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Presenting Balanced Geoengineering Information Has Little Effect on Mitigation Engagement

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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.

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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.¹⁻² Empirical evidence primarily relies on stated-preference surveys^{3,4}, which can fall prey to acquiescence bias, among other issues.⁵ The earliest controlled revealed-preference analysis (n~650) shows ‘inverse’ moral hazard or ‘crowding in’, hypothesized to be linked to fear of SRM⁶, a conclusion since supported by lab experiments.⁷ That experiment uses carbon offsets as a proxy for the desire to mitigate.

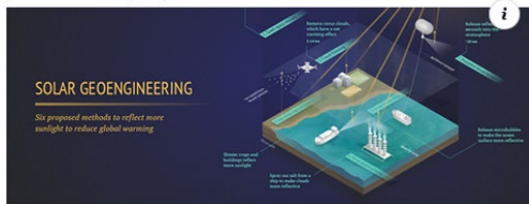
We here analyse several framings with two large-scale, revealed-preference social media experiments, each with n~170,000. In the first experiment, we soon zero in on ‘likely’ environmentalists (n~59,000) due to their significantly higher rates of engagement. In the second, we solely focus on that subgroup (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.⁸

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).

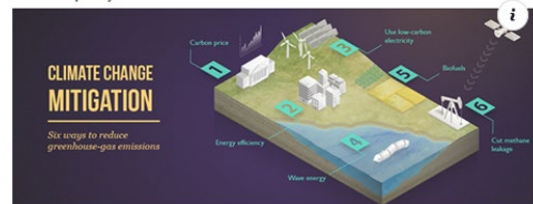
A

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



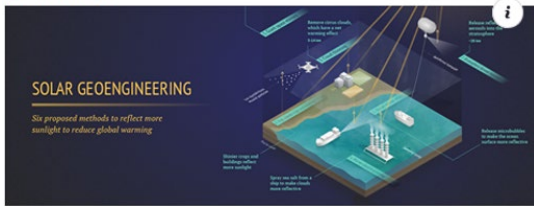
B

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



C

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



D

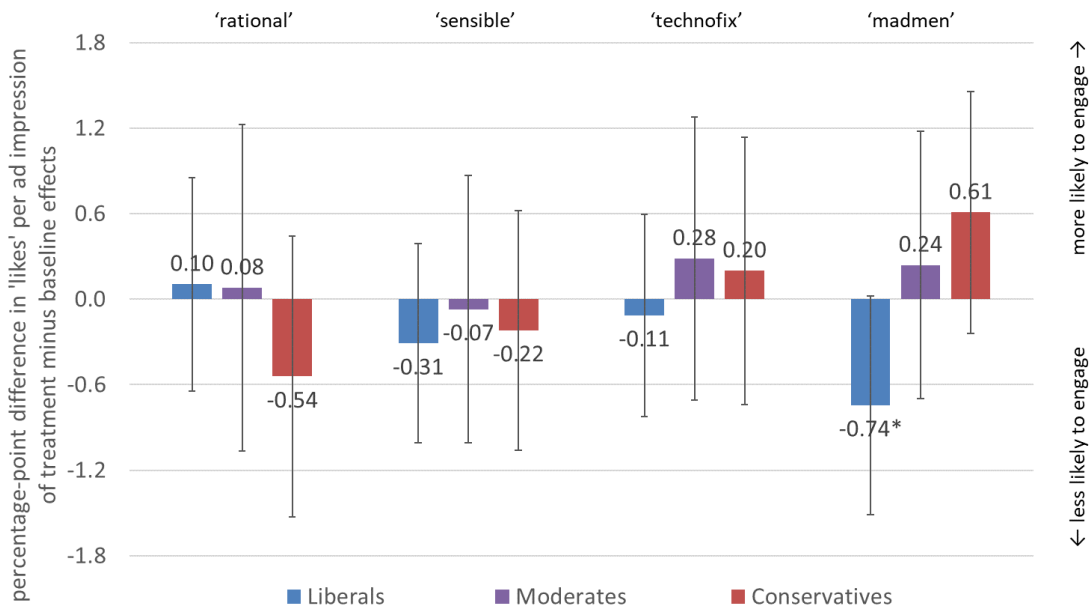
Solar geoengineering: Big Oil's latest excuse against climate action! Help us fight back



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.)

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).

A



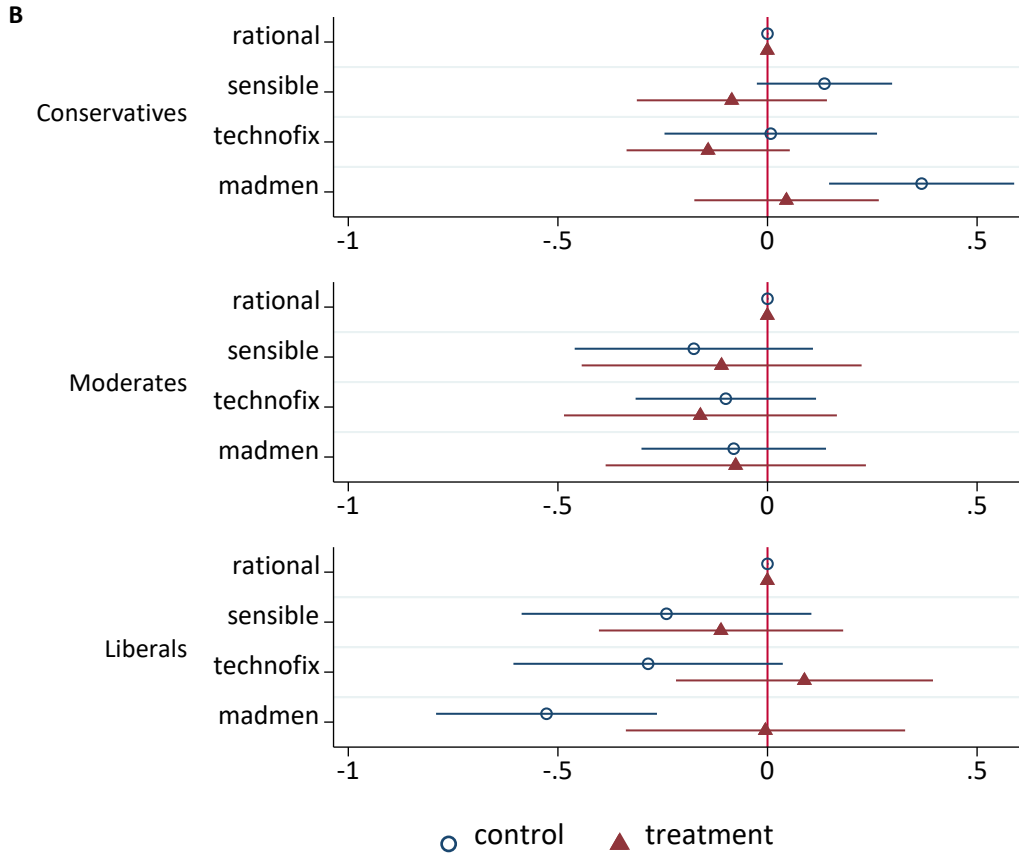


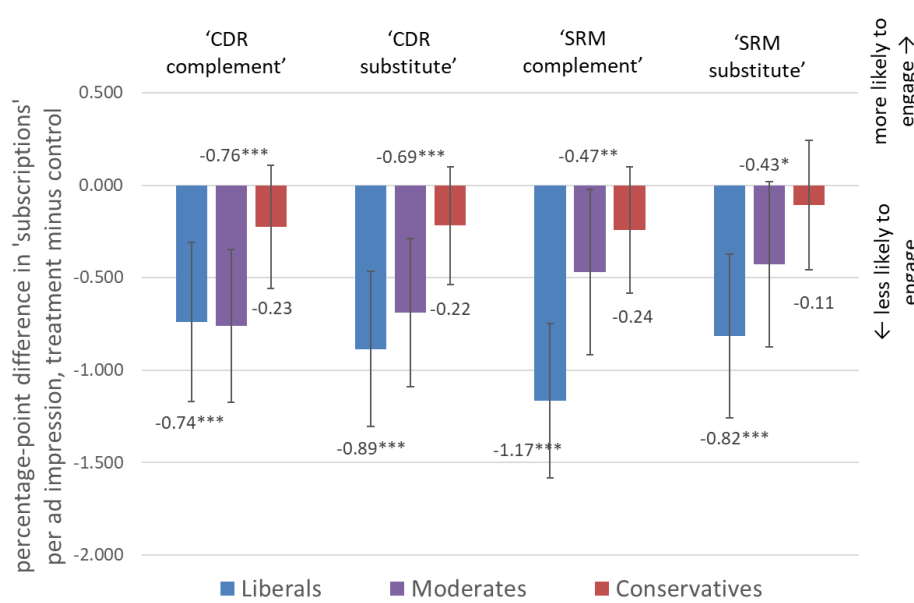
Figure 2—Treatment effect by framing and political leaning of Facebook ‘like’ campaign testing ‘rational’ and ‘sensible’ (Figure 1A versus B, with ‘sensible’, in part, replaced by ‘rational’ in the description limited to 90 characters), ‘technofix’ (Figure 1C), and ‘madmen’ (Figure 1D) in a campaign with $n \sim 59,000$ 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 1D), 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.⁹

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]

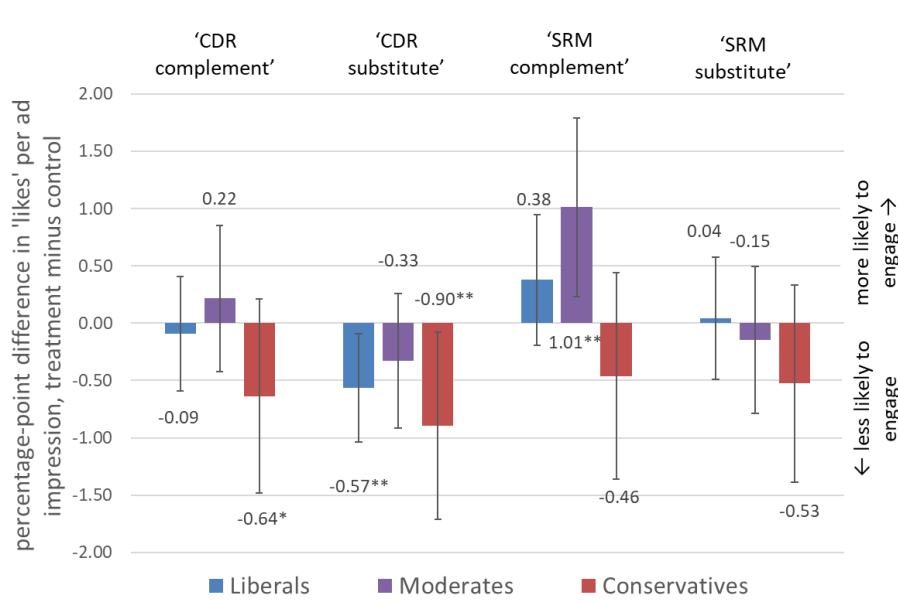
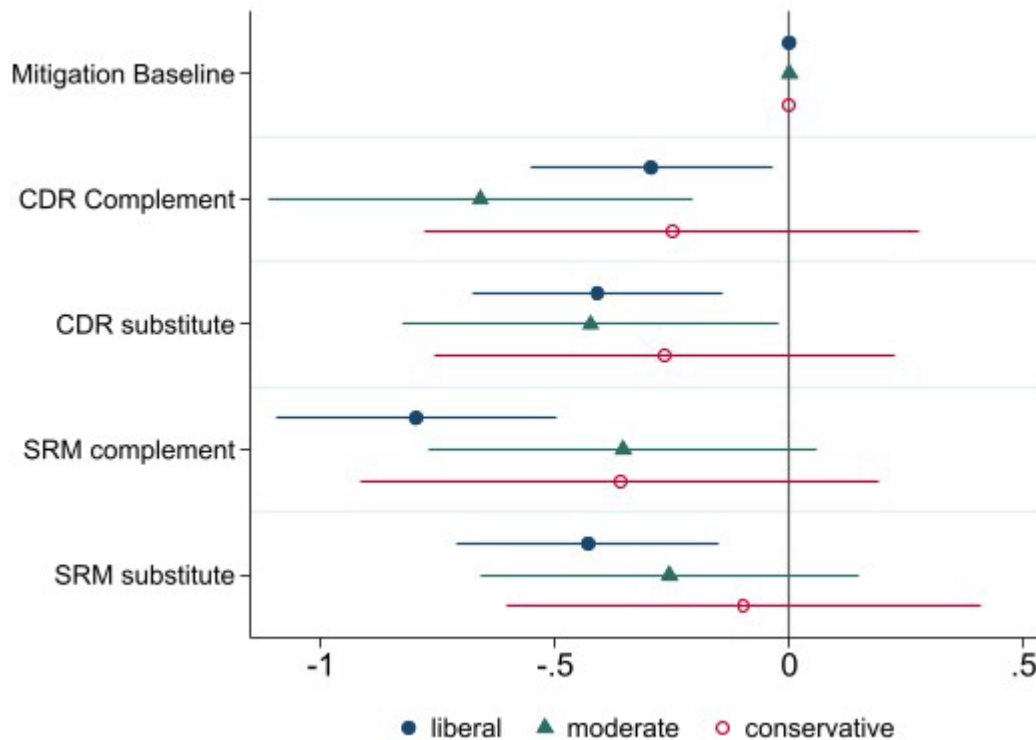


Figure 3 – Treatment effect by framing and political leaning of Facebook ‘newsletter sign-up’ campaign (panel A, n=90,955) and ‘like’ campaign (panel B, n=81,915) testing ‘CDR Complement’, ‘CDR substitute’, ‘SRM complement’ and ‘SRM substitute’ against the control framing ‘mitigation’ (Table A- 5). Figures show percentage point differences (treatment – control) and 95% confidence intervals for probability tests. * indicates statistical significance at the 10%-level, ** at the 5%-level, *** at the 1%-level. (See Supplemental Information Table A-5 for detailed results.)

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.

A [Newsletter sign-ups]



B ['like' campaign]

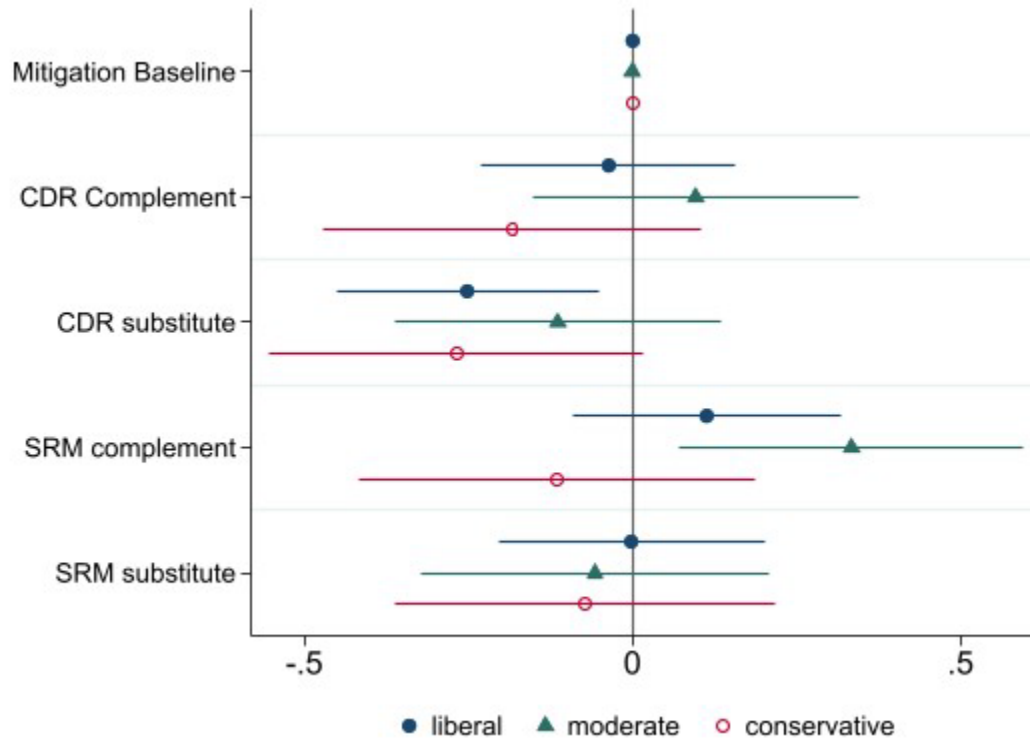


Figure 4 – Coefficient plots and 95% confidence intervals by political leaning for the newsletter campaign [A] and the like-campaign [B] testing the materials and messages in experiment 2 and 3 (see Figure A-9 and A-10), coefficients not shown: female, age, campaign round (only for newsletter), full 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 SRM¹⁰ 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^{4,7}, typically finds weak support for crowding-out.³ The one prior revealed-preference survey on SRM finds crowding-in.⁶ 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.¹¹ 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' perceptions¹² as well as on vested and institutional interests.¹³

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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

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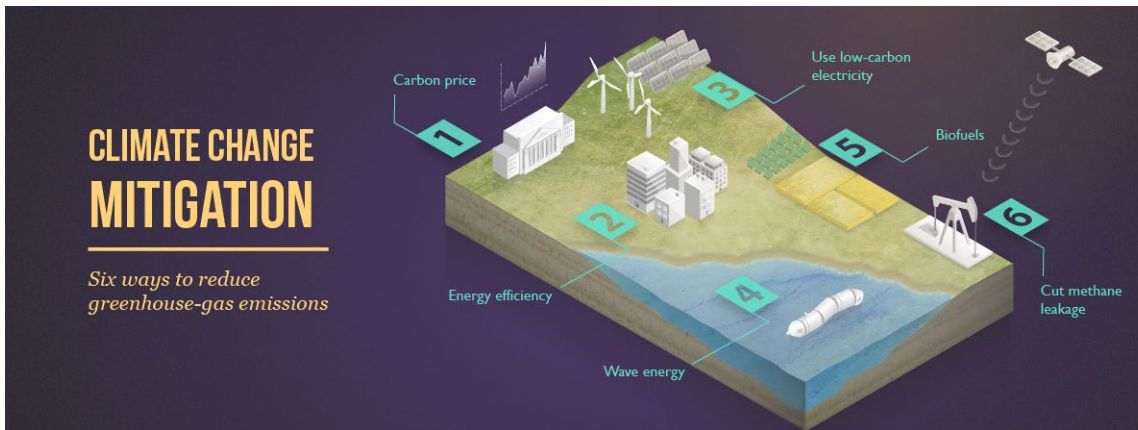
Methods

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.⁸)



Solar geoengineering



Madmen

[B] messaging [graphics]

Control

Treatment

Rational climate policy

Can clean technology help address climate change? Join us to promote rational policy
[Climate change mitigation]

Can solar geoengineering help address climate change? Join us to promote rational policy
[Solar geoengineering]

Sensible climate policy

Can clean technology help address climate change? Join us to promote sensible policy
[Climate change mitigation]

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

Technofix

Smart technology a fix to stabilize temperatures? Help us solve climate change
[Climate change mitigation]

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

Madmen

Big Oil is still making excuses against climate action! Help us fight back
[Madmen]

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

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

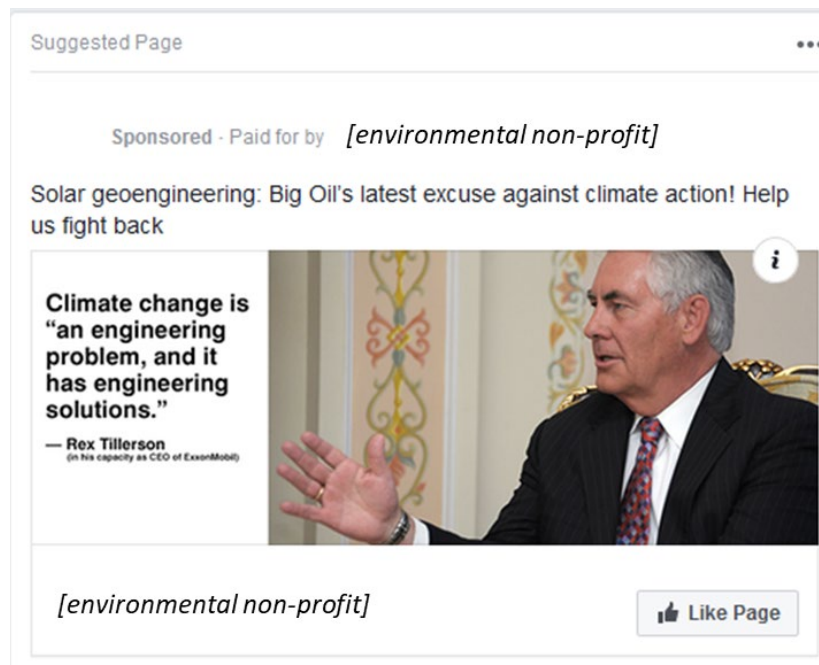


Figure A-2: Example post, experiment 1; name and logo of environmental non-profit blanked out

We ran experiment 1 with four different target 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).

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

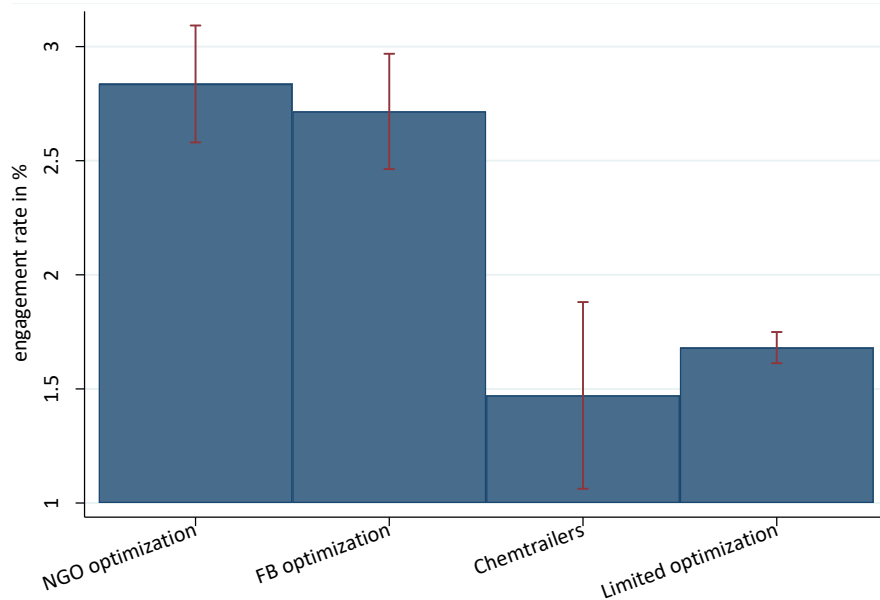


Figure A-3: Engagement rate by target group with error bars. Results from probability test: NGO = FB optimization, $p=0.512$; NGO = Chemtrailers, $p<0.000$; NGO = limited targeting, $p<0.000$; FB optimization = Chemtrailers, $p<0.000$; FB optimization = Limited optimization, $p<0.000$; Chemtrailers = 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; $p = 0.034$).

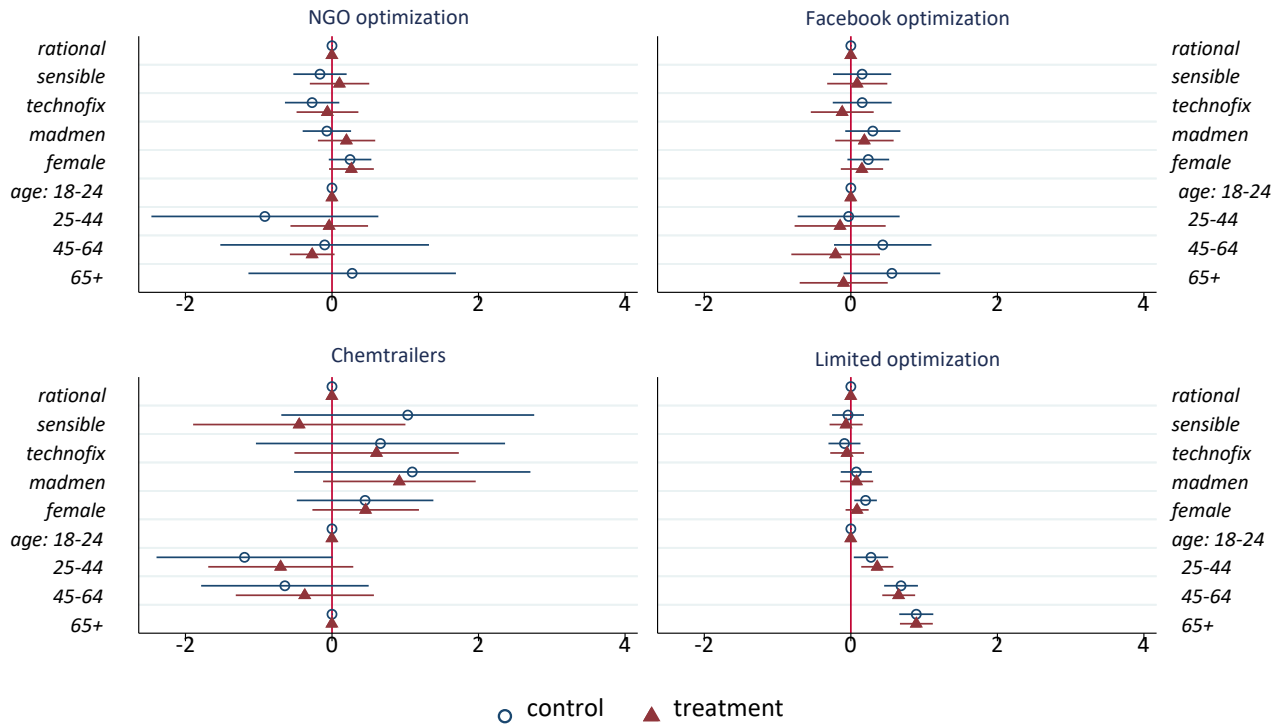


Figure A-4: Coefficients from logit regression likes (experiment 1) with 95%-confidence intervals for treatment and control groups by audience groups; treatment/control group-coefficients are relative to the base category `rational`

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.

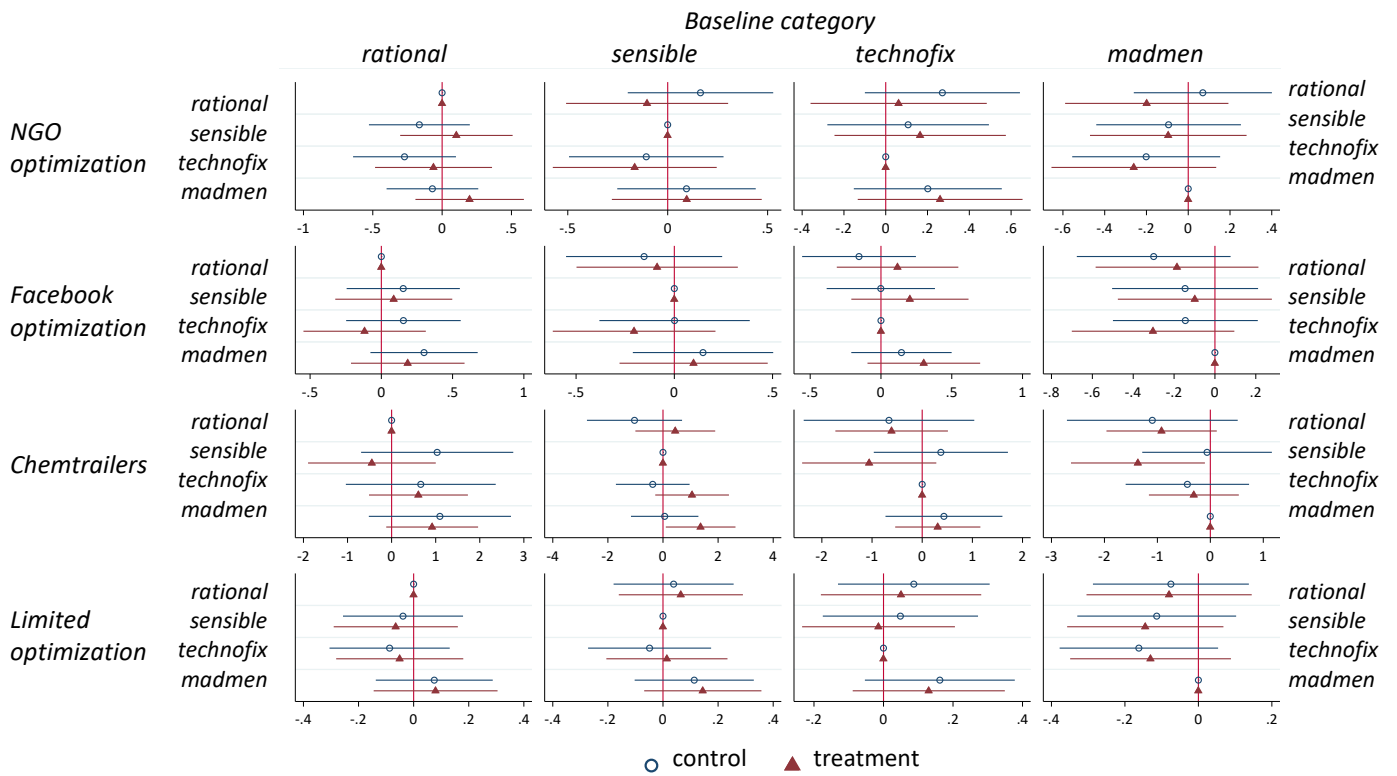


Figure A-5: Coefficients from logit regression likes (experiment 1) with 95%-confidence intervals for treatment and control groups by audience groups (rows) with different treatments as base categories (columns)

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 optimization		Facebook optimization		Chemtrailers		Limited optimization	
	Treatment	Control	Treatment	Control	Treatment	Control	Treatment	Control
<i>Framing, baselevel: rational</i>								
sensible	0.103 (0.207)	-0.164 (0.186)	0.087 (0.209)	0.154 (0.203)	-0.447 (0.739)	1.034 (0.881)	-0.065 (0.115)	-0.039 (0.111)
technofix	-0.062 (0.215)	-0.271 (0.189)	-0.117 (0.219)	0.155 (0.205)	0.609 (0.572)	0.662 (0.867)	-0.051 (0.118)	-0.087 (0.111)
madmen	0.199 (0.200)	-0.070 (0.169)	0.185 (0.203)	0.300 (0.192)	0.920 * (0.531)	1.095 (0.823)	0.080 (0.115)	0.075 (0.108)
Female	0.265 * (0.156)	0.247 * (0.148)	0.152 (0.147)	0.238 (0.145)	0.460 (0.371)	0.452 (0.475)	0.085 (0.080)	0.201 ** (0.079)
<i>Age, baselevel: 18-24</i>								
25-44	-0.037 (0.270)	-0.916 (0.790)	-0.146 (0.317)	-0.030 (0.355)	-0.700 (0.505)	-1.194 * (0.613)	0.361 *** (0.112)	0.275 ** (0.120)
45-64	-0.270 * (0.156)	-0.100 (0.727)	-0.207 (0.309)	0.435 (0.339)	-0.371 (0.481)	-0.643 (0.583)	0.653 *** (0.114)	0.685 *** (0.118)
65+	0.000 (.)	0.275 (0.722)	-0.098 (0.306)	0.560 * (0.337)	0.000 (.)	0.000 (.)	0.895 *** (0.114)	0.893 *** (0.119)
Constant	-3.774 *** (0.197)	-3.596 *** (0.721)	-3.547 *** (0.325)	-4.274 *** (0.362)	-4.161 *** (0.630)	-4.667 *** (0.783)	-4.593 *** (0.119)	-4.534 *** (0.110)
N	7702	8394	7155	8751	1628	1458	66936	69288
Pseudo R ²	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	-1135.481	-910.469	-1060.119	-148.080	-93.010	-5439.141	-6045.757

Table A-2: Logit regression on likes (experiment 1) for treatment and control groups; Reported are logit coefficients 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.

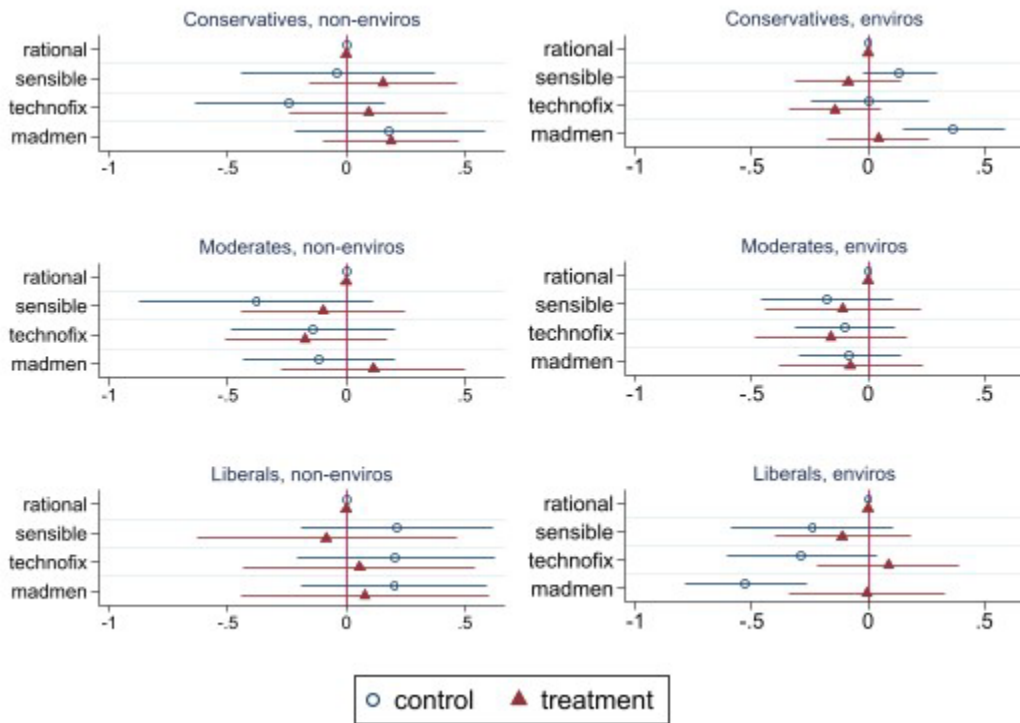


Figure A-6: Coefficients from logit regression on likes (experiment 1) with 95%-confidence intervals for treatment and control groups by non-enviros, i.e. users who have not shown an interest in environmental topics on Facebook before, and enviros, i.e. users who have shown an interest in environmental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

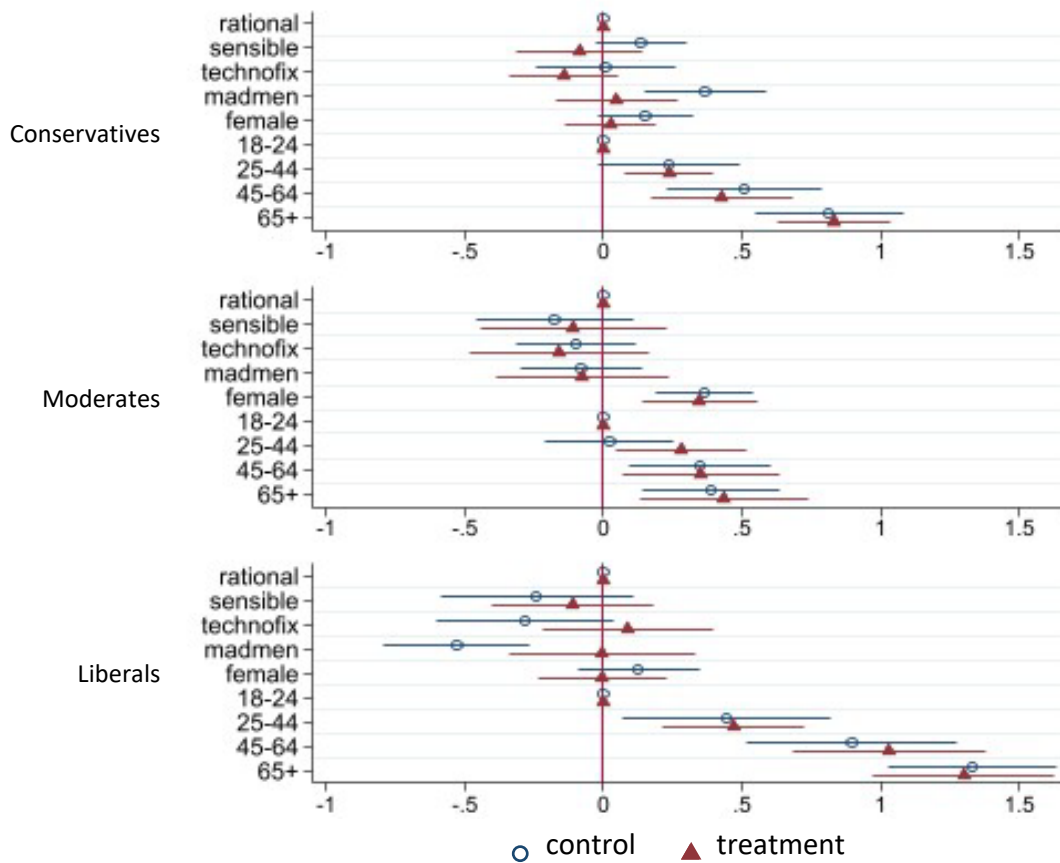


Figure A-7: Coefficients from logit regression on likes (experiment 1) with 95%-confidence intervals for treatment and control groups for the ‘limited optimization’ target group by political leaning; only users who are interested in environmental topics treatment/control-coefficients are relative to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

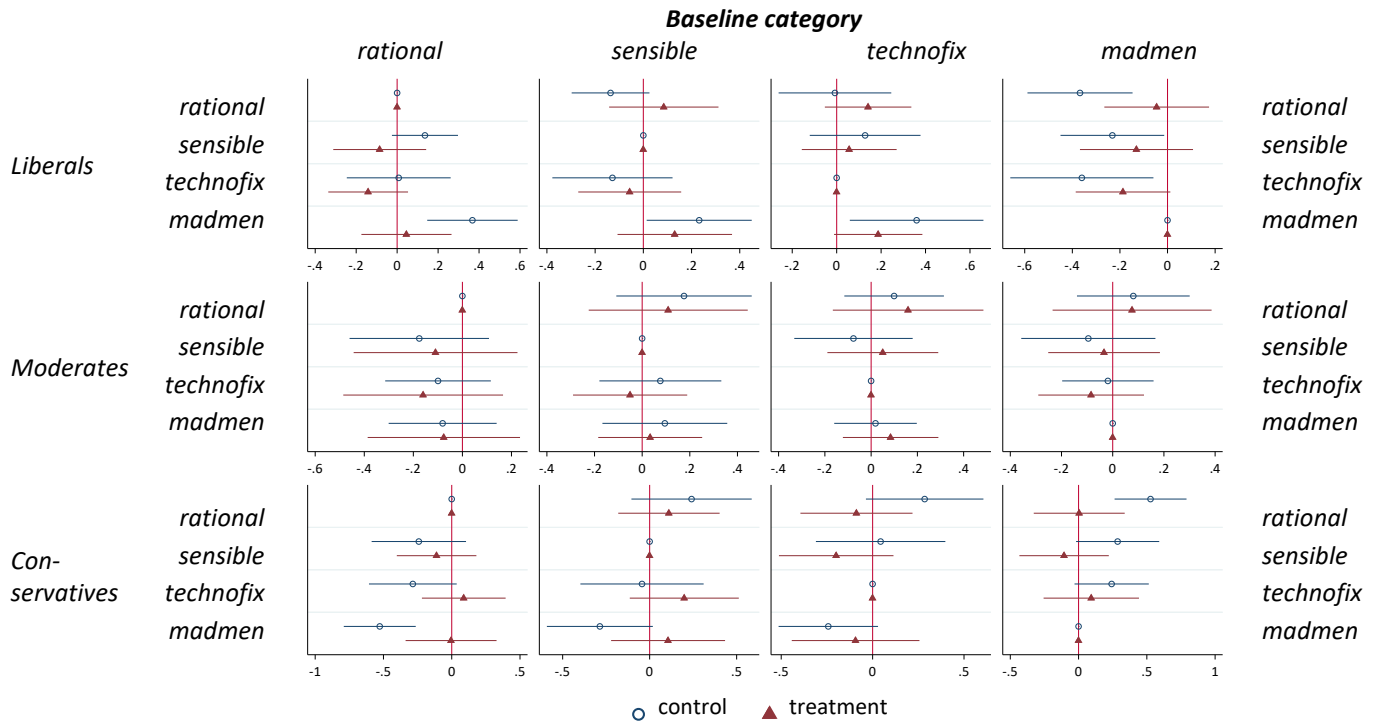


Figure A-8: Coefficients from logit regression on likes (experiment 1) with 95%-confidence intervals for treatment and control groups for the equal distribution setting by political leaning; only users who are interested in environmental topics, Like campaign

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.

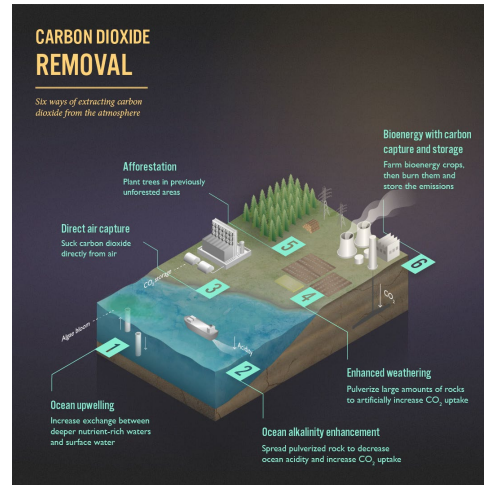
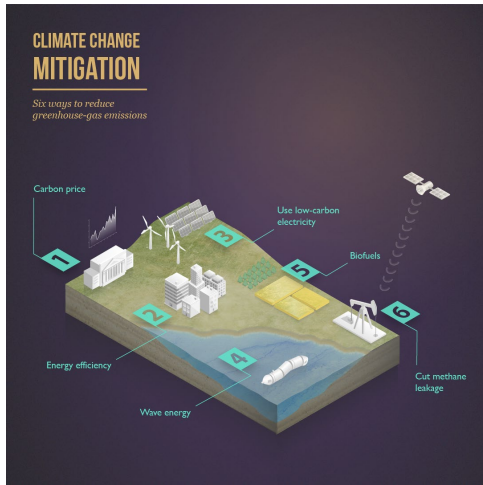
	Liberals		Moderates		Conservatives	
	Treatment	Control	Treatment	Control	Treatment	Control
<i>Framing, baselevel: rational</i>						
sensible	-0.085 (0.116)	0.136 * (0.082)	-0.109 (0.170)	-0.176 (0.145)	-0.111 (0.149)	-0.241 (0.176)
technofix	-0.141 (0.099)	0.008 (0.129)	-0.160 (0.166)	-0.099 (0.110)	0.088 (0.156)	-0.285 * (0.164)
madmen	0.045 (0.112)	0.368 *** (0.113)	-0.076 (0.158)	-0.081 (0.112)	-0.005 (0.170)	-0.527 *** (0.134)
Female	0.027 (0.083)	0.152 * (0.089)	0.346 *** (0.105)	0.366 *** (0.090)	-0.004 (0.118)	0.126 (0.112)
<i>Age, baselevel: 18-24</i>						
25-44	0.237 *** (0.083)	0.239 * (0.131)	0.281 ** (0.121)	0.023 (0.118)	0.470 *** (0.130)	0.444 ** (0.192)
45-64	0.427 *** (0.129)	0.507 *** (0.143)	0.350 ** (0.146)	0.346 *** (0.131)	1.029 *** (0.177)	0.896 *** (0.195)
65+	0.832 *** (0.105)	0.812 *** (0.136)	0.435 *** (0.154)	0.386 *** (0.125)	1.302 *** (0.167)	1.332 *** (0.155)
Constant	-4.182 *** (0.104)	-4.300 *** (0.124)	-3.841 *** (0.191)	-3.734 *** (0.138)	-4.438 *** (0.141)	-4.235 *** (0.188)
N	11785	13055	8728	9105	8050	8268
Pseudo R ²	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	-1225.172	-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; only users who are interested in environmental topics. 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

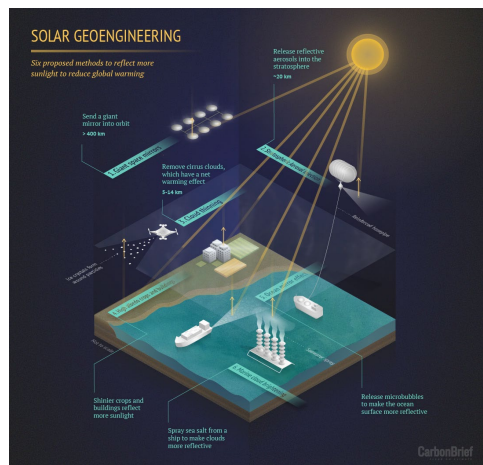
Experiment 2 was a `newsletter'-campaign testing the differences in engagement, i.e. newsletter sign-ups per impression. We compare engagement rates for 2 CDR campaigns and 2 SRM campaigns to a baseline mitigation campaign. We frame the technology either as a complement to reducing emissions or as a 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).

	Liberals			Moderates			Conservatives		
	T- C			T- C			T- C		
Newsletter	<i>n</i> =38,369			<i>n</i> =27,455			<i>n</i> =25,131		
<i>Mitigation [C]</i>	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	<i>n</i> =38,854			<i>n</i> =24,793			<i>n</i> =18,268		
<i>Mitigation [C]</i>	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.

	Newsletter			Like		
	Liberals	Moderates	Conservatives	Liberals	Moderates	Conservatives
<i>Treatment, baseline: Mitigation</i>						
CDR Complement	-0.295 ** (0.132)	-0.660 *** (0.231)	-0.251 (0.269)	-0.036 (0.099)	0.097 (0.127)	-0.183 (0.147)
CDR Substitute	-0.410 *** (0.136)	-0.425 ** (0.205)	-0.267 (0.252)	-0.251 ** (0.102)	-0.114 (0.127)	-0.268 * (0.146)
SRM Complement	-0.798 *** (0.153)	-0.355 * (0.212)	-0.361 (0.282)	0.113 (0.104)	0.334 ** (0.134)	-0.115 (0.154)
SRM Substitute	-0.430 *** (0.142)	-0.256 (0.206)	-0.098 (0.259)	-0.001 (0.104)	-0.057 (0.136)	-0.072 (0.148)
Female	0.091 (0.094)	0.246 (0.155)	0.568 *** (0.187)	0.106 (0.065)	-0.214 *** (0.081)	0.163 (0.095)
<i>Age, baseline: 18-24</i>						
25-34	-0.266 (0.325)	0.736 * (0.431)	-0.013 (0.629)	0.206 * (0.114)	-0.091 (0.129)	-0.076 (0.209)
35-44	-0.260 (0.318)	0.180 (0.477)	0.255 (0.579)	0.193 (0.123)	0.059 (0.140)	-0.245 (0.220)
45-54	-0.162 (0.297)	1.039 ** (0.418)	-0.201 (0.562)	0.159 (0.137)	-0.022 (0.166)	-0.141 (0.218)
55-64	0.232 (0.269)	1.246 *** (0.404)	0.037 (0.529)	0.484 *** (0.130)	0.279 * (0.165)	0.428 ** (0.201)
65+	0.488 * (0.262)	1.402 *** (0.402)	0.515 (0.520)	0.550 *** (0.130)	0.851 *** (0.154)	0.548 *** (0.199)
June/July 2019	0.226 ** (0.091)	0.091 (0.136)	0.386 ** (0.171)			
Constant	-4.362 *** (0.283)	-5.706 *** (0.425)	-5.734 *** (0.556)	-3.888 *** (0.122)	-3.624 *** (0.145)	-3.657 *** (0.206)
n	38369	27455	25131	38854	24793	18268
Pseudo R ²	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	-2969.89	-2278.74

*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.*

	Liberals			Moderates			Conservatives		
	comp - subst	SE	p	comp - subst	SE	p	comp - subst	SE	p
<i>Newsletter</i>									
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
<i>Like</i>									
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).

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⁴ 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.

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- ¹⁰ Tingley, Dustin, and Gernot Wagner. "Solar geoengineering and the chemtrails conspiracy on social media." *Palgrave Communications* 3, no. 1 (2017): 1-7.
- ¹¹ 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.
- ¹² 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.
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