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Climate change and technology: examining opinion formation of geoengineering

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Abstract
The term "climate change" has evolved from what was originally a technical term employed by scientists into a symbolic referent involving complex social, political, and moral considerations that have spurred worldwide debate. As evidence of the anthropogenic influence on the Earth's climate has grown over the past few decades, climate change has come to be viewed as a primary challenge to be confronted in the twenty-first century. Geoengineering, or climate engineering, is a set of large-scale technological interventions proposed to offset climatic changes. This study seeks to understand which factors contribute to, or alternatively, detract from public acceptance of geoengineering through robust path analytic modeling of public perceptions of geoengineering that may better serve the academic community and decision-makers. This study finds that familiarity, epistemic trust, preference for alternative solutions to climate change, and media consumption are interrelated in their influences on opinions toward geoengineering proposals and support for funding further geoengineering research. Such predictive modeling can enable risk communicators and policy-makers with vital information to support anticipatory governance approaches to policy initiatives and improve future public engagement and communication about geoengineering.

Keywords Climate change · Public opinion · Geoengineering · Path analysis

1 Introduction

The term "climate change" has evolved from what was originally a technical term employed by scientists into a symbolic referent involving complex social, political, and moral considerations that have spurred worldwide debate (Hulme 2009). As evidence of the anthropogenic influence on the Earth's climate has grown over the past few decades, climate change has come to be viewed as a primary challenge to be confronted in the twenty-first century. Historically, the majority of discussion of how to respond to climate change has focused on policy options in two domains, either reducing greenhouse gas emissions at the source point or adapting modern society to a changing world. In recent years, a third category for responding to climate change has emerged: "geoengineering" or "climate engineering" is a set of large-scale technological interventions proposed to offset climatic changes (Royal Society 2009).

The term "geoengineering" was coined in 1977 by Victor Marchetti who used it to describe the potential for disposing excess carbon dioxide (CO_2) in marine reserves (Marchetti 1977). Since the instantiation of the term, it has become an umbrella term to describe a host of technological fixes proposed to mitigate climate change in various ways. Most geoengineering proposals can be classified into one of two approaches: (1) solar radiation management (SRM) and (2) carbon dioxide removal (CDR). SRM proposals involve large-scale interventions to either deflect small amounts of solar radiation away from the Earth or to increase the reflective capacity of the Earth's atmosphere (albedo coefficient) that reflects solar radiation itself. CDR proposals involve intervention strategies to remove existing CO_2 and other greenhouse gases from the atmosphere and oceans.

At best, geoengineering's proposed technologies can only partially negate the changes occurring to the Earth's climate as no methods have "yet to be demonstrated to be effective at an affordable cost, with acceptable side effects" (Royal Society 2009, p. x). Furthermore, such technologies may pose great threats including diminished recovery of the ozone

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layer, changes to the water cycle and precipitation patterns, reductions in personal motivations and behaviors to reduce carbon emissions, and potential unknown environmental and social risks (Ricke et al. 2010). To date, most geoengineering technologies have not been researched to a reasonable degree to support wide use and a great deal of uncertainty remains regarding their efficacy to mitigate climatic change and to identify their potential influences on environmental systems (Corner et al. 2013; Vaughan and Lenton 2011).

Scientific debates around potential geoengineering interventions have received wide attention from academics, decision-makers, and media worldwide (Royal Society 2009). As Cummings et al. (2017) noted in their systematic review of public perceptions of geoengineering, such attention from various stakeholders "has garnered interest and concern from social groups, non-governmental organizations, and members of the public who accept or condemn technologies often prior to a considered understanding of their purpose and methods" (p. 248). Their literature review noted four key themes across the corpus of literature including (1) general low familiarity with geoengineering technologies among the public, (2) perceptions that risks associated with geoengineering likely outweigh potential benefits, with perceptions of CDR being more favorable than SRM proposals, (3) the public does not support current use of geoengineering, but does support greater research as well as potential future use, and (4) the public desires that some form of international governance be enacted to oversee both research and future use, but the form of governance and trust in stakeholders varies greatly by source (Cummings et al. 2017; Ipsos-MORI 2010; Parkhill et al. 2013).

Further, studies of public perceptions of geoengineering have employed multiple methods to evaluate public opinion ranging from qualitative interviews, focus groups, and deliberative engagement exercises to quantitative population-based surveys and experimental designs. Whereas qualitative studies are useful for identifying the range of thoughts people have about geoengineering, quantitative studies like the current one allow a researchers to probe specific concepts, such as attitudes toward geoengineering, and test specific relationships between variables of interest (Pidgeon et al. 2012). Most studies have assessed levels of familiarity with geoengineering, risk and benefit attitudes, support for funding of geoengineering research, and reactions to specific frames given to experimental participants.

Across the field of public perceptions, the great majority of reviewed studies evaluate and report simple descriptive evaluations of the proposals, and calls have been made to "acknowledge the host of antecedent value predispositions and information sources that also play vital roles in attitude formation" (Cummings et al. 2017, p. 261). It is from this premise that the current study seeks to move inquiry of public evaluations of geoengineering to a more robust path analytic model to examine public opinion formation of geoengineering that may better serve the academic community and decision-makers.

In particular, this study develops and tests a hypothetical model of relationships between public perception variables including familiarity with geoengineering, positive opinion of geoengineering, and support for government funding of geoengineering research, and as of yet unstudied variables including media attention, epistemic trust, and preferences for alternative mitigation strategies concerning climate change. Such path analytic approaches provide greater flexibility when estimating and interpreting causal mechanisms in order to evaluate the influences on geoengineering opinion formation which can better inform researchers and decision-makers of the complex dynamics of geoengineering attitude formation (Kaplan 2008).

1.1 Anticipatory governance

A useful function of this path analytic model is to inform an iterative and anticipatory version of governance that can prepare for the potential benefits, risks, and societal responses to geoengineering. Anticipatory governance uses a variety of available data to forecast policy options regarding the regulation and supported use of proposed technologies (Guston 2014; Foley et al. 2015). Data may come in many forms ranging from qualitative inputs like focus group results and expert opinion studies to more quantitative data related to technology risk, hazard, and exposure analysis, and "upstream" public opinion identification (Guston and Sarewitz 2002; Macnaghten et al. 2005). This approach facilitates improvements to technology governance by incorporating data into regulatory risk assessment protocols as they are reported. Thus, a major strength of anticipatory governance lies in its ability to provide balance between protecting against harmful outcomes and promoting an amenable environment for technological research and innovation (Fuerth 2009).

In this study, we identify factors that influence familiarity, risk and benefit attitudes, and support for geoengineering, which provides a nuanced understanding of how the public makes sense of geoengineering. This form of analysis goes beyond previous public perception studies in order to provide a more robust account of how such factors influence public perceptions. Such data may be useful in identifying needs and challenges in communication and decision-making as geoengineering technologies are continued to be researched and proposed for use. Granted, such public opinion data should be cautiously used by decision-makers as public opinion is not a fixed entity and is likely to change as geoengineering technologies become more near-term in dissemination. Furthermore, public opinion is likely to be idiosyncratic based on which public is polled. However, such

data are among the most robust empirical markers of public will.

1.2 Learning from the media

A great deal of the literature regarding new technologies has focused on the contention between "knowledge deficit" models of scientific understanding and emotive rationales for basing evaluations of new technologies (Besley and Shanahan 2005; Gaskell et al. 2005; Scheufele and Lewenstein 2005). According to the knowledge deficit model, public acceptance of science and technology is a function of how well the public understands it. This model has been criticized for failing to account for the contexts in which particular issues of science and technology have relevance not to the public in general, but to publics in particular (Michael 2009). Publics will accept science and technology not simply when they come to understand it, but when they regard it as relevant and important to their own lives.

In that vein, Brossard et al. (2009) found that people "use perceptual filters when reaching judgments about a controversial technology" and that the context in which people perceive and interpret a new technology and related facts are important factors for determining how people process information about risks and benefits (p. 547). Their study noted interesting findings including (1) a direct negative relationship between strength of religious beliefs and support for funding of nanotechnology, noting that religiosity serves as an interpretive tool for making sense of nanotechnology; (2) a positive relationship between science media use and attitude toward nanotechnology; and (3) that factual knowledge is likely to be interpreted through perceptual filters, such as religiosity. The current study takes up that mantle in order to better understand the complex relationships of many factors when evaluating public opinion formation of geoengineering.

Specifically, this study adds to the previous reports of public opinion of geoengineering, and other emerging technologies, by investigating the influence of media consumption habits, trust in the scientific process and scientists (epistemic trust), and preferences for alternative solutions to anthropogenic climate change. We begin with the influence of media, which often affects what issues the public think about and how they think about those issues (Scheufele and Tewksbury 2007). Media coverage has been shown to play an important role in attitude formation concerning science issues and technologies (Nisbet et al. 2002). Binder et al. (2012) examined how attention to science and political news affects understanding and beliefs about nanotechnology, finding that attention to television science news was positively related to knowledge about nanotechnology.

However, the amount of news attention such issues receive can vary considerably from one country to another (Friedman and Egolf 2011). In Singapore, from which our sample was drawn, news consumers mainly turn to local sources for information, but also use a variety of international sources (Neuman et al. 2017). We predict that consumption of news from both kinds of sources should be positively related to familiarity with geoengineering, and it would be interesting to understand which of the two sources has a greater influence on familiarity.

H1 Familiarity with geoengineering is positively related to (a) local news consumption and (b) international news consumption.

RQ1 Is familiarity with geoengineering more positively related to local news consumption or international news consumption?

1.3 Epistemic trust

Following from the logic provided by previous studies of geoengineering, beliefs about the capabilities of technology to solve environmental problems positively influence perceptions of emerging technologies (Cummings et al. 2017; Mercer et al. 2011). Also, trust in scientists has been shown to have a strong influence on public opinion of emerging technologies. For example, Critchley (2008) found that trust levels in scientists greatly influenced public opinions regarding stem cell research. Berube et al. (2010) also noted that trust can amplify or attenuate perceptions of risks of emerging technologies. These two concepts, trust in the ability of technologies to solve the challenges of climate change, as well as trust in scientists, can be viewed together as epistemic trust, or trust in the enterprise of science. Given such findings, we hypothesize that:

H2 Epistemic trust is positively related to (a) positive opinion of geoengineering and (b) support for government funding of geoengineering research.

1.4 Geoengineering as an alternative solution

As a set of technological solutions, geoengineering is still only one potential alternative toward curbing anthropogenic climate change. The most prominently proposed solution for curbing the effects of anthropogenic climate change has been to lower or stop the use of fossil fuels that create GHGs, especially CO_2. This mitigation approach has become quite apparent among the public as well over the past decade or so as the term "carbon footprint" has become commonplace in media stories, government reports, and industry relations (Wiedmann and Minx 2008). Although many members of the public may believe that averting climate change requires slowing or stopping fossil fuel consumption, there is also

evidence that public opinion supports alternative solutions, such as carbon capture and storage (Sharp et al. 2009). Such solutions do not involve stopping the use of fossil fuels because they target greenhouse gases post-emission. Geoengineering is, in that sense, the same kind of solution. Individuals who prefer such alternative solutions, and are aware of geoengineering as such a solution, should feel more positively about geoengineering. Thus, we hypothesize that:

H3 Preference for alternative solutions that do not involve stopping the use of fossil fuels is positively related to positive opinion of geoengineering.

2 Method

2.1 Sample

Data collection used a Qualtrics online research panel in Singapore. The panel manager invited 3630 members between the ages of 18 and 65 to participate in a Web-based survey. Invited panel members received up to four reminders, and the final dataset contained surveys from 1235 respondents. Most respondents were Singapore citizens (84.4%) or permanent residents (10.6%). Respondents indicated their ethnicity as Chinese (82.1%), Malay (6.2%), Indian (6.9%), Eurasian (.6%), and "Other" (4.3%). Gender was constrained by quota sampling, with roughly equal proportions of females (50.6%) and males (49.4%). Respondents had a median age of 36 years ($M = 37.02$, SD = 12.24), a median educational attainment of "Junior College/Pre-University/Polytechnic," and a median monthly household income of $6001 to $7000 (Singapore dollars).

2.2 Measurement

This study used a portion of data from a school-sponsored omnibus survey. The survey included questions from several researchers, each on a different topic. Given length restrictions, the researchers had to limit the number of items they could include. As a result, several of the measures employed single items. Although this method is an efficient way of collecting data, it limits estimations of construct reliability.

2.2.1 Support for funding

Respondents indicated their agreement with a single item, "Overall, I support Singapore government funding of geoengineering." Response options ranged from 1 (*strongly disagree*) to 5 (*strongly agree*) on a Likert scale ($M = 3.66$, SD = .81). Note that subsequent Likert scaling is identical.

2.2.2 Positive opinion of geoengineering

Respondents indicated their agreement with a single Likert scale item, "Geoengineering will turn out to be safe and effective[1]" ($M = 3.26$, SD = .68).

2.2.3 Familiarity with geoengineering

A single item asked respondents, "Prior to today, how much have you hears about geoengineering?" Response options ranged from 1 (*nothing at all*) to 5 (*a great deal*; $M = 2.05$, SD = .98).

2.2.4 Preference for alternative solutions

Respondents indicated their agreement with two Likert scale items, "We can reduce global warming without changing the amount of fossil fuel we use" and "We should reduce global warming without changing the amount of fossil fuel we use" ($M = 2.96$, SD = .98; Spearman–Brown $\rho = .72$).

2.2.5 Epistemic trust

Respondents indicated their agreement with two Likert scale items, "We must develop new technologies to solve global warming" and "If scientists agree that geoengineering can reduce the impacts of global warming, then I would support its use" ($M = 4.08$, SD = .63; Spearman–Brown $\rho = .57$).

2.2.6 Local/international news consumption

Six items about news consumption had the common root, "In a typical day, how often do you…." Response options for each item ranged from 1 (*never*) to 5 (*very often*). Items measuring local news consumption were "read print copies of local newspapers (e.g., Straits Times, Today)," "read local newspaper websites (e.g., straitstimes.com)," "watch local news on television (e.g., Channel 8)," and "listen to local radio" ($M = 3.17$, SD = .77; Cronbach's $\alpha = .60$). Items measuring international news consumption were "read print copies of international newspapers (e.g., New York Times)," "read foreign newspaper websites (e.g., nytimes.com)," and "watch news on cable television (e.g., CNN, BBC)"

[1] The authors note that this single-item measure is limited in its capacity to illustrate differences between safety and efficacy opinions, but was created to reflect the Royal Society's (2009) conclusion that geoengineering has "yet to be demonstrated to be effective at an affordable cost, with acceptable side effects" (p. x). Some participants may feel that geoengineering is safe but not effective, or vice versa, which cannot be extrapolated from the current data. However, this question still assesses general positive and negative opinions of geoengineering.

Table 1 Correlations among latent factors and observed variables

	1	2	3	4	5	6
1. Support for funding						
2. Positive opinion of geoengineering	.46					
3. Familiarity with geoengineering	− .17	− .21				
4. Preference for alternative solutions	.12	.26	− .15			
5. Epistemic trust	.54	.54	− .15	.14		
6. Local news consumption	− .18	− .15	.25	− .12	− .19	
7. International news consumption	− .12	− .15	.34	− .11	− .12	.65

For all correlations, $p < .01$

Table 2 Summary of findings with respect to hypotheses

Hypothesis	Results			
	B	95% CI	*β*	*p*
H1: Familiarity with geoengineering is positively related to				
(a) local news consumption and	− 0.05	− 0.29, 0.19	− .03	.719
(b) international news consumption	0.59	0.32, 0.87	.34	< .001
H2: Epistemic trust is positively related to				
(a) positive opinion of geoengineering and	0.81	0.67, 0.96	.50	< .001
(b) support for government funding	0.92	0.72, 1.11	.46	< .001
H3: Preference for alternative solutions that do not involve stopping the use of fossil fuels is positively related to positive opinion of geoengineering	0.14	0.09, 0.19	.17	< .001

($M = 2.25$, SD = .87; Cronbach's $\alpha = .73$). These variables had fairly low reliabilities; however, such a result is not surprising. Individuals who strictly consume either local news or international news will still have media-specific preferences.

3 Results

Structural equation modeling in Mplus version 6 tested the hypothesized relationships. First, a measurement model established construct validity. For variables with multiple indicators, unidirectional paths led from indicators to latent factors. Single-item variables were modeled as observed variables. The measurement model freely estimated bidirectional paths among all latent factors and observed variables (Table 1). There were four error covariances among news consumption items. Otherwise, there were no model modifications. The measurement model had acceptable fit, $\chi^2(34) = 102.54$, $p < .001$; CFI = .97; RMSEA = .040, 90% CI [.032, .049]; SRMR = .031. The results reported below include all model paths. Table 2 indicates which hypotheses the results supported.

Next, the structural model specified unidirectional paths as shown in Fig. 1 and constrained to zero, all other paths among latent factors and observed variables. The structural model had acceptable fit, $\chi^2(63) = 225.61$, $p < .001$; CFI = .95; RMSEA = .046, 90% CI [.039, .052]; SRMR = .041.

Familiarity with geoengineering was unrelated to local news consumption, failing to support H1a, and positively related to international news consumption, supporting H1b. The confidence intervals of the effects did not overlap, suggesting that the effect of international news consumption is significantly more positive than the effect of local news consumption. In support of H2a and H2b, epistemic trust was positively related to positive opinion of geoengineering and support for funding. In support of H3, positive opinion of geoengineering was positively related to preference for alternative solutions. The model explained 36.5% of the variance in support for funding, 32.3% of the variance in positive opinion of geoengineering, and 10.3% in familiarity with geoengineering.

4 Discussion

As geoengineering and other emerging technologies gain prominence in media and the public desire greater engagement with decision-making concerning emerging technologies, it is increasingly important for stakeholders to continue developing nuanced understanding of how public opinions are formed and what value predispositions likely serve as perceptual filters (Brossard et al. 2009). This study used a

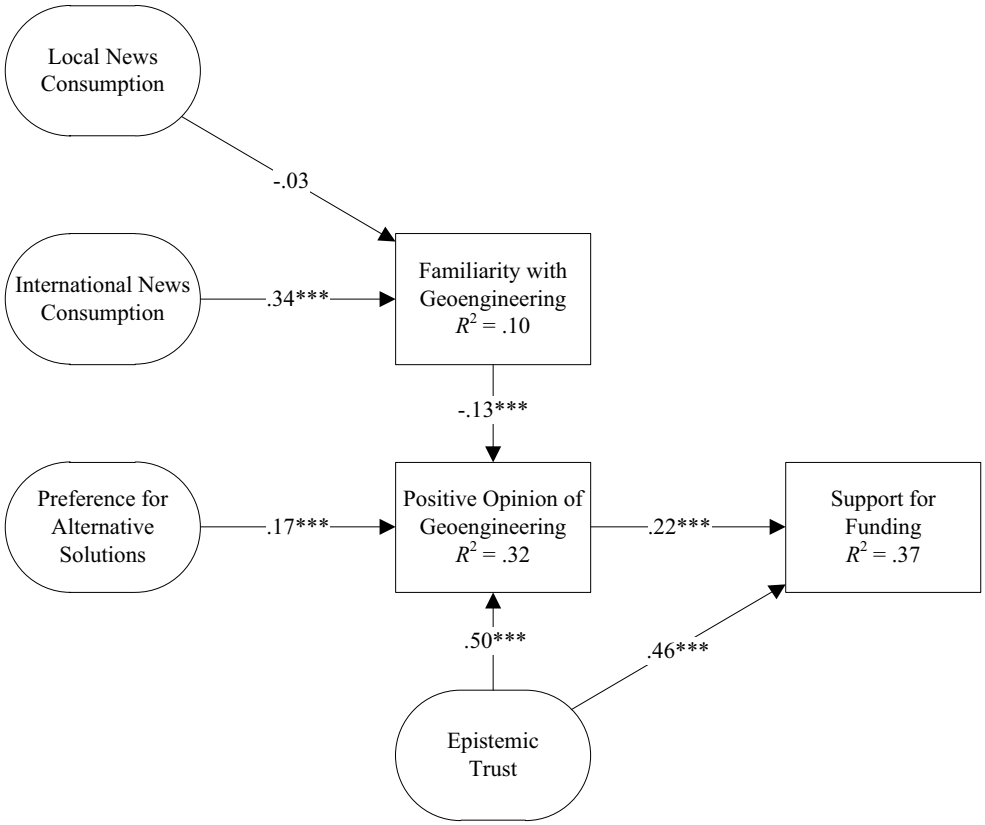

Fig. 1 Standardized estimates of structural paths. ***$p < .001$

large sample of Singapore residents to assess the relationships between value predispositions including epistemic trust and preference for alternative solutions to assess geoengineering proposals for mitigating anthropogenic climate change. It also examined effects of local and international media use on familiarity with geoengineering, opinion of geoengineering, and support for government funding of geoengineering research.

As hypothesized, this study confirmed previous findings that acceptance of geoengineering and public support for government funding of geoengineering were related to familiarity, epistemic trust, and preferences for alternative solutions that do not involve stopping the use of fossil fuels (Cummings et al. 2017; Corner and Pidgeon 2009; Bostrom et al. 2012). Consistent with previous research on media coverage of emerging technology, this study also noted a positive relationship between international news consumption and familiarity (Ho et al. 2011). Counter to our prediction, local news consumption was unrelated to familiarity. One explanation of these dissimilar effects is that geoengineering may be a more prominent feature of the international news agenda than of the local news agenda. However, we are unaware of any news content analyses that would allow for a test of that explanation. Whereas there are content analyses of emerging technology coverage in places outside Singapore (e.g., Romanach et al. 2015; Donk et al. 2012), there are no such analyses of the Singapore news media. We also note that our study is consistent with virtually all previous social scientific surveys of geoengineering in that familiarity is quite low, with only 7.7% of our respondents indicating that they had heard "quite a bit" or "a great deal" about geoengineering. Additionally, there was no significant relationship between media use and positive opinion of geoengineering. Post hoc analysis revealed that positive opinion is unrelated to both local media use ($\beta = .06$, $p = .328$) and international media use ($\beta = -.06$, $p = .311$). These observed relationships may be a product of the complex milieu of current media frames used to depict geoengineering (Hulme 2009). As mentioned previously, geoengineering has been discussed in a variety of ways ranging from risk, governance, and accountability to issues of economics, morality, security, and justice. Further content analytic study may be warranted to identify a typology of geoengineering media frames that can then be used as exemplars for more rigorous media effects message testing.

Of further value for discussion from our findings are the differing influences of familiarity and epistemic trust on opinions of geoengineering. Familiarity with geoengineering

was negatively related to positive opinion of geoengineering. In this case, it appears that the more individuals are familiar with geoengineering as a proposed initiative for curbing climate change, the more they feel that it is unsuitable as a solution at this time. This finding conforms well to other studies that discount the deficit model of public engagement with science, which attributes public skepticism and negative opinion toward science issues to a lack of knowledge (see Kearnes et al. 2006). It further highlights previous findings that many members of the public feel that the risks associated with geoengineering likely outweigh potential benefits (see Cummings et al. 2017 for a full review of both CDR and SRM public opinion studies).

Interestingly, while the relationship between familiarity and positive support for geoengineering is negative, epistemic trust is strongly positively related. This effect may be the result of a trust heuristic, where individuals who are trusting of the institution of science hold positive opinion of geoengineering—as a science-based solution—and support its funding (Slovic 1999). This is not to say that these individuals support use of geoengineering at the current time, but rather, they are more likely to believe that geoengineering will ultimately be safe and effective than those with lower levels of epistemic trust.

Given all of these considerations, this study provides a more nuanced view than have previous studies of how one public may regard geoengineering. This study also demonstrates that opinions about geoengineering are diverse and that opinions can be related to a variety of factors distinct from those related to support for government funding of geoengineering. This provides a glimpse of the complexity of public attitudes and may serve as a reminder that public attitude formation can be guided by a host of predispositional factors and media effects that filter public perceptions of emerging technologies like geoengineering.

Certainly, this model is incomplete; further research should examine such factors as environmental values, concern about climate change, and ascription of responsibility for addressing climate change. It would also be worthwhile to examine dimensions of trust specific to scientific institutions, government, and other relevant actors. Such additions would help make the model generalizable. Yet, there would still be a need to test the model outside Singapore. This is especially the case to test the effects of media consumption. In other parts of the world, there are distinctions between local and national news that do not exist in Singapore, where "national" and "local" are largely the same. The coverage of geoengineering and other emerging technologies likely differs from one media market to another, both within and between countries.

In terms of practical implications, it is important for policy-makers and academics to understand the evolution of opinion formation concerning emerging technologies, noting that individuals use a variety of perceptual filters to make sense of risks and benefits as well as decisions to support or reject a technology. Similarly, communication outreach initiatives must evolve and communicators should better understand the diversity among audiences and seek strategic communication with subpopulations based on value predispositions and media consumption habits. Although the specific effects from this study do not generalize to contexts outside Singapore, they suggest that governments and communicators need to be sensitive to subpopulations in those respects.

Should findings be similar among other publics beyond Singapore, it is also of value to note that international news consumption may be a driving force in familiarizing future citizenry with geoengineering proposals. Our findings also note that greater familiarity is related to more negative opinions of geoengineering. These findings suggest that further study of media impacts on geoengineering perceptions may be of prescient need. We recommend further study of how geoengineering is being communicated among publics around the world. Further description of what forms of communication, and what dominant frames are being communicated about geoengineering would help improve understanding of the dynamics of public opinion on this issue. From this descriptive level, subsequent experimental assessment of which media frames are most influential in opinion formation of geoengineering may help to address challenges faced by science communicators, risk communicators, and policy-makers.

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