

Article

Using Statistics to Increase Both Hope About Solving Climate Change and Acceptance/Concern About Global Warming

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Abstract

Hope is an important emotion for fostering action regarding global warming (GW). This article's experiment utilizes (a) a cognitive hope theory that combines agency and pathways-thinking and (b) prior (numerically driven inferencing) research on how estimating germane quantities, followed by surprising numeric feedback, impacts one's beliefs and decision-making. We designed and assessed a short intervention that focally had 226 Americans estimate quantities regarding the impact/uptake of three GW solutions: sustainable (e.g., solar) electrification, energy efficiency (e.g., recycling), or reduced meat consumption. Changes in climate-change hope and GW beliefs represented the intervention's effectiveness. (Nationalism, etc., were also assessed.) The intervention was generally successful—statistically significantly increasing participants' (1) hope about humanity's ability to tackle climate change and (2) GW acceptance/concern. Our results demonstrate climate-change hope's close relationship with various constructs (particularly, acceptance of GW's reality)—and that central facts can quickly modify such hope. We further replicated findings that core/surprising statistics can spawn environmental conceptual changes. Our results additionally support earlier-identified phenomena that people revise GW beliefs upon encountering salient, valid, surprising information. The findings (a) increase our laboratory's (now 12) ways in which brief materials will boost GW acceptance/concern, and (b) imply that GW messaging should balance climate-dangers explications with hopeful solutions.

Keywords: climate change cognition; global warming; sustainability; hope; sustainable development goals (SDGs); nationalism; education for sustainable development (ESD); cognitive science; educational psychology; numerically driven inferencing



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1. Introduction

Climate change is being driven by global warming (GW) due to humans' greenhouse gas emissions—yielding an extra, non-natural, greenhouse effect. As a result, our planet is nearing climatic tipping points—beyond which sudden, irreversible, environmental changes are likely to occur—unless the international community (i.e., governments, organizations, industries, and individuals) take virtually immediate and accelerative action (Moser, 2020; Sharpe & Lenton, 2021). The important target of sustainability (e.g., Sustainable Development Goals [SDGs]) is arguably best achieved by societies learning to inhibit—or optimally, reverse—GW. Although the vast majority of Americans accept that

GW is happening, concerning, and anthropogenic, concerted societal actions that address the issue have been lamentably slow and climate change has consistently failed to move towards the tops of the political agendas of either governments or citizens. Models of pro-environmental behavior ascribe this lack of action to psychological barriers including a lack of knowledge about, and engagement with, the issue (Zulkepli et al., 2024). Enhanced, GW-focused, communication—and approaches informed by Education for Sustainable Development (ESD)—are therefore needed to both deepen the public's knowledge about the science/impacts of GW and foster beliefs that individuals and societies can inhibit, or even end, GW's threats (Portus et al., 2024).

Efforts to inform the public about the impending threat of climate change have included those from the realms of politics (e.g., Guggenheim & Gore, 2006), journalism (e.g., Thier & Lin, 2022; Yarnall & Ranney, 2017), cognitive science (e.g., Ranney & Clark, 2016; Kihiczak & Ranney, 2023), psychology (e.g., van der Linden et al., 2017; Nielsen et al., 2024), education and learning sciences (e.g., Thacker & Sinatra, 2022; Senthilkumaran et al., 2023), as well as communication (e.g., Maibach et al., 2023; Velautham et al., 2019). One could argue that these efforts have been successful to some degree, given the public's current moderately high rate of acceptance of climate change (YPCCC & Mason 4C, 2025). Furthermore, although it is a broad generalization, the positions of climate denialists have been increasingly shifting from strong denials (e.g., denying the existence of global warming and/or climate change) to weaker denials, such as arguing that the problem is too giant/expensive to do anything about (Cherry et al., 2024; Holder et al., 2023). How one views this success is rather a proverbial “glass part-full/part-empty” contrast—or framing effect. If no one in the aforementioned realms had *ever* informed the public, acceptance/concern rates regarding climate change would be close to zero; but compared to the high levels of public concern necessary to drive actions to retard and mitigate climate change, the efforts have clearly been insufficient.

Regardless of how one frames this “glass,” and although the provision of increasingly accurate scientific information has made acceptance/concern inroads regarding climate change cognition, science communicators and educators increasingly understand that the populace's modest climate-change engagement is also an emotional and/or motivational problem (Brosch, 2021; Jones & Davison, 2021)—beyond being a problem of insufficient public knowledge. This is reflected by the fact that Americans primarily report negative emotions about climate change, such as anxiety (Whitmarsh et al., 2022), hopelessness (Ojala et al., 2021), anger (Gregersen et al., 2023), and guilt (Nielsen et al., 2024)—and they often use common psychological defense strategies such as denial, distraction, and distancing (Mah et al., 2020; Ojala, 2023b) to cope with them. Such negative emotions about climate change have been exacerbated by the portion of communicational approaches that have centered on shaming (or scaring) people into action—a strategy that has the potential to backfire, especially if the audience either (a) feels a low locus of control with respect to the issue or (b) is not sure how (or if) the problem can be solved (Dixon et al., 2023). There has been a subsequent call for climate change communicators and educators to engage with more affective and motivational dimensions of explication. Among motivational and anticipatory emotions, hope is noted by educational and health psychologists as an especially important emotion for positive wellbeing (Murphy, 2023) and for encouraging creative problem solving (Geiger et al., 2025). In particular, constructive hope (i.e., the ability to envision and enact suitable alternatives to the future) has been shown to have positive associations with pro-environmental behaviors and knowledge (Maartensson & Loi, 2022) and to be particularly influential in shaping perceptions of, and responses to, climate change (Ojala, 2023a). Before we describe our experiment, let us consider a taste of what shapes these perceptions and responses to information about global warming.

1.1. Examples of Emotional/Motivational Inhibitors of Conceptual Change re: Climate

Qualitative evidence of the emotional and motivational impediments to knowledge-uptake regarding climate change abound. To date, our research group has discerned at least a dozen different ways to increase even the most conservative participants' acceptance-and-concern levels regarding global warming (Senthilkumaran et al., 2023). Some of these 12 successful interventions followed in situ circumstances in which the present article's second author interviewed people who denied human-caused climate change for one reason or another. What follows are two of such contextualized examples, each tinged with elements of hope (and concerns about offspring).

1.1.1. Volcanoes Misconception

In this instance, a participant (an engineer) asserted that he thought global warming has been happening, but that it was part of a "natural cycle." When asked what was driving the warming, he said that it was "increased volcanic activity." He was then given a summary of the correct scientific explanation (i.e., the gist of our lab's 400-word text, used by Ranney & Clark, 2016: <https://www.howglobalwarmingworks.org/400-words.html>; accessed on 31 January 2026), yet he still preferred his volcanic explanation. He was informed that climatologists had already quantitatively disconfirmed volcanoes as a driver of the current warming. He then received an estimate of how small an effect volcanoes have in general—and was told that Earth would actually be cooling at this point in our natural cycles, were it not for humans. He was still reluctant to accept the normative explanation, though, so he was asked: "Why, on a cooling planet, would volcanic activity be increasing? What's the mechanism by which, right now, volcanoes 'decided' to be more globally active?" He replied that he had no idea why, and that he really was not *positive* that it was volcanoes. He was then asked, "Why would you consider volcanoes to be the cause of global warming when you can't explain the volcanoes-mechanism, especially when the scientific mechanistic explanation (with human-produced greenhouse gases increasingly absorbing earth's emitted infrared light) does explain global warming?" He then pivoted to say that the company he built/owned extruded plastic. After a pause, he said that he had several children and grandchildren and that he preferred to ignore the topic. It seemed as if he saw accepting anthropogenic climate change as tantamount to accepting guilt for effectively being part of the fossil fuel industry—and for its effects on his descendants.

1.1.2. Climate Emergency Denier

A similar interview involved a retired recreational bowler in Denver. In denying global warming, he cited as evidence a letter avowedly sent to the UN Secretary General claiming that there was no climate emergency, which was allegedly signed by 500 purported scientists. He was told that the interviewer had heard about the letter, and was then asked, "How many scientists do you think there *are*, in general?" He replied, "There are lots; probably thousands even just up the road in Boulder." (Of course, that is more than true.) Then the implication dawned on him, and he said, "Oh, I see what you're doing. You're trying to make me think that 500 scientists is a small portion of the world's scientists." When asked whether he had kids, he replied, "Yep; two adult sons." When he was asked what they thought, he replied, "They both totally believe in the global warming stuff." Like the other participant, he then said he would rather talk about other things. One might infer that hope for his children's future played a part in his denial of global warming. We examine climate-permeated hope explicitly in the experiment we describe now.

1.2. An Experiment About Hope and Climate Change

Snyder's (2002) cognitive theory of hope is widely used both in clinical practice and in positive psychology. According to this theory, hope is not so much a generalized desire or expectation for something to happen, but rather is comprised of the interaction of two core components: (a) "pathways thinking," by which one conceives of specific strategies to attain desired goals, and (b) "agency," by which one motivates oneself to adopt such pathways to achieve those desired goals. In practice, this means that to be truly hopeful, one's positive expectations (as opposed to certainties) about the future should be driven by clear, actionable, goals—and by active strategies to achieve them (Maartensson & Loi, 2022). Such a framing of hope is aligned with the cognitive appraisal theory of emotion (see Lazarus, 1982), in which rational thoughts and the cognitive appraisal of threat play essential roles in emotion formation (as opposed to emotions arising only from physiological sensations or bodily arousal). In this context, hope represents an active, motivational force that springs from a point of concern and is clearly associated with action (Li & Monroe, 2019; Ojala, 2023a)—in contrast to optimism, which Eagleton (2015) defined as the broadly generalized expectation of a positive future outcome.

Due to its close association with action, hope is an especially relevant emotion for encouraging proactive behavior, and it has successfully been applied in the context of environmental challenges (Mortreux et al., 2025). Much of the research involving hope and climate change, though, has been qualitative and exploratory. Example studies include either characterizing why it is important to be hopeful about climate change or studying the efficacy of classroom-based interventions for cultivating hope in students (Finnegan & d'Abreu, 2024; Marks et al., 2023). There is, however, a dearth of hope-inducing interventions that can be quickly and easily integrated into study materials—or disseminated by teachers and activists. The lack of quantitative assessments of hope-inducing interventions centered on climate change means that there is also scant empirical evidence of causal relationships between hope and other variables, such as global warming acceptance and/or other pro-social emotions. Not having such causal evidence inhibits the success of designed hope-centered interventions. Another limitation of current scholarship on the conjunction of hope and climate change is that most of the work centers on young people (e.g., students). This means that when recommendations for solutions or actions are made, they tend to highlight a narrow spectrum of individual, easy-to-enact, pro-environmental behaviors that youths can take, such as recycling—which may be ultimately virtually ineffective in the face of worldwide greenhouse gas emissions (the communication of which can, counterproductively, decrease hope; Ojala, 2017).

While individual behavior change plays an important role in global warming solutions, such change is primarily impactful if carried out on a collective scale and in combination with large-scale, societal-level, shifts. Despite the greater import of collective goals and pathways, climate education researchers tend to focus largely on researching individual energy conservation behaviors (Jorgenson et al., 2019). This is consistent with a criticism of Snyder's theory of hope: that it frames the pursuit of goals as an overly individualistic endeavor (Schornick et al., 2023). Snyder and Feldman (2000), however, claimed that a characteristic of high levels of hope is an implicit attendance to collective thinking (i.e., communal/shared goals and commensurate pathways/agency thoughts), enhancing both individual and shared future goals. To translate this implicit understanding into something more explicit, educators need to help people develop a sense of both the scale and the collective impact of their actions (i.e., to frame climate change as a collective problem to be tackled at collective levels). In other words, it is crucial for climate communicators to facilitate people's engagement in mechanistic thinking (namely, to develop an awareness and understanding of the relationships among individual-scale actions and global reduc-

tions in greenhouse gas emissions)—a kind of systems-level thinking that is challenging to perform well (Whitmarsh & Mitev, 2022; cf. physical–chemical mechanistic thinking: Joslyn & Demnitz, 2021; Ranney & Clark, 2016; etc.). If the collective impact of individual pro-environmental behaviors can be emphasized, this may reduce the “drop in the ocean” feelings of individual helplessness. It may also activate beliefs that collective actions will lead to success—and that one’s participation will contribute to it (Holahan & Lubell, 2022), thus increasing hope and a sense of empowerment and influence (Geiger & Fraser, 2025). One way that we hypothesize that such mechanistic thinking, systems-level thinking, and quantitative reasoning can be activated (other than simply reading mechanistic descriptions of pro-environmental behaviors) is through the numerically driven inferencing paradigm (NDI; e.g., Ranney et al., 2016).

Numerically driven inferencing is characterized by estimating salient quantities (and sometimes generating preferences) relating to policy issues (e.g., abortion) before receiving the actual/true values as feedback—which catalyze surprise-mediated changes in belief systems (Munnich & Ranney, 2019; Ranney & Velautham, 2021). During the act of estimating a numerical quantity, participants evoke networks of facts, set relationships, and causal (e.g., mechanistic) beliefs from among personal experiences, the media, and other sources—which in turn increase the likelihoods of conceptual changes (Ranney et al., 2012; Thacker & Sinatra, 2022). (The interaction of mechanistic and numerical reasonings has deep roots—even in Gestalt psychology, starting roughly 100 years ago.) It has additionally been shown by Ranney et al. (2016, etc.) that surprising numerical feedback can cause changes in one’s interconnected understandings, which affect (a) one’s policy preferences, (b) one’s sense of nationalism (e.g., for Americans when the quantities are US-centric), (c) how much one cares about a topic, and (d) keenly relevant to this experiment, one’s emotions (e.g., Munnich et al., 2004). Given research indicating the public’s innumeracy with respect to estimating emissions data and the quantitative impacts of sustainable behavior—especially for high-impact behaviors such as diet and travel (Johnson et al., 2024; Ludwig et al., 2025)—we predict that hope-engaging, corrective climate-change feedback will be markedly surprising, and hence be likely to yield changes in beliefs and/or emotions about society’s ability to successfully address GW.

Based on the preceding contexts—and interests in the attendant confluence of theory and methodology—this article’s experiment was designed to investigate GW-related hope with two primary hypotheses, H1a–c and H2:

H1a. *Exposure to an NDI-intervention centered around US-specific climate change solutions increases participants’ hope about humans’ ability to solve climate change.*

H1b. *Exposure to an NDI-intervention centered around US-specific climate change solutions increases participants’ climate change acceptance.*

H1c. *Exposure to an NDI-intervention centered around U.S.-specific climate change solutions increases participants’ nationalism. (Prior work has shown a robust link between nationalism and climate; e.g., Ranney et al., 2019.)*

H2. *Surprise (e.g., at the discrepancy between one’s estimate and the true numerical feedback) is a significant driver of any observed heightened hope about climate change.*

2. Materials and Methods

After (a) a search of the relevant scientific literature and (b) consultations with climate scientists, three societal-level-scale solutions were identified that have been heralded by scientists and policymakers as the most feasible and impactful ways to reduce greenhouse

gas emissions. Solutions were required to have an empirical justification in a prominent journal that had been widely accepted by the broad scientific community (i.e., solutions that had not attracted controversy or been “debunked”). The identified solutions were: (1) sustainable electrification, (2) energy efficiency, and (3) societal reduction in meat consumption. Once confirmed, each of the three solutions were then searched with Google.com and links from the first five pages of results were mined for surprising/germane quantitative statistics. Salient statistics were chosen because they either centrally related to impacts of behaviors or demonstrated the extent to which they have already been adopted and/or effective. Since participants were expected to be US-based, and nationalism was a construct of interest, statistics that demonstrated the effectiveness of the three solutions in a US context were given preference. Overall, ten surprising statistics were chosen for each of the three solutions and then reduced to five apiece—through iterative rounds of feedback with both scientists and pilot participants. The final five statistics associated with each solution appear in Table 1.

Table 1. Surprising statistics associated with each of the three identified solutions.

Solution	Statistic
Electrification	1. Greenhouse gas emissions associated with the U.S. power sector have [increased/ decreased *] by <u>28%</u> since 2005, due to changes in the kinds and amounts of fuels used to generate electricity. (Source: The U.S. Energy Information Administration)
	2. A new law requires California, the world’s fifth-largest economy, to have <u>100%</u> carbon-free (i.e., no fossil-fuel derived) electricity by 2045. (Source: California Energy Commission)
	3. In 2018, the United States had 249,983 solar workers (defined as those who spend 50% or more of their time on solar-related work) compared to the 198,583 people who worked in the coal-, oil-, and gas-extraction industries combined. (Source: The National Solar Jobs)
	4. <u>70%</u> of the state of Washington’s current electricity is generated from existing hydroelectric sources. (Source: U.S. Energy Information Administration)
	5. Between 2009 and 2014, the cost of solar electricity (measured in dollars per kilowatt-hour) in the U.S. [increased/ decreased *] by <u>78%</u> . (Source: California Public Interest Research Group)
Energy efficiency	1. From 1960 to today, the disposal of everyday (that is, non-industrial) U.S. waste directly to landfills has changed from 94% of the total waste generated to <u>52%</u> of the total waste generated. (Source: EPA)
	2. In 2017, the average American person recycled (including composting) <u>1.58</u> pounds of household material per day. (Source: EPA)
	3. The U.S. recycling industry generates 8.5 times as many jobs as the U.S. landfill industry, equating for the weight of material recycled versus landfilled. (Source: recycleacrossamerica.org)
	4. Recycling a single aluminum can save the equivalent of enough energy to power a TV for <u>3</u> h. (Source: EPA)
	5. In terms of energy savings, recycling a single can of aluminum can keep <u>19</u> cans from having to be mined and manufactured from raw materials. (Source: Stanford Recycling Center)
Meat Reduction	1. According to a recent study in the journal “Science Reports”, if everyone in the U.S. reduced their consumption of beef, pork and poultry 25% by substituting plant proteins, we’d reduce yearly greenhouse gas emissions by about <u>180,000,000,000</u> (180 billion) pounds. (Source: Science Reports)
	2. Americans’ current per capita beef consumption has [increased/ decreased *] by <u>33%</u> since the 1970s (Source: New York Times)
	3. A study published in the “Journal of Hunger and Environmental Nutrition” estimated that vegetarians saved \$ <u>750</u> per year, compared to meat eaters. (Source: Journal of Hunger and Environmental Nutrition)
	4. From a representative sample of Americans, <u>60%</u> report they have either stopped or reduced their meat consumption over the last ten years. (Source: Public Health Nutrition)
	5. A study published in “Environmental Research Letters” found that eating a plant-based diet had an average of <u>8</u> times a more positive environmental impact than upgrading light bulbs (in which “positive impact” is measured in terms of CO ₂ -equivalent emissions). (Source: Environmental Research Letters)

* For three items, participants had an extra action; they were to (a) indicate (i.e., click) either “increased” or “decreased,” and (b) as usual, write a number into the blank. (Correct indicating, bolded + underlined for the reader, was always “decreased.”).

2.1. Participants

Amazon Mechanical Turk (MTurk) participants were recruited early in 2021 and paid \$5 upon finishing their survey-style participation, such that 300 responses were collected. After incomplete responses were deleted and other exclusion criteria (detailed below) applied, 226 responses were analyzed; 62% of these were from men and 38% from women. Participants' mean age was 37.2 years, and 57% of the sample identified as Democrats, with 22% as Independents and 16% as Republicans. The average economic and social conservatism ratings were respectively 4.27 and 3.92 out of 9—indicating a reasonably centrist yet mildly liberal orientation.

2.2. Procedure, Design, and Analytic Strategy

After receiving informed consent, participants completed a pre-test that assessed their levels of hopefulness about climate change, climate change acceptance, and nationalism. (Participants were told that all the information they would receive was factually true—and that they could, of course, check that later.) Hopefulness was measured using our 12-item Hope About Climate Change scale (adapted from [Li & Monroe, 2018](#) 12-item scale), with Cronbach's alpha ranging from 0.88 to 0.90 across the pre- and post-tests. Eight items comprised our GW Acceptance/Concern scale (from [Ranney & Clark, 2016](#), and also used in [Velautham & Ranney, 2020](#)), with Cronbach's alpha ranging from 0.90 to 0.91 across the pre- and post-tests. Four items comprised our Nationalism scale (from [Ranney et al., 2019](#)), with Cronbach's alpha ranging from 0.69 to 0.76 across the pre- and post-tests. [For all pre-/post-test items used, see Appendix A herein (from [Velautham, 2022](#))]. Participants were randomly assigned to one of three conditions in which they read a brief text providing an overview of one of three solutions for climate change—electrification ($n = 67$), energy efficiency ($n = 82$), or meat reduction ($n = 77$)—after which they responded to two comprehension items relating to the text [for texts/comprehension items for each condition, see Appendix B herein (from [Velautham, 2022](#))]. Participants were then shown five statistics on their randomly assigned solution-topic (as per Table 1). For each statistic, a variation on NDI's EPIC procedure ([Munnich et al., 2004](#)), which is more similar to [Rinne et al.'s \(2006\)](#) PEIC procedure, was used: participants were shown the verbal framing of a statistic with the quantity blanked out and then asked to numerically estimate the quantity; for all five statistics, participants were then given feedback on their estimates (i.e., what the true number was, along with displaying the size of one's estimate's error)—as well as the estimates' sources. Participants were then asked to rate how surprised they were by the feedback-number on a 1–9 scale. After repeating this process for the five statistics corresponding to their solution/condition, participants completed a post-test that was identical in form to the pre-test. They were then asked to provide some demographic information before being thanked and dismissed.

2.3. Exclusion Criteria

Participants were assessed, regarding possible data exclusion, based on (a) their accuracy in responding to four catch items in the pre-/post-tests, (b) their written responses to the comprehension items, and (c) the relative duration of their pre-and post-tests (compared to the average completion duration of 18 min). They were excluded if (1) their score was above 25% of the total possible exclusion score across a-c, (2) they indicated that they were not American, or (3) their IP address indicated they participated from outside of the US. Thus, 74 were excluded, yielding the aforementioned 226 participants.

3. Results

3.1. Primary Analyses

Overall, the process of reading an overview of one of the three climate change solutions, plus estimating-and-receiving-feedback on quantities relating to it, yielded robust gains in both climate-change hope and global warming acceptance. Indeed, consistent with Hypotheses H1a–H1c, aggregating pre-to-post changes across the three experimental conditions yielded statistically significant increases for *all three* main dependent variables: hope ($t[225] = 7.0589$; $p < 0.01$, $d_z = 0.470$), global warming acceptance ($t[225] = 2.2219$; $p < 0.05$, $d_z = 0.148$), and nationalism ($t[225] = 2.5749$; $p = 0.01$, $d_z = 0.171$; with the paired-samples standardized mean change effect size calculated using the formula $d_z = t/\sqrt{n}$; see Table 2 for means, SDs, p -values, etc.).

Table 2. Pre-to-post changes in study variables ($N = 226$).

	Pre-Test/9		Post-Test/9		Average Pre-to-Post-Test Change	95% CI Mean Difference [Lower, Upper]	t -Value	df	p
	M	SD	M	SD					
Hope	6.31	1.22	6.54	1.26	+0.23	[0.164, 0.291]	7.059	225	2.061×10^{-11} **
GW acceptance	7.10	1.53	7.18	1.57	+0.08	[0.009, 0.143]	2.222	225	0.02728 *
Nationalism	5.50	1.59	5.61	1.65	+0.10	[0.024, 0.182]	2.575	225	0.01067 *

* $p < 0.05$; ** $p < 0.01$.

Including all conditions, Table 3 presents the means (and standard deviations) of, and the correlations among, the major dependent variables—hope, global warming acceptance and nationalism—along with conservatism. Conservatism has consistently been found to markedly *negatively* correlate with global warming acceptance (yet *positively* correlate with nationalism) in past studies (e.g., Ranney et al., 2019; Velautham & Ranney, 2020).

Table 3. Correlations of study variables, along with conservatism ($N = 226$).

	M	SD	2.	3.	4.	5.	6.	7.
1. Hope T1	6.31	1.22	0.493 **	0.072	0.924 **	0.482 **	0.072	−0.230 **
2. GW T1	7.10	1.53		−0.330 **	0.523 **	0.950 **	−0.340 **	−0.660 **
3. Nat T1	5.50	1.59			0.034	−0.278 **	0.932 **	0.360 **
4. Hope T2	6.54	1.26				0.510 **	0.036	−0.250 **
5. GW T2	7.18	1.57					−0.292 **	−0.640 **
6. Nat T2	5.61	1.65						0.380 **
7. Conservatism	4.09	2.32						

** $p < 0.01$.

Of 28 possible, 24 correlations were statistically significant—with the only non-significant correlations being those between *pre*-test hope and both pre-and-post-test nationalism, as well as between *post*-test hope and both pre- and post-test nationalism (see Table 3). These results indicate that people who are hopeful about global warming tend to have a higher acceptance that it is occurring. The data also add further support for the strongly negative relationship between global warming acceptance and nationalism—one that Ranney and colleagues have consistently demonstrated in both correlational and causal studies (e.g., Ranney, 2012; Velautham & Ranney, 2020). Indeed, Ranney et al. (2019, Experiments 3 and 4) further showed that the relationship is bidirectional (i.e., bi-causal) such that increasing global warming acceptance yielded reduced nationalism (and vice versa).

3.2. Change in Variables by Condition

As a secondary analysis, we also disaggregated our effects by climate-change solution, although the tests, of course, lost power in so doing. Still, participants in all three conditions experienced statistically significant increases in hope (i.e., pre-to-post-test): in

the electrification condition ($M = 6.24$ [$SD = 1.17$] to $M = 6.49$ [$SD = 1.14$]; t [66] = 4.5579, $p < 0.01$, $d_z = 0.557$), the energy efficiency condition ($M = 6.38$ [$SD = 1.29$] to $M = 6.62$ [$SD = 1.34$]; t [81] = 4.083, $p < 0.01$, $d_z = 0.451$), and the meat reduction condition ($M = 6.30$ [$SD = 1.20$] to $M = 6.49$ [$SD = 1.29$]; t [76] = 3.6352, $p < 0.01$, $d_z = 0.414$). Global warming acceptance increased in a borderline manner for the meat reduction condition: $M = 7.06$ ($SD = 1.53$) to $M = 7.19$ ($SD = 1.62$; t [76] = 1.9645, $p = 0.05$, $d_z = 0.224$). The electrification condition exhibited a significant increase in their nationalism ($M = 5.21$ [$SD = 1.66$] to $M = 5.44$ [$SD = 1.72$], t [66] = 2.837, $p < 0.01$, $d_z = 0.347$; see Table 4). (The energy efficiency condition yielded such a change marginally; $p = 0.09$.)

Table 4. Pre-to-post changes in study variables per condition ($N = 226$).

Condition	Variable	Pre-Test/9		Post-Test/9		Average Pre-to-Post-Test Change	95% CI Mean Difference [Lower, Upper]	<i>t</i> -Value	df	<i>p</i>
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>					
Electrification (<i>n</i> = 67)	Hope	6.24	1.17	6.49	1.14	+0.25	[0.145, 0.372]	+4.558	66	2.29×10^{-5} **
	GW acceptance	7.20	1.45	7.27	1.44	+0.07	[−0.057, 0.187]	+1.060	66	0.2932
	Nationalism	5.21	1.66	5.44	1.72	+0.23	[0.067, 0.388]	+2.837	66	0.0060 **
Energy Efficiency (<i>n</i> = 82)	Hope	6.38	1.29	6.62	1.34	+0.24	[0.121, 0.350]	+4.083	81	0.0001 **
	GW acceptance	7.06	1.60	7.10	1.64	+0.04	[−0.067, 0.148]	+0.749	81	0.4558
	Nationalism	5.53	1.60	5.64	1.66	+0.11	[−0.017, 0.236]	+1.729	81	0.0876 †
Meat Reduction (<i>n</i> = 77)	Hope	6.30	1.20	6.49	1.29	+0.19	[0.087, 0.299]	+3.635	76	0.0005 **
	GW acceptance	7.06	1.53	7.19	1.62	+0.13	[−0.002, 0.247]	+1.964	76	0.0531 †
	Nationalism	5.73	1.51	5.71	1.58	−0.02	[−0.140, 0.114]	−0.203	76	0.8394

† $p < 0.1$, and ** $p < 0.01$.

To compare the changes in variables across the different conditions, three one-way ANOVAs compared the effects of the three conditions regarding change in hope, change in global warming acceptance, and change in nationalism. It was found that the observed changes across the three main dependent variables were statistically equivalent across the conditions: for changes in hope (F [2,223] = 0.337, $p = 0.714$), global warming acceptance (F [2,223] = 0.53, $p = 0.589$), and nationalism (F [2,223] = 2.932, $p = 0.055$).

Participants were generally moderately-to-quite surprised by the numerical feedback. To analyze participants' estimates, the maximum and minimum estimate for each blanked-out quantity was calculated—along with the median estimate, participants' percent error (e.g., the discrepancy between the median estimate and the true feedback), the true quantity, and participants' average self-rated surprise at the discrepancy between their estimate and the true numerical feedback. Consistent with past NDI studies, participants' average percentage error for estimates exceeded 45% for all conditions and was found to be highest for the meat reduction condition—the condition yielding the highest surprise (and a mean error of 66%; see Table 5a–c, and recall that Table 1 has the statistics' wordings).

An ANOVA was used to assess whether participants' average surprise at the feedback they received for their estimates differed among conditions. A one-way ANOVA revealed a statistically significant difference in average surprise at feedback between at least two conditions (F [2,223] = 5.29, $p < 0.01$). Tukey's HSD test for multiple comparisons found that the average surprise significantly differed between conditions 2 and 3 ($p < 0.01$, 95% C.I. = [0.21, 1.36])—specifically, that the meat reduction statistics were more surprising than the energy efficiency statistics. There were no reliable differences in average surprise for the other two condition-contrasts ($p = 0.20$ and $p = 0.34$).

Table 5. (a) Estimates for the electrification statistics (i.e., Condition 1, $n = 67$); (b) estimates for the energy efficiency statistics (i.e., Condition 2, $n = 82$); (c) estimates for the meat reduction statistics (i.e., Condition 3, $n = 77$).

(a)					
Statistic	Estimate Range	Median Estimate	Actual Answer	% Error	Average Surprise/9
Electrification [1]	−70–+80%	−10%	−28%	4	4.94
Electrification [2]	0–100	80	100	20	4.72
Electrification [3]	15–550,000	91.842	249,983	63	6.64
Electrification [4]	8–89	40%	70%	43	6.03
Electrification [5]	−100–+70%	−20%	−78%	74	6.96
			Means:	53	5.86
(b)					
Statistic	Estimate Range	Median Estimate	Actual Answer	% Error	Average Surprise/9
Energy Efficiency [1]	2–98%	69%	52%	33	6.05
Energy Efficiency [2]	0.5–400	5	1.58	46	4.71
Energy Efficiency [3]	2–100,000	4.5	8.5	47	5.40
Energy Efficiency [4]	1–452	4	3	33	4.40
Energy Efficiency [5]	0.5–2,000,000	5	19	74	6.57
			Means:	47	5.43
(c)					
Statistic	Estimate Range	Median Estimate	Actual Answer	% Error	Average Surprise/9
Meat Reduction [1]	$1-1 \times 10^8$	500	180,000,000,000	99	7.80
Meat Reduction [2]	−75–+1200%	+1%	−33%	97	4.99
Meat Reduction [3]	6–2,500,000	500	750	33	5.58
Meat Reduction [4]	2–86%	15%	60%	75	7.47
Meat Reduction [5]	1.25–300	10	8	25	5.23
			Means:	65.8	6.21

3.3. Regression Analyses re: Hope and Surprise

Regression analyses were also carried out to assess the extents to which post-test hope was predicted by two models: Model 1 included pre-test GW acceptance, pre-test hope, conservatism, and the condition to which a participant was assigned. Model 2 subsumed Model 1, but further included the average surprise at the numerical feedback that participants received (see Table 6).

Table 6. Regression analysis regarding post-test hope ($N = 226$).

Variable	Model 1			Model 2 (i.e., Adding Surprise)		
	Coef	SE Coef	<i>t</i>	Coef	SE Coef	<i>t</i>
Intercept	0.190	0.270	0.71	0.250	0.290	0.850
Pre. H	0.910	0.030	29.93 *	0.910	0.031	29.50 *
Pre. GW	0.085	0.031	2.71 *	0.084	0.031	2.67 *
Condition						
Condition 2	−0.003	0.079	−0.04	−0.008	0.080	0.92
Condition 3	−0.005	0.080	−0.60	−0.045	0.080	0.58
Conservatism	0.010	0.019	0.54	0.011	0.019	0.57
Surprise				−0.011	0.021	0.61
R^2	0.8604			0.8605		
<i>F</i> for R^2 change	271.1			225.2		

Note: * $p < 0.05$. Condition was represented as two dummy variables; Condition 1 served as the reference group.

Model 1 fit with an R^2 of 0.8604 ($F [5,220] = 271.1, p < 0.01$), explaining roughly 86% of the variance. In this model, it was found that pre-hope significantly predicted post-hope ($b = 0.910$, $SE_b = 0.030$, $t [220] = 29.93$, $p < 0.01$), as did pre-GW-acceptance ($b = 0.085$, $SE_b = 0.031$, $t [220] = 2.71$, $p < 0.01$). Model 2, with its added term for surprise, evidenced an almost identical $R^2 = 0.8605$ ($F [6,219] = 225.2$, $p < 0.01$), also roughly explaining 86% of the variance. With Model 2, it was again found that pre-hope significantly predicted post-hope

($b = 0.910$, $SE_b = 0.031$, $t [220] = 29.50$, $p < 0.01$), as did pre-GW acceptance ($b = 0.084$, $SE_b = 0.031$, $t [220] = 2.67$, $p < 0.01$; see Table 6). Model comparison using an ANOVA indicated that Model 2's added term, surprise, in contrast with H2's prediction, did not significantly improve upon Model 1's predictive utility ($F [1,220] = 0.2649$, $p = 0.6073$).

4. Discussion

Using data from all conditions, the results show the basic intervention—that is, reading a brief overview of a societal solution that addresses climate change and then estimating-and-receiving-feedback on estimates of five quantities relating to it—produced statistically significant increases (Table 2) in three measures: (a) hope about (humans' ability to solve) climate change ($p < 0.01$), (b) global warming acceptance ($p < 0.05$), and (c) nationalism ($p < 0.01$; perhaps due to the information's US-affirming nature). These findings demonstrate that, as hypothesized, both climate-change hope and (replicating prior studies) GW acceptance can be changed with relevant information—and that using statistics conveying the quantitative impact of solutions (Table 1) seems an effective method to do so. Exposure to *each* of the conditions yielded statistically significant increases in hope (as Table 4 showed: $p < 0.01$, for the electrification group, $p < 0.01$, for the energy efficiency group and $p < 0.01$ for the meat reduction group); however, in the reduced-power, by-condition context, only the meat reduction intervention (which was most surprising for participants) yielded a marginally statistically significant increase in GW acceptance ($p < 0.05$; also in Table 4). Furthermore, the observed changes in climate-change hope, GW acceptance, and nationalism did not significantly vary across the conditions (i.e., all conditions yielded comparable effects on these variables). Thus, each of the solutions was roughly equally effective (with p 's < 0.001) in boosting our focal variable, hope about climate change. [Nb: We are reluctant to make too much of the overall nationalism increase because stimulus framing might have primed national identity: such priming may have more than fully countervailed the effects found in prior research that might have predicted a drop in nationalism. Over many studies (and noted in Section 3.1), nationalism has consistently been negatively connected to GW acceptance (Velautham & Ranney, 2020, etc.), including a bi-causal finding (Ranney et al., 2019). However, in the present experiment, while still negatively correlated, nationalism and GW acceptance moved in the same, positive, direction. Perhaps our stimuli convolved US hope-inducing aspects that overcame negative-default links, e.g., from nationalism's conflict with the need for international climate agreements—or from political associations between slogans such as “America first” and “drill, baby, drill.”]

Numerical estimates offer insights into the US public's perceptions of climate change solutions—particularly Americans' views of the feasibility, uptake, and efficacy of the climate change solutions touched on in the interventions. A review of estimates provided for each condition showed that participants gave, on average, the most inaccurate answers for the meat reduction condition's statistics and, accordingly, these yielded the highest average surprise at the discrepancies between the “meaty” estimates and their true values (see Table 5a–c). Analyses also showed that participants' mean surprise in the meat reduction condition was significantly higher than that in the energy efficiency condition. This may be because more vegetarianism is a comparatively less publicized strategy compared to energy efficiency. The two most surprising statistics from this condition (although not atypical of the condition's other three statistics) illustrated (a) the large impact of a relatively small reduction in meat consumption (meat item #1) or (b) the relatively large number of Americans who have either stopped, or reduced, such consumption in the past three years (meat item #4). Participants' high surprise at these two statistics indicates both an underappreciation of how effective rather small lifestyle changes are in terms of greenhouse gas emissions—and a general underestimation of other Americans' pro-environmental

actions and attitudes. This supports research showing that consumers do not accurately assess the effectiveness of high-impact behaviors like reducing meat consumption and mobility (Kretschmer, 2024), which likely limits people's ability to align their behaviors with growing sustainable intentions.

Statistically significant positive correlations were observed between climate-change hope and GW acceptance (as noted: $r = 0.493$, $p < 0.01$ for pre-test hope vs. pre-test GW acceptance), and also significant *negative* correlations between conservatism and, respectively, climatic hope and GW acceptance ($r = -0.23$, $p < 0.01$ re hope—and replicating what, as mentioned in Section 3, our lab has found in the past— $r = -0.66$, $p < 0.01$ re global warming; see Table 3). Regression models relatedly indicated that roughly 86% of the variance in post-test climatic hope was explained by the constructs of pre-test climatic hope, pre-test GW acceptance, condition, and conservatism—and that the model's predictive utility after adding participants' surprise-upon-feedback was unchanged (see Table 6). [Regarding conservatism: Note that our lab's prior research shows that many interventions increase GW acceptance/concern—even for participants who are the most conservative (economically and/or socially) and who are least accepting of GW at pre-test; thus, no polarization is observed from the materials (see Kihiczak & Ranney, 2023; Ranney et al., 2019; Ranney & Velautham, 2021; Senthilkumaran et al., 2023).]

This experiment's results strengthen the case for a notable positive relationship between the variables of climate change acceptance/concern and hope about climate change. What are salient implications of this observed hope-acceptance link regarding GW? A straightforward step is to make our statistical stimuli available to the public and (e.g., environmental) organizations, as has been done for some of our lab's other compelling, experimentally vetted, interventions (e.g., on our well-visited public outreach site: How-GlobalWarmingWorks.org). However, in contrast to more “pure fact interventions” that focused more on mechanisms, scientific phenomena, nationalism, and the nature of science (cf. Ranney & Velautham, 2021), hope has a different emotional and motivational character (Ojala, 2023a). Stemming even from behaviorist analyses (e.g., Spence, 1958) that action reflects one's drive and skill (e.g., generically: “performance = drive $\times$ ability”)—one can argue that hope (e.g., agency and pathways-thinking; Snyder, 2002) is a catalyst for drive. That is, if one has zero climate hope (e.g., no agency or sense of pathways to success; cf. Section 1.1's examples), acting is a waste of effort/time (cf. Brosch, 2021; Mortreux et al., 2025). In contrast, if one believes that one is filled with agency and sees many pathways that are not just “drops in the ocean” (mentioned in Section 1) to a better climate future, one will be infused with drives to act (cf. Maartensson & Loi, 2022). (This is likely why many climate-action advocates remind humanity of its success in shrinking the ozone hole: it is a global-scale existence-proof of pathways-thinking agency; see Ewart et al., 2015.) Therefore, while more physically oriented, etc., pure fact interventions have their places in fostering the public's drive to act, ways to foster *informed* hope (e.g., with Table 1's statistics), as reified in this experiment, will be crucial to tackling climate change.

Overall, the empirical study reported herein helps fill the void (described in Section 1) of quick, efficient, hope-inducing, causally relevant, experimentally assessed (non-exploratory), student- and adult-ready materials regarding GW. Further, results (due to our item-sets; Table 1) are more relevant to collective solutions, compared to researchers who primarily look at the individual conservation behavior of youthful students (cf. Jorgenson et al., 2019). How might climate communicators/educators further utilize our findings and reflections? We think it is instructive (for climate communicators/educators) that, when we ourselves are asked to give public climate talks, the invitations often come with a single request: “Please make it upbeat!” The talk organizer implicitly knows that the event will be less well-received if a doom-and-gloom tone of endless possible horrors

dominates hope in the presentation. Therefore, our lectures balance (A) the undeniable, information-based dangers that GW poses through climate change with (B₁) that humans already have the effective means to inhibit GW (e.g., the *pathways* of abandoning fossil fuels in favor of relatively inexpensive electrification via wind/solar/hydro/geo/etc. power) and (B₂) that the audience itself has the *agency* to act (through both personal behavior or political activism/voting/spending). We caution against imbalances that “scare” audiences without virtually immediately offering the prospect that solutions are within our collective mental horizon. It is noble to help people understand why anthropogenic greenhouse gases are threatening their futures, but that nobility may be inert if we do not also help instill constructive hope such that they will envision how their (and others’) actions can inhibit/stop the emission of those heat-retaining gases.

Limitations and Future Directions

This experiment’s design did not include a “filler task” control group (i.e., a similar group of participants completing the same pre- and post-surveys that straddled an alternative, unrelated activity in place of an experimental intervention). We chose to omit such a placebo-like control condition because hope about climate change is a relatively under-characterized emotion, so it is difficult to design alternative activities of the same length and content-type as the interventions under investigation that would not interact with hope in any way. As such, a primary next step would be to replicate and extend the experiment with a minimal active-control condition (e.g., neutral estimation feedback unrelated to climate) to better isolate the specific contribution of climate-solution statistics.

Another of this experiment’s design limits was that pathways-thinking and agency (sub-constructs in Snyder’s 2002 theory of hope) were not isolated in Li and Monroe’s (2018) Climate Change Hope Scale. This means that the precise mechanism by which each intervention increased hope (i.e., through the sub-construct of either/differentially agency or pathways-thinking) remains for future research. Likewise, although many NDI experiments have shown that statistical feedback alone (i.e., just solicited estimates, followed by feedback numbers) produces attitude change—and that many have shown GW acceptance change in particular—it is possible that this study’s brief prefacing texts enhanced the effect, the isolation of which represents another element for future research. Also left for future research are assessments of the interventions’ effect on longer-term changes in hope—and/or effects of hope-change on pro-environmental engagement or behavior.

To better determine the relationship between hope and other emotions, it would be valuable to obtain data sources beyond self-report measures (e.g., through biological sampling)—or to sample for a range of emotions in pre- and post-tests to better understand reactions to the interventions in a more nuanced way. A further question regards the generalizability of these results to the wider US population. Although US MTurk participants are more demographically aligned with the American population than US undergraduates (e.g., at UC-Berkeley or UT-Brownsville; Ranney & Clark, 2016, etc.), they are also slightly more liberal and younger than the average American (Huff & Tingley, 2015). On the other hand, future research might also examine whether the results found here extend to more specialized populations (e.g., environmental educators, teenagers, climate scientists, or strident skeptics) who either have a high proclivity towards climate-relevant information and/or who are more invested in the issue, compared to the average American. Our focus on US participants also raises some questions about the generalizability of these results outside of “American” contexts.

5. Conclusions

Although the theoretical value of cultivating constructive hope regarding sustainability and climate change had been identified by prior work, there is still a dearth of climate-change-specific ESD interventions that have been empirically demonstrated to increase hope about the issues. In this study's experiment, we sought to reduce that dearth by providing (and quantitatively assessing the effectiveness of) a climate hope-inducing intervention. The intervention, developed using the numerically driven inferencing (NDI) paradigm, solicited participants' estimates of germane quantities relating to the impact and relative adoption of societal-level climate change solutions (with a brief prefacing text)—followed by these learners' receipt of the quantities' actual numeric values as feedback. Results show that hope about our ability to successfully solve climate change can indeed be increased through the process of (following the brief prefacing text) (a) estimating quantities related to a societal-scale climate change solution (particularly illustrating the efficacy and uptake of each solution) and (b) receiving feedback on these estimates. Participants were most surprised by the numerical discrepancies between their estimates and the true quantities relating to the climate change solution of reducing meat consumption—as compared to the more commonly publicized climate change solutions of either electrification or energy efficiency. The results of our experiment also demonstrate the relationship between hope-about-climate-change and other constructs, such as global warming acceptance—giving insights into the mechanisms through which one can modify hope about climate change. This experiment's findings, in addition, add a new type of intervention to the 12-and-counting interventions produced by UC-Berkeley's Reasoning Group that have been shown to increase global warming acceptance among the American public (including Velautham, 2022's, Experiments 2 and 4; see Senthilkumaran et al., 2023; cf. Ranney & Velautham, 2021). Our results pragmatically point to the importance of leaders, communicators, and activists utilizing (especially surprising) *veridical* numerical quantities when trying to enhance emotion-relevant responses about socio-scientific topics, particularly in the service of SDGs. In particular, such information (e.g., Table 1's) that can foster hope seems crucial for climate action, in that the hope produced likely catalyzes action. With zero hope, we would not have seen the nontrivial climate progress evidenced so far (e.g., renewable energy's rise/inexpensiveness); with abundant hope, though, actions to much more dramatically inhibit global warming are obviously within humanity's grasp. Therefore, both communicators and learners would be wise to foster an abundance of hope.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (CPHS) of UC-Berkeley (protocol ID: 2020-09-13610; approved: 24 November 2020).

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Appendix A

Table A1. Items used in both pre/post-test surveys.

Hope About Climate Change scale (from Li & Monroe, 2018) (1–9 scale; extremely disagree = 1; strongly disagree = 2; disagree = 3; mildly disagree = 4; neither agree nor disagree = 5; mildly agree = 6; agree = 7; strongly agree = 8; extremely agree = 9); * = reverse-coded I am willing to take actions to tackle climate change. At the present time, I am energetically pursuing ways to tackle climate change. Climate change is beyond my control, so I won't even bother trying to solve problems caused by climate change.* The actions I can take are too small to help solve problems caused by climate change.* I know that there are things that I can do to tackle climate change. I can't think of what I can do to help solve problems caused by climate change.* If everyone works together, we can tackle climate change. I believe that scientists will be able to tackle climate change. Climate change is so complex we will not be able to tackle it.* I believe more people are willing to take actions to help tackle climate change. Even when some people give up, I know there will be others who will continue to try to tackle climate change. Every day, fewer people care about climate change.*
GW Acceptance/Concern scale (from Ranney & Clark, 2016) (1–9 scale; extremely disagree = 1; strongly disagree = 2; disagree = 3; mildly disagree = 4; neither agree nor disagree = 5; mildly agree = 6; agree = 7; strongly agree = 8; extremely agree = 9); * = reverse-coded The Earth isn't any warmer than it was 200 years ago.* Human activities are largely responsible for the climate change (global warming) that is going on. I am confident that human-caused global warming is taking place. Global warming (or climate change) isn't a significant threat to life on Earth.* If people burned all the remaining oil and coal on Earth, the Earth <u>wouldn't</u> be any warmer than it is today.* Global warmings, or climate changes, whether historical or happening now, are <u>only</u> parts of a natural cycle.* I am concerned about the effects of human-caused global warming. I would be willing to vote for a politician who believes that human-caused global warming doesn't occur.
Nationalism scale (from Ranney & Clark, 2016) (1–9 scale; extremely disagree = 1; strongly disagree = 2; disagree = 3; mildly disagree = 4; neither agree nor disagree = 5; mildly agree = 6; agree = 7; strongly agree = 8; extremely agree = 9) Generally speaking, the United States has done more harm than good.* The United States is one of the very best countries on our planet (for instance "in the top three"). The United States has had the best economy in the world for (at least) the last 100 years. In the two World Wars, the United States basically kept much of the world from being dominated by dictators and monarchs.
Catch Items (1–9 scale; extremely disagree = 1; strongly disagree = 2; disagree = 3; mildly disagree = 4; neither agree nor disagree = 5; mildly agree = 6; agree = 7; strongly agree = 8; extremely agree = 9) Please simply answer "Mildly Agree" for this item. Please simply select the number equal to five minus three. Please simply answer "Strongly Disagree" for this item. Please simply select the number equal to nine minus one.

* Indicates that an item was negatively phrased and thus negatively scored (i.e., reverse-coded).

Appendix B. Text and Comprehension Items Preceding Solution Statistics

Appendix B.1. Condition 1: Sustainable Electrification

Electrification is a widely supported strategy for inhibiting climate change. It replaces technologies that use combustion—like coal heaters, gasoline vehicles, and natural gas heating—with alternatives that use sustainable electricity, such as electric vehicles and heat pumps. We have the knowledge and means to generate renewable electricity with near-zero greenhouse gas emissions (through wind, solar, or hydroelectric technology, etc.) and we already generate considerable electricity with them. So, such renewable-electricity fuel sources result in lower average carbon dioxide (CO₂) emissions than those using fossil fuels—and emissions will likely decrease further as the grid runs more efficiently. Large-

scale electrifications, particularly of the transportation, building, and industrial sectors, are central components of achieving net-zero emissions by 2050. Other lower-emission benefits include lower long-term energy costs for individuals and companies—and reduced air pollution from not burning fossil fuels. [138 words]

Comprehension Items:

What is an example of a technology that runs on combustion that can be replaced by an alternative that runs on sustainable/renewable electricity?

Please provide two proposed benefits of sustainable electrification.

Appendix B.2. Condition 2: Energy Efficiency

Making new products often requires extracting many kinds of material from the earth—for instance, by mining for metals, drilling for oil, or harvesting trees. These extracted materials must be moved and processed, which also requires a lot of energy. Products that are thrown away (trashed) end up in landfills, producing the largest source of human-caused methane (CH₄), a greenhouse gas molecule that traps about 23 times more heat than carbon dioxide (CO₂). Landfills, etc., also bubble out cancer-causing air pollutants known as carcinogens that contaminate groundwater—which provides drinking water for the majority of Americans (and is used to irrigate a third of our crops). Reusing our resources (recycling) is an effective way to reduce the amount of waste that must be sent to landfills, preventing pollution—and saving energy, natural resources, and money for consumers. [137 words]

Comprehension Items:

What is the largest source of human-caused methane (CH₄)?

Please provide two benefits of recycling and/or re-using resources.

Appendix B.3. Condition 3: Reducing Meat Intake

An increasing number of scientists show that reducing meat and dairy intake is the single most effective way for individuals to reduce their impacts on the planet. Livestock farming produces potent greenhouse gases, such as methane (CH₄) and nitrous oxide (N₂O), through processes such as feed production, animal digestion, manure storage, and the use of fertilizers and pesticides. Raising animals also takes up a large portion of land, and thereby contributes to deforestation, water shortages, decreased biodiversity, and agricultural pollution (due to excessive nitrogen and phosphorus from fertilizer and manure). Such pollution causes both ocean “dead zones” and the depletion of freshwater resources. Reducing humans’ meat intake, even slightly, would reduce greenhouse gas emissions, and also reduce global ocean acidification, lake damage, eutrophication (e.g., algae blooms), and land use. Eating less meat would also provide health and cost benefits. [139 words]

Comprehension Items:

Please provide two concerns associated with livestock farming.

Please provide two benefits associated with reducing meat intake.

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