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Engaging attribute tradeoffs in clean energy portfolio development

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ABSTRACT

Governments and privately-held utilities will have to drastically reduce their carbon emissions to mitigate climate change. Such reductions will require transitioning electrical infrastructure to rely on cleaner fuels and power-generation technologies. Despite the myriad factors influencing both the process and eventual outcome of these transitions, it is typically transitions' cost and individuals' willingness to pay (WTP) for them that dominate both strategic planning and political discourse. Studies used to calculate the public's WTP however often rely on vague policy options, ignore important social and environmental attributes, and fail to provide individuals means for engaging tradeoffs. Here we report on three studies that provided individuals multiple choice tasks for evaluating real-world portfolio options across key social and environmental attributes. Our results show that individuals placed high importance on minimizing costs, yet also consistently ranked strategies highest that reduced both greenhouse gas (GHG) and air particulate emissions, even when those portfolios require considerable cost increases. When provided an opportunity to construct their own portfolios, participants again constructed costly portfolios that significantly reduced both GHG emissions and air pollution. Using multiple choice tasks, we demonstrated individuals' WTP for low-emission energy strategies to be higher than previous studies relying on contingent valuation suggest.

1. Introduction

In order to prevent global mean temperatures from increasing beyond 2 °C, governments and privately-held utilities would have to quickly and drastically reduce their greenhouse gas (GHG) emissions (Hoffert et al., 1998; Tollefson and Weiss, 2015). Such reductions would require a wholesale, disruptive transformation of electrical infrastructure with significant clean energy and carbon capture and storage (CCS) investment, development and deployment (Verbruggen et al., 2010). Despite the myriad factors influencing both the process and eventual outcome of these transitions, it is typically their cost and individuals' willingness to pay (WTP) for them that dominate both public discussion and political discourse.

This focus on the cost of transitioning and determining what individuals are capable and willing to pay for it is not without merit. Indeed, cost is considered to be the public's greatest concern in discussions about energy—along with energy's risk to human health (Ansolabehere and Konisky, 2014). However, recent research suggests that focusing on the cost of clean energy may reduce support, particularly for renewable portfolio standards (RPS) in the US (Stokes and Warshaw, 2017); RPS are state-specific standards that require electric suppliers to supply a minimum portion of their retail load using renewable energy. Such concerns raise the question of which attributes, instead of or in addition to cost, analysts should focus on when eliciting the public's energy preferences.

To try and answer this question, we present three studies in which individuals' WTP for clean energy and transition strategies in the US and Canada were investigated. These studies used an expanded range of attributes, specifically social and environmental attributes identified by community members, and multiple choice tasks, including portfolio construction, to help respondents engage tradeoffs between options and attributes. The results are WTP responses for clean-energy strategies, or strategies that dramatically reduce GHG and air particulate emissions, that are higher than many previous studies, particularly those relying on contingent valuation (CV), demonstrate.

1.1. Literature review

A wide spectrum of studies examines the US and Canadian public's WTP for clean energy production, provision and research—as well as

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RPS in the US. Most of these studies use either conjoint analysis (CJ) or CV. CJ provides respondents a brief opportunity to evaluate a few goods or options along a number of attributes, while CV typically asks respondents to assess the change in a single attribute. Considerable controversy exists regarding the latter; for instance, it has been argued that i) CV responses are not consistent with economic theory, i.e., they are scope insensitive (individuals' preferences for cleaning up one lake is roughly equal to cleaning up five) (Diamond and Hausman, 1994); ii) CV surveys capture one's WTP for the moral satisfaction of contributing to a public good rather than determining the good's *economic* value (Kahneman et al., 1986); and iii) due to individuals rarely thinking about environmental and public goods monetarily, CV surveys actually result in the construction rather than revelation of preferences (Gregory et al., 1993).

In both the CJ and CV studies examined below, the elicitation procedure, options and attributes vary considerably, as do the resulting WTP figures. For instance, in a CJ study, Roe et al. (2001) asked individuals to compare two electricity information sheets differing across the attributes monthly price, contract terms, fuel source mix (per cent renewables), and air emissions profile (NO_x, NO_2, CO_2). Their results show US individuals were willing to pay between $0.11 and $14.22/year for each 1% increase in renewables and 1% decrease in CO_2 emissions—a hedonic regression suggested a figure roughly in the middle, i.e., $6.21/year. In another CJ study, Borchers et al. (2007) presented individuals choice sets containing one of two cost increases (between $5 and $30/month) for different quantities of electricity (percentages between 10% and 25%) provided by different sources (i.e., wind, solar, biomass, farm methane or a generic green energy source). Their results show US residents willing to pay $37.29/month for a portfolio made up of 25% solar, but just $31.54/month for a portfolio made up of the same percentage of "green energy."

Studies relying on CV often delineate between government policy or pricing options. For example, Kotchen et al. (2013) showed participants one of three policy options to reduce emissions 17% by 2020: a cap-and-trade policy, a carbon-tax policy, and a "policy to regulate carbon dioxide as a pollutant," and 8 WTP responses ranging from $0 to $475 or more/year. They found US households' WTP to be between $79 and $89/year. Those same authors sought US households' WTP for a carbon tax, or a "tax on fossil fuels to help reduce global warming" in 2017, again using CV, and found a mean WTP of $177/year (Kotchen et al., 2017). Similarly, Wiser (2007) showed each participant one of four different interventions ranging from mandatory increases in all customers' utility bills to increases for only those who choose to pay (voluntary), and the funds collected then spent on renewable energy projects by either the government or by electricity suppliers. Using three different price points ($0.50, $3 and $8/month), the authors found 50% of US residents would pay $8/month in the form of mandatory payments for government-provided renewable energy; less than 40% would voluntarily pay $8/month for projects led by electricity suppliers.

Some CV studies rely on a specific RPS percentage to gauge respondents' WTP, while others use less precise targets. In a study using CV, Mozumder et al. (2011) asked participants to provide a single, open-ended, WTP for a scenario in which New Mexico's energy would come from 10% renewables (result: $14/month). Stokes and Warshaw (2017) presented individuals a more aggressive RPS of 35% by 2025, a set of statements that varied the RPS's impact on employment, clean air and GHG emissions, and a hypothetical price increase of either $0, $2, or $10/month. They found that proposed utility bill increases of only $2 and $10/month led to a 6% and 13% decline in support, respectively. Mills et al. (2015) asked participants if they would support an undisclosed "set portion" of electricity coming from renewables at a cost increase of either $25 or $50/year, while Borick et al. (2011) asked individuals to select from a range of $0 to $500 or more per year for simply "more renewable energy to be produced." The former showed that a majority of individuals in the US would no longer support an RPS if it cost $50 per family per year, while Borick et al. (2011) showed that 41% of those in the US were unwilling to pay anything for increased renewable energy production—up from 22% just two years prior, and only 13% were willing to pay upwards of $100/year. In that same report, only 21% of Canadians were unwilling to pay anything for increased renewable energy production, and 26% were willing to pay $100/year and 7% $500/year or more.

Finally, Krishnamurthy and Kriström (2016) used a single CV question, which asked respondents for the maximum annual percentage increase (on their utility bill) they would pay to use *only* renewable energy, while Rowlands et al. (2002) used CV around five price options ($0 to $50/month) for Waterloo, Ontario residents to select from to ensure that *all* of the electricity they use would come from "green" sources. The former found Canadians were willing to adopt a 12.4% utility premium increase for 100% renewables, while the latter showed over 90% willing to pay an additional $5 to $25/month for 100% "green" energy.

Each of the studies above varied the RPS, fuels, policy options, price points, or emission reductions in question, or else altered how such information was framed. The CJ studies resulted in higher WTP for clean energy than did the CV studies, with the former showing individuals willing to pay upwards of three to six hundred dollars per year for increased renewables, while CV often led to WTP responses of less than $100/year. Such differences in WTP figures, both within and between CV and CJ studies, complicates the development of publicly acceptable clean-energy policies. Additionally, the studies described above touched only briefly—or not at all—on the real-world social and environmental costs and benefits of supporting different clean energy and RPS options. We contend that studies which fail to make clear these costs and benefits may elicit less accurate WTP for energy transition plans and portfolios.

1.2. Expanding the range of and engaging tradeoffs between attributes

Indeed, research shows individuals consider a number of costs and benefits, or attributes, in their energy decisions. For instance, people consider energy's risk to human health (Ansolabehere and Konisky, 2014), its impact on air quality (Roe et al., 2001) and alterations required to local landscapes or changes in land use (Abbasi and Abbasi, 2000; Pasqualetti, 2011; Apostol et al., 2016)—especially regarding wind energy (Johansson and Laike, 2007; Pasqualetti, 2011). They consider energy's impact on employment (Stokes and Warshaw, 2017), wildlife habitat and biodiversity (Bergmann et al., 2006), and national security, as well as the extent to which energy relies on risky technologies (Huijts et al., 2007) or technical, social and market innovations (Wüstenhagen et al., 2007). Individuals also consider energy's role in mitigating GHG emissions (Howe et al., 2015), and it has been suggested that in order to better motivate mitigation policymakers should characterize GHGs as a *local* risk and focus people's attention on mitigation's *localized* benefits (van der Linden et al., 2015).

Making clear how different energy plans perform across such attributes is certainly important; however, simply expanding the range of attributes people consider may not go far enough. This is due to the technical and cognitive complexity associated with recognizing and confronting tradeoffs between attributes, a complexity which increases with the number of attributes included (Arvai, 2014). In such situations, particularly contexts that incorporate conflicting values and objectives, uncertainty, and nonlinear or complex adaptive systems (Payne et al., 1992; Dietz, 2013), people tend to rely more heavily on mental shortcuts and the systematic biases that plague them (Arvai et al., 2012). In such cases, structuring decision processes, working to de-bias choices, and decomposing complex problems into more cognitively manageable steps can improve decision outcomes, increase stakeholders and decision-makers' satisfaction (Gregory et al., 2012) and increase the degree to which people's choices align with their values (Bessette et al., 2016).

A recent advance in both tradeoff analysis and de-biasing choices involves building user interfaces that allow people to construct their own energy portfolios. Portfolio construction has been shown to increase energy literacy and people's understanding of how energy systems work (Bessette et al., 2016), and may encourage individuals to adopt different modes of thinking, in particular exchanging quick, affect-driven System 1 thinking for more analytical System 2 thinking (Kahneman, 2011). While System 1 thinking may be important in everyday decision-making, more analytical and deliberative processing is preferable in complex, unfamiliar, high-value decision contexts like developing clean energy plans. Additionally, because in these types of contexts individuals may be *constructing* their preferences during elicitation (Gregory et al., 1993; Slovic, 1995), studies examining the public's energy preferences must also provide detailed instructions and information about energy systems, fuels and power-generation technologies, as well as methods for meaningfully engaging tradeoffs. This is especially important when key tradeoffs may be ignored due to incommensurability (Arvai et al., 2012).

To examine the concerns outlined above, the three studies described below, conducted between 2014 and 2016 in the US and Canada, all presented individuals with multiple choice tasks aimed at improving tradeoff analysis, a wide range of energy portfolio options to consider, and more relevant social and environmental attributes to evaluate. The first two studies, conducted in Michigan, USA and Alberta, Canada, respectively, used an interactive energy system model and online interface in which participants could construct their own energy portfolio options and then engage in two choice tasks. The third study, conducted using a representative sample of Canadians, did not include an energy system model or portfolio construction, but instead used two choice tasks to examine larger, national-scale energy plans and attributes.

While certain pieces of information and the order of tasks were purposely varied across the studies to test for biases—these results are examined elsewhere (Bessette et al., 2014, 2016), the dominant structure and aim of the studies' tasks remained consistent. Each included relevant social and environmental attributes and multiple methods by which individuals could investigate and engage tradeoffs between those attributes more explicitly. The results suggest that individuals prized reducing both CO_2 and air emissions in addition to cost, and that their WTP for clean energy was higher than WTP elicited previously using CV.

2. Methods

2.1. Studies 1 and 2

Both Studies 1 and 2 used a 6-part online decision-support framework, which included an interactive energy system model. In Study 1, this framework was deployed via facilitated workshops to 182 randomly selected juniors and seniors at Michigan State University (MSU)—see Bessette et al. (2014) for more information. In Study 2 the framework and energy model was deployed via the Internet to a representative sample of 547 Albertans in Canada. Both the model and interface were adjusted slightly to represent and elicit Albertans' preferences regarding development of an energy portfolio for a realistic medium sized city in the province—see Bessette et al. (2016) for more information. Both studies incorporated three complimentary choice tasks: 1) portfolio construction, 2) the holistic ranking of portfolio options, and 3) the weighting of attributes. Each study also predicted performance of the energy portfolios using six key attributes. These six attributes were identified by stakeholders at a series of workshops and focus groups held earlier at MSU and with the university's surrounding residents. In the course of generating an extensive Means-Ends Network, or hierarchy of objectives (see Supplemental Information, Fig. S1) attendees identified i) minimizing the cost of new energy strategies, ii) reducing GHG emissions, iii) reducing air particulate (NO_x & SO_x) emissions; iv) minimizing additional land use; v) increasing full-time employment; and vi) maximizing the use of innovative technology as most relevant (in no particular order).

2.1.1. Task 1: portfolio construction

The first task, *portfolio construction*, allowed participants to construct their own unique energy portfolio option using an interactive energy system model. After reading an introductory primer and watching a short video describing the process, individuals were asked to build a portfolio by filling (up to) ten slots with different fuels and power-generation technologies. Participants could fill (up to) six powerplant slots, (up to) two decentralized energy slots and (up to) two outside-the-city-limits slots by selecting from twenty different fuels and technologies (e.g., small modular nuclear reactors, biofuels w/ CCS, natural gas, coal, distributed solar, wind farms—for a complete list see Bessette et al., 2014). Participants were also able to select one of four different energy-efficiency levels (ranging from zero efficiency improvements to aggressive improvements). The energy system model would predict each portfolio's performance with regard to the six attributes, as well as calculate the portfolio's contribution to electricity and steam supply and demand. Participants' portfolios could vary with regard to performance across the six attributes, but must *at a minimum* meet the model's energy supply and demand requirements (the status quo met these requirements at zero additional cost). Once these requirements were met, the participant could lock in their "User Generated" option; this option was then incorporated into Task 2 to be evaluated alongside other portfolio options.

Only half of the participants in Studies 1 and 2 engaged in the construction of their own portfolio; the other half began directly with Task 2—this was done to test the effect of portfolio construction on individuals' decisions; results show that participants who engaged in Task 1 reported significantly greater knowledge about energy systems (Bessette et al., 2014, 2016)

2.1.2. Task 2: holistic ranking

The second task, the *holistic ranking* of portfolio options, asked participants to review six different energy portfolio options characterized according to the six attributes described above. Both the portfolio options and attributes are shown in Table 1. *Task 2* asked participants to rank the six portfolio options from their most preferred to their least, with ties allowed. In Study 1, all participants evaluated the options solely based on how they performed across the six attributes; they were not shown the specific fuel and power generation technologies that made up each option. In Study 2, half of the participants were shown both the fuels and technologies making up each option and the option's performance across attributes, while the other half could only see the options' performance across attributes (see Table S1 in the Supplemental information). This was done to test whether providing information about the fuels and technologies comprising each option resulted in less consistent choices across Tasks 2 and 3; indeed it did (Bessette et al., 2016)

2.1.3. Task 3: attribute weighting

The third task, *attribute weighting*, asked participants to review the attributes that characterized the six portfolio options and make a judgment about the relative importance of each in guiding their choices. After being shown a video demonstrating the process, participants were instructed to assign weights in a manner that incorporated the range of performance of each attribute based on the portfolios presented in *Task 2*. Known as "swing weighting," participants were shown only the best and worst performance of each attribute based on the options from Task 2 and were asked to provide a weight out of 100 to represent how important it was for them to move each attribute from its worst to its best performance. Once again, ties were allowed. Once elicited, these weights were then input into a linear value function, which was used to establish an implied preference order for the six portfolios.

In Study 1, Tasks 2 and 3 were counterbalanced across treatments to

Table 1
Options, Attributes, Ranks & Preferences. Mean ranks and preference scores for each option across all study treatments are shown here. For individual treatment means see Table S1 in the Supplemental Information. Option preference scores were calculated by inserting respondents' weights from Task 3 into a linear value function. Highest ranked and most preferred options are in **bold**.

		Portfolio Options	Attributes						Ranks & Preferences	
			Land Use	Jobs	Innov-ation	Air %	GHG %	Cost	Mean Rank (*sd*) (*Lower ranks = more preferred*)	Option Preference Score (*sd*) (*higher scores = more preferred*)
Study 1: Michigan, USA (n = 181)	1		0	0	1	0	0	$0	5.07 (1.48)	126.98 (33.16)
	2	*The fuels & technologies*	13	5	1.6	13	28	$88	3.37 (1.40)	143.78 (26.68)
	3	*comprising options were not*	**13**	**41**	**2.5**	**84**	**91**	**$544**	**2.28 (1.33)**	265.75 (47.85)
	4	*shown to participants, however*	54	39	2	27	64	$362	3.04 (1.23)	172.05 (27.15)
	5	*were the same as in Study 2.*	**18**	**60**	**3**	**100**	**100**	**$776**	3.03 (1.76)	**284.36 (58.51)**
	6		0	0	1	14	30	$0	3.64 (1.46)	166.44 (28.83)
	–	*User Generated (mean)*	*151*	*36*	*2.57*	*53*	*64*	*$603*	2.86 (1.64)	158.72 (34.70)
Study 2: Alberta, Canada (n =547)	1	Coal (Status Quo)	0	0	1	0	0	$0	4.29 (1.84)	101.06 (47.11)
	2	**Natural gas, coal & CCS**	**13**	**5**	**1.6**	**13**	**28**	**$88**	**2.92 (1.54)**	122.79 (47.60)
	3	Nuclear & distributed natural gas	13	41	2.5	84	91	$544	2.99 (1.48)	206.18 (83.70)
	4	Biomass, CCS & Nuclear	54	39	2	27	64	$362	3.01 (1.45)	133.50 (50.36)
	5	**Nuclear**	**18**	**60**	**3**	**100**	**100**	**$776**	3.57 (1.67)	**219.91 (95.86)**
	6	Natural gas	0	0	1	14	30	$0	4.37 (1.76)	131.40 (49.82)
	–	*User Generated (mean)*	*162*	*23*	*2.2*	*33*	42	*$595*	3.03 (1.62)	115.60 (68.79)
Study 3: Canada (n = 1874)			**Public Opp**	**Glbl Temps**	**Catastrophic Potential**		**GHG %**	**Cost**		
	1	Status Quo	2	0	0		0	0	3.50 (1.58)	1.80 (0.50)
	2	**Efficiency Improvements**	**0**	**1**	**0**		**2**	**3**	**2.21 (1.14)**	**2.19 (0.55)**
	3	Decarbonization	4	2	2		4	5	2.82 (1.35)	1.58 (0.38)
	4	Geoengineering	5	4	3		0	1	3.30 (1.27)	1.36 (0.32)
	5	CCS	4	2	2		3	3	2.85 (1.30)	1.66 (0.34)

prevent order effects (see Table S1 in the Supplemental information); however, portfolio construction always preceded both. In Study 2, the order of tasks was not counterbalanced (see Table S1).

2.2. Study 3

Study 3 did not include portfolio construction, instead focusing on Tasks 2 and 3 from the previous studies. The study used a climate-energy decision scenario deployed via the internet to a representative sample of Canadians (n = 1874). Before engaging with the scenario, participants were again provided an introduction to the two choice tasks, shown an instructional video, and this time engaged with an initial tutorial scenario, which involved evaluating five hypothetical restaurants for a dinner out. Following the tutorial, the climate-energy scenario presented participants five options characterized according to five attributes. The options relied on a) efficiency improvements, b) decarbonization of the electrical system, c) geoengineering (i.e., solar radiation management), d) CCS, and finally e) a status quo option. The attributes included options' a) potential to reduce GHGs, b) potential to stabilize global temperatures, c) catastrophic potential, d) public opposition, and e) cost. The options and the attributes used to describe them, as well as the options' performance was evaluated and predicted by five experts engaged in climate-energy research using a 5-point Likert scale. Similar to Study 2, half of the participants were shown information describing each option as well as the option labels provided above, and for the remaining participants this information was hidden; i.e., options were only labeled Option 1, Option 2, etc. (see Table S1).

2.3. Data analysis

Descriptive statistics were used to show mean ranks and preference scores for treatments within each study, as well as attribute weights. Weights were input into a linear value function and option preference scores were computed using Microsoft Excel. Additionally, ANOVA and MANOVA were used to determine the extent to which participants' gender, age, political party, or initial knowledge predicted the attributes of participants' constructed portfolios in the first task. See Bessette et al. (2014, 2016) for further information about Studies 1 and 2, particularly the extent to which participants' choices in Tasks 2 and 3 were consistent.

3. Data

3.1. Task 1: portfolio construction

3.1.1. Portfolio performance

When given the opportunity to construct one's own portfolio in Studies 1 and 2, participants constructed high-performing portfolios with high costs (see Fig. 1). Participants in Study 1 constructed portfolios that required an annual tuition fee increase of $603.20 (*sd* = 303.03), or $44.26 per month, while participants in Study 2 generated options requiring an annual utility bill increase of $595.50 (*sd* = 367.59), or $49.63 per month. Both of these mean costs were slightly less than the most expensive canned option (Option 5, $776, or $64.66/month), and greater than the next most expensive canned option (Option 3, $544, or $45.33/month). For an average increase of $7.70 more per year, participants' portfolios in Study 1 far outperformed those portfolios constructed in Study 2. Study 1's participants achieved 22% less GHG emissions (for a total reduction of 64%), 20% less air particulate emissions (for a total reduction of 53%), 13 more jobs created (for a total increase in employment of 36 FTEs), and 11 less acres land used (151 acres total), all while relying on 0.39 greater innovation (2.57 on a 3-point scale).

3.1.2. Demographics & portfolio performance

Demographic variables were not significantly associated with participants' constructed attributes in Study 1; however, participants' gender and federal party affiliation were significantly associated with per cent GHG emissions reduced, FTE jobs created, and innovation outcomes in Study 2. Males in Study 2 (n = 142) on average reduced

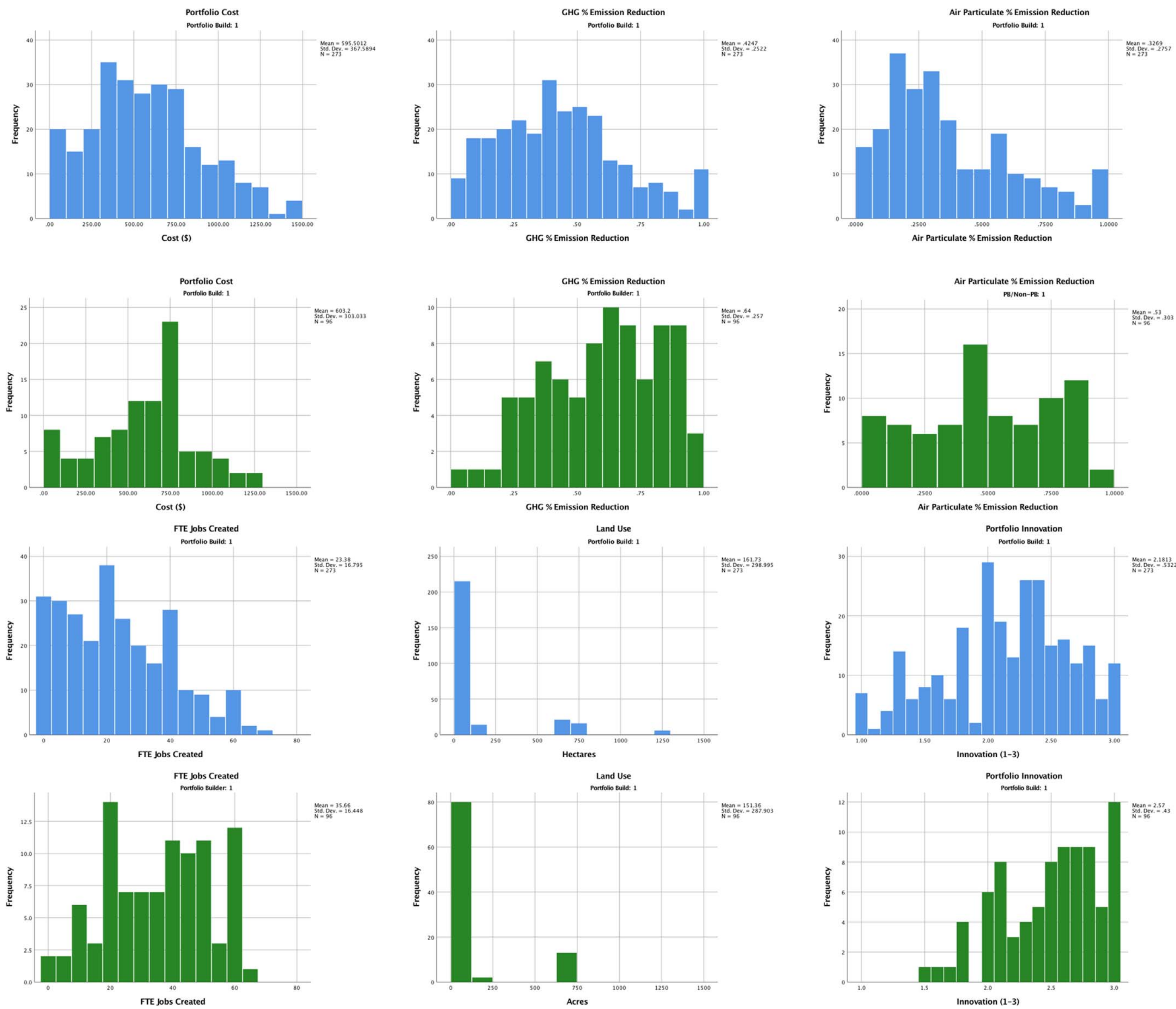

Fig. 1. Participants' user-generated portfolio outcomes (attributes) from Task 1: Study 1 is in green (Rows 2 & 4) and Study is in blue (Rows 1 & 3).

GHG emissions by 4.9% more than females (n = 128); created 3 more FTE jobs per portfolio, and adopted 0.06 higher innovation (on a 3-point Likert scale). Perhaps due to the number of political parties in Canada (here, there were 6), no discernible relationship was identifiable with respect to attributes and participants' political affiliation. Participants' initial knowledge of different energy types also did not significantly predict participants' constructed attributes in either study.

3.2. Task 2: holistic ranking

Across all three studies, the least costly options were ranked worst (i.e., least preferred) on average (see Table 1). In Studies 1 and 3 this option (Option 1) represented the status quo; *t*-tests showed this option to be the least preferred (Study 1: $t = 14.08$, df = 181, $p < 0.001$; Study 3: t = 4.10, df = 1873, p < 0.001). In Study 2, the two least costly options, i.e., the status quo (Option 1) and Option 6 (natural gas), were both ranked worst; *t*-tests showed no significant difference ($p > 0.05$) between these options' ranks; however, their mean ranks were significantly worse than the other four options. Alternatively, the best ranked (i.e., most preferred) options in Study 1 were also the costliest, i.e., Option 3 ($544/yr), Option 5 ($776/yr) and the user's own constructed portfolio (Mean cost = $603/yr, *sd* = $303/yr) (see Table 1). In Study 2, the best ranked options were Options 2 ($88/yr), 3 ($544/yr), 4 ($362/yr) and the user's own constructed portfolio ($595/yr); *t*-tests showed no difference between these four ranks ($p > 0.05$). In Study 3, the three best ranked options were also the three costliest, i.e., Options 2, 3, and 5.

3.3. Task 3: attribute weighting

3.3.1. Mean attribute weights

In Studies 1 and 2, cost, per cent GHG emissions and per cent air-particulate emissions reduced consistently received the three highest attribute weights (see Table 2; Table S2 in the Supplemental information for mean attribute weights across treatments). In Study 1, the per cent GHG emissions reduced received the highest total weight (81.5, *sd* = 21.9) and cost (80.9, *sd* = 23.5) the second highest weight across the 4 treatments. In Study 2, cost received the highest weight (66.4, *sd* = 32.4) and per cent air-particulate emissions reduced received the next highest weight (65.0, *sd* = 32.1) across all treatments. In study 3, potential to reduce GHGs received the highest weight (82.6, *sd* =24.2) and potential to stabilize global temperatures received the next highest

Table 2
Mean Attribute Weights. Participants' mean attribute weights from Task 3 across all study treatments are shown. For individual treatment means see Table S2 in the Supplemental information.

	Attributes	Range	Mean Attribute Weight (*sd*)
Study 1: Michigan, USA. (n = 181)	GHG Emission Reduction %	0 −100%	81.5 (21.9)
	Cost (Tuition Increase)	0 - $776	80.9 (23.5)
	Air Particulate Emission Reduction %	0 − 100%	78.1 (22.6)
	New Jobs (FTE)	0 − 60	56.1 (23.9)
	New Land Use (Acres)	0 − 54	46.3 (25.0)
	Innovation (Likert: 0 − 3)	1–3	37.4 (26.4)
		Range	
Study 2: Alberta, Canada. (n = 547)	Cost (Utility Bill Increase)	0 - $776	66.4 (32.4)
	Air Particulate Emission Reduction %	0 − 100%	65.0 (32.1)
	GHG Emission Reduction %	0 − 100%	58.7 (34.2)
	New Jobs (FTE)	0 − 60	42.6 (28.9)
	New Land Use (Hectares)	0 − 54	34.6 (27.0)
	Innovation (Likert: 0 − 3)	1–3	30.5 (27.3)
		Range	
Study 3: Canada (n = 1874)	GHG Emission Reduction %	0 − 5	82.6 (24.2)
	Potent. to stabilize temps	0 − 5	78.8 (25.0)
	Catastrophic Potential	0 − 5	78.3 (24.5)
	Cost	0 − 5	71.2 (27.8)
	Public Opposition	0 − 5	50.9 (29.9)

weight (78.8, *sd* = 25.0). Cost received the second *lowest* attribute weight (71.2, *sd* = 27.8) in Study 3. Degree of innovation received the lowest attribute weight in both Studies 1 (37.4, *sd* = 26.4) and 2 (30.5, *sd* =27.3); public opposition received the lowest attribute weight (50.9, *sd* =29.9) in Study 3.

3.3.2. Implied preferences

The most preferred options in Studies 1 and 2, calculated by inputting participants' attribute weights into a linear value function, were Options 5 and 3, respectively, with Option 5 achieving a preference score of 284.36 (*sd* = 58.51) and Option 3 achieving a preference score of 265.75 (*sd* = 47.85), both in Study 1 (see Table 1). In Study 2, Option 5 achieved a preference score of 219.91 (*sd* = 95.86), and Option 3 achieved 206.18 (*sd* = 83.70). Both options were the most expensive available to participants in non-portfolio construction treatments.

Regarding those participants who constructed their own portfolios in Task 1, these self-generated options were relatively poor performers, scoring only 158.72 (*sd* = 34.70) in Study 1 and 115.60 (*sd* = 68.79) in Study 2. Only the status quo and Option 2 performed worse in Study 1; in Study 2, only the status quo performed worse. In Study 3, Option 2, a moderately expensive option made up of efficiency improvements achieved the highest preference score of 2.19 (*sd* = 0.67); the Status Quo was the next best performer, scoring 1.80 (*sd* = 0.50). Option 4, a portfolio reliant solely on geoengineering, solar radiation management in particular, achieved the lowest preference score: only 1.36 (*sd* = 0.32).

4. Discussion

Considerable attention has been paid both to the public's WTP to mitigate GHG emissions (Kotchen et al., 2017) and the real social and environmental costs of not mitigating emissions. Regarding the latter, Hsiang et al. (Hsiang et al., 2017) recently showed a 1 degree (Celsius) increase in temperature results in US damages equal to ~1.2% of GDP. Studies that have internalized these social and environmental costs into the price of electricity have shown that transitioning to a cleaner, low-carbon—or even no-carbon—energy system will not actually cost consumers more but will instead be *less* expensive than the status quo (Budischak et al., 2013; Jacobson et al., 2015; Noel et al., 2017). There of course remains (some high profile) debate regarding the extent to which energy portfolios can incorporate renewables such as wind, solar and hydroelectric and the costs of doing so (Clack et al., 2017; Mooney, 2017). For example, Budischak et al. (Budischak et al., 2013) showed that a large-grid (72 gigawatts) relying on a portfolio of 90% renewables is the least-cost system in most cases (using 2030 technology prices), while MacDonald et al. (2016) showed that a portfolio of 38% wind, 21% natural gas, 17% solar, 16% nuclear and 8% hydroelectric could reduce CO_2 levels by 80% below 1991 levels without an increase in the levelized cost of electricity. Regardless of their cost all such transitions would require drastic changes to not only the grid, but to our regulatory, commercial and legal systems (MacDonald et al., 2016).

While analysts continue to disagree about the specific costs of transitioning and the sources we should rely on to generate clean energy, we have shown here that individuals may be willing to pay high costs for clean energy—indeed far higher costs than CV studies have shown previously. Individuals in Studies 1 and 2 exhibited a WTP range of $45 and $65/month for options that reduced GHG emissions between 91% and 100% and air particulates between 84% and 100%. Those same participants when tasked with constructing their own portfolios paid slightly less, between $44 and $50/month, respectively, for portfolios that reduced GHG emissions by 42–64% and air particulate emissions by 33–53%–due to the difficulty in constructing efficient portfolios in Task 3, slightly lower performance was not unexpected. It should be noted that part of the rationale for conducting Study 2 was concern regarding university students' tendency to adopt higher tuition fees as those fees may be passed onto parents or incorporated into student loans; however, the similarity between WTP responses in Study 1 and those in Study 2 across all three tasks alleviated much of this concern.

The three studies reported on here reveal a number of important trends. First and foremost, participants consistently deemphasized the cost of options, and sought to prioritize reductions in GHG and air particulate emissions even if the strategies associated with these reductions were expensive. Across all three tasks, participants ranked, weighted, preferred and constructed options that were both costly *and* significantly reduced GHG and air particulate emissions.

Certainly using surveys to predict individuals' WTP for public goods or policies as complicated and important as energy strategy development is not ideal (Kotchen et al., 2017); however, the WTP figures found here were based on a real energy system model, with real cost estimates developed to inform actual decisions. As such, they should not be especially surprising when one accounts for the real, immediate benefits of clean energy and the costs of fossil fuel-based energy (Hill et al., 2006; Owen, 2006; MacDonald et al., 2016; Noel et al., 2017). For instance, Millstein et al. (2017) show that the marginal benefits of wind and solar to climate and air quality alone to be 7.3 cents and 4 cents per kWh in the US, respectively. Despite significant geographical variation, these figures amount to savings of $63.75/month and $36.04/month, respectively, based on the average electricity used (901 kWh/month) by US residential customers in 2015 per the EIA (2017); such figures are similar to the WTP responses demonstrated in Studies 1 and 2. While Canada generates far more electricity using clean sources (59.3% from hydroelectric and 3.5% from wind) than does the US, Canadian utilities, primarily through burning coal, still generate 24% and 8% of Canada's SOx and NOx emissions, respectively (Government of Canada, 2017; Natural Resources Canada, 2017). Reductions in air pollution, though not in the form of direct savings on a utility bill or academic fees, remain especially important to individuals

(Ansolabehere and Konisky, 2014).

Even though the specific costs and performance of participants' constructed portfolios varied both within and across Studies 1 and 2, with regard to performance, most of the participants chose to reduce emissions by far more (see Fig. 1) than do the targets set forth by RPS currently in place in the US, perhaps only with the exception of Hawaii's RPS of 100%. Additionally, the option participants preferred most based on their attribute weights, i.e., the most expensive option, also completely eliminated GHG and air particulate emissions, and created 60 FTE jobs, while only requiring 18 acres of additional land use and maximizing innovation. Previous research shows all of these attributes to be critically important (Bergmann et al., 2006; Wüstenhagen et al., 2007; Mills et al., 2017), with growth in energy jobs having become a rallying cry for both US conservatives fighting to repeal the Clean Power Plan and clean-energy advocates. The landscape of US energy employment is of course complicated—and far from uniformly distributed—with approximately 750,000 Americans employed in clean energy including solar, wind, nuclear and hydroelectric in 2016, while 160,000 and 400,000 worked in coal and natural gas power, respectively (Department of Energy, 2017). In Canada, expectations are that employment in wind and solar are poised for substantial growth, particularly in Alberta following the province's passage of a $20/tonne carbon tax (McGarvey, 2017; Graney, 2017). In both the US and Canada which energy sectors will generate the most jobs, and what types of jobs they'll be moving forward, will largely be a question of federal, state and provincial energy policy. This study demonstrates that providing members of the public accurate data about energy employment performance is critical.

It should also be noted that both the options participants preferred most and the specific power-generation technology used most often by participants in Task 3 included nuclear power. The role nuclear power will and should play in mitigating CO_2 and air particulate emissions along with the cost effectiveness of continuing to operate and build future nuclear power plants is complicated (Corner et al., 2011; Kharecha and Hansen, 2013; Roth and Jaramillo, 2017). At the same time, one cannot ignore nuclear power's (near) zero percent emission profile (Sims et al., 2003). Our participants certainly did not and could not ignore it; as in both Studies 1 and 2 participants knowingly selected nuclear power as a technology in Task 3 and half of the participants in Study 2 compared portfolios in Task 1 in which nuclear power was identified as an energy source. These participants ranked portfolios including nuclear power (Options 3, 4 and 5) high—though not as high as participants in Study 1—a more specific accounting of the fuel and power-generation types used by participants in Study 1 exists in Bessette et al. (2014). This result is telling. While generally US university students tend to be more liberal and more supportive of nuclear power, Albertans and Canadians more generally tend to be opposed to nuclear power (Canadian Nuclear Association, 2012). Yet, here, when provided key social and environmental attributes, the performance of different energy portfolios and a means of engaging tradeoffs between portfolios, both study's samples overwhelmingly relied on nuclear power to reduce emissions.

Additionally, while Study 3 did not provide participants a nuclear option to compare, the specific costs of options to evaluate, or a portfolio building module by which participants could investigate energy systems, participants in this study again consistently ranked the three most expensive options in Task 1 highest. All three of these options dramatically reduced GHG emissions. In fact, they were the only three options that reduced emissions at all. These same three options performed best with regard to stabilizing global temperatures, with the exception of solar radiation management, which was the best performing option in this regard, but also the worst—along with the status quo—in mitigating emissions. Both overcoming public perceptions regarding and communicating information about geoengineering and SRM has proven difficult (Macnaghten and Szerszynski, 2013; Sütterlin and Siegrist, 2017). However, the consistency between participants' low ranks and low preference scores for geoengineering found here support both a lack of public support and the characterization of geoengineering's short-term and long-term impacts used here.

In addition to rejecting geoengineering, the majority of our participants rejected the status quo, ranking it lowest in two of the three studies (Studies 1 & 3) and second-lowest in Study 2. Such results align with recent research suggesting a majority of those in both the US and Canada are in favor of mitigating emissions via some form of renewable energy mandate (Borick et al., 2011; Mills et al., 2015). At the same time, the only option ranked lower than the status quo was an option that relied on natural gas to reduce both GHG and air particulate emissions by 30% and 14%, respectively, and at zero cost. This result is also telling. Due primarily to its cost savings over coal, portions of the US and Canada have shifted to burning natural gas, often shale gas, with that shift resulting in significant reductions in CO_2 emissions and freshwater consumption (Burnham et al., 2011; Laurenzi and Jersey, 2013; Thomas et al., 2017). The amount of methane emitted during shale gas production has been underreported however (Mayfield et al., 2017), though at the time of our studies shale production's methane emissions remained uncertain (Caulton et al., 2014); the risks associated with shale gas to communities are not yet fully understood (Jacquet, 2014); and individuals' perceptions of shale gas across the US and Canada remain in flux (Boudet et al., 2014; Thomas et al., 2017). Especially in those communities where unconventional oil and gas development is booming, individuals face difficulty in engaging the real and immediate tradeoffs between that development's (often) social and environmental costs and (sometime) economic benefits (Schafft et al., 2013). Such difficulty may explain why participants in Study 2 preferred a worse-performing option, i.e., the status quo, to an option that used only natural gas. Alberta currently relies principally on coal for electricity, but has adopted an RPS of 30% by 2030 and is phasing out all coal pollution by 2030 (Province of Alberta, 2017). Much of this phase-out will be powered by natural gas.

Another perhaps surprising, but promising, result from Study 3 involves participants ranking the option that relied on efficiency improvements highest. Improving efficiency has long been considered an effective tool for mitigating emissions, and yet at the same time is one plagued by public misunderstanding (Attari et al., 2010). Here participants evaluated information showing such improvements to be relatively straightforward, face little public opposition and have virtually no potential of catastrophic consequences. And yet such improvements also require significant up-front costs, which often due to heuristic roadblocks slow investment in such improvements (Gillingham and Palmer, 2014). While our study does not provide specific advice regarding overcoming these heuristics, it does suggest that focusing people's attention on the additional benefits of efficiency improvements, i.e., not just the long-term cost savings, but also the reduced emissions, may motivate adoption.

5. Conclusion

These three studies provided individuals multiple choice tasks in which they could evaluate real-world portfolio options across key social and environmental attributes. Across all three studies individuals placed high importance on minimizing costs and reducing GHG and air particulate emissions. When asked to assess a number of energy portfolios side by side individuals consistently ranked strategies best that reduced both GHG and air particulates considerably, even when those portfolios required considerable cost increases. Inputting participants' attribute weights into a linear value function showed the same results, namely that individuals preferred costly strategies that significantly reduce both GHG and air particulate emissions. Finally, when provided an opportunity to select their own energy efficiency levels, fuels and power-generation technologies and construct a unique, but realistic, energy portfolio, participants consistently constructed costly portfolios that significantly reduced both GHG emissions and air pollution.

These results suggest that while minimizing cost was indeed important to individuals, delineating the social and environmental health benefits alongside those costs—and providing means to explore the tradeoffs between those benefits and costs—generated higher WTP for clean energy portfolios than has been commonly found in studies using CV. Considering the serious consequences of unmitigated emissions, working to improve the processes by which we elicit the public's willingness to pay for clean energy is critical.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.enpol.2018.01.021.

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