Expert survey on carbon cycle modelling

Dear participant

Thank you for agreeing to participate in our expert survey about the representation of the carbon cycle in Earth System Models (ESMs) and Integrated Assessment Models (IAMs) and its role for analyzing Carbon Dioxide Removal (CDR).

The survey will take between 15 and 20 minutes to complete. You can interrupt the survey at any time, store your responses and resume later (see top right corner).

Your responses will be handled anonymously. The record of your survey responses does not contain any identifying information about you. Your access to this survey is personalized, but your individual link will not be stored together with your responses.

If you have any questions about the survey or any technical problems please do not hesitate to contact Christine Merk (Christine.Merk@ifw-kiel.de).

Please use only the 'Next' button at the bottom of the page to navigate, \underline{not} the back button of your browser .

There are 52 questions in this survey.

What kind of model do you <u>mainly</u> use for your research on CDR?
Please refer to this model when you are asked about the `model that you use' or `your model' in the following questions.
*
• Choose one of the following answers Please choose only one of the following:
Detailed process Integrated Assessment Model
Benefit-cost Integrated Assessment Model
Earth System Model of full complexity
Earth System Model of intermediate complexity
Other type of Climate Model
Other
How is the carbon cycle represented in the Integrated Assessment Model that you use? *
Only answer this question if the following conditions are met: G1Q00001 (/admin/questions/sa/view/surveyid/874333/gid/41/qid/842) == 'A1' OR G1Q00001 (/admin/questions/sa/view/surveyid/874333/gid/41/qid/842) == 'A2'
Choose one of the following answers Please choose only one of the following:
impulse-response representation
linear box-type representation
on-linear box-type representation
combination of impulse-response and linear box-type representation
combination of impulse-response and non-linear box-type representation
There is no carbon cycle representation.
◯ don't know
Which component(s) of the Earth System do you mainly research? *
Only answer this question if the following conditions are met:
G1Q00001 (/admin/questions/sa/view/surveyid/874333/gid/41/qid/842) >= 'A3'
Check all that apply Please choose all that apply:
atmospheric physics
atmospheric chemistry
ocean physics
ocean biogeochemistry
ocean sediments
sea ice I and ice
terrestrial biosphere
Other:

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e choose the appropriate response for each item.	not at all	implicitly	explicitly	don't know
pathway (A): atmosphere-to-terrestrial	0	0		0
pathway (B): terrestrial-to-geological	0	0	\circ	0
	0	0	\bigcirc	0
pathway (C): terrestrial-to-ocean				
	\circ	0	0	0
an carbon cycle response (D)	0	0	0	0
	(s) or fluxes in your IAM	sufficiently or insufficiently repres	sented to assess the efficient	ency of enhanced
an carbon cycle response (D) t do you think, are the respective CDR pathway hering on land?	(s) or fluxes in your IAM	sufficiently or insufficiently repres	sented to assess the efficiently	ency of enhanced
an carbon cycle response (D) do you think, are the respective CDR pathway hering on land? e choose the appropriate response for each item:				
an carbon cycle response (D) do you think, are the respective CDR pathway hering on land? e choose the appropriate response for each item:		somewhat sufficiently		
an carbon cycle response (D) It do you think, are the respective CDR pathway thering on land?		somewhat sufficiently		
an carbon cycle response (D) It do you think, are the respective CDR pathway thering on land? The choose the appropriate response for each item: R pathway (A): atmosphere-to-terrestrial R pathway (B): terrestrial-to-geological		somewhat sufficiently		

	phere	1			
c	В	A			
Land	Ocean				
Geolog	gical				
Carbon reservoir size increase	Carbon dioxide re	moval pathway			
Natural carbon redistribution in response to a perturbation	Carbon reservoir size i to CDR storage				
Carbon flux due to anthropogenic activities	Where carbon has bee	n deliberately oir			
ure: Global net negative emis	sions with DACCS pertu	rbation			
en determining the net rem way(s) and fluxes (A, B ar answer this question if the fo Q00001_SQ005.NAOK (/adm se choose the appropriate res	nd C , respectively, se llowing conditions are m nin/questions/sa/view/s	e Fig. above) implicitly, let:		M account for the carbon of th	dioxide removal (CDR)
R pathway (A): atmosphere	-to-geological		Implicately	C	don't know
an carbon cycle response (
estrial carbon cycle respon					
estrial carbon cycle respon	136 (0)	0	U	<u> </u>	0
-	sponse for each item:	insufficiently	somewhat sufficiently	sufficiently	don't know
se choose the appropriate res		insufficiently	somewhat sufficiently	sufficiently	don't know
se choose the appropriate res	-to-geological	insufficiently	somewhat sufficiently	sufficiently	don't know
R pathway (A): atmosphere-	-to-geological	insufficiently	somewhat sufficiently	sufficiently	don't know
R pathway (A): atmosphere-	-to-geological	insufficiently	somewhat sufficiently	sufficiently	don't know
at do you think, are the resse choose the appropriate resse choose the appropriate research at general information or in IAM? Please fill in keyword answer this question if the for Q00001_SQ005.NAOK (/adm se write your answer here:	-to-geological (B) use (C) uput from the Earth Syrds.	vstem Modelling commu	unity (e.g. parameterizations) would	0	0

Artificial ocean alkalinization (AOA)

Increase the alkalinity of the upper ocean to chemically increase the carbon storage capacity of seawater and thus, also increase CO_2 uptake

Afforestation

Plant or restore forests to increase CO₂ uptake (via primary production) and storage in biomass and soils

Enhanced weathering on land

Spread alkaline minerals on land to chemically remove CO₂ from the atmosphere in reactions that form ions, which are eventually transported to the ocean or in some cases solid minerals (geological sequestration), may also enhance vegetation productivity and subsequently soil carbon storage

Bioenergy with carbon capture and storage (BECCS)

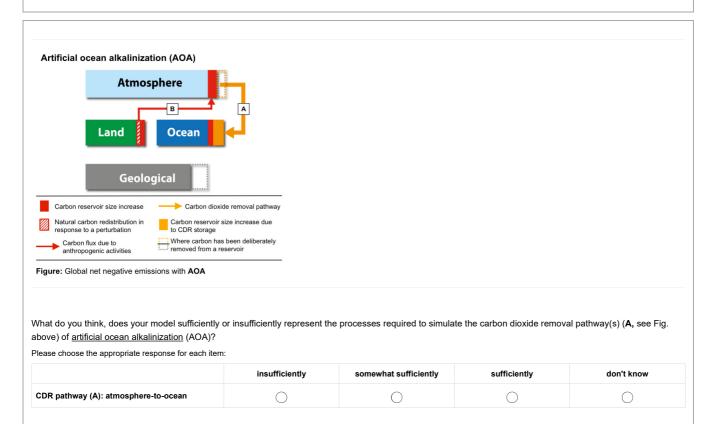
Grow terrestrial vegetation and use the biomass to create biofuels that can be burned in conjunction with carbon capture and storage technology

Direct air capture of CO₂ with storage (DACCS)

Technology that chemically or electro-chemically removes ${\rm CO}_2$ from air and concentrates it for storage

Only answer this question if the following conditions are met:

TCDRhelp (/admin/questions/sa/view/surveyid/874333/gid/47/qid/2349) == 'A1'



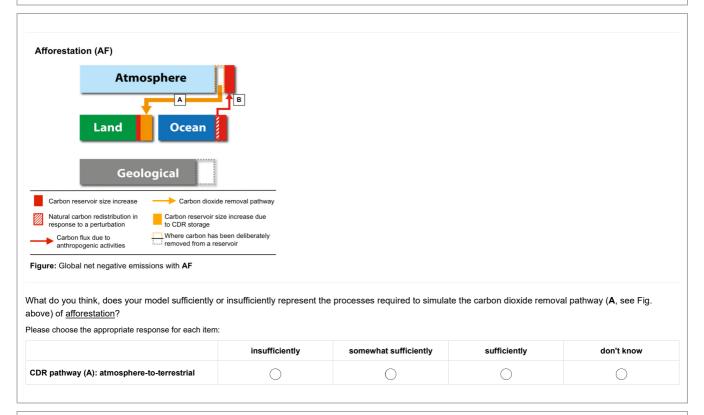
_	
	What processes should be improved in your model in order to better simulate the artificial ocean alkalinization induced CDR pathway (A , see Fig. above)? Please limit your answer to the three most important processes.
	Please write your answer here:

imeSurvey Professional - Your online survey service - Expert survey	https://spp1689.limequery.com/admin/printablesurvey/sa/index/survey.

What do yo think, how important would it be to improve the factors listed below in your model to better simulate the terrestrial carbon cycle response (**B**, see Fig. above) to **artificial ocean alkalinization**?

Please choose the appropriate response for each item:

	not at all important	somewhat unimportant	somewhat important	very important	don't know
CO ₂ fertilization parameterization	\circ	\circ	0	0	0
soil carbon cycling	\circ	\circ	\circ	\circ	\circ
hydrology and inland waters	\circ	\circ	\circ	\circ	\circ
vegetation representation	\circ	\circ	\circ	\circ	\circ
permafrost	\circ	\circ	\circ	\circ	\circ
representation of land-use change	\circ	\circ	\circ	\circ	\circ
disturbances (fires and pests)			\circ	\circ	



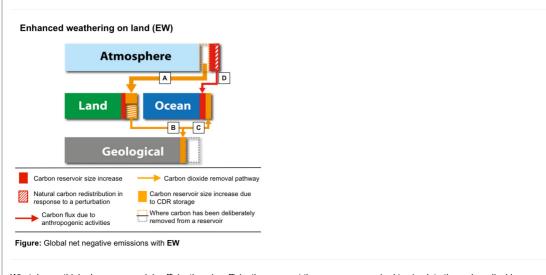
ove)?

imeSurvey Professional - Your online survey service - E	Expert survey	https://spp1689.limequery.	.com/admin/printablesurvey	//sa/index/survey.

What do you think, how important would it be to improve the factors listed below in your model to better simulate the ocean carbon cycle response (**B**, see Fig. above) to **afforestation**?

Please choose the appropriate response for each item:

	not at all important	somewhat unimportant	somewhat important	very important	don't know
air-sea gas exchange parameterization	\circ	\circ	\circ	\circ	\circ
ocean physical transport	\circ	\circ	\circ	\bigcirc	\circ
carbonate chemistry	\circ	\circ	\circ	\bigcirc	\circ
biology and biological pump	\circ	\circ	\circ	\bigcirc	\circ
marine sediments	\circ	\circ	\circ	\bigcirc	\circ
sea ice representation	\circ	\circ	\circ	\bigcirc	\circ
biogeochemistry along the land-ocean continuum	\circ	0	\circ	\bigcirc	\bigcirc



What do you think, does your model sufficiently or insufficiently represent the processes required to simulate the carbon dioxide removal pathways (**A**, **B** and **C**, respectively, see Fig. above) of enhanced weathering on land (EW)?

Please choose the appropriate response for each item:

	insufficiently	somewhat sufficiently	sufficiently	don't know
CDR pathway (A): atmosphere-to-terrestrial	\circ	\circ	\bigcirc	\circ
CDR pathway (B): terrestrial-to-geological	\circ	\circ	\circ	\circ
CDR pathway (C): terrestrial-to-ocean	\circ	\circ	\circ	\circ

What processes should be improved in your model in order to better simulate the enhanced weathering on land induced carbon dioxide removal pathway (A , B and C , see Fig. above)? Please limit your answer to the three most important processes.
Please write your answer here:

What processes should be improved in your model in order to better simulate the BECCS induced carbon dioxide removal pathways (A and B, respectively, see
Fig. above)? Please limit your answer to the three most important processes.
Please write your answer here:
riease write your answer riere.

Check all that apply lease choose all that apply:					
Direct air capture of CO ₂ with storage					
Bioenergy with carbon capture and storage (BECC	CS)				
Soil carbon sequestration (e.g., no-till farming)					
Afforestation					
Biochar Enhanced weathering on land					
Ocean alkalinization					
Ocean iron fertilization					
Artificial ocean upwelling Blue carbon (i.e., enhancing natural ocean carbon	sinks by mangroves sead	irassas or salt marchas)			
None of them	onno by mangroves, soag	racces of salt marches)			
Don't know					
w well can the current version of your model s ly answer this question if the following conditions ar _empty(G6Q00002_SQ011.NAOK (/admin/questi	re met:	-		SQ012.NAOK (/adn	nin/questions/sa/view/surve
74333/gid/42/qid/847))) ease choose the appropriate response for each item					
not at all po	oorly	decently	very w	rell	don't know
\bigcirc	\supset	\bigcirc			\circ
you want to know more about the technologies ease insert the numbers, which represent the for 'don't know' or 'no constraint' or 'weak constraint'	s you can open an infom	nation box below this o	question.	nethods listed belo	ow?
'hat do you think, are the following factors a we you want to know more about the technologies lease insert the numbers, which represent the for 'don't know' for 'no constraint' for 'weak constraint' for 'medium constraint' for 'strong constraint' Only numbers may be entered in these fields. Each answer must be between -1 and 3	s you can open an infom	nation box below this o	question.	methods listed belo	ow?
you want to know more about the technologies ease insert the numbers, which represent the for 'don't know' for 'no constraint' for 'weak constraint' for 'medium constraint' for 'strong constraint' Only numbers may be entered in these fields.	s you can open an infom	nation box below this o	question.	nethods listed belo	
you want to know more about the technologies ease insert the numbers, which represent the for 'don't know' for 'no constraint' for 'weak constraint' for 'medium constraint' for 'strong constraint' Only numbers may be entered in these fields.	s you can open an infom strength of the constrain	nation box below this on	question. every CDR method: Soil carbon		
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arbon cycle responses/feedbacks (e.g. ocean arbon uptake) limate feedbacks (e.g. change in albedo) on-CO ₂ forcing (e.g. methane) hysical CO ₂ removal capacity essource competition (e.g. land availability)	s you can open an infom strength of the constrain	nation box below this on	question. every CDR method: Soil carbon		
ease insert the numbers, which represent the for 'don't know' for 'no constraint' for 'weak constraint' for 'medium constraint' for 'strong constraint' Conly numbers may be entered in these fields. Each answer must be between -1 and 3 arbon cycle responses/feedbacks (e.g. ocean arbon outgassing due to deliberate terrestrial arbon uptake)	s you can open an infom strength of the constrain	nation box below this on	question. every CDR method: Soil carbon		
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Enhanced weathering on land					
Spread alkaline minerals on land to chemically rome cases solid minerals (geological sequestra	=	•			ted to the ocean or in
Bioenergy with carbon capture and storage (Grow terrestrial vegetation and use the biomass	•	can be burned in conj	unction with carbon cap	ture and storage techr	nology
Ü		·		Ü	0,
Soil and land carbon management					
imploy management practices, such as no-till a etention and storage in agricultural soils or mar	-	er crops, compost ar	mendments, wetland res	toration, and fire mana	agement, to increase C
fforestation					
lant or restore forests to increase CO ₂ uptake	(via primary production)	and storage in bioma	ass and soils		
Biochar					
Pyrolyze terrestrial biomass to form biochar and		e C can remain seque	estered (biochar is recald	citrant); biochar amend	dments may also
nhance vegetation productivity and soil carbon only answer this question if the following conditions a	_				
ICDRhelpchoose2 (/admin/questions/sa/view/sur		353) == 'A1'			
for 'no constraint' for 'weak constraint' for 'medium constraint'					
for 'no constraint' for 'weak constraint' for 'medium constraint' for 'strong constraint' Only numbers may be entered in these fields.		Ocean iron	Artificial ocean		Direct air capture o
for 'no constraint' for 'weak constraint' for 'medium constraint' for 'strong constraint' Only numbers may be entered in these fields. Each answer must be between -1 and 3	Ocean alkalinization	Ocean iron fertilization	Artificial ocean upwelling	Blue carbon	
for 'no constraint' for 'weak constraint' for 'medium constraint' for 'strong constraint' Only numbers may be entered in these fields. Each answer must be between -1 and 3 carbon cycle responses/feedbacks (e.g. ocean carbon outgassing due to deliberate terrestrial	Ocean alkalinization			Blue carbon	•
for 'no constraint' for 'weak constraint' for 'medium constraint' for 'strong constraint' Only numbers may be entered in these fields. Each answer must be between -1 and 3 carbon cycle responses/feedbacks (e.g. ocean carbon outgassing due to deliberate terrestrial carbon uptake)	Ocean alkalinization			Blue carbon	•
for 'no constraint' for 'weak constraint' for 'medium constraint' for 'strong constraint' Only numbers may be entered in these fields. Each answer must be between -1 and 3 carbon cycle responses/feedbacks (e.g. ocean carbon outgassing due to deliberate terrestrial carbon uptake) climate feedbacks (e.g. change in albedo)	Ocean alkalinization			Blue carbon	•
for 'no constraint' for 'weak constraint' for 'medium constraint' for 'strong constraint' Only numbers may be entered in these fields. Each answer must be between -1 and 3 carbon cycle responses/feedbacks (e.g. ocean carbon outgassing due to deliberate terrestrial carbon uptake) climate feedbacks (e.g. change in albedo) non-CO ₂ forcing (e.g. methane)	Ocean alkalinization			Blue carbon	•
for 'no constraint' for 'weak constraint' for 'weak constraint' for 'medium constraint' for 'strong constraint' for 'medium constraint' for 'strong co	Ocean alkalinization			Blue carbon	
1 for 'don't know' 1 for 'no constraint' 1 for 'weak constraint' 2 for 'medium constraint' 3 for 'strong constraint' 2 Only numbers may be entered in these fields. 2 Each answer must be between -1 and 3 carbon cycle responses/feedbacks (e.g. ocean carbon outgassing due to deliberate terrestrial carbon uptake) climate feedbacks (e.g. change in albedo) non-CO ₂ forcing (e.g. methane) physical CO ₂ removal capacity resource competition (e.g. land availability) environmental and human health side effects	Ocean alkalinization			Blue carbon	
for 'no constraint' for 'weak constraint' for 'weak constraint' for 'medium constraint' for 'strong constraint' for 'medium constraint' for 'strong co	Ocean alkalinization			Blue carbon	Direct air capture of CO ₂ with storage
for 'no constraint' for 'weak constraint' for 'weak constraint' for 'medium constraint' for 'strong constraint' Only numbers may be entered in these fields. Each answer must be between -1 and 3 carbon cycle responses/feedbacks (e.g. ocean carbon outgassing due to deliberate terrestrial carbon uptake) climate feedbacks (e.g. change in albedo) non-CO ₂ forcing (e.g. methane) physical CO ₂ removal capacity resource competition (e.g. land availability) environmental and human health side effects cost effectiveness	Ocean alkalinization			Blue carbon	
for 'no constraint' for 'weak constraint' for 'weak constraint' for 'medium constraint' for 'strong constraint' Only numbers may be entered in these fields. Each answer must be between -1 and 3 carbon cycle responses/feedbacks (e.g. ocean carbon outgassing due to deliberate terrestrial carbon uptake) climate feedbacks (e.g. change in albedo) non-CO ₂ forcing (e.g. methane) physical CO ₂ removal capacity resource competition (e.g. land availability) environmental and human health side effects cost effectiveness	Ocean alkalinization			Blue carbon	
for 'no constraint' for 'weak constraint' for 'weak constraint' for 'medium constraint' for 'strong constraint' for 'strong constraint' Only numbers may be entered in these fields. Each answer must be between -1 and 3 carbon cycle responses/feedbacks (e.g. ocean carbon outgassing due to deliberate terrestrial carbon uptake) climate feedbacks (e.g. change in albedo) non-CO ₂ forcing (e.g. methane) physical CO ₂ removal capacity resource competition (e.g. land availability) environmental and human health side effects	Ocean alkalinization			Blue carbon	
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Info box: Marine CDR methods and DACCS
Artificial ocean alkalinization (AOA)
Increase the alkalinity of the upper ocean to chemically increase the carbon storage capacity of seawater and thus, also increase CO ₂ uptake
increase the alkalinity of the upper ocean to chemically increase the carbon storage capacity of seawater and thus, also increase coop uptake
Ocean iron fertilization
Add micronutrients like iron to increase phytoplankton growth (CO ₂ fixation) and ocean carbon storage via the biological pump (the transport of this fixed carbon into
the deep ocean)
Artificial ocean upwelling
Use pipes or other methods to pump nutrient rich deep ocean water to the surface where it has a fertilizing effect; see ocean fertilization above
Blue carbon
Enhancing natural ocean carbon sinks by mangroves, seagrasses or salt marshes
Emiliarising rictard occur carbon crime by mangroves, coagraced or calciniarions
Direct air capture of CO ₂ with storage (DACCS)
Technology that chemically or electro-chemically removes CO ₂ from air and concentrates it for storage
Only answer this question if the following conditions are met:
MCDRhelp3 (/admin/questions/sa/view/surveyid/874333/gid/42/qid/2355) == 'A1'
For how many years have you already been working in research?
Choose one of the following answers
Please choose only one of the following:
○ <3 years
3-5 years
() 6-10 years
① 11-15 years
() >15 years
For how many years have you already been researching CDR?
Choose one of the following answers Change the control of the following answers
Please choose only one of the following:
() < 1 year
○ 1-2 years○ 3-5 years
○ 6-10 years
>10 years
O I do not research CDR.
What are your main recease interests with respect to CDD2
What are your main research interests with respect to CDR?
Please fill in keywords. Only answer this question if the following conditions are met:
G6Q00007 (/admin/questions/sa/view/surveyid/874333/gid/42/qid/840) >= 'A2'
Please write your answer here:

What are your current research topics? Please fill in keywords.
Only answer this question if the following conditions are met: G6Q00007 (/admin/questions/sa/view/surveyid/874333/gid/42/qid/840) == 'A1'
Please write your answer here:
Do you have any comments or suggestions about the survey?
Please write your answer here:

Thank you for taking the time to complete the survey! We truly value the information you have provided.

If you want to be informed about the results of the survey or can recommend any postdoc(s) from your group who should also participate in this survey, please send an email to Fabian Reith (freith@geomar.de).

Have a good day!

05.01.2019 - 12:45

Submit your survey.
Thank you for completing this survey.