission of greenhouse gases. However, emissions from land use would increase if biomass production were to be increased or imported from other regions. (Don et al., 2012) Expert judgment (J.F.)	Paludiculture on rewetted peatlands reduces CO2 emissions from soils but can lead to higher CH4 and N2O emissions. Tanneberger et al., 2021; Mires and Peat (https://pure.mpg.de/rest/items/item_3261366/component/file_3282083/content); LM M-V, 2017; Expert judgment (J.F.) specific to D	Rather small emissions could include: halocarbons can be released from algae; operation of vessels for managing / operating the farm could have negative impacts	Likely no major direct land use is involved Expert assessment (J.F., D.H.)	Likely no major direct land use is involved Own assessment; expert judgment	Does not involve major changes in land use. ERW can increase productivity and reduce CO2 emissions from agriculture. Own assessment; expert judgment	CCS itself does not involve large-scale land use changes. For this analysis, emissions from land use related to biomass production and BECCS are considered under the biomass-based CDR concepts. Own assessment; expert judgment	Rewetted peatlands reduce CO2 emissions from soils but can lead to higher CH4 and N2O emissions. Tanneberger et al., 2021; Mires and Peat (https://pure.mpg.de/rest/items/item_3261366/component/file_3282083/content); Expert judgment; Specific to D	Afforesting cropland areas would avoid emissions from agricultural activities. Own assessment; expert judgment	The aim is to keep carbon in the soil and to enhance carbon storage. Hence greenhouse gas emissions should be reduced. Own assessment; expert judgment	The aim is to keep carbon in the soil and to enhance carbon storage. Hence greenhouse gas emissions should be reduced. Own assessment; expert judgment	Uptake of carbon by seagrass. Expert judgment
		A 1.3 Net biophysical effect on local climate (different scales)	Likely negative Uncertain, likely negative Likely no change in impact Uncertain, likely positive Likely positive	Expert judgement (J.F.); Tölle et al., 2018	If forestry practices are similar to already existing practices and only the use of the biomass is different, then no differences in land use impacts are expected. Own expert assessment (J.F.)	If forestry practices are similar to already existing practices and only the use of the biomass is different, then no differences in land use impacts are expected.	Assuming the use of already existing biomass production and biogas plants, no additional biomass production is assumed and therefore no change in impact is expected. The impact on local climate is site specific and dependent on the specific land use. Expert judgment (J.F.)	High water table is keeping water in the landscape and has a cooling effect on the local climate. Gaudig et al., 2014; Joosten et al., 2013; Expert judgment (J.F.) specific to D	Likely no impact on local climate	Likely no direct impact on local climate as no large-scale changes in land surface are involved. Expert assessment (J.F., D.H.)	Likely no direct impact on local climate as no large-scale changes in the land surface. Own assessment; expert judgment	No analysis known; Own assessment; expert judgment	Does not involve large-scale land use changes Own assessment; expert judgment	High water table is keeping water in the landscape and has a cooling effect on the local climate. Gaudig et al., 2014; Joosten et al., 2013; Helbig et al., 2020; Expert judgment; Specific to D	Trees could have a cooling effect due to higher evapotranspiration (Wattenbach et al., 2007) Negative effect on albedo, but in small scale afforestation probably not as big; Bright et al., 2017; Wattenbach et al., 2007; Own assessment; expert judgment	Cover crops are unlikely to have a significant effect on the local climate. Own assessment; expert judgment	A different crop rotation is unlikely to have significant effect on local climate. Own assessment; expert judgment	Likely no impact expected. Expert judgment
		A 1.4 Net effects of audible noise on humans and ecosystems	Likely negative Uncertain, likely negative Likely no change in impact Uncertain, likely positive Likely positive	Own assessment (J.F.) based on the assumption that biomass production will have to be increased	The conversion plant can be a local source of the noise. If forestry practices are similar to already existing practices, then no additional noise is to be expected. Own expert assessment (J.F.)	The conversion plant can be a local source of noise. If forestry practices are similar to already existing practices, then no additional noiseis to be expected.	Assuming the use of already existing biomass production and biogas plants, no additional biomass production is assumed and therefore no change in impact is expected. Noise could increase if biomass production would be increased. Expert judgment (J.F.)	Sources of noise: harvesting and transportation of biomass. Expert judgment (J.F.)	Rather small impacts could include: vessels for managing / operating the farm could have negative impacts	Likely no major impact by DAC farms as potential noise would occur only at a very local scale similar to air conditioning. Expert assessment (J.F., D.H.)	Minimal noise by fans and pumps similar to ventilation systems or air conditioning. Own assessment; expert judgment	Higher noise pollution due to the use of large machinery for mining, grinding, and distribution of rock powder. Own assessment; expert judgment	Low noise related to compressor stations. Noise during construction. Own assessment; expert judgment	Rewetting of peatlands reduces agricultural activities that can be a source of noise. Expert judgment; Specific to D	Afforesting cropland areas would avoid noise pollution from agricultural activities Own assessment; expert judgment	Additional activities due to cover crop management might be possible. However, major additional noise emissions are unlikely. Own assessment; expert judgment	Additional activities due to change in crop rotation might be possible. However, major additional noise emissions are unlikely. Own assessment; expert judgment	Likely no impact expected. Expert judgment
	A2: Impact on land and sea use (from land use / sea use changes)	A 2.1: Area demand and competition for other area uses (land and/or sea)	Likely area demand + land under competition Likely area demand + not under competition Likely no change in area demand [illegible]	Based on the literature (Erlach et al., 2019; Donnison et al., 2020; Thrän, D. & Schindler, H., 2021) and on the assumption that biomass production will have to be increased; Expert judgment (J.F.); specific to D	It is the assumption that there is no additional use of wood biomass for bioenergy. If an increase is intendened, then there is a risk of increased land use and area demand. Most biomass from wood is already in use. Hence any additional use of wood for bioenergy production is in competition with other uses of woody biomass, which requires biomass imports leading to indirect land use changes also outside of Germany (Erlach et al. ,2019). About 2.25 Mt of lignocellulosic material (forest residues and wood waste) is needed to fuel the power plant. In Germany, approximately 30 Mt of such material are produced annually. However, these are already largely in use (for materials and energetic). The remaining unused potential [illegible]	It is the assumption that the wood currently used for bioenergy is used for pyrolysis and that there is no additional use of wood biomass for bioenergy. If an increase is intended, then there is a risk of increased land use and area demand. Most biomass from wood is already in use. Hence any additional use of wood for bioenergy production is in competition with other uses of woody biomass, which requires biomass imports leading to indirect land use changes also outside of Germany (Erlach et al., 2019). About 2.25 Mt of lignocellulosic material (forest residues and wood waste) is needed to fuel the power plant. In Germany, approximately 30 Mt of such material are produced annually. However, these are already largely in use (for materials and energetic). The remaining unused potential [illegible]	Assuming the use of already existing biomass production and biogas plants, no additional area demand in land use is to be expected. However, biomass production for bioenergy is always in competition with other land uses in particular food production. Hence there is always land use competition with other crops (Don et al. 2012). Area needed for energy crops cultivation: maize silage: 23,9 ha (yield 50t FM/ha), grass silage: 49 ha (yield 33t FM/ha) (FNR Biogasfaustzahlen: https://biogas.fnr.de/daten-und-fakten/faustzahlen). Area demand would increase if biomass production would be increased. Expert judgment (J.F.) specific to D	Taking into account the yield of reed canary grass of 11,6 t FM/ha, a total area of 1373 ha would be necessary to provide the feedstock for the 500 kWel biogas CHP plant. based on biomass yield of 4,5 t DM/ha (Moorwissen: https://www.moorwissen.de/en/paludikultur/imdetail/umsetzungsbeispiele/biomasseheizwerkmalchin.php) and 28% moisture content in fresh biomass (Oleszek et al., 2014). Expert judgment (J.F.) specific to D	Can be combined with multiple uses: fish farming, windpower farming, others	Likely to have only a limited impact by DAC farms as the need for space is rather small. Expert assessment (J.F., D.H.)	No area demand as it is integrated into existing building structures. Dittmeyer et al., 2019; Own assessment; expert judgment	Can be applied on agricultural areas, no land-use change necessary; Enhanced yield can reduce land demand. However, also the opposite effect is possible, where the higher yield can drive land use change, e.g. deforestation. Edwards et al., 2017 Own assessment; expert judgment	Competition for storage of high-value gases or geothermal. Own assessment; expert judgment	The land area of a model site is 650 ha. Zerbe et al., 2013 Expert judgment;	Even if low-productive croplands are converted to forest these land-use changes involve on areas that are potentially under competition for other land uses. Own assessment; expert judgment	Cover crops require land under agricultural use. However, due to the continued use for agricultural production, there is likely to be no enhancement in competition. Own assessment; expert judgment	Crop rotation requires land under agricultural use. However, due to the continued use for agricultural production, there is likely to be no increase in competition. Own assessment; expert judgment	Expanding seagrasses means there is area demand, but those marine areas are not under competition. Few trawling activities take place in shallow areas. Fishermen benefit from seagrass (potential co-benefit with local small-scale fishing activities) but need to be advised to use practices that do not destroy it. Expert judgment
		A 2.2: Biodiversity (ecosystems, species, genes)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] positive effects: use of native species; algae can improve water [illegible] provide habitat and protection [illegible]; Provide protection for fish by [illegible] no-take-zones where fishing is [illegible]cted, protecting fish species; [illegible] effects in particular if applied in [illegible] suffering from eutrophication [illegible] gae production can be used for [illegible] iation. Possible negative effect: [illegible] impacts natural ecosystems [illegible] habitat conditions for species; [illegible] petition with local species	Likely no impact as the need for space is rather small. Expert assessment (J.F., D.H.)	No impact as it is integrated into existing building structures. Own assessment; expert judgment	Too little is known about biodiversity impacts. Changes in pH could negatively impact soil organisms and turbidity in water could be increased. Edwards et al., 2017 Own assessment; expert judgment	Only little above-ground area demand. However, infrastructure related to pipelines for transportation and drilling can have an impact on biodiversity. "The regulation of releases that could lead to adverse impacts will be controlled under existing regulatory regimes but some significant impacts on biodiversity are likely to occur given the extent of the required network on and offshore." EEA, 2011 Own assessment; expert judgment	Rewetting peatlands has positive effects on biodiversity when compared to previous agricultural land use. Gaudig et al., 2014; Joosten et al., 2013; Expert judgment; Specific to D	Assuming afforestation will follow guidance of sustainable forest management practices, it can have positive impact on biodiversity. However, afforestation with monoculture plantations can lead to biodiversity loss. Own assessment; expert judgment	Cover crops can be designed as flower strips or low intensive land use (e.g. without pesticide use) with a mix of different species. This can have positive impacts on biodiversity. Own assessment; expert judgment	A switch in crop rotation does not by itself lead to higher biodiversity unless the crops and management a specifically targeted at enhancing biodiversity (e.g. leaving flower strips). Own assessment; expert judgment	Has a positive impact on biodiversity as seagrass meadows are a natural ecosystem and habitat to many native species. Reusch et al., 2021 Expert judgment
		A 2.3 Soils (chemical and physical quality)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] biomass sinks to the bottom it can enhance oxygen consumption	Likely no impact as the need for space and soil surface sealing is rather small. Expert assessment (J.F., D.H.)	No area demand or impact on soils as it is integrated into existing building structures. Own assessment; expert judgment	Similar to liming, it has the potential to counteract the acidification of agricultural practices; Depends on material, amount & additives; Edwards et al., 2017 Own assessment; expert judgment	Almost no above-ground area demand and no impact on soil if operated without leakage. However, in case of leakage, acidification of the soil can occur. EEA, 2011; Own assessment; expert judgment	Rewetting peatlands improves soil quality and reduces the loss of soil carbon and is beneficial for physical soil structure. Gaudig et al., 2014; Joosten et al., 2013; Expert judgment; Specific to D	Trees could help to enhance organic matter (humus); afforestation involves less intensive land use as compared with agricultural practices; Own assessment; expert judgment	Can enhance the quality of organic soil; enhance soil organic matter; reduced nitrate leakage; Thapa et al., 2018; Expert judgment	Can improve soil quality, enhance soil organic matter; reduced nitrate leaching, improve soil structure; Expert judgment	Seagrasses stabilize seabed and store carbon enhancing the quality of the seabed. Expert judgment
	A3: Impact on water	A 3.1 Ground water quality	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		Likely no impact as there is no major water use involved. Expert assessment (J.F., D.H.)	No impact on ground water as it is integrated into existing building structures. Own assessment; expert judgment	If impure rock is used as the feedstock for rock powder production, this might lead to contamination of the soils and consequently the groundwater, e.g. with heavy metals. Overall, data availability on this topic is low. Edwards et al., 2017 Own assessment; expert judgment	Drilling could impact ground water; small of amounts of pollutants could be released; Usually it is avoided to drill through drinking water aquifers. Under the condition of compliance with regulations it is expected to not cause any impacts on ground water. EEA, 2011; Own assessment; expert judgment	No water demand beyond restoring the natural water supply. Peatland restauration is practiced in landscapes with a natural abundance of water. It is the goal to restore and maintain the ground water table and the natural water balance of the ecosystem. Besides restoring the natural water supply no additional input of water is required. Paludicultres are practiced in landscapes with a natural high water abundance and it is essential to establish and maintain a high water level (ideally the water table should be close to the soil surface). Climate change with drought conditions and land use leading to lowering of water table can undermine the paludiculture potential. Maintaining a high water table can also have co-benefits for climate change adaptation by keeping water in the landscape like a sponge, which helps to buffer droughts and floods. Gaudig et al., 2014; Joosten et al., 2013; Expert judgment; Specific to D	Nitrate leaching to groundwater is likely to be reduced when formerly agriculturally used land is converted to forest; Own assessment; expert judgment	Reduced nitrate leakage, assuming no herbicide or pesticide use; "Overall, this meta-analysis confirms many prior studies showing that nonleguminous cover crops are an effective way to reduce NO3− leaching and should be integrated into cropping systems to improve water quality." Thapa et al., 2018; Expert judgment	Reduced nitrate leaching, assuming no additional herbicide or pesticide use;; Expert judgment	
		A 3.2 Water demand / local water availability	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	No freshwater demand	Likely no impact as there is no major water use involved. Expert assessment (J.F., D.H.)	No major water demand to be expected. Own assessment; expert judgment	No information about water demand for basalt mining or grinding was found. Own assessment; expert judgment	Water demand by power plants with CCS increases: "In several cases, water withdrawals for 2 CCS are 25–200% higher than plants without CCS (Yang et al. 2020; Rosa et al. 2020b)"; "... this may limit deployment and result in power plant shutdowns during summer months (Liu et al., 2019b; Wang et al., 2019c). The water use could be managed by changing heat integration strategies and implementing reuse of wastewater (Magneschi et al., 2017; Giannaris et al., 2020b)." Quotes from IPCC Report 2022 (Chapter 6) - Clarke et al., 2022; Gas injection (as supercritical gas) does not involve water; Only already used water could be used for reservoir maintenance purposes; No use of freshwater; No impact on local water access. Only from time to time water is needed for cleaning purpose of technical equipment. Own assessment; expert judgment	No water demand beyond restoring the natural water supply. Paludiculture is practiced in landscapes with a natural abundance of water. It is the goal to restore and maintain the natural water balance of the ecosystem. Besides restoring the natural water supply no additional input of water is required. Paludicultres are practiced in landscapes with a natural high water abundance and it is essential to establish and maintain a high water level (ideally the water table should be close to the soil surface). Climate change with drought conditions and land use leading to lowering of the water table can undermine the paludiculture potential. Maintaining a high water table can also have co-benefits for climate change adaptation by keeping water in the landscape like a sponge, which helps to buffer droughts and floods. Gaudig et al., 2014; Joosten et al., 2013; Wichtmann et al., 2015; Abu-Zahra et al., 2007; Newmark et al., 2010; Kalam et al., 2012 Expert judgment; Specific to D: site-specific, higher water demand could occur during the phase of rewetting, over the long-term likely positive impact by reducing water usage;	Water demand by trees could be higher as for some agricultural land use practices. Own assessment; expert judgment	Likely no addtional water demand assuming no irrigation; Expert judgment	Likely no additional water demand assuming no additional irrigation owing to improving crop rotations; Expert judgment	
		A 3.3 Surface water quality	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		Likely no impact as there is no major water use involved. Compliance with regulations for avoiding any leakage of substances is required. Expert assessment (J.F., D.H.)	Likely no impact as there is no major water use involved. Compliance with regulations for avoiding any leakage of substances is required. Own assessment; expert judgment	Overall effect is unclear; Possible positive impacts: silicates from ERW entering the water can reduce algal bloom and draw down CO2 in the water body; Possible negative effect: higher turbidity and sedimentation in water bodies; Edwards et al., 2017 Own assessment; expert judgment	A water protection program (chemical analysis of probes from groundwater wells) is mandatory to observe any changes in the groundwater bearing layers. Under the condition of compliance with regulations it is expected to not cause any impacts on water. However, in case of leakage, acidification of water can occur. EEA, 2011; Own assessment; expert judgment	Changing from agricultural use to restored peatlands is likely to improve water quality due to the reduction in soil impacts reduction in the use of pesticides. Improves water quality (reduces pollution from dissolved compounds). Flood risk control and prevention of saltwater intrusion. Gaudig et al., 2014; Expert judgment; Specific to D	Nitrate leaching to groundwater is potentially reduced; this could also benefit surface water quality; Own assessment; expert judgment	Reduced nitrate leakage, assuming no herbicide or pesticide use; "Overall, this meta-analysis confirms many prior studies showing that nonleguminous cover crops are an effective way to reduce NO3− leaching and should be integrated into cropping systems to improve water quality." Thapa et al., 2018; Expert judgment	Reduced nitrate leaching, assuming no additional herbicide or pesticide use; Expert judgment	
		A 3.4 Marine water quality	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] likely improve water quality by [illegible] up nutrients from ocean water. [illegible] can be used for bioremediation [illegible] of water quality) (Sanderson [illegible] 2012). However, there is also the [illegible] causing algae blooms in water [illegible] high eutrophication (Liu et al., 2009).	Likely no impact as there is no major water use involved. Compliance with regulations for avoiding any leakage of substances is required. Expert assessment (J.F., D.H.)	Likely no impact as there is no major water use involved. Compliance with regulations for avoiding any leakage of substances is required. Own assessment; expert judgment	The overall effect is still unclear; Possible positive effect: reducing ocean acidification ("Some products of mineral dissolution would precipitate in soils or be taken up by ecosystems, but a significant portion would be transported to the coastal zone and the open ocean, where the increase in alkalinity would partially counteract "ocean acidification" associated with the current marked increase in atmospheric CO2." Hartmann et al., 2013; Possible negative effect: enhanced turbidity and sedimentation in water bodies; Edwards et al., 2017 Own assessment; expert judgment	A water protection program (chemical analysis of probes from groundwater wells) is mandatory to observe any changes in the groundwater bearing layers. Under the condition of compliance with regulations it is expected to not cause any impacts on water. However, in case of leakage, acidification of water can occur. EEA, 2011; Own assessment; expert judgment	Reduction in agricultural land use, peatland restoration, and reduction in the use of pesticides improve the water quality of water flowing into the marine environment. Improves water quality (reduces pollution from dissolved compounds). Flood risk control and prevention of saltwater intrusion. Gaudig et al., 2014; Expert judgment; Specific to D	Nitrate leaching to groundwater is potentially reduced; this could also benefit surface water quality and thereby marine water quality; Own assessment; expert judgment	Reduced nitrate leakage, assuming no herbicide or pesticide use; "Overall, this meta-analysis confirms many prior studies showing that nonleguminous cover crops are an effective way to reduce NO3− leaching and should be integrated into cropping systems to improve water quality." Thapa et al., 2018; Expert judgment	Reduced nitrate leaching, assuming no herbicide or pesticide use; Expert judgment	Seagrasses stabilize seabed and store carbon enhancing the quality of the seabed. Expert judgment

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		

Colour	Meaning
dark green	no/low hurdles
light green	
yellow	medium hurdles
orange	
red	high hurdles
grey	Not applicable
white	No data

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Category	Criterion	Indicator	Traffic light system	WCom	WGas	WPyr	MxBG	PalBG
				hybrid (biological + technological)				
				BECC (+S)				
Technological	B1: Technology effiency/ Conversion efficiency	B1.1 Net energy demand vs. Provision	Net energy demand No energy provision Net energy provision	In principle, this technology produces energy in form of electricity and heat. Energy demand is related to biomass harvesting and processing (pellets preparation), plant operation (incl. CO2 separation process and solvent regeneration), and CO2 preparation for transport and storage. In general, the efficiency of BECCS systems is lower than that of non-CCS bioenergy power stations (Donnison et al., 2020). We assume a drop in plant thermal efficiency to 33%. Electric energy output equals 3.723 TWh Expert assessment (M.B., D.T.)	Main products are synthetic fuels produced by Fischer-Tropsch or other types of fuel synthesis. From the by-produced heat, electrical power and heat to operate the whole process are obtained making the process energy-autarkic. Energy stored in the biofuel produced is around 2255154 GJ/a. Own process simulation (N.D.)	Biocoal is the main product, which can be either use for energy production, material use, or for carbon storage by soil applications. The process is operated by by-produced energy, so essentially it is energy-autarkic. From the overall fuel energy input of around 1440000 GJ wood energy (50 MW thermal fuel capacity) of around 480240 GJ is used to supply the required process heat. The rest is converted into biocoal. Electrical power in the range of some ten kW is required. 25065 t/a biocoal (assumed as pure carbon) are produced as an energy carrier or for C-storage in soil applications. Energy stored in the biocoal produced is around 821131 GJ/a, assuming a Higher Heating Value of 32.76 MJ/kg. Own process simulation (N.D.)	In principle this technology produces energy in form of electricity and heat. Energy demand is related to biomass cultivation, harvesting and processing, biogas plant operation (anaerobic digestion, CO2 separation process and solvent regeneration - demand covered on site), and CO2 preparation for transport and storage. Biogas plant operation consumes 8% (1) and CO2 separation consumes 20% (2) of the generated electricity. Heat demand is related to heating up the substrate to 37°C and for solvent regeneration. FRN (Faustzahlen - www); Thrän, et al., 2020	In principle, this technology produces energy in the form of electricity and heat. Energy demand is related to biomass cultivation, harvesting, and processing, biogas plant operation (anaerobic digestion, CO2 separation process, and solvent regeneration - demand covered on site), and CO2 preparation for transport and storage. Biogas plant operation consumes 8% (1) and CO2 separation consumes 20% (2) of the generated electricity. Heat demand is related to heating up the substrate to 37°C and for solvent regeneration. FRN (Faustzahlen - www); Thrän, et al., 2020
		B1.2 CO2 removed per unit of energy produced/required	<0; Technology requires engergy per unit CO2 removed 0; The process of CO2 removal is energy neutral >0; Technology produces energy per unit CO2 removed	Technology removes 0.8037 t CO2 per MWh energy produced. Literature-based data Daggash et al., 2019	Amount of CO2 removed per MWh produced: 0.14 tCO2/MWh Own process simulation (N.D.)	Amount of CO2 removed per MWh produced: 0.44 tCO2/MWh; Own process simulation (N.D.)	Technology removes 0.73 t CO2 per MWh of energy produced. Own calculation (M.B., D.T.)	Technology removes 0.73 t CO2 per MWh of energy produced. Own calculation (M.B.)
	B2: Technology availability	B2.1 Technology Readiness Level (TRL)	Concept is theoretically defined, but is not scientifically proven yet (stage of development: theoretical concept/on Concept is defined, but only some components are scientifically proven (stage of development: tests on Most components are scientifically proven, but not yet combined (stage of development: demonstration in All components are scientifically proven, but not yet combined (stage of development: pilot implemented) All components are commercially available, value chain technically proven (stage of development:	All process components (biomass cultivation and harvesting, conversion and energy generation processes, carbon capture) are on TRL 9, however have not been combined yet on a market scale. Expert assessment (M.B., D.T.)	8 - 9. Gasification is a mature technique and since long established for coal and other fossil fuel conversion into synthesis gas. For biomass conversion, large pilot and demonstration plants are available, ready for commercial implementation. Expert assessment (N.D.)	8 - 9, there are some SME offering and selling this technology. However, market penetration is low due to missing business models so far, some processes are still in development; Expert assessment (N.D.)	All process components (biomass cultivation and harvesting, conversion and energy generation processes, carbon capture) are on TRL 9, however have not been combined yet on a market scale. Expert assessment (M.B., D.T.)	TRL 6, most process components are proven (exist in separated laboratory to full-market applications), but have not been combined yet Expert assessment (M.B., J.F.) LM M-V, 2017; Scholwin & Siegert, 2020
	B3: Infrastructure	B3.1 Compatibility of infrastructure	Complete infrastructure is not available and would require substantial efforts to be set up Some components of the infrastructure are not available; they need to be created Some components of the infrastructure are missing, but existing infrastructure can be expanded; does not require much All components of the infrastructure are available, but integration is not proven yet All components of the infrastructure are available and integration is proven	The technology uses already existing infrastructure for electricity and heat distribution. Power plant needs to be retrofitted from coal-fired to biomass-fired unit. Carbon capture technology needs to be implemented. Depending on the location, different CO2 transportation pathways are selected: road/railway transport or gas grids. Re-purposing natural gas grids into CO2 grids is an option. Expert assessment (M.B., D.T.) Specific to D	The technology uses already existing infrastructure both for biomass sourcing electricity supply and plant infrastructure (e.g. close to a chemical or refinery plant). CO2 transportation is assumed to be handled by road/railway transport or fed into a pipeline grid, when available. Expert assessment (N.D.)	The technology uses already existing infrastructure both for biomass sourcing and electricity supply. CO2 transportation is assumed to be handeled by road/railway transport unless there is dedicated infrastructure for CO2 logistics. Expert assessment (N.D.)	The technology uses already existing infrastructure for biomass sourcing, biogas production, and electricity and heat distribution. Depending on the plant location, different CO2 transportation pathways are selected: road/railway transport, pipelines, and shipping. Re-purposing natural gas grids into CO2 grids is an option. Expert assessment (M.B., D.T.) Specific to D	The technology preferably uses already existing infrastructure for biomass sourcing, biogas production, and electricity and heat distribution. The paludiculture area may need to be extended. However, due to the wetland surface characteristics, special machinery with broad tires (large surface) is required for biomass harvesting. Depending on the plant location, different CO2 transportation pathways are selected: road/railway transport, pipelines, and shipping. Re-purposing natural gas grids into CO2 grids is an option. Expert assessment (M.B., J.F.) LM M-V, 2017; Scholwin & Siegert, 2020 Expert assessment; Specific to D
	B4: Compatibility with the future energy system	B4.1 Effort of CO2 collection	Constant energy demand for CO2 capture Flexible energy demand (covered with fluctuating renewables) Major share of energy used for CO2 capture Minor share of energy produced used for CO2 capture No energy demand for CO2 capture	Parasitic energy loss due to capture and compression equals 24% (16% for separation, 8% for compression). Herzog et al., 2009	The process as such is practically energy-autarcic. From the overall fuel energy input of around 2880000 GJ/a wood energy (100 MW thermal fuel capacity) around 364867 GJ/a are used to supply the required process heat. In addition, electrical power is required in the order of 57974 GJ/a (ca. 2 MW). Own process simulation (N.D.)	The process as such is practically energy-autarkic. From the overall fuel energy input of around 1440000 GJ wood energy (50 MW thermal fuel capacity) of around 480240 GJ is used to supply the required process heat. The rest is converted into biocoal as a product. Own process simulation (N.D.)	20% of produced energy is used for CO2 capture. As CO2 is provided in a concentrated form, separation does not require much effort. Thrän, 2019	20% of produced energy is used for CO2 capture. As CO2 is provided in a concentrated form, separation does not require much effort. Thrän, 2019
		B4.2 Access to low carbon energy sources	No access to low carbon energy sources Limited access to low carbon energy sources Access to low carbon energy sources (and/or to process energy)	The energy demand related to the power plant operation (including CO2 capture unit) can be covered by process energy (e.g. process heat used to cover solvent regeneration heat demand). Expert assessment (M.B., D.T.)	The process as such is practically energy-autarkic. Expert assessment (N.D.)	The process as such is practically energy-autarkic. Expert assessment (N.D.)	The energy demand related to the biogas plant operation (including CO2 capture unit) can be covered by process energy. Expert assessment (M.B., D.T.)	The energy demand related to the biogas plant operation (including CO2 capture unit) can be covered by process energy. Expert assessment (M.B., J.F.)

Indicator	MABG	Farms	HVAC	ERW	GEOSTOR
	hybrid (biological + technological)	chemical			
	BECC (+S)	DACC (+S)			S
B1.1 Net energy demand vs. Provision	In principle this technology produces energy in form of electricity and heat. Energy demand is related to biomass cultivation, harvesting and processing, biogas plant operation (anaerobic digestion, CO2 separation process and solvent regeneration - demand covered on site), and CO2 preparation for transport and storage. Biogas plant operation consumes 8% (1) and CO2 separation consumes 20% (2) of the generated electricity. Heat demand is related to heating up the substrate to 37°C and for solvent regeneration. FRN (Faustzahlen - www); Thrän, et al., 2020	For operation, all DAC need electric power for pumps, fans, etc. The main share of energy is needed in form of heat, which has to be delivered at 100°C for LT-DAC (regeneration by steam and vacuum) and at 900°C for HT-DAC (regeneration by calcination of CaCO3). A mixed approach (ESA) only uses electric power, but is not ready yet for large-scale application. 6480000GJ at 1Mt capture capacity; Heß et al., 2020	6480000GJ at 1Mt capture capacity. For operation, all DAC need electric power for pumps, fans, etc. The major share of energy is needed in form of heat, which has to be delivered at 100°C for LT-DAC (regeneration by steam and vacuum). A mixed approach (ESA) only uses electric power, but is in an early state of development. Heß et al., 2020	Energy demand comes from ore rock mining [illegible], crushing [illegible], grinding [illegible] and spreading [illegible]. [illegible] Moosdorf et al., 2014	Is site specific. On-site energy for drilling and injections require ongoing pumping. Monitoring systems required by the regulation need also a power supply. Based on an energy approach from the Ketzin case, the specific energy consumption [illegible] injection has been estimated as 41 kWh/t CO2 by Wiese and Nimtz, 2019. In this case, pumping power comprises [illegible] of the total power of the injection facility. Expert assessment (C.S.-H., C.Y.)
B1.2 CO2 removed per unit of energy produced/required	Technology removes 0.73 t CO2 per MWh energy produced. Own calculation (M.B.)	300kWh of electricity and 1500 kWh of heat per ton of CO2. A typcial large-scale plant would have 1Mt capture capacity. Expert assessment (D.H.)	1500kWh of heat and 300kWh electric power per ton. Typical ventilation rates are 5-10 times an hour, where one m3 of air contains 0,8g of CO2. A large office builiding like the Frankfurt Fair Tower could therefore harvest 0,75 to 1,5t of CO2 per h (or 6-12kt/a @8000 working hours per year),which would translate to 11-22GWh per year for such a large building. Heß et al., 2020	1.6 to 9.9 GJ per tonne CO2 (Moosdorf et al., 2014) 656 - 3501 kWh tCO2-1 (net CO2 draw-down) (Renforth, 2012)	
B2.1 Technology Readiness Level (TRL)	7-8, most process components are proven (exist in separated pilot or full-market applications), but have not been combined yet Expert assessment (M.B., J.W.)	7-8; There are several pilots in operation (GT: Huntswill, CE: Squamish, Climeworks: Hinwil, Island, etc.) and bigger projects in planning (e.g., Haru Oni, Norsk eFuel, 1pointfive). Heß et al., 2020	The general technology of DAC is proven and there are small modules for LT-DAC and ESA in laboratories. However the implementation in real ventilaiton systems has still never been done. This is in planning and the concept is already been published. Therefore TRL could be set somewhere between 4 and 6. Heß et al., 2020; Dittmeyer et al., 2019	A few field studies have been conducted to quantify the effectiveness of EWR with mixed results. Basalt powder, for example, has been spread on sugar cane plantations in Brazil and Réunion Island since the 1960s. SPP Climate Engineering - www (https://www.spp-climate-engineering.de/index.php/enhanced-weathering-on-land.html) Löschke & Schröder, 2019	TRL 9 worldwide - several commercial storage projects ongoing. TRL 6 in Germany (only pilot phase - Ketzin). Expert assessment (C.S.-H., C.Y.)
B3.1 Compatibility of infrastructure	Need for infrastructure for macroalgae farming: floating mariculture platform & harvesting/seeding machines and vessels (Buck &Buchholz, 2004; Chen et al., 2015). The technology uses already existing infrastructure for biogas production and electricity and heat distribution. Depending on the plant location, different CO2 transportation pathways are selected: road/railway transport, pipelines, and shipping. Re-purposing natural gas grids into CO2 grids is an option. Expert assessment (M.B., J.W.)	DAC is only a means of harvesting CO2. Therefore the only infrastructure needed for DAC farms is energy supply and CO2 transportation (truck, railway, ship, (old gas) pipelines) away from the site. If PtL is done at site, infrstructure for chemicals and fuels can be used aswell. Infrastructure in general is similar to BECCS since both are centralized sources of CO2 with the difference of the energy supply. Expert assessment (D.H.)	DAC is only a means of harvesting CO2. Therefore the only infrastructure needed for DAC farms is energy supply and CO2 transportation (truck, railway, ship, (old gas) pipelines) away from the site. If PtL is done at the site, infrastructure for chemicals and fuels can be used as well. Special for the decentralized approach is, that a collecting system needs to be implemented if products or CO2 are used elsewhere. If they are used at the site, e.g. as energy storage, no transportation is required. Expert assessment (D.H.) Specific to D	Basalt, an abundant fast-weathering rock with the required mineral chemistry, could be ideal for implementing land-based ERW because of its potential co-benefits for crop production and soil health. In central Germany, there is an existing mining infrastructure for basalt. The mined rocks would then need to go into stone mills to be converted into milled basalt/ rock powder. Beerling et al., 2020	Requires creating wells deep underground to inject CO2. May also require monitoring equipement around the location. CO2 collection network is required to deliver CO2 to storage site. Expert assessment (C.S.-H., C.Y.)
B4.1 Effort of CO2 collection	20% of produced energy is used for CO2 capture. As CO2 is provided in a concentrated form, separation does not require much effort. Thrän, 2019	6480000GJ at 1Mt capture capacity; Heß et al., 2020	6480000GJ at 1Mt capture capacity; Heß et al., 2020	Major effort (energy demand) for rock preparation; Once the rock powder is admixed to the soil CO2 capture takes place through natural, chemical process of rock weathering.	Constant energy demand for CO2 (drilling, CO2 injection, monitoring systems); Expert assessment (C.S.-H., C.Y.)
B4.2 Access to low carbon energy sources	The energy demand related to the biogas plant operation (including CO2 capture unit) can be covered by process energy. Expert assessment (M.B., J.W.)	DAC requires a substantial amount of energy. To minimize transportation losses, DAC-farms should be placed at the source of renewable energies; Expert assessment (D.H.)	DAC requires a substantial amount of energy. To minimize transportation losses, DAC-farms should be placed at the source of renewable energies; Expert assessment (D.H.) Specific to D		

Indicator	PReW	agricAFF	agricCC	agricCR	SeaGr
	biological				
B1.1 Net energy demand vs. Provision	No energy production, low energy demand. Based on the pilot site, Zarnekow, there is no energy production. If harvesting biomass is not included, then no bioenergy is produced. Energy demand is related to water pumping activities, but the amount is unknown and dependent on site hydrological conditions. Expert assessment (A.K., T.S.)	No energy provision and very low energy demand. Expert assessment (C.D.) Smith, 2016	Very low energy input. Here referring to a bundle of measures to increase soil carbon sequestration. Expert assessment (C.D.) Smith, 2016	Very low energy input. Expert assessment (C.D.)	Energy demand related to seagrass plant transplant from adjacent meadow via rigid-hulled inflatable boat (RHIB) Expert assessment (A.S., T.R.)
B1.2 CO2 removed per unit of energy produced/required	No data available. Energy demand is related to water pumping activities, but the amount is unknown and dependent on site hydrological conditions.				
B2.1 Technology Readiness Level (TRL)	Estimated maturity of peatland rewetting in Germany: 7-9 (depending on the site), following the classification of (USDA NIFA, 2018; Hirschelmann et al., 2020). In Germany, in the area of Mecklenburg-Vorpommern, 30.000 ha (=11% of the peatland area) have been rewetted in various ways, which proves the successful application of peatland rewetting on a relevant scale. Expert assessment (A.K., T.S.)	TRL 9. Afforestation is a widely available and practiced measure. Expert assessment (C.D.)	TRL 9. Is is a widely available and practiced measure. Expert assessment (C.D.)	TRL 9. Is is a widely available and practiced measure. Expert assessment (C.D.)	TRL 9 Expert assessment (A.S., T.R.)
B3.1 Compatibility of infrastructure	Weir, water channels/pipes; However this is not always needed, sometimes just blocking the drainage is sufficient. Expert assessment (A.K., T.S.) Koebsch et al., 2020	Infrastructure requirements depend on intensification of management. Possibility to use already existing infrastructure. Expert assessment (C.D.)	Required infrastructure includes: 1) cover crop seed production: agricultural area 2) machinery for cover crops: seeder, mulcher, sprayer, irrigation system; 3) consumables: water, fertilizer, pesticides (if, applicable) Expert assessment (C.D.)	Required infrastructure includes: 1) agricultural area: no additional land requirements; usage of already cultivated land 2) machinery: same as for conventional agriculture (e.g. seeder, mulcher, sprayer, irrigation system); 3) consumables: water, fertilizer, pesticides (if, applicable) Expert assessment (C.D.)	Possibility to use already existing infrastructure. Laboratory for analysis of organic carbon content - probably a one time activity, unless changes occur. Expert assessment (A.S., T.R.)
B4.1 Effort of CO2 collection	CO2 capture takes place through a natural process of photosynthesis in plants. Expert assessment (A.K., T.S.)	CO2 capture takes place through a natural process of photosynthesis in plants. Expert assessment (C.D.)	CO2 capture takes place through a natural process of photosynthesis in plants. Expert assessment (C.D.)	CO2 capture takes place through a natural process of photosynthesis in plants. Expert assessment (C.D.)	CO2 capture takes place through a natural process of photosynthesis. Expert assessment (A.S., T.R.)
B4.2 Access to low carbon energy sources	Energy demand for pumping could possibly be covered by renewable energy sources.				

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		

no/low hurdles
medium hurdles
high hurdles

Not applicable
No data

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Dimension	Criterion	Sub-criterion	Traffic light system	WCom	WGas	WPyr	MxBG	PalBG	MABG
				hybrid (biological + technological) – BECC (+S)					
Economic	C1: Market costs	C1.1 Marginal removal cost (€ per unit of carbon dioxide removed)	High marginal removal cost X (180 € < X Moderate marginal removal cost X (100 Low marginal removal cost (X ≤ 100 €)	Numbers in the literature vary widely, no specific numbers for the concept available. Fuss et al., 2018: Costs of capture: "Combustion BECCS has higher costs ranging from US$88 to US$288/tCO2 (Akgul et al., 2014, Al-Qayim et al., 2015, Kärki et al. 2013)".	No sufficient expert input available for assessment	No sufficient expert input available for assessment	Numbers in the literature vary widely, no specific numbers for the concept available. BECCS anaerobic digestion: 139-313 €/tCO2 (gross costs, excluding revenues from electricity and fuels; IEAGHG, 2013) Expert assessment (K.K., E.G., M.B)	Numbers in the literature vary widely, no specific numbers for the concept available.	Numbers in the literature vary widely, no specific numbers for the concept available.
Economic	C1: Market costs	C1.2 Opportunity cost	High opportunity cost Moderate opportunity cost Low opportunity cost	Potential competition with other usage of wood residues, e.g. wood pellets in domestic chimney, smaller wood-based power plants. Expert assessment (K.K., E.G., M.B)	Competition with domestic firewood usage. Expert assessment (K.K., E.G., N.D.)	Competition with domestic firewood usage. Expert assessment (K.K., E.G., N.D.)	Competition for land with other land uses (food production, buildings, ...). Expert assessment (K.K., E.G., M.B)	Paludiculture on (rewetted) peatland excludes other options for economic use (e.g. food production, erection of buildings) - already high competition for scarce land area in Germany. Expert assessment (K.K., E.G., M.B, J.F.)	Scarce area in German North Sea EEZ: competition with other usages and nature conservation; however, cultivation areas are away from shipping lines and fishery grounds, macroalgae cultivation would be possible in offshore wind park areas. Expert assessment (K.K., E.G., M.B, J.W.)
Economic	C2: Dynamic cost efficiency	C2.1 Potential for cost reductions by technological progress	Low potential for cost reductions by technological progress Moderate potential for cost reductions by technological progress High potential for cost reductions by technological progress	Technology for bioenergy generation already highly efficient/mature, capturing technology might offer smaller potential for cost reduction by technological progress in large-scale appliances: e.g. membrane, oxyfuel. Expert assessment (K.K., E.G., M.B)	Technology for bioenergy generation is already highly efficient/mature, capturing technology might offer smaller potential for cost reduction by technological progress in large-scale appliances: e.g. membrane technology. Expert assessment (K.K., E.G., N.D.)	Technology for bioenergy generation already highly efficient/mature, capturing technology might offer smaller potential for cost reduction by technological progress in large-scale appliances: e.g. membrane technology Expert assessment (K.K., E.G., N.D.)	Technology for bioenergy generation already highly efficient/mature, capturing technology might offer the potential for cost reduction by technological progress: e.g. membrane, pressure-swing-absorption for capturing, modularisation approach for capturing unit(s) instead of tailor-made units. Expert assessment (K.K., E.G., M.B)	Low potential for technological progress in paludiculture; technology for bioenergy generation already highly efficient/mature; capturing technology might offer the potential for cost reduction by technological progress: e.g., membrane, pressure-swing-absorption for capturing, modularisation approach for capturing unit(s) instead of tailor-made units, uncertain technological progress potential in macroalgae production Expert assessment (K.K., E.G., M.B, J.F.)	Technology for bioenergy generation is already highly efficient/mature, capturing technology might offer the potential for cost reduction by technological progress: e.g. membrane, pressure-swing-absorption for capturing, modularisation approach for capturing unit(s) instead of tailor-made units, uncertain technological progress potential in macroalgae production. Expert assessment (K.K., E.G., M.B, J.W.)
Economic	C2: Dynamic cost efficiency	C2.2 Potential for economies of scale	Low potential for economies of scale Moderate potential for economies of scale High potential for economies of scale	Increasing plant size generally allows for scale effects in investment costs and biomass collection/supply, but decreasing scale effects in biomass supply if plant size demands larger transport distances: for the assumed plant size only low potential for economies of scale can be expected, however at plant sites with multiple power block units scale effects could be inherent (as DRAX in GB showed). Expert assessment (K.K., E.G., M.B)	Increasing plant size generally allows for scale effects in investment costs and biomass collection/supply, but decreasing scale effects in biomass supply if plant size demands for larger transport distances: for the asssumed plant size only low potential for economies of scale can be expected. Expert assessment (K.K., E.G., N.D.)	Increasing plant size generally allows for scale effects in investment costs and biomass collection/supply, but decreasing scale effects in biomass supply if plant size demands for larger transport distances: for the assumed plant size only low potential for economies of scale can be expected. Expert assessment (K.K., E.G., N.D.)	As retrofitting of existing plants is assumed, economies of scale can be counted for only for the capturing part: - modularisation allows for cost reductions of the capturing units (mass production) - costs for capturing go down significantly with rising plant size (but in the model concept a plant size of 500kW is set/assumed) Expert assessment (K.K., E.G., M.B)	Ambiguous: low or maybe even negative economies of scale in paludiculture (initial use of most economic sites, than increasing costs); For the capturing part: - modularisation allows for cost reductions of the capturing units (mass production) - costs for capturing go down significantly with rising plant size (but in the model concept a plant size of 500kW is set/assumed) Expert assessment (K.K., E.G., M.B, J.F.)	Theoretically, large-scale application can bring down costs significantly as the experience from Asia shows, however, the limited and scattered area in the German North Sea might limit the realisation of this potential. Expert assessment (K.K., E.G., M.B, J.W.)
Economic	C2: Dynamic cost efficiency	C2.3 Contribution margin of jointly produced goods (per tonne of carbon dioxide removal)	No jointly produced goods Jointly produced goods with low contribution margin Jointly produced goods with high contribution margin	Electricity and heat as co-products, however, their contribution margin can be expected to be rather low as Babin et al. 2021 for instance calculate that capital cost increase by almost 70 % while net power output decreases by about 40 % vis-à-vis conventional coal power plant without CCS. Expert assessment (K.K., E.G., M.B)	As today production cost of fuels is 2-3x as high as conventional ones, the contribution margin of fuels can be expected to be rather small. Expert assessment (K.K., E.G., N.D.)	As coal is stored in this model concept only energy output can be sold on the market, while capturing increases the cost of the process significantly: low contribution margin of energy output. Expert assessment (K.K., E.G., N.D.)	No reliable expert input on cost coverage of by-products (electricity, heat, digestate) available	No reliable expert input available: contribution margin depends on CHP services (heat, electricity); However, CHP related joint products would also accrue without carbon capturing, not clear to what extent usage of reed grass and capturing contribute to cost coverage.	No reliable expert input available: contribution margin depends on CHP services (heat, electricity), however, CHP-related joint products would also accrue without carbon capturing, not clear to what extent usage of algae input and capturing contribute to cost coverage. Expert assessment (K.K., E.G., M.B, J.W.)
Economic	C3: Transaction cost efficiency	C3.1 Public transaction costs		assessed in institutional dimension					
Economic	C3: Transaction cost efficiency	C3.2 Private transaction costs	High private transaction costs Moderate private transaction costs Low private transaction costs	Markets for energy and wood already established and used, markets for retrofitting of plants (machines, planning, installation) exist; capturing will require compliance with additional regulation, possibly contracts with storage companies to be arranged (but for a rather small number of plants). Expert assessment (K.K., E.G., M.B)	Significant transaction costs for the erection of the plants (construction & engineering companies, building authorities); for operation: markets for energy and wood already established and used, wood procurement as well as biofuel sales usually by long-term contracts, rather a small number of professional plant operators. Expert assessment (K.K., E.G., N.D.)	Significant transaction costs for the erection of the plants (construction & engineering companies, building authorities); for operation: markets for energy and wood already established and used, wood procurement as well as biofuel sales usually by long-term contracts, rather a small number of plant operators. Expert assessment (K.K., E.G., N.D.)	In general: BECCS might be associated with high private TAC (transactions for biomass input, energy sales, official permit of the plant, ...), however, since the concept assumes retrofitting of existing plants contractual arrangement for the BE part can be assumed to be established, however, transactions for the erection and operation of a capturing unit and the "sales" of the CO2 remain for a larger number of biogas plants. Expert assessment (K.K., E.G., M.B)	Ownership of peatland to be rewetted scattered, a big number of actors involved, coordination between neighboring land owners needed, land partially rented to/by farmers, potentially buying of areas by the state necessary, interaction with administration needed, contractual agreements between reed grass farmers and biogas plant owners/operators necessary (e.g. issues related to water law), where appropriate: application for funding; transactions for the erection and operation of capturing unit and the "sales" of the CO2, for a larger number of biogas plants necessary. Expert assessment (K.K., E.G., M.B, J.F.)	Market for macroalgae not yet established in Germany, involvement of different administrations necessary (environment, shipping, fishery, ...), new procurement and sales markets (related with high search and information costs), contracts to be agreed, liabilities to be clarified and agreed. Expert assessment (K.K., E.G., M.B, J.W.)
Economic	C4: External effects	C4.1 Other external costs per unit of carbon dioxide abated/removed		assessed in environmental dimension					
Economic	C4: External effects	C4.2 External benefits		assessed in environmental dimension					
Economic	C5: Effects on domestic/regional economy	C5.1 Potential for domestic/regional value added	Low potential for domestic/regional value added Moderate potential for domestic/regional value added High potential for domestic/regional value added	Equipment for retrofitting might come from international companies; installation, operation and monitoring of the capturing unit might rather take place by domestic/regional companies. Expert assessment (K.K., E.G., M.B)	Equipment might come from foreign companies, wood probably from regional sources (however model concepts assumes repurposing of domestic firewood use: no additional demand), plant operation and maintenance require ongoing employment of qualified staff. Expert assessment (K.K., E.G., N.D.)	Equipment might come from foreign companies, wood probably from regional sources (however model concepts assumes repurposing of domestic firewood use: no additional demand), plant operation and maintenance require ongoing employment of qualified staff. Expert assessment (K.K., E.G., N.D.)	Equipment for retrofitting might come from international companies; installation, operation and monitoring of the capturing unit might rather be carried out by domestic/regional companies. Expert assessment (K.K., E.G., M.B)	Domestic paludiculture can be assumed to replace other domestic feedstock production, equipment for retrofitting might come from international companies; installation, operation and monitoring of the capturing unit might rather take place by domestic/regional companies. Expert assessment (K.K., E.G., M.B, J.F.)	Regional origin of equipment unclear, regional resource input in operation likely. Expert assessment (K.K., E.G., M.B, J.W.)
Economic	C5: Effects on domestic/regional economy	C5.2 Potential for domestic/regional employment		assessed in the social dimension					
Economic	C6: Investment barriers	C6.1 Capital intensity (i.e. share of capital cost in total cost of CDR measure)	High capital intensity (high share of capital costs in total cost) Moderate capital intensity (medium share of capital costs in total cost) Low capital intensity (low share of capital costs in total cost)	Capital-related investment costs (Babin et al., 2021: about two thirds of the capital cost of a conventional coal-fired plant). Expert assessment (K.K., E.G., M.B)	Capital intense investment (hundreds of million € per plant) needed, operation costs rather low. Expert assessment (K.K., E.G., N.D.)	Capital intense investment (tens of million € per plant) needed, the share of operation costs rather low. Expert assessment (K.K., E.G., N.D.)	Installation of capturing unit can be assumed to be cost intensive. Expert assessment (K.K., E.G., M.B)	Installation of capturing unit can be assumed to be cost intensive. Expert assessment (K.K., E.G., M.B, J.F.)	Installation of capturing unit as well as macroalgae plantation infrastructure can be assumed to be cost intensive. Expert assessment (K.K., E.G., M.B, J.W.)
Economic	C6: Investment barriers	C6.2 Specificity of investment	High specificity of investment Moderate specificity of investment Low specificity of investment	No other use of the capturing unit possible, CO2 might be used as a commodity instead of storage, however, this might require additional investments (as e.g. erected pipelines for CO2 transport might not be suitable anymore), market size for CO2 uncertain. Expert assessment (K.K., E.G., M.B)	No other processing than gasification possible, however, other marketable goods for industrial use (e.g. methanol from non-fossil source) could be produced without high technological effort for switching. Expert assessment (K.K., E.G., N.D.)	To a smaller extent, the produced coal could be sold as charcoal, but limited demand. Expert assessment (K.K., E.G., N.D.)	No other use of the capturing unit possible, CO2 might be used as a commodity instead of storage, however, this might require additional investments (as e.g. erected pipelines for CO2 transport might not be suitable anymore), the market size for CO2 is uncertain. Expert assessment (K.K., E.G., M.B)	Paludiculture: optional use of reed grass as construction material or fuel possible; capturing unit: no other use of the capturing unit possible, CO2 might be used as a commodity instead of storage, however, this might require additional investments (as e.g. erected pipelines for CO2 transport might not be suitable anymore), the market size for CO2 uncertain. Expert assessment (K.K., E.G., M.B, J.F.)	In general, another usage of macroalgae is conceivable, but rather no markets established in Germany; no other use of the capturing unit possible, CO2 might be used as a commodity instead of storage, however, this might require additional investments (as e.g. erected pipelines for CO2 transport might not be suitable anymore), the market size for CO2 uncertain. Expert assessment (K.K., E.G., M.B, J.W.)
Economic	C6: Investment barriers	C6.3 Revenue risk	High revenue risk Moderate revenue risk Low revenue risk	Low technology-related risks (proven and mature technologies); usually long-term contracts for biomass input and energy sales, but competition with RE with decreasing costs, and CO2-markets were volatile in the past and subject to political decisions. Expert assessment (K.K., E.G., M.B)	Low technology-related risks (proven a Expert assessment (K.K., E.G., N.D.)nd mature technologies); usually long-term contracts for biomass input and fuel sales, but competition with other RE with decreasing costs, and CO2-markets were volatile in the past and subject to political decisions.	Low technology-related risks (proven and mature technologies); usually long-term contracts for biomass input and energy sales, but competition with RE with decreasing costs, and CO2-markets were volatile in the past and subject to political decisions. Expert assessment (K.K., E.G., N.D.)	Energy sales are usually subject to administered prices and/or long-term contracts, however in case of retro-fitting the lifetime (and thus the business case) of the capturing unit might exceed the guaranteed sales (prices) of energy products; carbon markets used to be quite volatile in the past and subject to political decisions. Expert assessment (K.K., E.G., M.B)	Energy sales are usually subject to administered prices and/or long-term contracts, however, in case of retrofitting the lifetime (and thus the business case) of the capturing unit might exceed the guaranteed sales (prices) of energy products; carbon markets used to be quite volatile in the past. Expert assessment (K.K., E.G., M.B, J.F.)	Macroalgae-related yield risks (total failure possible) result in disturbances of biogas plant operation - other procurement of macroalgae very difficult in Germany. Expert assessment (K.K., E.G., M.B, J.W.)

Dimension	Criterion	Sub-criterion	Farms	HVAC	ERW	GEOSTOR	PReW	agriCAFF	agriCC	agriCR	SeaGr
			chemical – DACC (+S)	chemical – DACC (+S)	chemical	S	biological	biological	biological	biological	biological
Economic	C1: Market costs	C1.1 Marginal removal cost	Removal cost of around 250-800$/t today. Heß et al., 2020 Expert assessment (K.K., E.G., D.H.)	Removal cost of around 250-800$/t today. Heß et al., 2020 Expert assessment (K.K., E.G., D.H.)	170 US$ / tCO2 /yr (Beerling et al., 2020); 200 US $ t−1 CO2 (Strefler et al., 2018); equals approx. 150 to 177 € / t CO2 (exchange rate of 1.13 €/US$) Expert assessment (K.K., E.G., C.D., N.M.)	Not applicable: no CDR technology, the Northern Lights project with a storage site under the seabed of the North Sea is targeting storage costs of €35-50/tCO2 (Keans et al., 2021). Expert assessment (K.K., E.G., C.Y., C.S.-H.)	10-15 €/t CO2e in Germany based on previous literature. Couwenberg et al., 2015 Expert assessment (K.K., E.G., A.K., T.S.)	Ambiguous: 0-240 USD/tCO2; depends on which costs are included and on regional differences (among others): range does not allow for classification in a specific color class. Expert assessment (K.K., E.G., C.D.)	-45 to 100 USD/tCO2; number refers to a bundle of methods to increase soil carbon sequestration; negative costs can occur. Fuss et al., 2018 Expert assessment (K.K., E.G., C.D.)	Comparable to other nature based measures; e.g. in Norway grass-clover production is 0.22 to 0.27 € per kg DM produced (based on 2014 prices). Flaten et al., 2020; Expert assessment (K.K., E.G., C.D.)	311 €/tCO2 - one-time cost, not a cost per year (Borchers et al., 2022)
Economic	C1: Market costs	C1.2 Opportunity cost	Requires building of plants on scarce land, however limited number of plants needed which can be erected on marginal land. Expert assessment (K.K., E.G., D.H.)	Integration of DAC unit in existing air conditioning. Expert assessment (K.K., E.G., D.H.)	No competition with current land use (agriculture), however, basalt use might compete with other appliances (e.g., (road) construction). Expert assessment (K.K., E.G., C.D., N.M.)	Scarce offshore underground storage sites in Germany, competing with gas storage for other purposes (which might be critical for the decarbonisation of the economy) e.g. hydrogen, methane. Expert assessment (K.K., E.G., C.Y., C.S.-H.)	Rewetted peatland excludes other options for economic use (e.g. agriculture, erection of buildings) - already high competition for scarce land area in Germany, however, the cultivation of paludiculture remains possible. Expert assessment (K.K., E.G., A.K., T.S.)	Afforestation excludes other options for economic use (e.g. agriculture, erection of buildings) - already high competition for scarce land area in Germany. Expert assessment (K.K., E.G., C.D.)	Not applicable (presumably included in C1.1)	Not applicable (presumably included in C1.1)	Planted at coastal habitat (up to 8 meters), maybe conflicting with bathing tourism (but it improves water quality on-site: less pathogenic bacteria), anchoring of hobby shippers might be affected (could be solved by mouring), coastal construction in shallow water (1-8 m) could be affected. Expert assessment (K.K., E.G., A.S., T.R.)
Economic	C2: Dynamic cost efficiency	C2.1 Potential for cost reductions by technological progress	Technology is already quite advanced, however new/advanced processes in capturing technology could provide for cost reductions Expert assessment (K.K., E.G., D.H.)	Technology is already quite advanced, however new/advanced processes in capturing technology could provide for cost reductions. Expert assessment (K.K., E.G., D.H.)	Ambiguous: basalt production as well as the appliance of other minerals (e.g. chalk) already widely established, usage of alkaline material from other sources (steel slag, desalination machines) might bear potential for future cost reductions. Expert assessment (K.K., E.G., C.D., N.M.)	No big cost reductions from technological progress to be expected. Expert assessment (K.K., E.G., C.Y., C.S.-H.)	Little technology input needed for rewetting with rather low potential for technological progress. Expert assessment (K.K., E.G., A.K., T.S.)	No sufficient data availavle	Already quite established agriculture practice - low potential for cost reductions by technological progress to be expected. Expert assessment (K.K., E.G., C.D.)	Already quite established agriculture practice - low potential for cost reductions by technological progress to be expected. Expert assessment (K.K., E.G., C.D.)	Ambigouos: today's manual planting could be mechanised, whether this allows for cost reduction or just for speeding up the process is hardly predictable today. Expert assessment (K.K., E.G., A.S., T.R.)
Economic	C2: Dynamic cost efficiency	C2.2 Potential for economies of scale	With scaling up to big centralized DAC plants, large-scale effects are expected (removal cost as low as 50$/t in 2050, probably mainly due to economies of scale). Expert assessment (K.K., E.G., D.H.)	With wide application of decentralized DAC plants economies of scale in production (mass production) can be realised (removal cost as low as 50$/t in 2050, probably mainly due to economies of scale). Expert assessment (K.K., E.G., D.H.)	Economies of scale can result from underproportional cost increases for basalt application on larger areas, however large scale production of basalt is already in place (little further economies of scale can be expected). Expert assessment (K.K., E.G., C.D., N.M.)	Pipelines for transport with large cost decreases with increasing volumes, storage: the bigger the reservoir the lower the per unit cost. Expert assessment (K.K., E.G., C.Y., C.S.-H.)	Economies of scale can result from under-proportional cost increases for rewetting bigger areas (e.g., plugging ditches), however, there are no supply-side effects from e.g. mass production of equipment. Expert assessment (K.K., E.G., A.K., T.S.)	No sufficient data availavle	Agriculture in Germany widely mechanised: only smaller-scale effects expectable, however, cultivation on bigger areas (with related lower costs for procurement) can allow for economies of scale. Expert assessment (K.K., E.G., C.D.)	Agriculture in Germany widely mechanised: only smaller-scale effects expectable, however, cultivation on bigger areas (with related lower cost for procurement) can allow for economies of scale. Expert assessment (K.K., E.G., C.D.)	Scattered planting area prevents from on-site large-scale application, however, there might be some potential for economies of scale on the supply side (plant breeding, machinery). Expert assessment (K.K., E.G., A.S., T.R.)
Economic	C2: Dynamic cost efficiency	C2.3 Contribution margin of jointly produced goods	No jointly produced marketable goods. Expert assessment (K.K., E.G., D.H.)	No jointly produced marketable goods. Expert assessment (K.K., E.G., D.H.)	No jointly produced marketable goods (however, the substitution of chalking of acidic soils might reduce the production cost of "conventional" agricultural business). Expert assessment (K.K., E.G., C.D., N.M.)	Saline water as by-product. Can be be a waste product, but probably also be used for geothermal energy production (probably no significant contribution to cost coverage). Expert assessment (K.K., E.G., C.Y., C.S.-H.)	No jointly produced goods in the MC (in general paludiculture would be possible). Expert assessment (K.K., E.G., A.K., T.S.)	No removal of wood assumed: no marketable jointly produced goods exist. Expert assessment (K.K., E.G., C.D.)	Since the produced biomass stays on the field no marketable jointly produced goods exist. Expert assessment (K.K., E.G., C.D.)	Depending on crops included, new/additional products may be possible. Expert assessment (K.K., E.G., C.D.)	Shed leaves could potentially be used for material (e.g. ecological construction material) and food applications, however, at the moment this doesn't seem to be a financially viable option. Expert assessment (K.K., E.G., A.S., T.R.)
Economic	C3: Transaction cost efficiency	C3.1 Public transaction costs	assessed in institutional dimension								
Economic	C3: Transaction cost efficiency	C3.2 Private transaction costs	Building and erection of plants needed with transactions with/of different third party actors (banks, land owners, building authority, planning company/architect, construction company, manufacturers, in case of DACCS contracts to be arranged with a storage company, in case of DACCU contacts with fuel refineries, a limited number of plants as compared to decentralized DAC. Expert assessment (K.K., E.G., D.H.)	Installation of DAC units in ventilation systems requires transactions with/of different third-party actors (owner/tenants, building authority, planning company/architect, construction company, in case of DACCS contracts to be arranged with the storage company and/or intermediaries, manufacturers in case of DACCU contacts with fuel refineries and/or intermediaries, for a large number of DAC installations. Expert assessment (K.K., E.G., D.H.)	Markets for input material established, application might require check/recording/concession by a large number of farmers and/or land owners (Soil protection and contamination ordinance, water law, immission protection law). Expert assessment (K.K., E.G., C.D., N.M.)	No offshore CO2 storage applied in Germany by now, storage as well as erection of the necessary infrastructure is subject to regulatory requirements to a large extent (planning law, environmental law), low acceptance for storage in Germany makes lawsuits very likely, contracts to be made with a potentially large number of CO2 suppliers. Expert assessment (K.K., E.G., C.Y., C.S.-H.)	Ownership of peatland to be rewetted scattered, a big number of actors involved, coordination between neighboring land owners needed, land partially rented to/by farmers, potentially buying of areas by the state necessary, interaction with administration needed (e.g., issues related to water law), where appropriate: application for fundings. Expert assessment (K.K., E.G., A.K., T.S.)	Afforestation on agricultural land requires an official permit, scattered land ownership, rental of agricultural land is common, if applicable application for afforestation subsidy: a high number of transactions is required if applied at a larger scale. Expert assessment (K.K., E.G., C.D.)	Low additional effort for transactions to be expected: application of cover crops already widely established, application for EU-GAP subsidies is regular business of farmers, however, search and information costs can accrue in individual cases. Expert assessment (K.K., E.G., C.D.)	Low additional effort for transactions to be expected: crop rotations already widely established. Expert assessment (K.K., E.G., C.D.)	Planting of seagrass requires different permits (e.g. for ammunition clearance, planting, and harvesting if applicable), in case of biomass selling transactions with consumers needed, resistance from local residents might require acceptance-increasing interaction, however, the areas are under public ownership of the Fed. Rep. of Germany (the number of involved actors is limited). Expert assessment (K.K., E.G., A.S., T.R.)
Economic	C4: External effects	C4.1 Other external costs per unit of carbon dioxide abated/removed	assessed in environmental dimension								
Economic	C4: External effects	C4.2 External benefits	assessed in environmental dimension								
Economic	C5: Effects on domestic/regional economy	C5.1 Potential for domestic/regional value added	Equipment might come from international companies; installation, operation and maintenance probably done by domestic/regional enterprises. Expert assessment (K.K., E.G., D.H.)	Equipment might come from international companies, installation, operation and maintenance probably done by domestic/regional enterprises. Heß et al., 2020 Expert assessment (K.K., E.G., D.H.)	Additional demand for rock flour requires increased mining/processing of basalt (which might (partially)take place in Germany, application of basalt powder constitutes additional task in agricultural business (which needs to be applied in large time intervals (half-life period of basalt about 12 years). Expert assessment (K.K., E.G., C.D., N.M.)	Some potential for regional value added can be expected: preparation of fields for storage, erection of some new pipelines, CO2 transportation; however, to some extent existing pipelines could be used. Expert assessment (K.K., E.G., C.Y., C.S.-H.)	Construction works for rewetting required: probably done by local enterprises, monitoring and regular maintenance with rather low effort needed. Moxey & Moran, 2014 Expert assessment (K.K., E.G., A.K., T.S.)	Preferably planting of autochtonous breeds (which can be assumed to stem from regional forest nurseries), afforestation might be done by regional enterprises, machinery might come from multinational firms (domestic added value unclear). Expert assessment (K.K., E.G., C.D.)	Seeding of cover crops related with only little additional effort for farmers, no additional machines required: low potential for domestic/regional value added. Landwirtschaftskammer Nordrhein-Westfalen, 2018; Kivelitz & Mühlen, 2017; Adetunji et al., 2020; Thapa et al., 2018; Ökoregion Kaindorf, 2020; Benker, 2021 Expert assessment (K.K., E.G., C.D.)	Little additional effort for farmers expected, no additional machines required: low potential for domestic/regional value added. Expert assessment (K.K., E.G., C.D.)	Harvesting, sorting and planting of plants can be expected to take place regionally, however, domestic value added predominantly accrues at the initial stage (no intensive post-planting ongoing action needed). Heckwolf et al., 2021 Expert assessment (K.K., E.G., A.S., T.R.)
Economic	C5: Effects on domestic/regional economy	C5.2 Potential for domestic/regional employment	assessed in the social dimension								
Economic	C6: Investment barriers	C6.1 Capital intensity (i.e. share of capital cost in total cost of CDR measure)	Erection of DAC plants and transport infrastructure requires larger investments, however, due to high operating costs their share can be assumed to be rather moderate. Expert assessment (K.K., E.G., D.H.)	Integration of DAC unit in existing air conditioning: biggest share of cost can be assumed to be operating cost. Expert assessment (K.K., E.G., D.H.)	Largest part of the removal cost for manufacturing and transport of basalt powder, share of direct basalt costs rather low (Strefler et al., 2018). Expert assessment (K.K., E.G., C.D., N.M.)	Large capital investments needed for infrastructure which account for the bulk of the total cost. Expert assessment (K.K., E.G., C.Y., C.S.-H.)	Little infrastructure/investment goods/equipment needed, most of the cost can be assumed to be labour/variable cost. Moxey & Moran, 2014; Artz et al., 2018; Okumah et al., 2019 Expert assessment (K.K., E.G., A.K., T.S.)	Cost for soil preparation, seedlings and planting occur, however expenditure for tree care can be discontinued if desired. ISIP, 2017; Höbarth et al., 2018; Smith, 2016 Expert assessment (K.K., E.G., C.D.)	Seeds require only low capital investment, machines usually already available, action to be repeated annually can be easily discontinued if not financially attractive anymore. Fuss et al., 2018 Expert assessment (K.K., E.G., C.D.)	Low capital investment expected. Expert assessment (K.K., E.G., C.D.)	Little infrastructure/investment goods/equipment needed, most of the cost can be assumed to be labour/variable cost. Expert assessment (K.K., E.G., A.S., T.R.)
Economic	C6: Investment barriers	C6.2 Specificity of investment	No other usage of DAC plants than for CO2 capturing, CO2 might be used as a commodity instead of storage, however, this might require additional investments (as erected pipelines for CO2 transport might not be suitable anymore), the market size for CO2 uncertain. Expert assessment (K.K., E.G., D.H.)	No other usage of DAC plants than for CO2 capturing, CO2 might be used as a commodity instead of storage, however, this might require additional investments, the market size for CO2 uncertain. Expert assessment (K.K., E.G., D.H.)	Application of basalt powder on agricultural land highly specific to CDR purpose. Expert assessment (K.K., E.G., C.D., N.M.)	Infrastructure specific for underground storage of gases, storage sites could be used for storage of other gases than CO2 (could require further investments for amendment of the transport infrastructure). Expert assessment (K.K., E.G., C.Y., C.S.-H.)	No other (economic) usage of invested goods possible, however drainage of the rewetted area for usage remains an option. Moxey & Moran, 2014; Artz et al., 2018; Okumah et al., 2019 Expert assessment (K.K., E.G., A.K., T.S.)	If economic case for CDR by afforestation fails, wood could be sold, reconversion to agricultural land or other usage of land possible but related to cost. ISIP, 2017; Höbarth et al., 2018; Smith, 2016 Expert assessment (K.K., E.G., C.D.)	Once applied seed cannot be removed from the field, however, biomass could be sold on the market instead of left on the field. Fuss et al., 2018 Expert assessment (K.K., E.G., C.D.)	Once applied crops cannot be removed from the field. Expert assessment (K.K., E.G., C.D.)	No other usage of seagrass plants, once applied seagrass plants cannot be removed easily, necessary ships are not specific for planting purposes. Expert assessment (K.K., E.G., A.S., T.R.)
Economic	C6: Investment barriers	C6.3 Revenue risk	Ambiguous: depends on the institutional setting: if solely relying on (volatile) CO2 pricing: rather high revenue risk, if DACCS contracted then the revenue risk can be rather low. Expert assessment (K.K., E.G., D.H.)	Ambiguous: depends on the institutional setting: if solely relying on (volatile) CO2 pricing: rather high revenue risk, if DACCS contracted then the revenue risk can be rather low. Expert assessment (K.K., E.G., D.H.)	Currently no revenue for ERW, potentially certificates for CDR could be generated on a voluntary market. Expert assessment (K.K., E.G., C.D., N.M.)	Offshore subsurface storage of CO2 is already deployed successfully in northern European countries, however, long-term evidence is lacking; technology-related risks assumed moderate, business case can be expected to depend on the (volatile) CO2-price. Expert assessment (K.K., E.G., C.Y., C.S.-H.)	Not applicable/ambiguous: potentially certificates for CDR could be generated on a voluntary market. Expert assessment (K.K., E.G., A.K., T.S.)	Subject to fixed EU-GAP greening premium, possibly an additional premium for initial afforestation receivable. Expert assessment (K.K., E.G., C.D.)	Subject to a fixed EU-GAP greening premium, the application can easily be discontinued if the greening premium doesn't cover the costs anymore. Expert assessment (K.K., E.G., C.D.)	Change of crop rotation impacts revenues: new methods and materials may be needed. Costs may differ, new market may be needed. Expert assessment (K.K., E.G., C.D.)	Not applicable/ambiguous: potentially certificates for CDR could be generated on a voluntary market, not yet established, jointly produced goods are subject to market risks. Expert assessment (K.K., E.G., A.S., T.R.)

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

no/low hurdles
medium hurdles
high hurdles
Not applicable
No data

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Institutional

Criterion	Indicator	Traffic light system	WCom (hybrid (biological + technological); BECC (+S))	WGas	WPyr	MxBG	PalBG	MABG
E1: Political maturity	E1.1 Placement within policy cycle	Not at all in any policy development; Agenda setting; Policy formulation and policy adoption; Policy implementation; Policy evaluation	Purr et al., 2019; Expert assessment (T.M., R.S.) specific to D			Purr et al., 2019; Expert assessment (T.M., R.S.) specific to D	Paludiculture is already practiced and implemented. It is in the process of being upscaled. LM M-V, 2017	Relatively unspecific, still in research phase: "Der Einsatz von Algenbiomasse als nachhaltige Rohstoffquelle für die Bioenergieerzeugung spielt derzeit noch keine Rolle und erfordert noch einigen Forschungsaufwand" (Fachagentur Nachwachsende Rohstoffe - FNR). Expert assessment (T.M., R.S.)
E2: Support for CDR within the current policy landscape	E2.1 Level of acceptance in policy debate	Low; Minor; High	"By 2050, biomass will contribute to energy provision to a limited extent, largely based on obtaining energy from waste and slurry, fermentation products and residues, in local applications to provide thermal energy for industry, commerce, trade, and services and the heat sector. [...] By contrast, the use of bioenergy from residues and waste products will make an important contribution to cross-sectoral energy provision and it will be possible to fully harness its sustainable potential". (BMUB, 2016 Climate Action Plan 2050, p. 35, 63) Purr et al., 2019; Expert assessment (T.M., R.S.) specific to D			"By 2050, biomass will contribute to energy provision to a limited extent, largely based on obtaining energy from waste and slurry, fermentation products and residues, in local applications to provide thermal energy for industry, commerce, trade, and services and the heat sector. [...] By contrast, the use of bioenergy from residues and waste products will make an important contribution to cross-sectoral energy provision and it will be possible to fully harness its sustainable potential". (BMUB, 2016 Climate Action Plan 2050, p. 35, 63) Purr et al., 2019; specific to D	Expert assessment (T.M., R.S.) specific to D	
	E2.2 Government supported research on CDR options	No; Under development; Yes	BMBF funding line for CDR (CDRterra & CDRmare); FONA - www specific to D	BMBF funding line for CDR (CDRterra & CDRmare); FONA - www	BMBF funding line for CDR (CDRterra & CDRmare); FONA - www	BMBF funding line for CDR (CDRterra & CDRmare); FONA - www specific to D	BMBF funding line for CDR (CDRterra & CDRmare); FONA - www	Without CCS: "Der Einsatz von Algenbiomasse als nachhaltige Rohstoffquelle für die Bioenergieerzeugung spielt derzeit noch keine Rolle und erfordert noch einigen Forschungsaufwand" (Fachagentur Nachwachsende Rohstoffe - FNR). BMBF funding line for CDR (CDRterra & CDRmare); FONA - www
	E2.3 Inclusion of CDR options in existing national and/or regional climate strategies	No; Proposal available; Yes	With CCS: "Sie ist nicht Bestandteil der Planung zur Erreichung der Klimaschutzziele 2030 und nicht in der deutschen Klimaschutzlangfriststrategie ("Klimaschutzplan 2050") enthalten." (Bundesregierung, 2019) Expert assessment (T.M., R.S.) specific to D	With CCS: "Sie ist nicht Bestandteil der Planung zur Erreichung der Klimaschutzziele 2030 und nicht in der deutschen Klimaschutzlangfriststrategie ("Klimaschutzplan 2050") enthalten." (Bundesregierung, 2019) Expert assessment (T.M., R.S.) specific to D	With CCS: "Sie ist nicht Bestandteil der Planung zur Erreichung der Klimaschutzziele 2030 und nicht in der deutschen Klimaschutzlangfriststrategie ("Klimaschutzplan 2050") enthalten." (Bundesregierung, 2019) Its use is not mentioned in the BMUB (2016) Climate Action Plan 2050. Expert assessment (T.M., R.S.) specific to D	BECCS is not part of the German climate action plan (BMUB, 2016). Bundesregierung, 2019 Expert assessment (T.M., R.S.) specific to D	Without CCS: "The German government will examine the possibility of consistent, permanent funding for paludiculture at the same time." (BMUB, 2016 Climate Action Plan 2050, p. 71) Expert assessment (T.M., R.S.) specific to D	Its use is not mentioned in the Climate Action Plan 2050. Expert assessment (T.M., R.S.)
E3: Legal & regulatory feasibility	E3.1 Possible scale of legal conflicts	Global conflict; Regional & transboundary conflict; Local conflict; No conflict	Impact on air/atmosphere, impact on land (land-use changes), impact of water. See: environmental dimension assessment. Creutzig et al., 2019; Anderson & Peters, 2016; Benoit & Mayer, 2019; Expert assessment (T.M., R.S.) specific to D			Impact on air/atmosphere, impact on land (land-use changes), impact of water. See: environmental dimension assessment. Creutzig et al., 2019; Anderson & Peters, 2016; Benoit & Mayer, 2019; Expert assessment (T.M., R.S.) specific to D	Impact on air/atmosphere, impact on land (land-use changes)/ impact of water (assessed in the environmental dimension) Expert assessment (T.M., R.S.) specific to D	
	E3.2 Conformity with human rights	Low; Minor; High	Potential conflicts with property rights, right to food and right to water. Benoit & Mayer, 2019; UBA, 2013 Expert assessment (T.M., R.S.) specific to D			Benoit & Mayer, 2019; UBA, 2013	Without CCS: In particular positive impacts for climate protection; Expert assessment (T.M., R.S.) specific to D	
	E3.3 Conformity with environmental laws and conservation requirements	Low; Minor; High	Benoit & Mayer, 2019; UBA 2013 specific to D			Benoit & Mayer, 2019; UBA, 2013	Abel et al., 2018B Expert assessment (T.M., R.S.) specific to D	
	E3.4 Conformity with climate laws	Low; Minor; High	Benoit & Mayer, 2019; UBA 2013 specific to D			Benoit & Mayer, 2019; UBA, 2013	Without CCS: In particular positive impacts for climate protection Abel et al., 2018B Expert assessment (T.M., R.S.) specific to D	
	E3.5 Regulatory effort	No overlap with existing regulations (legal effort); Some overlap requiring additional regulations (minor effort); Synergies / overlap with existing laws and regulations (low effort)	Expert assessment (T.M., R.S.) specific to D				No inclusion in European agricultural law yet (CAP); Expert assessment (T.M., R.S.)	
E4: Transparency and institutional capacity	E4.1 Monitoring, Reporting and Verification (MRV) system	Difficult to develop; Easy to develop; Already existing	Germany has not yet adopted a monitoring, reporting and verification system for this model concept as CDR measure. Monitoring geologically stored CO2 is straightforward, but monitoring direct and indirect emissions from land-use change in the case of cultivated biomass poses significant complications. Ariadne Report, 2021 Expert assessment (T.M., R.S.) specific to D	Germany has not yet adopted a monitoring, reporting and verification system for this model concept as CDR measure. Monitoring geologically stored CO2 is straightforward, but monitoring direct and indirect emissions from land-use change in the case of cultivated biomass poses significant complications. Expert assessment (T.M., R.S.) specific to D	Germany has not yet adopted a monitoring, reporting and verification system for this model concept as CDR measure. Monitoring geologically stored CO2 is straightforward, but monitoring direct and indirect emissions from land-use change in the case of cultivated biomass poses significant complications. Expert assessment (T.M., R.S.) specific to D	Germany has not yet adopted a monitoring, reporting and verification system for this model concept as CDR measure. Monitoring geologically stored CO2 is straightforward, but monitoring direct and indirect emissions from land-use change in the case of cultivated biomass poses significant complications. Expert assessment (T.M., R.S.) specific to D	Without CCS: MRV already exists for peatland restoration and paludiculture. With CCS: Germany has not yet adopted a monitoring, reporting and verification system for this model concept as CDR measure. Monitoring geologically stored CO2 is straightforward, but monitoring direct and indirect emissions from land-use change in the case of cultivated biomass poses significant complications. Expert assessment (T.M., R.S.) specific to D	Germany has not yet adopted a monitoring, reporting and verification system for this model concept as CDR measure. Expert assessment (T.M., R.S.) specific to D
	E4.2 Integration of negative emissions from CDR in national emission reporting	Difficult to include; Easy to include; Already included	specific to D				Abel et al., 2019 specific to D	
	E4.3 Integration of CDR in carbon market	Difficult to include; Easy to include; Already included	Rickels et al., 2021 specific to D	There is no data for this specific model. As a general BECCS measure: Expert assessment (T.M., R.S.)	There is no data for this specific model. As a general BECCS measure: Expert assessment (T.M., R.S.)	Rickels et al., 2021 specific to D	Rickels et al., 2021 specific to D	There is no data for this specific model. As a general BECCS measure: Expert assessment (T.M., R.S.)
	E4.4 Adaptive & responsive management	Difficult to include; Easy to include; Already included	specific to D				LM M-V, 2017 specific to D	
	E4.5 Administrative demand	High; Medium; Low	specific to D				High administrative demand during the early phase of establishing paludiculture (land use change from agricultural use to paludiculture use) Expert assessment (T.M., R.S.) specific to D	

Criterion	Indicator	Farms (chemical; DACC (+S))	HVAC (chemical; DACC (+S))	ERW (chemical)	GEOSTOR (S)	PReW (biological)	agricAFF	agricCC	agricCR	SeaGr
E1: Political maturity	E1.1 Placement within policy cycle	Policy debate about using DAC as option in BW, Germany Expert assessment (T.M., R.S.)	Heß et al., 2020; SRU, 2020; Expert assessment (T.M., R.S.) specific to D		"Die Bundesregierung hat mit dem Klimaschutzprogramm 2030 das Förderprogramm „CO2-Vermeidung und -Nutzung in Grundstoffindustrien" angekündigt, mit dem die Entwicklung von Carbon Capture and Utilization (CCU) sowie Carbon Capture and Storage (CCS) für anderweitig nicht vermeidbare prozess-bedingte Emissionen unterstützt werden soll". Deutscher Bundestag (2021)	Peatland restoration is already practiced and implemented and in the process of being upscaled. LM M-V, 2017 specific to D	BMUB, 2016 ; specific to D	Lütke Entrup, et al., 2018 Expert assessment (T.M., R.S.)	Already practiced and implemented; Expert assessment (T.M., R.S.)	see: https://www.bmuv.de/pressemitteilung/bmuv-und-bfn-aktiv-im-meeresnaturschutz-fuer-nord-und-ostsee specific to D
E2: Support for CDR within the current policy landscape	E2.1 Level of acceptance in policy debate		Purr et al., 2019; Bundesregierung, 2019; SRU 2019; specific to D		The Länder of Mecklenburg-Vorpommern, Lower Saxony and Schleswig-Holstein have completely excluded carbon dioxide storage for their territories. Deutscher Bundestag, 2018; Purr et al., 2019; Bundesregierung, 2019; SRU, 2020; Markus et al., 2021 Expert assessment (T.M., R.S.) specific to D	Potential conflict with farmers; Expert assessment (T.M., R.S.) specific to D	Expert assessment (T.M., R.S.) specific to D	Expert assessment (T.M., R.S.)	Already practiced and implemented; Expert assessment (T.M., R.S.)	As a climate protection measure within the framework of marine nature conservation. See e.g., management plan for the nature reserve "Pommersche Bucht - Rönneback". Also see: https://www.bmuv.de/pressemitteilung/bmuv-und-bfn-aktiv-im-meeresnaturschutz-fuer-nord-und-ostsee Expert assessment (T.M., R.S.) specific to D
	E2.2 Government supported research on CDR options	BMBF funding line for CDR (CDRterra & CDRmare); FONA - www	BMBF funding line for CDR (CDRterra & CDRmare); FONA - www; SPP 1689, 2019	BMBF funding line for CDR (CDRterra & CDRmare); FONA - www	"ACT, Accelerating CCS Technologies, ist eine internationale Initiative, um die Erforschung von CO2-Abtrennung, -Nutzung und -Speicherung zu etablieren. [...] Seit 2017 förderte die Bundesregierung im Rahmen von ACT insgesamt 24 Vorhaben in insgesamt zehn Verbünden mit einer Gesamtzuwendung in Höhe von 13,7 Mio. Euro. Aktuell befinden sich im Rahmen von ACT 2 Vorhaben zu CCS in der Durchführung mit einer gesamten Förderhöhe von 1,1 Mio. Euro." Deutscher Bundestag (2021)	BMBF funding line for CDR (CDRterra & CDRmare); FONA - www	BMBF funding line for CDR (CDRterra & CDRmare); FONA - www	BMBF funding line for CDR (CDRterra & CDRmare); FONA - www	BMBF funding line for CDR (CDRterra & CDRmare); FONA - www	Research project "Seastore", funded by BMBF; https://www.seegraswiesen.de/ specific to D
	E2.3 Inclusion of CDR options in existing national and/or regional climate strategies		specific to D		"Achieving the necessary reductions in process emissions by industry will require defining further steps in implementation no later than the 2020 – 2030 period.[...] This will require immediate major research and development work targeted to specific process innovations and to CCU, which builds on current activities; a potential role for CCS in this context must then be examined if that turns out to be necessary and acceptable". BMUB, 2016 specific to D	Concept for the conservation and use of peatlands in Mecklenburg-Vorpommern, peatland conservation programme in Baden-Württemberg; - Climate Action Plan 2050 (BMU 2016) - Concept for the conservation and use of peatlands in Mecklenburg-Vorpommern: https://www.lung.mv-regierung.de/insite/cms/umwelt/natur/lebensraumschutz_portal/moorschutz.htm - Peatland conservation programme Baden-Württemberg: https://um.baden-wuerttemberg.de/fileadmin/redaktion/m-um/intern/Dateien/Dokumente/2_Presse_und_Service/Publikationen/Umwelt/Naturschutz/Moorschutzprogramm_BW.pdf specific to D	Under the guiding principle for 2050 to maintain and enhance the capacity of forests to act as sinks. Expert assessment (T.M., R.S.) specific to D	BMUB, 2016; IEKK, 2014; Expert assessment (T.M., R.S.)	Agricultural production is also targeted by the German Climate Strategy; BMU, 2019; BMUB, 2016; IEKK, 2014 Expert assessment (T.M., R.S.)	
E3: Legal & regulatory feasibility	E3.1 Possible scale of legal conflicts		Markus et al., 2020 ; Hester, 2019; specific to D		CCS is associated with environmental risks. E.g.: "Auswirkungen auf das Grundwasser können sich vor allem durch den Aufstieg von CO2 in oberflächennahes Grundwasser sowie durch die Verdrängung von salinen Formationswässern ergeben. Beim Aufstieg von CO2 kann die Konzentration von CO2 erhöht werden, es kann zur Versauerung und erhöhten Schwermetallverunreinigungen kommen". UBA 2015, p. 9. See also p. 3-4.	Potential conflict with farmers; Expert assessment (T.M., R.S.) specific to D	Impact on land and land-use change, impact on water which relates to nature conservation law and protected areas; Expert assessment (T.M., R.S.) specific to D	Expert assessment (T.M., R.S.)	Expert assessment (T.M., R.S.)	Disputes may arise over boundaries and fishing rights, especially when fishing is restricted in certain areas reserved for seagrass meadows. Expert assessment (T.M., R.S.) specific to D
	E3.2 Conformity with human rights		BVerfG, 2021; specific to D			In particular positive impacts for climate protection; Expert assessment (T.M., R.S.) specific to D			Expert assessment (T.M., R.S.)	Positive impacts. Expert assessment (T.M., R.S.)
	E3.3 Conformity with environmental laws and conservation requirements		Hester, 2019; Markus et al., 2020; specific to D		Currently, German CO2-Storage Storage Law (Kohlenstoffspeichergesetz - KSpG) limits storage to 1.3 mio t/pa. (per project) and 4 mio t./pa (per year) in the entire area governed by the KSpG, see § 2 II Nr. 2 KSpG. The law has recently been evaluated and lifting the existing limitations is being considered. Bundesregierung, 2022; UBA, 2015; UBA, 2022	Expert assessment (T.M., R.S.) specific to D	- EU Common Agricultural Policy (CAP), federal (German Federal Forest Act) state and local laws and regulations for afforestation apply. There is EU funding (European Agricultural Fund for Rural Development) and state funding for the first afforestation of cropland available. '- The support of cropland would be canceled in case of afforestation (First pillar of the common agricultural policy (CAP) - Direct payments to farmers Expert assessment (T.M., R.S.) specific to D	Saatgutverkehrsgesetz (SaatG), EU Verordnung zum ersten GAP Säule (Regulation (EU) No. 1307/2013, Art. 46 together with Annex X), Direktzahlungen-Durchführungsgesetz (DirektZahlDurchfG), Düngeverordnung - DüV; Lütke Entrup et al., 2018; Geden & Schenuit, 2020	Saatgutverkehrsgesetz (SaatG), EU Verordnung zum ersten GAP Säule (Regulation (EU) No. 1307/2013, Art. 46 together with Annex X), Direktzahlungen-Durchführungsgesetz (DirektZahlDurchfG), Düngeverordnung - DüV; Lütke Entrup et al., 2018; Geden and Schenuit	Potential legal issues related to the protection of soil, flora and fauna through the planting or reintroducing new seagrass meadows. Expert assessment (T.M., R.S.) specific to D
	E3.4 Conformity with climate laws		Hester, 2019; Markus et al., 2020;			In particular positive impacts for climate protection; Expert assessment (T.M., R.S.) specific to D	Ensuring permanence of CO2 storage can be an issue, e.g. related to forest fires and use as fuel wood; Expert assessment (T.M., R.S.) specific to D	Lütke Entrup et al., 2018; Geden and Schenuit, 2020; Expert assessment (T.M., R.S.)	Removal of atmospheric CO2 by plants and storage in soil is part of several national and international initiatives; Geden and Schenuit, 2020; Expert assessment (T.M., R.S.)	Positive impacts for climate protection. Expert assessment (T.M., R.S.)
	E3.5 Regulatory effort		Hester, 2019; Markus et al., 2020; specific to D		"Damit CO2 im tiefen Untergrund auf dem Bundesgebiet gespeichert werden könnte, müssten Bestimmungen des Kohlendioxid-Speicherungsgesetztes (KSpG) geändert werden." Deutscher Bundestag, 2021; specific to D			Expert assessment (T.M., R.S.)	Expert assessment (T.M., R.S.)	There are various legal provisions applicable to the protection and planting of seagrass meadows in Germany. However, there may also be overlaps with regional or local laws, regulations and directives. In this case, depending on the respective region or federal state, other specific regulations relevant to seagrass meadows could be applicable. Expert assessment (T.M., R.S.) specific to D
E4: Transparency and institutional capacity	E4.1 Monitoring, Reporting and Verification (MRV) system	Germany has not yet adopted a monitoring, reporting and verification system for this model concept as CDR measure. Expert assessment (T.M., R.S.) specific to D	Germany has not yet adopted a monitoring, reporting and verification system for this model concept as CDR measure. Expert assessment (T.M., R.S.) specific to D		UBA, 2022 specific to D	Without CCS. Germany has not yet adopted a monitoring, reporting and verification system for this concept model as CDR measure. However, in Mecklenburg-Vorpommern a carbon credit scheme and monitoring for peatland restoration has been established. MoorFutures established a carbon credit scheme for peatland restoration: https://www.moorfutures.de/ Expert assessment (T.M., R.S.) specific to D	Without CCS. Germany has not yet adopted a monitoring, reporting and verification system for this model concept as CDR option. Expert assessment (T.M., R.S.) specific to D	Germany has not yet adopted a monitoring, reporting and verification system for agriculture. Expert assessment (T.M., R.S.)	Establishment of monitoring still needed; Expert assessment (T.M., R.S.)	
	E4.2 Integration of negative emissions from CDR in national emission reporting					specific to D	Expert assessment (T.M., R.S.) specific to D	Difficult to be included: if exact carbon storage is to be included. Easy to include: if legislators want to include with general assumptions. Expert assessment (T.M., R.S.)	Establishment of monitoring still needed; Expert assessment (T.M., R.S.)	
	E4.3 Integration of CDR in carbon market	There is no data for this specific model. As a general DAC measure: Expert assessment (T.M., R.S.)	There is no data for this specific model. As a general DACCS measure: Rickels et al., 2021		"Gemäß Treibhausgas-Emissionshandelsgesetz (TEHG), durch das die EU-Emissionshandels-Richtlinie in nationales Recht überführt worden ist, sind auch Einrichtungen im Rahmen der CCS-Kette vom Emissionshandel erfasst". UBA, 2022; specific to D	Germany has not yet adopted a monitoring, reporting and verification system for this concept model as CDR measure. However, in Mecklenburg-Vorpommern a carbon credit scheme and monitoring for peatland restoration has been established. MoorFutures established a carbon credit scheme for peatland restoration: https://www.moorfutures.de/ Expert assessment (T.M., R.S.) specific to D	Expert assessment (T.M., R.S.) specific to D	Expert assessment (T.M., R.S.)	Establishment of monitoring still needed; Expert assessment (T.M., R.S.)	
	E4.4 Adaptive & responsive management		specific to D			Mecklenburg-Vorpommern has established a peatland restoration programme. LM M-V, 2017 Expert assessment (T.M., R.S.) specific to D	Expert assessment (T.M., R.S.) specific to D	Regulation (UE) No 1307/2013 (OJ L 347, 20.12.2013, p. 608; Expert assessment (T.M., R.S.)	Crop rotations are already practiced as part of adaptive management; Expert assessment (T.M., R.S.)	
	E4.5 Administrative demand		Markus et al., 2020 specific to D		"Das KSpG lässt seit 2012 die Erforschung, Erprobung und Demonstration der CO2-Speicherung in begrenztem Ausmaß zu. Dabei begrenzt es die Menge des jährlich zu speichernden CO2 für Deutschland insgesamt sowie für die einzelnen Speichervorhaben. Zudem erlaubt das KSpG den Ländern gesetzlich zu bestimmen, in welchen Gebieten die Erprobung und Demonstration zulässig sein soll und in welchen nicht". UBA, 2022	In particular for establishing peatland restoration; Expert assessment (T.M., R.S.) specific to D	Expert assessment (T.M., R.S.) specific to D	Expert assessment (T.M., R.S.)	Already practiced Expert assessment (T.M., R.S.)	

	Abbreviation	Description	Abbreviation	Description
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		

no/low hurdles
medium hurdles
high hurdles
Not applicable
No data

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			Traffic light system	hybrid (biological + technological)						chemical				biological				
				BECC (+S)						DACC (+S)			S					
				WCom	WGas	WPyr	MxBG	PalBG	MABG	Farms	HVAC	ERW	GEOSTOR	PReW	agricAFF	agricCC	agricCR	SeaGr
Social	D1: Public perception of CDR approaches and/or process	D1.1 Perceived risk of CDR measure	Deemed high risk; Deemed medium risk; Ambivalent risk perception; Deemed low risk; Deemed risk free	Difficult to separate risk perception of storage from risk perception of biomass. The general public overall does not know about BECCS and thus assessing perception is difficult and depends on how it is introduced. Difficult to assess without the storage component as this is generally the critical part. Other concerns include biodiversity effects. In general, the literature seems to suggest that this is the most challenging form of BECCS because it is the option that interferes the most with nature. Cutting down trees = problematic even if it is "sustainable". The other BECCS options have less challenging biomass choices. Burgerforum - www (https://www.spp-climate-engineering.de/index.php/buergerforum.html) Expert judgment (T.T., two anonymous external experts)	Burning mature beech wood would probably be regarded to be problematic. Associated with loss of biodiversity. More negative risk perception if coupled with storage/CCS. Burgerforum - www (https://www.spp-climate-engineering.de/index.php/buergerforum.html) Expert judgment (T.T., two anonymous external experts) specific to D	Public risk perception mostly associated with storage/CCS. Hence, biochar could be related to a relatively positive attitude. However, using solid beech wood for this could be regarded as a risk to forests. Rating this similar to WCom due to similar raw material. Uncertain if the biochar part makes it seen more favorable. Burgerforum - www (https://www.spp-climate-engineering.de/index.php/buergerforum.html) Expert judgment (T.T.) specific to D	Difficult to separate risk perception of storage from risk perception of biomass. The general public overall does not know about BECCS and thus assessing perception is difficult and depends on how it is introduced. With storage - higher risk Burgerforum - www (https://www.spp-climate-engineering.de/index.php/buergerforum.html) Expert judgment (T.T., 2 external experts ranked low to medium risk)	Potentially some worries about flooding due to rewetting. See concept on rewetting in Borchers et al. (2022). Difficult to separate risk perception of storage from risk perception of biomass. The general public overall does not know about BECCS and thus assessing perception is difficult and depends on how it is introduced. As the main factor for risk perception of BECCS is effect on biodiversity, and paludiculture likely improves biodiversity, hence, this could be seen as a more acceptable BECCS option. At the same time, it is not NbS and it takes material away from the peatland. With storage - higher risk Burgerforum - www (https://www.spp-climate-engineering.de/index.php/buergerforum.html) Expert judgment (T.T.; anonymous external experts); specific to D	Difficult to separate risk perception of storage from risk perception of biomass. The general public overall does not know about BECCS and thus assessing perception is difficult and depends on how it is introduced. As the main factor for risk perception of BECCS is its effects on biodiversity. As macroalgae likely improve biodiversity, this could be seen as a more acceptable BECCS option. At the same time, it is not NbS, and it comes with an impact on the marine environment. Likely one of the options deemed less risk associated with biomass extraction. With CCS a higher risk. Very small risk that macroalgae will drift away. Burgerforum - www (https://www.spp-climate-engineering.de/index.php/buergerforum.html) Expert judgment (T.T., anonymous external experts) specific to D	A big technical facility could be deemed "unnatural" and tampering with nature. Expert judgment (T.T., technical expert)	If considered without CCS. Expert judgment (T.T.)	No data from Germany but study from US, UK, and Australia shows that most do not know what ERW is and when they are informed, risk perception varies with some finding it to be a good solution, some risky or dangerous. A common concern is the downstream effects on water. Spence et al., 2021; Expert judgment (T.T.)	Assumed on-shore CCS. In terms of public perception perhaps it makes more sense to go for offshore CCS first, despite technically on-shore being more feasible. The expert elicitation resulted in 2 responses for high risk, 1 for medium, and 1 for ambivalent. Much of the literature also points to a high risk perception of the public. That being said, some of the risks associated with fossil CCS such as delayed decarbonization are reduced with BECCS or DACCS application. (Oltra et al., 2012). Significantly higher support for CCU than CCS in Germany. Several references to previous studies on attitudes and CCS: Linzenich et al., 2019. Expert judgment (T.T., anonymous external experts) specific to D	Generally deemed low risk, but some people living close by could have concerns about flooding. Other than that, the key concern related to rewetting flagged in the literature seems to be the risk of lost income for farmers, but this aspect is considered below. Expert judgment (T.T.) Specific to D	Competition for land, light, water, soil quality etc. Based on ongoing scientific work in Germany, people in general seem very positive towards afforestation and do not raise risk concerns. Expert judgment (T.T., external expert) specific to D	Expert judgment (T.T.)	Public perception of risks will probably not change when comparing improved crop rotation with conventional agriculture. Expert judgment (T.T.)	No data available for Germany yet. Internationally generally low risk, some concerns about invasiveness. Expert judgment (T.T., external expert)
		D1.2 Trust in process	Distrust; Low level of trust; Ambivalent/medium level of trust; High level of trust; Very high level of trust	The process has not yet started but based on previous CCS experiences. Thus far, CDR has not been included in public deliberations on climate change. Expert judgment (T.T., two anonymous external experts) specific to D	Distrust likely to be related to CCS technology. Expert judgment (T.T., two anonymous external experts)	No major issues around trust expected; Expert judgment (T.T.)	2 external experts ranked high to medium. Based on previous experiences with CCS as the process has not really started yet. Expert judgment (T.T.)	Based on previous experience with CCS. Paludiculture - higher level of trust. Depends on the land user. Paludiculture currently not receiving subsidies Expert judgment (T.T.)	Process not really started. Based on previous experience with CCS. Expert judgment (T.T.)	process not started	process not started	Not really applied but could be compared to basalt mining or the fertilizer industry. Can be compared to liming. Has not been implemented as carbon removal measure yet. Expert judgment (T.T.)	Previous low level of trust (for early CCS in Germany). For BECCS the process has not really started yet (see e.g., Honegger et al. (2021) arguing that this is a risk). Public participation is expected to take place but at the moment it is unclear what this will look like for BECCS compared to early fossil CCS. Honegger et al., 2021; UNFCCC Side Event - www (https://cop26euside events.app.swapcard.com/event/eu-side-events-cop26/planning/[illegible]) Expert judgment (T.T., external experts) specific to D	Mainly related to private land: farmers will have to be convinced of rewetting peatlands that are currently under agricultural land use or of living the land to the state. Change of the EU CAP in favor of peatland rewetting needed (currently a gap). Tanneberger et al., 2020; Expert judgment (T.T.) Specific to D	While afforestation exists, it is usually not done with mitigation and carbon sequestration as main concern. Regional differences; Some subsidies available from the EU level managed by the federal state. Expert judgment (T.T.)		Expert judgment (T.T.)	Currently, there seems to be no issue related to distrust. The trust might decrease with large-scale implementation. ??
	D2: Social co-benefits	D2.1: Health	Negative effects; Uncertain, leaning to negative effects; No effect/no change; Uncertain, leaning to positive effects; Positive effects	Uncertain, depends on air pollution and scale. Outdoor air quality likely worsens. Expert judgment (T.T.) specific to D	Improved air quality when wood is used in technical plants rather than small scale ovens in homes. Current usage can be repurposed and used more efficiently. Expert judgment (T.T.)	No harmful health effects expected; Expert judgment (T.T.)	2 external experts ranked no or uncertain. Depends on the amount of air pollution. Air quality likely worsens (see environmental dimension). Expert judgment (T.T.)	Poorer air quality expected from biomass plant (see environmental dimension). Some worries about flooding could be imagined (see concept on rewetting peatlands in Borchers et al., 2022); Better water quality from run-off; Better air quality compared to agriculture - outweights risks from biomass plant; Expert judgment (T.T.); specific to D	Possible emissions of gases from algae production; Expert judgment (T.T.)	Could potentially clean the air but no data. Expert judgment (T.T.)	Could potentially clean the air but no data. Expert judgment (T.T.)	Potential increase of noise, pollution, and aerosol burden. Not just mining but also distribution. However, lack of studies on this. Some effects could be mitigated. Mining in specific areas and thus most people are not affected. Mining could increase. Expert judgment (T.T.)	With proper monitoring, leakage should be avoided. Leakage of CO2 to drinking water with bacterial development could be a risk but it is likely to happen under normal operations. Risks are well understood from previous research on CCS. Expert judgment (T.T., external experts) specific to D	Mosquitoes potentially as nuisance; Positive effects on mental health, water quality, biodiversity, more diverse landscape; Cooling effect on the landscape, positive for local climate; Expert judgment (T.T.) specific to D	Could temporarily increase noise pollution, but over long term reduce impacts from farming. Less pollution from fertilizers. Depending on how the afforestation is done, it could lead to a more varied landscape (but not if monocultures are planted). Potential recreational benefits. Expert judgment (T.T.)	Low effects. Assuming the use of fertilizers and pesticides. If not, then very low effect. Some noise from machinery but not in populated areas. Potentially positive effects on mental health if the landscape is deemed greener and more varied. Potentially less nitrate leakage with positive water quality effects. Less fertilizers needed. Legumes can capture N. Potentially positive for biodiversity. Expert judgment (T.T.)	Low effects. Assuming the use of fertilizers and pesticides. If not, then very low effect. Some noise from machinery but not in populated areas. Potentially positive effects on mental health if the landscape is deemed greener and more varied. Might reduce nitrate leaching with positive water quality effects. Expert judgment (T.T.)	Most people are probably not affected. Those living by the coast might be positively affected by the increased biodiversity and more living in coastal zones. Currently no data on the perception of smells from decomposing seagrasses on the beach. Expert judgment (T.T.)
		D2.2: Employment	Lost employment opportunities; Lost employment opportunities expected; No effect on employment expected/neutral; New employment opportunities expected; New employment opportunities	If existing plants are used, then the same employees should be able to stay and thus no change expected; Expert judgment (T.T.) specific to D	No change in employment; Expert judgment (T.T.)	No change in employment expected; Expert judgment (T.T.)	2 external experts ranked no or uncertain leaning toward new. If existing plants are used, then the same employees should be able to stay, and thus no change expected. Expert judgment (T.T.) specific to D	Worry that farmers would loose income and not be compensated properly. Currently no financial compensation available (National/EU); Potential for the future for new employment opportunities, but currently risk of lost opportunities. Ziegler et al., 2021; Expert judgment (T.T.); specific to D	Potentially some new jobs for producing the biomass. Expert judgment (T.T.)	The minimal workforce required. Expert judgment (T.T.)	The minimal workforce required. Expert judgment (T.T.)	Not many, only some. Expert judgment (T.T.)	Some new employment opportunities expected, e.g., related to the development and construction of new infrastructure. Expert judgment (T.T., external experts) specific to D	Can create new jobs, and adapted to what works for the area. The literature, however, flags worries among farmers for lost income. At the moment there are also few subsidies available. Tanneberger et al., 2020 Expert judgment (T.T.) specific to D	Assuming that lost employment opportunities within agriculture could be compensated by employment opportunities of forestry. Model concept specifies that preferrably areas with low land conversion opportunity costs should be target. An option for enhacing employment could be the introduction of agroforestry. Could provide diversity of income. Expert judgment (T.T.)	Low effects but assuming some additional employment opportunities due to more maintainance work. Expert judgment (T.T.)	Expert judgment (T.T.)	Low need for maintenance. Plans of using communal underwater gardening and divers' communities. Expert judgment (T.T.)
	D3: Inclusiveness / participation	D3.1: Participation during different steps of the process	Not existing; Low degree of public participation possible; Neither low nor high possibility for the public to participate; High degree of public participation possible; Very high degree of public participation possible	The process has not yet started. Judgment based on previous CCS experience. Expert judgment (T.T., two anonymous external experts) specific to D	The process has not yet started. Important to involve partners from forestry and agriculture (more than the general public); Expert judgment (T.T., two anonymous external experts) specific to D	specific to D	2 external experts ranked that public participation is possible. Honegger et al. (2021) argue that for CDR in general, Germany could do more and the potential for public participation is there due to well-developed structure. Expert judgment (T.T.) specific to D	Farmers offered land in exchange/compensation. Voluntary for farmers to rewet/take part in the exchange.; Expert judgment (T.T.); specific to D	process not started	process not started	process not started	Expert judgment (T.T.)	E.g. Honegger et al. (2021) is arguing that not enough has been done for public participation in the CDR debate in Germany. Expert judgment (T.T.) specific to D	Expert judgment (T.T.)	Expert judgment (T.T.)	Expert judgment (T.T.)	Expert judgment (T.T.)	
		D3.2: National dialogue/regional planning	No; Planned; Yes	At the latest German citizens' assembly on climate change NETs & CCS were not discussed. Expert judgment (T.T.)	Expert judgment (T.T.) specific to D	Expert judgment (T.T.) specific to D	Expert judgment (T.T., two anonymous external experts) specific to D	MV ongoing dialogue about rewetting peatlands + paludiculture; carbon capture not yet; Expert judgment (T.T.);	process not started	process not started	process not started		Likely to be planned. Expert judgment (T.T., external experts) specific to D			Expert judgment (T.T.)		
		D3.3: Transparency of process	Low degree of communication and; Low to medium degree of; Ambivalent/Medium degree of; Medium to high degree of; High degree of communication and	At the latest German citizens' assembly on climate change NETs & CCS were not discussed. Expert judgment (T.T.) specific to D	Expert judgment (T.T.) specific to D	Expert judgment (T.T.) specific to D	Expert judgment (T.T., two anonymous external experts) specific to D	Hight for the biomass part; low for carbon capture; Expert judgment (T.T.); specific to D	process not started	process not started	process not started	Not really applied for this purpose yet.	Expert judgment (T.T., external experts)					
	D4: Ethical considerations	D4.1: Discursive legitimation	Low; Uncertain, leaning to low; Ambivalent; Uncertain, leaning to high; High	Based on the literature, this seems to be the most problematic type of BECCS because it includes cutting down trees. Tampering with nature is generally not liked. However, when linked to biomass, some evidence suggests that discursive legitimation is higher. Dooley & Kartha, 2018; Carton, 2019; Wolske et al., 2021; Expert judgment (T.T.)	Cutting trees is likely to be seen as not positive. However, BECCS is likely to be regarded more positive than CCS. Dooley & Kartha, 2018; Carton, 2019; Wolske et al., 2021; Expert judgment (T.T.)	Likely preferred over fossil fuel CCS. Expert judgment (T.T.)	Ambivalent expert elicitation, but in general, BECCS seems to be changing from negative to more positive discourse. BECCS is however still seen as tempering with nature and NBS generally preferred. Wallquist et al., 2012; Haikola et al., 2019; Gough et al., 2014; Expert judgment (T.T., two anonymous external experts)	BECCS is seen as tampering with nature and people in general do not like this. Paludiculture could be seen as restoring nature, but that depends on how long the area has been dry. The agricultural area may also be seen as more natural because it has been dry for such a long time. Worries about farmers loosing their jobs. BECCS better than fossil CCS - seen as more natural and not to the same extent associated with delayed decarbonisation. Wolske et al., 2019; Ziegler et al., 2021; Wallquist et al., 2012; Expert judgment (T.T.); specific to D	BECCS is seen as tampering with nature and people, in general, do not like this. Macroalgae could be seen as natural and not really competing with other "land" uses, so it could be one of the more preferable BECCS options. Potentially positive effects on water quality: ocean health, biodiversity; Expert judgment (T.T.)	Could be regarded as tampering with nature with NBS preferred over technical solutions. Wolske et al., 2019; Expert judgment (T.T.)	Could be regarded as tampering with nature with NBS preferred over technical solutions. Wolske et al., 2019; Expert judgment (T.T.)	Mining is regarded as tampering with nature, and perceived risk of pollution of downstream watersheds (see above) (Spence et al., 2021). It is also an enhancement of a natural process (Wolske et al., 2019); Perceived safe compared to other CDR methods (solid material, natural process, etc.); Expert judgment (T.T.)	The discourse is possibly changing from delaying decarbonisation to more positive cleaning up the atmosphere with BECCS. The discourse still delegitimizes CCS but it might be changing. Wallquist et al., 2012; Haikola et al., 2019; Gough et al., 2014; Expert judgment (T.T., external experts)	Could create many co-benefits in terms of biodiversity, well being, but also lost income for farmers unless this issue is properly addressed. If the area has been dry for a long time, it may also be considered the traditional and most "natural" state. (Tanneberger et al., 2020; NBS preferred over technical solutions (Wolske et al., 2019). Expert judgment (T.T.)	Planting trees is seen as effective mitigation option in general with many other benefits like biodiversity and health effects (depending on type of plantation). Expert judgment (T.T., external expert) specific to D	Does not seem to affect the general public and also not seen as tampering with nature as cropland is already tampered with. Wolske et al., 2019. Expert judgment (T.T.)	Does not seem to affect the general public and also not seen as tampering with nature as cropland is already tampered with. Wolske et al., 2019. Expert judgment (T.T.)	Mainly positive related to nature restoration etc. Some concerns (internationally) about invasive species as well as the smell from decomposing seagrasses on land. Wolske et al., 2019. Expert judgment (T.T.)
		D4.2: Intergenerational equity	Low; Uncertain, leaning to low; Ambivalent; Uncertain, leaning to high; High	Depends if BECCS is seen as a way to fight climate change, then that would be for future generations. However, there is also a risk related to mitigation deterrence (Carton et al., 2021). McLaren et al., 2016; McLaren, 2020; Wolske et al., 2021; Expert judgment (T.T.)	Ambivalent as for other BECCS. See literature on mitigation deterrence, e.g., McLaren, 2020. McLaren et al., 2016; Wolske et al., 2021; Expert judgment (T.T.)	Ambivalent as for other BECCS. See literature on mitigation deterrence, e.g., McLaren, 2020. More sustainable land-use could be better for future generations. Expert judgment (T.T.)	One expert: uncertain leaning to low, one expert: one no data. See however also Carton et al. (2021) and literature on mitigation deterrence. McLaren, 2020; Expert judgment (T.T., two anonymous external experts) specific to D	Ambivalent as for other BECCS. See literature on mitigation deterrence, e.g., McLaren, 2020. More sustainable land-use could be better for future generations. Carton et al., 2021; Expert judgment (T.T.); specific to D	Ambivalent as for other BECCS. See literature on mitigation deterrence, e.g., McLaren (2020). More sustainable land-use could be better for future generations. Expert judgment (T.T.)	Potentially seen as mitigation deterrence. Carton et al., 2021; McLaren, 2020; McLaren et al., 2016; Expert judgment (T.T.)	Potentially seen as mitigation deterrence. Carton et al., 2021; McLaren, 2020; McLaren et al., 2016; Expert judgment (T.T.)	No lack of the resource (basalt) could have positive effects not only on the climate but also on the soil quality. However, mining comes with environmental impacts. Expert judgment (T.T.)	Responses varied from high to low. Respondents argued that it depends if CCS is seen as a way to combat climate change. If so, it might foster intergenerational equity. If not, then there is a risk for mitigation deterrence. Expert judgment (T.T., external experts) specific to D	The approach is about returning an ecosystem back to its old state and thus should be more sustainable and long-term. Expert judgment (T.T.) specific to D	Depends on how it is done - if monocultures with no good long-term maintenance plan, then this might lead to unsustainable land-use change and food insecurity. (Dooley & Kartha, 2018) NBS preferred over technical. (Wolske et al., 2019) Expert judgment (T.T.)	Unlikely to jeopardize future generations as this is something that can be done in parallel with other processes. But more SOC is positive long-term not just for the climate but also for the quality of the soil. Expert judgment (T.T.)	Unlikely to jeopardize future generations. Expert judgment (T.T.)	Over the long-term likely to have many added benefits for future generations. Expert judgment (T.T.)
		D4.3: Ethical reservations (of resource use)	High degree; Medium degree; Ambivalent/neither high nor low degree; Low degree; None/not applicable	Competition for land-use. All bioenergy and NbS come with the ethical consideration that it shifts the burden from the fossil fuel industry to the land-use sector. Carton et al., 2021; McLaren et al., 2016; Expert judgment (T.T.)	Competition for land-use expected. Shifting burden from fossil fuel sector to land sector. Carton et al., 2021; McLaren et al., 2016; Expert judgment (T.T.)	Uncertain; Expert judgment (T.T.)	Competition for land-use. All bioenergy and NbS come with the ethical consideration that it shifts the burden from the fossil fuel industry to the land-use sector. Expert elicitation ranges between high and medium. Ethical reservations mentioned: land-use change, land-use conflicts e.g., between food production or environmental values. Carton et al. (2021): "treating BECCS as a solution to continued fossil fuel emissions implicitly shifts the burden of mitigation from energy, industry, and transport to the land use sector, with ramifications for distributional justice and ecosystem functioning (Buck, 2016; DeCicco and Schlesinger, 2018; Seddon et al., 2020)." Dooley & Kartha, 2018 Expert judgment (T.T., two anonymous external experts)	Uncertain how to rate paludiculture biomass vs other options but probably seen as more sustainable than Biomass CHP. Ziegler et al., 2021; Expert judgment (T.T.); specific to D	Uncertain, but probably macroalgae could be one of the better options for BECCS because it does not compete with food production, etc. Expert judgment (T.T.)	High energy demand could create competition with other societal goals including energy security. Expert judgment (T.T.)	Energy use could be an issue. Expert judgment (T.T.)	No lack of the resource (basalt) could have positive effects not only on the climate but also on the soil quality. The process is energy intensive. Expert judgment (T.T.) specific to D	Ambiguous information about storage capacity: high according to HICAM, limited according to UBA (2014). Ethical reservations include competition for underground space. Limited capacity with most capacity being in the north. Could lead to unfair regional distribution of CCS activities. Natural resource use would be underground storage space primarily. Expert judgment (T.T., external experts) specific to D	One could argue that the land is a resource and thus there could be reservations about changing their usage. Overall, it is more about providing more resources than using resources. Expert judgment (T.T.) specific to D	If the land is counted as a resource then it depends on how this is done - could be positive, could be negative, see above. Dooley & Kartha, 2018; Expert judgment (T.T.)	Does not really use natural resources, but pesticides and fertilizers could perhaps be counted here. Expert judgment (T.T.)	Similar to other conventional cropping systems (e.g., use of crop products for fuel and feed, use of pesticides, fertilizer, etc.) Expert judgment (T.T.)	Would e.g. the fishing industry or pipelines be negatively affected? Expert judgment (T.T.)
	D5: Social context	D5.1 Previous experience of large-scale development/infrastructure projects	Very negative; Negative; Neutral/no previuous experience; Positive; Very positive									Most mines located in central Germany. People have experience and some are also employed in mining industry. Distribution could be done in agricultural areas. More flexible in terms of site. Assumed more cropland than pasture. Expert judgment (T.T.) specific to D	Expert judgment (T.T.)					
		D5.2 Local narrative	Very negative; Negative; Neutral/no previuous experience; Positive; Very positive										Expert judgment (T.T.)					

BECC-	WCom	woody biomass feedstock for combustion with CHP
	WGas	woody biomass feedstock for gasification for BtL production
	WPyr	woody biomass feedstock for pyrolosis for biochar production
	MxBG	mixed biomass feedstock for biogas with CHP
	PalBG	paludiculture feedstock for biogas with CHP
	MABG	macroalgae feedstock for biogas with CHP
DACC-	Farms	Direct Air Carbon Capture Farms
	HVAC	DACC installed in heat, ventilation, air-conditioning (HVAC) systems

ERW	terr. enhanced rock weathering on agriculture soils
GEOSTOR	geological storage solutions
PReW	rewetting of peatlands/organic soils
agricAFF	afforestation of croplands
agricCC	cover crops on agricultural soils
agricCR	crop rotation on arable soils
SeaGr	seagrass meadow restoration

Legend: no/low hurdles; medium hurdles; high hurdles; Not applicable; No data

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