

A Service of

ZBW

Leibniz-Informationszentrum Wirtschaft Leibniz Information Centre for Economics

Merk, Christine; Wagner, Gernot

## Working Paper Presenting Balanced Geoengineering Information Has Little Effect on Mitigation Engagement

CESifo Working Paper, No. 10104

**Provided in Cooperation with:** Ifo Institute – Leibniz Institute for Economic Research at the University of Munich

*Suggested Citation:* Merk, Christine; Wagner, Gernot (2022) : Presenting Balanced Geoengineering Information Has Little Effect on Mitigation Engagement, CESifo Working Paper, No. 10104, Center for Economic Studies and ifo Institute (CESifo), Munich

This Version is available at: https://hdl.handle.net/10419/267336

## Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

### Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



# WWW.ECONSTOR.EU



# Presenting Balanced Geoengineering Information Has Little Effect on Mitigation Engagement

Christine Merk, Gernot Wagner



## Impressum:

CESifo Working Papers ISSN 2364-1428 (electronic version) Publisher and distributor: Munich Society for the Promotion of Economic Research - CESifo GmbH The international platform of Ludwigs-Maximilians University's Center for Economic Studies and the ifo Institute Poschingerstr. 5, 81679 Munich, Germany Telephone +49 (0)89 2180-2740, Telefax +49 (0)89 2180-17845, email office@cesifo.de Editor: Clemens Fuest https://www.cesifo.org/en/wp An electronic version of the paper may be downloaded • from the SSRN website: www.SSRN.com

- from the RePEc website: <u>www.RePEc.org</u>
- from the CESifo website: <u>https://www.cesifo.org/en/wp</u>

## Presenting Balanced Geoengineering Information Has Little Effect on Mitigation Engagement

## Abstract

'Moral hazard' links geoengineering to mitigation via the fear that either solar geoengineering (solar radiation management, SRM) or carbon dioxide removal (CDR) might crowd out the desire to cut emissions. We test moral hazard versus its inverse in the first large-scale, revealed-preference experiments (n~340,000) and find that only extreme political messages lead to either outcome for some. Our results indicate the importance of actors and reasoned narratives of geoengineering to help guide public discourse.

JEL-Codes: Q540, Q580.

Keywords: climate change, geoengineering, moral hazard, revealed preference.

Christine Merk Global Commons and Climate Change Kiel Institute for the World Economy Kiel / Germany Christine.Merk@ifw-kiel.de Gernot Wagner\* Columbia Business School New York / NY / USA gwagner@columbia.edu

\*corresponding author

## Presenting balanced geoengineering information has little effect on mitigation

## engagement

Christine Merk & Gernot Wagner

Mere mention of either SRM or CDR might crowd out the desire to mitigate. This 'moral hazard' phenomenon is well-grounded theoretically.<sup>1-2</sup> Empirical evidence primarily relies on stated-preference surveys<sup>3,4</sup>, which can fall prey to acquiescence bias, among other issues.<sup>5</sup> The earliest controlled revealed-preference analysis (n~650) shows 'inverse' moral hazard or 'crowding in', hypothesized to be linked to fear of SRM<sup>6</sup>, a conclusion since supported by lab experiments.<sup>7</sup> That experiment uses carbon offsets as a proxy for the desire to mitigate.

We here analyse several framings with two large-scale, revealed-preference social media experiments, each with n~170,000. In the first experiment, we soon zero in on 'likely' environmentalists (n~59,000) due to their significantly higher rates of engagement. In the second, we solely focus on that subgroup (n~170,000). We proxy for the desire to mitigate by

'likes' and newsletter signups on the Facebook page of a major US environmental non-profit. The group is broadly perceived as standing for ambitious yet traditional climate policy. This allows us to widen the lens well beyond carbon offsets as a proxy for engagement with traditional climate policy. For us, 'mitigation', thus, stands for cutting greenhouse-gas emissions rather than the more expansive recent IPCC definition of including CDR as part of mitigation.<sup>8</sup>

The large samples allow us to test any number of frames and messages, from carefully presenting SRM or CDR as a 'sensible' part of a balanced climate policy portfolio to highly politicized 'madmen' and 'techno-fix' framings presenting it as anything but, while always comparing campaigns to baseline mitigation messages varying framings and images. We use both specifically designed explainer graphics for SRM, CDR, and mitigation, and carefully chosen and repeatedly tested images (see Figure 1 for a small sample, and Figure A-1 and Figure A-9 for a complete set of ads and messages). Engagement rates for users who have not shown prior interest in environmental topics are very low (1.1%) and do not vary across treatments (Figure A-6), hence us focusing on 'likely' environmentalists (2.44% engagement rate, Table A-1).

## Α

В

Can solar geoengineering help address climate change? Join us to promote sensible policy



Can clean technology help address climate change? Join us to promote sensible policy



Solar geoengineering a techno-fix to stabilize temperatures? Help us solve climate change



Solar geoengineering: Big Oil's latest excuse against climate action! Help us fight back



Figure 1—Sample of online ads in experiment 1 encouraging 'likes' for the Facebook page of a major US environmental non-profit. **A** frames solar geoengineering (SRM) as part of 'sensible' climate policy, with **B** presenting the same framing but for traditional mitigation options as control. **C** presents SRM as a 'techno-fix', and **D** as 'madmen' framing. (See Figures A-1 and A-9 for a complete set of ads and messages in all experiments.)

D

We find that presenting balanced geoengineering information (Figure 1A) calling for 'rational' or 'sensible' climate policy exhibits neither crowding in nor out compared to calling for 'rational' or 'sensible' mitigation policy, nor does presenting SRM or CDR as a 'technofix' (Figure 2).



## Α



Figure 2—Treatment effect by framing and political leaning of Facebook 'like' campaign testing 'rational' and 'sensible' (Figure 1A versus B, with 'sensible', in part, replaced by 'rational' in the description limited to 90 characters), 'technofix' (Figure 1C), and 'madmen' (Figure 1D) in a campaign with n~59,000 users who had shown an interest in environmental topics before. A shows percentage point differences (treatment – control) and 95% confidence intervals for probability tests. B shows the coefficients from logit regression with clustered standard errors controlling for age and gender and 95% confidence intervals, with n=16,318 for Conservatives, n=17,833 for Moderates, and n=24,840 for Liberals. \* indicates statistical significance at the 10%-level, \*\* at the 5%-level. (See Supplemental Information for detailed methods and results.)

Only extreme SRM framings presented in a highly polarized context evoke either crowding in or out, with large differences across the political spectrum. Adding SRM to a framing that presents Republicans' climate policy as 'madmen' and calling SRM "Big Oil's latest excuse against climate action" (Figure 1**D**), for example, increases conservatives' 'likes' compared to the baseline message that shows the same image but drops "solar geoengineering" from the text and instead calls out "Big Oil" more directly as "still making excuses against climate action!" (+0.61 percentage points, n = 4,325). It also decreases liberals' support (-0.74 percentage points, n = 6,705). One reason for this divergence might be that liberal environmentalists are more motivated by the baseline message (3.21% engagement rate; Table A-3, Figure 2 B), while conservatives are pushed away (2.30%); mentioning "solar geoengineering" in the 'madmen' framing does not influence liberals' or conservatives' level of engagement significantly compared to the 'rational' mitigation messaging. Thus, the difference is driven by the reactions to the baseline not the SRM treatment. This is hard to test conclusively. What we can say is that extreme climate mitigation messaging begets extreme responses.<sup>9</sup>

Conversely, 'reasoned' messaging even on SRM, presenting technologies as 'rational' or 'sensible' in broad-based 'like' campaigns, appears to have little effect on engagement with and support for traditional environmental policy (Figure 2). Talking about solar geoengineering does not motivate our study population to support a large US environmental non-profit; it also does not turn them off relative to the baseline.

## A [Newsletter sign-ups]





B ['like' campaign]



Probing further, we do find effects in both 'like' and newsletter signup campaigns that present either CDR or SRM explicitly as complements to ('crowding in') or substitutes for ('crowding out') traditional mitigation policies (Figures 3 and 4). Zeroing in on newsletter signups (n~91,000), liberals by and large are turned off by both CDR and SRM, regardless of whether either is presented as a substitute or complement (Figures 3A and 4A). It is tempting to interpret this finding as telling us something of significance about CDR or SRM. However, this finding might simply be an indication that 'traditional' environmental messaging campaigns around emissions reduction work as intended. This large US environmental non-profit is good at its job of motivating likely environmentalists to sign up for its newsletters, whereas our messaging around CDR and SRM failed to motivate especially liberals.





## **B** ['like' campaign]



Figure 4 – Coefficient plots and 95% confidence intervals by political leaning for the newsletter campaign [A] and the like-campaign [B] testing the materials and messages in experiment 2 and 3 (see Figure A-9 and A-10), coefficients not shown: female, age, campaign round (only for newsletter), full results see Table A-6)

The broad results also hold for various segments of the total population, for example focusing campaigns on so-called 'super-activists' who show the highest engagement for regular campaigns of the non-profit (Figure A-3), nor, perhaps surprisingly, does it alter our results when we focus on those most inclined to harbour conspiratorial ideas around SRM<sup>10</sup> or otherwise focus on subgroups of the total population (Figures A-4, A-5, Table A-2).

Our results stand in contrast to a relatively large stated-preference survey literature on the topic, which with rare exceptions<sup>4,7</sup>, typically finds weak support for crowding-out.<sup>3</sup> The one prior revealed-preference survey on SRM finds crowding-in.<sup>6</sup> In the end, our study population is

more swayed by external factors than the characteristics of SRM or CDR. They are not alone. Even experts exhibit biases: The worse climate damages are, the less inclined they are to support SRM; that conclusion changes as they expect worse climate damages in their home country.<sup>11</sup> Arguably, none of these findings, including ours, present a good guide for whether crowding in or out will occur. If anything, such effects might well depend more on policymakers' perceptions<sup>12</sup> as well as on vested and institutional interests.<sup>13</sup>

**Acknowledgments** We thank David Lazer and Dustin Tingley for early discussions and feedback, and Karen Pittel and the Ifo Institute for Economic Research in Munich for hosting us during the writing phase of this project.

**Competing financial interest**. The research was supported by the German Research Foundation Priority Program 1689 Climate Engineering, and by Harvard's Solar Geoengineering Research Program, which G.W. co-directed. Supplemental Information: Presenting balanced geoengineering information has little effect

## on mitigation engagement

Christine Merk<sup>1</sup> & Gernot Wagner<sup>2,\*</sup>

<sup>1</sup> Kiel Institute for the World Economy, Kiel, Germany

<sup>2</sup> Columbia Business School, New York, NY, USA

\* Corresponding author: <u>gwagner@columbia.edu</u>

## Methods

We used Facebook's advertising platform, testing reactions from Facebook users to various treatments presented as ads from a major US environmental non-profit. The main outcome variable was either 'likes' or newsletter sign-ups for the group's page. Our target audience was various subgroups of the U.S. population, utilizing Facebook's ad targeting mechanism to identify interest groups. We ran three different experiments.

## Experiment 1

Experiment 1 was a 'like'-campaign testing the differences in engagement, i.e. likes per impression, in four framings comparing mitigation and solar geoengineering. The campaign ran between June 26, 2018 and June 29, 2018. Figure A-1 summarizes the experimental setup. Each subject sees no more than one control or treatment variation on their Facebook timeline. The ads are a combination of a graphic (Figure A-1 [A] and a message (Figure A-1 [B]). Each ad is marked as "sponsored", indicating that they were paid for by the environmental NGO, respectively by us (Figure A-2).

## [A] graphics



Climate change mitigation (Note that our use of the term 'mitigation' focuses on reducing greenhouse-gas emissions, rather than encompassing a broader definition that might also include some carbon dioxide removal.<sup>8</sup>)



Solar geoengineering

Climate change is "an engineering problem, and it has engineering solutions."

 Rex Tillerson (in his capacity as CEO of Excention)



Madmen

## [B] messaging [graphics]

Control	Treatment
Rational cl	imate policy
Can clean technology help address climate	Can solar geoengineering help address climate
change? Join us to promote rational policy	change? Join us to promote rational policy
[Climate change mitigation]	[Solar geoengineering]
Sensible cl	imate policy
Can clean technology help address climate	Can solar geoengineering help address climate
change? Join us to promote sensible policy	change? Join us to promote sensible policy
[Climate change mitigation]	[Solar geoengineering]
Tecl	nnofix
Smart technology a fix to stabilize temperatures?	Solar geoengineering a techno-fix to stabilize
Help us solve climate change	temperatures? Help us solve climate change
[Climate change mitigation]	[Solar geoengineering]
Ma	dmen
Big Oil is still making excuses against climate	Solar geoengineering: Big Oil's latest excuse against
action! Help us fight back	climate action! Help us fight back
[Madmen]	[Madmen]

Figure A-1: Experiment 1 - Like campaign, graphics [A] and messaging [B]



Figure A-2: Example post, experiment 1; name and logo of environmental non-profit blanked out

We ran experiment 1 with four different targets groups (Table A-1). Group 1, the *NGO* optimization, is a target group often used by the NGO as these are users with profiles similar to the NGO's super activists, they should thus be very likely to engage with the NGO's content. These users have shown an interest in environmental issues, donated to environmental and wildlife causes and engaged with liberal political content in the past. They are most closely resembling highly active supporters of the environmental NGO. This is a setup which would be used under realistic conditions for a like-campaign. We necessarily excluded those who had already 'liked' the NGO's page.

In group 2, *Facebook optimization*, we let the platform optimize the distribution of the ads without restricting age, gender, or prior interests. We test how the FB-algorithm would distribute the treatments across gender and age groups without additional targeting.

In group 3, *Chemtrailers*, we target users who have shown an interest in geoengineering, climate engineering or the conspiracy theory chemtrails before. This group is explicitly excluded in the three other target groups to keep Facebook from delivering the solar geoengineering treatments dominantly to these users.

In group 4, *limited optimization,* we set up 48 audience groups to restrict the influence of Facebook's algorithm on the distribution of the treatments and to learn about the engagement with the ads among groups that are more difficult to reach because they have not shown any interest in similar content in the past or because they are in general less likely to engage with Facebook-content. The 48 groups are defined by gender, 4 age groups (18-24, 25-44, 45-64, and 65+), interest in environmental causes (yes, no), and 3 political leanings (conservative, moderate, and liberal).

13

					Limited optimization			
		NGO	Facebook		NON-environ-	environ-		
		optimization	optimization	Chemtrailers	mentalists	mentalists	Total	
Rational	treatment	2.43%	2.67%	1.21%	1.00%	2.46%	1.61%	
		1,849	1,645	413	9,398	6,708	16,106	
	control	3.32%	2.14%	0.54%	1.17%	2.59%	1.76%	
		1,986	2,102	368	9,119	6,492	15,611	
Sensible	treatment	2.71%	2.91%	0.73%	1.00%	2.20%	1.51%	
		1,885	1,751	414	10,042	7,422	17,464	
	control	2.95%	2.55%	1.44%	1.09%	2.37%	1.68%	
		1,900	2,194	278	9,456	8,093	17,549	
Technofix	treatment	2.29%	2.36%	2.17%	1.00%	2.26%	1.53%	
		1,879	1,778	415	9,458	6,721	16,179	
	control	2.62%	2.62%	0.92%	1.11%	2.33%	1.61%	
		1,948	2,064	543	10,453	7,282	17,735	
Madmen	treatment	2.90%	3.18%	2.83%	1.15%	2.53%	1.77%	
		2,140	1,981	495	9,475	7,712	17,187	
	control	3.28%	3.22%	1.73%	1.31%	2.71%	1.96%	
		2,560	2,391	404	9,832	8,561	18,393	
Total		2.84%	2.72%	1.47%	1.10%	2.44%	1.68%	
		16,147	15,906	3,330	77,233	58,991	136,224	

## Table A-1: Engagement rates in % and impressions by treatment groups and target groups

Overall, the ads appeared on the timeline of 171,607 users and generated 3,229 likes for the NGO's page. This is an overall engagement rate of 1.88%. Engagement varies between 1% (limited optimization, non-environmentalists, `rational', treatment) and 3.28% (NGO optimization, `madmen', control). It is especially low in the subgroup of non-environmentalists in the limited optimization setup, i.e. those who have never shown any interest in environmental topics or causes on Facebook before. Engagement is significantly higher in the groups with the NGO and the Facebook (FB) optimized targeting compared to the Chemtrailers and Limited optimization target groups (pairwise probability test: p<0.000, Figure A-3). Contrary to our expectation, engagement rates among the Chemtrailers and those who have shown a

prior interest in geoengineering are low (1.47%) and only somewhat higher in the `madmen' treatment (2.83%) with the pugnacious message "Solar geoengineering: Big Oil's latest excuse against climate action! Help us fight back".



Figure A-3: Engagement rate by target group with error bars. Results from probability test: NGO = FB optimization, p=0.512; NGO = Chemtrailers, p<0.000; NGO = limited targeting, p<0.000; FB optimization = Chemtrailers, p<0.000; FB optimization = Limited optimization, p<0.000; Chemtrailers = Limited optimization, p=0.352; Group in NGO optimization is also called `super-activists'

We do not find significant differences between the treatment and the control settings in any of the audience groups (Figure A-4 and Figure A-5). Also, engagement rates do not vary significantly between treatments in the groups. The exception is among the `Chemtrailers', where we see a significant difference between the `sensible' framing that implies that solar geoengineering could play a part in sensible climate policy and the `madmen' treatment that calls for engagement against solar geoengineering (Figure A-5; p = 0.034).



Figure A-4: Coefficients from logit regression likes (experiment 1) with 95%-confidence intervals for treatment and control groups by audience groups; treatment/control group-coefficients are relative to the base category `rational'

Note: Models include robust standard errors. For the `limited optimization' group standard errors are clustered by subgroups. The plots are based on the same logit regressions as the first column in Figure A-5 (`rational', see also Table A-2), however, here the sub-graphs use the same scale on the x-axis (different from Figure A-5). Chemtrailers N=3,330; FB optimization N=15,906; NGO optimization N=16,147; Limited optimization: N=136,224. 65+ is reference category in the Chemtrailers group when 18-24 group empty. Results see also Table A-2.



Figure A-5: Coefficients from logit regression likes (experiment 1) with 95%-confidence intervals for treatment and control groups by audience groups (rows) with different treatments as base categories (columns)

Note: Models include gender and age as control variables (not shown here) and use robust standard errors. For the `Limited optimization' group standard errors are clustered by subgroups. Chemtrailers N=3,330; FB optimization N=15,906; NGO optimization N=16,147; Limited optimization: N=136,224. Subgraphs use individual x-axes because some of the confidence intervals have broad ranges and differences in other subgraphs with smaller ranges would not be legible anymore.

	NGO o	GO optimization Facebook optimization Chemtrailers		ilers		Limited	optir	nization								
	Treatmen	t	Control		Treatme	ent	Control		Treatme	ent	Control		Treatment		Control	
Framing, bas	selevel: rati	ional														
sensible	0.103		-0.164		0.087		0.154		-0.447		1.034		-0.065		-0.039	
	(0.207)		(0.186)		(0.209)		(0.203)		(0.739)		(0.881)		(0.115)		(0.111)	
technofix	-0.062		-0.271		-0.117		0.155		0.609		0.662		-0.051		-0.087	
	(0.215)		(0.189)		(0.219)		(0.205)		(0.572)		(0.867)		(0.118)		(0.111)	
madmen	0.199		-0.070		0.185		0.300		0.920	*	1.095		0.080		0.075	
	(0.200)		(0.169)		(0.203)		(0.192)		(0.531)		(0.823)		(0.115)		(0.108)	
Female	0.265	*	0.247	*	0.152		0.238		0.460		0.452		0.085		0.201	**
	(0.156)		(0.148)		(0.147)		(0.145)		(0.371)		(0.475)		(0.080)		(0.079)	
Age, baselev	el: 18-24															
25-44	-0.037		-0.916		-0.146		-0.030		-0.700		-1.194	*	0.361	***	0.275	**
	(0.270)		(0.790)		(0.317)		(0.355)		(0.505)		(0.613)		(0.112)		(0.120)	
45-64	-0.270	*	-0.100		-0.207		0.435		-0.371		-0.643		0.653	***	0.685	***
	(0.156)		(0.727)		(0.309)		(0.339)		(0.481)		(0.583)		(0.114)		(0.118)	
65+	0.000		0.275		-0.098		0.560	*	0.000		0.000		0.895	***	0.893	***
	(.)		(0.722)		(0.306)		(0.337)		(.)		(.)		(0.114)		(0.119)	
Constant	-3.774	***	-3.596	***	-3.547	***	-4.274	***	-4.161	***	-4.667	***	-4.593	***	-4.534	***
	(0.197)		(0.721)		(0.325)		(0.362)		(0.630)		(0.783)		(0.119)		(0.110)	
N	7702		8394		7155		8751		1628		1458		66936		69288	
Pseudo R <sup>2</sup>	0.004		0.012		0.002		0.010		0.035		0.041		0.011		0.013	
df	6		7		7.000		7		6		6		7		7	
Log						_				_						
likelihood	-927.089		-1135.48	31	-910.469	ł	-1060.119		-148.080	J	-93.010		-5439.14	41	-6045.75	o/

Table A-2: Logit regression on likes (experiment 1) for treatment and control groups; Reported are logitcoefficients and standard errors in parentheses. \* p<0.1, \*\* p<0.05, \*\*\* p<0.01

Note: Models include robust standard errors. For the `limited optimization' group standard errors are clustered by subgroups. Results see also Figure A-4 and A5. 65+ is reference category in the Chemtrailers group when 18-24 group empty.

The `limited optimization' setup allows us to observe political leanings and interest in environmental causes in addition to gender and age. Engagement rates among users that are not interested in environmental topics are comparatively low and do not vary substantially or significantly between treatments (Table A-1 and Figure A-6). We, therefore, focus on users in the 'limited optimization' target groups that are interested in environmental topics.



Figure A-6: Coefficients from logit regression on likes (experiment 1) with 95%-confidence intervals for treatment and control groups by non-enviros, i.e. users who have not shown an interest in environmental topics on Facebook before, and enviros, i.e. users who have shown an interest in environmental topics on Facebook before in the `Limited optimization' group.

Note: Models include gender and age as control variables (not shown here) and use standard errors clustered by subgroups. The plots for enviros are shown for comparison and are the same as in Figure 2B. Non-enviros: Liberals n=30,347; Moderates n=24,708; Conservatives n=22,178. Enviros: Liberals n=24,840; Moderates n=17,833; Conservatives n=16,318.

Table A-3 shows the engagement rates by treatment and political leaning and the differences

between treatment and control in percentage points for the environmentalists that are

displayed in Figure 2, Panel A. Figure A-7 displays the logit coefficients comparing treatment and

control by political leanings; the differences displayed in Figure 2, Panel B are based on these

regressions.

		Liberals		Ν	1oderates	5	Conservatives			
	Т	С	T - C	Т	С	T - C	Т	С	T - C	
Rational	2.18%	2.08%	0.1	3.21%	3.29%	0.08	2.15%	2.70%	-0.54	
Sensible	1.98%	2.29%	-0.31	2.79%	2.72%	-0.07	1.89%	2.11%	-0.22	
Technofix	1.88%	1.99%	-0.11	2.63%	2.91%	0.29	2.42%	2.22%	0.20	
Madmen	2.29%	3.03%	-0.74	2.97%	3.21%	0.24	2.30%	1.70%	0.61	

Table A-3: Engagement rates treatment group, control group, and treatment (T) – control (C) (see also Figure 2, Panel A) by political leaning only users interested in environmental topics for `Limited optimization'.



Figure A-7: Coefficients from logit regression on likes (experiment 1) with 95%-confidence intervals for treatment and control groups for the `limited optimization' target group by political leaning; <u>only users</u> <u>who are interested in environmental topics</u> treatment/control-coefficients are relative to the base category `rational'

Models include clustered standard errors by subgroups. The plots are based on the same logit regressions as in Figure A-6, however, here sub-graphs use the same scale on the x-axis (different from Figure A-8). Results see also Table A-4. Conservatives n=16,318; Moderates n=17,833; Liberals n=24,840.



Figure A-8: Coefficients from logit regression on likes (experiment 1) with 95%-confidence intervals for treatment and control groups for the equal distribution setting by political leaning; <u>only users who are interested in environmental topics, Like campaign</u>

Note: Models include gender and age as control variables (shown in Figure A-7 and Table A-4) use standard errors clustered by subgroups. Sub-graphs use individual x-axes because some of the confidence intervals have broad ranges and differences in other subgraphs with smaller ranges would not be discernible anymore (different from Figure A-7). Conservatives n=16,318; Moderates n=17,833; Liberals n=24,840.

	Libera	ls	Mo	derates		Conservat	tives
	Treatment	Control	Treatment	Co	ontrol	Treatment	Control
Framing, bas	selevel: rational						
sensible	-0.085	0.136 *	-0.109		-0.176	-0.111	-0.241
	(0.116)	(0.082)	(0.170)	(0	0.145)	(0.149)	(0.176)
technofix	-0.141	0.008	-0.160		-0.099	0.088	-0.285 *
	(0.099)	(0.129)	(0.166)	(0	0.110)	(0.156)	(0.164)
madmen	0.045	0.368 ***	-0.076		-0.081	-0.005	-0.527 ***
	(0.112)	(0.113)	(0.158)	(0	0.112)	(0.170)	(0.134)
Female	0.027	0.152 *	0.346	***	0.366 ***	-0.004	0.126
	(0.083)	(0.089)	(0.105)	(0	0.090)	(0.118)	(0.112)
Age, baselev	el: 18-24						
25-44	0.237 ***	0.239 *	0.281	**	0.023	0.470 ***	0.444 **
	(0.083)	(0.131)	(0.121)	(0	D.118)	(0.130)	(0.192)
45-64	0.427 ***	0.507 ***	0.350	**	0.346 ***	1.029 ***	0.896 ***
	(0.129)	(0.143)	(0.146)	(0	D.131)	(0.177)	(0.195)
65+	0.832 ***	0.812 ***	0.435	***	0.386 ***	1.302 ***	1.332 ***
	(0.105)	(0.136)	(0.154)	(0	0.125)	(0.167)	(0.155)
Constant	-4.182 ***	-4.300 ***	-3.841	***	-3.734 ***	-4.438 ***	-4.235 ***
	(0.104)	(0.124)	(0.191)	(0	0.138)	(0.141)	(0.188)
N	11785	13055	8728		9105	8050	8268
Pseudo R <sup>2</sup>	0.010	0.013	0.006		0.007	0.026	0.027
df	7	7	7		7	7	7
Log likelihood	-1183.194	-1446.701	-1138.537	-1	225.172	-824.563	-832.441

Table A- 1: Logit regression on likes (experiment 1) for treatment and control groups in the `limited optimization' target group by political leaning; <u>only users who are interested in environmental topics</u>. Reported are logit coefficients and standard errors in parentheses. Models include clustered standard errors by subgroups. \* p<0.1, \*\* p<0.05, \*\*\* p<0.01

## Experiment 2 and 3

Experiment 2 was a 'newsletter'-campaign testing the differences in engagement, i.e. newsletter sign-ups per impression. We compare engagement rates for 2 CDR campaigns and 2 SRM campaigns to a baseline mitigation campaign. We frame the technology either as a complement to reducing emissions or as a substitute for reducing emissions. Figure A-9 and Figure A-10 show the experimental setup, the graphics and the messaging. Signing up for a newsletter shows a higher level of engagement and interest than liking a post, as it takes more time to submit the email address and it means that you will receive regular emails. Therefore, we also test the same framings as a 'like'-campaign in experiment 3. The newsletter campaign ran in two waves, first between March 29, 2019 and April 14, 2019 and again between June 23, 2019 and July 15, 2019. The like-campaign was active between May 26, 2019 and June 8, 2019. Facebook initially restricted the visible text in 'like' campaigns to 90 characters (experiment 1). Experiment 2 and 3 tested longer, more nuanced messages including presenting SRM and CDR explicitly as complements or substitutes for reducing greenhouse-gas emissions.

## [A Graphics]





## Mitigation

Carbon dioxide removal



Solar geoengineering

### [B messaging]

#### Newsletter sign-up

### Like campaign

#### Mitigation

Climate change mitigation is all about addressing the root cause: greenhouse-gas emissions. We need to focus on cutting them. **Sign up to help** *[ENGO name]'s* work on reducing emissions. Climate change mitigation is all about addressing the root cause: greenhouse-gas emissions. We need to focus on cutting them. Like [ENGO name] to help our work on reducing emissions.

## CDR complement

Carbon dioxide removal takes carbon out of the atmosphere and stores it in the ocean or ground. It limits climate changes without addressing the root cause: greenhouse-gas emissions. We need to focus on cutting them. Don't be distracted by carbon dioxide removal. **Sign up to help** *[ENGO name]'s* work on reducing emissions.

Carbon dioxide removal takes carbon out of the atmosphere and stores it in the ocean or ground. It limits climate changes without addressing the root cause: greenhouse-gas emissions. We need to focus on cutting them. Don't be distracted by carbon dioxide removal. Like [ENGO name] to help our work on reducing emissions.

#### CDR substitute

Carbon dioxide removal takes carbon out of the atmosphere and stores it in the ocean or ground. It helps limit climate changes without needing to cut greenhouse-gas emissions. We need to focus on looking into these methods. **Sign up to help** *[ENGO name]'s* work exploring carbon dioxide removal.

Carbon dioxide removal takes carbon out of the atmosphere and stores it in the ocean or ground. It helps limit climate changes without needing to cut greenhouse-gas emissions. We need to focus on looking into these methods. Like [ENGO name] to help our work exploring carbon dioxide removal.

## SRM complement

Solar geoengineering could partially block sunlight and lower global temperatures. It limits climate changes without addressing the root cause: greenhouse-gas emissions. We need to focus on cutting them. Don't be distracted by solar geoengineering. **Sign up to help** [ENGO name]'s work on reducing emissions. Solar geoengineering could partially block sunlight and lower global temperatures. It limits climate changes without addressing the root cause: greenhouse-gas emissions. We need to focus on cutting them. Don't be distracted by solar geoengineering. Like [ENGO name] to help our work on reducing emissions.

### SRM substitute

Solar geoengineering could partially block sunlight and lower global temperatures. It helps limit climate changes without needing to cut greenhouse-gas emissions. We need to focus on looking into these methods. **Sign up to help** *[ENGO name]'s* work on exploring solar geoengineering. Solar geoengineering could partially block sunlight and lower global temperatures. It helps limit climate changes without needing to cut greenhouse-gas emissions. We need to focus on looking into these methods. Like [ENGO name] to help our work on exploring solar geoengineering.

Figure A-9: Experiment 2 and 3 – Newsletter sign-up and Like campaign, graphics [A] and messaging [B]



Figure A-10: Example post, experiment 2 newsletter sign up; name and logo of environmental non-profit blanked out

The target group for the newsletter- and the like-campaign are Facebook users who have shown an interest in environmental topics before excluding users who have shown an interest in chemtrails, geoengineering or climate engineering before. The political leanings, liberal, moderate and conservative are targeted separately to avoid that Facebook's algorithm only shows the ads to more liberal users who have a higher likelihood to engage with the content and the NGO.

The newsletter campaign appeared on the timeline of 90,955 users, the like campaign on 81,915 timelines. The average engagement rate was 0.96% and 2.64%, respectively. As expected, the

engagement rates are substantially lower in the newsletter campaign than in the like campaign

(Table A-5).

	Lil	berals	Mo	derates	Conservatives		
		T- C		T- C	T- C		
Newsletter	n=38,	.369	n=27,4	455	n=25,1	131	
Mitigation [C]	2.06%		1.34%		0.75%		
CDR complement [T]	1.32%	-0.74 ***	0.57%	-0.77 ***	0.53%	-0.22	
CDR substitute [T]	1.17%	-0.89 ***	0.64%	-0.70 ***	0.53%	-0.22	
SRM complement [T]	0.89%	-1.17 ***	0.86%	-0.48 **	0.51%	-0.24	
SRM substitute [T]	1.25%	-0.81 ***	0.90%	-0.44 *	0.65%	-0.10	
Like	n=38,	854	n=24,2	793	n=18,268		
Mitigation [C]	2.70%		2.55%		3.32%		
CDR complement [T]	2.60%	-0.09	2.76%	0.22	2.69%	-0.64 *	
CDR substitute [T]	2.13%	-0.57 **	2.22%	-0.33	2.43%	-0.90 **	
SRM complement [T]	3.07%	0.38	3.56%	1.01 **	2.86%	-0.46	
SRM substitute [T]	2.74%	0.04	2.40%	-0.15	2.80%	-0.53	

Table A-5: Engagement rates in % by treatment groups and political leaning and difference between treatment groups [T] and control group [C] in percentage points; see also Figure 3.

			Newslette	er			Like					
	Liberals	5	Modera	tes	Conservat	tives	Liberals	6	Modera	tes	Conserva	tives
Treatment, baseline: Mi	tigation											
CDR Complement	-0.295	**	-0.660	***	-0.251		-0.036		0.097		-0.183	
	(0.132)		(0.231)		(0.269)		(0.099)		(0.127)		(0.147)	
CDR Substitute	-0.410	***	-0.425	**	-0.267		-0.251	**	-0.114		-0.268	*
	(0.136)		(0.205)		(0.252)		(0.102)		(0.127)		(0.146)	
SRM Complement	-0.798	***	-0.355	*	-0.361		0.113		0.334	**	-0.115	
	(0.153)		(0.212)		(0.282)		(0.104)		(0.134)		(0.154)	
SRM Substitute	-0.430	***	-0.256		-0.098		-0.001		-0.057		-0.072	
	(0.142)		(0.206)		(0.259)		(0.104)		(0.136)		(0.148)	
Female	0.091		0.246		0.568	***	0.106		-0.214	***	0.163	
	(0.094)		(0.155)		(0.187)		(0.065)		(0.081)		(0.095)	
Age, baseline: 18-24												
25-34	-0.266		0.736	*	-0.013		0.206	*	-0.091		-0.076	
	(0.325)		(0.431)		(0.629)		(0.114)		(0.129)		(0.209)	
35-44	-0.260		0.180		0.255		0.193		0.059		-0.245	
	(0.318)		(0.477)		(0.579)		(0.123)		(0.140)		(0.220)	
45-54	-0.162		1.039	**	-0.201		0.159		-0.022		-0.141	
	(0.297)		(0.418)		(0.562)		(0.137)		(0.166)		(0.218)	
55-64	0.232		1.246	***	0.037		0.484	***	0.279	*	0.428	**
	(0.269)		(0.404)		(0.529)		(0.130)		(0.165)		(0.201)	
65+	0.488	*	1.402	***	0.515		0.550	***	0.851	***	0.548	***
	(0.262)		(0.402)		(0.520)		(0.130)		(0.154)		(0.199)	
June/July 2019	0.226	**	0.091		0.386	**						
	(0.091)		(0.136)		(0.171)							
Constant	-4.362	***	-5.706	***	-5.734	***	-3.888	***	-3.624	***	-3.657	***
	(0.283)		(0.425)		(0.556)		(0.122)		(0.145)		(0.206)	
n	38369		27455		25131		38854		24793		18268	
Pseudo R <sup>2</sup>	0.015		0.023		0.018		0.005		0.012		0.014	
df	11.000		11.000		11.000		10.000		10.000		10.000	
Log likelihood	-2631.45		-1260.65		-886.37		-4667.31		-296	9.89	-227	8.74

Table A-6: Results from logit regression, coefficients and standard errors in parentheses for Newsletter (experiment 2) and Like campaign (experiment 3) for Conservatives, Moderates, and Liberals \* p<0.1, \*\* p<0.05, \*\*\* p<0.01; see also coefficient plots in Figure 4.

	Li	berals	Mod	erates		Conse	Conservatives			
	comp - subst	SE	р	comp - subst	SE	р	comp - subst	SE	р	
Newsletter										
CDR	0.115	0.136	0.397	-0.235	0.228	0.303	0.016	0.254	0.951	
SRM	-0.367 **	0.164	0.025	-0.099	0.216	0.648	-0.263	0.280	0.347	
Like										
CDR	0.215 **	0.098	0.028	0.210 *	0.117	0.071	0.085	0.137	0.536	
SRM	0.114	0.104	0.270	0.391 **	0.133	0.003	-0.043	0.146	0.768	

Table A-7: Hypotheses tests of difference between the logit coefficients CDR complement [compl] – CDR substitute [subst] = 0 and SRM complement [compl] – SRM substitute [subst] = 0 from regression in Table A-6, standard errors and p-values; \* p<0.1, \*\* p<0.05, \*\*\* p<0.01; See also Figure 4

In the newsletter campaign, engagement is either not significantly different compared to traditional mitigation messaging – for conservatives in all framings and for moderates in the SRM framings - or it is lower – for liberals in all framings (Figure 4, Panel A). Presenting CDR and SRM as complements or substitutes to mitigation makes a difference only for liberals (0.36 percentage points see Table A-6; test for difference between coefficients p=0.025, Table A-7). The newsletter sign-up in the second campaign round in June/July 2019 was significantly higher for liberals and conservatives compared to the probability to sign up during the first newsletter campaign in March/April 2019 (Table A-6). In the like campaign, the results are more mixed. The complement framing shows significantly higher engagement rates compared to the substitute framing for Liberals/CDR (p=0.028), Moderates/CDR (p=0.071) and Moderates/SRM (p=0.003, TableA-7).

<sup>&</sup>lt;sup>1</sup> Wagner, Gernot, and Daniel Zizzamia. "Green moral hazards." *Ethics, Policy & Environment* (2021): 1-17.

<sup>&</sup>lt;sup>2</sup> Lawrence, Mark G., and Paul J. Crutzen. "Was breaking the taboo on research on climate engineering via

albedo modification a moral hazard, or a moral imperative?." Earth's Future 5, no. 2 (2017): 136-143.

<sup>&</sup>lt;sup>3</sup> Burns, Elizabeth T., Jane A. Flegal, David W. Keith, Aseem Mahajan, Dustin Tingley, and Gernot Wagner. "What do people think when they think about solar geoengineering? A review of empirical social science literature, and prospects for

<sup>&</sup>lt;sup>4</sup> Cherry, Todd L., Steffen Kallbekken, Stephan Kroll, and David M. McEvoy. "Does solar geoengineering crowd out climate change mitigation efforts? Evidence from a stated preference referendum on a carbon tax." *Climatic Change* 165, no. 1 (2021): 1-8.

<sup>5</sup> Mahajan, Aseem, Dustin Tingley, and Gernot Wagner. "Fast, cheap, and imperfect? US public opinion about solar geoengineering." *Environmental Politics* 28, no. 3 (2019): 523-543.

<sup>7</sup> Cherry, Todd L., Stephan Kroll, David M. McEvoy, David Campoverde, and Juan Moreno-Cruz. "Climate cooperation in the shadow of solar geoengineering: an experimental investigation of the moral hazard conjecture." *Environmental Politics* (2022): 1-9.

<sup>8</sup> IPCC (2022). Summary for Policymakers. In P. R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum,... J. Malley (Eds.), *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK, New York, NY, USA: Cambridge University Press. doi: 10.1017/9781009157926.001

<sup>9</sup> Barberá, Pablo. "Social media, echo chambers, and political polarization." *Social media and democracy: The state of the field, prospects for reform* 34 (2020).

<sup>10</sup> Tingley, Dustin, and Gernot Wagner. "Solar geoengineering and the chemtrails conspiracy on social media." *Palgrave Communications* 3, no. 1 (2017): 1-7.

<sup>11</sup> Dannenberg, Astrid, and Sonja Zitzelsberger. "Climate experts' views on geoengineering depend on their beliefs about climate change impacts." *Nature climate change* 9, no. 10 (2019): 769-775.

<sup>12</sup> Andrews, Talbot M., Andrew W. Delton, and Reuben Kline. "Anticipating moral hazard undermines climate mitigation in an experimental geoengineering game." *Ecological Economics* 196 (2022): 107421.

<sup>13</sup> Buck, Holly Jean. After geoengineering: Climate tragedy, repair, and restoration. Verso Books, 2019.

<sup>&</sup>lt;sup>6</sup> Merk, Christine, Gert Pönitzsch, and Katrin Rehdanz. "Knowledge about aerosol injection does not reduce individual mitigation efforts." *Environmental Research Letters* 11, no. 5 (2016): 054009.