Supplementary Information for
(Mis)conceptions about Modelling of Negative Emissions Technologies

SI.A.1 Descriptive Information on the Expert Survey

IAM-Models represented on the invitation list: AIM-CGE, BEAM, BET, C-Roads, DIAM, DICE/RICE, DIME, EMF, EMF Lead, ETP Model, FARM 3.2, FARM 3.3, FARM 3.4, FUND, GCAM 4.2, GCAM 4.3, GCAM 4.4, GEM-E3, GEM-E4, GEM-E5 , GENeSYS-MOD, GRAPE, GRAPE-15.1.0, GRAPE-15.1.1, IAMC, IEA World Energy Model, IMACLIM, IMAGE, MERGE-ETL, MESSAGE, PAGE, POLES, REMIND, TIAM-FR, WITCH.

ESM-Models represented on the invitation ESM list: ACCESS, AWI-ESM, Bern3D-LPX, BICYCLE box model, BNU-ESM, CAS-ESM, CanESM, CESM, CESM2, Climate models of reduced complexity, CNRM-ESM, CORDEX, EC-Earth, FAMOUS, GENIE, GFDL, GISS, HadGEM2-ES, HadCM3L, MIROC-ES2, Mk3l-COAL, MPI-ESM, NorESM, Uvic, IPSL ESM.

Table SI.A.T1 Main research foci of ESM-respondents
(multiple responses allowed)

Main research foci in ESM	N
Atmospheric physics	12
Atmospheric chemistry	3
Ocean biogeochemistry	19
Ocean physics	10
Ocean sediments	2
Sea ice	3
Land ice	0
Terrestrial biosphere	15
Other	1

SI.A.2 Number of responses for constraint-technology combinations

Table SI.A.T2 Number of responses for constraint-technology combinations

Constraint/Technology	AF	BECCS	BC	EW	SC	DAC	BLC	AOA	OIF	AOUp
non-CO2 forcing	29	27	24	20	27	27	18	19	21	17
climate feedbacks	33	31	28	26	30	30	23	22	24	21
en&human health se.	31	31	28	25	29	28	22	24	26	21
resource competition	34	32	28	26	32	29	23	23	24	22
carbon cycle response	32	30	30	29	31	29	23	24	25	22
political feasibility	32	31	30	27	32	31	23	22	23	20
cost effectiveness	32	32	28	25	31	29	24	26	26	24

SI.A.3 Assessment of the Capability of the Own Model to Simulate NETs portfolios

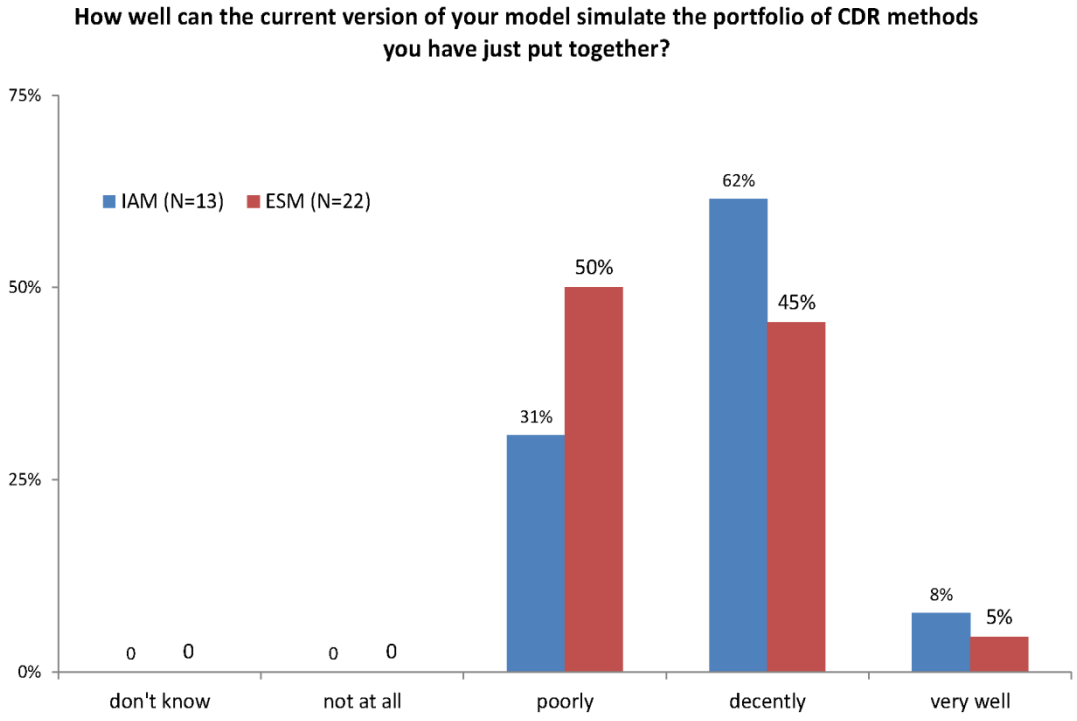

Figure SI.A.F1 Conception about modelling of CDR Portfolios.

SI.A.4 ESM-IAM Free Answers Analysis

ESM Summary: Which factors need to be improved for better modelling of NETs?

General: Poor understanding of climate-carbon cycle feedbacks in response to any methods, i.e., the backfluxes from other reservoirs. All aspects of the land-sea interface are not well represented in models (if represented at all).

AOA: Several respondents (4) indicated that ocean physics needed to be improved to better simulation AOA, although it is not clear if improvements should be made to the models or because AOA has always been simulated in an idealized manner in relatively coarse resolution models and we do not know how AOA efficacy is affected by model resolution. There were also several (3) respondents who did not think that sinking and dissolution of particulate AOA minerals was adequately resolved. One respondent also suggested that ESM AOA results are only valid for the next few decades, i.e., we cannot adequately simulate responses at longer time scales.

Regarding chemistry, there were several comments (7) pointing out that carbonate chemistry, especially alkalinity, could be improved in the models. So far AOA has been simulated in an idealized manner and we do not have a great understanding of what the actual chemical reactions would be if we added different alkaline minerals.

Afforestation: Several respondents indicated that their terrestrial model needed to be improved. Responses focused on the need for more plant functional types (PFTs) and better vegetation dynamics, better land use schemes that include management capabilities, the inclusion of pest and disease dynamics, and higher resolution. Better understanding of the CO2 fertilization effect and how it is simulated was also indicated as a critical need. Several respondents (4) also indicated that the

hydrological cycle needed to be improved. Three respondents also indicated that vegetation nutrient biogeochemistry need to be improved. The simulation of soil dynamics was also pointed to as in need of improvement.

Enhanced Weathering: Six respondents indicated that their current ESM could not simulate enhanced weathering. They lacked the necessary terrestrial processes, e.g., soil biogeochemistry, and would need a better representation of inland waterways and biogeochemical cycling along the land-ocean continuum.

BECCS: Responses were similar to those for afforestation, although there was more of an emphasis on needing to better represent bioenergy crops and their management, including the need to actually remove harvested biomass from the C-cycle (currently many models simulate bioenergy crops, but just return the C to the terrestrial C pool with C removal simulated more as DACCS). Some also mentioned that they would like to simulate actual CCS and include things like leakage.

DACCS: Most respondents (7) said that their models could easily do this by just removing CO2 from the atmosphere. Uncertainties and suggested improvements centered on how the ocean and land responded to removal, in which cases many of the improvement had to do with better simulating air-sea gas exchange and terrestrial carbon cycling. Two respondents wondered whether they should also simulate CCS or other aspects of DACCS, e.g., the footprint of massive DACCS plants.

IAM Summary: What kind of input is needed from ESM by IAM to improve modelling of NETs

Afforestation: Only two respondents required input from the ESM community regarding afforestation, asking in particular about the modelling of the terrestrial carbon saturation (time) and the temperature feedback on terrestrial carbon uptake.

Vegetation and Soils: Several respondents (5) indicated input from the ESM community required, however some responses have overlap with afforestation. In particular, input was required regarding the CO_2 fertilization effect and the ability to represent carbon in soil better (in IAMs). Furthermore, IAM experts require spatially defined forest carbon densities (soil and vegetation) for mature and recovered forests and spatially defined re-growth curves (vegetation biomass as a function of time) to optimize forest development.

Enhanced Weathering: Only two respondents indicated requirement for ESM input, asking for advice regarding the inclusion/input from state-of-the art vegetation/soil and geological weathering models and ESM information regarding the ratio of terrestrial-to-geological/terrestrial-to-ocean carbon fluxes as response to enhanced weathering application (i.e. the ocean carbon cycle response to increased geological-terrestrial carbon uptake).

BECCS: Three respondents indicated requirement for ESM input, asking for better representation of soil carbon dynamics (from vegetation and soil models) to have a better representation/understanding for all relevant carbon flows in terrestrial sinks, including also the sensitivities with respect to irrigation and fertilization input.

Ocean: For the various NETs listed above, the IAM experts have been asked about the ocean carbon cycle response and how to improve it (we had no responses regarding a specific ocean NET). While one respondent indicated that their model accounts for ocean outgassing, the other respondents indicated input required from the ESM community. They required input regarding the ocean carbon cycle representation and the outgassing parametrization (ideally as function of the amount of net carbon removal in dependence of the speed of carbon removal). More specifically, they required information about the symmetry between net carbon emissions versus net carbon removal, i.e. requesting information about the ocean carbon cycle response in a dynamic, non-equilibrium situation.

General comments: As indicated in the main text, IAM experts appear to be somewhat more confident regarding the proper simulation of NETs than ESM experts. In particular those who rely in their IAM on the reduced-from atmospheric chemistry model MAGICC indicated that the model should be up-to-date regarding carbon cycle modelling, including CO_2 fertilization and temperature feedbacks and ocean outgassing. However, this is not a unanimous view as indicated by the various inputs required from the ESM community listed above. In addition, one respondent also explicitly pointed to the limitations of the ocean carbon cycle response in MAGICC.