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Anticipating public attitudes toward underground CO_2 storage

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ABSTRACT

Carbon capture and storage (CCS) may play a central role in managing carbon emissions from the power sector and industry, but public support for the technology is unclear. To address this knowledge gap, and to test the use of discrete choice analysis for determining public attitudes, two focus groups and a national survey were conducted in Canada to investigate the public's perceptions of the benefits and risks of CCS, the likely determinants of public opinion, and overall support for the use of CCS.

The results showed slight support for CCS development in Canada, and a belief that CCS is less risky than normal oil and gas industry operations, nuclear power, or coal-burning power plants. A majority of respondents indicate that they would support the use of CCS as part of a greenhouse gas reduction strategy, although it would likely have to be used in combination with energy efficiency and alternative energy technologies in order to retain public support.

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1. Introduction

One option for greenhouse gas (GHG) emission reduction is carbon capture and storage (CCS), which involves the capture of carbon dioxide (CO_2) from large stationary sources and its disposal underground in deep geological formations. Industry has accumulated decades of experience with underground injection technology through acid gas injection, hazardous waste disposal, and enhanced oil recovery, in which CO_2 is injected into depleted oil reservoirs to increase resource recovery (IPCC, 2005; Jaccard, 2005; Wilson et al., 2003). However, while a significant research effort has focused on the technical issues involved in implementing large-scale geological disposal of CO_2, less research has been done to date on the likely public acceptability of this new technology (IPCC, 2005).

CCS involves separating pure CO_2 from the waste stream of facilities such as natural gas and oil processing plants and electricity generating stations, transporting the CO_2 to a disposal site, and then injecting it deep underground into stable geological formations such as depleted oil and gas wells, coalbeds (as part of enhanced coalbed methane recovery), or deep saline aquifers. Internationally, there is experience with CCS at the Sleipner project in the Norwegian North Sea, where 1 million tonnes of CO_2 per year (Mt/y CO_2) are stripped from natural gas and sequestered, at the In Salah project in Algeria, where up to 1.2 Mt/y CO_2 will be sequestered, and at over 70 CO_2-enhanced oil recovery sites in North America, including an operation in Weyburn, Saskatchewan, which disposes of 1.5 million Mt/y CO_2 (Gale, 2007; IPCC, 2005; Williams, 2002). Forty-five acid gas injection sites are also in operation in Alberta and British Columbia, Canada, and have provided additional experience with storing CO_2 safely underground (Keith, 2002; Gunter and Bachu, 2003).

Given rising global GHG emissions and the commitment to the Kyoto Protocol, as well as the predicted continuing global reliance on fossil fuels, it is not surprising that CCS has been suggested as a promising option for GHG emission reductions. As a technology that renders oil and gas industry expansion and GHG reduction no longer mutually exclusive, CCS enjoys government support in several countries, including Canada, where the federal government has allocated $375 million Cdn in financial support to CCS-related activities since 2006, including $240 million for a commercial CCS demonstration plant in Saskatchewan. The provincial government will match this funding (SaskPower, 2009; SaskPower, 2008; Mining Weekly, 2008). In its 2009 budget, the federal government committed an additional $1 billion over five years to clean energy technologies, with only CCS explicitly identified as a recipient of this funding, and instituted tax breaks for CCS projects (Department of Finance Canada, 2009). The Alberta government has committed $2 billion to fund a portion of the construction costs of 3–5 large scale carbon capture and storage projects by 2015, with the final project selection to occur by spring 2009 (Alberta Energy, 2008). However, public attitudes toward CCS are largely unknown, because few large-scale CCS projects aimed specifically at climate protection are operational, and awareness of the technology is low. The importance of public attitudes should not be underestimated–large-scale public opposition to a technology (such as nuclear

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power or genetically modified foods) can lead to political opposition, and make it difficult to gain approval for new projects (Frewer and Shepherd, 1995; Mazur, 1981; Kim, 2002).

CCS presents various local risks to the environment and people, and as a result, is at risk of facing this same opposition. This study aims to anticipate potential public attitudes toward CCS and to understand the key determinants that may shape perceptions of the technology, by investigating how people in a particular country, Canada, perceive the risks and benefits of CCS, and how their views are likely to change as various risks become more widely understood and communicated. The specific research areas of interest were to:

1. Identify the general state of knowledge of CCS in an industrialized country and compare the results to those from other countries.
2. Identify and prioritize likely public concerns about, and reasons for support for CCS.
3. Separate and identify the opposition stemming from concern about the *risks* of CCS from *fundamental* opposition to CCS as the wrong solution to climate change.
4. Identify and understand some of the features that might determine the degree of public support for CCS as a GHG mitigation measure.
5. Determine the potential impact of media information and international experience with CCS on support for the technology.
6. Determine how attitudes toward CCS differ between residents of regions with a significant fossil fuel endowment and those in regions without.

It must be clearly noted that it is not possible to accurately predict the public reaction to future large-scale CCS development as it will be strongly dependent upon the way the public debate evolves, the way in which CCS development is managed, and whether a strong NIMBY (Not In My Backyard) movement develops in reaction to specific siting decisions. However, at least in Canada, several CCS projects are currently underway, and no concerted opposition has emerged. The world's largest carbon dioxide enhanced oil recovery (EOR) project is located in Weyburn, Saskatchewan, and enjoys a good relationship with the local community. At least five other EOR projects and one enhanced coalbed methane project have also been undertaken in the provinces of Alberta and Saskatchewan (Canadian Centre for Energy Information, 2008; Bulut, 2007). Acid gas injection (AGI) is a partial analogue for CCS, where acid gas from the natural gas industry (with a CO_2 content ranging from 20% to over 90%) is disposed of predominantly by injection into deep saline aquifers. There are over 45 AGI sites in Alberta, some quite close to major population centers, but the public permitting process has generally been uncontroversial (Keith, 2002; Gunter and Bachu, 2003).

1.1. Previous research

Although there has been no previous research into Canadian public attitudes toward CCS, researchers in other countries have increasingly been investigating this issue. In the Netherlands, Huijts (2003) found that residents living above a likely CO_2 storage site had neutral to positive attitudes about CCS, but did not support its development nearby, and de Best-Waldhober and Daamen (2006) found that informed respondents rated a variety of different large-scale CCS projects as 'adequate'. Shackley et al. (2004) found in England that attitudes started off slightly negative but became slightly positive after additional information about CCS was presented. In Japan, Itaoka et al. (2004), Uno et al. (2004), and Tokushige et al. (2004) found support for CCS in general, but not if it were to be locally situated, with additional information about CCS leading to increased support. Australian researchers found that on average, Queensland residents felt that CCS was a promising technology (cLET, 2006), while in Sweden, a majority of survey respondents were open to using CCS to address climate change (Reiner et al., 2006). In the United States, Palmgren et al. (2004) found the opposite effect, with members of her survey sample starting out slightly opposed to CCS, and becoming increasingly opposed as additional information was presented. Curry (2004) also found that there was little support for CCS in the United States in comparison to lower-carbon alternatives, although when information on the relative costs of different technologies was presented, CCS regained some ground.

A common theme through many of the international studies was the influence that climate change beliefs, information about CCS, and siting decisions can have on public support. By comparing the studies, we also observe that despite methodological differences, survey respondents in Japan, Europe, and Australia generally rated CCS more favorably than did respondents in the United States. However, this observation held only partially true when researchers controlled for methodological differences by asking the same survey questions in Japan, the UK, Sweden, and the United States. In that study, respondents in Japan and the UK were more receptive to CCS than respondents in the US, with Swedish respondents least favorably inclined to the use of CCS (Reiner et al., 2006).

Previous research into public attitudes toward CCS has used a variety of methodologies, including individual interviews and focus groups (Huijts, 2003; Shackley et al., 2004; Palmgren et al., 2004; Uno et al., 2004; Tokushige et al., 2004), and large statistically significant surveys (Curry, 2004; Itaoka et al., 2004; Reiner et al., 2006). While smaller scale interviews and focus groups can allow a more thorough investigation of the thought processes contributing to attitudes about CCS, their small scale reduces the applicability of their findings to a larger audience. Large population surveys on the other hand can provide a statistically defensible picture of current opinions, but because they do not generally allow respondents the freedom to ask questions, choose answers other than those provided, and clarify their responses, the results may still be misleading (Nassar-McMillan and Borders, 2002; Krueger and Casey, 2009). Among the studies existing at the time, this research was the first to combine both methodologies, to achieve the benefits of focus groups in delineating the range of attitudes, concerns, and questions held by the public, and the benefits of a large national survey in drawing conclusions about the attitudes held by the sample population. The information about CCS (both quantity and tone) that is provided to respondents also has an important potential influence on survey results. Because awareness of CCS is low in Canada (and in most countries where public opinion studies have been conducted), opinions are generally considered uninformed and less stable until information about CCS is provided (de Best-Waldhober and Daamen, 2006). Several studies have tested the impact of information on attitudes toward CCS, including de Best-Waldhober and Daamen (2006) and Itaoka et al. (2004). In the current study, an extensive description of CCS was provided to respondents, and in addition, the variability in respondent attitudes that occurs when given positively or negatively biased information was tested.

In order to improve the interview and analysis processes, previous research has tested the use of additional analytical tools, including mental model interviews (Palmgren et al., 2004) and factor analysis (Itaoka et al., 2004). This research is the first to apply discrete choice analysis, which forces respondents to make tradeoffs and enables the researcher to identify the relative importance of different factors. Discrete choice experiments (DCEs) are frequently used in product marketing research, but this study tested their potential use for estimating and anticipating public attitudes toward, and support for CCS. The study methodology is detailed in Section 2. The results from the attitudinal questions, the DCE, and a linear multiple regression analysis are presented in Section 3. Section 4 concludes with a discussion of the key findings, recommendations for CCS development, and suggestions for future research.

2. Methods

The study data was collected in two phases: focus groups were conducted in order to determine the range of likely attitudes toward CCS as well as the perceived benefits and risks, and this information was then used to develop a closed-form national survey (Morgan et al., 2001; Dillman, 2000; Nassar-McMillan and Borders, 2002; Krueger and Casey, 2009). The focus groups were held in Edmonton, Alberta and Toronto, Ontario, to provide both local and distanced geographical perspectives about CCS respectively. Participants were recruited predominantly through random digit telephone dialing, and were pre-screened to ensure that the resulting group was balanced across age, gender, education level, and familiarity with CCS. The focus groups involved 20 participants in total and took place in late August 2004. Each 1.5-hour session included moderated group discussions on environmental issues, climate change, and CCS. In addition, participants were provided handouts for complicated parts of the discussion, and on some questions (such as level of support for CCS in Canada) participants wrote out their responses and handed them back to the moderator.

The information obtained from the focus groups was then used to design a national survey containing more targeted and accurate questions than would have been possible otherwise. The survey started with general questions about important issues in Canada, awareness of CCS, and attitudes toward climate change. Next, respondents were presented with a neutral two-page description of climate change and CCS that was developed in conjunction with experts in the field, and a number of specific questions about CCS. A discrete choice experiment followed (described in more detail later in this section), with instructions on how to complete the questions, and nine separate choice tasks for each respondent. The final section of the survey presented respondents with either a very positive or very negative newspaper article, and repeated an earlier question asking for an overall evaluation of CCS. The questions asked attempted to identify general attitudes about CCS that might have relevance for other countries.

2.1. Survey sample

The survey was administered online, in order to enable randomization within questions, to prevent respondents from returning to earlier questions once they received additional information about CCS, and to reduce administration costs so that a larger sample could be surveyed. Before administering the survey to the full sample, a field test was conducted with 35 colleagues, and the test data was analyzed and modeled in order to identify any problems with the survey. Synovate, a Canadian market research firm, was hired to provide a representative survey sample from its online panel of 70,000 Canadian households. The sample was weighted so that 40% of the respondents would come from Alberta and Saskatchewan (AB/SK), where CCS will be predominantly developed, and 60% would come from the rest of the country (CAN), with each of the two sub-samples designed to be representative of that region's population in terms of gender, age, geographic distribution, income and education level. Synovate sent out 8500 password-protected email invitations in a staggered March 2005 mail-out that allowed for a quick analysis of the results from 10% of the survey sample to ensure that there were no errors before the full sample was invited to complete the survey. Overall, 1972 surveys were completed within 14 days (775 in Alberta and Saskatchewan and 1197 in the rest of Canada), for a 23.2% response rate.

Synovate provided full socio-demographic information for each of the survey participants. The final survey samples were slightly older and more male than the populations they were drawn from, with average ages of 50.8 years (CAN), and 47.7 years (AB/SK). The CAN sample was 45.8% female and the AB/SK sample was 47.9% female. The survey sample is biased toward respondents with Internet access and some computer knowledge and therefore suffers from some coverage error. However, Internet penetration rates have been rising, and 73% of Canadian households were estimated to have online access in the year the survey was administered (TNS, 2005). All sampling methods demonstrate some drawbacks and sources of bias; telephone and mailing lists often omit large segments of the population and are especially prone to coverage error, and in-person surveys are infeasible and prohibitively expensive for national-level research (Dillman, 2000). As a result, Internet-administration was determined to be the most appropriate and cost-effective option for this survey.

In both the focus groups and survey, the term 'geological disposal of carbon dioxide' (GDC) was used instead of CCS, as research conducted in the United States shows that the public understands that the goal of this technology is disposal, rather than storage of CO_2 (which implies later removal and use), and that the public gravitates toward 'disposal'-related terms when describing the technology (Palmgren et al., 2004). However, the term CCS is used throughout this article (except in the reproduction of survey questions) as it has become the standard in this field.

2.2. Discrete choice experiment

A discrete choice experiment (DCE) was included in this study in order to investigate the research question using more than one methodology. One of the benefits of using discrete choice experiments is that they force respondents to make tradeoffs and allow the utility associated with a good or service (in this case the development of CCS) to be decomposed into the utility associated with each of the different attributes of that good or service. This provides information on the *relative* importance of various attributes of CCS to the public. Discrete choice experiments have not been previously used to understand public preferences about CCS, but they have been used to gain useful information about preferences for other relatively unknown or controversial technologies, such as genetically modified foods (Burton et al., 2001), and space travel (Crouch, 2001).

Discrete choice modeling (DCM), the process of conducting and analyzing DCEs, is based on Random Utility Theory (RUT) and assumes that individuals view products as bundles of characteristics, each of which has an associated importance, and that individuals choose between products by comparing their utilities, which are calculated by taking a weighted sum of the characteristics and each characteristic's associated importance (Louviere et al., 2000). The utility that an individual receives from a product "j" (U_j) is comprised of a portion that the analyst can observe and measure (V_j), by taking the weighted sum of the observable characteristics of a product and the importance that the individual places on each characteristic, as well as a non-observable component (ε_j). A possible disadvantage of DCM is thus that respondents' decision-making heuristics may be different from those assumed by RUT. A multinomial logit model was used to analyze the results, and so the non-observable component is assumed to follow a Type 1 Extreme Value (Weibull) distribution.

Table 1 presents three policy-relevant CCS characteristics that were selected for the experiment, based on the results of the focus

Table 1
The attributes used in the discrete choice experiment, with the three possible levels of each attribute.

Entity: Entity responsible for managing long-term risks and liability Levels: Federal government, provincial government, industry
Share: Proportion of Canada's GHG reduction targets met with CCS, versus a combination of energy efficiency, renewable energy, and nuclear power Levels: 5%, 20%, 50%
ElecBill: Increase in monthly electricity bill (average monthly bill is $80) Levels: $5, $25, $50

groups and consultations with experts in the field. While many more characteristics are of interest, we limited the experiment to three, as any more may have made the choice task too difficult for respondents, and hence increased the magnitude of the error term (Swait and Adamowicz, 1997), especially considering the unfamiliar subject matter. (The small number of characteristics that could be investigated at one time was a limitation of the DCE approach.) Each characteristic was assigned three possible levels, to allow tradeoffs to be assessed over a reasonable range. A sample question from the online survey is presented in Fig. 1.

Recall that utility is the sum of measurable and non-measurable utility (Eq. (1)).

$$U_j = V_j + \varepsilon_j \tag{1}$$

Eq. (2) shows the resulting utility function which was estimated. In this case β_j is the intercept and β_1, β_2 and β_3 are coefficients that measure the importance of each characteristic to the respondents.

$$V_j = \beta_j + \beta_1 \times \mathrm{Entity}_j + \beta_2 \times \mathrm{Share}_j + \beta_3 \times \mathrm{ElecBill}_j \tag{2}$$

A Shifted Triples 3^3 fractional factorial design (Bunch et al., 1996; Chrzan and Orme, 2000) was used to design the experiment, which consisted of a series of 9 choices between three different configurations of CCS. While this efficient design does not allow for the analysis of interaction effects, it compensates by providing a very high number of observations for each choice–a tradeoff considered acceptable given the unfamiliar subject matter. Respondents were forced to make a choice between the three configurations but could indicate in a follow-up question if their selected alternative was actually acceptable to them, with a negative answer coded and modeled as a choice for the base case (status quo).

The results were analyzed using Limdep Version 8.0 and the conditional multinomial logit model. The model initially included four intercepts, but when no statistically significant difference was observed between them, it was re-coded with a single intercept. The observable utility function (Eq. (2)) was estimated for both the CAN and AB/SK sub-samples, and then for respondents with different socio-demographic and attitudinal characteristics within each of the sub-samples.

2.3. Linear multiple regression

Linear multiple regression was also used in order to identify whether or not respondents' attitudes and demographic characteristics had a significant impact on their support for CCS in Canada. The results from a survey question asking "Do you support or oppose the use of geological disposal of CO_2 in Canada?" (1 = strongly oppose to 7 = strongly support, or do not know) were used as the dependent variable, and responses to five questions about climate change beliefs, awareness of CCS, and respondent certainty about their ratings, as well as seven socio-demographic characteristics were used as independent variables. Ordinary least squares linear multiple regressions were run using SPSS, first including all of the independent variables, and subsequently including only those variables that were significant at the 95% level on the first run. Models were run for both the CAN and AB/SK geographic sub-samples.

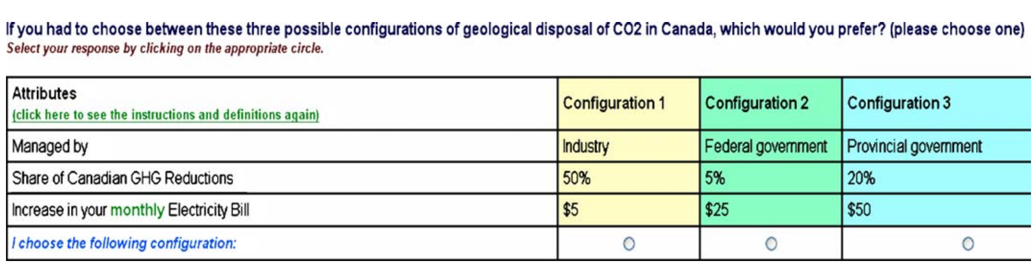
3. Results

3.1. Attitudes about climate change and CCS

The first section of the survey was designed to identify attitudes toward climate change and prior awareness of CCS. Sample questions and responses from this section are presented in Table 2. Next respondents received a two-page introduction to CCS, after which they answered nine questions about their thoughts on the technology. Selected questions and responses are shown in Table 2 and Figs. 2–4. The discrete choice experiment followed, and the survey closed with each respondent reading either a very positive or a very negative newspaper article about CCS and indicating a final opinion about the use of CCS in Canada.

The results showed that a strong majority of respondents (nearly 80% of the CAN sub-sample and nearly 70% of the AB/SK sub-sample) believe that climate change is occurring and some action should be taken to address it (Table 2). This is a much higher result than in the United States, where 53% of Curry's CCS survey respondents answered a near identical question the same way (the only difference was the substitution of the term "climate change" in the Canadian survey for the original "global warming") (Curry, 2004). However, there is a 1.5 year gap between these two studies, so there is a possibility that a portion of the differential may be the result of increasing concern about climate change over time, a trend that has been documented by pollsters in both Canada and in the United States (McAllister Opinion Research, 2007; Fineren, 2007).

Despite recognition of the seriousness of climate change, respondents rated it very low in importance compared to other national issues, and it was the lowest ranked environmental issue, with water pollution and hazardous waste attracting much higher concern. These issues pose a much more visible, direct, and seemingly immediate threat to the public, while the direct impact of climate change is harder for the public to see. These results are consistent with other Canadian surveys; McAllister Opinion


If you had to choose between these three possible configurations of geological disposal of CO2 in Canada, which would you prefer? (please choose one)
Select your response by clicking on the appropriate circle.

Attributes (click here to see the instructions and definitions again)	Configuration 1	Configuration 2	Configuration 3
Managed by	Industry	Federal government	Provincial government
Share of Canadian GHG Reductions	50%	5%	20%
Increase in your monthly Electricity Bill	$5	$25	$50
I choose the following configuration:	○	○	○

Fig. 1. An Internet page image capture of one choice task from the discrete choice experiment, exactly as seen by respondents completing the survey.

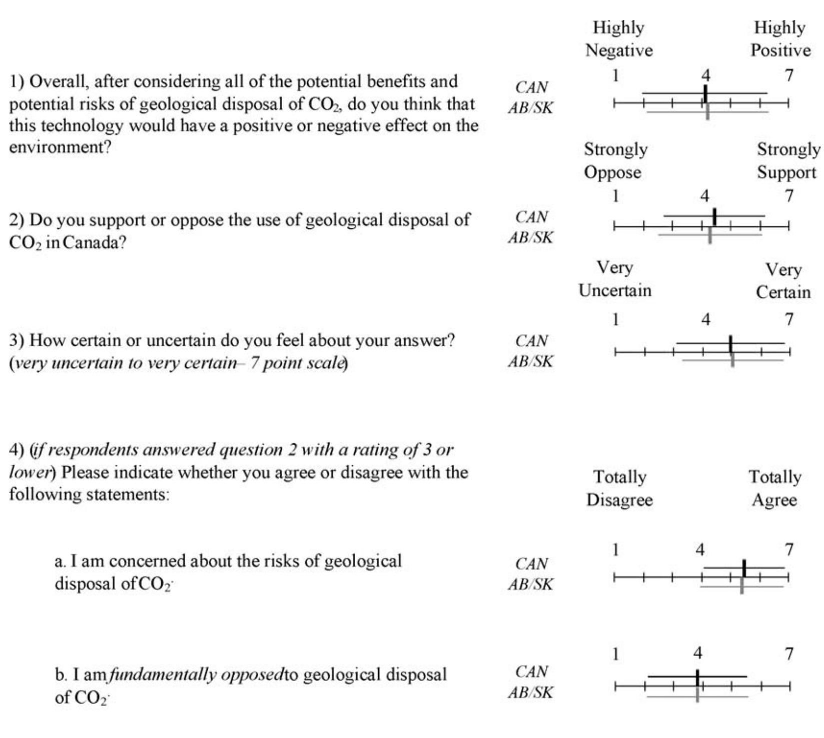
Table 2
Exact text of selected attitude and awareness questions from the survey, and the percentage of respondents that selected each answer.

Question	Possible responses	Percent of respondents
	AB/SK	CAN
Have you ever heard of geological disposal of carbon dioxide?		
Yes	15.4	10.5
No	67.6	68.2
Unsure	17.1	21.4
From what you know about climate change (global warming), which of the following statements comes closest to your opinion?		
Climate change has been established as a serious problem and immediate action is necessary.	29.1	43.3
There is enough evidence that climate change is taking place and some action should be taken.	39.2	36.7
We do not know enough about climate change and more research is necessary before we take any action.	23.2	15.6
Concern about climate change is unwarranted.	7.1	3.3
No opinion	1.3	1.2

Research found that the percentage of Canadians who believe that climate change is a very serious problem was only 40% in 2003, with this figure rising to 66% by 2007. Other polls confirmed that climate change and environmental issues ranked very low in comparison to issues such as health care, with air and water pollution the environmental issues of top concern (Environics Research Group, 2005; CBC News, 2005; McAllister Opinion Research, 2007). The results are also consistent with those from very similar questions on American CCS surveys; Palmgren et al. (2004) found that improving education and improving healthcare were rated as the most important issues facing the United States, while reducing climate change was ranked last of 15 social and environmental issues. Curry et al. (2005) also found that terrorism and health care were selected as the two most important issues, while the environment ranked 13th of 22 issues, and climate change was ranked sixth in importance among environmental issues.

Knowledge of CCS among survey respondents was low, at 10.5% and 15.4% of the CAN and AB/SK sub-samples respectively (Fig. 2), which was higher than the awareness results reported by researchers in the United States (4%, Curry, 2004), but lower than in the Netherlands (42%, Huijts, 2003) or in Japan (31%, Itaoka et al., 2004). The results from the Japanese and American studies are readily comparable to the Canadian results, as they used similar question wording and were also large population surveys. However the Dutch study was less comparable, as it focused on a small non-representative sample located above a likely future CO_2 storage area.

When respondents were tested to determine if they actually knew what environmental problems CCS addressed, only 5.6% and 6.2% of the CAN and AB/SK sub-samples respectively were able to correctly identify that CCS addressed climate change, with respondents more likely to believe that CCS was a solution for the hole in the ozone layer. In the American survey (Curry, 2004), when a very similar question was asked, only 0.5% of respondents were able to correctly identify the purpose of CCS. Given the scale of the difference in awareness between Canada and the United



None of the results are statistically different between the two geographic sub-samples.

Fig. 2. Exact text of questions about support for CCS. Short vertical bars represent the mean response, and long horizontal bars represent one standard deviation on either side of the mean. Standard error of the mean ranges between 0.04 and 0.07, and is too small in all cases to be visible in the figure.

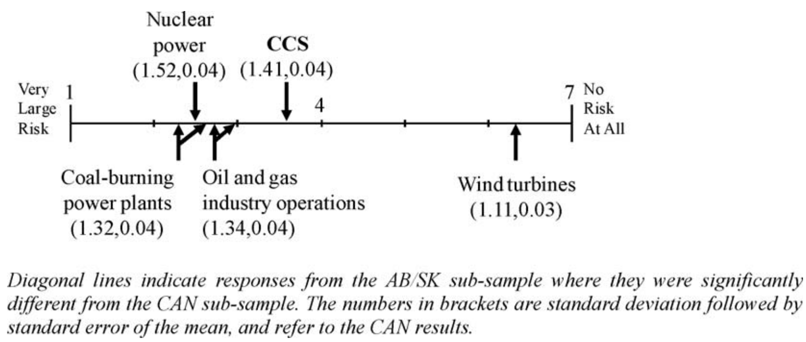


Fig. 3. Evaluation by respondents of the perceived risk of CCS compared to other technologies. Respondents were asked ''On a scale of 1–7, where 1 is not at all risky, and 7 is extremely risky, where would you place each of the following technologies?''. The technology names in the figure were used, with the exception of the term ''geological disposal of CO_2'' instead of CCS, and the clarification ''(production and refining)'' after oil and gas industry operations.

States, the authors believe that significantly higher awareness of CCS exists in Canada, even considering the year and a half between the administration of the two studies.

Overall, respondents were slightly supportive of CCS development in Canada, rating their support at 4.44 and 4.29 (CAN and AB/SK sub-samples respectively, results not statistically different), where 1 indicated strong opposition and 7 indicated strong support (question 2 in Fig. 2). When asked how certain or uncertain they felt about their answer, respondents indicated that they were somewhat certain of their opinions, but not completely set on them (question 3 in Fig. 2). CCS was perceived as having a just above neutral net impact on the environment (question 1 in Fig. 2), indicating that there is still substantial concern about the potential impacts of CCS, yet respondents rated CCS as less risky than normal oil and gas industry operations, nuclear power, and coal-burning power plants, all of which are extensively used in Canada (Fig. 3). To a certain extent, this is likely due to the fact that the impacts of all three of these energy technologies are readily visible to the public, while CCS is still theoretical. If problems occur at early CCS operations, opinions are likely to change drastically. However, respondents' perception that CCS is less risky than these common energy technologies still indicates that the public may be receptive to its use.

Respondents were also asked to evaluate a number of positive and negative statements about CCS, and indicate how much they agreed or disagreed with each statement on a 7-point scale. The top-rated positive statements were (in order of agreement):

1. One reason why this technology is good is that it can be a bridging technology to achieve short-term reductions in greenhouse gas emissions while we develop other long-term alternatives.
2. One reason why this technology is good is that it can be done in conjunction with enhanced oil and gas production, increasing the amount of oil and gas produced and reducing water use in the production process.
3. One reason why this technology is good is that it may allow greenhouse gas emissions to be reduced more quickly and at a lower cost than other alternatives.

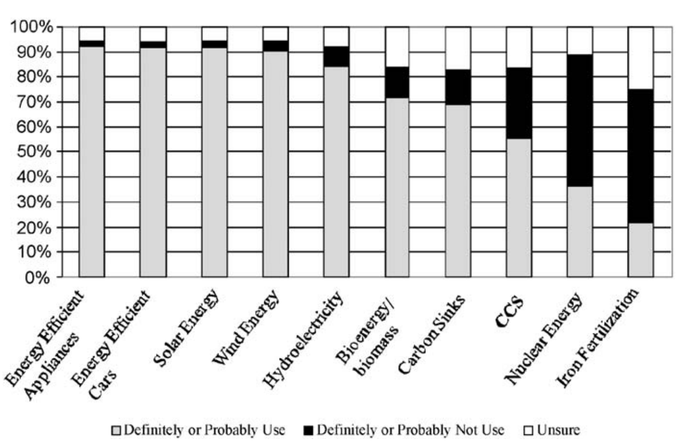


Fig. 4. Respondents were asked ''The following technologies have been proposed to address climate change. If you were responsible for designing a plan to address climate change, which of the following would you use?'' The options were ''definitely use, probably use, probably not use, definitely not use, and not sure''. Each technology listed was accompanied by a brief description.

The negative statements received higher agreement ratings than the positive statements. The top-rated concerns, in order of rating, included:

1. I am concerned that there may be unknown future impacts.
2. I am concerned about potential contamination of groundwater.
3. I am concerned about the potential safety risks of a large CO_2 leak.
4. I am concerned about potential harm to plants and animals near the disposal site or to underground organisms.

Over half of respondents would likely use CCS in a climate change strategy, while just over a quarter of respondents would likely not include it, as shown in Fig. 4. CCS was preferred to nuclear power, but was a much less popular choice than energy efficiency and renewable energy technologies, which nearly all respondents would include if they were designing a climate change strategy for the country. This corresponds with the results of other opinion surveys, which indicate that energy efficiency and renewable energy technologies are far more popular with the public than other energy technologies (The Strategic Council, 2008; EKOS, 2004). It must be emphasized that opinions are likely to change once large-scale projects are sited, and as we will discuss later in the paper, media portrayal of CCS, opinions of influential stakeholders, and use of CCS in other countries will all impact public opinions. These results provide an understanding of initial public opinions, but the evolution of future opinions cannot be predicted. It must also be stressed that the responses only provide information on the respondents' perceptions of the desirability of different technologies. When full information on costs, efficiency and feasibility is presented, the public's initial preferences often change.[1] While this was beyond the scope of the current project, it would be a useful inclusion in future CCS research. It is interesting to note that when the identical question was asked in the United States, respondents favored nuclear power over CCS by a significant margin (Curry, 2004). A different American study also

[1] Palmgren et al. (2004) asked respondents for their willingness to pay for different energy packages that would reduce CO_2 emissions by 50%, while Curry (2004) tested the impact of providing price information on support for a variety of energy technologies.

found a higher willingness to pay for nuclear power than CCS (Palmgren et al., 2004).

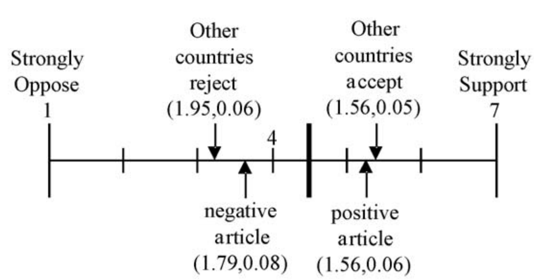
Those respondents who opposed CCS were asked several additional questions in order to better characterize their opposition. The results showed that they were generally concerned about the risks of CCS, rather than fundamentally opposed to the technology (question 4 in Fig. 2). This indicates that CCS likely does not yet face the type of public opposition that technologies such as nuclear power and genetically modified organisms have historically faced. Itaoka et al. (2004) asked a similar question in Japan and obtained comparable results; only 17.6% of those opposed to CCS indicated that they were fundamentally opposed, while 82.4% responded "it depends". When given a list of eight actions that focus group respondents indicated were critical to public support for CCS, and asked which actions, if any, would reduce their opposition to CCS, approximately 80% of respondents stated that more information about the technology would reduce their opposition. "More information" can be interpreted in two ways: better sharing of existing information with the public, and continued research into aspects of CCS, thereby creating new information to address key public concerns. Many CCS researchers, including Shackley et al. (2004), Curry (2004), Itaoka et al. (2004), Tokushige et al. (2004), Curry et al. (2005), and de Best-Waldhober and Daamen (2006), have tested the impact of information directly, by providing different quantities or types of information to two or more survey samples, and assessing the impact on attitudes toward CCS. Virtually all found that providing more information about CCS was associated with more positive attitudes toward the technology, with only Itaoka et al. (2004) finding no change in opinion between the two information groups. However, Palmgren et al. (2004) found that American respondents became more negatively inclined toward CCS when they were provided with more information. Regarding the Canadian results specifically, the high importance that opponents of CCS place on getting more information is likely linked with the other survey finding that respondents rated the "unknown effects" of CCS as their top concern. Other actions that were selected by over half of opposed respondents were the development of a strong regulatory and monitoring framework involving independent experts and NGOs, which would reduce the perceived risk associated with CCS; and a commitment to not develop CCS at the expense of renewable energy and energy efficiency, which are respondents' first choices for reducing GHG emissions.

Several factors had an impact on rated support for CCS (Fig. 5). The first was the extent to which CCS was accepted and used in other countries. When asked to rate their support for CCS under a scenario where almost all other countries in the world had rejected it as an unsafe option, respondents became slightly opposed to the use of CCS. Conversely, in a scenario in which most other countries in the world were using CCS and had declared it safe, respondents became moderately supportive. Because CCS is still a relatively unknown technology, and because the public is not entirely certain of their opinions, the media also will play a critical role in shaping public opinion. Half of the respondents were shown a negative newspaper article about CCS at the end of the survey, and their final rating of CCS shifted from slight support to slight opposition. The other half of the survey sample received a positive newspaper article about CCS. Predictably, their final rating of CCS then moved from slight support to moderate support. These results emphasize that respondent opinions are new and not fully formed, and their evolution will be strongly dependent on how CCS is portrayed in the media as development continues.

3.2. Discrete choice experiment

The discrete choice experiment resulted in a data set containing 17,748 choices between alternative configurations of CCS, including 1972 observations for each of the nine different choice questions. The results are presented in Table 3. The CAN data had an R^2 value of 0.1512, indicating that 15.12% of the variation in the data can be explained by the model, and a likelihood ratio index of 0.146, where 0 indicates that the model has no explanatory power and 1 indicates that the model can perfectly predict the data. The AB/SK model had a slightly lower R^2 value of 0.1429, and a likelihood ratio index of 0.1414. These figures are both very low, indicating that respondents' choice patterns were not consistent, and there was significant random variation in the data. This is likely because CCS is a new technology, and respondents have not yet developed fully formed opinions about the technology and decided which characteristics will be important to them. It is also possible that respondents inferred the existence of other characteristics for each profile presented, and based some of their choices on this other information.

Additionally, since only three characteristics could be tested in order to avoid overwhelming respondents, judgment was used to select the characteristics likely to be most important to the public. It is possible that the wrong characteristics were chosen and the results would have been more consistent if the scenarios were different. A design issue may also have decreased the explanatory power of the model. As discussed in Section 2, respondents were forced to make a choice between three alternative configurations of CCS, and then answer a follow-up question asking if their selected configuration would actually be acceptable to them. Comments solicited at the end of the survey indicate that some



The solid black line indicates initial support for CCS. All results are for the CAN sub-sample. The scenarios with arrows indicate rated support under different conditions. The numbers in brackets are standard deviation followed by standard error of the mean.

Fig. 5. Respondents were asked to rate their support for CCS under scenarios where almost all other countries in the world were using CCS and had declared it safe, and where almost all other countries in the world had rejected it as an unsafe option. Respondents also rated their support for CCS at the end of the survey after reading either a very positive or a very negative newspaper article. These ratings are compared to the initial support rating to show the variability that is possible given different media reports and international conditions.

Table 3
Discrete choice modeling results.

Variable	Coefficient		Standard error		*P*-value		Monetized value	
	CAN	AB/SK	CAN	AB/SK	CAN	AB/SK	CAN	AB/SK
Entity-Provincial	0.251	0.458	0.029	0.035	0.000	0.000	−$6.34	−$11.37
Entity-Federal	0.549	0.342	0.027	0.035	0.000	0.000	−$13.88	−$8.50
Share (+1%)	0.021	0.018	0.001	0.001	0.000	0.000	−$0.53	−$0.46
ElecBill (+$1)	−0.04	−0.04	0.001	0.001	0.000	0.000	$1.00	$1.00
Intercept	0.164	0.136	0.024	0.03	0.000	0.000	−$4.14	−$3.37
R^2	0.1512	0.1429						
Log likelihood function	−12,677	−8,288						
Likelihood ratio index	0.146	0.1414						

R^2 represents the proportion of the variation in the data that can be explained by the model. The log likelihood function is another measure of the model's explanatory power, but the value increases with sample size, so it cannot be evaluated on its own. The likelihood ratio index combines the modeled log likelihood function with the log likelihood function of a model with all coefficients set to zero. A value of 0 indicates the model has no explanatory power and a value of 1 indicates that the model can perfectly predict the data.

respondents misunderstood the question and thought they were being asked the same question a second time. These respondents presumably indicated the previously selected configuration was acceptable, leading to an under-selection of the status quo. Overall, the low explanatory power of the model indicates that undue weight should not be put on the monetary values presented in Table 3; however, the results still provide an initial indication of general public preferences with respect to the modeled characteristics.

All of the coefficients are significant at the 99% significance level and have logical signs. The characteristic 'Managing Entity' was dummy-coded in the model, so Industry was chosen as the base case, and the coefficients for Entity-Provincial and Entity-Federal are relative to Industry. All of the variables were standardized to the monetary attribute (increase in Electricity Bill) so that they could be compared, with a negative monetized variable indicating that the specified Entity level, or a one-unit increase in Share, has the same value to respondents as a *decrease* in their monthly electricity bill of the same amount. Table 3 shows that the entity that manages CCS is an important characteristic to both geographic sub-samples, with the CAN sub-sample preferring federal management of CCS and the AB/SK sub-sample preferring that their provincial governments take on this role. Part of the reason for this is clearly a desire for protection of local interests, as most Canadian CCS opportunities lie in Alberta and Saskatchewan, and so it is reasonable for respondents in these provinces to prefer local management of their resources. However, a deeper issue is also at play here, as many Albertans have distrusted the Federal government ever since it instituted the National Energy Program in 1980, which controlled national energy prices and increased the federal share of oil production income, transferring wealth from oil-rich Alberta to the rest of the country (Scarfe, 1981). Increasing the share of Canada's GHG emission reduction targets that is met with CCS versus a combination of energy efficiency, renewable energy and nuclear power is also considered positive by both groups of respondents, probably due to the slightly positive opinions about CCS and negative attitudes toward nuclear power, as well as the belief that CCS needs to be developed on a large enough scale to make the investment and the risks worthwhile. This result also indicates that the earlier findings of slight support for CCS overall are likely robust.

Within each of the geographic sub-samples, separate models were also calculated for males and females, for those who support or oppose action on climate change, and for those who support or oppose CCS development in Canada, and a comparison of the coefficients revealed statistically significant differences between groups of respondents that had been hidden within the overall results. Not surprisingly, when compared to those who are opposed, respondents who support action to address climate change and respondents who support the use of CCS derive a much higher utility from increasing the share of GHG emission reduction targets met with CCS. On the question of which entity should manage CCS in Canada, an interesting result emerged in Alberta and Saskatchewan, where respondents who supported taking action to address climate change as well as respondents who supported the use of CCS in Canada are nearly indifferent between federal and provincial management (both of which are preferred to industry management), but respondents who are opposed to taking action on climate change consider federal government management to have similar or worse utility than industry management. In the rest of Canada, respondents across all segments derived significantly more utility from federal management of CCS than from provincial or industry management. A reason for this may be that the Alberta government in particular has historically taken an antagonistic approach to climate change, debating the science and opposing climate change policies (Smith, 1998), while the federal government has crafted a pro-climate change action reputation, and ratified the Kyoto Protocol in 2002 over Alberta's objections (Harrison, 2006). In addition, as discussed above, the Federal government is believed by many Albertans to have been responsible for a significant transfer of wealth from Alberta to the rest of the country with 1980s National Energy Program. As a result, those respondents who are opposed to taking action on climate change likely believe that provincial government management of CCS will ensure that CCS is developed in a way that benefits the province where it is implemented, rather than developed to satisfy federal climate change regulations.

3.3. Multiple regression analysis

Multiple regression analysis was used to help understand if there is a connection between respondents' attitudinal and demographic characteristics and their support for CCS. The final model for the CAN sub-sample had four significant explanatory variables: being female, believing that climate change is not a problem, awareness of CCS, and certainty of opinion about CCS. Each of the independent variables was highly significant, and they were also jointly significant. However, the overall explanatory power of the model was very low, with an R-squared value of only 0.032, indicating that only 3.2% of the variation in the data can be explained by these independent variables. The AB/SK model had seven significant explanatory variables, including three levels of beliefs about climate change, being in the two highest income brackets, having attended university, and being female. Again, all of these variables were significant and jointly significant. While this model is a slightly better predictor than the CAN sub-sample model, with an adjusted R-squared of 0.098, the low explanatory power still indicates that we have not captured the key attitudinal and demographic determinants of public opinion regarding CCS. It is also possible that the public's low awareness of the technology contributes to the substantial variability and randomness in people's opinions, and significant determinants of support for the technology do not yet exist.

Although these variables play a very small role in determining support for CCS, it is still interesting to investigate the trends they identify. One common result between both the CAN and AB/SK models was that support for CCS was proportional to respondents' perceptions of the seriousness of climate change; low belief in climate change led to low support for CCS, while a high importance placed on addressing climate change corresponded with higher support for CCS. As public awareness of climate change and its potential impacts increases, this suggests that support for CCS is also likely to rise.

4. Discussion

A number of the results of this research suggest positive attitudes toward CCS. Over half of respondents would definitely or probably use CCS in a climate change plan, while only a little over a quarter of respondents probably or definitely would not use it. Overall, respondents were slightly in support of CCS development in Canada. In particular, the fact that the respondents believe CCS to be less risky than normal oil and gas industry operations, nuclear power, and coal-fired power plants–which suffer from occasional high profile accidents and environmental problems, yet are still tolerated by the public–suggests that CCS will be accepted, and eventually may grow to be considered a standard activity associated with fossil fuel use. Despite this, the respondents have some key concerns about CCS, and care must be taken to protect public health and environmental quality as CCS is developed. These results are partially transferable to other jurisdictions, as Canada has a number of characteristics in common with the United States and Europe, including a relatively wealthy and educated population, fossil fuel resources in some regions, low awareness of the potential for using fossil fuels without emitting GHGs, and growing public support for stronger and more effective GHG reduction policies. At the same time, there are unique aspects to Canada, and so while the general attitudes identified may be transferable, the detailed results should not be considered strongly applicable to other countries.

4.1. Comparison with results from other countries

When compared with studies of public attitudes toward CCS in other countries, this study was most similar in methodology to Curry's 2004 U.S. study, which was an Internet-based survey with a similar sample size, although it focused on energy and climate change issues in general, with emphasis on CCS. Several questions from that study were replicated in the current survey, and the responses to the shared questions indicated higher awareness of CCS and support for CCS in Canada than in the United States. The same questions were also asked on a series of large statistically significant population surveys conducted in Japan, the UK, and Sweden (Reiner et al., 2006). The results of the Japanese study (Itaoka et al., 2004) showed that both awareness and public support for CCS in Japan were significantly higher than observed in Canada. However, when respondents in all countries were asked what technologies they would be likely to use if they were designing a climate change plan, the Canadian respondents were more than twice as likely to include CCS than respondents in the US, the UK, Japan, or Sweden (Reiner et al., 2006). Most of the other international public attitude surveys used methodologies that were not directly comparable with the current survey. The UK study by Shackley et al. (2004) and the US study by Palmgren et al. (2004) used Citizen Panels (extended focus groups) and individual interviews respectively, as well as relatively small convenience samples for their surveys, while the Dutch study by Huijts (2003) was administered to a randomly selected but small survey sample living above a likely CO_2 storage site. Among these studies, the UK and Netherlands surveys found higher support for CCS than was seen in the Canadian results, while the US study found lower support, but due to significant differences in the study methodologies and in the questions ascertaining public support, the comparability of these opinions to the Canadian results is more tenuous. However, a rough picture of comparative international public support for CCS emerges from an examination of all of these studies, with Canadian support likely in line or slightly below that observed in Europe and Japan, and American support appearing lower. Within the current survey's results, public support for action to address climate change was associated with higher support for CCS. An interesting topic for future research would be an evaluation of whether or not this trend holds internationally, with citizens' support for CCS proportional to their support for action on climate change, and how that in turn is linked with their governments' stances on climate change.

4.2. Factors impacting attitudes toward CCS

At this stage there has been little public debate about CCS and public opinions are not fixed, so the management and communication of CCS will have a substantial influence on whether it is supported or opposed. Media reports about CCS and the extent to which it is used in other countries both had significant impacts on respondents' rated support for the technology in this survey. In addition, those respondents who are opposed to CCS are generally concerned about the risks, rather than fundamentally opposed, and they identified a number of actions that could be taken to increase their support for the technology. Overall though, the results of this research suggest that with good management and responsiveness to public concerns, CCS will likely be publicly acceptable, and therefore politically feasible, as part of a balanced climate change portfolio.

Based on the findings from the focus groups and survey, several recommendations can be made to ensure that CCS is developed in a publicly acceptable manner. First, public education about climate change is critical, as climate change ranked very low in importance compared to other national issues, and was ranked last in importance among environmental issues, although concern about climate change has risen in the years since the survey was administered (McAllister Opinion Research, 2007). The focus groups showed that there is also substantial public confusion about what CO_2 is, and what environmental problems it causes. The public has a number of outstanding questions about CCS, and in order to answer them, public outreach efforts should address the role CCS can play in addressing the threat of climate change and provide more information about how the technology works, the probability of negative effects, the extent to which it has been used historically and around the world, its potential use in EOR, where it would be developed, how much CO_2 would be stored, and what would be done with emissions that could not easily be captured and stored, such as those from vehicles.

CCS at the scale required to significantly reduce GHG emissions would be a new technology application with the potential for harm to human health and the environment if it were mismanaged. Unanticipated impacts must be identified and remediated quickly. As a result, CCS needs to be strictly regulated and managed in order to protect public health and environmental quality. A key aspect of this is ensuring that either the national or local government takes a significant role in managing the long-term risks and liabilities involved in CCS. Finally, the respondents prefer that CCS be used aggressively to reduce GHG emissions, but also want it to function as a bridging technology that will allow near-term reductions in GHG emissions while long-term alternatives are developed. There is substantial public support for the use of energy efficiency and renewable energy to address climate change, and so it appears from this study that CCS will lose public support if it is developed at the expense of projects in these areas.

4.3. Improving the analytical tools

As research into public attitudes toward CCS continues, one area of interest is how to get higher explanatory power from the analytical tools that are used. The final DCE models in this study explained only $\sim$15% of the observed choice behavior, and as discussed, the newness of CCS to respondents and hence the difficulty of the choice tasks is one potential reason for this. Additionally, without firm opinions, which require more time and information to develop, respondent preferences likely changed somewhat between choice tasks. One way to improve the explanatory power of discrete choice models in future applications may be to include additional characteristics that are demonstrably important to the public. Huijts (2003) found a significant NUMBY (Not ''Under'' My Backyard) effect in the Netherlands, which lends credence to the idea that location is an important variable to respondents, and could increase the consistency and certainty with which they make choice decisions. As a result, it would be interesting to include the distance from respondents' homes as a characteristic in future experiments. Other characteristics that have been identified as highly important to the public could also be included in a DCE, and would likely increase the explanatory power of the models.

However, choice task complexity will remain a barrier to widespread effective use of discrete choice analysis to determine general attitudes toward CCS, or to determine preferences about any policy issue about which there is little respondent knowledge. While limited information can be gained from a DCE with only three characteristics, the addition of any more would make the results even less meaningful, as it is unlikely that respondents could consistently process the information they were given.

For this reason, discrete choice analysis may be better suited for policy issues with high public awareness, or for studies involving a significant respondent education effort. The methodology would also likely perform better in studies where several specific tradeoffs need to be investigated (rather than general attitudinal research), such as a study to inform the development of a CCS project in a specific community. Discrete choice analysis is a valuable analytical tool, particularly because it forces respondents to make tradeoffs, which are necessary in the real world, but often not included in public opinion research. For studies where the topic is not ideally suited to the use of a DCE, survey questions should be designed in a way that forces respondents to make tradeoffs (such as by using ranking rather than rating questions). Some sense of the relative importance of different issues is much more actionable to policy makers than results in which a number of incompatible preferences are all rated as ''very important'' by the public.

The two linear multiple regression models used in this study to analyze the determinants of attitudes toward CCS had low explanatory power, likely due to low prior awareness of the technology, which meant that the dependent variable (support for CCS) was not firmly defined. As with the DCE, one way to increase explanatory power would be to include additional potential determinants of attitudes in the survey. For example, in order to test whether support for CCS can be explained by the distance between CCS developments and respondents' homes, the information about CCS that is provided to respondents could explicitly provide a location for future development. The distance between each respondent's postal code and the CCS location could be calculated and tested as an explanatory variable.

Another way to increase explanatory power would be to include additional analytical tools. A Japanese study on the same topic also employed regression analysis, but obtained a much higher explanatory power, with R-squared values ranging from 0.355 to 0.451 (Itaoka et al., 2004). One reason for this may be the higher awareness of CCS in Japan (more than twice that found in Canada), which suggests that attitudes toward the technology may be better formed. However, another reason is the researchers' use of factor analysis. While socio-demographic variables contributed little to explaining Japanese public opinion toward CCS (as in the current study), the use of factor analysis allowed for a greater proportion of respondents' opinions about CCS to be explained by attitudes identified through patterns of responses to previous questions. This technique could be employed in future studies to gain a better understanding of determinants of public opinion toward CCS.

5. Conclusion

Overall, this research showed that respondents are mildly supportive of CCS, and if the technology is developed and managed in a way that addresses the public's preferences and concerns, then support could increase significantly. CCS is perceived to be less risky than many other commonly used energy technologies, including normal oil and gas industry operations. This should provide confidence to decision-makers that large-scale CCS development will likely be both publicly and politically acceptable.

This research also tested the use of a variety of methodologies, some of which were very successful and are recommended to other researchers, such as using focus groups to inform the development of a large statistically significant survey, and testing the variability in attitudes that results from providing different information to respondents (an indication of the degree to which attitudes are fixed). However, the DCE had low explanatory power, and likely was too complex, given respondent awareness of CCS. Our research suggests that discrete choice analysis may be more useful for issues with high respondent awareness, or to investigate very specific tradeoffs, than for general attitudinal research.

Additional materials

The Internet-based survey instrument is available online at http://www.carbonsurvey.rem.sfu.ca/, UserID: ws, Password: remmer, Survey type: CAN.

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