A quantitative evaluation of the public response to climate engineering

Wright, M., Teagle, D. and Feetham, P. (2014) A quantitative evaluation of the public response to climate engineering, *Nature Climate Change*, 4(2), 106-110

http://dx.doi.org/10.1038/nclimate2087

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VERSION DATE 25 November 2013

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Atmospheric greenhouse gas concentrations continue to increase, with CO_2 passing 400 parts per million in May 2013. To avoid severe climate change and attendant economic and social dislocation, existing energy efficiency and emissions control initiatives may need support from some form of climate engineering. Because climate engineering will be controversial, there is a pressing need to inform the public and understand their concerns before policy decisions are taken. To date engagement has been exploratory, small scale or technique-specific. We depart from past approaches to draw on the associative methods used by corporations to evaluate brands, developing a systematic, quantitative and comparative approach for evaluating public reaction to climate engineering. Applying this approach reveals that the overall public evaluation of climate engineering is negative. Where there are positive associations they favour Carbon Dioxide Removal (CDR) over Solar Radiation Management (SRM) techniques. Therefore, as SRM techniques become more widely known they are more likely to elicit negative reactions. Two climate engineering techniques, Enhanced Weathering and Cloud Brightening, have indistinct concept images so are less likely to draw public attention than other CDR or SRM techniques.

The United Nations has sought carbon dioxide (CO_2) emissions controls to address the risks of climate change through the Kyoto Protocol and the Copenhagen Diagnosis. The Intergovernmental Panel on Climate Change warn that if average global surface temperatures rise more than 2 °C above pre-industrial levels, the effects on the Earth's eco-systems and species will be extensive.[1] Average global surface temperatures have risen around 0.74 °C in the last one hundred years and a further rise of 0.6 °C is believed inevitable.[2] Unless CO_2 emissions are reduced by 50 percent before 2050, average global surface warming will exceed 2 °C this century.[3] Present methods of mitigation and adaptation appear inadequate, as growth in atmospheric carbon dioxide continues unchecked.[4,5,6,7]

The failure of existing mitigation methods has led to investigation of alternative solutions including climate engineering, defined as deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change.[4] CDR technologies seek to reduce atmospheric carbon dioxide concentration and include: Afforestation; Biochar; Enhanced Weathering; Ocean Fertilisation; Ocean Liming; and various forms of Air Capture. SRM technologies seek to reduce temperatures by using reflective technologies to alter the balance of solar radiation and include: Cloud Brightening; Stratospheric Aerosols; Roof Whitening; and Mirrors in Space.[5,8] To assist the policy making process regarding geoengineering, climate experts and public opinion experts must work together to understand likely public reaction to these technologies.[2,9]

Initial qualitative work to engage the public on climate engineering has taken place in the United Kingdom and included small group discussions, open access events and a qualitative on-line survey of stakeholders.[10,11] These showed low awareness of climate engineering, but a preference for CDR over SRM on the basis that CDR techniques mitigate increasing atmospheric CO_2, the root cause of anthropogenic climate change. This small-sample qualitative approach was further applied to stratospheric aerosols, identifying considerable public discomfort with this particular technique.[12,13]

Large-scale quantitative work remains at an exploratory stage. One study examined public perceptions of SRM and the characteristics of those who were more, or less, opposed in North America and the United Kingdom, but did not compare specific SRM or CDR techniques.[14] Another US-based study used a split sample to compare two relatively safe (n=506) and two less safe (n=500) climate engineering techniques. However, the concept presentations were not adequately controlled, and a large bias eventuated between the subsamples.[15] A third study (n=1822) used one sentence descriptions of CDR and SRM to gauge relative support in the United Kingdom, but did not investigate any technique in detail.[16]

Here we report large-scale quantitative work that systematically examines and compares public reaction to six climate engineering techniques in a controlled fashion. We draw on techniques from Marketing, a discipline with extensive experience in public engagement and evaluation of concepts. Brand researchers are lead users of the psychological techniques used to elicit congitive associations, and have deployed these in large-scale surveys to evaluate brand image for over 20 years. [17, 18, 19] These approaches are based on Human Associative Memory theory[20] and the Adaptive Control of Thought model[21] as these describe the encoding, storage and retrieval of information in memory, and explain how an external stimulus causes cascading activation through a network of associated nodes (the basic unit of semantic memory). When an external stimulus brings a concept to mind, these associated memory nodes are likely to be retrieved into working memory to assist problem solving. Brand researchers have developed these theories into a systematic and quantitative approach to eliciting cognitive associations for brands. These developments can also be adapted to concepts in other domains, such as evaluation of climate engineering techniques. This provides a method of understanding public reaction to scientific, as well as commercial, concepts, in that it identifies the memory structures likely to be evoked by discussion of the concepts. We therefore apply recent advances in these techniques[19] to climate engineering, assisted by standard techniques for the presentation and evaluation of new concepts[22].

In doing so, we find it helpful to distinguish between Deliberative, Persuasive and Descriptive public engagement with science. Deliberative engagement provides opportunities to build a shared understanding of the local, cultural and social factors that affect engagement with science.[23] Persuasive engagement may effect behavioural change, but can be contested if its objectives do not have broad scientific or community support.[24] Our approach is

Descriptive, and instead seeks to provide inputs for policy decisions, providing controlled comparisons between techniques and a method for tracking changes in public perceptions over time.

Although this represents a departure from existing work on public engagement with science, it seeks to extend rather than supplant such research. Existing qualitative and ethnographic approaches are well suited to engaging with Deliberative or reflective thinking. Our Descriptive approach extends the measurement of public engagement to the associative or intuitive thinking that dominates much of everyday cognition. To quote Daniel Kahneman: associative thinking is "more influential than your experience tells you, and it is the secret author of many of the choices and judgments you make."[25] Unless both types of thinking are considered, the measurement of public engagement with geoengineering will be incomplete.

The brand association metrics we use are identical to those applied commercially[19] with two minor exceptions. First, due to the nature of the research, attribute associations are prompted by the climate engineering techniques, whereas in commercial research they are usually prompted by the product category. Prior research shows that such alternative elicitation methods deliver virtually indistinguishable results, with commercial approaches simply adopting the method that yields the most efficient data collection.[26] Second we construct and evaluate an overall net positive measure specifically for this research, in contrast to brand research that concentrates on positive rather than negative associations.[27]

We proceed through qualitative (n=30) and quantitative (n=2028) phases. The qualitative phase uses in-depth interviews to reveal attributes that represent the memory nodes most relevant to climate engineering. We first identify a wide range of attributes, and then truncate these to 12 representative attributes for quantitative data collection. Following data collection and diagnostic tests in the quantitative phase[19] we reduce the attributes analysed to 10.

The quantitative data are gathered using a commercial provider of online surveys in Australia (AU, n=1006) and New Zealand (NZ, n=1022). Six climate engineering concepts are tested: Biochar (making charcoal from vegetation to lock in CO_2); Enhanced Weathering (increasing the rate that carbon dioxide dissolves silicate minerals to form limestone); Air Capture (building structures that filter CO_2 from the air); Stratospheric Aerosols (spreading very small particles in the upper atmosphere to reflect sunlight); Cloud Brightening (automated ships spraying small seawater droplets over the ocean to reflect sunlight); and, Mirrors in Space (placing large mirrors or sunshade structures in orbit to block or reflect sunlight). Participants viewed an on-screen visual of each climate engineering technique and read a brief definition of the concept inclusive of advantages and disadvantages.

The primary outcome measures are the count of attribute associations elicited from individual participants for each technique, analysed in line with brand image analysis methdology.[19] We report quantitative results by country to avoid aggregation bias and to provide built-in replication as a robustness check.

The results show substantial variation in attribute popularity, measured as each attribute's share of all associations (Table 1). The variation in attribute popularity has a correlation between countries of r = .99.

TABLE 1 HERE

Of the 10 attributes analysed, the most frequently chosen are the five negative attributes, and the least frequently chosen are the five positive attributes. Over two thirds of all associations are made to negative attributes. Two attributes – *unknown effects* and *risky* - account for around 40% of associations.

When the same data are aggregated by climate engineering concept, public support for techniques can be ranked by subtracting negative associations from positive associations to provide a ‘net positive’ association metric (Table 2) that is approximately normally distributed (Supplementary Figures 1 to 4). Univariate and multivariate tests show that net positive scores do not vary with respondent characteristics, except for a slight tendency to increase with age (Supplementary Tables 3 and 4). For both countries, the highest net positive association rates are for CDR techniques and the lowest are for SRM techniques. The correlation between AU and NZ data is again *r* = .99.

TABLE 2 HERE

This high inter-study reliability is familiar to brand image researchers as attribute popularity and brand image rankings are typically very stable.[19] Also, here as in other brand image studies, there is structure in the data (Supplementary Table 6). The individual attribute scores vary with the overall popularity of the attribute and with the association rate for the particular concept. Interpretation requires a chi-square calculation of expected cell counts. Concept image is then reported as a chart of the percentage point skews (deviations) from these expected values (Supplementary Table 7) to show the distinctive image for each concept.

This practice is illustrated with diametrically opposed concept images for Biochar and Mirrors in Space in New Zealand (Figure 1). Here the order of attribute presentation is the inverse of popularity, placing the positive attributes at the top. Biochar skews towards the positive attributes (such as *environmentally friendly* and *long-term sustainability*) and away from the negative attributes, whereas Mirrors in Space skews away from the positive attributes and towards most of the negative attributes (particularly *risky* and *unknown effects*.)

FIGURE 1 HERE

In subsequent surveys concept maps may change. If the x-axis skews alter, then the concept image has changed. For example, Biochar may skew less towards *environmentally friendly* and more towards *artificial*. If y-axis order changes, the relative popularity of the attributes, or the relative accessibility of each memory node, will have changed. It might be, for example, that for all concepts participants become less likely to mention *risky* and more likely to mention *controllable*. Repeated surveys will show how concept image and category knowledge evolve over time.

There are 12 concept images in the present research. These are presented below in an abbreviated format (Figure 2) that maintains the order of attributes used in the illustrative concept maps.

FIGURE 2 HERE

The concept images are similar for Australia and New Zealand, but vary between techniques. Biochar and Air Capture have the most positive concept images, although Air Capture also skews heavily towards *eyesore* (the sixth attribute). Stratospheric Aerosols and Mirrors in Space have the most negative concept images, generally skewing away from positive attributes and towards negative attributes. Taken together, the results show that public evaluation of climate engineering is negative. Where there are positive associations, they heavily favour CDR techniques over SRM. One implication is that as SRM techniques become more widely known, they are more likely than CDR techniques to elicit negative public reactions.

A further point is that techniques vary considerably in distinctiveness: Biochar and Air Capture have distinctive and positive concept images; Stratospheric Aerosols and Mirrors in Space have distinctive and negative concept images; Enhanced Weathering and Cloud Brightening are not very distinctive (their skews are small). Branding theory predicts that more attention will be directed at distinctive stimuli.[28] Therefore, public reaction to Enhanced Weathering and Cloud Brightening may be comparatively muted.

The attribute list indicates the language people recognise as well as the associations they hold. Memory theory indicates that people process familiar stimuli more easily, and that each time a concept or related association is activated, the chances of future activation are increased.[20,21] It also suggests that the chances of processing will be reduced if competing concepts are also present in working memory.[20] Although our primary objective is Descriptive engagement, these findings may provide guidelines for effective communication in Deliberative or Persuasive settings. Communication will be more effective if the specific positive and negative terms elicited in this research are used to construct messages, and if intereference from competing concepts is minimised. This will facilitate activiation of the relevant concept nodes, making public interaction with climate engineering proposals more likely.

These results quantify public perceptions of climate engineering, provide controlled comparisons of techniques to inform policy, and identify language to be used for effective public communication. The process is systematic and the outputs are both quantitative and comparative. However, the results of this study reflect a particular set of information at a particular point in time. The results will likely change as the public dialogue unfolds, as the public are exposed to other climate engineering concepts and provided with additional scientific information on the techniques presented here. Re-applying the present methods provides a solution to the problem of assessing the exposure impact of scientific information in a real world setting.[29] That is, it provides a method of tracking changes in public perceptions if climate engineering moves from conceptual discussion to possible implementation.

Methods

The qualitative phase used depth interviews to examine Biochar, Air Capture, Cloud Brightening, and Stratospheric Aerosols. Participants viewed concept boards similar to those developed for the Experiment Earth deliberative workshops[10] but also including later work in this area[8,30]. Concept boards were presented to a convenience sample of 30 New Zealanders purposely selected to maximise demographic diversity. The sample varies from 18 to 77 years in age, with 47% male and 53% female, and qualifications ranging from none to post-graduate degree (Supplementary Table 1). Fifteen participants described their impressions by selecting from lists of pre-determined attributes. The other 15 were interviewed using Kelly's Repertory Grid, a method for evoking attributes from comparisons of similarities and differences between concepts. The terminology elicited from Kelly's Repertory Grid, along with language common across both methods, was adopted in the quantitative phase of the research. Some similar-seeming attributes were selected for the quantitative phase (*unknown effects, unpredictable,* and *risky*) to reflect various uncertainties about collateral effects, impact on global warming, and difficulty in reversing the intervention.

For the quantitative phase, Enhanced Weathering and Mirrors in Space were added to the concepts examined. This maintained a balance between CDR and SRM techniques, and included the six techniques judged by the authors to be of most interest in current scientific debates. A commercial online panel provider (ResearchNow, http://www.researchnow.com) was engaged to recruit participants. To avoid response bias, participation invitations refered to social research rather than climate engineering specifically. The provider issues invitations to panel members continuously, achieving demographic quotas by monitoring responses and issuing additional invitations to under-represented groups. Demographic representation in the sample is widespread and appropriately balanced for age, gender, education and location (Supplementary Table 2). There are some small demographic differences between the sample and census data, but few significant differences on the net positive variable between demographic groups. There may be some recruitment bias from panel formation; however, this is unlikey to be substantial due to the size of the panels (n=75,000 in New Zealand, and n=189,000 in Australia). Coverage bias is minimised with Australia and New Zealand having over 80% of the population as Internet users. Fieldwork included both weekdays and weekends.

Other measures taken to minimize framing effects and bias included: (i) to activate relevant memory networks, participants were initially asked negatively phrased questions about global warming (this was intended to force participants to parse the sentences, ensuring they were fully considered in working memory) and then given a brief explanation of the possible need for climate engineering; (ii) the specific concept descriptions were matched for pictorial content, concept elaboration, concept length, and the positive and negative aspects of the description; (iii) the pictures selected represented attempts by experts to present each technique, and were matched for size, colour, complexity and labels; although no attempt is made to evaluate visual processing, the inclusion of concept pictures was necessary to reduce the risk that some semantic elements of the concept statement become over-salient;[31] (iv) to minimize fatigue, each participant evaluated only four concepts; (v) to minimize item order effects, the order of presentation of both concepts and adjectives was rotated; (vi) to avoid priming responses through stimulus frequency, the attributes were balanced between positive and negative adjectives (vii) to avoid self-generated validity effects, the concept descriptions did not use the adjectives allocated to attribute measurement; (viii) to check the adequacy of the concept descriptions, participants were asked whether they could explain the concept to somebody else; (ix) for quality control, the questionnaire was checked by experts and pre-tested with members of the online panel.

The concept presentations were adequate: 37% to 50% of participants agreed that they could explain each concept to somebody else; 34% to 45% were neutral; whereas, only 18% to 24% disagreed.

The tendency of attributes to access the same memory structures was assessed using Kendall Tau-b correlations (Supplementary Table 5).[19] As a result, the attributes *unpredictable* and *beneficial* were dropped from further analysis. In commercial research, negative attributes are often dropped as they fail to discriminate between users and non-users.[27] In this case they are retained, as all participants are non-users and the usage-effect in brand image association rates is not relevant. *Quick-fix* is counted as a negative attribute, as this was the perception during the qualitative phase. Also, *quick-fix* predominantly correlates positively with negative attributes and negatively with positive attributes (Supplementary Table 5).

There were three treatments within each survey, resulting in minor sample size variations. There were no significant differences in the net positive variables between treatments (Supplementary Table 4). We report raw numbers for the net positive variables (Table 2) but otherwise normalize sample sizes to the value in the largest sub-sample (Table 1, Figures 1 and 2). All statistical tests are conducted on unadjusted numbers.

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Acknowledgements

This work was supported by a grant from the Massey University Research Fund. Thanks to M. Comrie, P. Gendall, L. Stocchi, the Editor and the four anonymous *Nature Climate Change* reviewers for helpful and thought-provoking suggestions.

Author Contributions

DAHT conceived of the project, advised on the climate engineering concepts and contributed to writing. MJW developed the research design, raised funds and undertook analysis and writing. PMF managed the fieldwork and contributed to analysis and writing.

Competing Financial Interests

None.

Figure Legends

Figure 1: Sample Concept Maps

Description: Percentage point deviations from expected attribute counts.

See attached file.

Figure 2: Summary of All Concept Maps

Description: Percentage point deviations from expected attribute counts.

The order of attributes used in the concepts maps is the same as in Figure 1.

See attached file.

Table 1: Attribute Association Rankings

Ranking	Attribute	Australia % share of all associations	New Zealand % share of all associations
1	Unknown effects	24	25
2	Risky	16	16
3	Artificial	12	13
4	Quick-fix	8	7
5	Eyesore	8	9
6	Understandable	7	8
7	Controllable	7	7
8	Environmentally friendly	7	6
9	Long-term sustainability	6	6
10	Cost-effective	5	3

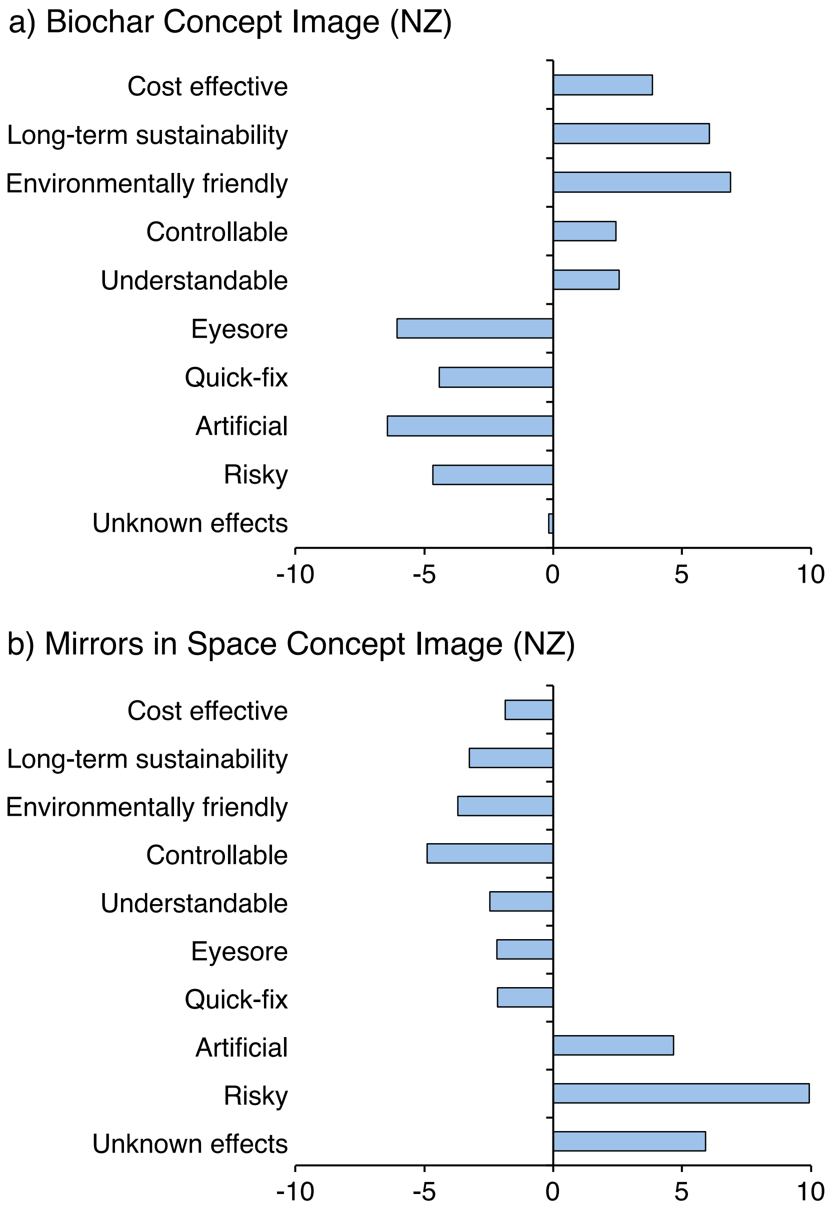
Table 2: Memory Associations for Climate Engineering Techniques

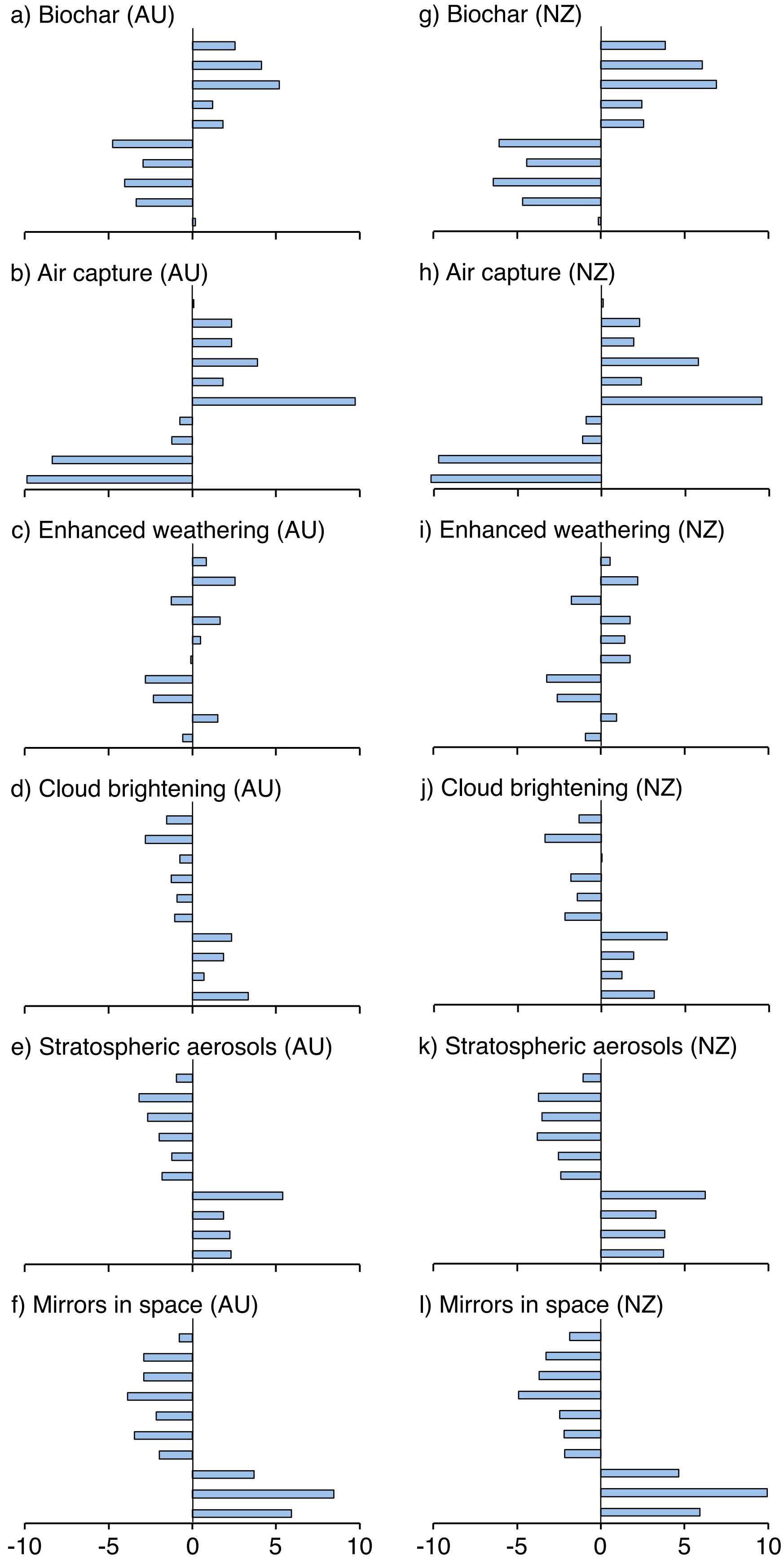
AUSTRALIA	**Biochar**	**Air Capture**	**Enhanced Weathering**	**Cloud Brightening**	**Stratospheric Aerosols**	**Mirrors in Space**	**TOTAL**
n*	672	674	666	672	666	674	1006
count of associations	1600	1885	1581	1706	1789	1594	10155
positive associations	48%	43%	37%	26%	23%	20%	33%
negative associations	52%	57%	63%	74%	77%	80%	67%
net positive associations	-4%	-13%	-26%	-49%	-54%	-59%	-34%

NEW ZEALAND	**Biochar**	**Air Capture**	**Enhanced Weathering**	**Cloud Brightening**	**Stratospheric Aerosols**	**Mirrors in Space**	**TOTAL**
n*	670	691	683	670	683	691	1022
count of associations	1774	2130	1708	1860	1917	1800	11188
positive associations	52%	42%	34%	22%	15%	14%	30%
negative associations	48%	58%	66%	78%	85%	86%	70%
net positive associations	3%	-16%	-32%	-57%	-70%	-73%	-40%

*To minimize fatigue, each participant evaluated only four concepts

Note: X^2 tests for independence show significant differences for both countries (Supplementary Table 6). For the positive and negative associations reported in Table 2, the standard errors of the proportions range from .008 to .012 (or .08% to 1.2%). The z–values for the differences between adjacent techniques range from -3.7 to -25.4. Therefore, all differences in Table 2 are statistically significant.


a) Biochar Concept Image (NZ)
Cost effective
Long-term sustainability
Environmentally friendly
Controllable
Understandable
Eyesore
Quick-fix
Artificial
Risky
Unknown effects
-10
-5
0
5
10
b) Mirrors in Space Concept Image (NZ)
Cost effective
Long-term sustainability
Environmentally friendly
Controllable
Understandable
Eyesore
Quick-fix
Artificial
Risky
Unknown effects
-10
-5
0
5
10



a) Biochar (AU)
b) Air capture (AU)
c) Enhanced weathering (AU)
d) Cloud brightening (AU)
e) Stratospheric aerosols (AU)
f) Mirrors in space (AU)
g) Biochar (NZ)
h) Air capture (NZ)
i) Enhanced weathering (NZ)
j) Cloud brightening (NZ)
k) Stratospheric aerosols (NZ)
l) Mirrors in space (NZ)
-10
-5
0
5
10

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Supplementary Information

The supplementary information has four purposes. First, it demonstrates that the sample is appropriately representative. Second, it demonstrates that the net positive measure is approximately normal and thus suitable for analysis. Third, it tests for the effects of treatment and demographics on the overall net positive variable. Fourth, using the Australian data, it provides an illustration of key steps in the method to facilitate replication and further application. Comments on each stage follow.

Supplementary Tables 1 and 2 provide a demographic breakdown of the sample for the qualitative and the quantitative phases of the research, together with census data comparisons for age and gender for the quantitative phase. This shows that participants are broadly spread across demographic groups, and that gender and age distributions for the quantitative phase are close to those of census data except for a slight skew towards older participants in New Zealand. This sample composition is acceptable for the purposes of this research.

Supplementary Figures 1, 2, 3 and 4 examine the properties of the Net Positive variable for each country. In both cases a Kolmogorov-Smirnov test rejects the null hypothesis of no difference from a normal distribution. However, the histograms in Figures 1 and 3 do show an approximately normal distribution, as do the normal probability plots in Figures 2 and 4. While there is an obvious peak in each distribution, Kurtosis is low at -.074 for Australia (std. error = .154) and -.146 for New Zealand (std. error = .153). Skewness is also low at -.257 for Australia (std. error .077) and -.136 for New Zealand (std. error .077). Therefore, the Net Positive variable approximates a normal distribution in both countries and is acceptable for further analysis for the purposes of this research.

Supplementary Table 3 shows univariate tests for associations between the net positive variable and both survey treatment and the demographic variables. No differences are expected for survey treatment, as participants were randomly assigned and the treatments were balanced between CDR and SRM. We use ANOVA for all demographic tests except Age, where bivariate correlation is appropriate. Due to the large number of tests we employ the Bonferroni correction to critical p-values. On this basis, the only statistically significant relationship is for Age in New Zealand. Age is a negatively coded ratio variable (Yearborn), indicating that in New Zealand older people tend to be more positive about climate engineering than younger people; however, the effect is small and visual inspection of the scatterplot shows very little structure.

We test the robustness of this univariate analysis using a multifactor random effects General Linear Model, with treatment as a fixed effect, demographics as random effects, and Age as a covariate. We test for interactions as well as main effects. Again we employ the Bonferroni correction to critical p-values. As the Bonferroni correction depends on the number of tests conducted we also report the Bonferroni critical p-value for main effects alone. *Supplementary Table 4* presents these results: the only effects that are statistically significant after the Bonferroni correction are in New Zealand, for the intercept term and for Age.

Supplementary Table 5 shows the matrix of nonparametric attribute correlations for the Australian data. This is the average of six correlation matrixes, one for each climate engineering technique. The table is divided into quadrants to assist grouped analysis of the negative and positive attributes. None of the reported correlations are high, as all are less than .50. However three correlations are above .37 and also substantially exceed the average correlations for the attributes involved. This meets the criteria for eliminating attributes to reduce overlapping memory structures.[19] The results for New Zealand data are substantially similar, enabling consistent treatment across both samples, with *unpredictable* and *beneficial* selected for removal.

Supplementary Table 6 shows the raw attribute counts for the remaining ten attributes. The row, column and total counts are used to calculate a chi-square expected cell count, and *Supplementary Table 7* shows the deviation between the observed count in *Supplementary Table 6* and this expected count, expressed as a percentage. These are the deviations reported graphically in Figure 2.

The *Australian online questionnaire* is provided to show the stimuli, question wording and question flow. This has been amended from the field version in that most images have been deleted and replaced with web links where they can be viewed online. The New Zealand questionnaire was substantially similar to the Australian questionnaire.

Cleaned SPSS data files are available on request from the first author. These contain individual records for all survey questions reported in this paper. Data for survey questions not reported in this paper will be withheld, pending use in other research projects.

Supplementary Table 1: Demographic Breakdown of the Qualitative Samples

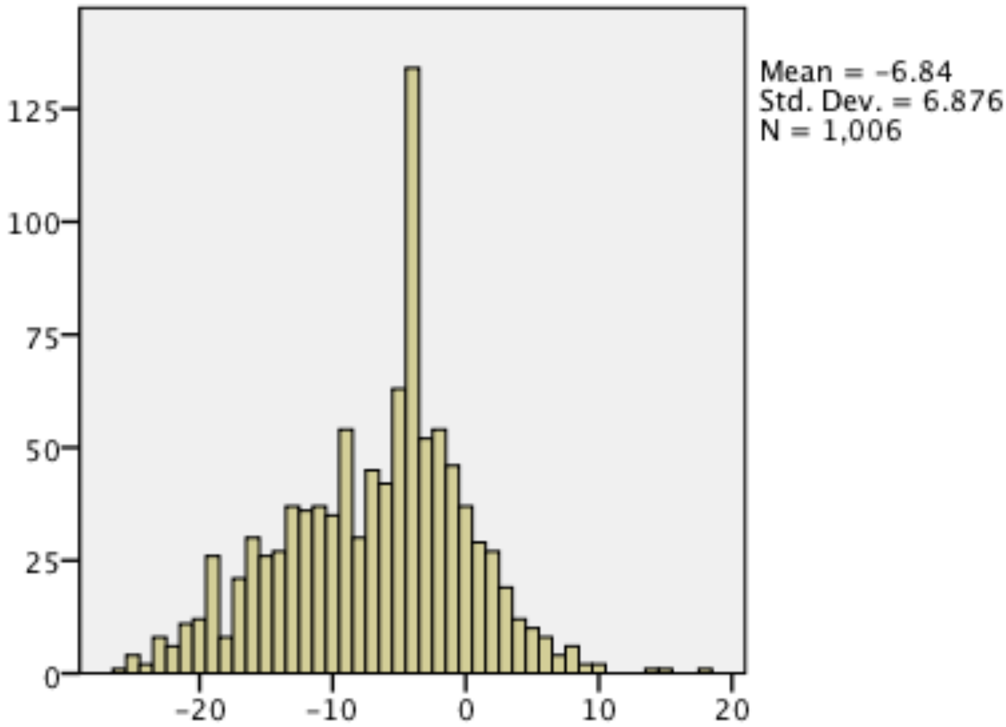
Subject	Gender	Qualification	Age	Occupation
KELLY				
1	male	school qualification	24	university student
2	male	certificate/diploma	29	own business
3	female	school qualification	20	university student
4	male	school qualification	21	university student
5	female	certificate/diploma	54	management
6	female	school qualification	36	cafe owner
7	male	school qualification	20	university student
8	male	post graduate	49	IT technician
9	female	certificate/diploma	61	business owner
10	male	post graduate	73	retired principal
11	male	post graduate	52	principal
12	male	post graduate	51	hospital orderly
13	female	no formal qualification	48	retail
14	female	school qualification	62	swim instructor
15	female	school qualification	22	university student
PREDETERMINED				
1	female	school qualification	72	weight loss leader
2	male	certificate/diploma	20	chef
3	female	bachelor's degree	71	retired teacher
4	female	certificate/diploma	70	social worker
5	male	school qualification	40	librarian
6	male	post graduate	70	retired journalist
7	male	trade qualification	37	council engineer
8	male	no formal qualification	75	retired soldier
9	male	trade qualification	65	council engineer
10	female	certificate/diploma	42	retail
11	female	school qualification	29	student nurse
12	female	no formal qualification	40	teacher aide
13	female	bachelor's degree	40	teacher
14	female	no formal qualification	77	retired
15	female	school qualification	18	polytechnic student

Supplementary Table 2: Demographic Breakdown of the Quantitative Samples

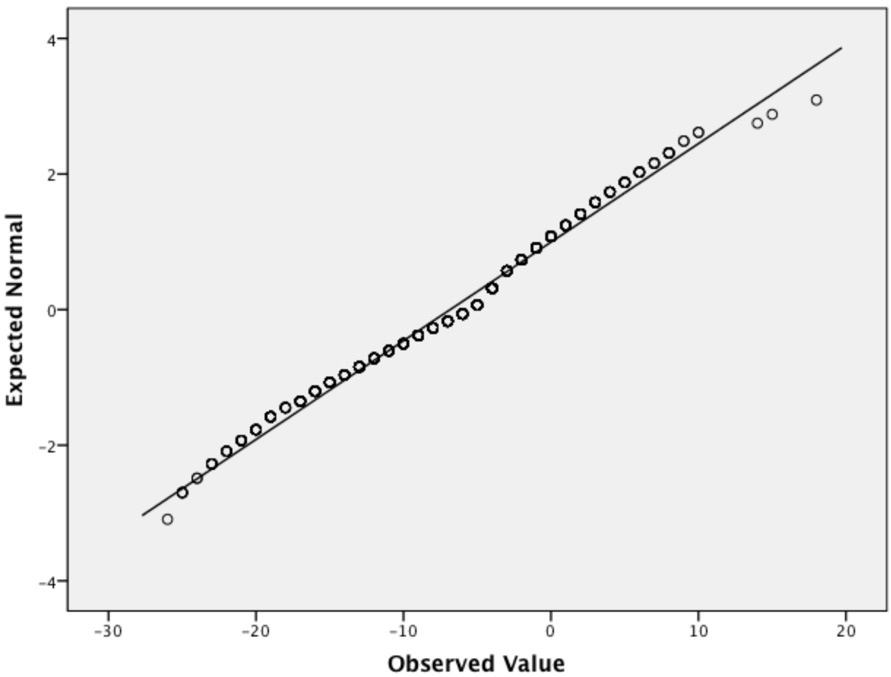
	Australia (n=1006)	AU Census	New Zealand (n=1022)	NZ Census
Age (years)*	%	%	%	%
16-24	15	16	12	17
25-34	20	19	14	17
35-44	22	18	14	17
45-54	23	17	14	18
55-64	15	15	21	15
65-82	6	15	26	15
Gender				
Male	46	50	51	49
Female	54	50	49	51
Education				
Primary/High School	38		30	
Trade/Technical	23		24	
Some University	14		18	
Completed Undergraduate	14		17	
Completed Postgraduate	10		11	
Household Yearly Income (In local currency)				
<$10,000	7		4	
$10,001-20,000	8		8	
$20,001-40,000	17		25	
$40,001-60,000	19		18	
$60,001-80,000	15		15	
$80,001-100,000	13		12	
$100,001-120,000	7		8	
$120,001-140,000	5		4	
>$140,000	9		6	
Location				
Rural area	11		10	
Small town (less than 1,500)	7		8	
Large town (1,500-60,000)	18		22	
Small city (60,001-300,000)	15		22	
Medium city (300,001-1million)	13		17	
Large city (more than 1 million)	35		20	

* Census data for Age is calculated as the the proportion of the 16-82 age group.

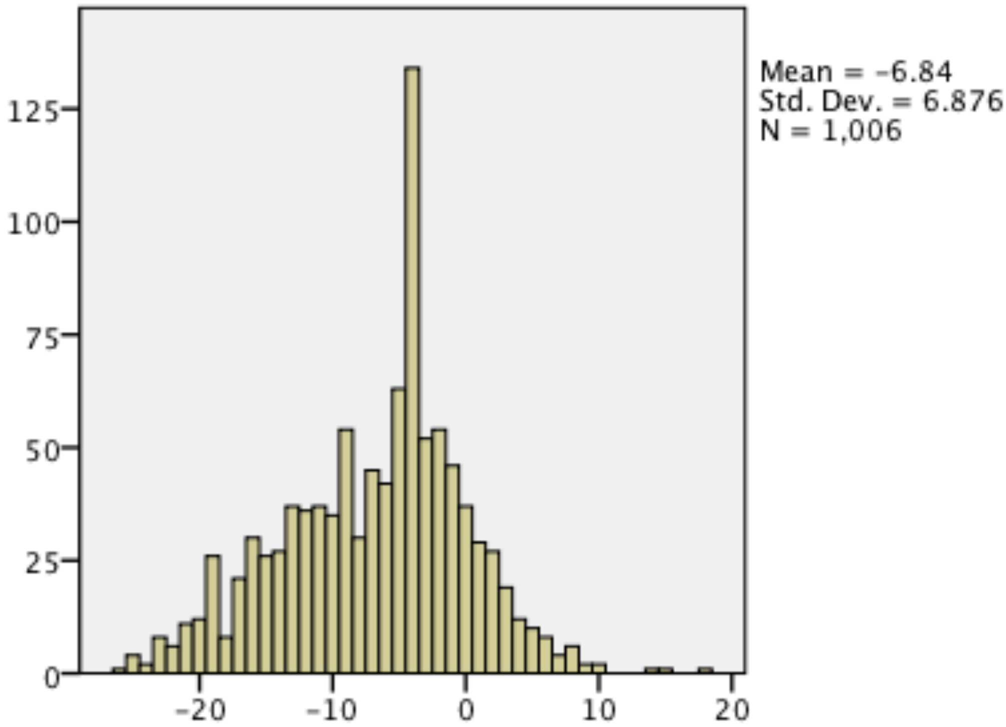
Supplementary Figure 1: Histogram of Net Positive Measure (Australia, n=1006)



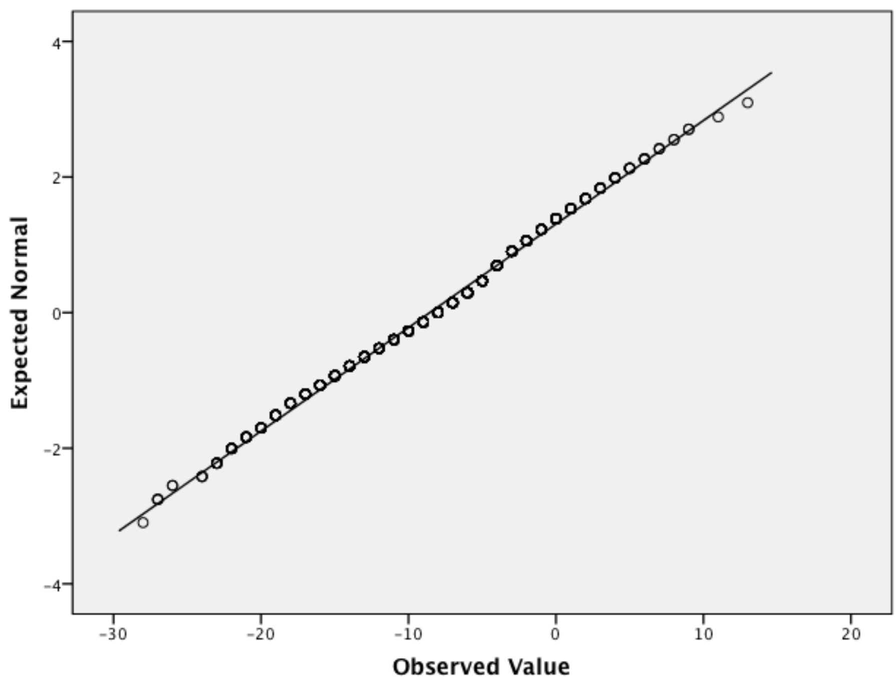
Supplementary Figure 2: Normal Q-Q Plot of Net Positive Measure (Australia)



Supplementary Figure 3: Histogram of Net Positive Measure (New Zealand)



Supplementary Figure 4: Normal Q-Q Plot of Net Positive Measure (New Zealand)



Supplementary Table 3: Univariate Tests for Differences on the Net Positive Variable

		Test statistic	Test statistic value	P value	Bonferroni-corrected critical P value
AU data					
Treatment	Oneway Anova	$F_{(.05, 2, 1003)}$	0.25	.778	.008
Gender	Oneway Anova	$F_{(.05, 1, 1004)}$	0.11	.739	.008
Location	Oneway Anova	$F_{(.05, 5, 1000)}$	1.81	.109	.008
Education	Oneway Anova	$F_{(.05, 5, 1000}$	1.67	.134	.008
Household Income	Oneway Anova	$F_{(.05, 8, 997)}$	1.87	.061	.008
Age	Correlation	R	-0.290	<.001	.008
NZ Data					
Treatment	Oneway Anova	$F_{(.05, 2, 1019)}$	2.81	.061	.008
Gender	Oneway Anova	$F_{(.05, 1, 1020)}$	1.03	.391	.008
Location	Oneway Anova	$F_{(.05, 5, 1016)}$	0.88	.492	.008
Education	Oneway Anova	$F_{(.05, 5, 1016)}$	1.59	.161	.008
Household Income	Oneway Anova	$F_{(.05, 8, 1013)}$	2.04	.039	.008
Age	Correlation	r	-0.202	<.001	.008

Supplementary Table 4: Multivariate Tests for Differences on the Net Positive Variable

		F value	P value	Bonferroni-corrected critical P value*
AU Data	1. Intercept	9.62	0.006	.002
	2. Treatment	2.04	0.134	.002
	3. Gender	2.22	0.151	.002
	4. Location	2.50	0.032	.002
	5. Education	1.89	0.113	.002
	6. Household Income	1.04	0.409	.002
	7. Age	2.24	0.135	.002
	3x4 Interaction	0.46	0.808	.002
	3x5 Interaction	1.16	0.328	.002
	3x6 Interaction	0.98	0.450	.002
	3x7 Interaction	1.05	0.306	.002
	3x2 Interaction	1.05	0.351	.002
	4x5 Interaction	0.67	0.874	.002
	4x6 Interaction	0.99	0.490	.002
	4x7 Interaction	1.11	0.356	.002
	4x2 Interaction	0.86	0.574	.002
	5x6 Interaction	0.81	0.779	.002
	5x7 Interaction	1.39	0.225	.002
	5x2 Interaction	2.07	0.025	.002
	6x7 Interaction	0.82	0.586	.002
	6x2 Interaction	0.79	0.704	.002
	7x2 Interaction	0.82	0.443	.002
NZ Data	1. Intercept	43.45	<0.001	.002
	2. Treatment	1.87	0.166	.002
	3. Gender	0.04	0.852	.002
	4. Location	0.56	0.731	.002
	5. Education	1.04	0.400	.002
	6. Household Income	1.16	0.330	.002
	7. Age	15.20	<0.001	.002
	3x4 Interaction	2.86	0.014	.002
	3x5 Interaction	2.04	0.087	.002
	3x6 Interaction	0.94	0.484	.002
	3x7 Interaction	0.72	0.395	.002
	3x2 Interaction	0.72	0.486	.002
	4x5 Interaction	1.55	0.056	.002
	4x6 Interaction	1.16	0.228	.002
	4x7 Interaction	1.22	0.297	.002
	4x2 Interaction	0.92	0.510	.002
	5x6 Interaction	1.31	0.122	.002
	5x7 Interaction	2.09	0.080	.002
	5x2 Interaction	1.75	0.084	.002
	6x7 Interaction	0.70	0.692	.002
	6x2 Interaction	1.16	0.297	.002
	7x2 Interaction	5.33	0.005	.002

* If only main effects are considered, the Bonferroni-corrected critical p value becomes p=.007.

Supplementary Table 5: Matrix of Average Kendall Tau-b Nonparametric Correlations (Australian Data)

	Unknown effects	Unpredict -able	Risky	Artificial	Quick-fix	Eyesore	Under-standable	Beneficial	Controll-able	Env. friendly	Long-term s.	Cost effective
Unknown effects		0.27	0.23	0.14	0.05	0.06	-0.13	-0.24	-0.18	-0.23	-0.18	-0.15
Unpredictable	0.27		**0.39**	0.25	0.13	0.13	-0.05	-0.16	-0.15	-0.17	-0.13	-0.06
Risky	0.23	**0.39**		0.24	0.14	0.13	-0.07	-0.18	-0.16	-0.17	-0.13	-0.01
Artificial	0.14	0.25	0.24		0.18	0.21	0.04	-0.02	-0.01	-0.04	0.00	-0.01
Quick-fix	0.05	0.13	0.14	0.18		0.15	0.07	-0.02	0.01	0.00	-0.05	0.05
Eyesore	0.06	0.13	0.13	0.21	0.15		0.05	-0.02	0.01	-0.02	-0.02	-0.01
Understandable	-0.13	-0.05	-0.07	0.04	0.07	0.05		0.31	0.32	0.29	0.24	0.17
Beneficial	-0.24	-0.16	-0.18	-0.02	-0.02	-0.02	0.31		**0.37**	**0.39**	0.33	0.21
Controllable	-0.18	-0.15	-0.16	-0.01	0.01	0.01	0.32	**0.37**		0.32	0.31	0.19
Env. friendly	-0.23	-0.17	-0.17	-0.04	0.00	-0.02	0.29	**0.39**	0.32		0.33	0.23
Long-term sustain.	-0.18	-0.13	-0.13	0.00	-0.05	-0.02	0.24	0.33	0.31	0.33		0.24
Cost effective	-0.15	-0.06	-0.01	-0.01	0.05	-0.01	0.17	0.21	0.19	0.23	0.24	

Supplementary Table 6: Attribute Counts After Elimination of Overlapping Attributes (Australian Data)

	Biochar	Air Capture	Enhanced Weathering	Could Brightening	Stratospheric Aerosols	Mirrors in Space	TOTAL	%
Unknown effects	371	254	352	448	448	460	2333	24%
Risky	193	136	263	273	310	376	1551	16%
Artificial	120	194	144	226	235	240	1159	12%
Quick-fix	81	136	81	174	233	96	801	8%
Eyesore	48	323	118	113	104	68	774	8%
Understandable	143	169	120	107	106	81	726	7%
Controllable	131	204	135	99	90	52	711	7%
Environmentally friendly	189	171	87	103	74	63	687	7%
Long-term sustainability	163	160	136	59	55	54	627	6%
Cost effective	117	92	88	57	69	65	488	5%
TOTAL	1556	1839	1524	1659	1724	1555	9857	
%	16%	19%	15%	17%	17%	16%		

Note: The Chi-Square values for the test of independence are $X^2 = 1312$ for the Australian data in Supplementary Table 6, and $X^2 = 2631$ for the equivalent New Zealand data. These exceed the critical value for statistical significance at p=.001, $X^2_{(.999,\ 45)} = 80$.

Supplementary Table 7: Percentage Point Deviations from Expected Attribute Counts (Australian Data)

	Biochar	Air Capture	Enhanced Weathering	Could Brightening	Stratospheric Aerosols	Mirrors in Space
Unknown effects	0%	-10%	-1%	3%	2%	6%
Risky	-3%	-8%	2%	1%	2%	8%
Artificial	-4%	-1%	-2%	2%	2%	4%
Quick-fix	-3%	-1%	-3%	2%	5%	-2%
Eyesore	-5%	10%	0%	-1%	-2%	-3%
Understandable	2%	2%	1%	-1%	-1%	-2%
Controllable	1%	4%	2%	-1%	-2%	-4%
Environmentally friendly	5%	2%	-1%	-1%	-3%	-3%
Long-term sustainability	4%	2%	3%	-3%	-3%	-3%
Cost effective	3%	0%	1%	-2%	-1%	-1%

Default Question Block

Dear Panelist

Thank you for clicking through to our survey. It should take you 10-15 minutes to complete.

The survey is being conducted to help better understand public reaction to important scientific issues.

Your participation is voluntary. No identifying information will be collected. The survey findings only report summarized results and will not identify specific individuals.

This project has had ethical peer review and has been judged to be low risk.

To proceed to the survey please click on the 'Next >>' button at the bottom right of the page.

Once you click the 'Next >>' button you cannot go back and change your answers. If you lose your connection to the Internet at any point, please go back to the original email to click the link again. It will restart the survey at the point you left off.

For a number of years, global warming has been in the news. Global warming refers to the idea that the world's average temperature has been increasing over the past 150 years, that it may increase more in the future, and that the world's climate is changing as a result. This increase is attributed to increased emissions of greenhouse gases such as carbon dioxide.

Please read the statements below and then indicate whether you agree or disagree by clicking **ONE** button beside each statement

	Strongly agree	Agree	Neutral	Disagree	Strongly Disagree	Don't know
Global warming is not causing climate changes.	○	○	○	○	○	○
Humans are not primarily responsible for global warming.	○	○	○	○	○	○
The International community should not try to reduce global warming.	○	○	○	○	○	○

Scientific research shows that over the past 100 years the Earth's temperature has increased by 0.74 degrees Celsius. If this warming continues it will have a profound effect on ecosystems and human social systems. Some scientists believe it is too late to stop global warming through control of carbon emissions. They think that, to avoid the effects of global warming, we may have to directly engineer the climate to reduce the Earth's temperature.

There are two broad approaches to doing this. One is to remove carbon dioxide from the atmosphere. The other involves reflecting sunlight back into space. There are many different techniques suggested for each of these approaches.

We would like to know what you think about some of these climate engineering techniques. In the following pages we will present four of these techniques and ask some questions about each one. There are no right or wrong answers in this survey. Rather we are interested in your opinion.

Block 4

Enhanced weathering

Copyright: Dave Craw

Enhanced weathering involves increasing the rate that carbon dioxide dissolves minerals to form limestone. This can be achieved through greater exposure to the atmosphere, fine grinding or heating of the minerals, and could be applied to volcanic ash, sand or mine tailings. The resulting limestone traps the carbon dioxide for thousands of years. Enhanced weathering can be implemented locally, increased gradually, and stopped at any time. It could take decades to lower global temperatures. It will produce large amounts of limestone and could use a lot of water. It has similar environmental impacts to mining.

Which of the descriptions in the list below do you think applies to Enhanced weathering? Please select as many as apply.

☐ Eyesore ☐ Understandable

☐ Quick-fix ☐ Risky

- [ ] Beneficial
- [ ] Unpredictable
- [ ] Controllable
- [ ] Long-term sustainability
- [ ] Cost effective
- [ ] Environmentally friendly
- [ ] Artificial
- [ ] Unknown effects

Please read the statements below and indicate whether you agree or disagree by clicking ONE button beside each statement.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I think **Enhanced weathering** could help reduce global warming.					
I think **Enhanced weathering** is practical with modern technology.					
I think **Enhanced weathering** is a technique most people would support.					
I think **Enhanced weathering** might have bad side effects.					
After reading the description I think that I could explain **Enhanced weathering** to somebody else.					

Block 3

Air capture image based on:

http://fortunebrainstormtech.files.wordpress.com/2011/10/carbon_engineering_slab_air_contactor.jpg

Air capture involves building structures that filter carbon dioxide from the air. The captured molecules would be transported and stored in old oil wells or underground rock formations, reducing atmospheric carbon dioxide. The captured molecules are harmless. Air capture structures could be concentrated in large-scale sites, like factories, or placed locally as part of the community, like utilites. Air capture can be implemented in small increments. The operation could run continuously, but is easily stopped at any time. To lower global temperatures quickly, many air capture structures would have to be built. Costs are incurred for electricity, transport and storage. The structures might be unattractive.

Which of the descriptions in the list below do you think applies to Air capture? Please select as many as apply.

- [ ] Quick-fix
- [ ] Environmentally friendly
- [ ] Controllable
- [ ] Beneficial
- [ ] Long-term sustainability
- [ ] Unpredictable
- [ ] Risky
- [ ] Understandable
- [ ] Artificial
- [ ] Eyesore
- [ ] Cost effective
- [ ] Unknown effects

Please read the statements below and indicate whether you agree or disagree by clicking ONE button beside each statement.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I think **Air capture** would help reduce global warming.					
I think **Air capture** is practical with modern technology.					
I think **Air capture** is a technique most people would support.					
I think **Air capture** might have bad side effects.					
After reading the description I think that I could explain **Air capture** to somebody else.					

Block 2

Stratospheric aerosols image based on:

http://static.guim.co.uk/sys-images/Environment/Pix/pictures/2011/08/31/SPICEpipebaloon2.gif

Stratospheric aerosols could be used to spread very small, shiny particles in the upper atmosphere. This would reflect some sunlight back into space, reducing the Earth's temperature. Stratospheric aerosols would be delivered using large balloons connected to ultra-long but lightweight pipes. Sulfates could be used in quantities that would not add to acid rain. Use of stratospheric aerosols requires international agreement and large-scale investment. The aerosols would spread widely and start to lower temperatures within a year. The effect would be temporary, so the procedure would need to be continuously applied. The effect on the ozone layer, high altitude clouds and rainfall are not well understood.

Which of the descriptions in the list below do you think applies to Stratospheric aerosols? Please select as many as apply.

- ☐ Quick-fix
- ☐ Unpredictable
- ☐ Eyesore
- ☐ Risky
- ☐ Understandable
- ☐ Environmentally friendly
- ☐ Cost effective
- ☐ Beneficial
- ☐ Long-term sustainability
- ☐ Controllable
- ☐ Artificial
- ☐ Unknown effects

Please read the statements below and indicate whether you agree or disagree by clicking ONE button beside each statement.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I think **Stratospheric aerosols** would help reduce global warming.	○	○	○	○	○
I think **Stratospheric aerosols** is practical with modern technology.	○	○	○	○	○
I think **Stratospheric aerosols** is a technique most people would support.	○	○	○	○	○
I think **Stratospheric aerosols** might have bad side effects.	○	○	○	○	○
After reading the description I think that I could explain **Stratospheric aerosols** to somebody else.	○	○	○	○	○

Block 1

Biochar image based on:

http://www.biochar.org/joomla/images/stories/OkimoriBiochar1.jpg

Biochar is the process of making charcoal from decomposing vegetation. Carbon dioxide is locked into the charcoal, which would be buried for thousands of years. When Biochar is made, bio-fuels are produced and can be sold. Biochar, used as a soil additive, might also increase agricultural productivity. Biochar can be implemented locally, in small increments. Processing would need to continue for a long time, and it could take decades to lower global temperatures. Making, transporting and burying Biochar will use additional energy. The long-term effect on eco-systems is not well understood. There could be controversy if land is farmed for Biochar and its beneficial side products, instead of being used for crops.

Which of the descriptions in the list below do you think applies to Biochar? Please select as many as apply.

- ☐ Risky
- ☐ Quick-fix
- ☐ Controllable
- ☐ Beneficial
- ☐ Understandable
- ☐ Unpredictable
- ☐ Artificial
- ☐ Long-term sustainability
- ☐ Cost effective
- ☐ Environmentally friendly
- ☐ Eyesore
- ☐ Unknown effects

Please read the statements below and indicate whether you agree or disagree by clicking ONE button beside each statement.

	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
I think **Biochar** would help reduce global warming.	○	○	○	○	○
I think **Biochar** is practical with modern technology.	○	○	○	○	○
I think **Biochar** is a technique most people would support.	○	○	○	○	○
I think **Biochar** might have bad side effects.	○	○	○	○	○
After reading the description I think that I could explain **Biochar** to	○	○	○	○	○

somebody else.

Block 6

Mirrors in space image based on:

http://scienceillustrated.com.au/blog/wp-content/uploads/2010/11/space-mirrors.jpg

Large mirrors or sunshade structures could be placed to orbit the Earth. They would block or reflect some sunlight before it reached the atmosphere and lower global temeratures. Mirrors in space, or sunshade structures, would stimulate growth of the space industry. They would require international agreement and large scale investment. They may have an uneven cooling effect, and could be difficult to remove without creating hazards to space navigation. The effects on weather and ecosystems are not well understood. It is not clear how quickly mirrors or sunshades could be developed and deployed.

Which of the descriptions in the list below do you think applies to Mirrors in space?
Please tick as many as apply.

- ☐ Environmentally friendly
- ☐ Controllable
- ☐ Risky
- ☐ Unpredictable
- ☐ Eyesore
- ☐ Quick-fix
- ☐ Understandable
- ☐ Cost effective
- ☐ Long-term sustainability
- ☐ Beneficial
- ☐ Artificial
- ☐ Unknown effects

Please read the statements below and indicate whether you agree or disagree by clicking ONE button beside each statement.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I think **Mirrors in space** would help reduce global warming.	○	○	○	○	○
I think **Mirrors in space** is practical with modern technology.	○	○	○	○	○
I think **Mirrors in space** is a technique most people would support.	○	○	○	○	○
I think **Mirrors in space** might have bad side effects.	○	○	○	○	○
After reading the description I think that I could explain **Mirrors in space** to somebody else.	○	○	○	○	○

Block 5

Cloud brightening image based on:

http://ecofriend.com/wp-content/uploads/2012/07/marine-cloud-whitening_YiR4J_69.jpg

Cloud brightening involves automated ships spraying small seawater droplets over the ocean. These droplets would increase the number of bright clouds, which in turn would reflect more sunlight and lower global temperatures. Spraying would need to be widespread to have an effect and purpose built ships would be required. Cloud brightening may require international agreements, and could be expensive. It would only work for a short time unless spraying is continuously repeated. It may cause significant cooling in localized areas. The effects on sea life and weather are not well understood.

Which of the descriptions in the list below do you think applies to Cloud brightening?
Please select as many as apply.

- ☐ Controllable
- ☐ Understandable
- ☐ Artificial
- ☐ Quick-fix
- ☐ Environmentally friendly
- ☐ Risky
- ☐ Beneficial
- ☐ Eyesore
- ☐ Long-term sustainability
- ☐ Cost effective
- ☐ Unpredictable
- ☐ Unknown effects

Please read the statements below and indicate whether you agree or disagree by clicking ONE button beside each statement.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I think **Cloud brightening** would help reduce global warming.	○	○	○	○	○
I think **Cloud**					

brightening is practical with modern technology.	○	○	○	○	○
I think **Cloud brightening** is a technique most people would support.	○	○	○	○	○
I think **Cloud brightening** might have bad side effects.	○	○	○	○	○
After reading the description I think I could explain **Cloud brightening** to somebody else.	○	○	○	○	○

Did you know about climate engineering techniques before you began this survey?

- ○ Yes
- ○ No

Which of the following climate engineering techniques had you heard of before participating in this survey?
Please select as many as apply.

- ○ Afforestation
- ○ Iron fertilzation of algae
- ○ Mirrors in space
- ○ Biochar
- ○ Stratospheric aerosols
- ○ Enhanced weathering
- ○ Air capture
- ○ Liming the ocean
- ○ Roof whitening
- ○ Cloud brightening
- ○ Other (write in the text box below)

Now we would like to ask a few questions about your views on the environment. Please read the statements below and indicate whether you agree or disagree by clicking ONE button beside each statement.

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
I am not willing to pay more for eco-friendly products.	○	○	○	○	○
I do not think it is important for companies to have environmental programs.	○	○	○	○	○
I do not think mining for minerals is more important for the economy than the need for conservation.	○	○	○	○	○
My personal actions will have little impact on the environment.	○	○	○	○	○

On a scale of 0 - 10, what is the likelihood that you will search for more information on climate engineering techniques in the next **three** months.
Please move the cursor along to the number that applies.

	Not very likely				Likely				Very likely		
	0	1	2	3	4	5	6	7	8	9	10
Click to write Choice 1											

Finally, some questions about you.

Are you?

- ○ Male
- ○ Female

Which of these best describes the place that you live?

- Rural area
- Small town (less than 1,500 people)
- Large town (1,501 to 60,000 people)
- Small city (60,001 to 300,000 people)
- Medium city (300,001 to 1 million people)
- Large city (more than 1 million people)

Which of these best describes your highest formal qualification?

- Primary School
- High School
- Trade/Technical
- Some university
- Completed undergraduate
- Completed Postgraduate

Which of the following categories best describes your household's yearly income, from all sources, before tax?

- < $10.000
- $10,001 - $20,000
- $20,001 - $40,000
- $40,001 - $60,000
- $60,001 - $80,000
- $80,001 - $100,000
- $100,001 - $120,000
- $120,001 - $140,000
- > $140,000

Which year were you born?

If you have any comments about climate change or climate engineering, please write them here.