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LETTER

Understanding the carbon dioxide removal range in 1.5 °C compatible and high overshoot pathways

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Abstract

Carbon dioxide removal (CDR) features prominently in the 1.5 °C compatible and high overshoot pathways in the IPCC's Sixth Assessment Report (AR6, WGIII). However, the amount of CDR varies considerably among scenarios. We analyze the range in CDR volumes in AR6 WGIII pathways by exploring relationships between variables as potential driving forces, focusing on CDR in 2050 and scenario properties linked to reaching net-zero CO_2. It is also shown how the relative and absolute contribution of CDR to total mitigation up until reaching net-zero CO_2 substantially differs across scenarios. The volumes of CDR in 2050 and 2100 and the cumulative amount throughout the 21st century were most strongly correlated to the degree to which CO_2 emissions are reduced as a means of reaching net-zero CO_2. CDR in 2050 is also substantially correlated to the timing of net-zero CO_2. The robustness of the analyzed relationships was evaluated by comparing different scenario filtering and data-cleaning approaches. Beyond filtering and cleaning, additional factors that influence CDR deployment in scenarios, such as discount rates, carbon price trajectories, and scenario design choices, were discussed.

1. Introduction

Beyond ambitious emission reductions, carbon dioxide removal (CDR) has been identified as a necessity in mitigation pathways compatible with the 1.5 °C climate target (Rogelj *et al* 2013, 2015), with more recent studies corroborating these findings (Rogelj *et al* 2018a, 2018b, Luderer *et al* 2018, Strefler *et al* 2018, Clarke *et al* 2022). CDR comprises 'anthropogenic activities removing CO_2 from the atmosphere and durably storing it (…) but excludes natural CO_2 uptake not directly caused by human activities.' (Matthews *et al* 2018: 544) CDR may pose risks if sustainable deployment volumes are exceeded (Fuss *et al* 2018, Hilaire *et al* 2019).

CDR is featured prominently in the 1.5 °C compatible and high overshoot pathways in the IPCC's Sixth Assessment Report (AR6, WGIII) (Byers *et al* 2022). Most of these scenarios integrate CO_2 removal primarily through bioenergy with carbon capture and storage (BECCS) and afforestation and reforestation, while to a smaller extent, CO_2 removal through direct air carbon capture and storage (DACCS) and enhanced weathering are also considered (Riahi *et al* 2022, Strefler, *et al* 2021b). The amount of CDR deployed throughout the 21st century (2020–2100) varies considerably across AR6 pathways that limit or return warming to 1.5 °C in 2100. In the case of BECCS, cumulative CO_2 removal ranges from 32 $GtCO_2$ in scenarios with no or limited overshoot up to 842 $GtCO_2$ in scenarios with high overshoot (5–95 percentile range) (Riahi *et al* 2022). This large range in the amount of CDR calls for investigating the pathway characteristics that impact CDR deployment. Understanding the factors linked to CDR deployment between scenarios may inform policymaking that pursues ambitious climate action while limiting the reliance on CDR, which has been discussed controversially (Schenuit *et al* 2021, Waller *et al* 2021).

Here, we evaluate the range in CDR between mitigation pathways by exploring the relationships between CDR deployment and a set of scenario characteristics linked to the various purposes of CDR for mitigation. CDR volumes are further evaluated in terms of their relative and absolute contribution to total mitigation up until reaching net-zero. We use a subset ($n = 83$) of all 1.5 °C compatible and high overshoot pathways ($n = 230$) in the AR6 Scenario Database to account for different approaches in reporting carbon sequestration on land across integrated assessment models (IAMs) and to allow for a consistent scenario comparison. The method and data are detailed in section 2, and the results of the analysis are described in section 3. We then critically reflect on the robustness of our limited scenario subset and elaborate on additional factors that affect CDR deployment (section 4).

2. Methods and data

Scenario data were retrieved from the AR6 Scenario Database (version 1.0), hosted by the International Institute for Applied Systems Analysis (Byers *et al* 2022). Two mutually exclusive categories of scenarios were considered (Rogelj *et al* 2018b, Guivarch *et al* 2022, Schleussner *et al* 2022):

C1: *scenarios limiting warming to* 1.5 °C *in* 2100 ($>$50% *probability*) *with no or limited overshoot* ($\leqslant$67% *exceedance probability of* 1.5 °C)

C2: *scenarios returning to warming of* 1.5 °C *in* 2100 ($>$50% *probability*) *after a high overshoot* ($>$67% *exceedance probability of* 1.5 °C)

Pathways in category C1 with no or limited overshoot are considered 1.5 °C compatible, while pathways of category C2 return to 1.5 °C in 2100 after a high overshoot and are not considered 1.5 °C compatible (IPCC 2018, Schleussner *et al* 2022). We limit our analysis to these two scenario categories, as these are seen as especially policy-relevant for highly ambitious climate action. Only scenarios passing the IPCC's vetting process and with climate assessment were considered ($n = 230$), as advised by Riahi *et al* (2022) and Byers *et al* (2022). Scenario variables that were not available in the AR6 Scenario Database were constructed based on available data. A complete list of considered variables, including construction approaches, can be found in table S1 in SI.

To compute cumulative CDR from 2020 to 2100, a linear interpolation between the available data points in the time series was performed to retrieve values for all years. A similar approach was pursued when computing gross CO_2 emissions at the time (year) of net-zero CO_2.

A set of exclusion criteria was developed for filtering scenarios to ensure the use of consistent and accurate data on CDR. This was done to account for different approaches across IAMs when assessing and reporting data on CDR from agriculture, forestry, and other land use (AFOLU). In some cases, CDR from AFOLU in the AR6 Scenario Database is based on a combination of removals and gross emissions. In other cases, CDR from AFOLU is defined in relation to different baselines (Riahi *et al* 2022). For some scenarios, no carbon sequestration data from land use is available even though respective negative AFOLU emissions are reported (Byers *et al* 2022). As a consequence of the different reporting methodologies concerning CDR from AFOLU, total CDR deployment cannot be quantified and compared accurately for all scenarios, as described in the corrigenda of Riahi *et al* (2022).

The exclusion criteria shown in table 1 were used to address the described reporting issues to allow for accurate quantification and comparison of CDR for a subset ($n = 83$) of the initial set ($n = 230$) of scenarios of categories 1–2. A complete list of included and excluded scenarios and IAMs, including respective warming categories, can be found in tables S2–5 in SI.

Cumulative CDR throughout the 21st century and CDR deployment rates in 2050 and 2100 were correlated with scenario variables that are conceptually linked to one of three purposes of CDR: (i) to accelerate net-emission reductions to rapidly achieve net-zero targets, (ii) to offset residual CO_2 and non-CO_2 emissions, and (iii) to achieve net-negative CO_2 emissions after reaching net-zero CO_2 to reverse potential overshoot (Rogelj *et al* 2018b, Hilaire *et al* 2019, Babiker *et al* 2022). An overview of these correlations is given in figure 1.

Relationships between CDR deployment and the considered scenario characteristics were further explored by plotting CDR deployment against the scenario characteristics that showed substantial correlations. The focus lay on CDR deployment in 2050, as this was perceived as especially policy-relevant due to the shorter timescale and a stronger link to the current policy focus on net-zero targets (Höhne *et al* 2021). The analysis of relationships linked to net-zero is complemented by an evaluation of the absolute and relative contribution of CDR for transitioning from today's (2020) net CO_2 levels to net-zero CO_2.

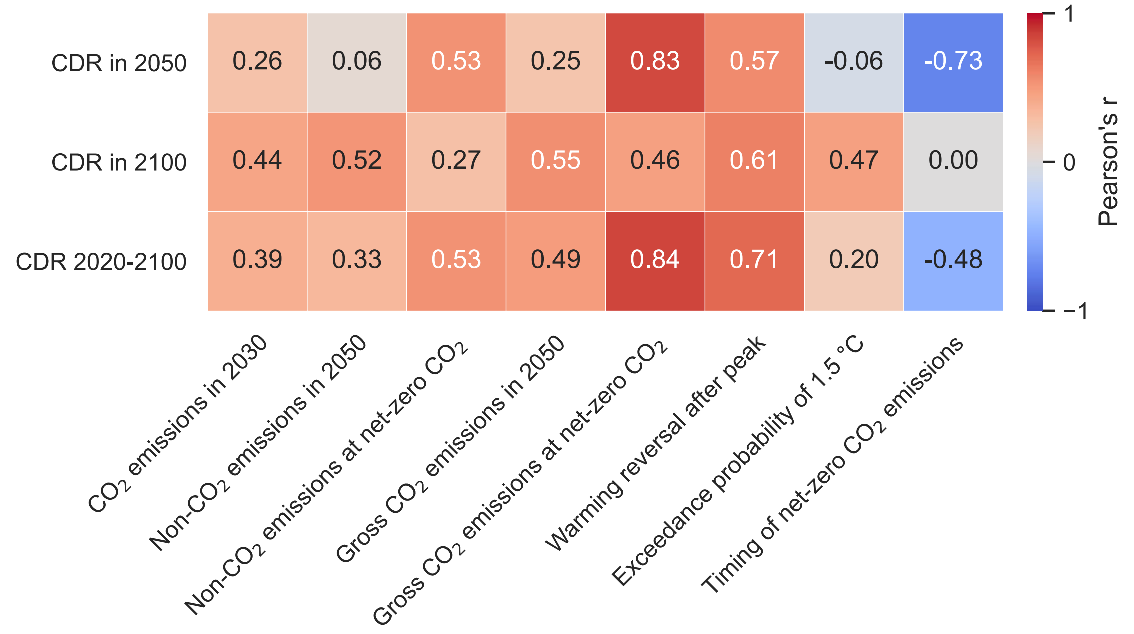

Figure 1. Relationships between CDR deployment and the conceptually linked scenario characteristics.

Table 1. Scenario exclusion criteria including rationale and number of excluded scenarios.

Exclusion criteria (EC1–3)		Rationale	#
Scenarios were excluded when:			
EC1	no data on 'Carbon Sequestration|Land Use' but net-negative 'Emissions|CO2|AFOLU' were reported	Net-negative CO_2 emissions in the AFOLU sector indicate carbon sequestration on land. If carbon sequestration on land is not reported, totals for CDR deployment will be inaccurate.	84
EC2	AFOLU CO_2 gross emissions <0 for any given year (tolerance $= 1$ $MtCO_2$)	Negative AFOLU CO_2 gross emissions indicate errors in 'Carbon Sequestration|Land Use' because net-removal cannot be larger than gross-removal.	47
EC3	'Carbon Sequestration|Land Use' >1 $GtCO_2$ in/before 2020	High removal rates on land before the conceptually expected scale-up of CDR indicate deviant definitions for 'Carbon Sequestration|Land Use'.	16

3. Results

3.1. Overview

As shown in figure 1, the scale of CDR deployment in 2100 is primarily correlated with the degree to which warming is reversed between peak warming and end-century warming ($r = .61$), as well as the gross CO_2 emission levels ($r = .55$) and non-CO_2 emissions in 2050 ($r = .52$).

The cumulative amount of CDR throughout the 21st century (2020–2100) most strongly correlates with the level of CO_2 gross emissions at the time of net-zero CO_2 ($r = .84$) and the level of reversed warming after peak warming ($r = .71$), followed by the amount of non-CO_2 emissions at the time of net-zero CO_2 ($r = .53$).

The amount of deployed CDR in 2050 is most strongly related to the level of CO_2 gross emissions at the time of net-zero CO_2 ($r = .83$), the timing of net-zero CO_2 ($r = -.73$), the warming reversal after peak warming ($r = .57$), and the non-CO_2 emissions at the time of net-zero CO_2 ($r = .53$). Subsequently, the relationships between the amount of CDR deployed in 2050 and the three substantially correlated scenario characteristics with links to net-zero targets are described further. Additional information on the relationship between CDR in 2050 and the warming reversal after peak warming can be found in figure S1 in SI.

3.2. CDR in 2050 and CO_2 gross emissions at the time of net-zero

In figure 2, the relationship between CDR deployment in 2050 and the amount of CO_2 gross emissions at the time of net-zero CO_2 is visualized, showing a positive and statistically significant correlation. Almost all scenarios that keep removal rates equal to or below 5 $GtCO_2$ yr^{-1} in 2050 show CO_2 gross emissions lower than

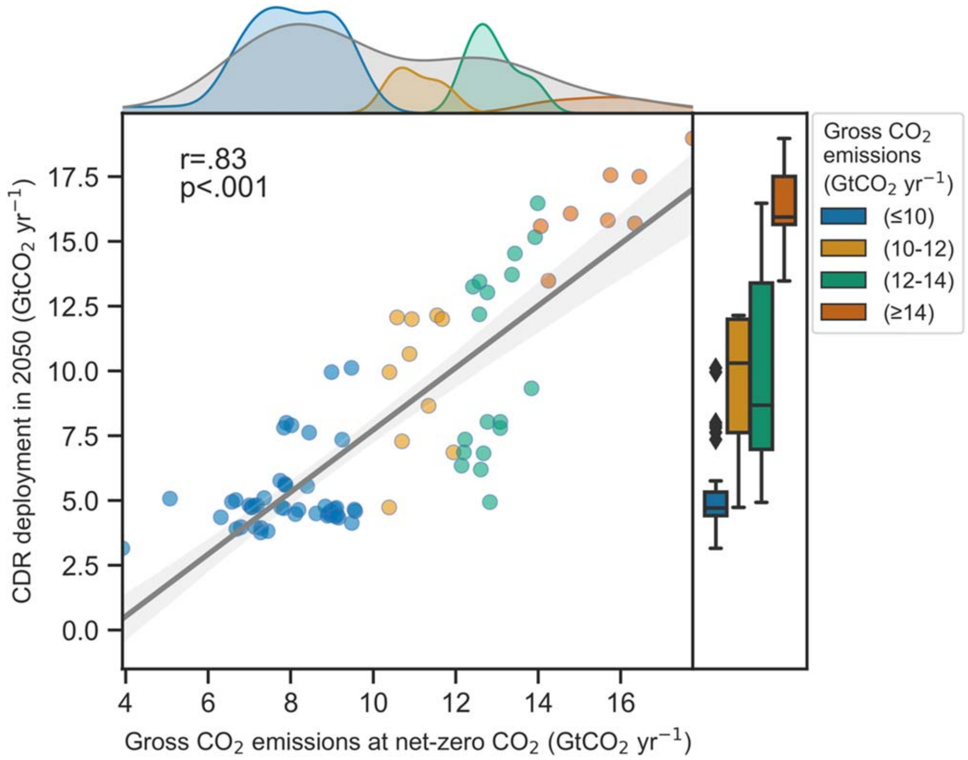

Figure 2. Relationship between CDR in 2050 and CO_2 gross emissions at the time of net-zero CO_2. The marginal boxplots in the right panel show CO_2 gross emissions at the time of net-zero CO_2 in four bins in relation to CDR in 2050 to emphasize the relationship shown in the scatterplot in the center panel. The relationship is further emphasized by a grey regression line with a 95% confidence interval in the center panel. The kernel density estimation plot in the upper panel highlights the distribution of data points on the *x*-axis (binned density presented in colors and non-binned density presented in grey). The legend (upper-right) depicts the values of the three bins.

10 GtCO$_2$ yr^{-1} at the time of net-zero CO_2 (blue bin). All scenarios with CO_2 gross emissions of 14 GtCO$_2$ yr^{-1} or more at the time of net-zero CO_2 (red bin) show CDR deployment beyond 13 GtCO$_2$ yr^{-1} in 2050.

The variance in CDR in 2050 is especially high among scenarios that reach net-zero CO_2 with a volume of 12 to 14 GtCO$_2$ yr^{-1} in gross CO_2 emissions (green bin): The amount of CDR ranges between 5 and 16.5 GtCO$_2$ yr^{-1}. Ninety-two percent of the variance in CDR among these scenarios can be explained through the variance in the respective timing of net-zero CO_2 ($r = -.96$, $p < .001$, $R^2 = .92$).

3.3. CDR in 2050 and the timing of net-zero

In figure 3, the relationship between CDR deployment in 2050 and the time of net-zero CO_2 is visualized, showing a negative and statistically significant correlation. Out of 18 scenarios that reach net-zero CO_2 in or before 2050 (blue bin), 15 show CDR higher than 10 GtCO$_2$ yr^{-1} in 2050. The majority of scenarios that reach net-zero CO_2 in or after 2060 (green bin) show CDR of less than 5 GtCO$_2$ yr^{-1} in 2050. Among the scenarios that reach carbon neutrality in or after 2060, only one shows CDR higher than 10 GtCO$_2$ yr^{-1} in 2050.

The variance in CDR deployment in 2050 is especially high among scenarios that reach net-zero CO_2 around mid-century, where the amount of CDR ranges between 5 and 19 GtCO$_2$ yr^{-1}. Ninety-five percent of the variance in CDR deployment of scenarios reaching net-zero CO_2 during this period (2048–2052) can be explained through the variance in respective gross CO_2 emissions at the time of net-zero CO_2 ($r = .98$, $p < .001$, $R^2 = .95$).

Comparatively high variance is also observed in the timing of net-zero CO_2 (range from 2050 to 2070) among scenarios that limit CDR to no more than 5 GtCO$_2$ yr^{-1} in 2050. The different timings of carbon neutrality among these scenarios with similar volumes of CDR in 2050 can partly be explained through the different levels of gross CO_2 emissions at the time of net-zero CO_2 ($r = .73$, $p < .001$, $R^2 = .53$).

3.4. CDR in 2050 and non-CO_2 emissions at the timing of net-zero

In figure 4, the relationship between CDR deployment in 2050 and non-CO_2 emissions at the time of net-zero CO_2 is visualized, indicating a positive correlation. Out of all scenarios ($n = 37$) that limit non-CO_2 emissions to no more than 7.5 GtCO$_2$eq yr^{-1} at the time of net-zero CO_2 emission (blue bin), 70 percent restrict CDR to less than 5 GtCO$_2$ yr^{-1} in 2050.

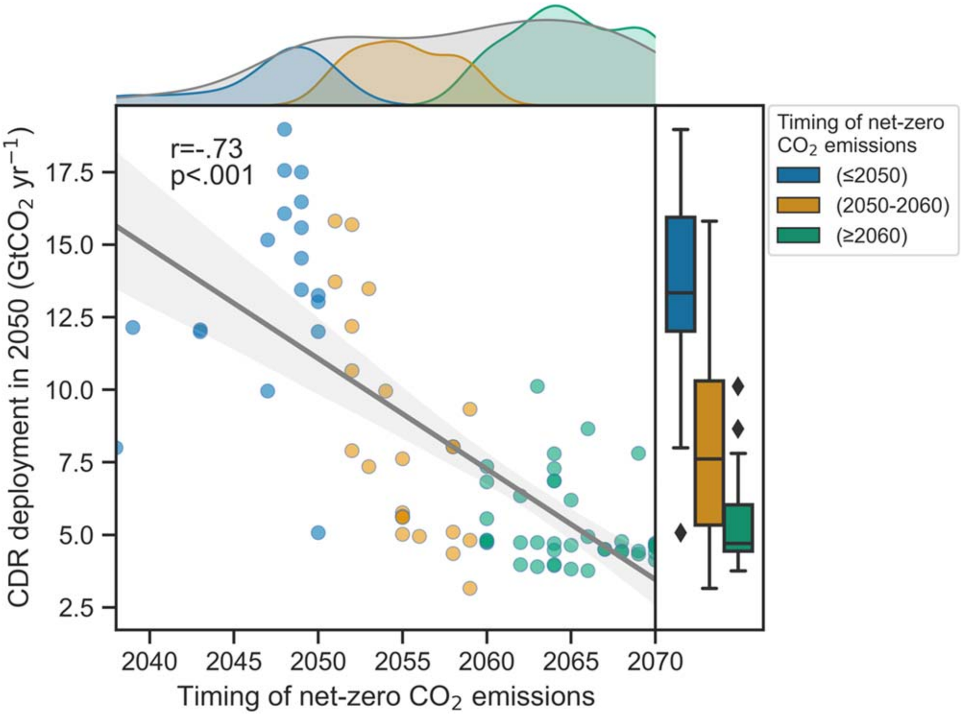

Figure 3. Relationship between CDR deployment in 2050 and the time of net-zero CO_2. The marginal boxplots in the right panel show the time of net-zero CO_2 in three bins in relation to CDR in 2050 to emphasize the relationship shown in the scatterplot in the center panel. The relationship is further emphasized by a grey regression line with a 95% confidence interval in the center panel. The kernel density estimation plot in the upper panel highlights the distribution of data points on the *x*-axis (binned density presented in colors and non-binned density presented in grey). The legend (upper-right) depicts the values of the three bins.

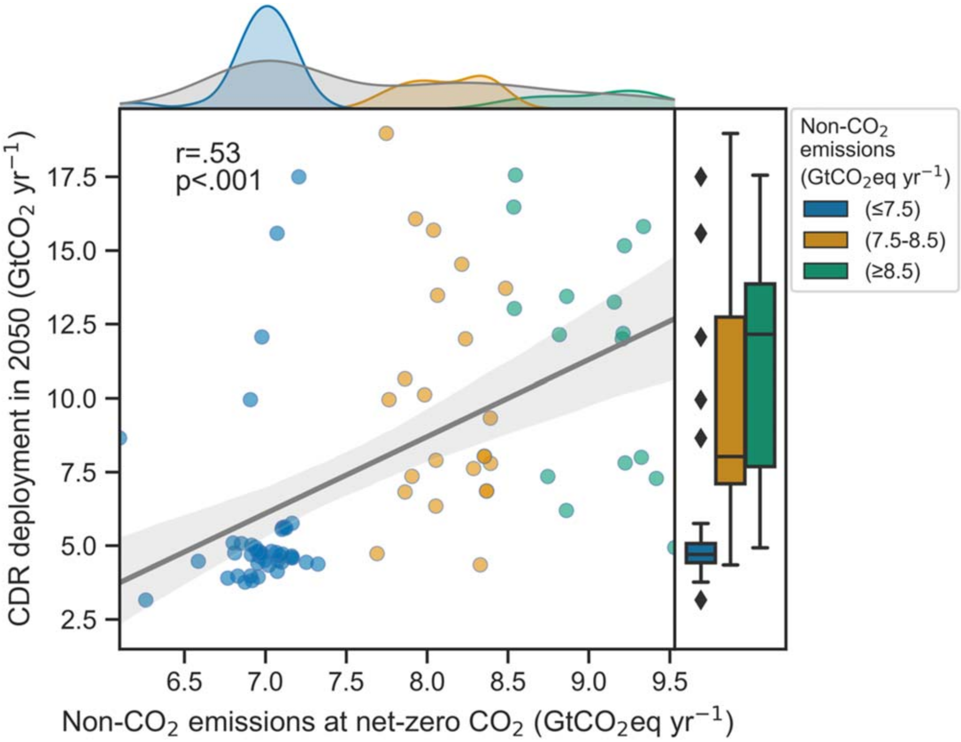

Figure 4. Relationship between CDR in 2050 and non-CO_2 emissions at the time of net-zero CO_2 emissions. The marginal boxplots in the right panel show non-CO_2 emissions at the time of net-zero CO_2 in three bins in relation to CDR in 2050 to emphasize the relationship shown in the scatterplot in the center panel. The relationship is further emphasized by a grey regression line with a 95% confidence interval in the center panel. The kernel density estimation plot in the upper panel highlights the distribution of data points on the *x*-axis (binned density presented in colors and non-binned density presented in grey). The legend (upper-right) depicts the values of the three bins.

Figure 5. Absolute and relative contribution of CDR deployment across scenarios (n = 83) for achieving net-zero CO_2. Differences in total mitigation (upper panel) stem from differences in implied net CO_2 emission levels in 2020 across scenarios. The removal and emission reduction rates in the upper panel represent the difference in the respective annual rate at the timing of net-zero CO_2 compared to the rate in 2020.

Figure 4 shows a high range in CDR deployment among scenarios that limit non-CO_2 emissions at the time of net-zero CO_2 to around 7 (mostly blue bin), 8 (mostly yellow bin), and 8.5 $GtCO_2eq\ yr^{-1}$, respectively. Sixty-seven percent of the variance in CDR deployment of scenarios that reach net-zero CO_2 with a volume of roughly 7 (6.8–7.2) $GtCO_2eq\ yr^{-1}$ in non-CO_2 emissions can be explained through the variance in gross CO_2 emissions at the time of net-zero CO_2 ($r = .82, p < .001, R^2 = .67$).

For scenarios that reach net-zero CO_2 with a volume of roughly 8 (7.8–8.2) $GtCO_2eq\ yr^{-1}$ in non-CO_2 emissions, the variance in CDR deployment can partly be explained through with different temperature outcomes in 2100 ($r = -.78, p = .002, R^2 = .61$), and the volume of gross CO_2 emissions at the time of net-zero CO_2 ($r = .76, p = .003, R^2 = .58$). For scenarios that reach net-zero CO_2 with a volume of roughly 8.5 (8.3–8.7) $GtCO_2eq\ yr^{-1}$ in non-CO_2 emissions, the variance in CDR deployment can partly be explained through the relationship with the temperature reversal between peak warming and end-of-century warming ($r = .75, p = .005, R^2 = .56$), and the volume of gross CO_2 emissions at the time of net-zero CO_2 ($r = .71, p = .010, R^2 = .50$).

3.5. CDR contribution for reaching net-zero

Figure 5 shows how the contribution of CDR for shifting from today's net CO_2 emissions levels to net-zero CO_2 varies across scenarios. The relative contribution of CDR to total mitigation up until reaching net-zero CO_2 ranges between 8 and 45 percent, with a median contribution of 21 percent. In absolute terms, the ramp-up of annual CDR deployment at the timing of net-zero CO_2 compared to 2020 levels spans from 3.5 to 17.9 $GtCO_2$ with a median upscaling of 9 $GtCO_2$.

4. Discussion

This study explored relationships between CDR and a set of scenario characteristics to evaluate the large range in CDR volumes among 1.5 °C compatible and high overshoot pathways. A focus was given to CDR in 2050, as this was perceived as especially policy-relevant due to the shorter timescale and a stronger link to the current policy focus on net-zero targets. It was further shown how the relative and absolute contribution of CDR to total mitigation up until reaching net-zero varies considerably across scenarios. With a median relative contribution of roughly 20 percent and up to 45 percent, IAMs tend to deploy CDR beyond what is conceptually postulated as a sensible ratio of 90:10 between gross emission reductions and CDR deployment (Geden and Schenuit 2020).

In the following, the relationships explored in section 3 are further discussed. The level of CO_2 gross emissions at the time of net-zero CO_2 is significantly and positively correlated with CDR in 2050, 2100, and the

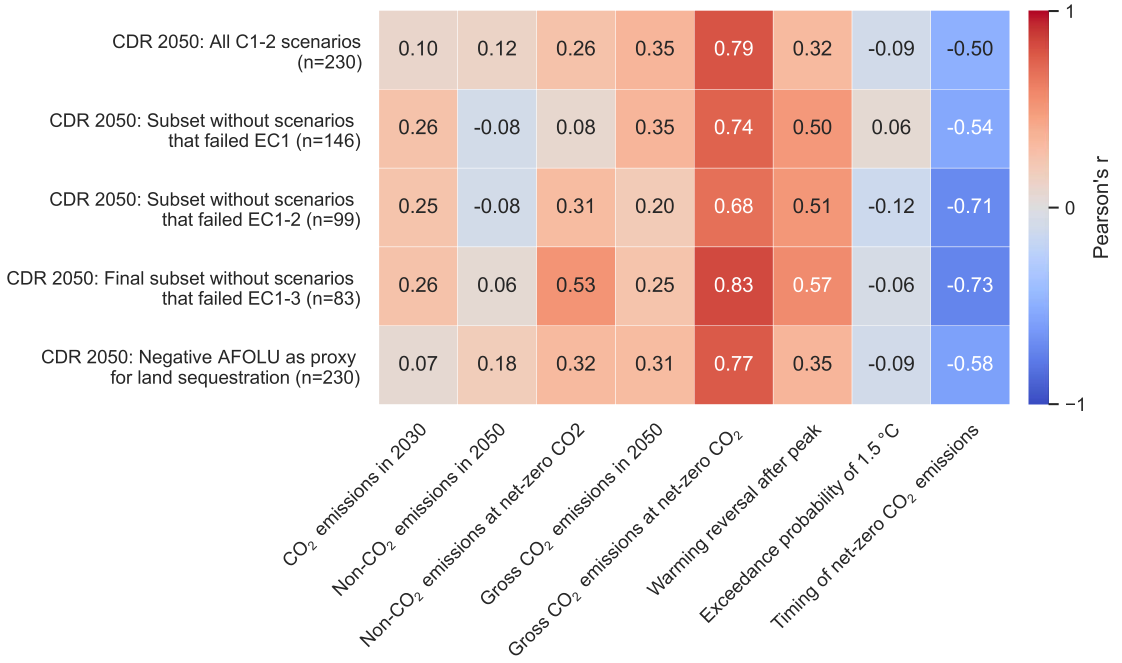

Figure 6. Relationships between CDR deployment in 2050 and the considered scenario characteristics for the three statements of the scenario exclusion criteria (EC1–3) and for an alternative CDR estimation approach using net-negative AFOLU CO_2 emissions as a substitute for land sequestration.

cumulative amount of CDR throughout the century. The warming reversal after peak warming also correlates with CDR. These correlations link to two purposes of CDR, namely, to offset remaining gross CO_2 emissions and to achieve net-negative CO_2 emissions in the second half of the century to reverse warming and to compensate for overshoot (Rogelj *et al* 2018b, Hilaire *et al* 2019, Babiker *et al* 2022). The volume of CDR in 2050 is also substantially negatively correlated to the time of net-zero CO_2. This relationship reflects another purpose of CDR, namely, to accelerate net CO_2 emission reductions to rapidly achieve net-zero CO_2 conditions (Rogelj *et al* 2018b, Hilaire *et al* 2019, Babiker *et al* 2022). Based on the used subset of pathways, the volume of CDR in 2050 appears to be positively correlated to the amount of non-CO_2 emissions at the time of net-zero CO_2.

Policy-relevant conclusions need to be drawn with care, as causation cannot be inferred, nor can reverse 'causality' between the evaluated variables be ruled out. Also, the used subset of pathways represents only a limited and unbalanced sample of the scenario space. Several 1.5 °C compatible and high overshoot pathways from AR6 ($n = 147$) were not considered. This exclusion of scenarios accounted for different approaches across IAMs when assessing and reporting data on CDR from AFOLU (Byers *et al* 2022, Riahi *et al* 2022).

To evaluate the robustness of the correlations, changes in the relationships between CDR in 2050 and the considered scenario characteristics were explored for the different scenario exclusion steps described in table 1. Changes in relationships were also compared to an alternative CDR aggregation approach described in the literature, where net-negative AFOLU CO_2 emissions are used as a substitute for land sequestration to account for inconsistent or missing data on land use sequestration (Warszawski *et al* 2021, Schleussner *et al* 2022). Detailed information on CDR ranges and relationships based on this alternative approach is shown in figures S2–7 in SI.

Figure 6 shows how the strength of the analyzed relationships between CDR in 2050 and the considered scenario characteristics varies depending on the used scenario subset. In most cases, the tendencies of the relationships remain stable regardless of the different scenario exclusion steps. However, the degree to which CDR in 2050 is correlated with other scenario characteristics tends to increase throughout the three scenario exclusion steps, resulting in stronger correlations in the final subset compared to the initial unfiltered set of 1.5 °C compatible and high overshoot pathways. This variation in the strength of correlations is especially sizeable for the relationship between CDR in 2050 and the amount of non-CO_2 emissions at the time of net-zero CO_2. Based on this robustness evaluation, the tendency of the discussed relationships between CDR in 2050 and the analyzed scenario characteristics appear to be mostly sound, while the strength of the correlations varies depending on the selection of considered scenarios. This is also supported by the comparison with the relationships found for the alternative CDR estimation approach using net-negative AFOLU CO_2 emissions as a proxy for land use sequestration (Warszawski *et al* 2021, Schleussner *et al* 2022). The relationship between CDR in 2050 and the non-CO_2 emissions at the time of net-zero CO_2 needs to be interpreted with caution due to the comparatively high variation in the strength of the correlations depending on the considered scenario subset. The robustness is further debatable as this relationship appears to be driven by a dense cluster of pathways entirely coming from MESSAGEix-GLOBIOM 1.1, indicating that the relationship might be a result of a sampling bias (see blue bin in figure 4). Generally, the scenario subset is dominated by MESSAGEix-GLOBIOM and REMIND-MAgPIE, while some other models are largely filtered out, resulting in an unbalanced set of underlying IAMs (see tables S2–5 in SI).

To improve the robustness of the analyzed relationships, a more comprehensive integration of pathways and IAMs would be desirable to ensure a more balanced representation of the scenario space. This is especially true, as several scenarios with inherent CDR volumes at the lower end of the spectrum were filtered out by the scenario exclusion criteria, including two of the illustrative mitigation pathways (IMPs), namely Ren and SP (Soergel *et al* 2021, Luderer *et al* 2022). We applied various tolerance thresholds for exclusion criteria EC2 (1–10 $MtCO_2$ threshold) and EC3 (1–2.5 $GtCO_2$ threshold) to explore whether results changed by increasing the tolerance thresholds to pass more scenarios. For EC2, the increased tolerance threshold did not pass more scenarios. For EC3, six additional scenarios were passed when increasing the tolerance threshold to 2.5 $GtCO_2$ in or before 2020. However, this merely altered the correlations (maximum change in Pearson's $r = .06$).

Beyond scenario sampling, the discussed relationships between CDR and other scenario characteristics depend on inherent properties of underlying IAMs and the scenario design itself: The volume of CDR across scenarios is also driven by discount rates applied in IAMs, which determine how mitigation costs over the course of the 21st century are perceived today. Relatively high rates (5%) promote delayed mitigation using higher volumes of CDR in the second half of the century compared to more near-term emission reductions and less reliance on CDR under lower discount rates (2%) (Emmerling *et al* 2019, Köberle 2019). The shape of the carbon price trajectory further influences CDR deployment. Exponentially increasing prices following the Hotelling rule lead to high carbon prices at the end of the century and consequently high CDR deployment, associated with a high overshoot. Scenarios using alternative carbon price trajectories or explicit climate target formulations are able to reduce CDR deployment (Rogelj *et al* 2019, Strefler *et al* 2021a). Currently, most modeled mitigation pathways are based on economic optimization, where emission reductions for meeting a target in 2100 are implemented at the lowest cost, which typically favors CDR as a central mitigation component (Rogelj *et al* 2019). Meanwhile, alternative but not cost-optimized modeling approaches exist that can achieve similar emission reductions (Fuss *et al* 2014, Gambhir *et al* 2019, Haikola *et al* 2019). The degree to which such alternatives for modeling emission reductions are considered in the available scenarios, such as demand side reductions or other low-carbon technologies, further impacts the amount of CDR across scenarios (Köberle 2019).

Ultimately, the way CDR is scaled up and deployed continuously until the end of the 21st century in most scenarios in this analysis is not per se a necessity. In many cases, the rate of annual CDR continues to increase after reaching net-zero CO_2. While a continued increase in CDR after reaching net-zero CO_2 might be deliberate to reverse warming to return to pre-industrial levels, alternative pathways after reaching net-zero CO_2 may exist, indicating that the discussed relationship between CDR deployment and warming reversal might be an artifact of the scenario design (Rogelj *et al* 2019, Schleussner *et al* 2022).

All the above-described factors may impact the amount of CDR in pathways that limit or return warming to 1.5 °C in 2100, which emphasizes the need to interpret the analyzed correlations with care and underlines the importance of considering a broad scenario space of potential futures in the context of climate policymaking to avoid any blind spots.

5. Conclusion

This study explored the large range in CDR deployment volumes across 1.5 °C compatible and high overshoot pathways by evaluating the relationships between CDR and conceptually linked scenario characteristics, with a particular focus on CDR in 2050 and scenario characteristics linked to reaching net-zero CO_2. CDR volumes were further evaluated in terms of their relative and absolute contribution to total mitigation up until reaching net-zero CO_2, showing considerable variation across scenarios with a median relative contribution of around 20 percent. The level of CO_2 gross emissions at the time of net-zero CO_2 was most strongly correlated with CDR volumes in 2050, 2100, and the cumulative amount of CDR throughout the century. The volume of CDR in 2050 is also substantially correlated to the timing of net-zero CO_2.

While these discussed relationships are statistically significant, their power to precisely explain the range in CDR volumes among scenarios is limited as the set of pathways in this analysis does not represent the full spectrum of possible scenarios. Several scenarios were excluded because they applied incomparable emission reporting methodologies.

While the tendencies of the relationships between CDR in 2050 and the considered scenario characteristics remained mostly stable when modifying the scenario exclusion criteria, the strength of the relationships varied depending on the underlying scenario subset. Besides scenario sampling, additional factors that impact the volume of CDR in pathways, such as discount rates, carbon price trajectories, and scenario design choices, were discussed.

Future studies may aim to either systematize reporting on CDR from AFOLU or to advance the imputation of inconsistent or missing data on land use sequestration to avoid the necessity to exclude scenarios for the sake of comparability.

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Data availability statement

The data underlying this analysis is hosted by IIASA. A free guest login is required to access the dataset. Alternatively, the data can be shared by the corresponding author upon request. https://doi.org/10.5281/zenodo.5886911.

The code for processing and visualizing the data is available from the corresponding author upon request.

Conflict of interest

The authors declare no conflict of interest.

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