Supplementary Information

1. Literature scoping protocol

The fundamental requirement for submissions to *Environmental Research Reviews* is transparency over "how articles were accumulated and what criteria were used to justify inclusion/exclusion in the review". In order to formalize this procedure, ensure consistency across "technology teams" as well as reproducibility to the extent possible, the project team developed a scoping protocol. This protocol comprises three main steps: first, we defined the *search query* used to capture relevant papers in the Web of Science and Scopus literature databases; second, we *filtered and excluded* documents not relevant for an overall scientometric assessment of the NETs literature; third, we *filtered and identified* a sub-set of documents specifically relevant for assessing global NET potentials, costs and selected side-effects.

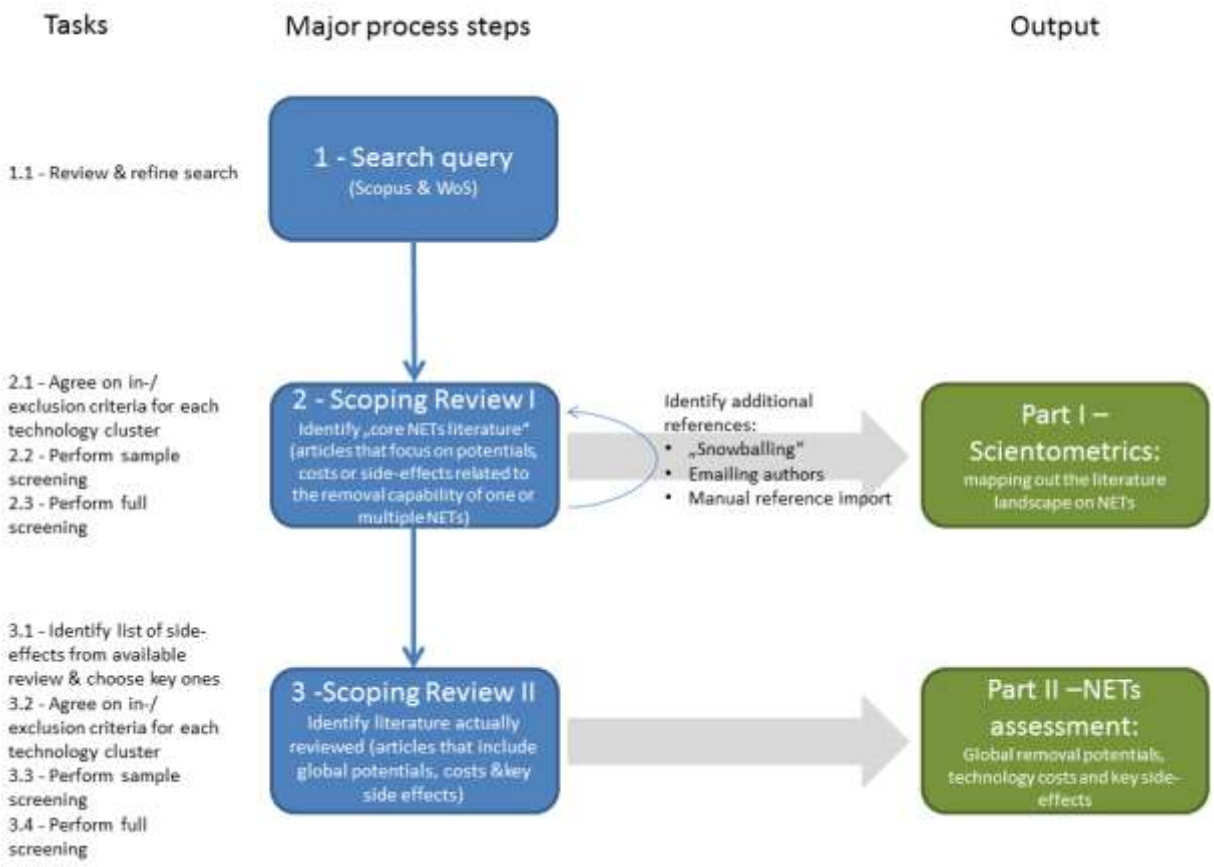

Figure S.1: Overview of scoping procedure (see below for description of tasks and processes).

An IT system has been set up to help us follow this process. It is documented in the IT wiki here.

This protocol cannot describe all possible eventualities, so we have set up an FAQ to collect and answer questions about what we should do in circumstances that are unclear.

1. Defining the search query

The project team developed a search query for the relevant NETs in Minx et al. (2017). This is available in the Supplementary Information of the paper and readily available in our *review portal (wiki)*. The purpose of this query was to have a high-quality search that could be quickly reproduced for the sake

of transparency. It is therefore rather restrictive in scope. It was also only applied and optimised for search results from the *Web of Science* (WoS).

In this systematic review project, we seek to be as comprehensive as possible in terms of literature coverage. Therefore, we will also search *Scopus*, and take additional measures to identify further references (see Section 4). We also hand-filter search results here, meaning we can expand the scope of the search query and remove irrelevant results as they appear.

1.1. **Review and refine the search query**: We want a search query that speaks to the research question "What is the relevant literature corpus on NETs?" Relevant articles are those that focus on the CO_2/GHG removal potential or the technology costs or side-effects related to the removal capability of one or multiple NETs. Each technology team should review and refine the search query based on this, making sure that the existing query is not too restrictive and does not miss relevant articles. Note that each technology team will hand-select articles in the next steps (Scoping Review I and II in Figure S.1), so search quality is not so much of a concern as it is in Minx et al. (2017) – particularly for NETs with a modest literature corpus.

2. Scoping Review I: Identifying the relevant literature

Scoping Review I aims to identify the relevant literature corpus on NETs for Part 1 of the trilogy of review papers on NETs - based on the results from the above search query as well as additional measures outlined in Section 4. Hence, as the project developed, additional articles have been imported into the online review system. Technology teams were informed by the online system, as new references are imported for review. To ensure transparency and reproducibility, scoping reviews needed to be undertaken by multiple (at least 2) people.

2.1. **Agree on inclusion and exclusion criteria**: Before starting the scoping review the technology team defined inclusion and exclusion criteria and made them explicit within the review system

2.2. **Sample screening**. The technology team screened random samples of documents (e.g. in batches of 25) on the online platform to become familiar with the procedure and train their judgements on which documents are relevant based on their inclusion and exclusion criteria. A document is either: (1) included (it deals with the NET as the core subject of study); (2) marked as relevant for a different NET (or this and another NET); or (3) excluded. The teams regularly discussed the screening results. In case of divergence in judgements, inclusion and exclusion criteria could be revisited and refined (2.1). Sample screening was successful, if at least 90% of the judgements are consistent across reviewers.

2.3. **Full individual screening.** Documents were divided between the team and screened on the online platform, as above. NETs that have a larger body of literature required more individuals – as necessary – to work on the screening.

3. Scoping Review II: Identifying potentials, costs and side-effects

Scoping Review II started from the hand-selected sample of studies for the respective NETs. It identified the relevant studies for Part 2 of the trilogy (i.e. this paper) that aims to assess the global CO_2/GHG removal potential, technology costs as well as key side effects discussed in the literature.

3.1. **Identify key side-effects**: The project team provided a list of review articles to the technology teams relevant for the respective NET. In a first step, a comprehensive list of side-effects discussed in these reviews were compiled by the technology teams. In a second step, the

technology teams selected the five most relevant side-effects based on the authors' assessments.

3.2. **Agree on inclusion and exclusion criteria**: Each technology team identified the relevant inclusion and exclusion criteria for the selection of studies for their assessment of global CO_2/GHG removal potential, technology costs as well as selected side-effects.

3.3. **Sample screening**. As above. Each technology team screened random samples of documents (25 total) on the online platform to become familiar with the procedure and train their judgements on which documents are relevant based on their inclusion and exclusion criteria. A document is either: (1) included (it deals with the NET as the core subject of study); or (2) excluded. Each technology team should meet and discuss the screening results. In case of divergence in judgements, inclusion and exclusion criteria could be refined (3.1). Sample screening was successful, if at least 90% of the judgements were consistent across reviewers.

3.4. **Full individual screening.** All documents were divided between the team and screened on the online platform, as above.

4. Additional measures for a comprehensive identification of NETs literature

Our search query is restricted to *WoS* and *Scopus*. This does not represent the entire peer-reviewed literature and leaves out most of the non-peer-reviewed literature. We took three additional measures to widen the coverage beyond *WoS* and *Scopus*.

4.3 **"Snowballing"**. The project team traced the citations and references of relevant articles from the *WoS* and *Scopus* forward (citations) and backward (references). Such a procedure can highlight articles which have not been captured by our search queries.

4.4 **Emailing authors**: The project team built an email list including all corresponding authors of relevant articles identified in *WoS* and *Scopus*. Standardised emails were sent to all these authors with a list of relevant papers on NETs they have (co-)authored. They were asked to notify us of any missing publications.

4.5 **Manual reference import**: Each author team might have had additional references at hand that are not covered by other procedures. In this case they were asked to manually import them to the online system.

Note that the online system automatically kept track of the way how a reference was identified. This is crucial for transparency and reproducibility.

2. Technical guidance for technology assessment

For the purpose of data collection across studies and technologies, we decided to create a Google spreadsheet harmonised across technologies. The technology spreadsheet (TS) that we developed aims at balancing ease-of-use, flexibility, transparency and standardization. Each TS contains 22 columns and has a header with 3 rows. The first three columns, in grey, are used to identify a document by using information on author (AU), publication year (PY) and title (TI). The next 15 columns are used for the qualitative and quantitative data that we wanted to systematically collect across studies, i.e. potentials, costs and side effects.

Data categorisation

Columns 4-6 are used to categorise qualitative and quantitative data. They are highlighted in orange. We distinguish 3 main categories: year, system boundaries and system conditions.

- Year: the year of the data (if available)

- System boundaries: the spatial scope of the data (e.g. global, regional, national, local, biome, plant-level, technology-level …)
- System conditions: any type of categorical data that identifies the data. Multiple conditions can be put in this column. They must be separated by a semi-colon. (e.g. species-specific, on degraded land, monoculture, technology, site, ...)

Potentials

Potentials are located in columns 7-11 and are highlighted in blue. The common unit is defined in the first row (e.g. tCO_2/yr). The variables relative to potentials are defined in the third row. The first two columns contain the original unit, as found in the document, and the conversion factor to the common unit. The next columns can be used to enter estimates or ranges of total potentials. For transparency purposes, one could add additional columns before the total potentials that are sub-categories of the totals. For instance, a few BECCS studies provide ranges for a variety of crop types. One could add new columns for each of these crop types and the sum of estimates would be placed in totalPotentials. Quantitative variables contain a name (e.g. dedicatedCrops) and a statistic (e.g. estimate, min, max …) separated by a dot. (e.g. dedicatedCrops.min). In case of cumulative values, the suffix "_cum" was appended to the statistic (e.g. totalPotential.estimate_cum). To keep things tidy, these columns could be hidden later. When several estimates and/or ranges existed in a document, multiple entries could be added to the spreadsheet as long as they were categorised using the data categorisation columns. If no data was found, columns were left empty.

Costs

Costs are located in columns 12-16 and are highlighted in red. Likewise, the common unit is defined in the first row (e.g. $US(2011)/$tCO_2$) and the variables relative to costs are defined in the third row. The year of currency was noted whenever possible. When several estimates and/or ranges existed in a document, multiple entries could be added to the spreadsheet as long as they were categorised using the data categorisation columns. If no data was found, columns were left empty.

Side effects

Side effects are located in columns 17-20 and are highlighted in green. We separated positive and negative side effects (see second row). Each side effect was then allocated to a column in the third row. If no information was found, columns were left empty. If qualitative information was available (e.g. significant or insignificant impact on the albedo, but no quantitative estimate), an additional column was added in the same way as described under "Potentials".

Comments and exclusion criteria

Comments could be added when necessary. Exclusion criteria were clearly stated when a study is discarded.

3. Search query and exclusion criteria for scoping process

Bioenergy with Carbon Capture and Storage (BECCS)

The assessment of BECCS involves three parts: the assessment of global bioenergy potentials, geological storage potentials as well as the literature including the entire technology. Therefore, the BECCS query was supplemented by a query targeting global bioenergy potentials, particularly for years 2050 and 2100 and a query targeting global geological storage potentials.

Table S.1 shows the query for the global bioenergy potentials. Overall, the queries yields 119 unique entries, with a further 31 added by authors after email solicitation. 12 additional documents were

added to the set, these were found as estimates cited within the queried papers, or cited in review papers used to prepare the query. The full screening resulted in 43 remaining articles (27% of the query).

Scoping stage	Details	Document yield after exclusions
Search query	*Web of Science* • TI = ((potential* OR supply OR production OR source* OR resource*) AND (bioenergy OR bio-energy OR (biomass* NEAR/5 energy)) AND (global OR future OR 2050 OR 2100 OR scenario*)) *Scopus* • TITLE ((potential OR supply OR production OR source OR resource) AND ((bioenergy OR bio-energy) OR (biomass* W/5 energy)) AND (global OR future OR 2050 OR 2100 OR scenario)) • *Added by authors* *Added manually* [Document restrictions (year, type, language): none]	87 111 31 12 162 (total)
Full screening (abstracts)	*Exclusion criteria* • Documents on global bioenergy potentials in any resource category (except algae) • Documents that did not mention some explicit bottom-up considerations for potential calculations were excluded	78
Full screening (full texts)	*Exclusion criteria* • As above (exhaustively applied to full texts) • Exclude if full text could not be attained	43

Table S.1 - Description and results of scoping process for global bioenergy potentials

Scoping stage	Details	Document yield after exclusions
Search query	*Web of Science* • TS =(((potential OR capacity OR availability OR resource) NEAR/3 ((CO2 OR "carbon dioxide" OR "CO(2)" OR CD) NEAR/3 (storage OR sequestration OR disposal)) AND (geological OR aquifers OR underground OR (coal seams OR coal-bed OR coalbed) OR reservoirs OR subterranean OR ((oil OR gas) NEAR/3 fields) OR saline aquifer OR sedimentary OR formation)) OR (geocapacity)) NOT (TS = (soil OR nano* OR mesoporous OR leak* OR molecul* OR lithium OR hydrate OR catalyst OR (life cycle) OR seismic* OR *fract* OR geochem* OR mineralog* OR sensor OR monitor* OR wettability OR (energy plan) OR gypsum OR electrochem* OR fluvial OR "water injection" OR isotherm OR laboratory))	239

	Scopus • ((TITLE-ABS-KEY ((potential OR capacity OR availability OR resource) W/3 ((co2 OR "carbon dioxide" OR "co(2)" OR cd) W/3 (storage OR sequestration OR disposal))) AND TITLE-ABS-KEY (geological OR aquifers OR underground OR (coal seams OR coal bed OR coalbed) OR reservoirs OR subterranean OR ((oil OR gas) W/3 fields) OR saline aquifer OR sedimentary OR formation) OR geocapacity) AND NOT TITLE-ABS-KEY (soil OR nano* OR mesoporous OR leak* OR molecul* OR lithium OR hydrate OR catalyst OR(life cycle) OR seismic* OR *fract* OR geochem* OR mineralog* OR sensor OR monitor* OR wettability OR (energy plan) OR gypsum OR electrochem* OR fluvial OR "water injection" OR isotherm OR laboratory))	339
	Added by authors	8
	[Document restrictions (year, type, language): none]	486 (total)
Full screening (abstracts)	*Exclusion criteria* • documents geological sequestration of CO2 at a global scale • EOR utilization estimates and storage of EOR associated CO2 capture were excluded • documents without quantitative information on removal potentials were excluded	230
Full screening (full texts)	*Exclusion criteria* • As above (exhaustively applied to full texts) • Exclude if full text could not be attained	10 – global

Table S.2 - Description and results of scoping process for CO2 storage potentials

Table S.2 targets global CO2 storage potentials. After removing duplicates the queries yielded 478 results, based on 239 from Web of Science and 339 from Scopus. 8 documents were added by authors after email solicitation for a 486 total. Abstracts were screened for potential estimates at a global scale, EOR storage estimates were not included. Although many more papers contained subnational, national or regional estimates only 10 papers were found to have global estimates of geological storage potential.

A supplemental cost query yielded 202 results, 45 underwent full text screening; only 8 actually contain storage or mitigation costs. Most contained only CCS or biomass combustion estimates, but not the full BECCS chain cost estimates. From the general BECCS query, results are much improved. Of 199 entries, either from the BECCS query or tagged as relevant from other users, 23 contain cost estimates. After removing duplicates 26 studies were recorded.

Scoping stage	Details	Document yield after exclusions

Search query	*Web of Science* • TS = ((((mitigation OR abatement) NEAR/2 cost*) AND (biomass OR bioenerg* OR BECCS OR bioccs OR bio-ccs))) OR TS = (((mitigation OR abatement) NEAR/2 cost*) AND (((BIGCC OR biomass IGCC) OR gasification combined cycle) OR ethanol fermentation OR bioethanol OR black liquor OR BST or post-combustion OR pre-combustion OR oxy-fuel combustion))	139
	Scopus • TITLE-ABS-KEY ((((mitigation OR abatement) W/2 cost) AND (biomass OR bioenerg OR BECCS OR bioccs OR bio-ccs))) OR TITLE-ABS-Key (((mitigation OR abatement) W/2 cost) AND (((BIGCC OR biomass IGCC) OR gasification combined cycle) OR ethanol fermentation OR bioethanol OR black liquor OR BST or post-combustion OR pre-combustion OR oxy-fuel combustion))	147 202 (total)
	[Document restrictions (year, type, language): none]	
Full screening (abstracts)	*Exclusion criteria* • documents that contain estimates for any full BECCS chain, including bioenergy, CCS and transport components • Localized or general estimates	45
Full screening (full texts)	*Exclusion criteria* • As above (exhaustively applied to full texts) • Exclude if full text could not be attained	8

Scoping stage	**Details**	**Document yield after exclusions**
Search query	*Web of Science* • TS = (BECCS OR ((biomass OR bioenerg*) AND ("CCS" OR "Carbon capture and Storage" OR "Carbon dioxide capture and Storage" OR "CO2 capture and storage")) NOT "co-fir*" NOT "co-generat*" NOT cogeneration NOT coal)	285

	Scopus • TITLE-ABS-KEY(BECCS OR ((biomass OR bioenerg*) AND ("CCS" OR "Carbon capture and Storage" OR "Carbon dioxide capture and Storage" OR "CO2 capture and storage")) AND NOT ("co-fir*" OR "co-generati*" OR cogeneration OR coal)) *Added by authors* [Document restrictions (year, type, language): none] •	396 39 473 (total) – after BECCS scoping assessment (beyond costs and potentials)
Full screening (abstracts)	*Exclusion criteria* •	**209**
Full screening (full texts)	*Exclusion criteria* • documents that contain mitigation/abatement or storage cost/potential estimates or side effects for any full BECCS chain, including bioenergy, CCS and transport components • Localized or general estimates Exclude if full text could not be attained	27

Table S.4 - Description and results of scoping process for BECCS

Afforestation and reforestation (AR)

The search for AR combines keywords for afforestation, carbon, and sequestration (Table 4). After deleting doubles, it results in 1,486 documents based on 1,271 entries from Scopus and 966 from the Web of Science (WoS). 48 documents were added by authors after email solicitation, resulting in 1534 documents in total.

According to a review of random samples, the queries returns relatively high quality results – e.g. publications that primarily focus on active forest management for climate change mitigation – and does not require further restrictions. However, several criteria were developed to exclude articles in the following full screening stage: (1) documents on avoided emissions (e.g. REDD+) are removed as these do not imply net negative sequestration, but rather refer to avoided emissions; (2) documents that investigate site- or species-specific sequestration potentials are excluded (but tagged for follow-up investigation), as these provide very narrow per hectare potentials that cannot be feasibly scaled up into area-level estimates; and (3) studies that do not offer quantitative information on removal potentials and costs, or qualitative information on potential side-effects are excluded (as with other NETs). The full screening narrowed our literature set to 509 (3% of the queries and added documents).

On final inspection of this screened document set, 271 papers were included in the final analysis (36 global, all including side effects, i.e. not only potentials). Further removals were due to a more exhaustive application of the exclusion criteria (on full texts), or because full texts could not be attained.

Scoping stage	Details	Document yield after exclusions

Search query	*Web of Science* • TS = ((afforestation OR reforestation) AND ((carbon OR CO2) NEAR/3 (sequest* OR storage))) *Scopus* • TITLE-ABS-KEY ((afforestation OR reforestation) AND ((carbon OR co2) W/3 (sequest* OR storage))) *Added by authors* [Document restrictions (year, type, language): none]	966 1,271 48 1,534 (total)
Full screening (abstracts)	*Exclusion criteria* • documents on avoided emissions (e.g. REDD+) that do not imply net negative sequestration • documents on site or species specific sequestration potentials (tag these for follow-up investigation) • documents without quantitative information on removal potentials and costs; or quantitative/qualitative information on side-effects	509
Full screening (full texts)	*Exclusion criteria* • As above (exhaustively applied to full texts) • Exclude if full text could not be attained	267

Table S.5: Description and results of scoping process for afforestation and reforestation literature

Direct Air Carbon Capture and Storage (DACCS)

The literature is very limited, 222 relevant articles identified from queries, and dominated by technology studies in chemistry journals. However the growth rate is substantial with about 25 articles between 2000 and 2010, and more than 100 between 2011 and 2015 published. Abstract reading resulted in 75 articles that were relevant with respect to costs, potentials, or side effects. 14 out of the 75 papers communicated cost estimates for sequestering $1tCO_2$ from ambient air. 50 studies were added by authors after email solicitation, of which 22 were relevant and 1 contained costs, potentials or side effects.

Even given its nascent stage, some underlying chemistry processes have been used in industrial scale for a long time. Notably, the Kraft process has been used in the paper industry from 1884 onwards to extract cellulose from wood. The same principle can also be used for CO_2 extraction from air. In submarines and other closed-circuit breathing systems direct air capture is commonly implemented. However, the specific methods are not easily scalable to industrial scale.

Scoping stage	**Details**	**Document yield after exclusions**
Search query	*Web of Science* • (TS = (((capture OR extraction OR absorbtion) NEAR/3 (air OR atmosph*)) AND (ambient OR "atmosph* pressure*") AND (CO2 OR carbon)) OR TS = (((captur* OR extract) NEAR/3 (direct* OR "carbon dioxide") NEAR/3 (air OR atmosph*)) AND (CO2 OR carbon)) OR TS = ((*sorbent OR amine) AND capture AND (carbon OR CO2) AND ("ambient air")) OR TS = ((captur* NEAR/3 CO2 NEAR/3 (air OR atmosph*)) AND solar)) NOT TS = (phenolic OR PCB* OR particulate OR NOx	212

	OR isotope OR "heat pump" OR polycyclic OR *bacteria* OR lignin OR sink OR pollution OR biofuel* OR sugar) *Scopus* • (TITLE-ABS-KEY(((capture OR extraction OR absorbtion) W/3 (air OR atmosph*)) AND (ambient OR "atmosph* pressure*") AND (CO2 OR carbon)) OR TITLE-ABS-KEY(((captur* OR extract) W/3 (direct* OR "carbon dioxide") W/3 (air OR atmosph*)) AND (CO2 OR carbon)) OR TITLE-ABS-KEY((*sorbent OR amine) AND capture AND (carbon OR CO2) AND ("ambient air")) OR TITLE-ABS-KEY((captur* W/3 CO2 W/3 (air OR atmosph*)) AND solar)) AND NOT TITLE-ABS-KEY(phenolic OR PCB* OR particulate OR NOx OR isotope OR "heat pump" OR polycyclic OR *bacteria* OR lignin OR sink OR pollution OR biofuel* OR sugar)	238
	Added by authors [Document restrictions (year, type, language): none]	50
		368 (total)
Full screening (abstracts)	*Exclusion criteria* • If focus on DACCS only • Technical processes only that exclude cost or potential considerations (the absence of side effects was no effective exclusion criteria as no article discussed side effects in the abstract)	250
Full screening (full texts)	*Exclusion criteria* • As above (exhaustively applied to full texts) • Exclude if full text could not be attained	

Table S.6: Description and results of scoping process for DAC literature

Enhanced Weathering (terrestrial and ocean)

The obtained results for EW represent a total yield of 195 documents for Web of Science (WoS) and Scopus entries. Compared to other NETs, the quantity of published papers are low. From the 195 obtained papers only 18 papers were used for the review, representing a small amount. This value was obtained after excluding documents without quantitative information on removal potentials and costs, and qualitative/quantitative information considering side effects. Another exclusion criterion was the language. Some papers were in languages other than English and could not be used even if they seemed to have interesting information in the English abstract. 8 papers were added by authors after email solicitation of which 2 were relevant and 1 contained costs, potentials or side effects.

Scoping stage	**Details**	**Document yield after exclusions**
Search query	*Web of Science* • *(TS = (("ocean liming") AND (remov* OR stor*) AND (CO2 OR carbon*)) OR TS = ((geoengineer*) AND (silicate OR olivine OR albite OR CACO3)) OR TS = ((silicate OR olivine OR albite OR CACO) AND (mitigat* NEAR/3 ("climate*	101

	change" OR "global warming" OR geoengineer))) OR TS = (("ocean alkalini*") AND (remov* OR storage OR mitigat* OR sequest*) AND (CO2 OR carbon*)) OR TS = (((enhance* OR artificial*) NEAR/2 weathering) AND ((carbon OR CO2 OR "climate change" OR "global warming") NEAR/3 (remov* OR sequest* OR storage OR sink OR mitigat* OR reduc*))) OR (TS = ((enhance* OR artificial* OR chemical OR accelerate) NEAR/2 weathering) AND TS = ((carbon OR CO2 OR "climate change" OR "global warming") NEAR/3 (remov* OR sequest* OR storage OR sink OR mitigat* OR reduc*) OR cycl*)) AND TS = (mineral* OR rock) AND TS = ("global warming" OR "climate change" OR greenhouse OR geoengineer OR "carbon negative" OR "enhanced weathering" OR "ocean alkalini*" or "ocean liming")) NOT TS = (glaci* OR ice* OR ordovic* OR Aptian OR Cenozo* OR Paleo* OR Mezoso*)* • *Exclusions: NOT TS = ("bioactive equivalent combinatorial components" OR "bandwidth-efficient-channel-coding-scheme" OR "bronchial epithelial cell cultures" OR "california current system" OR comet OR mars OR exoplanet* OR "competition chambers" OR gastric OR (mercury NEAR/3 capture) OR (image NEAR/3 capture) OR "canary current system" OR "heavy metal" OR eicosanoid OR "companion cells" OR "calcium carbonate sand" OR "copper chaperone" OR "commercial cane sugar" OR "Cindoxin reductase" OR "coupled dissolution reprecipitation" OR "carbon dioxide reforming" OR rats OR "complementarity determining regions" OR deoxycytidine)*	
	Scopus • *(TITLE-ABS-KEY((geoengineer*) AND (silicat* OR olivin* OR albit* OR CACO* OR forsterit* OR mafic OR basalt* OR calcit* OR feldspar OR pyroxen*)) OR TITLE-ABS-KEY((geoengineer* AND (marin* OR coastal) AND weathering) OR (coastal AND spreading AND (rock OR olivine*) AND dissolution)) OR TITLE-ABS-KEY((silicat* OR olivine* OR albit* OR CACO* OR calcit* OR feldspar OR pyroxen* OR forsterit* OR basalt* OR mafic*) AND (mitigat* W/3 ("climate change" OR "global warming" OR geoengineer* OR "climate engineering"))) OR TITLE-ABS-KEY(((enhance* OR artificial* OR (enhance* W/3 marine) OR (enhance* W/3 coastal) OR coastal) W/2 weathering) AND ((carbon OR CO2 OR "climate change" OR "global warming") W/3 (remov* OR sequest* OR storage OR sink OR mitigat* OR reduc*))) OR TITLE-ABS-KEY((enhance* OR artificial* OR chemical OR accelerate* OR stimulat*) W/2 weathering) AND TITLE-ABS-KEY((carbon OR CO2 OR "climate change" OR "global warming") W/3 (remov* OR sequest* OR*	143

	storage OR sink OR mitigat OR reduc*) OR cycl*) AND TITLE-ABS-KEY(mineral* OR rock) AND TITLE-ABS-KEY("global warming" OR "climate change" OR greenhouse OR geoengineer OR "carbon negative" OR "enhanced weathering" OR "global change")) AND NOT (TITLE-ABS-KEY(glaci* OR ice* OR ordovic* OR Aptian OR Cenozo* OR cretac* OR trias* OR phanero* OR precambri* OR Paleo* OR Mesozo* OR "cold event" OR "anoxic event" OR "ozone" OR (saline W/3 aquifer*)) OR TITLE-ABS-KEY(oxic W/7 anoxic)) NOT TITLE-ABS-KEY("bioactive equivalent combinatorial components" OR "bandwidth-efficient-channel-coding-scheme" OR "bronchial epithelial cell cultures" OR "california current system" OR comet OR mars OR exoplanet* OR "competition chambers" OR gastric OR (mercury W/3 capture) OR (image W/3 capture) OR "canary current system" OR "heavy metal" OR eicosanoid OR "companion cells" OR "calcium carbonate sand" OR "copper chaperone" OR "commercial cane sugar" OR "Cindoxin reductase" OR "coupled dissolution reprecipitation" OR "carbon dioxide reforming" OR rats OR "complementarity determining regions" OR deoxycytidine)* *Added by authors* *[Document restrictions (year, type, language): none]*	8 **203 (total)**
Full screening (abstracts)	*Exclusion criteria* • *documents without quantitative information on removal potentials and costs; or quantitative/qualitative information on side-effects* • *documents that did not belong to EW method* • *documents in languages other than English*	*40*
Full screening (full texts)	*Exclusion criteria* • *As above (exhaustively applied to full texts)* • *Exclude if full text could not be attained*	*19*

Table S.7: Description and results of scoping process for enhanced weathering literature

Ocean fertilization

The obtained results for OF represent a total yield of 397 documents for Web of Science (WoS) entries. From the 397 obtained papers only 27 papers were used for the review, representing a small amount. This value was obtained after excluding documents without quantitative information on removal potentials and costs, and qualitative/quantitative information considering side effects. Another exclusion method was language. Some papers were in languages other than English and could not be used, even if they seemed to have interesting information in the English abstract. 59 Documents were added by authors after email solicitation of which 20 were relevant and 7 contained costs and potentials.

Scoping stage	Details	Document yield after exclusions
Search query	*Web of Science*	

		397
	*TS = (ocean NEAR/5 iron NEAR/5 (fertili*ation OR enrichment) NOT natural NOT ice* NOT glaci*) OR TS = (carbon OR CO2) AND (TS = ("ocean fertili*ation" OR "enhanced upwelling") OR TS = (upwell* NEAR/2 nutrient*))* *Exclusions:* *NOT TS = ("bioactive equivalent combinatorial components" OR "bandwidth-efficient-channel-coding-scheme" OR "bronchial epithelial cell cultures" OR "california current system" OR comet OR mars OR exoplanet* OR "competition chambers" OR gastric OR (mercury NEAR/3 capture) OR (image NEAR/3 capture) OR "canary current system" OR "heavy metal" OR eicosanoid OR "companion cells" OR "calcium carbonate sand" OR "copper chaperone" OR "commercial cane sugar" OR "Cindoxin reductase" OR "coupled dissolution reprecipitation" OR "carbon dioxide reforming" OR rats OR "complementarity determining regions" OR deoxycytidine)* *NOT PY = 2018*	
	Added by authors	59
	Filter: *[Document restrictions (year, type, language): none]*	456 (total)
Full screening (abstracts)	*Exclusion criteria* • *documents without quantitative information on removal potentials and costs; or quantitative/qualitative information on side-effects* • *documents that did not belong to EW method* • *documents in languages other than English*	*232*
Full screening (full texts)	*Exclusion criteria* • *As above (exhaustively applied to full texts)* • *Exclude if full text could not be attained or if information from abstract could not be used*	*34*

Table S.8: Description and results of scoping process for ocean fertilisation literature

Biochar

The search for biochar is relatively broad (Table 9), combining keywords for biochar and carbon with sequestration, storage, stock, accumulation, or capture. After deleting doubles, it results in 863 documents based on 784 entries from Scopus and 591 from WoS.

According to a review of random samples, this query returns relatively high-quality results that primarily focus on different aspects of biochar soil amendment in agriculture including soil carbon sequestration and does not require further restrictions. However, several criteria were developed to exclude articles in the following full screening stage: (1) studies that do not offer quantitative information on removal potentials and costs, or qualitative information on potential side-effects were excluded (as with other NETs).

The full screening narrowed our literature set to 79 (9% of the query).

On final inspection of this screened document set, 11 papers were included in the final analysis. Further removals were due to a more exhaustive application of the exclusion criteria (on full texts), or because full texts could not be attained. 27 documents were submitted by authors after email solicitation, of which 22 were relevant and 12 contained costs, potentials or side effects.

Scoping stage	Details	Document yield after exclusions
Search query	*Web of Science* • TS = (biochar* AND ((carbon OR CO2) NEAR/3 (sequest* OR storage OR stock OR accumulat* OR capture)))	591
	Scopus • TITLE-ABS-KEY (biochar* AND ((carbon OR co2) W/3 (sequest* OR storage OR stock OR accumulat* OR capture)))	784
	Additional literature search	15
	Added by authors	27
	[Document restrictions (year, type, language): none]	878 (total)
Full screening (abstracts)	*Exclusion criteria* • documents without quantitative information on carbon sequestration potentials or costs or side-effects • documents describing side-effects and costs of feedstock/distribution were reviewed for discussion in paper	101
Full screening (full texts)	*Exclusion criteria* • As above (exhaustively applied to full texts) • Exclude if full text could not be attained	23

Table S.9: Description and results of scoping process for biochar literature

Soil Carbon Sequestration (SCS)

The search for papers dealing with SCS used the search terms as given in the table below. A large number of studies were identified. After deleting doubles, it results in 908 documents, based on 660 entries from Scopus, 637 from WoS and 5 referred to us by other reviewers.

According to a review of random samples, this query returns relatively high quality results that primarily focus on soil carbon stocks and sequestration at specific sites, collections of site or regions, with few providing global estimates of costs and/or potentials. However, several criteria were developed to exclude articles in the following full screening stage: (1) studies that do not offer quantitative information on removal potentials and costs, or qualitative information on potential side effects were excluded (as with other NETs). The full screening narrowed our literature set to 449 (49% of the query).

On final inspection of this screened document set, 20 papers included global estimates of technical potential or cost for all SCS options, including 3 listed economic potentials at 20, 50 or 100 US$/t$CO_2$e, and a further two provided global estimates of potential for specific measures only, namely croplands,

desertification control, reclamation of salt affected soils (all Lal, 2012), grazing optimization on grazing land, and legume sowing on grazing land (the latter two Henderson et al., 2015). Not all of the articles quoting global estimates provided original estimates, with a number citing these values from other studies. The remainder of articles either gave SCS rates for plots or small areas (e.g. for a particular experiment in t C/ha/yr), for regions (e.g. Chinese croplands in TgC/yr), reported only stocks rather than stock changes, did not have quantitative information on soil stock change, or the full text could not be accessed. To allow comparison, all global estimates were converted from original reported units to Gt CO_2/yr. 76 documents were added by authors after email solicitation of which 14 were relevant and 3 contained costs potentials or side effects.

Scoping stage	Details	Document yield after exclusions
Search query	*Web of Science* • TS = ((soil NEAR/3 (carbon OR CO2) NEAR/3 (sequest* OR storage)) AND ("climate change" OR "global warm*") AND (manag* OR practice* OR restoration OR land-use))	637
	Scopus • TITLE-ABS-KEY ((soil W/3 (carbon OR co2) W/3 (sequest* OR storage)) AND ("climate change" OR "global warm*") AND (manag* OR practice* OR restoration OR land-use))	660
	Additional literature search	5
	Added by authors	76
	[Document restrictions (year, type, language): none]	984 (total)
Full screening (abstracts)	*Exclusion criteria* • documents without quantitative information on carbon sequestration potentials or costs or side-effects • documents describing side-effects and costs of feedstock/distribution were reviewed for discussion in paper	463
Full screening (full texts)	*Exclusion criteria* • As above (exhaustively applied to full texts) • Exclude if full text could not be attained	25

Table S.10: Description and results of scoping process for soil carbon sequestration literature

5. IAM data

The scenario evidence used and plotted in section 2 of the main text ("Scenario evidence on the role of negative emissions") is a compilation of IAM results from publicly available databases (i.e. AMPERE, LIMITS, RoSE and SSP) and from recent studies focusing on the 1.5°C climate goal (Luderer et al. (2013), Rogelj et al. (2015, 2018)). In the next paragraphs, we describe the data processing steps that we applied to these original datasets.

For the purpose of this analysis, we created 2 datasets (D1 and D2). Both datasets include data from the AMPERE, LIMITS, RoSE, and Luderer et al. (2013) studies. However, D2 does not contain the MESSAGE scenarios from Rogelj et al. (2015) because information about technological limitations and policy timing was not available. Only D1 contains the SSP and Rogelj et al. (2018) data.

D1 is used in Figure 3 and the associated text whereas D2 is used in Figure 4 and the associated text.

Information on models

The 20 model versions employed in this analysis have different structures and rely on different assumptions (see Table 3). These model structures can be broadly categorized along their coverage of the economic system (i.e. partial equilibrium vs. general equilibrium) and the optimization method upon which they rely (recursive dynamic vs. intertemporal optimization). Partial equilibrium models (GCAM, IMAGE, POLES, TIAM-ECN) provide a rich description of energy conversion processes and energy markets but do not account for macro-economic feedbacks (based on economic growth projections). In contrast, general equilibrium models (AIM/CGE, IMACLIM, MERGE, MESSAGE, REMIND, WITCH) describe a closed economy but often have a coarser representation of the energy sector. Recursive dynamic models (AIM/CGE, GCAM, IMACLIM, IMAGE, POLES) are characterized by a myopic behaviour in the sense that optimization occurs at each individual time steps but not over time. Conversely, intertemporal optimisation models (MERGE, MESSAGE, REMIND, TIAM-ECN, WITCH) have perfect foresight over the entire time horizon (e.g. 2005-2100) about future energy and economic production and consumption and consequently, they can inform about investment dynamics under (idealized) rational expectations. These model characteristics can have substantial implications for NETs. For instance, under the assumption of perfect foresight, it is cost optimal to deploy NETs towards the end of the time horizon when carbon prices are high. This in turn reduces the pressure to dramatically reduce GHG emissions in the near-term because the resulting GHG emissions can be compensated by NETs later on. This also implies that overshooting is allowed.

In addition to the coverage of the economic system and the optimization method, the means of representing the energy sector (and particularly mitigation technology options) is an important factor driving model results. On the supply side, the higher the availability of energy carriers and energy conversion technologies, the more flexible a model is to mitigate CO_2 emissions. For instance, models differ in the representation bioenergy technologies that combine liquids, gases or hydrogen production with CCS (see supplementary materials to Krey et al. (2014)). On the demand side, the representation of end-use technologies and consumer behavior, substitution between energy and other production factors, and elasticity of demands also affect model flexibility and thus results. Finally techno-economic assumptions (e.g. fuel cost, investments and operation and maintenance costs of technologies, and technical parameters like plant efficiency, load factor and lifetime play) partially explain the variety of model results.

Model	Number of versions	Model category / Economic coverage	Spatial resolution	Time horizon	Intertemporal vs. myopic	Optimization method
AIM/CGE	1	General equilibrium	17 regions	2100	Myopic	Recursive dynamic
GCAM	3	Partial equilibrium	14-32 regions	2100	Myopic	Recursive dynamic
IMACLIM	1	General equilibrium	12 regions	2100	Myopic	Recursive dynamic
IMAGE	2	Hybrid (systems dynamic model and GE for agriculture)	26 regions	2100	Myopic	Recursive dynamic
MERGE	1	General equilibrium	8 regions	2100	Perfect foresight	Intertemporal optimization
MESSAGE	2	Hybrid (systems engineering partial equilibrium models linked to aggregated GE)	11-13 regions	2100	Perfect foresight	Intertemporal optimization
MESSAGE-GLOBIOM	1	General equilibrium	11 regions	2100	Perfect foresight	Intertemporal optimization
POLES	1	Partial equilibrium	57 regions	2100	Myopic	Recursive dynamic
REMIND	3	General equilibrium	11 regions	2100	Perfect foresight	Intertemporal optimization
REMIND-MAgPIE	1	General equilibrium	11 regions	2100	Perfect foresight	Intertemporal optimization
TIAM-ECN	1	Partial equilibrium	15 regions	2100	Perfect foresight	Intertemporal optimization
WITCH	2	General equilibrium	13 regions	2100	Perfect foresight	Intertemporal optimization
WITCH-GLOBIOM	1	General equilibrium	13 regions	2100	Perfect foresight	Intertemporal optimization

Table S.11 Main characteristics of integrated assessment models considered in this review.

Data classification

Temperature categories

We define temperature categories (i.e. 1.5°C, Likely 2°C, Medium 2°C, Likely 3°C) based on IPCC definitions and by using the variable "Temperature|Exceedance Probability|X.X degC|MAGICC6" where X.X corresponds to a temperature target (e.g. 1.5, 2). Concretely, 1.5°C scenarios have a 1.5°C exceedance probability lower than 50% in 2100. Likely 2°C scenarios have a 2°C exceedance probability lower than 33% over the period 2010-2100 and a 1.5°C exceedance probability greater than 50% in 2100. Medium 2°C scenarios have a 2°C exceedance probability greater than 33% and lower than 50% over the period 2010-2100. Likely 3°C scenarios have a 3°C exceedance probability lower than 33% over the period 2010-2100 and a 2°C exceedance probability greater than 50% over the period 2010-2100.

It is important to note that no probabilistic temperature projections were available for SSP scenarios. They were hence assigned a category based on their respective radiative forcing targets (see Table S.12).

Radiative forcing target in SSP scenario	Allocated temperature category
1.9 W/m2	1.5°C
2.6 W/m2	Likely 2°C
3.4 W/m2	Medium 2°C
4.5 W/m2	Likely 3°C
>6.0 W/m2	Other

Table S.12 Allocation of SSP scenarios to temperature goal categories based on radiative forcing targets

Policy timing categories

In this analysis we focus on 2 policy timing categories: immediate climate action and delayed action until 2030.

Technology categories

In this analysis we focus on 4 technology categories: full portfolio (which corresponds to the default model structure and parameterization), Low energy intensity, Limited biomass and, no CCS/BECCS.

Filtering

In order to obtain to robust dataset, we manually remove pathways with extreme behavior. In particular, we filter out scenarios containing the name GEAL (Rogelj et al (2015)) because the underlying assumptions featured lower-end and optimistic estimates of socio-economic dimensions (e.g. low energy demand, low energy efficiency). We also remove GCAM scenarios that are likely to achieve the 3°C target because of their extremely rapid and high reliance on negative emissions.

Statistical summary of datasets

In this sub section we provide a list of tables with statistics summarizing the content of the D1 and D2 datasets. The statistic is the number of pathways.

Statistics	D1	D2
Number of pathways	594	264
Number of models	20	13
Number of scenarios	293	97

Table S.13: Number of pathways in the scenario datasets D1 and D2

Temperature category	D1	D2
1.5°C	38	5
Likely 2°C	101	41
Medium 2°C	201	62
Likely 3°C	120	74
Other	134	82

Table S.14: Number of pathways in the scenario datasets D1 and D2 split by temperature category

Policy timing and technology categories	D1	D2
Full portfolio	NA	51
Low energy intensity	NA	28
Limited bioenergy – No CCS/BECCS	NA	69
Delay 2030	NA	38

Table S.15: Number of pathways in the scenario datasets D1 and D2 split by policy timing and technology category

Temperature category	AMPERE	LIMITS	RoSE	SSP	Luderer et al. (2013) & Rogelj et al. (2015)	Rogelj et al. (2018)
1.5°C	0	0	0	0	25	13
Likely 2°C	31	9	0	18	43	0
Medium 2°C	50	20	12	23	96	0
Likely 3°C	77	15	9	19	0	0
Other	58	15	21	40	0	0

Table S.16: Number of pathways in the scenario dataset D1 split by temperature category and model intercomparison project

Temperature category	AMPERE	LIMITS	RoSE	Luderer et al. (2013)
1.5°C	0	0	0	5
Likely 2°C	24	4	0	13
Medium 2°C	33	5	10	14
Likely 3°C	62	3	9	0
Other	57	6	19	0

Table S.17: Number of pathways in the scenario dataset D2 split by temperature category and model intercomparison project

IAMC variable	D1	D2
Emissions|CO2	594	264
Emissions|CO2|Carbon Capture and Storage|Biomass	576	254
Emissions|CO2|Fossil Fuels and Industry	460	226
Emissions|CO2|Land Use	289	147

Table S.18: Number of pathways in the scenario datasets D1 and D2 split by standard IAMC (Integrated Assessment Modelling Consortium) variables

Statistic	D1	D2
Model	20	13
Names	AIM/CGE, GCAM 3.0, GCAM 3.1, GCAM4, IMACLIM v1.1, IMAGE 2.4, IMAGE, MERGE_EMF27, MESSAGE V.4, MESSAGE, MESSAGE-GLOBIOM, POLES AMPERE, REMIND 1.4, REMIND 1.5, REMIND, REMIND-MAGPIE, TIAM-ECN, WITCH_AMPERE, WITCH_LIMITS, WITCH-GLOBIOM	GCAM 3.0, GCAM 3.1, IMAGE 2.4, MERGE_EMF27, MESSAGE V.4, POLES AMPERE, REMIND 1.4, REMIND 1.5, REMIND, TIAM-ECN, WITCH_AMPERE, WITCH_LIMITS

Table S.19: Number of models and model names (including version) in the scenario datasets D1 and D2

Dependence of negative emissions on technological options and policy timing in 2°C scenarios

In Figure 4 in the main text, likely and medium 2°C scenarios are bundled up. In this section we replicated figure 4 for Likely 2°C scenarios and Medium 2°C scenarios separately.

Likely 2°C scenarios

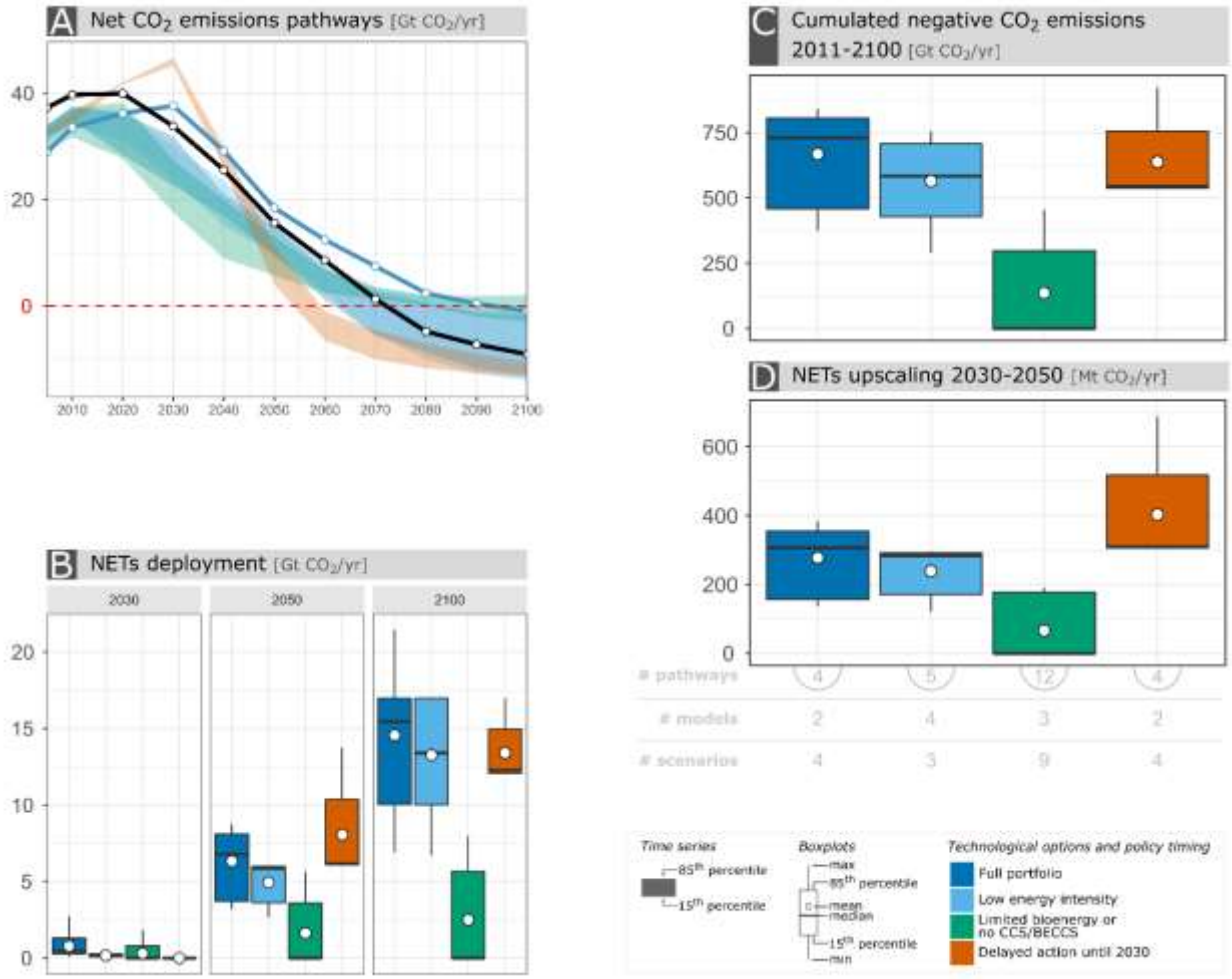

Figure S.2 Negative emissions have a distinct role in Likely 2°C scenarios depending on the technological options and policy timing. This is a version of Figure 4 in the main text but for Likely 2°C scenarios only. Technological options and policy timing are indicated with various colours (dark blue for full technological portfolio, light blue for low energy intensity, green for limited biomass and no CCS/BECCS, and red for delay action until 2030). The cases Full portfolio, Low energy intensity and Limited biomass or no CCS/BECCS assume climate action from 2010 onward. Net CO_2 emissions are displayed in panel (A) (top-left). Ribbons indicate the 15th and 85th percentiles for each pathway category. The original RCP-2.6 (also called RCP-3PD) and the SSP2-2.6 marker scenarios are provided for orientation purposes. The boxplots in panels (B), (C) and (D) provide the same statistics. The range between the minimum and maximum values is indicated with a vertical solid line. The range between the 15th and 85th percentiles is indicated by a blue-filled rectangle. The median is shown with a solid horizontal line whereas the mean is indicated by a white point. NETs deployments in 2030, 2050 and 2100 are shown in panel (B). Cumulative gross negative CO_2 emissions between 2011 and 2100 are shown in panel (C). Annually averaged gross negative CO_2 emissions between 2030 and 2050 are displayed in panel (D). Basic descriptive statistics of the underlying data are provided under panel (D), and more detailed data is available in the SI. 2°C scenarios include both likely 2.0°C and medium 2.0°C scenarios. A description of the models is provided in the SI.

Medium 2°C scenarios

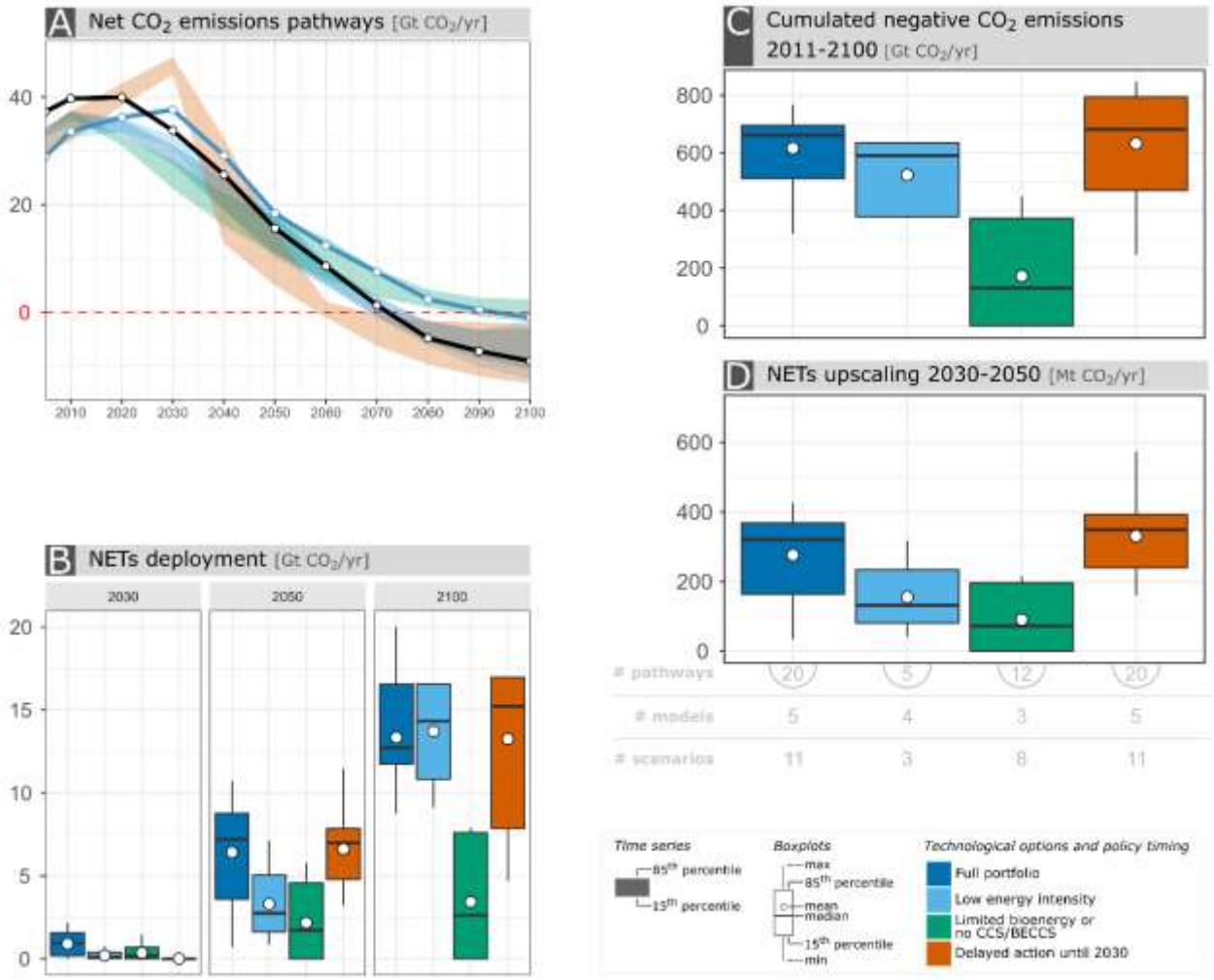

Figure S.3 Negative emissions have a distinct role in Likely 2°C scenarios depending on the technological options and policy timing. This is a version of Figure 4 in the main text but for Medium 2°C scenarios only. Technological options and policy timing are indicated with various colours (dark blue for full technological portfolio, light blue for low energy intensity, green for limited biomass and no CCS/BECCS, and red for delay action until 2030). The cases Full portfolio, Low energy intensity and Limited biomass or no CCS/BECCS assume climate action from 2010 onward. Net CO_2 emissions are displayed in panel (A) (top-left). Ribbons indicate the 15th and 85th percentiles for each pathway category. The original RCP-2.6 (also called RCP-3PD) and the SSP2-2.6 marker scenarios are provided for orientation purposes. The boxplots in panels (B), (C) and (D) provide the same statistics. The range between the minimum and maximum values is indicated with a vertical solid line. The range between the 15th and 85th percentiles is indicated by a blue-filled rectangle. The median is shown with a solid horizontal line whereas the mean is indicated by a white point. NETs deployments in 2030, 2050 and 2100 are shown in panel (B). Cumulative gross negative CO_2 emissions between 2011 and 2100 are shown in panel (C). Annually averaged gross negative CO_2 emissions between 2030 and 2050 are displayed in panel (D). Basic descriptive statistics of the underlying data are provided under panel (D), and more detailed data is available in the SI. 2°C scenarios include both likely 2.0°C and medium 2.0°C scenarios. A description of the models is provided in the SI.