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Original article

Human-induced seismicity and the public acceptance of hydraulic fracturing: A vignette experiment

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ABSTRACT

Despite years of debate, hydraulic fracturing (HF) remains controversial. While the balance of perceived economic benefits and environmental costs of "fracking" has generated much debate, the question of whether citizens could accept the risk of induced earthquakes from HF remains largely unanswered. This paper uses data from a survey-based vignette experiment with (n=1,300) individuals in Western Canada to analyze factors in public perceptions and the acceptance of HF projects. Scenario attributes explicitly address the role of distributional and procedural fairness in the siting of projects together with seismicity risks modelled by a modified Mercalli intensity scale. The analysis controls for proximity and common negative environmental externalities of HF. Random effects models suggest that the notion of earthquake risks alone stands in the way of public acceptance of HF; independent of where individuals stand on the HF controversy. Affiliation with the energy industry, perceived knowledge of HF, and support for and/or concerns with different energy sources and their environmental impacts are found to shape individuals' perceptions, including benefits and risks, and the overall acceptability of HF projects. We find this polarization to extend to (mis-)trust in different sector and policy stakeholders.

1. Introduction

Despite the growing evidence of the impacts of climate change on society, the energy market shock of 2022 has renewed interest in one of the most controversial fossil energy technologies – Hydraulic Fracturing (HF) or "fracking" of shale gas that has become an expanding energy source worldwide. According to the International Energy Agency (2021), by 2040 global demand for natural gas and oil is projected to increase by 31% and 21%, respectively. While fracking remains under a moratorium in some US states, and across much of Europe, the UK is among the first to lift its ban (Mathis, 2022) and German politicians are debating a subject formerly considered a taboo (Braun, 2022).

For decades, the United States (US) and Western Canada have been dominating the development of shale oil and gas through HF of shale formations (Thomas et al., 2017), an unconventional way of extracting oil and natural gas that involves fracturing rock formations using fluid injections of sand-based proppants (Atkinson et al., 2020). In Canada, HF was first used in Alberta in 1953. Since then, over 170,000 oil and gas wells have been fractured mainly across Western Canada (National Energy Board, 2011). Alberta, more than any other Canadian jurisdiction, relies on fossil fuel extraction for economic activity and employment, 22% and 6%, respectively (National Energy Board, 2019), making public debates over energy of particular importance to both policymakers and energy industry stakeholders. The economic, social, and especially environmental effects, particularly on directly affected communities across Canada (Davidson, 2017; O'Connor and Fredericks, 2018) and the US (Howell et al., 2019) have led to increasingly controversial positions on HF, reflected in proliferating literature (Howell et al., 2019; Sovacool, 2014). A dominating theme in this literature has been the balance, and perceptions thereof, of economic benefits and often hidden environmental costs (risks) of shale gas and oil development (Christenson et al., 2017; Howell et al., 2017; Sovacool, 2014). In particular, numerous studies have fed concerns over water and air pollution when climate change is making society keenly aware of the consequences of the fossil energy economy to human health and the environment. Moreover, inequalities in the distribution of the benefits and costs of HF and their effects on communities have emerged in the literature (e.g., Evensen, 2015; Fry et al., 2015).

A particular feature and risk factor associated with HF that has received little attention in the public perceptions literature is that of

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induced seismicity, shallow earthquakes caused by human activity (Atkinson et al., 2020). As pointed out by Ritchie et al. (2021), recent studies on the risk perceptions of HF have increasingly made a connection between the technology and seismic activity. However, induced seismicity has not been viewed as a primary risk factor in citizen evaluations of oil and gas developments with HF. Other studies suggest that misconceptions about induced seismicity coupled with low levels of understanding of HF risk permanently shaping perceptions of HF technologies (Porter et al., 2018). Empirical research that explicitly investigates how perceptions of induced seismicity and its risks affect public opinion regarding the benefits and costs of HF remains scarce (Campbell et al., 2020; Drummond and Grubert, 2017; McComas et al., 2016).

The objective of this study is to analyze public perceptions and acceptance of HF projects in the context of the economic benefits and environmental risks including induced earthquakes they pose to individuals and their community in the vicinity of HF installations. We conduct a population survey study in Western Canada. Embedded in an online survey, we employ a fractional factorial survey or vignette experiment (Auspurg and Hinz, 2015) that presents respondents with hypothetical HF project proposals in the form of text-based scenarios; a departure from simple survey questions and discrete choice experiments that have been widely used in the energy and environmental economics literature to elicit public perceptions and preferences (Ritchie et al., 2021; Yao and Sui, 2020; O'Connor and Frederick, 2018). We follow Liebe and Dobers (2020) and others arguing that choice experiments are less suitable when measuring risk perceptions in situations where distributive and participatory justice, as well as normative beliefs, hold significant importance (e.g., Liebe et al., 2017; McComas et al., 2016; Parkins et al., 2022). Issues that have dominated the literature on public perceptions of HF to date. Our vignette project scenarios ask citizens to evaluate HF projects made up of contrasting attributes of distance, the severity and probability of seismicity risk events, other environmental health hazards, against consultation, access to information, and community compensation, deemed desirable (benefits) to individuals and affected communities.

2. Literature

Given the controversies of HF in the public debate, there is no shortage of literature documenting public perceptions and a general lack of support for HF in the US and to a lesser extent in Canada (O'Connor and Fredericks, 2018; Thomas et al., 2017) and the UK (Evensen et al., 2022). Like other fields of research on energy issues, public perceptions of the development of HF have been analyzed through the lens of NIMBYism (not-in-my-backyard) (Lachapelle et al., 2018; Jerolmack and Walker, 2018), a perspective often altered by age and gender (Howell et al., 2017), individuals' personal or community-level experience, knowledge, and familiarity with the energy industry and especially HF (Boudet et al., 2018; Thomas et al., 2017). This literature concludes that experience with HF has led to more polarized position on HF in the US (Thomas et al., 2017) with those having worked in the energy (HF) sector or otherwise being knowledgeable of the technology to be significantly more likely to support HF (Stedman et al., 2016; Truong et al., 2019). This polarization of opinions is also driven by individuals with higher education often holding less conservative, egalitarian worldviews who oppose HF mainly for environmental pollution concerns associated with HF (Choma et al., 2016; Howell et al., 2019; Lachapelle et al., 2018).

A common theme of the literature on the development of HF has been the assessment of the economic opportunities of HF, mainly in the form of local employment and economic activities that are often found to stand against social (equity) and environmental risks posed by "fracking" (O'Connor and Fredericks, 2018; Thomas et al., 2017). Consultation and financial compensation of communities affected by new energy projects have become a mainstay of perception studies in the renewable energy literature (Jorgensen et al., 2020; Parkins et al., 2022). Part of the debate over benefit-cost trade-offs in HF has also been a small literature that explores social license issues and trust along the lines of political affiliations and the framing of the HF debate (Colville et al., 2021; Evensen et al., 2022; McNally et al., 2018). While these studies and existing public perceptions literature reviewed above provide important insights on opinions about HF, the contradictory nature of empirical findings also highlights the potential pitfalls of relying on survey research for assessing public preferences and concerns for a globally expanding fossil fuel technology. Here, the absence of induced seismicity as a major (perceived) risk factor in individuals' evaluation of HF in the literature presents a clear knowledge gap in the understanding of public preferences.

Several recent studies have made the connection between HF, its induced seismicity risks (Evensen et al., 2022; Ritchie et al., 2021), and how existing misconceptions of HF's induced seismicity risks are shaping public perceptions (McComas et al., 2016; Porter et al., 2018). This literature establishes that public misperceptions of the risks posed by HF stem from overestimating the risk posed by induced seismicity relative to the same seismic risks occurring from natural earth tremors. Moreover, when frequently discussed benefit cost (risk) considerations are evaluated the notion of corporate benefits from the induced seismicity makes their public acceptance even less likely. Comprehensive empirical analyses that investigate individuals' risk perceptions of induced seismicity in the context of other concrete attributes of HF remain scarce and limited to mainly qualitative evidence for a single US state, Oklahoma (Campbell et al., 2020; Drummond and Grubert, 2017; McComas et al., 2016). These include perceptions around localized economic benefit, other non-seismicity related pollution concerns, and more generally public preferences for fossil energy technology development that individually have been shown to influence public acceptance and support of HF (Knoblauch et al., 2018).

The analysis in this paper fills an important void in the public perceptions literature on HF by conducting a quantitative analysis of individuals' evaluation of HF project proposals in Western Canada. We specifically focus our analysis on investigating how perceptions of induced seismicity risk using a modified Mercalli seismicity intensity scale (USGS, 2022) affects individuals' acceptance of HF in the presence of more obvious issues of environmental pollution concerns and distributional fairness. We overcome the challenge of disentangling the effects of multiple, complex decision factors that enter individuals' evaluation of HF: proximity, environmental pollution concerns, fairness of consultation and compensation schemes, trust, and the risk of induced seismicity by employing a factorial survey (vignette) experiment (Auspurg and Hinz, 2015). To date, only a handful of studies (Liebe et al., 2017; Liebe and Dobers, 2019; McComas et al., 2016; Parkins et al., 2022) have utilized vignette experiments to examine public perceptions mainly for attributes of renewable energy developments. To the best of our knowledge, vignette-based public evaluations of HF or other traditional fossil energy technologies are lacking in the literature.

In contrast to choice experiments (CE) that ask respondents to select their most preferred alternative, vignette experiments (VE) emphasize the effect of multiple factors on the overall acceptance of a specific scenario when attitudes, social norms, and perceptions are central to the research question. Low levels of public knowledge of HF and especially its induced seismicity risks suggest that a CE approach may overburden respondents and thus may lead to measurement errors (Auspurg and Hinz, 2015). Our VE circumvents such restrictions by allowing individuals to reflect upon the risks, benefits, and fairness concerns of alternative HF development scenarios based on an ordinal rating scale that diminishes the risk of social-desirability bias (Liebe and Dobers, 2020). Moreover, we collect complementary survey data that allows us to control for the effects of energy source preferences, energy sector employment experience and knowledge, perceptions, concerns and perceived economic importance of HF, trust in stakeholder groups, and existing earthquake experience.

Table 1
Vignette experimental attributes and levels.

Attribute	Level
Proximity	• Less than 3 km from the home • Between 3 and 15 km from the home • Over 15 km from the home
Truck traffic	• Less than 10 heavy equipment trucks per day • Between 10 and 50 heavy equipment trucks per day • Over 50 heavy equipment trucks per day
Fracking operation	• Between the hours of 8 am and 8 pm • At all hours of the day
Project consultation	• Community not informed of plans for operation • Community informed of plans for operation • Directly affected landowners consulted about operation • Full two-way consultation with community in every step of the planning process
Project benefits	• No financial benefits for community • Preferential hiring of local services and employers • Annual cash grants between $10k and $25k donated to community • Fully funded community project donated to community
Anticipated induced seismicity	• Nonexistent • Too small to be felt • Persistent and repeating, but too small to cause structural damage • Infrequent, but large enough to potentially cause moderate structural damage

3. Study design

The study draws on data from a large-scale online survey conducted between March and June 2019 using the Qualtrics survey platform (Qualtrics.com) after receiving research ethics approval (*blinded for review*). A total of 1311 survey responses were collected from individuals residing in Western Canada using a recruitment strategy that did not involve a market research company. Participant recruitment included university, regional newspapers, and media articles, as well as using online platforms (e.g., Facebook) to contact municipal or country leaders to help promote participation in the 20-minute questionnaire. To minimize selection bias the study was titled as "study of the Oil and Gas Industry in Western Canada". Eligible individuals were at least 18 years of age and reported living in Western Canada. Recruitment quotas ensured acceptable representativeness of the resulting sample compared to the Canadian census for Alberta (>70% of our sample reported living in Alberta) (Table A.1). Although there are random elements to this sample, this population is a non-probability sample, reflecting the challenges and investment required in securing the participation of the local public in a voluntary research study that did not provide monetary compensation, a common practice among commercial survey companies.

3.1. Vignette experiment

The factorial survey experiment at the center of this study was comprised of six attributes expressed in different levels (Table 1). Attributes were designed based on a review of comparable research (Liebe and Dobers, 2020; Parkins et al., 2022; Richie et al., 2021) and consultation with industry experts and geophysics researchers specializing in induced seismicity.

First, we consider an HF project's proximity to homes and the community to account for the risk perception that is expected to be greatest when HF takes place in close proximities as the intensity of induced earthquakes diminishes with increasing distance. This effect is often attributed to the NIMBY (Not in My Back Yard) effect in energy literature (Lachapelle et al., 2018; Parkins et al., 2022). However, for the case of HF the evidence for or against distance effects on risk perceptions and NIMBYism remains weak (Thomas et al., 2017).

Second, we include two of the most visible environmental health hazards of HF activities, the intensity of heavy truck traffic associated with the supply and removal of fracking fluids, and the time span of HF activities. Noise (and dust) pollution resulting from truck traffic that may also damage local road infrastructure as well as added light pollution from HF operations are known factors in community concerns expressed over energy development and HF (O'Connor and Fredericks, 2018).

Third, improved procedural justice leading to greater perceived fairness through consultation has been demonstrated predominantly in the renewable energy literature, where several studies confirm a positive link between consultation (inclusion) of local communities in decision-making and increased acceptance of (renewables) projects (Liebe and Dobers, 2019; Parkins et al., 2022). Despite an intense public debate and new regulation of consultation requirements for energy-related projects in Canada (Canada Energy Regulator, 2022), McComas et al. (2016) and Williams et al. (2017) appear to be the only studies to mention the role of consultation as a factor in the public perception of HF. We, therefore, are particularly interested in investigating the (geographical) extent, from informing affected landowners to a full two-way consultative process, the public regards as being needed to accept HF in their vicinity.

Fourth, much of the existing survey-based literature on HF has explored perceptions of economic benefits and environmental costs of HF (Howell et al., 2019; Christenson et al., 2017; Evensen et al., 2014; Sovacool, 2014). We model anticipated benefits of HF projects not primarily in terms of their expected boost to local employment as such gains are often temporary in nature. Instead, we follow the renewable energy acceptance literature that explores how forms of community-level financial support through grants and projects may compensate perceived costs and risks. Results, including from experimental survey studies, show that such forms of compensation can be successful in at least partially offsetting the perceived costs and risks of such projects. In the HF literature, McComas et al. (2016) is the only study to suggest that both benefits and beneficiaries may be able to alter public acceptability of induced seismicity risks from HF (in the US).

Fifth, the main attribute of interest is the effect differences in the likelihood and anticipated severity of an induced seismicity may have on individuals and their immediate environment (property). To avoid the potential misinterpretation of respondents caused by the ambiguous language often linked with seismic events (Roberts et al., 2021), we specify this attribute using a modified Mercalli seismicity intensity scale (USGS, 2022). Several recent empirical public perception studies on HF have explicitly included seismicity as a (major) risk factor. However, the studies by Campbell et al. (2020), Drummond and Grubert (2017) and McComas et al. (2016) were qualitative in nature and unable to investigate the effects within a multivariate model that can account for the potential interactions between (seismicity) risks, benefits, and procedural factors likely to influence individuals' perceptions of HF and acceptance of alternative project scenarios. The latest survey-based study by Evensen et al. (2022) for the UK suggests that different ways of framing of induced seismic risk of HF or related information provision efforts may make little difference to public opinion and acceptance of the technology when loosening regulation is at stake. Following previous HF perception literature, we are particularly interested in whether perceived benefits from compensation and consultation may be able to mitigate widespread (mis-)perceptions of induced seismicity from HF in this part of Canada. Moreover, we expect our complementary survey questions ranging from individuals' degree of HF support, employment and familiarity with the oil and gas industry, or related concerns and perceptions to provide valuable additional data in this regard.

We implement the attributes and their levels into a full factorial design of 1152 unique HF vignette scenarios. We then applied an orthogonal fractional factorial or "fold over" design (Auspurg and Hinz, 2015) allowing for two-way interactions so that attributes vary independently of each other within and across vignettes. This step reduces the number of scenarios to be implemented to 144 vignettes. Each respondent was then presented with six randomly drawn vignette scenarios without replacement to avoid learning and order effects in

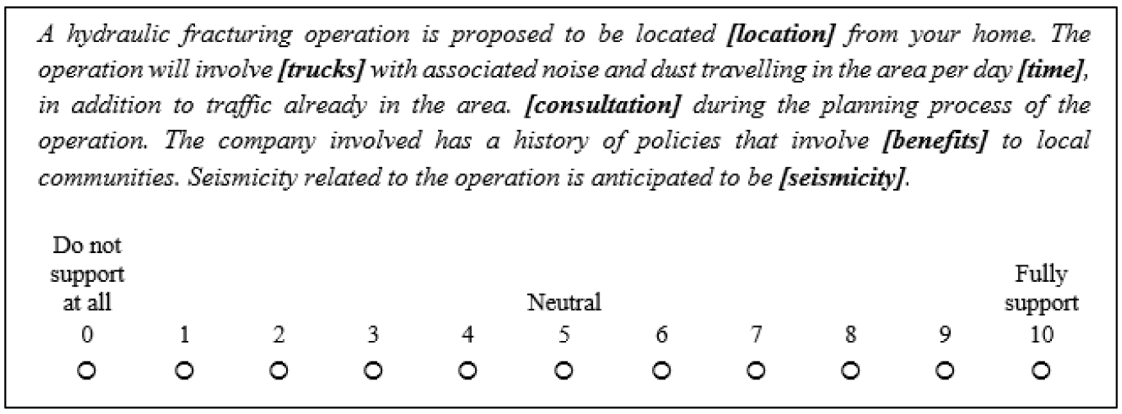

Fig. 1. Vignette scenario design template.
Note: Following an orthogonal fractional factorial or fold over experimental design, levels of the six vignette experimental attributes (see Table 1) are replaced with the highlighted attribute placeholders to create unique experimental vignette scenarios describing HF projects to participants.

Table 2
Respondent support for sources of energy.

Variable	n	Mean	Std. Dev.	Min	Max
Non-renewables					
Oil	1159	3.906	1.402	1	5
Natural gas	1157	4.198	1.173	1	5
Coal	1159	2.514	1.456	1	5
Nuclear	1156	3.187	1.450	1	5
Renewables					
Solar	1160	4.224	1.085	1	5
Wind	1159	3.773	1.337	1	5
Geothermal	1158	4.351	0.852	1	5

Note: Respondent rating on a 5-point Likert scale ranging from 1 = strongly oppose to 5 = strongly support.

respondents' vignette ratings. Six vignette evaluations avoid respondent fatigue while providing us with a large statistically adequate samples for each vignette and total number of vignette evaluations for this study. To assure an equal baseline understanding, respondents were given definitions of HF and induced seismicity in laymen's terms as part of a short study script (Fig. A.1) commonly used in the stated preference literature (Mariel et al., 2021) to inform participants of the task at hand before entering the experiment. In the vignette experiment, respondents were then asked to evaluate individual scenarios on an eleven-point response scale ranging from 0 (do not support at all) to 10 (fully support) to allow individuals to adequately express their opinion (Auspurg and Hinz, 2015). An example of a general vignette scenario is given in Fig. 1.

After the vignette experiment, the remaining survey included questions that allowed us to quantify a range of variables relevant to respondents' perceptions and evaluation of HF, yet independent of the vignette experiment itself, using Likert-scale question formats. Survey questions included respondents' relationships to the energy industry, energy industry-related knowledge, support for different energy sources, concerns and risk perceptions related to the Canadian fossil energy industry, trust in sector stakeholders, as well as personal experience with earthquakes. To check how much respondents value the place where they live (including the environment and the community), we adopted a subset of questions used by Raymond et al. (2010) and finally asked for the relevant respondent socioeconomic and demographic factors (Table A.1).

3.2. Econometric analysis

We analyze the vignette data using random effects models (RE) over ordinary least squares (OLS) regression to take the nested structure of

Table 3
Respondents' perception of HF treatments.

Statement	N	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
HF technology acceptance						
Hydraulic fracturing is an acceptable way to extract hydrocarbon resources	1181	28.6	24.5	10.1	11.4	15.4
Economic importance						
My community currently benefits economically from nearby oil and gas activities	1173	45.5	21.2	11.4	5.5	5.9
Statement	N	Very safe	Somewhat safe	Uncertain	Somewhat risky	Very risky
HF risk perception						
How risky do you consider HF?	1169	22.1	19.1	7.0	24.7	16.2
How risky do you consider economic reliance on oil and gas exploration?	1166	20.4	14.1	6.8	22.8	24.9
Statement	N	Very unconcerned	Somewhat unconcerned	Neither concerned nor unconcerned	Somewhat concerned	Very concerned
HF concerns						
Damage concerns [a)]	1159	14.0	11.6	10.2	27.4	25.2
Ground water contamination due to induced earthquakes	1156	12.4	11.4	7.2	22.4	34.7
Surface water contamination due to induced earthquakes	1156	15.0	11.5	7.8	22.5	31.4
Noise pollution	1158	12.3	17.3	15.2	29.3	14.3
Air pollution	1157	10.5	13.8	11.4	30.8	21.7
Induced seismicity	1157	13.4	12.9	12.0	27.7	22.3

[a)] Damage to personal items, homes, or local infrastructure due to induced earthquakes.
Note: Differences to 100% = prefer not to say

Table 4
Trust in energy sector stakeholder groups.

Variable	n	Mean	Std. Dev.	Min	Max
Environmental organizations	1150	2.645	1.378	1	5
Oil and gas industry					
Local	1151	3.282	1.398	1	5
Multinational	1150	2.910	1.424	1	5
Government					
Government regulators	1151	3.088	1.283	1	5
Local municipalities	1149	3.207	1.103	1	5
Provincial government	1149	2.750	1.337	1	5
Politicians	1148	2.604	1.182	1	5

Note: 5-point Likert scale ranging from 1 = very untrustworthy to 5 = very trustworthy.

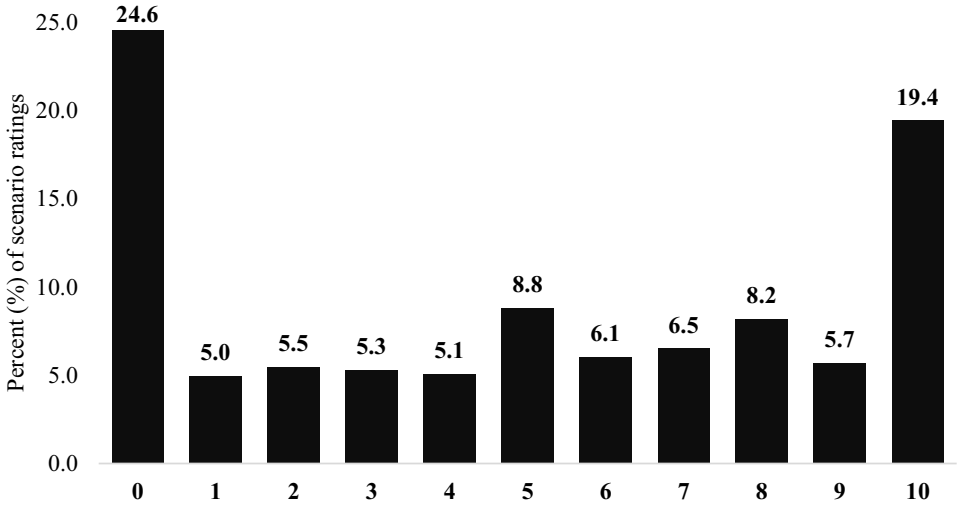

Fig. 2. Frequency distribution of respondent vignette scenario ratings.
Notes: percent of total scenario ratings (n = 7623). Vignette ratings are based on an 11-point scale from 0 to 10 where endpoints were described as completely unacceptable to completely acceptable.

the rating data at the respondent level, as well as differences between respondents, into account (Atzmüller and Steiner, 2010). Moreover, Random Intercept models, a variant of RE, allow us to incorporate and evaluate various second-order respondent characteristics deemed important to explaining differences in vignette ratings across a heterogeneous respondent population. We use likelihood-ratio tests to verify preferred RE models against OLS. Based on the provision of laypeople definitions of key study concepts (HF and induced seismicity), we assume that respondents did not differ in their understanding of vignette acceptance questions and thus provided vignette ratings that reflect their true preferences, thus avoiding the need to correct differences in response scales in RE model estimation (Greene et al., 2021).

4. Results and discussion

Of the 1311 survey responses collected 1132 were complete, resulting in a completion rate of 86%.[1] Descriptive respondent statistics are summarized in Table A.1, indicating a survey population that is slightly more male, younger, and more highly educated with approximately 74% of respondents having some form of post-secondary education compared to the Alberta census average of 55% (Statistics Canada, 2022). Most respondents (88%) claim to have at least some knowledge of the energy industry in Western Canada (mostly oil and gas). Approximately two in three respondents (61%) report prior employment in the energy sector (Table A.1). Where does this sample population stand on the issue of fossil energy, HF technology, and its potential benefits and risks? Regarding respondents' support for different energy sources, our results are in line with the findings of previous studies, including a recent Alberta-centered study by Parkins et al. (2022) revealing strong support for natural gas (4.2 of 5) and oil (3.9), while geothermal (4.4) is the most preferred form of renewables (Table 2).

Backed by this support, most respondents are in favor of using HF technology to extract oil and natural gas, with 53% agreeing or strongly agreeing with the statement "hydraulic fracturing is an acceptable way of extracting hydrocarbon resources" (Table 3). Given the province's long history with the fossil energy industry, a clear majority of 67% considers the sector economically beneficial (Table 3). Our results are in line with prior public perception studies that indicate significant public support across the US, Canada and the UK, but also point to the contested, political character of the debate that polarizes individuals over 'acceptable' risks versus benefits of the technology (Thomas et al., 2017; Whitmarsh et al., 2015).

Relative to their expression of acceptance, Table 3 summarizes respondents' overall and specific risk perceptions of HF. Here we find a more balanced distribution, with around 40% each considering HF to be (very) safe or (very) risky. This balance shifts towards risk aversion when the overall economic reliance on fossil energy extraction, presumably including using HF, is considered. An aspect mostly neglected in prior public perception studies (Thomas et al., 2017) worthwhile noting is that only a small fraction of between 7 to 15% of respondents appear to be undecided on the key issues concerning HF; speaking to the

[1] The nature of the participant recruitment process prevents us from reporting a traditional response rate.

growing public polarization on issues of energy repeatedly discussed in the literature (Evensen et al., 2022).

Of particular interest to this analysis are participants' responses to survey statements about known environmental health risks of HF. Table 3 reveals that majorities of respondents are concerned about the possible environmental outcomes of HF, including induced seismicity. Out of all risk factors, the contamination of groundwater stands out as the main point of concern over HF, an issue also raised by respondents in Drummond and Grubert (2017), Evensen et al. (2017), Pollard and Rose (2019), and Williams et al. (2017) among others. When assessed on their own, the risk factors induced seismicity and related damage to property do not stand out. This result may speak for the existing positive record of the Alberta oil and gas industry. It also may support prior findings (Evensen et al., 2022; Knoblauch et al., 2018; Mattfeldt, 2022) in that presentation format and context matter much to how members of the public rate the true risk of low-probability high-consequence threats such as induced seismicity from HF. Evidence in the public perceptions of (energy) technology literature unequivocally suggests that trust in relevant stakeholder groups plays a key role in the public's evaluation of technology risks (Colville et al., 2021; O'Connor and Fredericks, 2018; Whitmarsh et al., 2015). We asked respondents for their levels of trust in various stakeholder groups present in the province's oil and gas industry (Table 4).

Our results indicate broad-based trust in the local oil and gas industry, local government, and the regulator. Foreign industry players, and particularly political actors are viewed as being less trustworthy. While this finding is indicative of majority support for the oil and gas industry, it stands in contrast with Thomas et al. (2017) and Colville et al. (2021) who find that trust varies considerably across regions in Canada, the US, and China and by levels of exposure to the industry and its issues. Gehman et al. (2017) find trust in the energy industry in Western Canada at 13% to be substantially lower than in the farming (62%) and forestry sectors (32%).

4.1. Vignette model analysis

Each participant was asked to rate six HF vignette scenarios randomly drawn from the sample design (refer to Study Design). Fig. 2 provides a frequency distribution of respondents' vignette acceptability ratings independent of any differences in the attribute composition of scenarios.

With a mean rating of 4.9 and a relatively large standard deviation of 3.8, we find no clear indication of public acceptance or rejection of HF projects. However, as with their opinions about HF, respondents appear heavily polarized in their stated acceptability of proposed (hypothetical) HF project scenarios. The bipolar distribution of Fig. 2 is the result of respondents who consistently rated any scenarios shown to them as either completely unacceptable, 13% of all zero ratings, or completely acceptable, accounting for 7% of all ratings of ten regardless of scenario attribute composition. Our results provide empirical evidence of the polarization the topic of HF evokes in individuals previously described by Evensen et al. (2014), O'Connor and Fredericks (2018), and Whitmarsh et al. (2015). When these "extreme" responses are removed, the mean rating of scenarios rises to 5.2 (St. dev. 3.4). As this response behavior does not appear to present a major bias, we consider all scenario ratings in the estimation of RE models presented in Table 5.

Model 1[2] only includes the six vignette attributes (Table 1) and subsequent specifications successively introduce additional variables in the form of respondent survey answers and characteristics including industry relationship, subjective knowledge, and support for HF. Model 3 introduces concerns, risk perceptions, and trust, and Model 4 specifically accounts for perceptions of induced seismicity and respondent earthquake experience. Likelihood-ratio tests indicate that RE model specifications are highly preferred over ordinary least square regressions. Intra-class correlation coefficients ranging between 0.7978 and 0.443 indicate an overall satisfactory correlation among respondents' six vignette evaluations. Coefficient estimates for each attribute are presented relative to the status quo for HF in Western Canada.

Across model specifications we find strong evidence of the negative impact perceived HF risks have on acceptance; a common result reported in the literature (O'Connor and Fredericks, 2018). A key result of this study and contribution to the literature is the attribute estimates for the seismicity risks associated with HF projects in proximity to respondents' place of residence. Building on previous survey studies that have made a connection between HF technology and the risks of seismic activity (Ritchie et al., 2021), we find all levels of assumed induced seismicity risks to lead to significant reductions in the stated acceptance levels of HF by, ceteris paribus, between -0.1 and -1.8 scale points (Table 5). This includes a negative response to a minimal level of earthquake intensity, *too small to be felt*, as a likely risk event for HF. However, this result is in line with recent survey-based evidence by Evensen et al. (2022) that indicates outright public opposition to the existence of earthquake events with HF, and not primarily to their damage effects. Respondents' perceived negativity of hypothetical non-damaging earthquake events with HF holds significance for the regulatory future of HF and other subsurface technologies, including carbon capture and storage and geothermal energy that are frequently discussed as part-solution for an energy future under climate change.

Different forms of compensation to offset public opposition to energy projects repeatedly discussed in the renewable energy literature (e.g., Jorgensen et al., 2020; Parkins et al., 2022) appear unable to sway the public into accepting HF once risks of earthquake damages are part of the scenario (Knoblauch et al., 2018). The magnitudes of coefficient estimates appear sufficient to offset (ease) the negativity of low-intensity earthquakes, where fully funded community projects are consistently preferred to local preferential contracting. However, offering direct economic benefits or community support is unable to compensate for the threat of moderate structural damage to infrastructure, however unlikely, to be expected from HF induced earthquakes. Model specifications allowing for two-way interactions between benefits and seismicity show that negative perceptions of seismic risks decreases with economic benefits. However, the overall negative effect of seismic risk perceptions remains for threat levels of moderate structural damage to infrastructure even when the highest level of economic benefits is offered. Here our results provide much needed quantitative empirical evidence on the nexus of perceived risks and economic benefits, or opportunity repeatedly raised by survey-based and qualitative studies on HF that have pointed to the increasingly intense controversy over issues such as HF (e.g., Campbell et al., 2020; O'Connor and Fredericks, 2018; Thomas et al., 2017). However, Table 5 also reveals that induced seismicity and compensation alone do not fully explain public perceptions or the acceptance of HF.

Apart from earthquake risks and compensation, consultation emerges as an important factor in the public acceptance of HF projects (Thomas et al., 2017). Public consultation, that is regulated in Alberta to involve affected landowners, relevant authorities (e.g., municipalities), and may include residents within a range of distances (Alberta Energy Regulator, 2019, p. 29) has been a growing topic in the Canadian debate over the inclusion of the public in major energy development decisions at a time when environmental sustainability and climate concerns matter. Several studies in the energy literature find positive effects of consultative and participatory processes on public support for or acceptance of energy industry developments (Liebe and Dobers, 2019; Thomas et al., 2017; Williams et al., 2017). Our coefficient estimates unequivocally indicate that upfront information (transparency) (0.60–0.62) and more demanding two-way consultations (0.91–0.96) contribute to the public acceptance of HF. Noteworthy is that the effects

[2] A fixed-effects specification of model 1 was estimated as a robustness check and yielded stable coefficient estimates in both sign and magnitude (Table A.3).

Table 5
Results of random effects models for vignette attributes and controls.

Vignette rating / Attribute	Model 1	Model 2	Model 3	Model 4
Location (< 3 km)				
3 km to 15 km	0.441***	0.438***	0.427***	0.428***
	(0.05)	(0.068)	(0.048)	(0.062)
> 15 km	0.89***	0.916***	0.912***	0.914***
	(0.057)	(0.071)	(0.06)	(0.077)
Trucks (less than 10)				
10 to 50	-0.214***	-0.228***	-0.24***	-0.239***
	(0.043)	(0.063)	(0.062)	(0.059)
> 50	-0.201***	-0.217***	-0.231***	-0.233***
	(0.048)	(0.059)	(0.06)	(0.052)
Time (8 am - 8 pm)				
All hours of the day	-0.301***	-0.331***	-0.338***	-0.337***
	(0.045)	(0.048)	(0.049)	(0.053)
Consultation (community not informed)				
Community informed of plans	0.602***	0.621***	0.613***	0.614***
	(0.072)	(0.085)	(0.066)	(0.072)
Affected landowners consulted	.655***	.687***	.679***	.678***
	(0.074)	(0.077)	(0.065)	(0.067)
Full two-way consultation	.907***	.955***	.937***	.938***
	(0.081)	(0.078)	(0.074)	(0.062)
Benefits (no financial benefits)				
Local preferential hiring	1.112***	1.146***	1.145***	1.146***
	(0.056)	(0.077)	(0.077)	(0.087)
Community cash grants	0.951***	0.966***	0.963***	0.964***
	(0.059)	(0.068)	(0.077)	(0.096)
Fully funded community projects	1.345***	1.388***	1.392***	1.392***
	(0.065)	(0.075)	(0.077)	(0.092)
Seismicity (seismicity nonexistent)				
Too small to be felt	-0.111*	-0.143**	-0.134*	-0.134*
	(0.057)	(0.073)	(0.069)	(0.07)
Persistent, repeating, but no damage	-0.571***	-0.652***	-0.651***	-0.652***
	(0.052)	(0.07)	(0.071)	(0.069)
Infrequent, large, causing moderate structural damage	-1.685***	-1.796***	-1.798***	-1.8***
	(0.064)	(0.093)	(0.095)	(0.087)
Energy industry work experience		0.643***	0.258*	0.266*
		(0.16)	(0.143)	(0.138)
Subjective knowledge		0.708***	0.554*	0.573**
		(0.259)	(0.316)	(0.232)
Support for non-renewables		0.286***	0.122***	0.121***
		(0.035)	(0.033)	(0.035)
Support for renewables		-0.307***	-0.115**	-0.112**
		(0.052)	(0.05)	(0.047)
HF acceptance		1.265***	.555***	.559***
		(0.063)	(0.07)	(0.091)

Vignette attributes	Model 1	Model 2	Model 3	Model 4
Oil & gas concerns			-0.014	-0.015
			(0.014)	(0.019)
HF concerns			-0.064***	-0.067***
			(0.015)	(0.014)
HF risk			-0.536***	-0.538***
			(0.079)	(0.066)
Economic reliance risk			-0.09*	-0.086*
			(0.049)	(0.048)
Economic importance			0.176***	0.174***
			(0.049)	(0.048)
Trust in environmental organizations			.023	.021
			(0.062)	(0.056)
Trust in oil & gas industry			0.183***	0.183***
			(0.04)	(0.042)
Trust in government			-0.014	-0.016
			(0.02)	(0.021)
Trust in politicians			-0.061	-0.06
			(0.055)	(0.061)
Induced earthquakes				0.033
				(0.077)
Earthquake experience				-0.184
				(0.124)
Place attachment		-0.019	-0.009	-0.007
		(0.03)	(0.032)	(0.031)
Age		-0.012	-0.004	.009
		(0.044)	(0.035)	(0.037)
Gender (Ref - Female)		0.167	0.121	0.116
		(0.156)	(0.123)	(0.126)

(*continued on next page*)

Table 5 (*continued*)

Vignette attributes	Model 1	Model 2	Model 3	Model 4
Urban (Ref - Rural)		-0.232	-0.14	-0.156
		(0.152)	(0.112)	(0.126)
Post-secondary education		-0.282	-0.24	-0.218
		(0.18)	(0.151)	(0.151)
Constant	3.951***	-0.201	4.151***	4.141***
	(0.127)	(0.82)	(0.825)	(0.829)
Std. dev. random effect	3.236	1.876	1.553	1.551
St. dev. error	1.728	1.736	1.739	1.74
Intra-class correlation	0.778	0.539	0.444	0.443
Log-likelihood	-16,981.6	-13,031.4	-12,696.8	-12,675.3

*** $p < 0.01$
** $p < 0.05$
* $p < 0.1$
Standard errors are in parentheses.
Note: Reference attribute levels in brackets. For detailed (full) wording of attribute levels see Table 1.

of consulting landowners, anchored in current regulation, are slightly more preferred than the inclusion (informing) of the wider community. Our result stands in contrast to Evensen et al. (2022) who found information provision to have no effect on the perceived negativity of induced seismicity with HF among UK citizens. Overall, consultation and information sharing are viewed as measures protecting against widely held perceptions that energy development decisions tend to be taken behind closed doors without consideration of risks or benefits of HF to the public and the need for adequate public consultation; issues that nurture distrust in decision-making bodies (Thomas et al., 2017). We capture environmental pollution concerns (Howell et al., 2019; Sovacool, 2014) that loom large in the debate over HF via levels of heavy truck traffic and operations hours that may cause noise, dust, and light pollution as well as damages to local roads. As expected, across model specifications fewer trucks (-.2xx) and limited daytime operations (-0.3xx) of HF are preferred. As has become customary in the (renewables) energy literature, our estimates for location or the proximity of a proposed HF development to participants' place of residence provide further evidence of NIMBYism, as participants prefer HF to take place as far away from home as is possible (0.9xx, > 15 km) (Boudet et al., 2018).

The addition of participant-specific survey responses as a source of heterogeneity in models two to four allows us to capture how largely polarized opinions about HF (e.g., O'Connor and Fredericks, 2018), its perceived risks and benefits, affect public acceptance. It also provides evidence of the robustness of our vignette attribute estimates.[3] We consider variables that capture respondents' knowledge of and affiliation (work experience) with the oil and gas industry, alongside stated support for fossil and renewable sources of energy and perceptions of risks and benefits associated with HF. Finally, we measure respondents' trust in key stakeholder groups and account for prior experience with earthquakes. Place attachment and socio-demographic factors are controls.

Several studies on HF and literature on energy development (e.g., Campbell et al., 2020; Howell et al., 2017; Parkins et al., 2022; Thomas et al., 2017; Truong et al., 2019) conclude that energy industry employment and/or related experiences are critical factors shaping individuals' perceptions of benefit-risk distributions and overall acceptance of HF. Collectively, energy industry work experience (0.63), subjective knowledge (0.71), and expressed support for fossil energy (0.29) positively affect levels of acceptance of HF projects. Respondents who indicated their direct support for HF as an acceptable technology in the survey rated scenarios by an average of 1.27 scale points higher. The largest effect magnitude among non-attribute variables is considered. As expected, the positive effects of variables considered to measure industry support are mitigated by the inclusion of different factors of concerns with HF. Within a population where 53% of respondents indicate direct employment relations to the oil and gas industry and one generally supportive of HF, positive perceptions around HF are only slightly diminished by the perceived riskiness of HF (-0.54).

Concerns factors known to drive opposition to energy development in the literature (Thomas et al., 2017), from general concerns about HF, dependence (reliance) on oil and gas exploration and its (often) dominant economic role are significant in our model, yet do not shift HF ratings much at all. Our results provide further support for studies (e.g., Drummond and Grubert, 2017; Evensen et al., 2017; Fry et al., 2015) in that overall public perceptions of HF and benefit-risk considerations are heavily dependent on individuals' polarized beliefs about the industry and its use of technology (McComas et al., 2016). In contrast to previous studies (e.g., Drummond and Grubert, 2017; O'Connor and Fredericks, 2018; Thomas et al., 2017), trust (public mistrust) does not emerge as a major (significant) factor shaping public perceptions of HF in Western Canada. With 49% of our respondents finding local oil and gas companies (very) trustworthy, trust in the oil and gas industry is the only significant variable that further reinforces the positive effect industry support has on HF scenario ratings, albeit small in magnitude (0.18). In contrast, Evensen et al. (2022) report that only 12% of UK respondents trust the shale gas industry when induced seismicity is part of the conversation. Finally, control variables including place attachment (Liebe and Dobers, 2020) and stated prior experience with earthquakes thought to influence respondents' acceptance of HF elicited outside of the vignette experiment remain insignificant.

5. Conclusions and policy implications

On the question of where this population stands on the issue of HF, our analysis suggests that despite the evident polarization around HF (and fossil energy overall) among respondents, negativity over the possibility of HF induced earthquakes that grows at the suggestion of any damages, never mind how unlikely they might be, is a major unifying factor standing in the way of HF acceptance in Western Canada. Consistent with the findings of Christenson et al. (2017) and Howell et al. (2019), a pathway towards acceptance via compensating affected communities has the anticipated positive effect but is unable to fully compensate for the combined negative perceptions of earthquake and environmental impacts of HF. With these findings in mind, what are the characteristics of HF that would render HF most acceptable to individuals? Results from our vignette experiments identify several procedural and design elements that can enhance public acceptance of HF. One such optimal design is illustrated in the below vignette scenario that received the highest mean acceptance rating of 7.5 (of 10) among all scenarios:

[3] Removing respondents with extreme vignette ratings, those that consistently rated vignettes zero or ten independent of attribute compositions, only leads to minor changes in the magnitudes of coefficient estimates for control variables (Table A.2).

"A hydraulic fracturing operation is proposed to be located over 15 km from your home. The operation will involve less than 10 heavy equipment trucks with associated noise and dust travelling in the area per day between 8 am and 8 pm, in addition to traffic already in the area. Your community will have full two-way consultation in every step of the planning process of the operation. The company involved has a history of policies that involve fully funded community projects to benefit local communities. Seismicity related to the operation is anticipated to be nonexistent."

While this 'optimal HF scenario' holds implications for both policy-makers and industry stakeholders wanting to secure public trust (social license) in HF energy policy for oil-rich Western Canada, it also reflects the general reluctance of the public to entertain the risks associated with the economic benefits generated by HF activity. In line with previous literature, our results confirm that even within a population with majority support and trust for fossil energy (and industry), the difficult trade-off between earthquake risks, pollution concerns, and the perceived economic benefits the industry provides remains. In other words, people don't want HF projects anywhere near them and they certainly reject any notion of induced seismicity, yet they welcome compensation and full consultation. Our results regarding compensation and consultation are particularly relevant to the policy debate surrounding HF. Previous survey studies (e.g., Evensen et al., 2022; O'Conner and Fredricks, 2018) conclude that information provisions alone are unable to shape perceptions of HF. Our findings suggest that the public appreciates community-level information provision on energy projects but prefers more comprehensive exchange in the form of two-way consultation; a topic that has shaped the recent discourse on (fossil) energy developments across Western Canada (Trumpener, 2022). Consequently, we see a desire for more inclusion in decision-making (Liebe and Dobers, 2020) that could render otherwise controversial energy projects more acceptable to citizens in affected regions. Although previous studies point to the role political affiliation and framing play in individuals' benefit-cost assessment of HF, we did not ask respondents for their political views. Yet, the polarized response to HF (Fig. 2) and evidence reported by Parkins et al. (2022) support Choma et al. (2016) of an ideological divide with respect to preferences for energy sources and technology.

Finally, a note of caution in the interpretations of the vignette results is also warranted. The analysis we present has limitations in that our survey participants stretch across a large province that is the size of countries. Despite their uniform evaluation of scenarios, many respondents are separated by large distances from any oil and gas activity and thus may differ in characteristics beyond the scope of this paper. Moreover, a common to experimental valuations, although respondents in our sample found certain hypothetical designs of HF projects acceptable, in practice, the work of siting and approving fossil energy projects in Canada is an increasingly complex regulated process between multiple stakeholders extending beyond the scope of this study. In this sense, the findings of this analysis inform possible avenues towards greater public acceptance of HF, with insights into key attributes of induced earthquakes, compensation and consultation that have not received sufficient attention in the literature and yet are likely to matter in the development and implementation of oil and gas projects across Western Canada.

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Appendix

Table A.1
Descriptive statistics of the respondent sample.

Variables	Sample N	%	Census %[a]		Sample n	%
Age				**Subjective knowledge**[e]		
18–24	88	6.7	5.8[b]	Knowledgeable	1150	87.7
25–34	274	20.9	14.1	Not knowledgeable	53	4
35–44	222	16.9	15.2	Prefer not to say	108	8.2
45–54	203	15.5	12.7			
55–64	204	15.6	12.6			
65–74	89	6.8	8.9			
75 or over	22	1.7	5.8			
Prefer not to say	209	15.9				
Gender				**Energy industry work experience - personal**		
Female	476	36.3[c]	50.1			
Male	613	46.8	49.9	Yes	797	60.8
Other	8	0.6		No	514	39.2
Prefer not to say	214	16.3				
Post-secondary education[d]						
Yes	968	73.8	55.3			
No	134	10.2	44.8			
Prefer not to say	209	16				
Rural/Urban						
Rural	454	34.6	15.2			
Urban	626	47.8	84.8			
Prefer not to say	231	17.6				

[a] Source: Statistics Canada. (2022).
[b] The category of 18–24 does not exist for the Statistics Canada data, so it is approximated using the 20–24 age range.

[c] Although female respondents in our sample are relatively low compared to the Statistics Canada (2022) values, having over a third of our respondents be women is encouraging since energy is a topic that is often assumed to interest primarily men.

[d] Statistics Canada (2022) reports these values for 15 years and older while our sample consists of respondents who are 18 years and older. This might be the cause for the relative differences between sample statistics and census data.

[e] We asked respondents "How would your friends and family rate your knowledge of the energy industry in Western Canada?" to measure subjective knowledge.

Table A.2
Results of random effects models for vignette attributes and controls – without extreme vignette ratings.

Vignette rating / Attribute	Model 1	Model 2	Model 3	Model 4
Location (< 3 km)				
3 km to 15 km	0.509***	0.503***	0.488***	0.49***
	(0.065)	(0.081)	(0.073)	(0.085)
> 15 km	1.081***	1.097***	1.09***	1.093***
	(0.072)	(0.076)	(0.091)	(0.076)
Trucks (less than 10)				
10 to 50	-0.233***	-0.256***	-0.27***	-0.269***
	(0.056)	(0.065)	(0.076)	(0.075)
> 50	-0.211***	-0.233***	-0.247***	-0.248***
	(0.057)	(0.056)	(0.065)	(0.06)
Time (8 am - 8 pm)				
All hours of the day	-0.367***	-0.389***	-0.397***	-0.397***
	(0.058)	(0.056)	(0.061)	(0.058)
Consultation (community not informed)				
Community informed of plans	0.789***	0.789***	0.782***	0.783***
	(0.077)	(0.099)	(0.081)	(0.078)
Affected landowners consulted	0.833***	.849***	0.834***	0.833***
	(0.085)	(0.089)	(0.095)	(0.088)
Full two-way consultation	1.143***	1.176***	1.151***	1.154***
	(0.088)	(0.088)	(0.107)	(0.069)
Benefits (no financial benefits)				
Local preferential hiring	1.374***	1.389***	1.376***	1.376***
	(0.081)	(0.084)	(0.088)	(0.091)
Community cash grants	1.147***	1.155***	1.139***	1.142***
	(0.076)	(0.086)	(0.101)	(0.073)
Fully funded community projects	1.598***	1.62***	1.615***	1.615***
	(0.078)	(0.075)	(0.083)	(0.086)
Seismicity (seismicity nonexistent)				
Too small to be felt	-0.139*	-0.183***	-0.177**	-0.175*
	(0.072)	(0.068)	(0.087)	(0.091)
Persistent, repeating, but no damage	-0.692***	-0.797***	-0.799***	-0.797***
	(0.08)	(0.08)	(0.088)	(0.091)
Infrequent, large, causing moderate structural damage	-2.058***	-2.153***	-2.148***	-2.15***
	(0.109)	(0.097)	(0.095)	(0.108)
Energy industry work experience		0.697***	0.347**	0.364**
		(0.17)	(0.156)	(0.162)
Subjective knowledge		0.807***	0.568**	0.587**
		(0.27)	(0.276)	(0.272)
Support for non-renewables		0.25***	0.117***	0.117***
		(0.042)	(0.041)	(0.04)
Support for renewables		-0.27***	-0.111**	-0.11**
		(0.047)	(0.052)	(0.051)
HF acceptance		1.051***	0.418***	0.425***
		(0.078)	(0.077)	(0.076)
Vignette attributes	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Oil & gas concerns			-0.012	-0.015
			(0.015)	(0.017)
HF concerns			-0.066***	-0.071***
			(0.012)	(0.014)
HF risk			-0.483***	-0.49***
			(0.085)	(0.088)
Economic reliance risk			-0.08*	-0.072
			(0.044)	(0.052)
Economic importance			0.182***	0.179***
			(0.047)	(0.062)
Trust in environmental organizations			0.017	0.017
			(0.064)	(0.056)
Trust in oil & gas industry			0.163***	0.163***
			(0.051)	(0.051)
Trust in government			-0.014	-0.016
			(0.023)	(0.022)
Trust in politicians			-0.085	-0.085
			(0.066)	(0.065)
Induced earthquakes				0.071
				(0.07)
Earthquake experience				-0.21*
				(0.12)

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Table A.2 (*continued*)

Vignette rating / Attribute	Model 1	Model 2	Model 3	Model 4
Place attachment		0.007	0.005	0.005
		(0.035)	(0.043)	(0.035)
Age		-0.058	-0.047	-0.032
		(0.044)	(0.038)	(0.046)
Gender (Ref - Female)		0.303*	.218*	.211
		(0.163)	(0.122)	(0.141)
Urban (Ref - Rural)		-0.304**	-0.178	-0.196
		(0.139)	(0.165)	(0.129)
Post-secondary education		-0.068	-0.068	-0.045
		(0.203)	(0.203)	(0.187)
Constant	4***	-0.301	4.146***	4.134***
	(0.137)	(0.76)	(0.91)	(1.106)
Std. dev. random effect	2.703	1.806	1.504	1.499
St. dev. error	1.846	1.847	1.849	1.85
Intra-class correlation	0.682	0.489	0.398	0.397
Log-likelihood	-13,946.9	-10,906.3	-10,667.1	-10,654.2

*** $p < 0.01$
** $p < 0.05$
* $p < 0.1$
Standard errors are in parentheses.
Note: Reference attribute levels in brackets.

Table A.3
Results of a fixed effect models for vignette attributes and controls.

Vignette rating / Attribute	Model 1
Location (< 3 km)	
3 km to 15 km	0.447***
	(0.053)
> 15 km	0.89***
	(0.053)
Trucks (less than 10)	
10 to 50	-0.213***
	(0.053)
> 50	-0.209***
	(0.053)
Time (8 am - 8 pm)	
All hours of the day	-0.303***
	(0.044)
Consultation (community not informed)	
Community informed of plans	0.602***
	(0.061)
Affected landowners consulted	0.661***
	(0.062)
Full two-way consultation	0.913***
	(0.061)
Benefits (no financial benefits)	
Local preferential hiring	1.102***
	(0.061)
Community cash grants	0.937***
	(0.061)
Fully funded community projects	1.336***
	(0.061)
Seismicity (seismicity nonexistent)	
Too small to be felt	-0.107*
	(0.061)
Persistent, repeating, but no damage	-0.563***
	(0.062)
Infrequent, large, causing moderate structural damage	-1.686**
	(0.061)
Constant	3.934***

(*continued on next page*)

Table A.3 (*continued*)

Vignette rating / Attribute	Model 1
	(0.084)
Std. dev. random effect	3.322
St. dev. error	1.729
Intra-class correlation	0.787

*** $p < 0.01$
** $p < 0.05$
* $p < 0.1$
Standard errors are in parentheses
Note: Reference attribute levels in brackets.

"Although these are hypothetical scenarios and some may not seem like "real" options, please respond as if you were actually in that situation. The results from this section may be used to guide policy makers and help make Alberta's energy system work better for its communities".

*"You may have more thoughts on the oil and gas industry or hydraulic fracturing, and we will be asking you more about that later in the survey. For the purposes of this task, please assume that any concerns related to environmental safety, drinking water safety, and freshwater use are **not** an issue. In other words, please assume that these operations will be **safe** and **profitable**".*

"Please keep these assumptions in mind as you provide your opinions.
You may find the following definitions useful:

- *Hydraulic fracturing refers to the process of pumping specially engineered fluids at high pressures and rates into the ground, which causes a fracture to open. This fracture allows fluids such as oil or gas to flow to the well. Hydraulic fracturing operations can last from a few days to a few weeks.*
- *Induced seismicity refers to earthquakes triggered by human activities which may or may not be felt at the surface".*

Fig. A.1. Participant information script.

References

Alberta Energy Regulator. (2019). Directive 056 (Issue October). https://static.aer.ca/prd/2020-07/directive-0560.pdf (accessed Nov 1, 2022).

Atkinson, G.M., Eaton, D.W., Igonin, N., 2020. Developments in understanding seismicity triggered by hydraulic fracturing. Nat. Rev. Earth & Environ. 1 (5), 264–277. https://doi.org/10.1038/s43017-020-0049-7.

Atzmüller, C., Steiner, P.M., 2010. Experimental vignette studies in survey research. Methodol. Eur. J.Res. Methods for the Behav. So. Sci. 6 (3), 128. https://doi.org/10.1027/1614-2241/a000014.

Auspurg, K., Hinz, T., 2015. Factorial Survey Experiments. SAGE Publications, Inc., United States https://doi.org/10.4135/9781483398075, 2455 Teller Road, Thousand Oaks California 91320.

Boudet, H.S., Zanocco, C.M., Howe, P.D., Clarke, C.E, 2018. The effect of geographic proximity to unconventional oil and gas development on public support for hydraulic fracturing. Risk Anal. 38 (9), 1871–1890. https://doi.org/10.1111/risa.12989.

Braun, S., 2022. Germany Considers Fracked Gas Amid Energy Crisis. August 18. DW. https://www.dw.com/en/will-fracking-make-a-comeback-in-germany-in-face-of-gas-crunch/a-62814035 (accessed Sept 14, 2022).

Campbell, N.M., Leon-Corwin, M., Ritchie, L.A., Vickery, J., 2020. Human-induced seismicity: Risk perceptions in the state of Oklahoma. The Extractive Ind. Soc. 7 (1), 119–126. https://doi.org/10.1016/j.exis.2020.01.005.

Canada Energy Regulator. (2022). Consultation and engagement. https://www.cer-rec.gc.ca/en/consultation-engagement/(accessed Oct 5, 2022).

Choma, B.L., Hanoch, Y., Currie, S., 2016. Attitudes toward hydraulic fracturing: The opposing forces of political conservatism and basic knowledge about fracking. Glob. Environ. Change 38, 108–117. https://doi.org/10.1016/j.gloenvcha.2016.03.004.

Christenson, D.P., Goldfarb, J.L., Kriner, D.L., 2017. Costs, benefits, and the malleability of public support for "Fracking. Energy Policy 105, 407–417. https://doi.org/10.1016/j.enpol.2017.03.002.

Colville, S., Steen, J., Gosine, R., 2021. Do public review processes reflect public input? A study of hydraulic fracturing reviews in Australia and Canada. Energy Policy 155, 112303. https://doi.org/10.1016/j.enpol.2021.112303.

Davidson, D.J., 2017. Evaluating the effects of living with contamination from the lens of trauma: a case study of fracking development in Alberta, Canada. Environ. Sociol. 4 (2), 196–209. https://doi.org/10.1080/23251042.2017.1349638.

Drummond, V., Grubert, E., 2017. Fault lines: Seismicity and the fracturing of energy narratives in Oklahoma. Energy Res. Soc. Sci. 31, 128–136. https://doi.org/10.1016/j.erss.2017.05.039.

Evensen, D.T., 2015. Policy decisions on shale gas development ('fracking'): the insufficiency of science and necessity of moral thought. Environ. Values 24 (4), 511–534. https://doi.org/10.3197/096327115X14345368709989.

Evensen, D., Jacquet, J.B., Clarke, C.E., Stedman, R.C., 2014. What's the 'fracking' problem? One word can't say it all. The Extractive Ind. Soc. 1 (2), 130–136. https://doi.org/10.1016/j.exis.2014.06.004.

Evensen, D., Stedman, R., Brown-Steiner, B., 2017. Resilient but not sustainable? Public perceptions of shale gas development via hydraulic fracturing. Ecol. Soc. 22 (1) https://doi.org/10.5751/ES-09022-220108.

Evensen, D., Varley, A., Whitmarsh, L., Devine-Wright, P., Dickie, J., Bartie, P., Napier, H., Mosca, I., Foad, C., Ryder, S., 2022. Effect of linguistic framing and information provision on attitudes towards induced seismicity and seismicity regulation. Sci. Reports 12 (1), 1–13. https://doi.org/10.1038/s41598-022-15448-4.

Fry, M., Briggle, A., Kincaid, J, 2015. Fracking and environmental (in) justice in a Texas city. Ecol. Econ. 117, 97–107. https://doi.org/10.1016/j.ecolecon.2015.06.012.

Gehman, J., Lefsrud, L.M., Fast, S., 2017. Social license to operate: Legitimacy by another name? Canadian Public Administration 60 (2), 293–317. https://doi.org/10.1111/capa.12218.

Greene, W., Harris, M., Knott, R., Rice, N, 2021. Specification and testing of hierarchical ordered response models with anchoring vignettes. J. Royal Statistical Soc. Series A-Statistics in Soc. 184, 31–64. https://doi.org/10.1111/rssa.12612.

Howell, E.L., Li, N., Akin, H., Scheufele, D.A., Xenos, M.A., Brossard, D, 2017. How do US state residents form opinions about 'fracking' in social contexts? A multilevel

analysis. Energy Policy 106, 345–355. https://doi.org/10.1016/j.enpol.2017.04.003.
Howell, E.L., Wirz, C.D., Brossard, D., Scheufele, D.A., Xenos, M.A, 2019. Seeing through risk-colored glasses: risk and benefit perceptions, knowledge, and the politics of fracking in the United States. Energy Res. Soc. Sci. 55, 168–178. https://doi.org/10.1016/j.erss.2019.05.020.
International Energy Agency. (2021). World energy outlook 2021. https://www.iea.org/reports/world-energy-outlook-2021 (accessed June 8, 2022).
Jerolmack, C., Walker, E.T., 2018. Please in my backyard: Quiet mobilization in support of fracking in an Appalachian community. Am. J. Sociol. 124 (2), 479–516. https://doi.org/10.1086/698215.
Jørgensen, M.L., Anker, H.T., Lassen, J., 2020. Distributive fairness and local acceptance of wind turbines: The role of compensation schemes. Energy Policy 138, 111294. https://doi.org/10.1016/j.enpol.2020.111294.
Knoblauch, T.A., Stauffacher, M., Trutnevyte, E., 2018. Communicating low-probability high-consequence risk, uncertainty and expert confidence: Induced seismicity of deep geothermal energy and shale gas. Risk Anal. 38 (4), 694–709. https://doi.org/10.1111/risa.12872.
Lachapelle, E., Kiss, S., Montpetit, É., 2018. Public perceptions of hydraulic fracturing (Fracking) in Canada: Economic nationalism, issue familiarity, and cultural bias. The Extractive Ind. Soc. 5 (4), 634–647. https://doi.org/10.1016/j.exis.2018.07.003.
Liebe, U., Bartczak, A., Meyerhoff, J., 2017. A turbine is not only a turbine: The role of social context and fairness characteristics for the local acceptance of wind power. Energy Policy 107, 300–308. https://doi.org/10.1016/j.enpol.2017.04.043.
Liebe, U., Dobers, G.M., 2020. Measurement of fairness perceptions in energy transition research: A factorial survey approach. Sustainability 12 (19), 8084. https://doi.org/10.3390/su12198084.
Liebe, U., Dobers, G.M., 2019. Decomposing public support for energy policy: What drives acceptance of and intentions to protest against renewable energy expansion in Germany? Energy Research & Soc. Sci. 47, 247–260. https://doi.org/10.1016/j.erss.2018.09.004.
Mariel, P., Hoyos, D., Meyerhoff, J., Czajkowski, M., Dekker, T., Glenk, K., Jacobsen, J.B., Liebe, U., Olsen, S.B., Sagebiel, J., Thiene, M., 2021. Environmental Valuation With Discrete Choice Experiments: Guidance on Design, Implementation and Data Analysis. Springer Nature, p. 129. https://doi.org/10.1007/978-3-030-62669-3.
Mathis, W., 2022. UK Lifts Shale Gas Fracking Ban in Bid to Boost Fuel Supply. September 8. Bloomberg. https://www.bloomberg.com/news/articles/2022-09-08/uk-lifts-ban-on-shale-gas-fracking-in-push-to-boost-fuel-supply (accessed Sept 14, 2022).
Mattfeldt, A., 2022. Risk in discourses around fracking: a discourse linguistic perspective on the UK, the USA and Germany. J. Risk Res. 25 (3), 317–330.
McComas, K.A., Lu, H., Keranen, K.M., Furtney, M.A., Song, H., 2016. Public perceptions and acceptance of induced earthquakes related to energy development. Energy Policy 99, 27–32. https://doi.org/10.1016/j.enpol.2016.09.026.
McNally, H., Howley, P., Cotton, M., 2018. Public perceptions of shale gas in the UK: framing effects and decision heuristics. Energy, Ecol.Environ. 3 (6), 305–316. https://doi.org/10.1007/s40974-018-0102-2.
National Energy Board. (2019). 2018-19 Annual report to parliament. https://www.cer-rec.gc.ca/en/about/publications-reports/annual-report/2018/nnlrprt2018-eng.pdf (accessed June 8, 2022).
National Energy Board. (2011). Tight oil developments in the western canada sedimentary basin - energy briefing note. https://www.cerrec.gc.ca/nrg/sttstc/crdlndptrlmprdct/rprt/tghtdvlpmntwcsb2011/tghtdvlpmntwcsb2011-eng.html#s5_2 (accessed Sept 14, 2022).
O'Connor, C.D., Fredericks, K., 2018. Citizen perceptions of fracking: The risks and opportunities of natural gas development in Canada. Energy Res. Soc. Sci. 42, 61–69. https://doi.org/10.1016/j.erss.2018.03.005.
Parkins, J.R., Anders, S., Meyerhoff, J., Holowach, M., 2022. Landowner acceptance of wind turbines on their land: Insights from a factorial survey experiment. Land Econ. 98 (4), 674–689. https://doi.org/10.3368/le.98.4.012521-0008R1.
Pollard, J.A., Rose, D.C., 2019. Lightning rods, earthquakes, and regional identities: Towards a multi-scale framework of assessing fracking risk perception. Risk Anal. 39 (2), 473–487.
Porter, R.T.J., Striolo, A., Mahgerefteh, H., Faure Walker, J., 2018. Addressing the risks of induced seismicity in subsurface energy operations. WIREs Energy Environ. 8, e324 https://doi.org/10.1002/wene.324.
Raymond, C.M., Brown, G., Weber, D, 2010. The measurement of place attachment: Personal, community, and environmental connections. J. Environ. Psychol. 30 (4), 422–434. https://doi.org/10.1016/j.jenvp.2010.08.002.
Ritchie, L.A., Long, M.A., Leon-Corwin, M., Gill, D.A., 2021. Citizen perceptions of fracking-related earthquakes: exploring the roles of institutional failures and resource loss in Oklahoma, United States. Energy Res. Soc. Sci. 80, 102235 https://doi.org/10.1016/j.erss.2021.102235.
Roberts, J.J., Bond, C.E., Shipton, Z.K., 2021. Fracking bad language–hydraulic fracturing and earthquake risks. Geosci. Commun. 4 (2), 303–327.
Sovacool, B.K., 2014. Cornucopia or curse? Reviewing the costs and benefits of shale gas hydraulic fracturing (fracking). Renew. Sustain. Energy Rev. 37, 249–264. https://doi.org/10.1016/j.rser.2014.04.068.
Statistics Canada. (2022). Census profile. 2021 census of population. Statistics Canada Catalogue no. 98-316-X2021001. Ottawa. Released April 27, 2022. https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/index.cfm?Lang=E (accessed June 20, 2022).
Stedman, R.C., Evensen, D., O'Hara, S., Humphrey, M., 2016. Comparing the relationship between knowledge and support for hydraulic fracturing between residents of the United States and the United Kingdom. Energy Res. Soc. Sci. 20, 142–148. https://doi.org/10.1016/j.erss.2016.06.017.
Thomas, M., Pidgeon, N., Evensen, D., Partridge, T., Hasell, A., Enders, C., Herr Harthorn, B., Bradshaw, M., 2017. Public perceptions of hydraulic fracturing for shale gas and oil in the United States and Canada. Wiley Interdisciplinary Rev.: Clim. Change 8 (3), e450. https://doi.org/10.1002/wcc.450.
Trumpener, B., 2022. Fracking Promises Prosperity — But What If It's Happening in Your Front Yard? April 27 CBC. https://www.cbc.ca/news/canada/british-columbia/fracking-lng-northeast-bc-impact-1.6426927 (accessed Nov 21, 2022).
Truong, D., Davidson, D.J., Parkins, J.R., 2019. Context matters: Fracking attitudes, knowledge and trust in three communities in Alberta, Canada. The Extractive Ind. Soc. 6 (4), 1325–1332. https://doi.org/10.1016/j.exis.2019.09.004.
USGS. (2022). The modified Mercalli intensity (MMI) scale assigns intensities as ... https://www.usgs.gov/media/images/modified-mercalli-intensity-mmi-scale-assigns-intensities.
Whitmarsh, L., Nash, N., Upham, P., Lloyd, A., Verdon, J.P., Kendall, J.M., 2015. UK public perceptions of shale gas hydraulic fracturing: The role of audience, message and contextual factors on risk perceptions and policy support. Appl. Energy 160, 419–430. https://doi.org/10.1016/j.apenergy.2015.09.004.
Williams, L., Macnaghten, P., Davies, R., Curtis, S, 2017. Framing 'fracking': Exploring public perceptions of hydraulic fracturing in the United Kingdom. Public Understanding of Sci. 26 (1), 89–104. https://doi.org/10.1177/0963662515595159.
Yao, L., Sui, B., 2020. Heterogeneous preferences for shale water management: Evidence from a choice experiment in Fuling shale gas field, southwest China. Energy Policy 147, 111831. https://doi.org/10.1016/j.enpol.2020.111831.