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How stable are preferences among emerging electricity generation technologies

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Abstract

Coal-fired power plants with carbon capture and sequestration (CCS), natural-gas-fired power plants with CCS, and Small Modular Reactors (SMR) are potentially important emerging energy technologies that could help mitigate climate change and contribute to a low-carbon future. Public opinion and preferences towards these technologies will affect their adoption when they are technologically ready to be implemented. This study examines the nature and stability of public preferences among these options. We find that participants have internally consistent preferences, when tested in several ways. Overall, they prefer SMRs to natural gas with CCS to coal with CCS. On a group level, these preferences depend on the choice alternatives, but not on how fully the technologies are described nor how far away a hypothetical power plant would be sited. On the individual level, preferences are related to participants' perceptions of the technology and their political ideology. Our findings suggest that presenting the three technologies together will produce the most balanced, informed judgment, with the least influence of political ideology.

1. Introduction

Public opposition has stopped or stalled many energy projects, including nuclear power plants [1] and CCS demonstration projects [2], because of their perceived risks or the desire for local political control [3]. Previous studies have compared public preferences for currently available nuclear power and fossil fuel power plants with CCS [4, 5]. In this study, we extend that work to emerging electricity generation technologies that are not widely available today. Whether they will ever be available depends, in part, on how the public views them. Here, we ask whether lay respondents can form stable preferences among such technologies, based on short descriptions.

We presented the technologies as the replacement for a soon-to-be-retired conventional coal-fired power plant, as one of the incremental decisions that can shape an evolving energy portfolio [6]. Specifically, we asked people to compare a (1) Small Modular Reactor (SMR), (2) natural-gas-fired power plant with CCS (NG-CCS), and (3) coal-fired power plant with CCS (Coal-CCS), assuming that they will be available commercially in 2030. These three technologies have been touted as stable and continuous carbon-free or low-carbon technologies that could play an important role in a low-carbon future [7, 8]. We chose these three non-renewable emerging technologies in order to provide a choice set with limited options that could feasibly be sited near participants' communities and require tradeoffs among shared attributes. The design allowed us to assess the stability of the participants' preferences, a necessary condition to guide energy policies.

We employ standard expert elicitation and risk communication methods to characterize and convey these technologies [9], hoping to produce the most stable preferences possible with such hypothetical judgments [10]. We also conduct several tests of our success, examining the construct validity of these expressed preferences, asking whether they are appropriately sensitive and insensitive to relevant and irrelevant task changes, respectively.
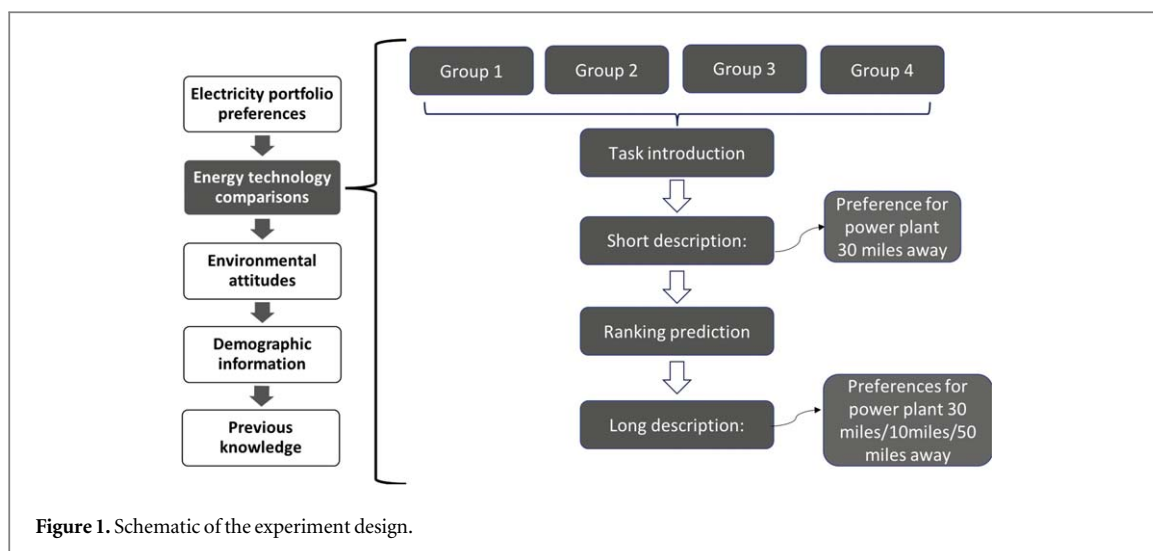
Figure 1. Schematic of the experiment design.

One such test examines sensitivity to context effects, normatively irrelevant changes in how options are presented that can affect poorly articulated preferences. Specifically, we look for evidence of the attraction effect [11], which violates the assumption of Independence of Irrelevant Alternatives (IIA). It occurs when adding an asymmetrically dominated option (or decoy) to a choice set increases the attractiveness of an option that dominates it [12]. (See Herne [1997] [13] for an example involving Finnish public opinion regarding energy options.) Here, we compare preferences among different combinations of energy options (e.g., NG-CCS versus SMR, NG-CCS versus Coal-CCS, Coal-CCS versus SMR, and NG-CCS versus Coal-CCS versus SMR). Presenting these technologies results in a less clean test of the attraction effect than is possible in experiments using artificially generated stimuli. However, we can still examine consistency across comparisons.

We also examine the sensitivity of these preferences to two features of the tasks and several features of the respondents. The two task properties are how extensively the technologies are described [14] and the geographic proximity of the proposed replacement plant [15]. The respondent factors are ones that have been found to predict responses in other studies: self-reported knowledge, political ideology, age, income, global warming belief [16, 17], and perceptions of energy technology features, such as cost and environmental impact [18].

As our concern is how (and how well) people form such preferences under different experimental conditions, our analyses focus on comparisons between randomized groups exposed to those conditions. If these preferences are deemed stable enough to guide policy, then sampling from properly representative samples would be warranted. Responses in those samples could help predict initial preferences among local residents at the beginning of public deliberation over energy proposals.

2. Methods

2.1. Experimental protocol

The survey had five sections: (1) electricity portfolio preferences, (2) energy technology comparisons, (3) environmental attitudes, (4) demographics, and (5) previous knowledge. Figure 1 shows the experimental design with the sequence of tasks on the left, expanding the second task, which included the experimental manipulation and key dependent measures.

(1) Electricity portfolio preferences. Participants selected three energy sources from a list of the seven largest U.S. sources in 2017 [19]: Coal, Natural Gas, Nuclear, Geothermal, Solar Photovoltaics power station, Wind, and Hydroelectric. They then ranked them in order of preference. They used 7-point scales anchored at *Completely disagree* (=1) and *Completely agree* (=7) to rate their agreement with statements about three properties of the current electricity system: (1) provides reliable electricity, (2) is environmentally sound, and (3) charges reasonable rates. Finally, they estimated their monthly household electricity bill.

(2) Energy technology comparison. Participants were randomly divided into four groups, each evaluating different combinations of the three energy technologies, as described below in Table 1.

Before reading any materials, participants were asked to imagine being members of a Citizens Advisory Panel for their state, with the task of deciding which energy technology should replace an old coal-fired power plant, at the same site, 30 miles away. They were told that the new power plant would be constructed by 2030.

Table 1. Experimental group assignment.

Group	Technologies compared
Group 1	NG-CCS, SMR.
Group 2	Coal-CCS, SMR.
Group 3	NG-CCS, Coal-CCS.
Group 4	NG-CCS, Coal-CCS, SMR.

NG-CCS = Natural-gas-fired power plant with carbon capture and sequestration.
Coal-CCS = coal-fired power plant with carbon capture and sequestration.
SMR = Small Modular Reactor.

They then read short descriptions of their assigned technologies, followed by several attention checks, a question asking for their preferences, and their best guess at the technologies' rating on three attributes: Cost, Environmental Impact, and Safety Risk. They then read long descriptions of each technology, including technical experts' predictions for the three attributes. After answering the same preference question, they were asked for their preferences, if the new plant was built 10 or 50 miles away at a new site, rather than 30 miles away at the same site of the old coal-fired power plant. Finally, they answered open-ended questions about their decision criteria and desire for additional information.

(3) Environmental attitudes. Global warming belief was assessed using one question, 'Recently you may have noticed that global warming has been getting some attention in the news. Global warming refers to the idea that the world's average temperature has been increasing over the past 150 years, may be increasing more in the future, and that the world's climate may change as a result. What do you think? Do you think that global warming is happening?' [20], with the options of Yes, No, and I don't know. Those who answered Yes or No, also indicated how certain they were (1 = I am not at all sure; 5 = I am extremely sure). A 4-item scale assessed their environmental attitudes [21].

(4) Demographic information. Participants answered questions about their age, gender, income, political standing, education, and science education [22].

(5) Previous knowledge. Participants were asked 'How much did you know about [e.g. natural-gas-fired power plants] before doing this survey?' ranging from 1 = Not at all to 7 = A lot.

2.2. Materials

Previous studies have found that most people have no opinion about CCS and become slightly supportive when told about its potential contribution to mitigating CO_2 emissions [14]. As a result, our descriptions assumed that respondents knew very little. Our materials were based on peer-reviewed studies of the technologies, especially ones from the Global CCS Institute [23] and the World Nuclear Association [24], and were reviewed by experts (see SI section A, available online at stacks.iop.org/ERC/1/071002/mmedia for details). SI Figures A1 and A2 show the short and long descriptions.

In creating these descriptions, we sought estimates that were feasible given sustained investment in the technologies (which might depend on investors' and regulators' perceptions of public perceptions). The *Cost* section was expressed as changes to current electricity bills, were each technology to replace the existing plant. The *Water Requirements* section explained the role of cooling water in thermal power plants, before giving a rough estimate of withdrawals required for electricity production, compared to normal residential water usage. The *Pollution* section described relevant sources and regulations, in general terms. *Safety* briefly described possible safety risks and their probabilities, using verbal quantifiers to provide gist.

2.3. Analytical approach

2.3.1. Test of randomization

We used one-way Analysis of Variance (ANOVA) to compare the four groups in terms of their willingness to pay for cleaner energy and to get electricity from cleaner energy sources.

2.3.2. Sensitivity to context effects

We compared participants' preferences when comparing two technologies alone (Groups 1–3) or in the set of three (Group 4). The assignment is shown in Table 1. If preferences are not influenced by context (hence

demonstrate Independence of Irrelevant Alternatives (IIA)), the ratio of those choices should be the same, which is called 'proportionality' or 'constant ratio' in Luce's Choice Axiom [25]. An 'attraction effect' violates proportionality by having a higher probability of choosing an alternative that dominates the additional option (called a 'decoy') in the set of three.

2.3.3. Sensitivity to changes in description and location
We used within-subject comparisons to examine the effects of description length (short versus long) and plant location (30 miles baseline versus 10 miles and 50 miles).

2.3.4. Predictors of preferences
We conducted logistic regressions predicting preferences in Groups 1–3, using SMR as the reference technology for Groups 1 and 2, and NG-CCS for Group 3. Our predictors were the demographic variables and participants' 'best guess' prediction of each technology's future cost, environmental impact, and safety risk.

$$\log\left(\frac{p(x)}{1 - p(x)}\right) = \beta_0 + \beta_1 * gw + \beta_2 * age + \beta_3 * gender + \beta_4 * pl + \beta_5 * edu$$
$$+ \beta_6 * costpred + \beta_7 * envpred + \beta_8 * riskpred$$

To assess the stability of these influences, we compared the coefficients in these logistic regressions when repeated for the short and long descriptions and for the three distances (10 miles, 30 miles, and 50 miles). We used an additive model, for reasons explained in the SI section E.

For Group 4, with three outcomes, we used a Generalized Extreme Value (GEV) model. Our dependent measure was the random utility U_{ij} for individual i choosing alternative j. It consists of two parts: (1) the 'observed' part expressed as a function of the alternative attributes x_j (cost, environmental impact, safety risk) and individual demographic attributes z_i, and (2) the 'unobserved' part ϵ_{ij}. SMR is used as the reference level for utility comparison. We used an additively separable model, assuming that independent variables are linear. We decided on a nested logit model allowing correlation of unobserved factors over alternatives within a nest structure, which relaxed the requirement of IIA in multinomial logit model to capture whether 'context effect' existed in this study. See SI section F for the rationale of our model choice.

$$U_{ij} = \beta x_j + \gamma_j z_i + \epsilon_{ij}$$

As with Groups 1–3, we assessed the stability of influencing factors by comparing regression coefficients for models predicting preferences with the two description lengths and the three distances.

2.4. Participants
The survey was approved by the Institutional Review Board of Carnegie Mellon University. All participants provided consent and affirmed that they were over 18 years old.

Participants were adult U.S. residents, recruited on Amazon Mechanical Turk (MTurk) in August 2018. MTurk is a large online platform on which registered 'requesters' (task creators) can post tasks and recruit registered 'workers' (paid task completers) to participate [26]. Previous studies comparing behavioral experiments using MTurk and other recruitment methods have found few systematic differences in how people respond to decision-making tasks [27, 28]. For example, a recent research project replicated 15 experiments to examine the generalizability of MTurk results, for manipulations such as framing and priming. The results found good correspondence regarding the responses of MTurk and nationally representative samples regarding *how* people respond to such manipulations [29]. However, results cannot be directly generalized to *what* other populations believe or want. 400 out of 413 participants finished our survey. According to self-reports, their average age was 34.5 (*Median* = 31.0, *SD* = 10.6, *Range* = 18–82), 41% were female, and 72% White or European American. All had a high school level degree, with 55.3% having at least some college education. About 85% had taken at least one high-school level science class; 60% at least one college-level science class; 10% had worked in the energy industry. Median household income was in the $25 000–$50 000 range. About 70% had no more than 3 people in their household, with an average of 2.86 persons; about 61% had no children under 18 living at home. On average, they skewed slightly liberal (*M* = 3.42, *Median* = 3), on a scale anchored at *Extremely Liberal* (=1) and *Extremely Conservative* (=7). Nearly all (91.5%) believed that global warming is happening (5% no; 3.5% not knowing). SI Table B1 compares our sample to the U.S. Census. They were paid $2.50 for approximately 15 minutes of work.

2.4.1. Randomization
Table 2 compares the four experiment groups. Although there is group disparity in gender ratio, one-way ANOVAs revealed no differences across the four groups in participants' willingness to pay for cleaner electricity

Table 2. Group breakdown of demographic information.

	Group 1 n = 100	Group 2 n = 102	Group 3 n = 101	Group 4 n = 97
Age (Mean)	34.2 (SD = 10.9)	34.6 (SD = 10.6)	34.8 (SD = 11.7)	34.3 (SD = 8.9)
Gender (Female)	40 (40.0%)	32 (31.4%)	44 (43.6%)	48 (49.5%)
Race (White or European-American)	71 (71.0%)	71 (69.6%)	73 (72.3%)	73 (75.3%)
Education (Bachelor's degree or higher)	60 (60.0%)	49 (48.0%)	62 (61.4%)	50 (51.5%)
Household income above $50 K	42 (42.0%)	44 (43.1%)	52 (51.5%)	53 (54.6%)
Average Persons per household	2.89	2.64	2.78	3.13

($F_{3,396} = 0.02, p > .05$) or desire for electricity from clean sources ($F_{3,396} = 0.68, p > .05$), indicating successful randomization (see SI Table C5 for test results).

3. Results

We report, in turn, (1) participants' preferences and knowledge regarding conventional energy sources, (2) participants' preferences among the three emerging energy technologies, (3) the factors predicting baseline preferences, (4) the stability of those preferences across choice sets, (5) the effects of reading the long descriptions, and (6) the effects of changing the distance to the plant site (from 30 to 10 or 50 miles).

3.1. Preferences and knowledge regarding current energy portfolio

In their responses to the introductory questions, participants preferred renewable energy sources most and coal the least. SI section C provides details on their preferred energy portfolios.

Given the non-normal distribution of responses, we used the non-parametric Kendall's tau correlation coefficient, which typically has a lower absolute value than the comparable parametric Pearson's r. These correlations found that participants' beliefs about the current electricity system appeared internally consistent. Those who saw their own electricity as more affordable also had higher incomes ($\tau = 0.12$) and lower electricity bills ($\tau = -0.22$); they also predicted lower future electricity costs ($\tau = -0.14$) and saw current rates as more reasonable ($\tau = 0.37$). Respondents who had higher electricity bills ($\tau = -0.16$) or predicted higher future electricity costs ($\tau = -0.20$) were less likely to see current rates as reasonable. See SI Tables C2 and C3 for details.

Participants reported low prior knowledge about conventional energy technologies (coal-fired power plants: $M = 3.33, SD = 1.47$; natural-gas-fired power plants: $M = 3.22, SD = 1.56$; nuclear power plants: $M = 3.33, SD = 1.48$). Paired sample t-tests found no significant difference in self-reported prior knowledge for the technologies considered by each group. See SI Table C4 for details.

3.2. Preferences for emerging energy technologies and predictors of preferences

Figure 2 shows the reported preferences. The first column for each group shows the initial baseline judgment, evaluating the options for a new plant at the same site (30 miles away), based on short descriptions of the technologies. The first column for Group 1 shows that 57% preferred SMR to NG-CCS. Moving to the right, that percentage was the same for preferences made after reading the longer description and similar after considering the plant being built 10 or 50 miles away (58% and 62%, respectively).

In Group 1, although SMR was always preferred to NG-CCS, that proportion was never significantly different from 50%, at $p < .01$. SMRs are, however, significantly preferred to Coal-CCS in Group 2, $\chi^2(1) = 9.42, p < .01$. NG-CCS is significantly preferred to Coal-CCS in Group 3, $\chi^2(1) = 54.22, p < .001$. Intriguingly, the preference for NG-CCS over Coal-CCS (87%–13% = 64%) is significantly greater than the preference of SMR over CCS (66%–34% = 32%), despite SMR being marginally preferred to NG-CCS, in Group 1, $\chi^2(1) = 1.69, p > .05$. When all three technologies are compared, NG-CCS is still strongly preferred to Coal-CCS (39% versus 9%). However, in the direct comparison, SMR is preferred to NG-CCS (52% versus 39%), by roughly the same marginally significant margin as in Group 1.

Table 3 shows logistic regressions predicting the baseline binary preferences in the first row (short description, 30 miles) for Groups 1–3. In Group 1, participants were more likely to prefer SMR over NG-CCS if they were less conservative and if they saw less risk and environmental impact with SMR. Group 2 revealed a similar pattern, in that participants were more likely to prefer SMR over Coal-CCS, if they were less conservative and perceived less safety risk and less environmental impact with SMR. In Group 3, participants were more likely to prefer NG-CCS over Coal-CCS, if they were less conservative and perceived less environmental impact of NG-CCS.

Figure 2. Preferences for energy technologies in each experiment group.
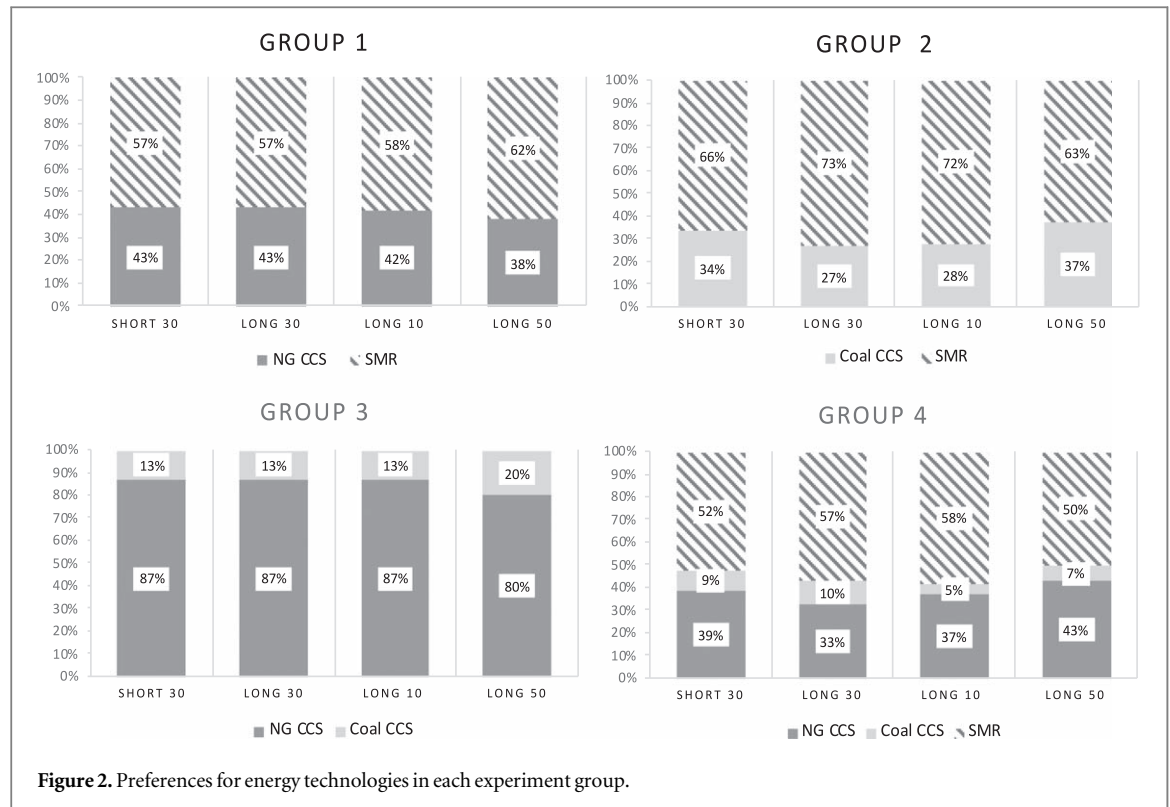
In Group 4, there was only one statistically significant predictor of any comparison between pairs of technologies: participants were more likely to prefer Coal-CCS over SMR if they were more educated (Relative Risk Ratio = 2.53, $p < .05$), see SI Table F2 for details.

3.3. Context effects

Table 4 contrasts the preference patterns when technologies are presented in pairs (Groups 1–3) or all together (Group 4). The first column shows proportions of preferred technologies in Group 4. The other columns show preferences for the technology in each row, when one of the other technologies is removed. The first statistic shows the proportion preferring it in the paired comparison (as in the first column in Figure 2, for that group). The second statistic shows the percentage change, compared with Group 4. For example, Coal-CCS became much more popular, when NG-CCS was no longer an option and it was compared solely to SMR (+278%). It became somewhat more popular when SMR was no longer an option and it was compared solely to NG-CCS (+44%). Each technology is somewhat more attractive when a competitor is removed. However, the changes vary greatly, depending on the alternative, violating proportionality. As mentioned, Coal-CCS becomes somewhat more attractive when compared to NG-CCS (Group 3), but much more attractive when compared to SMR (Group 2), although it is still less attractive. NG-CCS becomes much more attractive when compared to Coal-CCS alone (Group 3), but not much more attractive when compared just to SMR (Group 1).

One explanation for this pattern is that NG-CCS and Coal-CCS differ on just one dimension (the fuel source), whereas SMR differs from each on more than one dimension, creating less stable preferences. When comparing NG-CCS and Coal-CCS, it is natural (and normative) to cancel their shared attribute (CCS). Having done that, most people then have a strong, easily applied, preference for natural gas over coal (Group 3). However, the tradeoffs between SMR and the other two energy technologies are more complicated, and influenced by the concerns that Coal-CCS evokes. Given the option of avoiding fossil fuels altogether, most participants prefer SMR. That preference is greater for Coal-CCS than for NG-CCS, but not as much as one might expect from the strong preference for NG-CCS over Coal-CCS. This pattern might indicate that the difference between NG-CCS and Coal-CCS on one dimension is clearer than the tradeoffs between fossil fuels and nuclear on several dimensions.

3.4. Effects of text length

As seen in Figure 2, preferences are quite similar for the Short 30 and Long 30 judgments, indicating that providing additional details about the technologies had little effect. Using McNemar's test for Groups 1–3 and the McNemar-Bowker test for Group 4 revealed no significant group differences. (See SI Tables D6 and D7 for details). About one fourth of individual participants changed their preferences after reading the long

Table 3. Logistic regressions for Groups 1–3. predicting preferences for the reference energy technology (= 1) from participant demographics and judgments of technology features.

	Group 1 ($n = 100$) (SMR = 1, NG-CCS = 0)			Group 2 ($n = 102$) (SMR = 1, Coal-CCS = 0)			Group 3 ($n = 101$) (NG-CCS = 1, Coal-CCS = 0)		
	Odds Ratio	p	95%CI		Odds Ratio	p	95%CI		Odds Ratio	p	95%CI	
Global warming belief (1 = Yes, 0=No or don't know)	1.31	0.78	0.20	9.33	0.12	0.14	0.00	1.65	1.34	0.84	0.05	18.98
Age	0.99	0.85	0.94	1.05	0.98	0.51	0.93	1.03	1.05	0.26	0.97	1.17
Gender (male = 1, female = 0)	1.06	0.93	0.29	3.68	2.93	0.13	0.76	12.57	0.73	0.70	0.13	3.60
Conservative ideology	0.48	0.00	0.31	0.68	0.48	0.00	0.30	0.70	0.62	0.04	0.37	0.95
Education	0.99	0.99	0.49	2.01	0.85	0.65	0.40	1.72	0.50	0.16	0.18	1.25
Income	1.17	0.63	0.62	2.22	1.10	0.79	0.54	2.28	1.63	0.27	0.71	4.21
Cost prediction for reference technology	3.33	0.09	0.86	14.43	2.74	0.16	0.71	12.12	0.17	0.06	0.02	0.92
Environmental impact prediction for reference technology	0.09	0.00	0.02	0.33	0.20	0.02	0.05	0.73	0.14	0.02	0.02	0.70
Safety risk prediction for reference technology	0.14	0.00	0.03	0.51	0.05	0.00	0.01	0.26	1.12	0.89	0.24	6.08

Table 4. Changes in reference patterns when options are presented together (Group 4) or in pairs (Groups 1–3).

Alternatives	(Group 4)	(Group 1)	(Group 2)	(Group 3)
Coal-CCS	.09	NA	.34 (+278%)	.13 (+44%)
NG-CCS	.39	.43 (+10%)	NA	.87 (+123%)
SMR	.52	.57 (+10%)	.66 (+27%)	NA

descriptions. For example, in Group 1, 13 switched in each direction, leaving group preference for SMR or NG-CCS unchanged.

There were, however, some differences in the factors predicting these preferences. In logistic regressions paralleling those in Table 3, there were interactions with text length for several predictions (see SI Table E6). In Group 1, with the long description, judgments of SMR risk no longer significantly predicted preferences (Odds Ratio (OR) = 0.93, $p > .05$) (see SI Table E2), with a significant interaction (Risk * Text: OR = 6.49, $p < .05$). Here, reading the longer description may have allayed some fears. For Group 2, education became a significant predictor of preferences for SMR among those who read the long description (OR = 2.79, $p < .01$), also with a significant interaction (Education * Text: OR = 3.29, $p < .05$). Here, the longer text may have had greater impact for better educated readers. In Group 3, judgments of risk became a significant predictor of preferring Coal-CCS among those who read the longer form (OR = 0.03, $p < .05$), with a significant interaction (Risk * Text: OR = 0.03, $p < .05$). Here, those better able to read the long description may have better understood the limits to NG-CCS. With respect to Group 4 (see SI Table F3), text length was unrelated to individual participants' preferences.

3.5. Distance influence on preferences

The two right-hand columns for each group in Figure 2 show preferences when participants were asked to consider the new (replacement) plant at different sites (after having read the long descriptions). We had no specific predictions here and found few significant overall differences. Participants preferred Coal-CCS to SMR somewhat more when it was further away, $\chi^2(1) = 4.5$, $p < .05$ (see SI Tables D8 to D11 for McNemar's test results).

Here, too, there were some suggestive interactions with distances in the logistic regressions (see SI Table E7). In Group 1, SMR became more attractive at 50 miles even for those who saw greater costs (see SI Table E4) (OR = 4.69, $p < .05$), with a significant interaction (Cost * Distance: OR = 2.59, $p < .05$). In Group 2, those with higher income were more likely to prefer SMR at 10 miles (OR = 3.20, $p < .01$) and 30 miles (OR = 3.22, $p < .01$), but not 50 miles (OR = 1.30, $p > .05$) (see SI Tables E2 to E4), with a significant interaction (Income * Distance: OR = 0.59, $p < .05$). Thus, as distance increased, higher income participants' preference for SMR declined. In Group 3, those who saw greater safety risk of NG-CCS were less likely to prefer it at 30 miles (OR = 0.03, $p < .05$), but not at 10 miles (OR = 0.28, $p > .05$) or 50 miles (OR = 2.28, $p > .05$), with a significant interaction (Risk * distance: OR = 3.63, $p < .05$). In Group 4, there were no significant interactions with distance (see SI Table F3).

4. Discussion and policy implications

Participants evaluated three advanced energy technologies that, with proper investments, might be available in time to replace an aging power plant in 2030. In some ways, participants' preferences were quite stable, changing little when they read more about the technologies or when they considered changes in the distance to the plant site. From these perspectives, and in all comparisons, a coal-fired power plant with CCS was the least preferred option. That choice was consistent with the energy portfolio preferences that participants expressed in the study's initial section.

However, the strength of that preference depended on what else participants were offered. When compared to natural-gas with CCS, coal with CCS was preferred by only one participant in eight. When compared to SMR, coal with CCS was preferred by one in three—despite SMR being somewhat preferred to natural gas with CCS when the two were paired. The simplest explanation is that it was easy to compare the two fossil-fuel technologies, with natural gas being the clear winner over coal. However, SMR evoked more complex, less clear, and less stable concerns. Discomfort with nuclear power may have made coal more acceptable to some people, when just those two were paired. When paired with natural-gas with CCS, though, SMR might have been seen as a kind of clean energy.

Thus, preferences among these technologies depend on the alternatives. That result exemplifies the basic research finding that, when faced with unfamiliar choices, people 'construct' their preferences through inferential processes that draw on contextual cues [30]. Of particular relevance here, from that research, is the attraction effect, whereby preferences between two alternatives can change when a third is introduced [11, 12, 31]. Here, such sensitivity was observed with advanced technologies, which were described with details that made them more realistic choices than the options offered in typical experiments, but also made it harder to discern the precise psychological mechanisms involved.

Individual-level analyses also suggested orderly personal preferences. In Group 1, after participants read the long descriptions, their perceptions of SMR safety risk no longer predicted their preferences. In contrast, in Group 3, after participants read the long descriptions, their perceptions of NG-CCS safety risk became stronger predictors of their preferences. There may have been no overall effect of reading the long description on preferences because participants took away different messages, some changing their preferences in one direction, some in the other.

The present results extend the applied research finding that energy technologies may be judged differently in isolation and as part of a portfolio [4, 5]. The scenarios evaluated here are meant to reflect a process whereby energy portfolios evolve incrementally, through decisions made about individual power plants. The options available for such decisions will depend on local political, economic, and regulatory conditions. They will also depend on research-and-development decisions that depend, in turn, on perceptions of what the public wants and will accept. Responses like those observed here could inform those decisions.

The specific preferences observed here cannot be confidently generalized to other populations. However, their internal consistency and reasonableness suggest that similarly educated audiences can form relatively stable preferences, when provided clear communications and a chance to reflect. The results also suggest that considering all viable options together produces the most balanced evaluations. For example, although some individual attributes (e.g., political ideology, income) predicted pair-wise choices, there was only one weak correlation when participants considered all three.

One limitation to these analyses is that we elicited judgments of cost, environmental impact, and safety risk only once, after participants had read the short description, but before they had read the long one. As a result, we cannot establish how reading it changed any of these judgments or their relationship to the preferences. The effects of varying information on the elasticity of public preferences towards different attributes bear further study [32]. A second limitation is that we used just one variant of each technology and one set of plausible estimates of their performance. Other plausible estimates might lead to other beliefs and preferences. However, we speculate that different estimates would not affect the patterns of internal consistency, unless they greatly changed the relative locations of the alternatives in the choice set [33].

A third limitation of this study is using a relatively well-educated MTurk convenience sample [27], leaving it uncertain how well less literate and numerate individuals might have understood the materials and formed preferences [34]. We cannot generalize these preferences observed here to the U.S. public. However, if they were borne out with larger, more representative samples, our results might encourage investments in SMR and natural gas with CCS—and suggest the challenges facing coal with CCS to win public support. Of course, winning public support (in polls) is only one step toward the development of these emerging energy technologies. Their fate will also depend on public discourse when facing specific energy proposals, both in society as a whole and in the communities asked to host them [35, 36].

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