Public Perception of Hydraulic Fracturing and the Oil and Gas Industry in Western Canada: What the Frack is Going On?

by

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Abstract

Hydraulic fracturing (HF), colloquially known as fracking, is an extremely divisive topic. One of its associated risks is the potential for induced seismicity (IS). Although HF has been around since the 1950s in Alberta, factors affecting public perception of the risks of IS are not fully understood. Public perception can influence social license to operate. Thus, understanding the factors that influence public perception can lead to smoother interactions between industry and the public and improve the reputation of industry. A better understanding may also ensure safe and economic energy production can continue. In the spring of 2019, we distributed a survey to the public to explore the opinions and perceptions of HF and the oil and gas industry in western Canada. This allows us to evaluate public preferences for, and acceptability of, HF operations and related public perceptions of risk using statistical analysis. While some outcomes are not surprising, such as the concept of NIMBY ("Not In My Back Yard"), many of the conclusions will be able to provide new insights to inform policy and best practice reviews within the industry and regulatory bodies. Support not only for oil and gas, but also for specific HF scenarios that include different levels of anticipated seismicity was explored, along with the influence of things like prior earthquake experience, energy industry work experience, and knowledge. The main concerns the public have in relation to the oil and gas industry are shown to be related to water quality, water usage, and surface spills. Overall, the results of this survey enable us to make policy recommendations, such as the creation of a resource that the public can use to access information about operations near them. These recommendations could bring local industry, integral to the Alberta economy, more in line with the perceptions and preferences of the Alberta public.

Preface

This thesis is an original work by Jordan Phillips. The research project, of which this thesis is a part, received ethics approval from the University of Alberta Research Ethics Board, Project Name "Study of the Oil and Gas Industry in Western Canada," No. Pro00088384, February 12, 2019.

To the 1,311 people who filled out my survey. Your voices were heard, and this is the result.

To my Mom, for your unconditional support.

To my partner Roshan, for helping me stick with it.

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List of Abbreviations

AER .... Alberta Energy Regulator
BCOGC .... British Columbia Oil and Gas Commission
DYFI ....Did You Feel It
FSA.. Forward Sortation Area
FSE... Factorial Survey Experiment
HF.. Hydraulic Fracturing
IS ....Induced Seismicity
LC ....Latent Class
NIMBY ....Not In My Back Yard
NRCan.. Natural Resources Canada
OLS ....Ordinary Least Squares
SO .... Subsurface Order

Chapter 1: Introduction

1.1 Motivations

With hydraulic fracturing (HF), also known as "fracking," becoming an increasingly common way of extracting hydrocarbon resources, it is becoming correspondingly increasingly important to understand how this practice, and the associated phenomenon of induced seismicity (IS), is perceived and accepted by the public. This interdisciplinary thesis brings together knowledge from geophysics and social sciences, and aims to primarily study three things:

1. The current public perception of IS and the oil and gas industry. This pertains particularly to risks (perceived or otherwise), concerns, and the acceptability of practices like HF.
2. Things that may influence perceptions and opinions, such as compensation, potential adverse effects, or a respondent's personal background.
3. Whether respondents have felt earthquakes, which may have been natural or induced, and how this compares to HF activity, Natural Resources Canada reports, and topographical and subsurface information.

1.2 Questions to answer and main objectives

Questions that this thesis aims to answer are:

1. What is the process of designing and analyzing a survey on public perceptions of the oil and gas industry in western Canada?
2. What is the state of public perception, and therefore social license, of the industry?
3. Of the studied attributes, which have the highest influence on support for or opposition to HF scenarios?
4. What underlying characteristics contribute to support for HF scenarios?
5. Which respondent characteristics influence the likelihood of being a protester or keener with regard to HF operations?
6. How do locations of felt earthquakes compare to HF locations? To topography? To population distribution?

Answering these questions gains us insight into the survey process and how it might be applied effectively to oil and gas research in the future, an assessment of the public's perception of industry, an idea of what influences a person's opinion of HF operations, and a comparison of existing earthquake data with respondents' own experiences.

1.3 Contributions

To address the research objectives, I created an online public survey that was aimed primarily at western Canadians. Using this survey and its associated analyses, this thesis will contribute a better understanding of western Canadian, particularly Albertan, perceptions of the oil and gas industry. There is a focus here on HF and IS, which are increasingly common in the western Canadian energy landscape. This thesis also expands the use of Factorial Survey Experiment (FSE) vignette scenarios in oil and gas industry perception research, which has so far seen limited application both in general and in Canada especially. A further contribution is a comparison of spatial and frequency distributions of survey respondents who have felt earthquakes with existing databases as well as with topographical and subsurface information.

1.4 Thesis structure

This thesis is organized as follows. Chapter 2 reviews the literature surrounding the oil and gas industry, HF, IS, and their interactions with public perception. Chapter 3 describes the method and approach taken in the development of the survey, from preliminary steps to question sources and choices to FSE methods and choices to administration and analysis. It includes an overview of the survey questions, which can be found in their entirety in Appendix A and C (Appendix C contains the FSE vignette scenarios, while the majority of the survey is found in Appendix A). Chapter 4 delves into the traditional-style survey questions, organized by individual “mini investigations.” These include a brief look at some of the demographics of the respondents, a discussion of their energy experience and knowledge, a first look at support for energy sources and acceptability of HF, IS, and oil and gas, a comparison of trust and transparency, an investigation of risk perceptions, and a look at concerns related to the oil and gas industry. The results of any questions from the survey that are not covered in this chapter are included in Appendix B. Chapter 5 focuses specifically on the results from the FSE vignette scenarios, including their interaction with respondent characteristics. This expands on the earlier first look at acceptability of HF and IS. Chapter 6 discusses respondents who have experienced an earthquake and compares these results from the survey with “Did You Feel It” (DYFI) information obtained from Natural Resources Canada, and HF well locations. Here we also discuss the potential effects of subsurface geology on how widely an earthquake will be felt. Chapter 7 discusses limitations, additional analyses, and suggestions for future work. Chapter 8 concludes the thesis and provides some recommendations based on the survey results.

Chapter 2: Background and literature review

2.1 Overview of hydraulic fracturing and induced seismicity context

In recent years, there has been an increase in fluid injections associated with hydraulic fracturing (HF) (Atkinson et al., 2016; Vengosh et al., 2014). This comes with an increase in the risk of induced seismicity (IS) as well as increasing scrutiny from both the public and regulators (Atkinson et al., 2016). While IS is often associated with production of shale gas and oil through HF, it can also be the result of production of other kinds of energy, such as deep geothermal. Knoblauch et al. (2018) explore the effect of the type of energy on the perception of IS among the public, finding that geothermal sources of IS were perceived less negatively than shale gas sources. There are also other risks associated with HF and IS, including overuse and contamination of fresh water sources (Vengosh et al., 2014).

HF has become a highly divisive, controversial topic (Boudet et al., 2014; Howarth et al., 2011; Ladd, 2013; Smith & Richards, 2015; Theodori et al., 2014). With HF becoming an increasingly common way of extracting hydrocarbon resources, there is an increasing need to understand how this practice is perceived and accepted by the public.

The process has been used in Alberta since the 1950s (Government of Alberta, 2016a; Wood, 2014) and although HF fluids do contain chemicals, they are typically predominantly water and sand (BC Oil and Gas Commission, n.d.-b; GFZ Helmholtz Centre Potsdam, n.d.-a). IS can be a result of HF activity, but may not always be felt by humans at the surface (GFZ Helmholtz Centre Potsdam, n.d.-b). While most drinking water aquifers are found within 0-150 m of the surface (BC Oil and Gas Commission, n.d.-b), HF is usually comparatively deep. It has a median depth of 2490 m in the United States between 2008 and 2013, although some wells were as shallow as 30 m (Jackson et al., 2015). In Canada, however, the formations that are hydraulically fractured are typically found at depths of 600-2900 m (National Energy Board, 2011).

2.2 Overview of knowledge, experience, support, and risk perception

Experience and knowledge are believed to play a role in the public's perception of the oil and gas industry, and HF in particular. Crowe et al. (2015) found that government officials were more likely to desire a ban on HF if they had sent someone to visit another community that was developing its shale plays, and if their own community had a strong economy. They hypothesize a few reasons for this finding. First, that there may be a selection bias with this finding, since it is possible that leaders who view shale development and HF more negatively may be more likely to visit areas experiencing HF development before deciding whether they desire a ban on the activity. Second, those who visit HF sites may feel that their environmental values are threatened, and therefore recommend against allowing HF activity. Third, the negative effects of HF activities may be more visible and impactful than the positive effects. Crowe et al. (2015) recommended that further research be conducted to better establish how knowledge and experiences, among other things, influence perceptions of the consequences of potentially risky activities like HF.

Thomas et al. (2017) describe how past experiences with energy extraction in a community may influence perceptions of proposed operations, suggesting that areas with more development experience may hold more polarized and nuanced views. Jacquet (2012) explored employment experience in relation to perceptions of natural gas drilling and found strong correlations between a respondent's employment and positive perceptions. They also found that employment of friends and family had comparatively weaker correlations with this positive attitude towards gas development.

Although Crowe et al. (2015) explore perceptions using a value-belief-norm model, where decisions are made based more on beliefs and values than on calculated logic, they do discuss the possibility that knowledge about an issue can be part of the decision-making process as well, as claimed by Whitfield et al. (2009). This influence of knowledge also seems to be implied to some extent by Lachapelle and Montpetit (2014), although they find that being more knowledgeable does not reliably make a person more supportive. Actually, having more information could make a person more OR less supportive depending on whether their values include egalitarianism (assessed using a question about redistribution of wealth).

While there certainly exist objective risks, there is also a perceived level of risk associated with IS from industry activities. Public perception of the risks associated with induced seismic events can affect the ability of the oil and gas industry to operate and thrive in a given location; i.e. public perception influences social license to operate.

Risk aversion has been considered to be a function of stigma and emotion (Peters et al., 2004), and it is inherent to many parts of modern society, including living with natural disasters, evolving attitudes toward food, and contemporary energy production. Aversion to risk can lead to negative public perceptions of perceived risky activities, such as HF. A study of risk factors affecting mental health in the United Kingdom following devastating floods in 2007 found that things such as being evacuated or disruptions to essential services had negative impacts on the mental health of local residents. These findings led to proposed risk mitigation efforts that targeted these factors (Paranjothy et al., 2011). The assessment of opinions related to risk relies on "scales"; for example the Food Technology Neophobia Scale developed by Evans et al. (2010) to assess reception of new food-related technologies, or the New Environmental Paradigm scale, designed by Dunlap and Van Liere (1978) to measure attitudes towards the environment. Scales to assess risk attitudes and risk-related behaviour have been developed by Weber et al. (2002), who find that perceptions of risks can vary between individuals based on things like gender and between different risk settings or domains. Weber et al. (2002) also assert that aversion to risk differs based on the perception of benefits and risks related to potentially risky activities.

Risk aversion is particularly interesting in the energy industry. Topics ranging from nuclear power to HF to climate change are all controversial and divisive, with their risk levels the subject of much public debate. Gehman et al. (2016) have gone so far as to say that although negative public perceptions of risk are often exaggerated, under some very specific circumstances they may be closer to the truth than expert assessments. This sentiment is supported by the idea that although the general public may lack some information about risks and hazards, their concept of risks can be complex and include legitimate concerns that may not be included in expert assessments of risk (Slovic, 1987).

It is primarily still the case, however, that common social settings have a tendency to amplify negative perceptions of risk, even when expert assessments indicate the risk to be relatively minor (Kasperson, 2012). The internet has made it possible and simple to share opinions — which can lead to a single voice dominating the conversation surrounding a particular risk, regardless of how reliable their information is. The media, including and especially social media, forms a significant part of the framework of risk perception and interpretation. This means that one opinion, shared widely and loudly enough, can have a profound impact on overall public opinion surrounding a given topic — for example, hydraulic fracturing (Chung, 2011). The prevalence of social media use gives a multitude of opportunities for opinions to be shared volubly, whereas in decades past, information came from other sources such as newspapers, which have more curation of their content than does social media.

Amplified negative perceptions of risk can affect other aspects of society as well, such as the economy. Communication surrounding risks and hazards can be unclear, and perceptions can be altered depending on the tone, emphasis, wording, or bias of the communication source (Kasperson, 2012). With this in mind, it is increasingly important to communicate risks accurately and effectively to the public regarding energy production.

2.3 Literature review

There are a number of studies that have investigated different facets of risk perceptions (particularly negative perceptions based on widespread risk aversion), knowledge, experience, support, and concerns about oil and gas operations and activities. Below are discussed several of these contributions to the field.

2.3.1 Oil and gas and hydraulic fracturing in North America and Canada

The oil and gas industry in North America in its industrialized form began in the mid 19th century (Cope, 2009; Klass & Meinhardt, 2015), and it was recently estimated that 17.6 million people live within one mile of at least one active oil or gas well in the US (Czolowski et al., 2017). In Canada, over 500,000 oil and gas wells have been drilled as of 2014, and over 375,000 of those are found in Alberta (Rivard et al., 2014). The products from these wells are then transported to refineries, and eventually end consumers. One method of transportation is pipelines, which have been in use in the US since the mid 19th century (Klass & Meinhardt, 2015), and have become increasingly significant from resource, economic, and social standpoints in Canada (Forrester et al., 2015). Development of oil and gas resources in Canada is ongoing, with many new projects being proposed or developed (Canadian Association of Petroleum Producers, n.d.; Government of Alberta, n.d.).

Production of oil and gas began to use HF techniques in the 1940s and 1950s in the US and Canada (Government of Alberta, 2016b; Montgomery & Smith, 2010; Wood, 2014). While remaining conventional oil and gas reserves are beginning to dwindle, HF, in addition to horizontal drilling techniques, has changed the fossil fuel industry landscape (Rivard et al., 2014). Shale gas developments often imply the use of HF techniques (Thomas et al., 2017), and the first production of gas from a shale formation in

Canada was located in the Montney basin in northeast British Columbia in 2005, and the Horn River basin in northeast British Columbia in 2007 (Rivard et al., 2014). Since then, production has expanded, and as of 2012 there were over 1,100 shale gas wells in Canada, mostly in Alberta and British Columbia.

Regulation of fossil fuel extraction, including HF use in development of low-permeability shale formations, is under provincial jurisdiction in Canada, with different provinces having different regulatory bodies and requirements (Grafton et al., 2017; Rivard et al., 2014). Interprovincial and international energy trading, cross-jurisdiction pipelines, exports/imports, and natural resource regulation in the Canadian Arctic, offshore marine areas, and Indigenous lands fall under federal jurisdiction (Rivard et al., 2014).

2.3.2 Induced seismicity due to hydraulic fracturing

Seismic events triggered by HF operations are routinely recorded (Rivard et al., 2014), although IS due to HF is more common in western Canada than in the US, where most IS is due to wastewater injection (Atkinson et al., 2016; Rubinstein & Mahani, 2015). Due to the nature of HF, small-magnitude IS events are a direct result of operations; however, issues may arise when events are large enough to be felt by humans at the surface (Foulger et al., 2018; Rubinstein & Mahani, 2015). Among the largest recorded IS events that resulted from HF activity are two magnitude 4.4 earthquakes in central west Alberta and northeast British Columbia (Foulger et al., 2018; Rubinstein & Mahani, 2015). Felt IS typically results from injected fluids reactivating nearby faults (Atkinson et al., 2016; Rubinstein & Mahani, 2015), and mitigation of IS during HF operations can include reducing the volume of fluid injected, reducing the amount of proppant (e.g. sand, to hold fractures open) within the fluid, skipping some of the planned HF locations along the horizontal leg of a well, and flowing injected fluids back to the surface. It is difficult to determine whether these actions are successful in mitigating IS events, due to the many variables at play during HF operations (BC Oil and Gas Commission, 2014).

Determining whether events that have been detected were natural or induced by fluid injection (for HF or wastewater disposal) has been a challenge for decades. Davis and Frohlich (1993) proposed the use of seven questions about recent events to determine whether or not they were induced. These questions address four factors: background seismicity, temporal correlation, spatial correlation, and current injection practices. Earthquakes that are categorized as “clearly induced” share several characteristics. They are often among the first, if not the first, known earthquakes of their type or magnitude in the region. There is a clear correlation between the timings of injection and clearly induced seismicity. Epicenters of the clearly induced earthquakes are near wells (within 5 km), with some occurring at or near injection depths. If clearly induced earthquakes are not near wells, at or near injection depths, there are known geologic structures that may channel fluids to the earthquake site. Changes in fluid pressures at well bottoms are sufficient to encourage clearly induced seismicity, and changes in fluid pressures at hypocentral locations are sufficient to encourage clearly induced seismicity (Davis & Frohlich, 1993).

The seven questions Davis and Frohlich (1993) created are still used by the Alberta Energy Regulator, Alberta Geological Survey, and others to determine whether seismic events are likely to have been natural or induced by HF or wastewater injection (Alberta Geological Survey, 2017; National Research Council et al., 2013).

2.3.3 Hydraulic fracturing, induced seismicity, and potential risks to the western Canadian public

Finding a way to communicate risks accurately and effectively to the public is essential to the continued advancement of the oil and gas industry. Knoblauch et al. (2018) studied whether quantitative information, qualitative, or a mix of both is the best approach to sharing risk-related information. The authors found that respondents considered the quantitative format more exact and easier to understand, and as a result liked it over other options. They also found that including a statement of uncertainty and limited expert confidence led to increases in public concern, though this style may potentially convey the complexity of the risks in a more realistic way. Lastly, Knoblauch et al. (2018) found that the *type* of technology for which risks are communicated influences public perception of identical levels of consequences. That is, for the same communication format with the same levels of consequences, technologies related to shale gas were perceived as riskier than technologies related to deep geothermal energy. This study did not explore the use of graphics or images in the risk communications, such as risk or hazard maps.

It is not just the format of the risk communication that is important — the framework of understanding within the population is also crucial. Kahlor et al. (2019) completed a study in an attempt to better understand the risk communication climate surrounding seismicity in Texas. Within their respondent population, there was awareness of the issue and participants appeared to be factually knowledgeable. There was a relatively low level of perceived risk due to seismicity, which influenced other factors such as ambivalence about risk communications and seeking out information related to potential risks. Things such as social norms and attitudes to risk information seeking, both components in the study by Kahlor et al. (2019), along with the extent to which respondents might benefit from the technology (for example, through employment), can influence risk perceptions, and are part of the framework of understanding for risk in our society.

It is possible for perceptions of risk to become amplified or attenuated depending on how the risks and circumstances surrounding them are presented in the media or discussed among members of the public (Kasperson, 2012; Smith & Richards, 2015). This can lead to the perception of risk being significantly higher or lower than the actual risk presented by a technology, operation, or scenario.

Some risks that arise from HF activities can include: contamination of fresh water aquifers due to leaky or damaged well casings and annuli, or through migration via faults and fractures that may be either natural or a result of HF activity; impacts to surface water and soils from leaks and spills of flowback and produced water, discharge of insufficiently treated wastewater, and direct disposal of wastewater without treatment; and overuse of freshwater sources leading to local water shortages and quality degradation (though water usage can vary drastically by location, formation, and operator) (Vengosh et al., 2014).

Many risks related to seismic activity are related to impacts on infrastructure. Generally speaking, it is the intensity of ground shaking that is a better predictor of risk to infrastructure than the magnitude. This is because the same magnitude event can have vastly different surface effects depending on the geological characteristics of the area (Lowrie, 2007). Risk maps can be created using historic data and geological characteristics to predict the estimated earthquake hazard in a given area, such as those shown by Ghofrani et al. (2019). Events that are felt by humans are typically larger than magnitude 3, and those larger than magnitude 5 are more likely to be damaging (National Research Council et al., 2013).

Hazard assessment takes into account things like industry activity (potential for induced events), typical natural seismicity in an area, past seismic events, event magnitudes, and intensity of ground motion (Ghofrani et al., 2019; Lowrie, 2007). Seismic hazard is typically calculated using the probabilistic seismic hazard analysis framework, which assesses the likelihood of exceeding specified levels of ground motion (Atkinson, 2017). Hazard associated with induced events can either be avoided, by creating exclusion zones around sensitive infrastructure where actions that may induce seismic events are prohibited, or mitigated, by enacting monitoring and response protocols in areas around activities with the potential for IS (Atkinson, 2017).

In Alberta and British Columbia, both the Alberta Energy Regulator (AER) and British Columbia Oil and Gas Commission (BCOGC) monitor seismic activity in relation to industry activity and have regulations and protocols in place to prevent and mitigate induced seismic events. These include things like setback distances, shutdown protocols in the event of an earthquake, and regulations related to the geologic formation and project parameters.

Some parts of Alberta are subject to Subsurface Orders (SOs), which set out specific seismic protocols to limit the impact and potential of IS from HF. These orders mandate the use of traffic light systems, wherein companies are required to inform the AER of seismic events over a specified size, and either invoke a response plan or immediately cease operations, depending on the magnitude of the event (Alberta Energy Regulator, n.d.). Alberta currently has seven SOs, three of which (numbers two, six, and seven) relate to IS (Alberta Energy Regulator, n.d.).

SO number two (SO2) was made on February 19, 2015 and regulates HF activities near Fox Creek that may produce IS. SO number six (SO6) was made on May 27, 2019 and regulates HF activity west of Red Deer. SO number seven (SO7) was made on December 9, 2019 and also regulates HF activity west of Red Deer. All of these SOs specify the required sensitivity of seismic monitoring equipment and the magnitude thresholds at which certain actions must be taken. Monitoring equipment must be able to detect, within 5 km of the HF well, a seismic event of magnitude 2.0 for SO2 and magnitude 1.0 for SO6 and SO7. When events greater than these threshold magnitudes are detected (yellow light events), companies must take action to eliminate or reduce the magnitude of seismic events and must report the event to the regulator. If an event occurs of minimum magnitude 4.0 for SO2, 2.5 for SO6, and 3.0 for SO7 (red light events), operations must be immediately suspended, the well site must be made safe, and the event must be reported to the regulator.

In British Columbia, the BCOGC maintains areas where ground motion must be monitored in association with drilling activity. In these areas, equipment must be installed within 3 km of the well pad that can detect and record ground motion (BC Oil and Gas Commission, 2017). Province-wide, operators who detect a magnitude 4.0 event or larger linked to injection operations must immediately suspend activity (BC Oil and Gas Commission, 2019b; Grafton et al., 2017). Additionally, all felt events are required to be reported to the regulator (BC Oil and Gas Commission, 2019b).

2.3.4 Public perceptions of the oil and gas industry

Trust and acceptance of the energy industry in western Canada (13%) is substantially lower than trust of the farming industry (62%) and forestry industry (32%), and similar to the mining industry (14%). From 1989–2015, news articles about development of oil resources in Canada contained highly negative language twice as often as articles about natural gas, forestry, mining, electricity, pipelines, and railroads (Gehman et al., 2017).

Not all perceptions of the oil and gas industry in western Canada are negative, however. Individuals in some rural Saskatchewan communities appear to identify with and strongly support the industry from a shared values perspective (Eaton & Enoch, 2018).

It seems to be the case that energy projects are often presented in terms of their economic contributions at the municipal, provincial, or federal level, rather than being discussed in terms of all of their contributions and impacts; this can lead to resistance to new developments (Shaw et al., 2015). In fact, in 2012, it was reported that nearly 66% of Americans have a negative view of the oil and gas industry (Smith & Richards, 2015). According to Thomas et al. (2017), trust of the gas industry in the US is shaky at best as well, which could result from varying levels of exposure to industry, perceived unfairness, failure on the industry's part to provide adequate information, and industry practices that could be construed as bullying. Trust of the oil industry was not mentioned.

2.3.5 Public perceptions of hydraulic fracturing and induced seismicity

HF is a highly contentious subject, with many arguments both for and against it (Howarth et al., 2011; Soeder, 2018). Whitmarsh et al. (2015) showed that factors such as gender, rurality, political affiliation, and environmental values — specifically place attachment, environmental identity, and climate change skepticism — are strong influences on perceptions of shale gas HF in the UK. A significant proportion of their survey respondents felt that the risks of shale gas HF, including water contamination and IS, outweighed the benefits. However, Whitmarsh et al. (2015) also indicated that *awareness* of risks appeared to be greater than awareness of the benefits of shale gas HF. This also seems to be the case for residents in Quebec, and this heightened awareness of risk also seems to contribute to reluctance to allow HF operations, if not outright opposition to them (Lachapelle & Montpetit, 2014). Overall, Whitmarsh et al. (2015) determined that people who are initially ambivalent with regard to HF are the most susceptible to persuasive information, whether it presents HF in a positive light or a negative one.

Support for HF in the US tends to be fairly polarized; women, people who have egalitarian worldviews, people who read newspapers more than once a week, people who are more familiar with HF, and people who associate HF with environmental impacts are more likely to oppose HF, while supporters tend to watch TV news more than once a week, be older, be more educated, be politically conservative, and associate HF with positive economic or energy supply outcomes (Boudet et al., 2014). There are also other instances of supporters pointing to economic benefits while those opposed name environmental impacts (Ladd, 2013; Thomas et al., 2017). In New York and Pennsylvania, residents were more likely to support natural gas developments than oppose them, with a sizable fraction of participants responding that they felt uncertain or neutral about developments (Stedman et al., 2012).

McComas et al. (2016) explored perceptions surrounding IS from several sources: injection of waste water, enhanced geothermal systems, carbon capture sequestration, and HF. In general, it is believed that natural earthquakes are perceived as being more acceptable than those induced by human activity. The study done by McComas et al. (2016) corroborated that, as well as indicated that there are several trade offs with the potential to mitigate negative perceptions of IS. These include environmental benefits, such as reducing greenhouse gas or providing an alternative source of heat and energy; benefits for parties such as private companies, schools, or people across the planet; and varying amounts of procedural fairness during the decision-making process, in which local residents have some level of input on projects in the area. The authors go on to specify that improved acceptance of IS does not necessarily indicate wholesale acceptance of the technology that produces it, as these kinds of technologies often have many other risks, such as pollution or financial costs. The general conclusion of the study is that encouraging acceptance of energy technologies requires an understanding of the perceived risks, benefits, beneficiaries, and fairness of the decision-making and implementation processes.

2.4 Study contributions

There have been several studies and reports compiling the impacts HF may have on society, energy production, and the environment (Perry, 2012; The Academy of Medicine Engineering and Science of Texas, 2017; Vengosh et al., 2014; Willow & Wylie, 2014), as well as public perceptions of HF (Boroumand, 2015; Kahlor et al., 2019; McComas et al., 2016; Rassenfoss, 2019; Whitmarsh et al., 2015). While enlightening, few of these are based on the public of western Canada — a region with unique challenges, considerations, and implications of energy production. Boroumand (2015) looked at perceptions among Canadian energy professionals, but a new study was needed to further explore the public perception of the oil and gas industry in western Canada. This gap includes perceptions of HF and IS specifically, in addition to the oil and gas industry at large. In addition to my own conclusions on this matter, the review done by Thomas et al. (2017) also calls for extending HF perception research into Canadian regions. In order to compare with existing studies, new research should also explore factors influencing perception, such as risks and benefits from HF operations. This also gives the opportunity to compare expert assessments of risk with publicly perceived risks.

Room exists for us to explore the relationship between earthquake experiences and HF and IS perceptions. Although Natural Resources Canada collects information about seismic events that have been felt (Natural Resources Canada, n.d.-a), this has remained largely separate from any research that would seek to combine earthquake experiences with HF and IS perceptions. This could be broadened to include an examination of how subsurface geology may contribute to events being felt, and thus perhaps be related to HF and IS perceptions as well.

There have also been few instances of Factorial Survey Experiment (FSE) vignette scenario use in fossil fuel energy perception research, with the study by McComas et al. (2016) providing the most notable contribution. This leaves an opening for us to contribute by expanding fossil fuel energy perception research methods into FSE vignette scenario territory.

Within this thesis, we first describe our methods for survey development, collection, and analysis (Chapter 3), and then we discuss the results and analysis that relate to traditional-style survey questions (Chapter 4), the FSE vignette scenarios (Chapter 5), and earthquake experiences of our respondents (Chapter 6). We conclude with a discussion of future research avenues (Chapter 7), overall conclusions (Chapter 8), and recommendations for stakeholders that have arisen from the survey results (Chapter 8).

Chapter 3: Method and approach

3.1 Overall approach

Following previous related literature, we chose to approach this research with a public survey. This method was chosen over an interview approach so that we could reach a larger number of respondents and have the ability to examine the influences of a wider array of respondent characteristics, such as geographic location, land ownership, and experience with the energy industry. We arrived at the final version of our survey through a stepwise process, which began with a toy model (Marzuoli, 2018) and a smaller test survey before we began creating our main survey. The toy model and test survey are discussed in Chapter 7. The survey developed for this thesis then took ten months to create and refine, and we received feedback from stakeholders in regulatory bodies, government groups, industry companies and groups, and academic groups. The survey uses traditional-style survey questions as well as Factorial Survey Experiment (FSE) vignette scenarios. The FSE scenarios help to mitigate biases like social norm expectations and offer simplified realistic scenarios to respondents who then make trade-offs in their evaluations and responses.

3.2 Structure and composition of survey

Our aim was to create a survey that would help us understand the scenario attributes that have the highest influence on support for or opposition to hydraulic fracturing (HF) scenarios, the underlying respondent characteristics that contribute to support for HF scenarios, which respondent characteristics influence the likelihood of being a protester or keener, and how locations of felt earthquakes compare to HF locations and to topography. Taken all together, this aim would also allow us to examine the state of public perception, and therefore social license, of the industry. To fulfill these aims, we designed a survey that was structured to find the answers to our research questions.

The full survey included eight sections, presenting each respondent with approximately 35 questions. These sections are broken down in Table 3.1 below and then explored in further detail in the following section. Some responses were removed due to non-completion of section two, and persons under the age of 18 were not permitted to take the survey. All responses from participants over the age of 18 who completed at least part of section two were accepted.

Except where otherwise specified, I created the survey questions in collaboration with my supervisors, after which various academic, industrial, and regulatory parties gave feedback that allowed us to refine the questions into the ones discussed below and shown in Appendix A.

Table 3.1: Outline of survey

Section	Theme	Number of Questions
1	Demographics	9
2	Hydraulic fracturing FSE scenarios	6
3	Knowledge of HF and O&G	2
4	Acceptability of HF, O&G, IS	3
5	Risk	1
6	Energy support and concerns, stakeholder roles	6
7	Earthquake experience	2
8	Additional demographics	6

3.3 Overview of survey questions

Except for section two, the full survey can be found in Appendix A. Section two showed respondents six scenarios at random out of 144. The full list of scenarios can be found in Appendix C. Here, I discuss themes and sources for the questions included in the survey.

The demographics in section one covered a variety of topics and were inspired by multiple sources. Whitmarsh et al. (2015) inspired us to ask whether respondents or their family had worked in energy-related organizations. While Whitmarsh et al. (2015) turned this essentially into a yes or no question of energy industry employment, we asked about a handful of specific organization types to give a slightly finer scale of evaluation (see question four in Appendix A.1). Our question of how long the respondent had lived in their current area was inspired jointly by Whitmarsh et al. (2015) and Raymond et al. (2010). While Raymond et al. (2010) asked respondents to give the number of years they had lived at their current residence, we chose to use the ordinal scale found in Whitmarsh et al. (2015) due to its higher level of anonymity for the respondent (see question one in Appendix A.1).

Raymond et al. (2010) also introduced the idea of place attachment, or how much respondents valued the place where they lived (including the environment and the community). We asked a subset of place attachment questions from that study, adapted to be less place specific. We used a subset rather than the whole suite of place attachment questions due to space constraints and a difference of study focus (see question three in Appendix A.1).

We asked respondents whether they owned land or property, inspired by Raymond et al. (2010) and their discussion of rural landowners, although in their case the survey was distributed only to landowners rather than the general public as was the case for our survey. This land ownership question referred to “small” and “large” land holdings, which we described as less than or more than 250 acres, respectively (see question two in Appendix A.1). This number was chosen after researching average farm sizes in North America (Dunckel, 2013; Statistics Canada, 2018).

After discussions with industry and regulatory representatives, we also decided to include questions to determine a respondent’s frequency of social media use (question four in Appendix A.1), frequency of discussions related to the environment and oil and gas (question six in Appendix A.1), their primary information sources for environment and oil and gas topics (question seven in Appendix A.1), their engagement levels with informational meetings (question eight in Appendix A.1), and their community involvement (question nine in Appendix A.1). These questions were intended to give a picture of their interest in and possible information sources for the topics we aimed to study in the survey, which also gives an idea of some of their biases.

While we did not wish to prime (Strack, 1992) our respondents to think of their employer and place of residence before considering their perceptions of risk related to hydraulic fracturing, we felt these demographics were important to collect, and should the respondent choose to only complete part of the survey we would still have access to this information for analysis purposes.

Section two presented respondents with HF scenarios to evaluate. The preamble for these scenarios included definitions for HF and induced seismicity (IS), which were adapted from Schlumberger Ltd. (n.d.) and Kahlor et al. (2017), respectively, to be easily understood by the general public and specifically applicable to the scenarios we showed respondents. The definitions were included to ensure all respondents had a minimum baseline understanding of the terminology that was used in the survey. The introduction to the section aimed to pre-empt the effect of concerns over water and economic considerations on the scenarios in an effort to focus primarily on the attributes used in the scenarios. This introduction is included in Appendix A.2. I discuss the methodology behind this section of the survey more fully in Section 3.4.

Section three of the survey focused on knowledge of HF and oil and gas topics using both objective and subjective evaluations. We used a series of true and false statements to assess objective knowledge of HF (question one in Appendix A.3), and asked respondents to rate their own perceived level of knowledge of the energy industry in western Canada (question two in Appendix A.3). The two types of knowledge assessment were intended to compare how knowledgeable a respondent felt about the energy industry with how much they knew about HF operations. I compiled the true and false statements from a variety of sources with the intent of testing the most basic aspects of HF operations as well as a few that I have personally found to be misconstrued by people of different backgrounds. I chose five questions so that we could have a reasonable coverage of information about HF without fatiguing respondents. Topics for the true and false questions were how long HF has been in use in Alberta (Energy BC, n.d.; Government of Alberta, 2016b; Wood, 2014), ingredients in HF fluids (BC Oil and Gas Commission, n.d.-b; GFZ Helmholtz Centre Potsdam, n.d.-a), ability of humans to feel all IS at the surface (GFZ Helmholtz Centre Potsdam, n.d.-b), and depths of drinking water aquifers compared to HF operations (BC Oil and Gas Commission, n.d.-a; Jackson et al., 2015; National Energy Board, 2011). The basic definition of HF used in this section was adapted from the Schlumberger definition (n.d.) to be more easily understood by the general public, and identical to the one used in section two of the survey.

Section four asked respondents about factors affecting the acceptability of HF and oil and gas operations under different conditions. I can compare responses from this section with responses to the scenarios in section two of the survey, giving a juxtaposition of respondents' self-identified opinion and their more nuanced underlying opinions. We created questions about the economic impacts of oil and gas activities on respondents' communities to explore how big a role compensation and economic stimulus might play in a person's opinion of the oil and gas industry (question two in Appendix A.4). One of the questions in this section concerns procedural fairness and explores the acceptability of non-damaging IS under various circumstances (question three in Appendix A.4). This question was adapted from McComas et al. (2016), who used it as a one-attribute FSE vignette scenario in their study and focused on earthquakes in general rather than IS. We chose to include it as a traditional-style question rather than FSE, in addition to reducing the number of scenarios, for simplicity's sake, and we altered the preamble to focus specifically on IS.

Perception of risk is the focus of section five, with respondents rating their level of perceived risk associated with HF, traditional vertical oil and gas wells, transporting petroleum products through inhabited areas by pipeline and by train, economic reliance on oil and gas exploration, and placing oil and gas wells near drinking water wells or surface water bodies (question one in Appendix A.5). We developed the items in this section in collaboration with industry and regulatory representatives to focus on a small set of realistic and pertinent risk topics.

The themes covered in section six of the survey include energy support, concerns, and stakeholder roles. Questions that address these themes include indicating a level of support for different energy sources (question one in Appendix A.6), a level of concern for a variety of items related to oil and gas exploration and HF operations (questions two and three in Appendix A.6), a level of trust for various stakeholder parties (question four in Appendix A.6), a level of expected responsibility for adverse effects of HF of those same stakeholder parties (question five in Appendix A.6), and a level of perceived transparency for those same stakeholder parties (question six in Appendix A.6). The range of energy sources included were chosen to address common existing or potential sources in western Canada (primarily Alberta, which is why hydro-electric power was not included). Some potential items of concern were adapted from a publication by the Academy of Medicine Engineering and Science of Texas (2017), while others were included after discussion with industry and regulatory experts. The adapted items of concern were picked after reading the publication and assessing which might be applicable and realistic in western Canadian operations. We anticipated this survey to have potential impacts on public image and social license of industry and regulators. To this end, we used the questions related to stakeholder parties to explore the current perceptions and expectations of them. The named stakeholder parties we included were chosen in collaboration with industry and regulatory representatives.

Section seven addressed the respondent's level of personal experience with earthquakes. These questions were inspired by and adapted from McComas et al. (2016). In that study, they asked how many earthquakes a respondent had felt in their lifetime, and how many they had felt at their current place of residence. We asked the same questions and used the same response categories but asked about more locations they may have felt earthquakes – Canada, Alberta, and British Columbia (see questions one and two in Appendix A.7).

The concluding demographics in section eight included gender, age, highest educational attainment, and place of residence given as the first three characters of the postal code for Canadians (see questions one, two, three, four, and five in Appendix A.8). This section also contained an open-ended final question asking respondents to share any other pertinent information with the researchers (question six in Appendix A.8). Although largely typical, the demographic items included in this section were chosen after reading studies by Whitmarsh et al. (2015) and Kahlor et al. (2019), which both included gender, age, and highest educational attainment. Both studies were targeted at specific geographic regions, giving the researchers information about the respondents' places of residence as well. Since our survey was intended to be available to any member of the public with access to the internet, we had to determine geographic locales by asking respondents to provide the first three characters of their postal code.

3.4 Factorial survey experiment within survey

Surveys contain a series of independent questions that assess a respondent's view or opinion on a specific topic. However, traditional surveys do not allow respondents to assess more complex, and therefore realistic, situations. FSE vignette scenarios can fill this gap and be used to build realistic scenarios for the purpose of assessing broader respondent feedback and preferences. We embedded within the survey an FSE that used vignette scenarios. Section two of the survey contained these FSE scenarios.

The basic premise of FSEs is that we show complex scenarios to respondents and ask them to rate their level of support for the whole scenario (Auspurg & Hinz, 2015). Within a single question we can vary multiple dimensions; by presenting respondents with complex scenarios, we force them to make trade-offs in their evaluations, which can lead to a truer representation of their opinions. When asked a direct question, most respondents are biased by things like social norms and expectations, but when we present them with a more complex scenario these biases can be mitigated. With a controversial topic like HF and IS, we wanted to see whether a respondent's professed opinion in a point-blank question (assessed through use of the majority of the questions in the survey) would match their underlying opinion as determined through the use of FSE scenarios.

Researchers have used FSE scenarios to investigate the public perception of energy topics before (Aklin & Urpelainen, 2013; Berk & Schulman, 1995; McComas et al., 2016; Sharp et al., 2009), although a focus on HF, IS, and western Canada appears to be lacking. As mentioned in Section 3.3, the study by McComas et al. (2016) uses a between-subjects factorial experiment to explore the perceptions of different causes of non-damaging earthquakes, which is essentially a one-attribute FSE scenario. Sharp et al. (2009) use a discrete choice method, where respondents are asked to indicate their preference between two side-by-side scenarios, whereas others present respondents with one scenario at a time and ask for a rating of each scenario. Auspurg and Hinz (2015) discuss response scales in detail, and also point out that discrete choice models can lead to problems if a respondent is given two scenarios that they feel the same about (i.e. they are forced to rank one over the other despite perceiving them as the same rank). Additionally, discrete choice methods may impose more restrictions on the data analysis, requiring a larger minimum number of observations to estimate the regressions (Auspurg & Hinz, 2015). We chose to present respondents with one scenario at a time and ask them to rate each one on an eleven-point response scale ranging from 0–10. We decided that this would give a fine enough scale for respondents to adequately express their opinion, and the values felt intuitively connected to the end-point evaluations of “do not support at all” and “fully support,” and would thus be easy for respondents to interpret and use. Using an eleven-point scale also gave us a logical centre point to represent neutral opinions (value of 5). To address the lack of Canadian HF- and IS-focused research, our scenarios were designed with a particular interest in IS due to HF and presented to Canadian respondents. We used a variety of attributes to create scenarios that reflected simplified versions of real-world operations.

The FSE contained in this survey had six attributes or dimensions, each of which had between two and four attribute levels. These are shown in Table 3.2 below. These attributes were chosen after much deliberation and consultation with knowledgeable industry, regulatory, and academic experts, and aimed at addressing what we believed to be some of the main factors influencing support for or opposition to HF scenarios. Auspurg and Hinz (2015) also indicate that a range of five to nine dimensions is appropriate, balancing the burden of reading very long scenarios (many dimensions) with the boredom of reading very similar scenarios (few dimensions). The attributes shown in Table 3.2 are combined into a single FSE scenario that is then shown to the respondent. Each respondent was presented with 6 randomly selected scenarios.

The structure of the scenario is shown below. The six attributes are shown in square brackets and individual levels for each attribute, shown in Table 3.2, would be inserted to create each unique scenario.

> A hydraulic fracturing operation is proposed to be located **[location]** from your home. The operation will involve **[trucks]** with associated noise and dust travelling in the area per day **[time]**, in addition to traffic already in the area. **[Consultation]** during the planning process of the operation. The company involved has a history of policies that involve **[benefits]** to local communities. Seismicity related to the operation is anticipated to be **[seismicity]**.

Do not support at all					Neutral					Fully support
0	1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○	○

Table 3.2: FSE attributes and attribute levels

Attribute	Attribute Level Number	Attribute Level
Location[1]	1	Less than 3 km from the home
	2	Between 3 and 15 km from the home
	3	Over 15 km from the home
Trucks[2]	1	Less than 10 heavy equipment trucks per day
	2	Between 10 and 50 heavy equipment trucks per day
	3	Over 50 heavy equipment trucks per day
Time[3]	1	At all hours of the day
	2	Between the hours of 8 am and 8 pm
Consultation[4]	1	Community not informed of plans for operation
	2	Community informed of plans for operation
	3	Directly affected landowners consulted about operation
	4	Full two-way consultation with community in every step of the planning process
Benefits[5]	1	No financial benefits for community
	2	Preferential hiring of local services and employers
	3	Annual cash grants between $10k and $25k donated to community
	4	Fully funded community project donated to community
Seismicity[6]	1	Nonexistent
	2	Too small to be felt
	3	Persistent and repeating, but too small to cause structural damage
	4	Infrequent, but large enough to potentially cause moderate structural damage

[1] Minimum setbacks in Alberta for wells with H_2S can be as low as 100 m from permanent dwellings depending on the type of development and level of H_2S involved (Alberta Energy Regulator, 2015). In BC, minimum distance within which there is a duty to consult is 200 m for pipelines and 1 km for a small wellsite, with distances depending on the type of development (BC Oil and Gas Commission, 2020, p. 277).

[2] Number of trucks required to move equipment and materials can easily be in the hundreds to thousands over the lifetime of one HF well (New York State Department of Environmental Conservation, 2011, p. 810). In areas with high levels of development, there may be dozens to hundreds of trucks per day.

[3] Hours during which work is actively being completed can vary over the lifetime of an HF well.

[4] In both Alberta and BC, notification and consultation includes landowners, relevant authorities, and may include residents within a range of distances (Alberta Energy Regulator, 2019, p. 29; BC Oil and Gas Commission, 2019a).

[5] Economic benefits to the local community are at the discretion of the company and are irrespective of HF well development. Hiring of local employers and services is common.

[6] In the Western Canadian Sedimentary Basin, ~0.3% of HF wells were associated with $M \geq 3.0$ seismic events (potentially able to be felt by humans) between 1985 and 2015 (Atkinson et al., 2016). All HF wells induce seismicity, although it is typically microseismicity that cannot be felt by humans (Rubinstein & Mahani, 2015).

An example scenario is shown below with attribute levels indicated by boldfaced, italicized text. The full list of scenarios used can be found in Appendix C. Respondents were asked to indicate to what extent they supported or opposed the given scenario.

> A hydraulic fracturing operation is proposed to be located ***less than 3 km*** from your home. The operation will involve ***over 50 heavy equipment trucks*** with associated noise and dust travelling in the area per day ***at all hours of the day***, in addition to traffic already in the area. ***Directly affected landowners in your community will be consulted*** during the planning process of the operation. The company involved has a history of policies that involve ***donating community grants ranging from $10,000 to $25,000 annually*** to local communities. Seismicity related to the operation is anticipated to be ***infrequent, but large enough to potentially cause moderate structural damage***.

Do not support at all					Neutral					Fully support
0	1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○	○

3.4.1 Experimental design and data analysis

If we were to use every possible combination of the attributes, known as a full factorial design, we would have 1,152 scenarios. This is the product of the number of options per attribute. For statistical rigour, each scenario should be evaluated multiple times, meaning we would easily need many thousands of respondents if we wish to present each person with only a small number of scenarios. If we want only a few hundred participants, each person would have to evaluate several dozen scenarios. The benefits of using a full factorial design lie in the orthogonality of the attribute variables. In the “full vignette universe,” none of the dimensions or interactions between dimensions are correlated with one another. Additionally, there is “level balance,” which means that all the levels of each dimension occur with equal frequency in the full vignette universe. However, in order to achieve the necessary statistical rigour, we would need to either drastically reduce the number of dimensions and levels of the design or find a way to reach a very large number of respondents.

Alternatively, a fractional design is used to maintain a high level of independence between attributes while lowering the needed number of respondents. The most basic fractional design uses a simple random sample of the full vignette universe. While easy to create, these random samples may introduce bias to the results and are less precise when estimating parameter coefficients, making them inefficient. Better designs intentionally select a specific subset of the full universe such that the dimensions remain nearly orthogonal, the levels remain nearly balanced, and a high level of precision in estimating parameter coefficients can still be achieved with fewer respondents.

An efficient fractional design maximizes the statistical information that can be obtained from reasonable numbers of respondents and vignette scenarios and optimizes orthogonality and level balance. Choosing an efficient design minimizes the variance and covariance of coefficients that are estimated in the analyses, which in this case consist of several types of regressions. Construction plans for efficient designs are found in design catalogs published in textbooks or on websites, or they can be determined using computer algorithms such as the one suggested by Auspurg and Hinz (2015).

We used an orthogonal fractional factorial design that considered two-way interactions via a "foldover design." Foldover designs improve the resolution (how well the design captures effects and possible interactions of variables (Auspurg & Hinz, 2015)) of a design by systematically switching the levels of the dimensions in the original design (Ankenman, 1999). In this way, we reduced the number of scenarios in our FSE from 1,152 to 144. To do this, we used Ngene software by Choicemetrics Pty Ltd., version 1.2, 2018. First, to minimize the number of scenarios we needed to test, we decided on a design that used only 1/16th of our original universe, or 72 scenarios. The combinations of dimension levels that made up these 72 scenarios were optimized by the computer algorithm to have the most efficient recovery of the full universe (Scenario IDs 1–72, Foldover block 1 in Table C.2 in Appendix C). Then, the foldover design converted any attributes that had more than two levels, such as location or seismicity, into a two-level equivalent variable (see Table 3.3 and Table 3.4) (Ankenman, 1999; NIST/SEMATECH, n.d.). The original 72 scenarios were then duplicated, and each two-level equivalent variable was given the opposite sign (see Table 3.5) to create a foldover design of 72 scenarios (Scenario IDs 73–144, Foldover block 2 in Table C.2 in Appendix C). These new, opposite, 72 scenarios were added to the original scenarios, giving us 144 total scenarios. The object of the foldover design is to ensure main effects remain unconfounded; that is, any main effects found by the regressions are real effects rather than a result of interaction effects that were unaccounted for.

Table 3.3: Decomposition of a three-level dimension into two two-level equivalent variables.

Three-Level Dimension	**Two-Level Equivalent Variables**	
Location	**A**	**B**
< 3 km	-1	-1
3–15 km	+1	-1
3–15 km	-1	+1
> 15 km	+1	+1

Table 3.4: Decomposition of a four-level dimension into two two-level equivalent variables.

Four-Level Dimension	**Two-Level Equivalent Variables**	
Seismicity	**A**	**B**
Nonexistent	-1	-1
Too small to be felt	+1	-1
Persistent and repeating, but small	-1	+1
Infrequent but large	+1	+1

Table 3.5: Example of how foldover design would affect a four-level dimension.

Two-Level Equivalent Variables with Opposite Signs		**Corresponding Four-Level Dimension**
A	**B**	**Seismicity**
+1	+1	Infrequent but large
-1	+1	Persistent and repeating, but small
+1	-1	Too small to be felt
-1	-1	Nonexistent

We presented six scenarios, selected at random, to each respondent for evaluation. In order to ensure accurate results, we wanted each scenario to be evaluated at least 20 times. Therefore, for minimum rigour, we needed at least 480 respondents to complete the survey, as shown in Equation 3.1.

$$(144\ scenarios) \times \left(\frac{20\ evaluations}{1\ scenario}\right) \times \left(\frac{1\ individual}{6\ evaluations}\right) = 480 \text{ individuals} \qquad \textit{Equation 3.1}$$

Analysis of FSE results involves converting recorded responses from wide format, where each respondent is contained in a single row with multiple columns for the different vignette evaluations, to long format, where all vignette evaluations are contained in a single column and each respondent is spread across multiple rows. This allows us to individually examine the ratings for each evaluated vignette scenario. Once this is accomplished, the data are examined first using mean, median, and mode, with histogram visualizations (also called 1D marginal probability distribution functions), and then using regression models. The mean, median, mode, and histograms can be created using any statistically capable software, such as MS Excel, R, or Stata. The regression models for this study were performed in Stata/IC 15 (StataCorp LLC, 2019), using Auspurg and Hinz (2015) as a guide.

The first regression model was a simple ordinary least squares (OLS) regression model (Auspurg & Hinz, 2015), where we used

$$\begin{gathered} \mathrm{Y}_{ij} = \beta_0 + \beta_1 X_{ij1} + \beta_2 X_{ij2} + \cdots + \beta_p X_{ijp} + \varepsilon_{ij} \\ \text{with } i = 1, \ldots, n_d;\, j = 1, \ldots, n_r \end{gathered} \qquad \textit{Equation 3.2}$$

to estimate the relationship between the independent variables (the attribute levels) and dependent variable (the respondent's rating of the scenario). Y_{ij} is the dependent variable, the respondent's rating of the scenario, for single vignettes *i* from respondents *j* on the *p* vignette attributes (such as location or trucks; denoted by X). β_0 is the intercept of the model, β_1 to β_p denote the regression coefficients for each vignette attribute. ε_{ij} denotes the random errors in judgement, n_d denotes the number of vignettes presented to single respondents, and n_r denotes the number of respondents.

In our case, we have six vignette attributes (p = 6, giving $\beta_1 X_{ij1}$ to $\beta_6 X_{ij6}$), six vignettes per respondent (n_d = 6), and 1,311 respondents (n_r = 1,311), which when we substitute into Equation 3.2 gives us, for a given vignette scenario *i* presented to a given respondent *j*,

$$Rating_{ij} = constant + \beta_1(location)_{ij} + \beta_2(trucks)_{ij} + \beta_3(time)_{ij} + \beta_4(consultation)_{ij} + \beta_5(benefits)_{ij} + \beta_6(seismicity)_{ij} + (error\ term)_{ij}$$
$$\text{with } i = 1, \dots, 6; j = 1, \dots, 1311.$$

Equation 3.3

Equation 3.3 incorporates the fact that In the OLS models, the dependent variable Y_{ij} is considered to be continuous. In the plain OLS model, the standard errors are calculated separately for each Y_{ij}, resulting in random standard errors. An OLS regression was then performed with cluster-robust standard errors to adjust for any unequal variances in the error terms of the independent variables (Auspurg & Hinz, 2015). Because responses may vary not only from scenario to scenario (within respondents) but also from person to person (between respondents), the error terms become multilevel. The cluster-robust approach is one of the simplest ways of dealing with this, by clustering the standard errors around individuals (the j index) to account for variation between respondents. Both the OLS and OLS cluster-robust models use Equation *3.3*.

Another approach to dealing with multilevel error terms is the random intercept equation, which is a special case of the OLS model that determines a specific error term, u_j, for each individual. The random intercept equation (Anders, 2020; Auspurg & Hinz, 2015),

$$Y_{ij} = \beta_0 + \beta_1 X_{ij1} + \beta_2 X_{ij2} + \cdots + \beta_p X_{ijp} + u_j + \varepsilon_{ij}$$
$$\text{with } i = 1, \dots, n_d; j = 1, \dots, n_r,$$

Equation 3.4

aims to directly estimate and account for the amount of variation in responses that can be attributed to differences between respondents (u_j in Equation 3.4), giving a result that is assumed to show only the difference in attribute levels (Auspurg & Hinz, 2015).

Traditional survey questions from sections one and three to eight of the survey were analyzed with a simple mean, median, mode approach, as well as 1D probability density function displays (histograms). Some of the questions were selected to explore their relationship with the outcomes of the FSE scenarios, in addition to this step. This additional analysis used an alternative approach, probit regression modelling (Liao, 1994), to estimate the likelihood of specific vignette outcomes. The probit modelling was also completed using Stata/IC 15 (StataCorp LLC, 2019). Probit models are based on generalized linear equations, as is the ordinary linear Equation 3.2, and are structured such that (Anders, 2020)

$$\text{Probability}(outcome) = f(characteristics) + error\ term.$$

Equation 3.5

The dependent variable in this probit model is the binary outcome of being a protester or not, or a keener or not, and this variable is not continuous, unlike the OLS-based models above. When we apply this to our data set, we see something like:

$$\text{Prob}(Protest = True) = f(knowledge, experience, age, etc.) + error\ term.$$

Equation 3.6

In general, a probit model with a binary outcome variable Y will look like

$$\text{Probability} = \Phi^{-1}(Y), \qquad \textit{Equation 3.7}$$

where Φ^{-1} is the inverse of the standard normal cumulative distribution function (Liao, 1994).

The probit models tell us what the probability is of obtaining a given outcome (such as the respondent being a protester) based on characteristics such as knowledge, energy industry experience, age, and so on. This allows us to investigate whether protesters and keeners have defining characteristics that set them apart from other respondents, or perhaps characteristics in common with one another.

Together, these models help explore answers to the research objectives of this thesis, and relate specifically to research questions one, three, four, and five from Section 1.2: analyzing survey data, influence of attributes on HF support, characteristics contributing to HF support, and respondent characteristics influencing the likelihood of being a protester or keener.

The results of the regression models will be discussed in Chapter 5, but first we look at the traditional survey questions in Chapter 4.

3.5 Survey implementation

We received ethics approval for the *Study of the Oil and Gas Industry in Western Canada* from the University of Alberta Research Ethics Board on February 12, 2019 (ID: Pro00088384). We then officially released the survey on March 11, 2019 and it remained open until June 24, 2019. The survey platform we used was Qualtrics (n.d.).

When the survey was released online, the University of Alberta Faculty of Science did a media release and shared the story on their website (Willis, 2019). This was followed by stories on Calgary 660 News (Craddock, 2019) and CTV Edmonton (Antoneshyn, 2019). I personally contacted 110 people and organizations to share the U of A news release, including personal contacts, churches, community council members, community organizations, and people who gave feedback on the survey design. Through this word of mouth manner, we collected 1,311 survey responses. A total of 305 additional surveys were begun but not completed beyond the first section, disqualifying them from the analysis which required at least partial completion of section two. As part of our ethics approval, we deleted all response sets that were disqualified for not completing any of section two, so we were unable to compare non-response and response bias (differences between respondents who did and did not complete the survey). Of the 1,311 valid surveys, 1,132 fully completed the survey (i.e. clicked "submit" on the final page after being presented with all questions). The remaining 179 respondents completed at least part of section two of the survey, meaning their responses were used in the analysis, but did not click the "submit" button on the final page and may not have seen all of the questions after section two. This gives us a full completion rate (clicked "submit") of 70% and a partial completion rate (completed at least part of section two but did not click "submit") of 81%. Due to the nature of distribution, it is impossible to know how many potential participants we reached and thus we cannot estimate the percentage of the population that our 1,311 responses represent, making a more traditional response rate unknown.

Chapter 4: Results and analysis of key survey questions

In this chapter, we show the majority of results from sections 1 and 3–8 of the survey. First, we discuss the demographics to set the context for the rest of the results. After that, we have five sections that cover energy experience and knowledge; support for energy sources and acceptability of hydraulic fracturing (HF), oil and gas, and induced seismicity (IS); risk perception; concerns; and trust and transparency. Each of these sections is relatively self-contained, ending with a discussion before moving on to the next section.

As mentioned in Section 3.4.1 these traditional-style survey questions, where we ask a single direct question and give respondents the opportunity to choose a response from a set of options, were analyzed using a mean, median, mode approach, as well as visualized using 1D probability density functions (histograms). From the histograms, we can see that many of the questions have bimodal response distributions, indicating a polarity of opinion. Questions with response options that are ordinal but still categorical (for example, strongly disagree to strongly agree) are discussed in terms of their median and mode responses, although the mean may also be discussed where it makes sense to do so. Questions with response options that can be interpreted numerically are discussed in terms of mean, median, and mode (for example, the levels of objective knowledge measured using (in)correct responses to true or false questions). Questions that are purely categorical, and not ordinal, are discussed purely in terms of their mode (for example, gender).

Any questions that were part of the survey as laid out in Appendix A but are not discussed in this chapter are shown as histograms in Appendix B. This includes several of the other demographic questions as well as the expected responsibility levels of various stakeholder parties. The Factorial Survey Experiment (FSE) vignette scenarios are covered separately in Chapter 5.

4.1 Demographics of survey respondents

We collected 1,311 valid survey responses between March 11 and June 24, 2019. In the survey, we asked respondents to provide the first three characters of their postal code, known as a Forward Sortation Area (FSA). Although we received responses from across Canada, the majority were from western Canada, and primarily Alberta. Figure 4.1 shows the distribution of respondents across Canada, mapped using the provided FSAs. Figure 4.2 shows the same distribution, zoomed in to show western Canada, and Figure 4.3 zooms in further to show the Edmonton–Calgary corridor in greater detail.

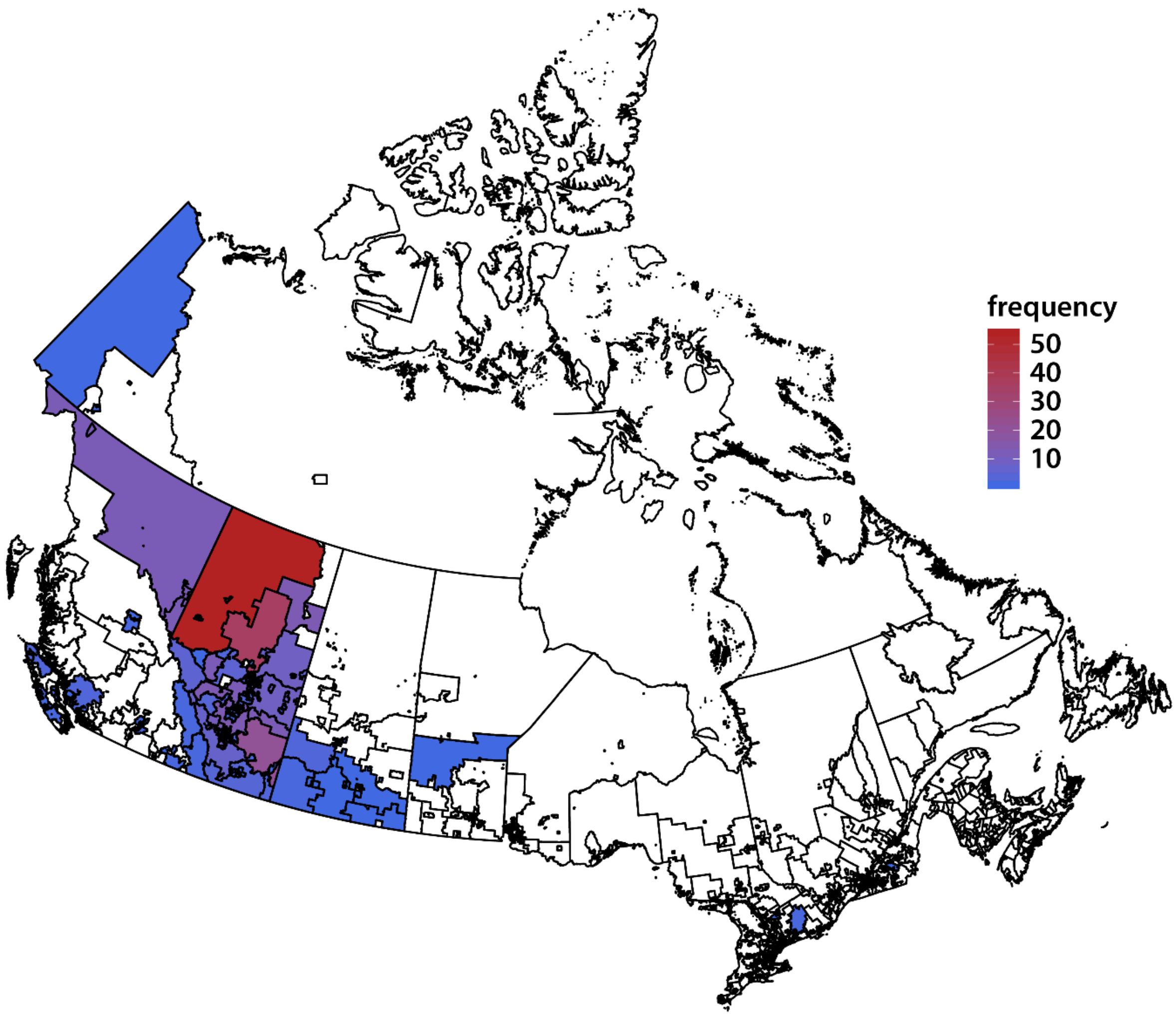


Figure 4.1: Map of all respondents who participated in the survey and provided their FSAs. The colour bar shows the frequency of responses from each FSA, and ranges from 1 in blue to over 50 in red.

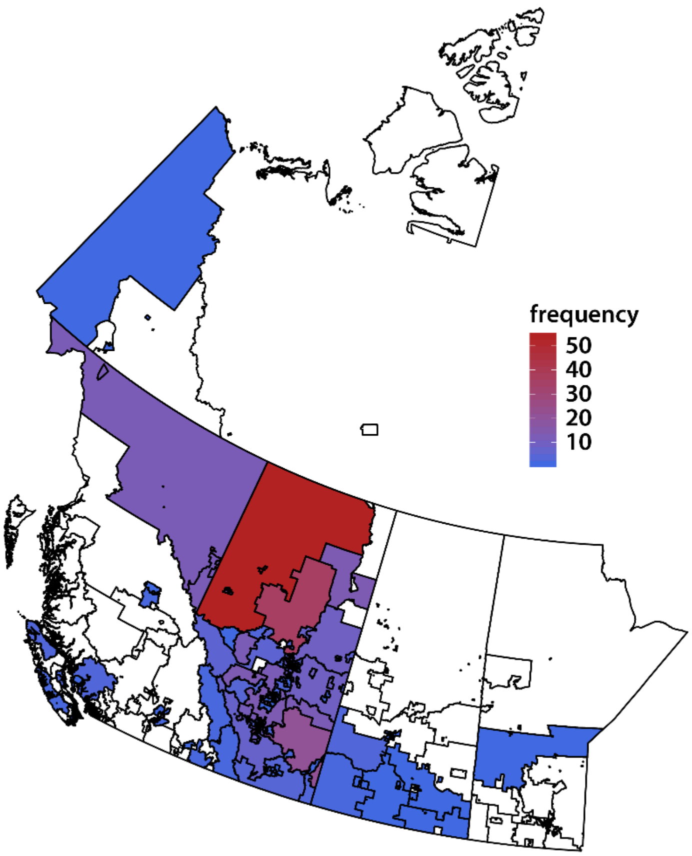


Figure 4.2: Map of respondents, zoomed in to show western Canada.

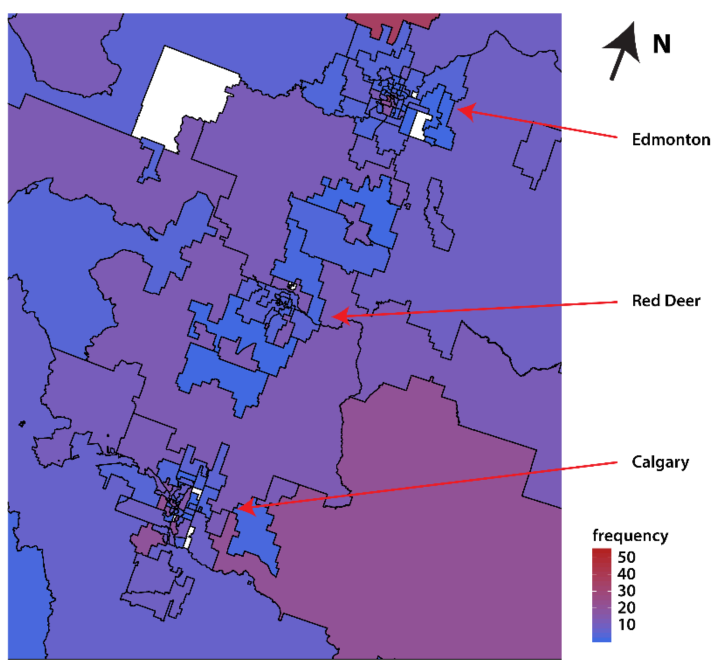


Figure 4.3: Map of respondents, zoomed in to show the Edmonton-Calgary corridor in greater detail.

Figure 4.4 below shows the age distribution of respondents (green). There is a broad range of ages in the respondents, and approximately 69% of respondents are in their prime working years of 25–64. While our data does not perfectly match the values for Canadian residents as reported by Statistics Canada (2019b) (blue), the values for age categories below an estimated retirement age of 65 are similar.

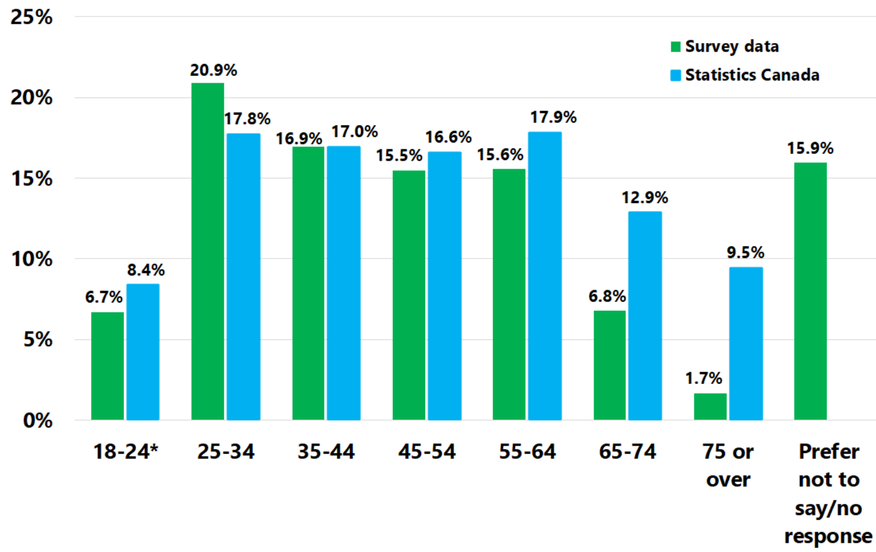


Figure 4.4: Age distribution of respondents (green) and of Canadians (blue). Respondent data given as percent of total respondents, n = 1,311. Data for Canadians obtained from Statistics Canada values for 2019 (Statistics Canada, 2019b) *and given as percent of total population over the age of 20. The category of 18-24 did not exist for the Statistics Canada data, so it is approximated using the 20–24 age range.*

Figure 4.5 illustrates that approximately 74% of respondents have some form of post-secondary education. This is slightly above the typical value for Canada, where roughly 65% of the working-age population has some post-secondary education (Statistics Canada, 2019a). The Statistics Canada data is not shown in Figure 4.5 due to the fact that the categories they use are organized differently than the ones in our figure.

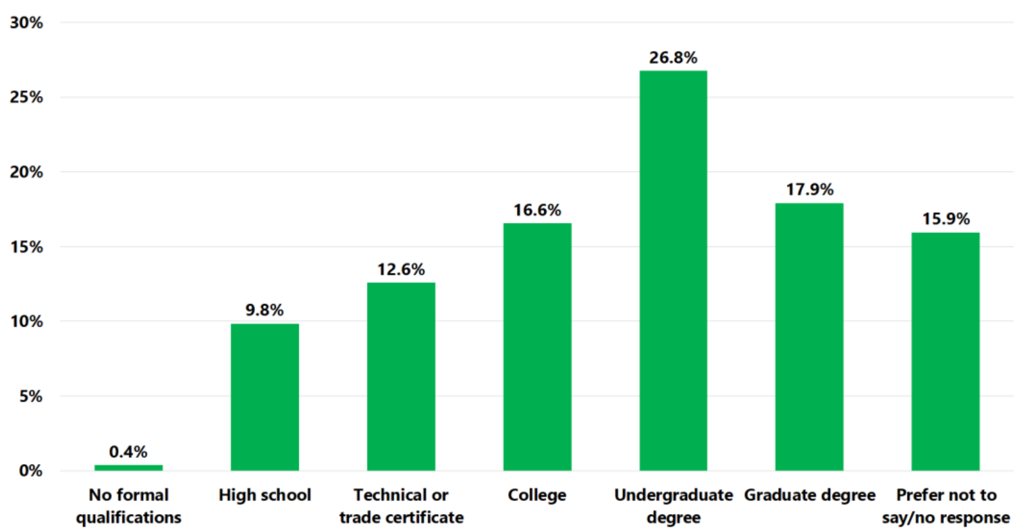


Figure 4.5: Highest educational attainment of respondents. Given as percent of total respondents, n = 1,311.

Figure 4.6 shows the gender distribution of the respondents who chose to share that information. While Statistics Canada reports a population of 50.7% females over the age of 20 (2019b), we see that 36.3% of our respondents are female. Although a lower value, having over a third of our respondents be women is encouraging, since energy is a topic that is often assumed to interest primarily men. The mode response for gender was “male.”

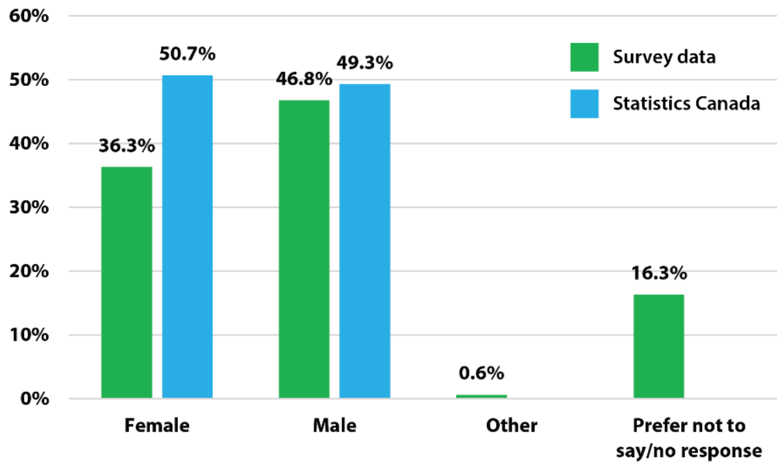


Figure 4.6: Gender distribution of respondents (green) and Canadians over the age of 20, as of 2020 (blue). Survey data given as percent of total respondents, n = 1,311, Statistics Canada data given as percent of Canadians over the age of 20, as of 2020, n = 29,865,726.

The comparison of age, education, and gender with the Statistics Canada data shows that the distribution of respondents is fairly representative of Canadian averages. This level of representativeness is particularly good given the word–of–mouth distribution method and voluntary nature of the survey.

4.2 Energy experience and knowledge

One aim of the survey was to explore the background knowledge and experience of our respondents, and whether this would influence their responses and perceptions. To this end, we collected information about respondents’ personal experience with the energy industry, as well as their families’, their level of knowledge from both subjective and objective points of view, and the sources of their information regarding oil and gas and environmental topics.

Figure 4.7 displays the level of work experience of the respondents and their families in various positions and organizations that may be related in some way to the energy industry. The top three categories were the energy industry itself (primary mode), a consulting organization (secondary mode for family experience), and none of the above (secondary mode for personal experience). This means we have a range of opinions from people with and without inside knowledge of how the industry operates.

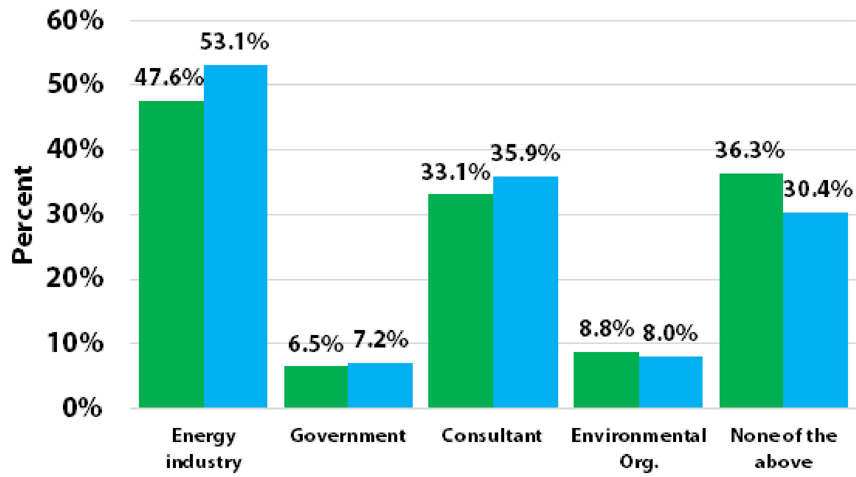


Figure 4.7: Work experience of respondents (green) in various positions, and of the respondents' families (blue). Given as percent of total respondents, n = 1,311. These questions were a "check all that apply" question. The "Government" and "Consultant" categories were clarified to be energy-related positions when presented to respondents.

Figure 4.8 shows the respondents' self-assessed subjective knowledge of the energy industry in western Canada. The vast majority of respondents claimed to have at least some knowledge of the industry, with the primary mode response of "somewhat knowledgeable" and the median response of "knowledgeable."

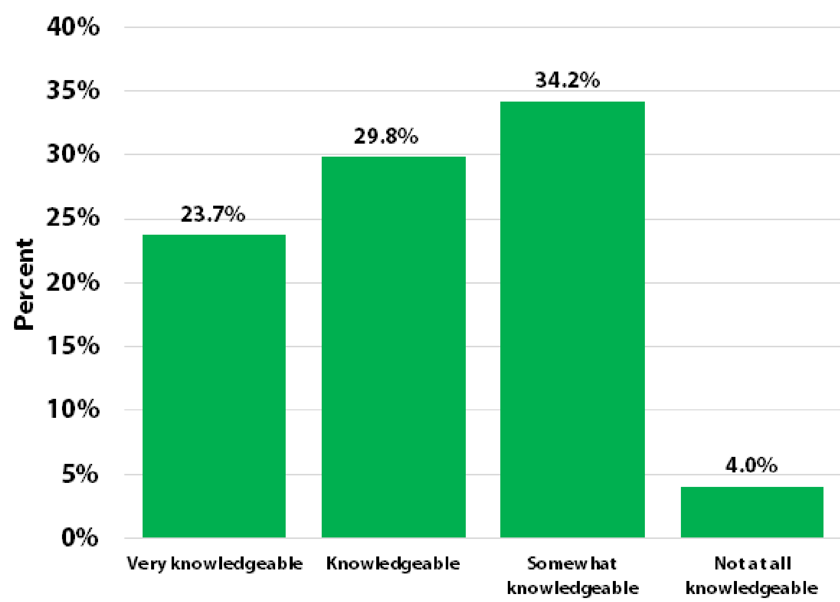
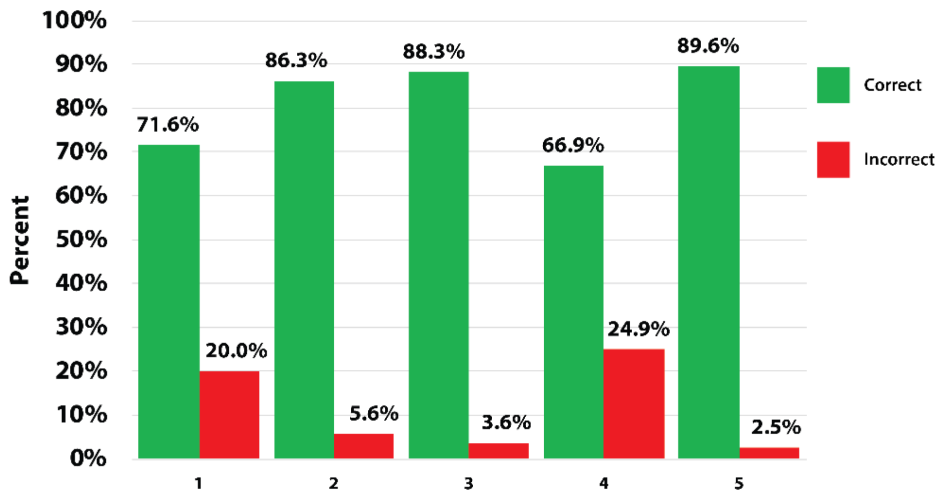


Figure 4.8: Self-assessed subjective knowledge level. Given as percent of total respondents, n = 1,311.

Figure 4.9 shows the frequency of (in)correct responses to the true or false questions regarding HF operations. The mode level of objective knowledge was five out of five questions correct, indicating that respondents are reasonably accurate in their self-assessment of their knowledge levels. The median level of objective knowledge was four out of five questions correct, and the mean of 4.02 rounded to four out of five questions correct as well.



1. The process of hydraulic fracturing has been in use in Alberta since the 1950s. (T)
2. Fluids used for hydraulic fracturing operations are composed primarily of water, with sand and chemicals being other common components. (T)
3. Hydraulic fracturing will always cause earthquakes, which can always be felt by humans at the surface. (F)
4. Hydraulic fracturing operations occur deep under the surface, well below groundwater aquifers. (T)
5. Hydraulic fracturing is the pumping of fluids at high pressures into the ground to break the rock and remove oil or gas. (T)

Figure 4.9: Results of the true or false questions in section three of the survey. Green indicates a correct answer; red indicates an incorrect answer. Given as percent of total respondents, n = 1,311. The T and F indicated in parentheses after each question is the correct response for that question. A small percentage of respondents abstained from answering these questions, meaning that the total percentages shown will sum to less than 100%.

Figure 4.10 shows the sources of information that respondents use when exploring oil and gas or environmental topics. News coverage is by far the most popular source (primary mode for both topics), indicating that news media coverage is highly important in shaping the public's understanding of these topics.

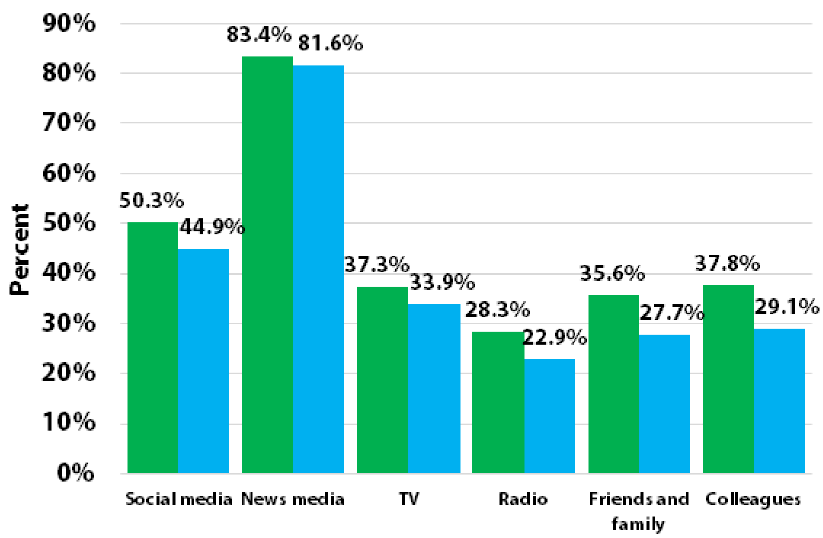


Figure 4.10: Sources from which respondents access information about the oil and gas industry (green) and about the environment (blue). Given as percent of total respondents, n = 1,311.

4.2.1 Discussion

Experience and knowledge are believed to play a role in the public's perception of the oil and gas industry, and HF in particular. Thomas et al. (2017) describe how past experiences with energy extraction in a community may influence perceptions of proposed operations in the US and Canada, suggesting that areas with more development experience may hold more polarized and nuanced views. In our survey, we chose to explore experience from a work experience stance — respondents who have personally or by proxy (their family) experienced energy operations may perceive those operations differently than people who have no experience. Jacquet (2012) also explored employment experience in relation to perceptions of natural gas drilling in Pennsylvania and found strong correlations between employment and positive perceptions. They also found that employment of friends and family had comparatively weaker correlations with this positive attitude towards gas development. It must also be considered that prior experience with the energy industry and associated organizations may contribute to the results of the knowledge assessments, both subjective and objective.

Thomas et al. (2017) discuss the precedence of measuring respondent knowledge through both subjective and objective means, and call for greater usage of objective assessments to reduce bias. While other surveys tend to use one method or the other, we opted for both, and were therefore able to also evaluate whether people were accurately assessing their own knowledge levels.

Subjective knowledge was assessed via self-reporting, as seen in Figure 4.8, and objective knowledge was assessed via a true or false section, as seen in Figure 4.9. A majority of respondents rated themselves as somewhat knowledgeable about the energy industry in western Canada, which seems to hold true when we compare with the results of the true or false section, where we found a mean of four correct responses out of five. In Figure 4.9, the two questions with the fewest correct responses were questions one and four, which relate to how long HF has been in use in Alberta and the depth at which HF operations occur in the subsurface, respectively. Approximately one in five respondents was incorrect in their belief about how long HF has been in use in Alberta, with the correct answer being since the 1950s (Energy BC, n.d.; Government of Alberta, 2016b; Wood, 2014). I believe this is due to HF often being conflated with horizontal drilling operations, which are a much more recent development in Canada. The first Canadian operations that produced natural gas using horizontal drilling and HF together were located in northeast British Columbia in 2005 and 2006 (Natural Resources Canada, 2016).

Approximately one in four respondents were incorrect in their belief about the depth at which HF operations occur in the subsurface. While most drinking water aquifers are found within 0–150 m of the surface (BC Oil and Gas Commission, n.d.-a), HF is usually comparatively deep. There was a median depth for these operations of 2490 m in the United States between 2008 and 2013, although some wells were as shallow as 30 m (Jackson et al., 2015). In Canada, however, the formations that are hydraulically fractured are typically found at depths of 600–2900 m (National Energy Board, 2011).

Respondents seemed reasonably well-informed about the remaining three questions related to the fluids used, the ability to feel IS at the surface, and what HF is.

Thomas et al. (2017) identified mass media, newspapers, industry groups, environmental groups, landowner coalitions, and peers as key information sources for HF topics in the US. According to Theodori et al. (2014), newspapers and the natural gas industry are the top sources of information about HF development in Pennsylvania. In Figure 4.10 we saw that news media was the primary mode response of information sources for both oil and gas and environmental topics, which matches the findings in Pennsylvania. With news media so influential in shaping public perceptions, it is crucial that there be balanced, well-informed coverage of topics that may significantly impact communities, like HF. This will help increase the public's understanding and knowledge of both the positive and negative impacts of HF operations. Knowledge and its interaction with HF opinions will be discussed again in Chapter 5, where its interaction with the FSE vignette scenarios will be covered.

4.3 Support for energy sources and acceptability of hydraulic fracturing, oil and gas, and induced seismicity

Among the research aims for this thesis was exploring the public perception of the oil and gas industry, including acceptability of HF and things that might influence support, like compensation. Here, we want to know what the level of support is for a variety of different energy sources, and how acceptable people find HF to be. This acceptability will be compared to the FSE vignette scenario results in Chapter 5. We also want to know how acceptable respondents find oil and gas operations to be when accounting for potential compensation to the community, and the acceptability of IS under a variety of circumstances.

Figure 4.11 shows the level of support or opposition for seven different energy sources: oil, natural gas, coal, nuclear, solar, wind, and geothermal. The four most strongly supported energy sources are oil, natural gas, solar, and geothermal, each with a primary mode of "strongly support." Natural gas and oil have secondary modes, which are much smaller than the primary modes. For oil, the secondary mode is "strongly oppose", and for natural gas the secondary mode is "somewhat oppose." The source facing the most opposition is coal, with a primary mode of "strongly oppose." Oil, natural gas, solar, and geothermal sources have a median response of "strongly support," wind has a median of "somewhat support," nuclear has a median of "neither support nor oppose," and coal has a median response of "somewhat oppose."

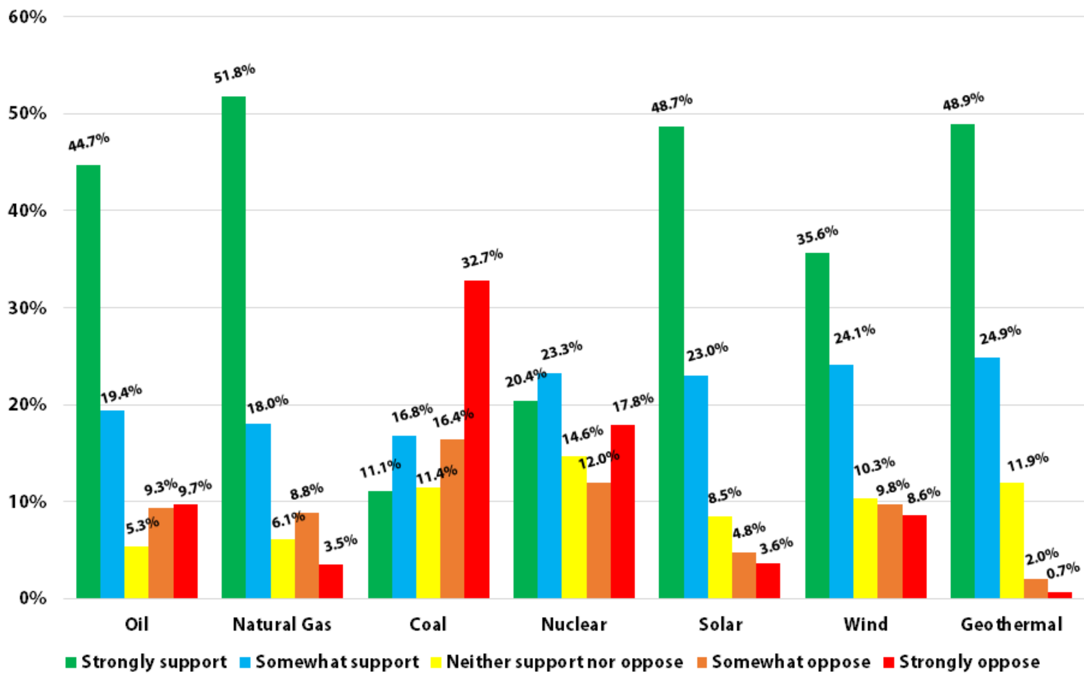


Figure 4.11: Support for energy sources. Given as percent of total respondents, n = 1,311.

Figure 4.12 shows the distribution of responses to the statement "Hydraulic fracturing is an acceptable way of extracting hydrocarbon resources." There is a bimodal distribution, with the primary mode of "strongly agree" and the secondary mode of "strongly disagree," indicating how polarizing this topic can be, with a low number of respondents feeling neutral towards HF operations. The median response is "somewhat agree," indicating that the distribution is skewed towards agreement with the statement.

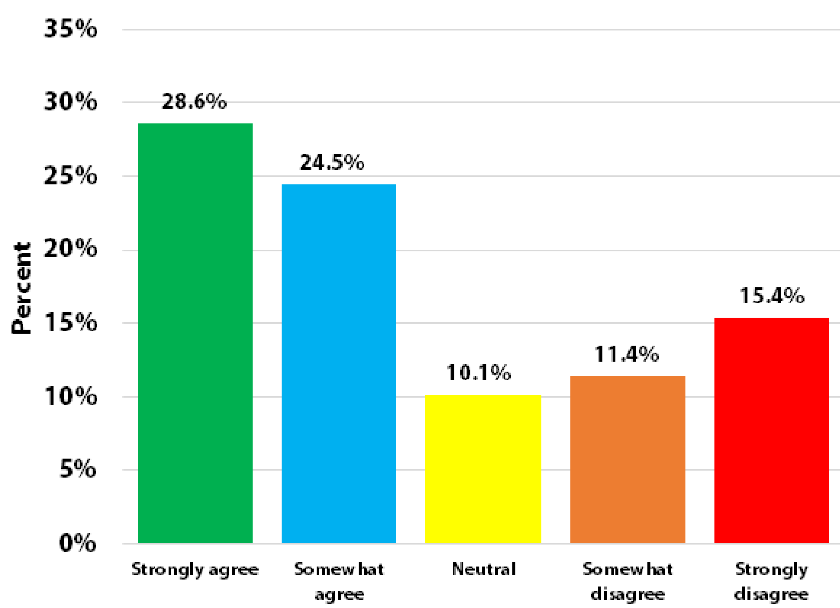


Figure 4.12: Response to the statement "Hydraulic fracturing is an acceptable way of extracting hydrocarbon resources." Given as percent of total respondents, n = 1,311.

Figure 4.13 shows the distribution of agreement with statements about community compensation and the economy in the context of oil and gas activities. What we see is general agreement with the five statements presented, meaning compensation and economic impacts of oil and gas activities are considered important to respondents. All four compensation statements have a primary mode of “strongly agree.” The first statement, which claims that compensation is a factor in the respondent’s opinion, has a smaller secondary mode of “strongly disagree.” The median response for the first statement is “somewhat agree,” while the median response for the remaining three statements is “strongly agree.”

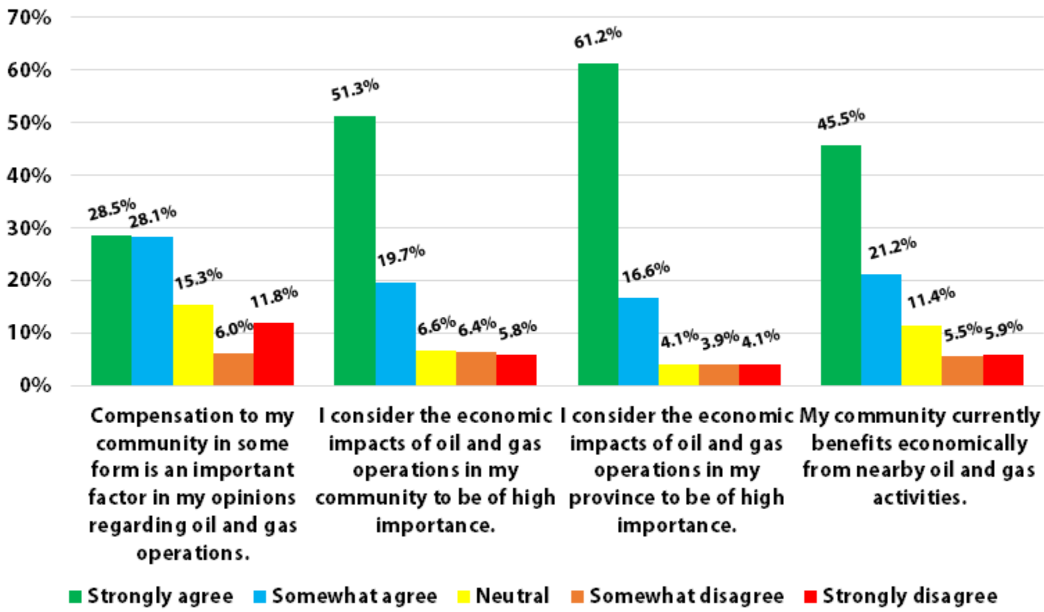


Figure 4.13: Response to statements about community compensation and the economy. Given as percent of total respondents, n = 1,311.

Figure 4.14 shows responses to a variety of statements that relate to the acceptability of experiencing non-damaging IS under different circumstances. The most acceptable scenario is the one where research data related to the decision-making are made freely available to the public (scenario four, mode of “strongly agree,” median of “somewhat agree”), but in general any scenario that gives some power over the decision back to the community was met with higher acceptability ratings. The least acceptable was the scenario where locals were not consulted in the planning and the decision was made by outside parties (scientists). This scenario (three) had a mode response of “strongly disagree,” and a median response of “somewhat disagree.”

The first two scenarios shown in Figure 4.14 have a primary mode of “somewhat agree,” a secondary mode of “strongly disagree,” and a median response of “somewhat agree.” The last scenario has a primary mode of “neutral,” a secondary mode of “strongly disagree,” and a median response of “neutral.”

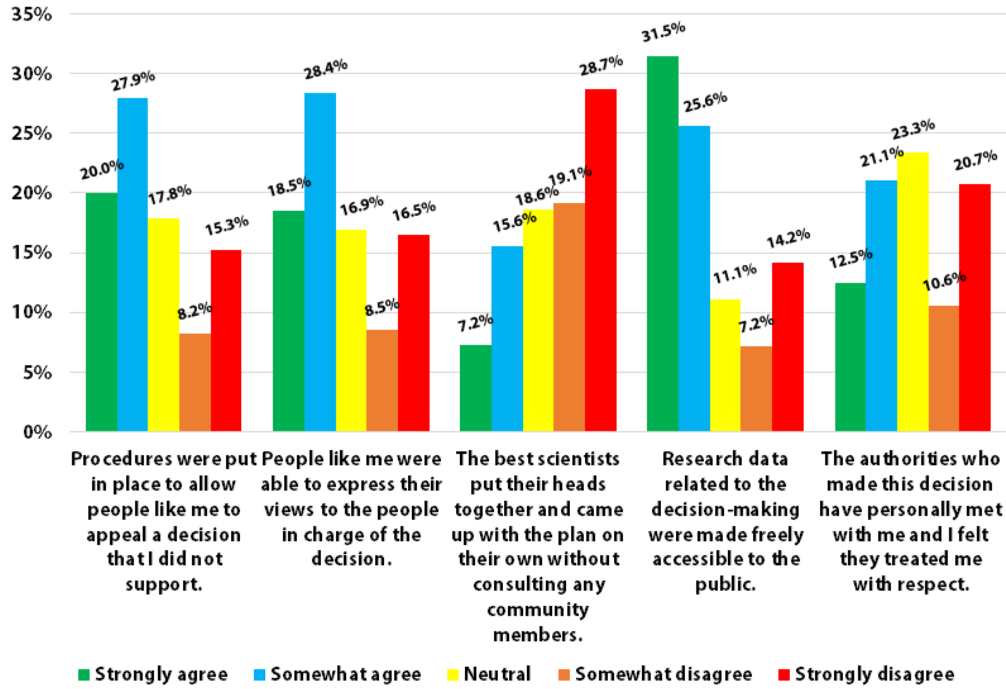


Figure 4.14: Response to statements that conclude the sentence "I would find it acceptable to experience a human-induced earthquake, which could be felt but caused no damage in my local area and resulted from a technology that was only implemented after..." Given as percent of total respondents, n = 1,311. This question was adapted from McComas et al. (2016).

4.3.1 Discussion

Figure 4.11 shows the level of support for seven different energy sources: oil, natural gas, coal, nuclear, solar, wind, and geothermal. Coal was strongly opposed, and support for nuclear energy was low. Oil, natural gas, solar, wind, and geothermal energy sources were all relatively well supported. These findings suggest that while there is significant support for oil and natural gas, there may also be public support for investments into renewable energy in western Canada. Previous studies in the US have found support for natural gas developments to be highly polarized, while support for wind developments are less so (Jacquet, 2012; Thomas et al., 2017). Thomas et al. (2017) also discuss that support for or opposition to HF appears to be tied to beliefs about potential impacts, with supporters tending to consider the positive economic impacts and those who oppose HF tending to consider the environmental impacts. Often, renewable energy sources are seen as preferable to fossil fuels (Comeau et al., 2015; Pew Research Center, 2013; Thomas et al., 2017).

With all the potential risks, benefits, and concerns, it comes as no surprise that the acceptability of HF has a bimodal distribution as seen in Figure 4.12. These opinions of HF are likely also influenced by potential compensation and the economic impacts of oil and gas operations, as shown in Figure 4.13. The idea that compensation would improve acceptability is supported by McComas et al. (2016). It also appears that the acceptability of potential IS from HF operations could be increased if certain measures are taken, like sharing research data related to the decision-making with the public, as described in Figure 4.14. This would be an action of transparency, which may improve trust in parties active in the oil and gas industry (Thomas et al., 2017). Trust and transparency will be discussed more directly in Section 4.6.

We also see from Figure 4.14 that respondents want to be informed of operations in their community. Generally speaking, unilateral decisions are not welcome, particularly if they appear to lack consultation. Respondents also want to have options to appeal if adverse effects occur during the operation. Personal and respectful contact with decision-making authorities seems appreciated but is likely insufficient, indicated by the bipolar distribution for this scenario.

The bimodality of support for HF in Figure 4.12 may have many contributing factors, some of which will be discussed in the FSE vignette scenario analyses in Chapter 5. Jacquet (2012) shows that perceptions and acceptance of natural gas drilling in Pennsylvania is noticeably polarized, similar to our bimodal support for HF. The bimodality of HF support is also corroborated by research conducted in the US by the Pew Research Center (2013).

Often, HF is a highly contentious topic, and it is not unusual for it to be presented in a biased manner. The Council of Canadians (2014), a non-profit organization, reported the results of an EKOS survey that investigated support for a national moratorium on HF. The survey consisted of two main questions — awareness of HF and support for the moratorium — as well as a selection of demographics. The wording of the questions included the use of “fracking” rather than HF; usage of the word fracking typically has higher incidence of negative connotations (Evensen et al., 2014) and is something that was specifically avoided in our survey. The Council of Canadians (2014) found that there was significant support for a moratorium, even across regional, political, gender, age, income, and education differences. However, the question that asks the level of support leads the respondent by stating that there is a lack of scientific research on topics related to “fracking,” and then asking whether they support or oppose a moratorium until “fracking” is scientifically proven to be safe. This kind of biased question and information presentation can strongly influence public perceptions and acceptance of HF.

Another influence on acceptability may be the provision of compensation for consequences of HF operations (Israel et al., 2015; Jacquet, 2012). The study by Jacquet (2012) found that in Pennsylvania, respondents who received compensation from the lease or development of their land were more likely to view natural gas drilling in a positive light. Willow (2014) also discusses the issue of environmental degradation due to HF activity in the US in areas where there has been little or no consultation, minimal transparency, and few benefits to those impacted, aspects which contribute to low support for HF operations. Lachapelle and Montpetit (2014) found that Quebec residents were opposed to HF, perhaps due to pervasive egalitarianism — the act of HF may produce benefits for a larger community, but the related risks are borne unequally by smaller groups of people.

4.4 Risk perception

The public perception of the oil and gas industry includes the public’s perceptions of risk for activities related to oil and gas operations, so we aimed to investigate how risky respondents feel a variety of activities to be. Figure 4.15 describes risk levels for each activity. All response category distributions are bimodal for this question, making risk a rather polarized topic. In order to compare the riskiness of the different items to one another, it is necessary to discuss the mean for each category, despite responses being given on an ordinal scale. For this purpose, we assume the ordinal scale to be a discrete representation of a continuous scale. HF has a primary mode of “somewhat risky” and a mean and median response of “uncertain.” The secondary mode for HF of “very safe” is only slightly lower than the primary mode, displaying significant polarization of risk perceptions. Traditional vertical oil and gas wells have a primary mode of “very safe,” a median response of “somewhat safe,” and a mean response between “somewhat safe” and “uncertain.” Transportation of petroleum products via pipeline has a primary mode and median response of “very safe,” and a mean response of “somewhat safe,” making it the safest item evaluated. Transportation of petroleum products via rail has a primary mode and median response of “somewhat risky,” and a mean response between “uncertain” and “somewhat risky” (rounding closer to “somewhat risky”). This makes rail transport the riskiest item, a noticeable difference from transportation via pipeline. Economic reliance on oil and gas exploration has a primary mode of “very risky” and a median response of “somewhat risky,” with a mean response between “uncertain” and “somewhat risky.” Placing oil and gas wells near drinking water wells or surface water bodies has a primary mode of “very risky,” a median response of “somewhat risky,” and a mean response between “uncertain” and “somewhat risky.”

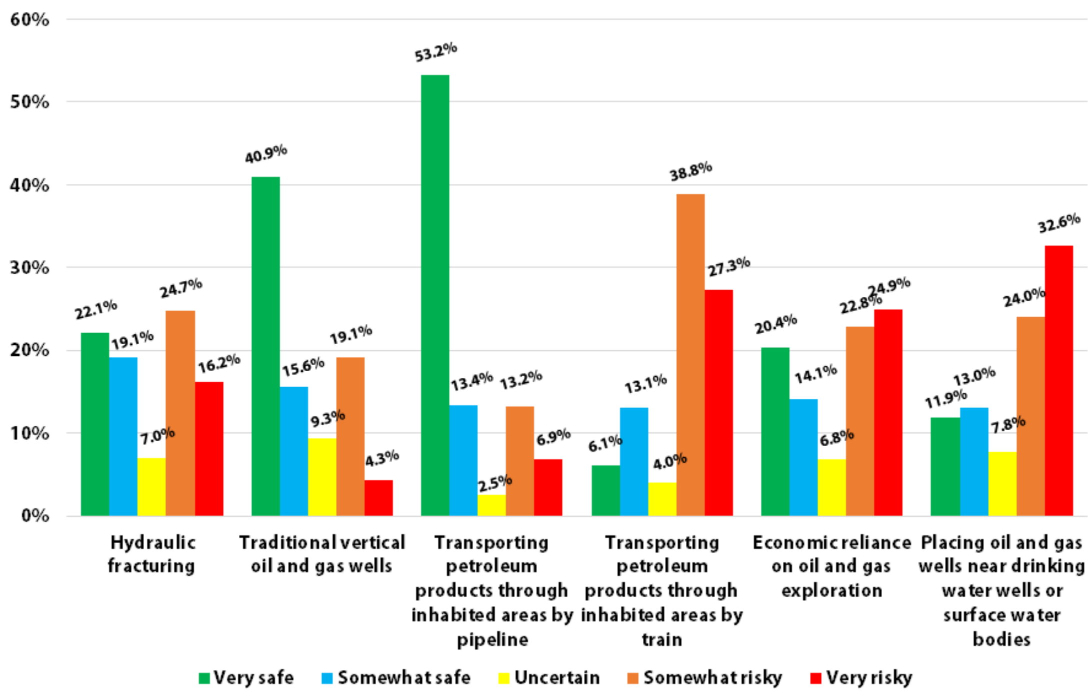


Figure 4.15: Perceived risk of various items related to the oil and gas industry. Given as percent of total respondents, n = 1,311.

4.4.1 Discussion

Respondents were asked to rate their level of perceived risk for various activities related to the oil and gas industry. As we saw in Figure 4.15, transporting petroleum products via pipeline was rated to be the safest of the given items, while transporting these products by train was considered to be quite risky.

Traditional vertical oil and gas wells were considered relatively safe, except when placed near drinking water wells or surface water bodies. The distributions for economic reliance on oil and gas exploration and for HF were bimodal, indicating polarization on the perceived riskiness of these topics.

Well locations and transportation of oil and gas products can be considered as risk amplifiers, meaning that these items have the potential to increase the likelihood or severity of hazards and their consequences. In the US, locating wells near drinking water wells or surface water bodies and transporting petroleum products were listed as risk amplifying concerns by Israel et al. (2015), with location of wells being the more common concern. These risk amplifiers could be mitigated by implementing or improving monitoring systems and information sharing practices (Israel et al., 2015). The sharing of information would contribute to transparency, which will be discussed more directly in Section 4.6.

There is also a contrast between the support for oil and natural gas seen in Figure 4.11 with the perception that economic reliance on oil and gas exploration is relatively risky as seen in Figure 4.15. This seems to suggest that while there is support for the oil and gas industry, there is a desire to diversify the economic interests from their reliance on hydrocarbon exploration. This is touched on briefly by Thomas et al. (2017) as they discuss the possibility of negative and limited economic impacts due to HF. Jacquet (2014) discusses risks to communities in Pennsylvania that include categories of rapid industrialization and uneven distribution of costs and benefits, which would certainly validate trepidation around economic reliance on oil and gas exploration. Whitmarsh et al. (2015) indicate that the public perceives more risks than benefits in the UK when it comes to shale gas developments.

4.5 Concerns

Many perceptions of the oil and gas industry are influenced by concerns over various aspects of oil and gas activity. Thus, to expand our understanding of the public perception of industry, we explored the level of concern for a variety of items related to the oil and gas industry, and specifically investigated whether respondents were highly concerned about items related to HF and IS. Figure 4.16 shows the distribution of levels of concern over items related to oil and gas activities. Nearly all the category distributions appear to be bimodal. If we assume responses to be discrete choices along a continuous spectrum between "very concerned" and "very unconcerned," we can take the mean of these responses in addition to the median and mode. The three items that are deemed most concerning by their mean value are underground contamination of freshwater aquifers, overuse of local fresh water supplies, and surface spills, with mean responses between "somewhat concerned" and "uncertain." Underground contamination of freshwater aquifers and overuse of local fresh water supplies have a primary mode of "very concerned" and median of "somewhat concerned." Surface spills have a primary mode and median of "somewhat concerned." The least concerning item is light pollution at night, with a mean response between "uncertain" and "somewhat concerned." This item has a primary mode and median of "somewhat concerned."

IS and disposal of produced salt water are ranked similarly to odours and dust/air pollution in Figure 4.16, with means between "somewhat concerned" and "neutral," and primary modes and medians of "somewhat concerned." Noise levels and traffic concerns also have mean responses between "somewhat concerned" and "neutral," primary modes of "somewhat concerned," and medians of "neutral."

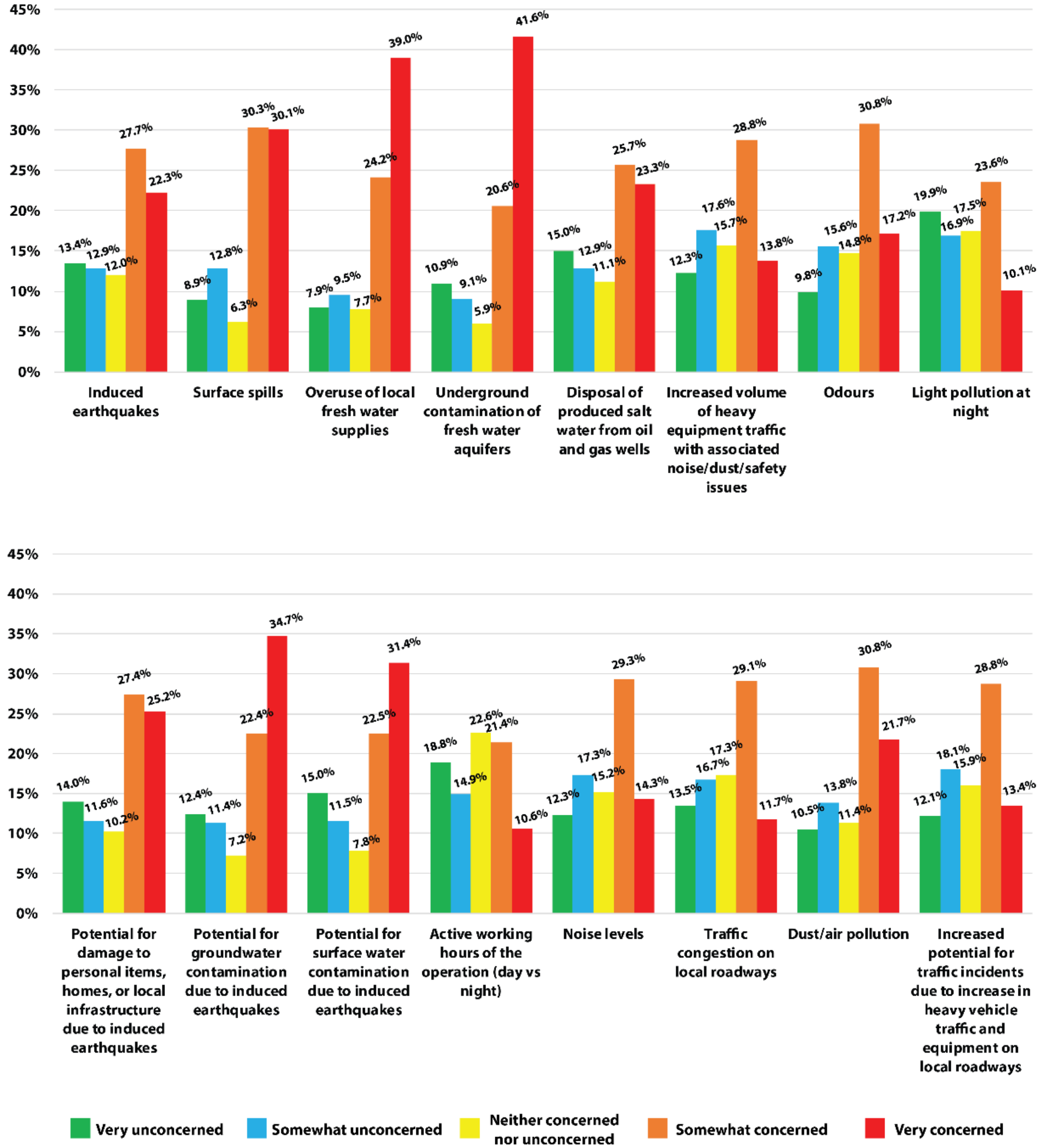


Figure 4.16: Concern about items related to the oil and gas industry. Given as percent of total respondents, n = 1,311.

4.5.1 Discussion

Respondents were asked to rate their level of concern for various items related to oil and gas activities. Figure 4.16 describes levels of concern for each item. The top three concerns were found to be surface spills, overuse of local fresh water, and underground contamination of freshwater aquifers, making water-related items the category of highest concern. The least concerning item was light pollution at night. IS had a similar concern distribution to odours and dust/air pollution. Respondents of this survey were also comparatively less concerned with traffic issues or noise levels. This is different than what has been demonstrated in the United States, where traffic issues and the potential for traffic incidents are at higher levels of concern (Hess et al., 2019; Perry, 2012; The Academy of Medicine Engineering and Science of Texas, 2017; Thomas et al., 2017; Willow & Wylie, 2014).

This question highlights water-related items as the largest category of concern for the public. Traditional vertical oil and gas wells are perceived to be relatively safe as seen in Figure 4.15, except when placed near drinking water wells or surface water bodies — again highlighting risks to water as concerning.

These top concerns are by no means unexpected or irrational — in fact, water concerns are well-founded. Vengosh et al. (2014) discuss these specific concerns as well as several others from a technical perspective in a US context. Fresh water aquifers may become contaminated through leaky or damaged well casings and annuli, or through migration via faults and fractures that may be either natural or a result of HF activity. Surface water and soils can be impacted by leaks and spills of flowback and produced water, discharge of insufficiently treated wastewater, and direct disposal of wastewater without treatment. Usage of fresh water varies drastically by location, formation, and operator, but overuse can lead to local water shortages and degradation of quality. Improvements of policy and best practices can mitigate these concerns, leading to a more environmentally conscious industry as well as higher public support.

4.6 Trust and transparency

There are several questions we wanted to investigate which I will discuss in this section. How trusted are the main stakeholders in the oil and gas industry? How transparent are these stakeholders perceived to be? Are trust and transparency related?

Figure 4.17 shows the distribution of trust levels for seven different stakeholder parties in oil and gas activities: local oil and gas companies, multinational oil and gas companies, government regulators, local politicians, environmental organizations, local municipalities, and the provincial government. The top three most trustworthy parties were felt to be local oil and gas companies, government regulators, and local municipalities, although local oil and gas companies show bimodal distribution along with multinational oil and gas companies, environmental organizations, and the provincial government. If we again take the responses to be discrete choices along a continuous scale, we can calculate the means in addition to the medians and modes. All three of the top parties had a mean response between “uncertain” and “somewhat trustworthy” and a primary mode response of “somewhat trustworthy.” The least trusted party is indicated to be local politicians, with a mean response between "somewhat untrustworthy" and "uncertain" and primary mode response of "somewhat untrustworthy."

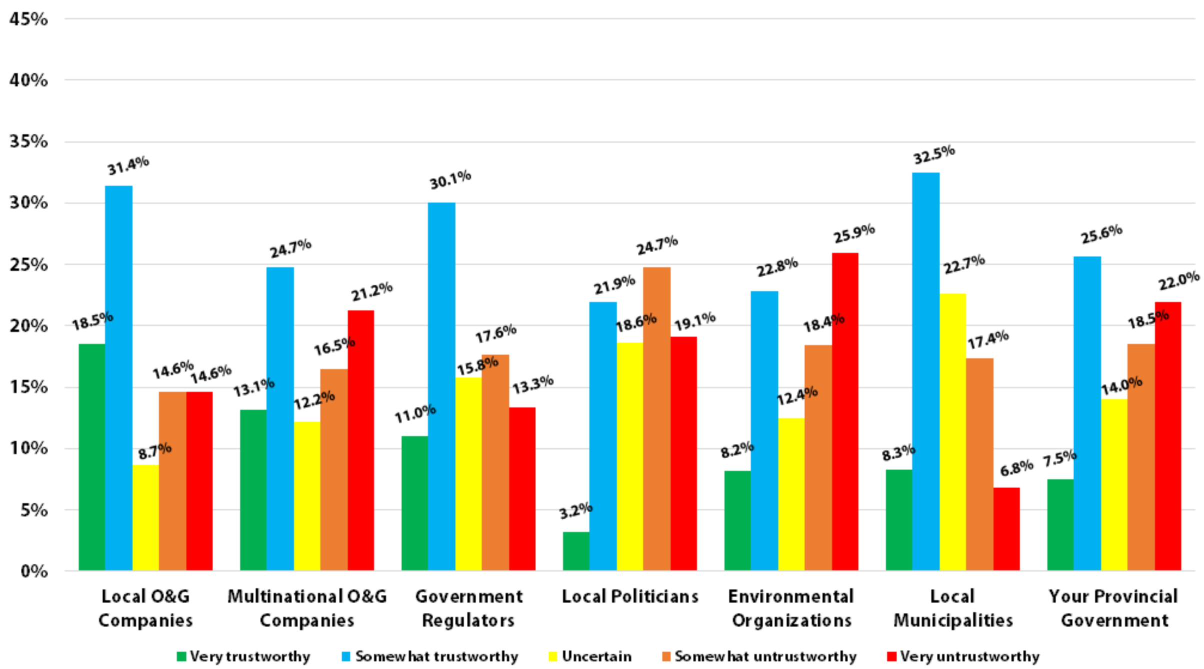


Figure 4.17: Trust of stakeholder parties. Given as percent of total respondents, n = 1,311.

Figure 4.18 shows the distribution of perceived transparency for the seven stakeholder parties. As with trust, the top three most transparent parties are felt to be local oil and gas companies, government regulators, and local municipalities. All three had a mean response between "uncertain" and "somewhat transparent" and a primary mode response of "somewhat transparent." The least transparent party is a tie between local politicians, mirroring trust, and environmental organizations, with both having a mean response between "somewhat non-transparent" and "uncertain," and a primary mode response of "somewhat non-transparent" and "not at all transparent" respectively. We see bimodal response distributions for local and multinational oil and gas companies, government regulators, environmental organizations, and the provincial government. It may be worth noting that Alberta held a provincial election while the survey was open, with government being formed by the New Democratic Party when the survey opened and by the United Conservative Party by the time it closed.

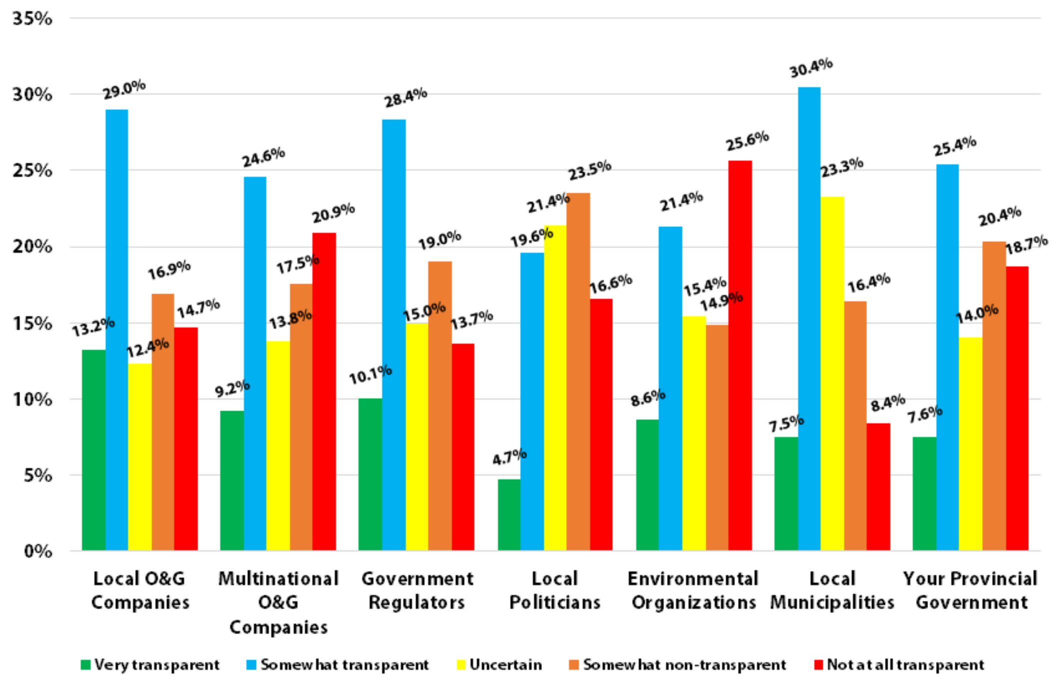


Figure 4.18: Perceived transparency of stakeholder parties. Given as percent of total respondents, n = 1,311.

4.6.1 Discussion

We asked respondents to rate their level of trust for specific oil and gas industry stakeholder parties, in addition to the perceived transparency of those same parties. Figure 4.17 describes trust levels for each party. The top three most trustworthy parties were felt to be local oil and gas companies, government regulators, and local municipalities, while the least trustworthy was local politicians.

Figure 4.18 describes transparency levels for each party. Similar to the trustworthiness shown in Figure 4.17, the top three most transparent parties are local oil and gas companies, government regulators, and local municipalities. The least transparent was a tie between local politicians, similar to trust, and environmental organizations.

There is a notable difference in opinion regarding local oil and gas companies and multinational oil and gas companies, with local companies being perceived as both more trustworthy and more transparent. This appears to be an interesting “buy local” effect, with local companies being more trusted than multinational companies, despite the fact that most, if not all, operators have assets across two or more provinces, or perhaps the world. Public engagement efforts by companies and getting to know the communities they are working in could improve their perceived trustworthiness and transparency.

Using the “correl” command in MS Excel, we can calculate correlation coefficients for each stakeholder party. This works by comparing the trust variable and transparency variable for each party to see how strongly the two are related to one another. When we calculate the correlation coefficients for each stakeholder party, as in Table 4.1, we see that there is positive correlation of varying strengths between trust and transparency. The party with the weakest correlation between trust and transparency is local municipalities with a correlation coefficient of 0.51, while the strongest is environmental organizations with a correlation coefficient of 0.73. The correlation coefficient ranges from -1, fully negatively correlated, to +1, fully positively correlated, with 0 representing no correlation at all. The coefficient values in Table 4.1 are indicative of reasonably strong correlations between trust and transparency. We also see from Table 4.1 that the mean ratings for trustworthiness and transparency are approximately 3 (“uncertain”) for all parties. This indicates that there is room for improvement from all parties on their perceived trustworthiness and transparency.

Table 4.1: Correlation coefficients, mean trustworthiness ratings, and mean transparency ratings for seven stakeholder parties.

Stakeholder party	Correlation coefficient	Mean trustworthiness rating	Mean transparency rating
Local O&G Companies	0.71	3.3	3.1
Multinational O&G Companies	0.70	2.9	2.8
Government Regulators	0.62	3.1	3.0
Local Politicians	0.57	2.6	2.7
Environmental Organizations	0.73	2.7	2.7
Local Municipalities	0.51	3.2	3.1
Your Provincial Government	0.63	2.8	2.8

From this analysis, it appears that trust is correlated with transparency. The level of this correlation does not necessarily indicate whether the organization has good or bad trust and transparency ratings, however. For example, environmental organizations show lower transparency and trust ratings, but have a 73% correlation. While correlation does not necessarily equal causation, this correlation relationship could indicate a need for strong, transparent communication with the public in order to improve public trust of stakeholder parties associated with the oil and gas industry. Transparency from industry, combined with balanced news coverage, may positively affect the perceived trustworthiness of stakeholders in the oil and gas industry.

Chapter 5: Analysis of the Factorial Survey Experiment vignette scenarios

Section two of the survey contained a set of Factorial Survey Experiment (FSE) vignette scenarios. Six randomly selected scenarios out of a total 144 scenarios were shown to each respondent for evaluation on a scale of 0 (do not support at all) to 10 (fully support). This chapter shows the results of that section of the survey.

With this section of the survey, there were several things we wanted to know. What is the general public perception of hydraulic fracturing (HF) operations? Is there a difference in ratings based on location? How strongly does induced seismicity (IS) affect perception of HF operations? What effects do the different scenario attributes have on perceptions of HF operations? We expect, based on previous studies such as that of Crowe et al. (2015), that support for or opposition to HF operations will be influenced not only by the attributes within the scenarios, but also the characteristics of the respondents themselves. The use of FSE vignette scenarios allows respondents to consider a more complete scenario that reflects real-world operations, which are often more nuanced than a question about an isolated attribute can evaluate.

5.1 Overview of results

Figure 5.1 shows the frequency distribution of FSE scenario responses. The mean rating of all FSE scenarios together is 4.9, with a relatively large standard deviation of 3.8. Together, these indicate a broad, balanced range of responses that is not skewed towards either support or opposition. Figure 5.1 also shows "protest" and "keener" votes. These indicate responses from individuals who always selected 0 or 10, respectively, regardless of how the FSE scenario was changing. When these responses are removed, the mean rating of all FSE scenarios is 5.2 with a standard deviation of 3.4 – still a relatively broad, balanced range of responses. The HF category in Figure 4.15 showed the perception of HF risk to be bimodal, and overall acceptance of HF was also bimodal, as shown in Figure 4.12. At first glance, the results from the FSE scenarios seem similarly bimodal. However, once we account for the protest and keener votes, the levels of support for HF scenarios become more nuanced and balanced. In this case, using the FSE scenarios allowed us to see the protest and keener votes, while the more direct questions covered in Chapter 4 did not allow for us to examine the results in the same level of detail. Additionally, once the protest and keener votes are accounted for, the remaining "normal" votes are influenceable by specific project considerations presented in the FSE scenarios.

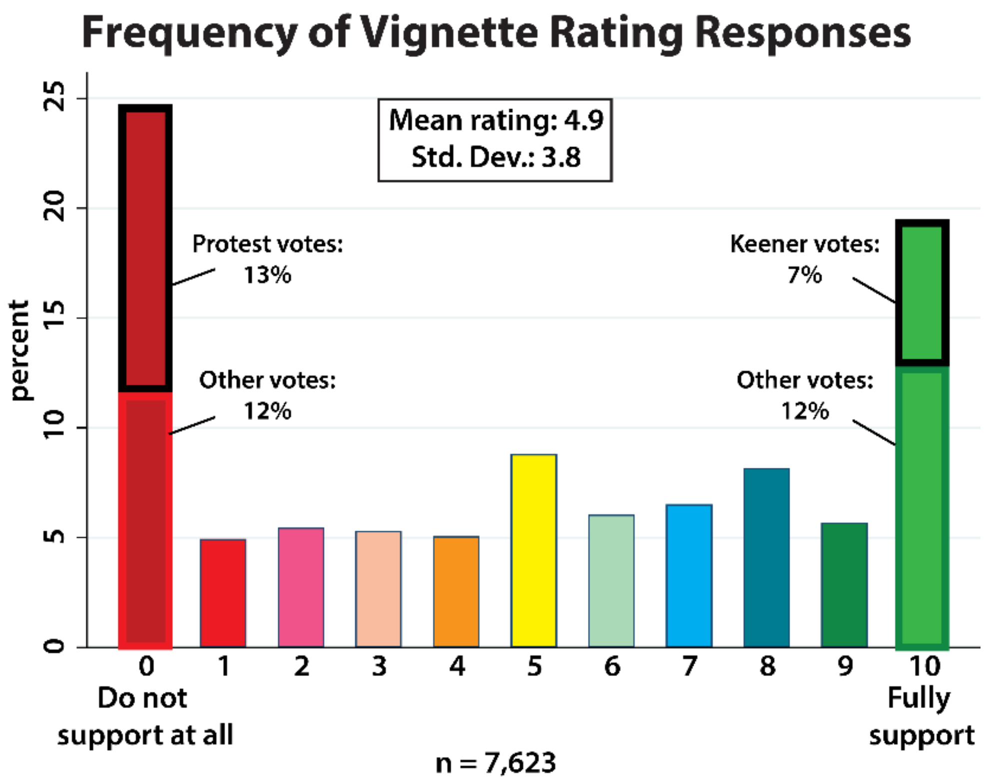


Figure 5.1: Frequency distribution of FSE scenario responses. Given as percent of total FSE scenario ratings, n = 7,623.

Some questions emerge from this first glance at the results. What is the geographical distribution of support or opposition to HF operations? Which of the FSE scenario attribute levels were preferred and which were not? What are some of the personal characteristics of respondents who voted more in favour or less in favour? The first two questions we begin to examine below, while the third is addressed in Section 5.3.

Figure 5.2 shows a map of mean FSE scenario ratings by Forward Sortation Area (FSA), where red indicates a mean rating of zero (do not support at all) and green a mean rating of ten (fully support). It is overlaid with a map of hydraulically fractured wells from 1985–2015 (red dots); the dataset for this overlay was obtained from Atkinson et al. (2016). Figure 5.3 shows the details of the Edmonton-Calgary corridor in Alberta more clearly. Notably, areas of higher HF activity tend to have lower mean ratings for the FSE scenarios.

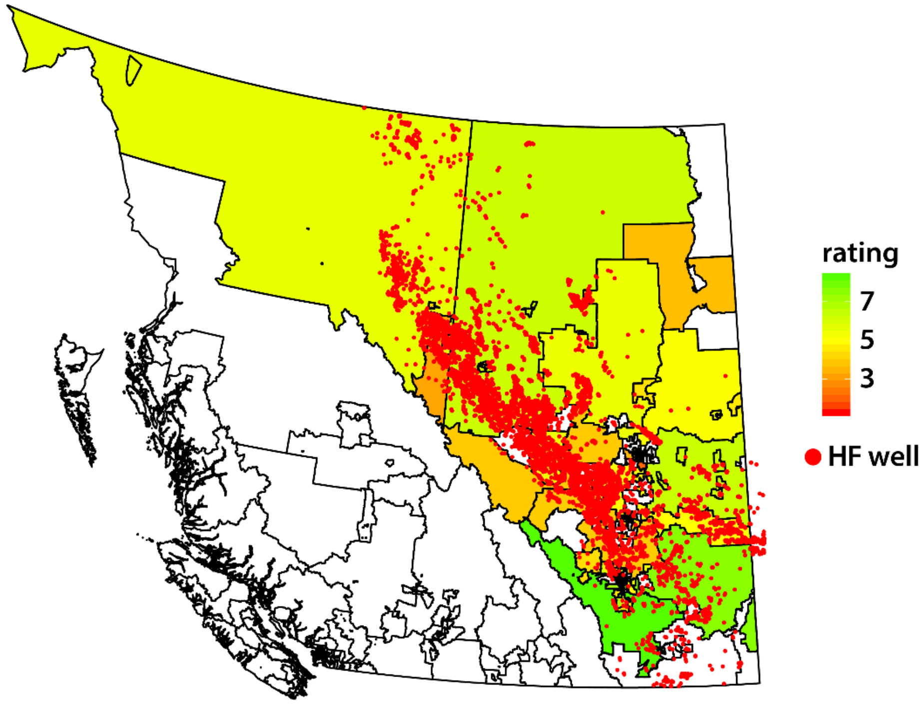


Figure 5.2: Map of mean FSE scenario response ratings for each FSA with five or more respondents. Red dots indicate locations of hydraulically fractured wells. HF activity is from 1985–2015; dataset was obtained from Atkinson et al. (2016). White regions had fewer than five respondents.

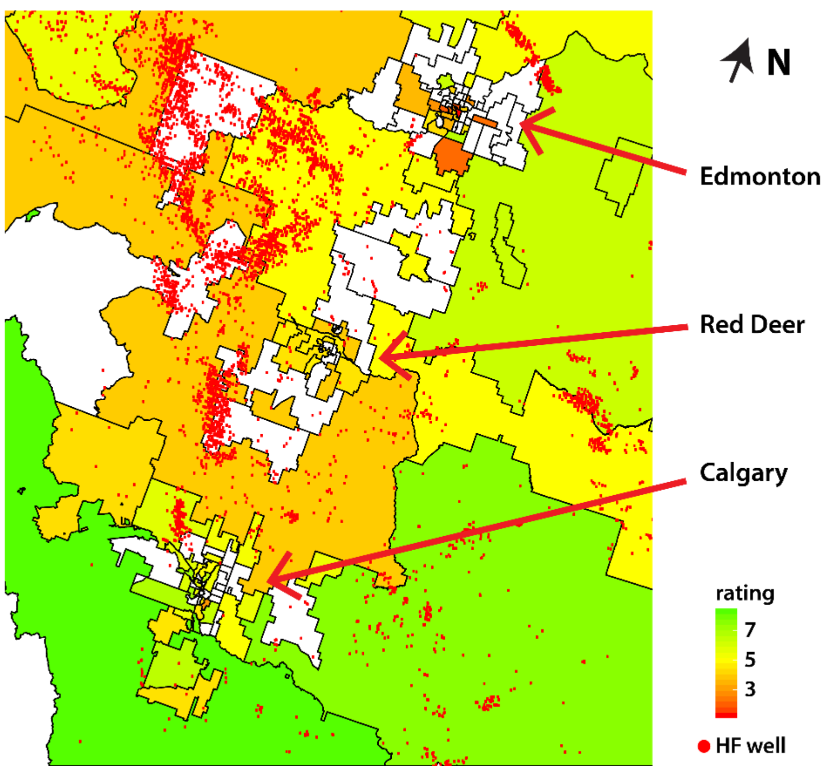


Figure 5.3: Map of mean scenario response ratings for each FSA, zoomed in to show the Edmonton-Calgary corridor of Alberta. Red dots indicate locations of hydraulically fractured wells. HF activity is from 1985–2015; dataset was obtained from Atkinson et al. (2016). White regions had fewer than five respondents.

Figure 5.4 shows the distribution of mean response ratings for each attribute level of the FSE scenarios described in Table 3.2 in Section 3.4. Option numbers refer to attribute level numbers given in Table 3.2. There are higher levels of support for scenarios that place an HF operation farther from the respondent's home, involve community consultation, provide economic or financial benefits to the community, and involve lower levels of anticipated seismicity. This is unsurprising and makes intuitive sense. We examine these effects in further detail in the three regression models shown in Table 5.1.

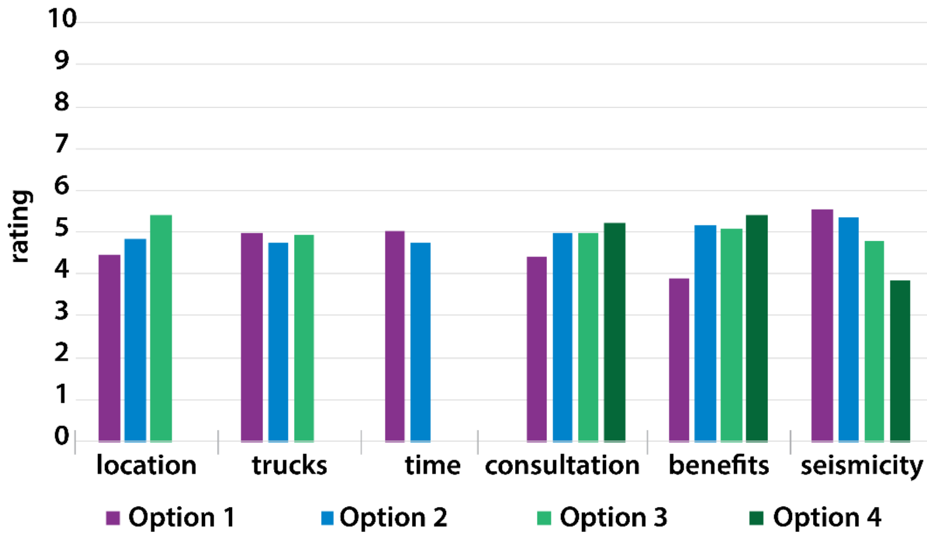


Figure 5.4: Distribution of mean response ratings for each attribute level. Option numbers correspond to numbers seen in Table 3.2 in Section 3.4.

Figure 5.5 shows the mean HF scenario support by respondents' self-rated knowledge of the energy industry. There appears to be a correlation between higher scenario ratings and higher self-rated knowledge. That is, the more a respondent feels they know about the energy industry, the more they support HF scenarios. This implies that information campaigns may be of significant influence on public opinion regarding HF, and particularly information campaigns that improve a person's confidence in their own knowledge.

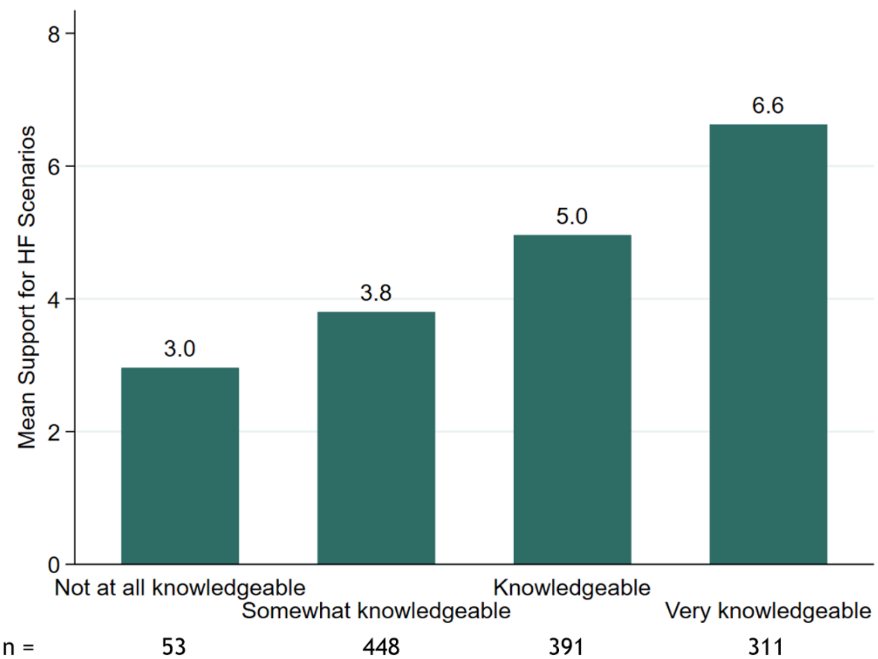


Figure 5.5: Mean support for HF scenarios by level of self-rated subjective knowledge. Total number of respondents is n = 1,203.

5.2 Analysis of attribute effects on FSE vignette scenario ratings

Table 5.1 shows three different regression models used on the results of the FSE responses. The three linear regression models shown, ordinary least squares (OLS), OLS cluster-robust, and random intercept, were described in Section 3.4.1 using *Equation 3.2*, *Equation 3.3*, and *Equation 3.4*. In Table 5.1, each of the six attributes described in Table 3.2 in Section 3.4 are represented in the first column and each is showing all but one of its levels. Each attribute in Table 5.1 is missing the first level given in Table 3.2, and this missing level serves as the reference against which the remaining levels are compared for each respective attribute. The range for the values from the regressions is based on the range of the scenario ratings — in this case, -10 to +10. For instance, if the reference level had a mean response of zero, and the level being compared had a mean of 10, the value shown in the table would be +10. If the reference level had a mean of 10 and the level being compared had a mean of zero, the value shown in the table would be -10. In this case, the theoretical limit is not reached since the mean response is not zero for any of the attribute levels, as seen in Figure 5.4. Standard error values in the table are given in parentheses and p-values are shown in the adjacent column. These values were calculated in Stata/IC 15 (StataCorp LLC, 2019) at the same time as the linear regression coefficients.

The p-values in Table 5.1 indicate the statistical significance, or probability of the calculated value being wrong — a lower p-value indicates a lower probability that the value is incorrect; i.e. more confidence in the results (StatsDirect Limited, n.d.). Values of less than 0.05 indicate a less than 5% probability that the calculated value is incorrect, values of less than 0.01 indicate a less than 1% probability that the calculated value is incorrect, and so on.

Table 5.1: Regression models used for FSE scenario analysis. Standard error values are given in parentheses.

	OLS	**OLS p-values**	**OLS with Cluster-Robust Standard Error**	**OLS CR p-values**	**Random Intercept**	**RI p-values**
Location – middle distance	0.467 (0.117)	0.000	0.467 (0.122)	0.000	0.461 (0.0613)	0.000
Location – far distance	1.023 (0.118)	0.000	1.023 (0.116)	0.000	0.961 (0.0615)	0.000
Trucks – medium	-0.333 (0.118)	0.005	-0.333 (0.113)	0.003	-0.201 (0.0615)	0.001
Trucks – many	-0.147 (0.117)	0.212	-0.147 (0.110)	0.184	-0.202 (0.0613)	0.001
Time – restricted hours	0.293 (0.0960)	0.002	0.293 (0.0994)	0.003	0.349 (0.0504)	0.000
Consultation – community informed	0.637 (0.136)	0.000	0.637 (0.133)	0.000	0.654 (0.0709)	0.000
Consultation – landowners consulted	0.652 (0.136)	0.000	0.652 (0.142)	0.000	0.705 (0.0716)	0.000
Consultation – full two-way	0.991 (0.136)	0.000	0.991 (0.138)	0.000	0.991 (0.0708)	0.000
Benefits – local hiring	1.400 (0.135)	0.000	1.400 (0.135)	0.000	1.149 (0.0707)	0.000
Benefits – cash grants	1.294 (0.135)	0.000	1.294 (0.139)	0.000	1.003 (0.0712)	0.000
Benefits – community project	1.528 (0.136)	0.000	1.528 (0.135)	0.000	1.395 (0.0712)	0.000
Seismicity – too small to be felt	-0.0254 (0.135)	0.851	-0.0254 (0.127)	0.841	-0.0573 (0.0701)	0.414
Seismicity – too small to cause damage	-0.661 (0.136)	0.000	-0.661 (0.138)	0.000	-0.604 (0.0713)	0.000
Seismicity – infrequent but large	-1.747 (0.135)	0.000	-1.747 (0.140)	0.000	-1.798 (0.0706)	0.000
Number of scenarios	5718		5718		5718	
R^2	0.0843		0.0843		0.0828	

Values for the OLS and OLS cluster-robust models are the same but vary in their standard errors, as is expected. Many of the random intercept values are similar to the first two regressions. Positive values indicate an increase in support for that attribute level over the reference level, while negative values indicate a decrease in support for that level compared to the reference level.

Looking at the Random Intercept column for the “local hiring” level of the benefits attribute, we see that scenarios where companies hired local employers and services were rated an average of 1.149 points higher than scenarios where companies provided no economic benefits to the local community. The p-value for this comparison was 0.000, indicating a very high confidence in this evaluation. This means that there is a higher level of support for scenarios involving local hiring practices.

If we then look at the Random Intercept column for the "infrequent but large" seismicity attribute level, we see that scenarios where the operation anticipates large, infrequent seismic events were rated an average of 1.798 points lower than scenarios that anticipated seismicity to be nonexistent. The p-value for this comparison was again 0.000, indicating high confidence in the evaluation. This means that there is lower support for scenarios involving the potential for large seismic events.

From Table 5.1 we can see that the largest positive effect on scenario responses is due to benefits in general, and the donation of fully funded community projects specifically. This implies that perception of HF operations may be linked to how those operations benefit local communities. There was also a positive impact on responses due to consultation – communities want to be involved in the planning and placement of operations where possible. Unsurprisingly, placing operations more than 15 km from a respondent's home had a significant positive effect on responses. The last main point to be taken from Table 5.1 is the significantly negative effect of increasing levels of anticipated seismicity associated with the operation.

If we look at specific FSE scenarios, the one with the greatest support, with a mean rating of 7.5, was

> A hydraulic fracturing operation is proposed to be located ***over 15 km*** from your home. The operation will involve ***over 50 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 ***preferential use of local services and employers to benefit local communities***. Seismicity related to the operation is anticipated to be ***too small to be felt***.

The scenario with the least support, with a mean rating of 2.1, was

> A hydraulic fracturing operation is proposed to be located ***between 3 and 15 km*** from your home. The operation will involve ***10-50 heavy equipment trucks*** with associated noise and dust travelling in the area per day ***at all hours of the day***, 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 ***providing no financial benefits to local communities***. Seismicity related to the operation is anticipated to be ***infrequent, but large enough to potentially cause moderate structural damage***.

These scenarios show that despite the relative ranking of the attribute levels as seen in Table 5.1 and Figure 5.4, the overall scenario ratings may differ from expectations when respondents are required to trade off all the attributes in a single scenario. That is, a scenario that has one of the lowest ranked attribute levels will not necessarily have a low overall rating, depending on which other attribute levels were included in the scenario.

5.2.1 Discussion

The mean rating of all FSE scenario responses is 4.9 with a standard deviation of 3.8, indicating a broad, balanced range of responses. When compared geographically with locations of hydraulically fractured wells like in Figure 5.2 and Figure 5.3, it can be seen that areas of higher HF activity tend to have lower mean ratings for the FSE scenarios. It also appears that higher levels of self-assessed knowledge about the energy industry in western Canada are correlated with higher scenario ratings. Within the scenarios, there appears to be higher support for operations that are located farther from respondents' homes, involve some level of community consultation, provide the community with some amount of financial or economic benefits, and have lower levels of anticipated seismicity. In other words, there is some amount of NIMBY sentiment – "Not In My Back Yard." Benefits to the community have the largest positive influence on scenario ratings. In particular, donation of a fully funded community project (such as a recreation centre) had the largest impact. Unsurprisingly, increasing levels of anticipated seismicity have increasingly negative impacts on FSE scenario ratings, with the largest level of seismicity having the strongest impact on ratings.

NIMBY has been a result of previous studies as well (Crowe et al., 2015; Lachapelle & Montpetit, 2014), although Thomas et al. (2017) caution that the term NIMBY can be used dismissively when community members voice valid concerns about potential local impacts. Other studies have also found evidence that knowledge of or beliefs about risks and benefits associated with operations affected public support (Clarke et al., 2015; Thomas et al., 2017).

In Chapter 4 we saw that the perceived risk of HF was bimodal in Figure 4.15. In Figure 4.12 we also saw that acceptability was bimodal. Between those two figures, the overt opinion of HF seems to be noticeably split. At first glance, we see a similar split when we introduce some of the confounding factors seen in real life, such as proximity and benefits. However, when we account for protest and keener votes the support for HF is far more nuanced and balanced. Assessing support for HF using the FSE method allowed us to see those protest and keener votes, which we could not do with the simple question in Figure 4.15. It is useful to be able to separate out the protest/keener votes since these respondents are unlikely to change their minds about HF regardless of the scenario. The remaining votes are based on the given situation and could be influenced one way or another with specific project considerations.

Overall, public perception of HF operations appears very polarized, but may be less so when trade-offs are made regarding attributes of theoretical real-world scenarios, in which case the distribution of support is fairly broad and balanced. We see higher levels of support for scenarios that occur farther from homes, require fewer heavy trucks, have restricted hours of operation, include community consultation, provide local economic benefits, and anticipate little to no seismicity. The largest influences on support for HF operations appear to be location, benefits, and seismicity.

Support for HF operations, measured using the FSE vignette scenarios, may be slightly influenced by proximity to existing HF activity, with areas of high activity showing lower support than areas of low activity. However, this is a generalization and would merit further study. Perceptions of HF operations are also strongly negatively influenced by the possibility of IS events, with support decreasing dramatically for increasing steps of IS levels. Counteracting these negative influences were positive influences on support from benefits, consultation, and increasing distance from homes. The number of trucks associated with the operation and the time of day work occurs did not appear to have strong effects on support or opposition.

5.3 Influence of respondent characteristics on the likelihood of being a protester or keener

In addition to the main results of the FSE vignette scenarios, we wanted to explore whether individual respondent characteristics affect the scenario ratings, and what contributes to a person being a protester or keener. Importantly, can the likelihood of being a protester or keener be explained? We investigate the influence of: geography, objective and subjective knowledge, personal energy work experience, age, residential landownership, community compensation, support of oil as an energy source, risk perception, urbanity, informational meeting attendance, years living at current residence, social media use frequency, use of social media as a source for oil and gas information, gender, education level, the frequency with which oil and gas discussions are followed, and the general level of concern over oil and gas topics.

Figure 5.1 included protest and keener votes – responses from individuals who selected 0 or 10, respectively, for every FSE scenario they were given, regardless of how the scenario was changing. In the court of public opinion, there is always a question of which influences will have the biggest effect in swaying your target demographic towards a particular viewpoint. It is therefore important to know which characteristics are associated with protesters and keeners, since you are unlikely to change their minds and focusing efforts in the wrong place can be a waste of time and effort.

There has been very little prior research done on protest voters, and seemingly none done on protest voters in studies that utilize factorial survey experiments (FSE) and vignette scenarios. Brouwer and Martín-Ortega (2012) explored protest voters in the context of willingness to pay to prevent an environmental disaster. They found that age and distance from the hypothetical site did not have a significant effect, but that familiarity with the area did.

Chen and Hua (2015) explored protest voters in the context of their willingness to pay for governmental decisions involving provisional changes of environmental resources. They found that frequency of visiting the resource (heritage trees), knowledge of heritage tree conservation, subjective evaluation of the effectiveness of heritage tree conservation in situ, and income were significant in differentiating protest voters.

The distribution of protest and keener votes compared to the number of normal votes for our survey are shown in Figure 5.6. There are far more normal votes than protest and keener votes combined, and there are nearly twice as many protest votes as keener votes. In Figure 5.7 and Figure 5.8 we see the spatial distribution of these protest and keener votes, with HF well locations from 1985–2015 overlaid in orange (Atkinson et al., 2016).

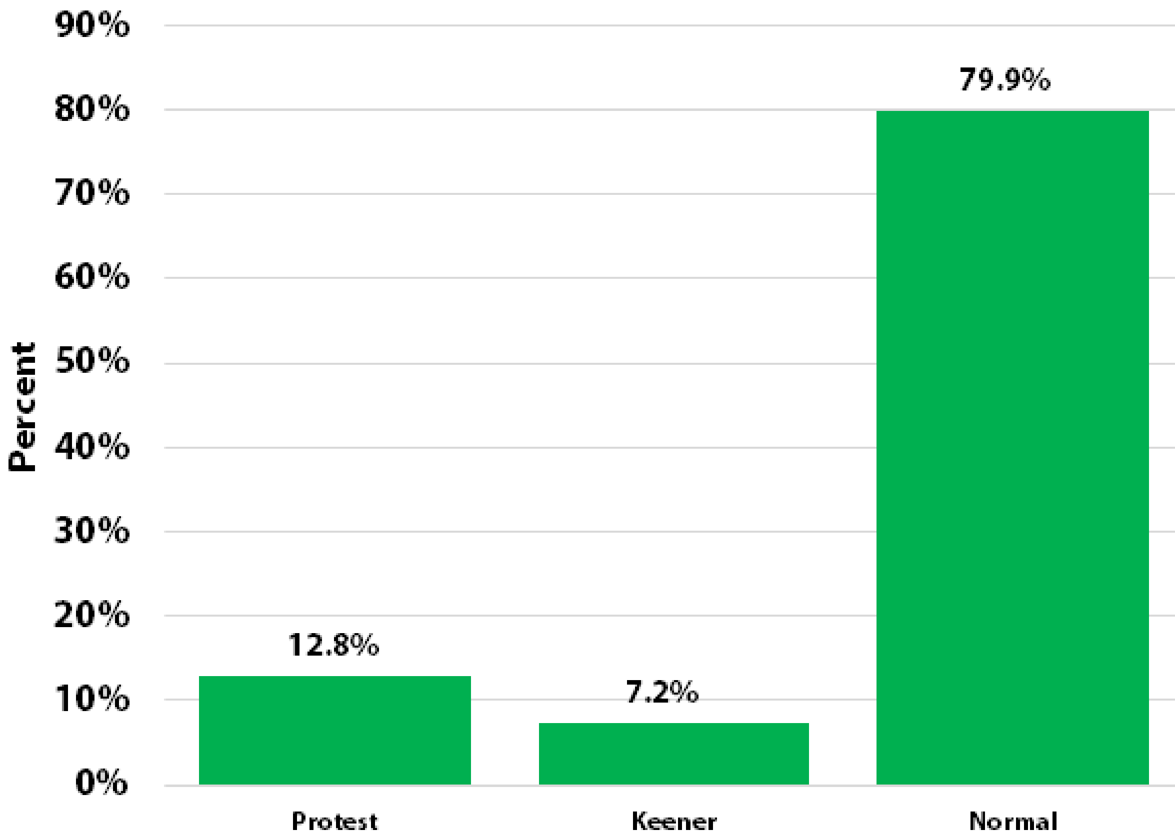


Figure 5.6: Distribution of protest, keener, and normal votes for the FSE vignette scenarios. Given as percent of total respondents, n = 1,311.

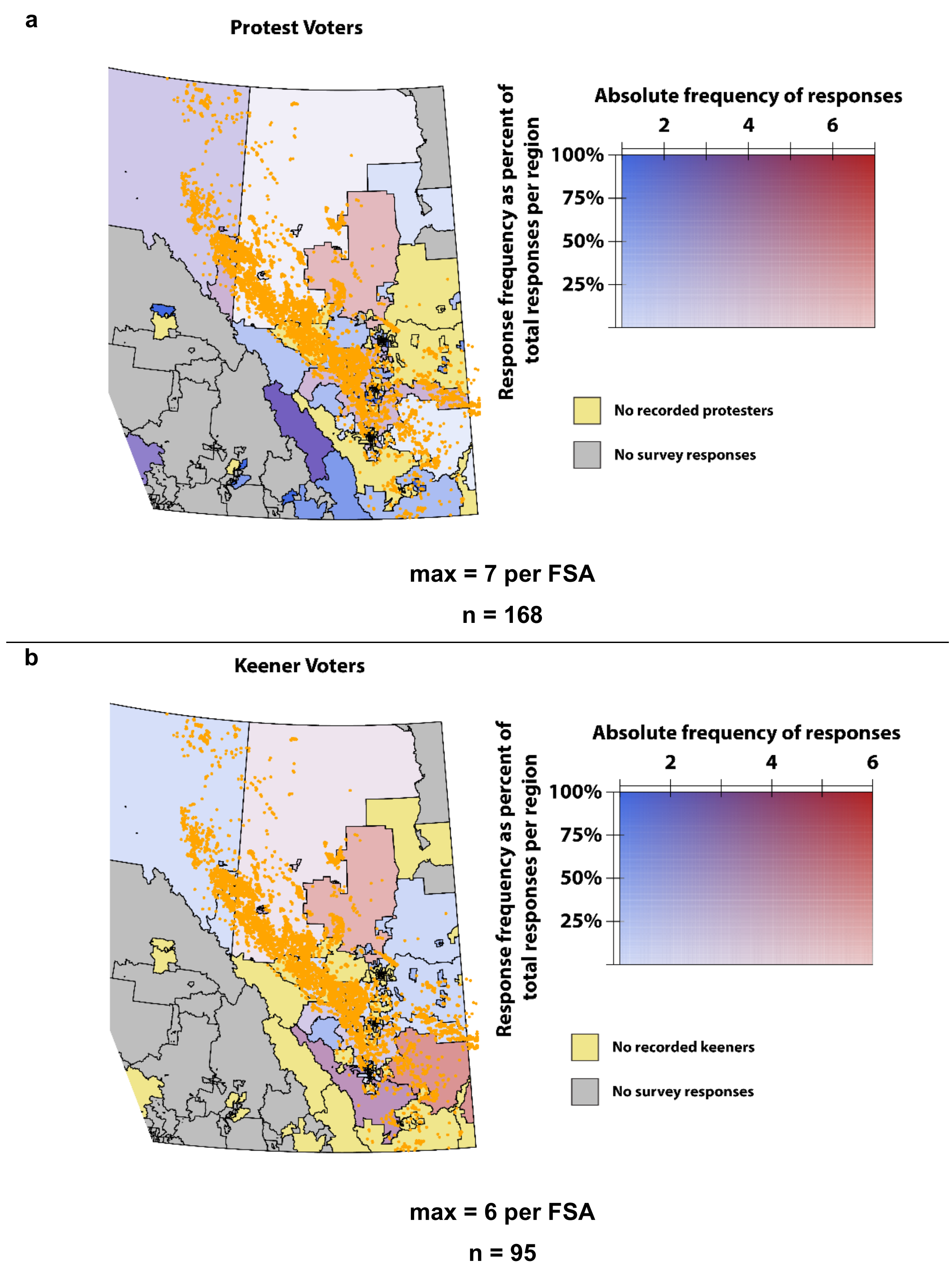


Figure 5.7: Postal code distribution of protest voters (a) and keener voters (b). Regions in red have many protesters/keeners, regions in blue have few. Opacity of the colours indicates percentage of the total respondents from that region who are categorized as protesters/keeners. Regions where we had survey respondents who were not categorized as protesters/keeners are shown in light yellow. Regions where we had no survey responses are shown in grey. Total number of respondents used to create the colour map in this figure is 168/95; total number of respondents used to create opacity filter in this figure is 1,311. The maximum number of protesters per FSA was seven in the T6G region (Edmonton, urban); the maximum number of keeners per FSA was six in both the T0G region (extending north from Edmonton, rural) and the T0J region (extending east from Calgary, rural). The maximum number of respondents of any opinion for one FSA was 54 for the T0H region (Grande Prairie region, northwest Alberta, rural). Locations of HF wells from 1985–2015 are overlaid in orange (Atkinson et al., 2016).

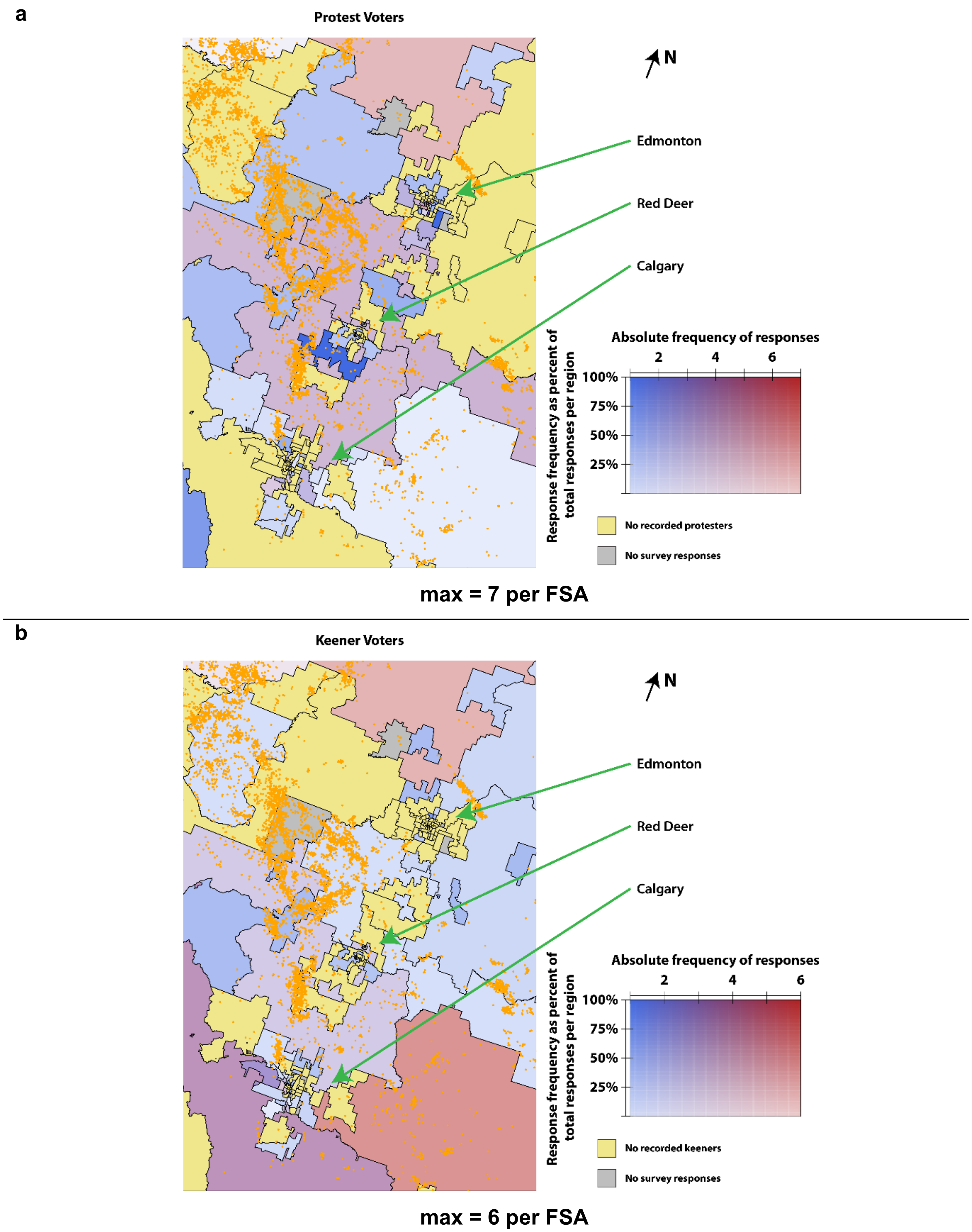


Figure 5.8: Postal code distribution of protest voters (a) and keener voters (b) zoomed in to show the Edmonton–Calgary corridor. Regions in red have many protesters/keeners, regions in blue have few. Opacity of the colours indicates percentage of the total respondents from that region who are categorized as protesters/keeners. Regions where we had survey respondents who were not categorized as protesters/keeners are shown in light yellow. Regions where we had no survey responses are shown in grey. Total number of respondents used to create the colour map in this figure is 168/95; total number of respondents used to create opacity filter in this figure is 1,311. Locations of HF wells from 1985–2015 are overlaid in orange (Atkinson et al., 2016). Same legend as for Figure 5.7.

It seems from Figure 5.8 that the Edmonton and Red Deer regions are more likely to have protest voters, and the Calgary region is more likely to have keener voters. This appears to correlate with the mean HF scenario ratings shown in Figure 5.3, where Edmonton and Red Deer have lower mean support ratings than Calgary. Beyond that, it is hard to draw any significant conclusions from the spatial distribution of the protest and keener votes.

Locations of HF wells from 1985-2015 (Atkinson et al., 2016) are overlaid on Figure 5.7 and Figure 5.8. However, again there seems to be little spatial correlation between HF well locations and protest or keener locations.

The colour map in Figure 5.7 and Figure 5.8 indicates the number of protest or keener respondents per FSA, and the opacity indicates the percentage this number represents of the total number of respondents from that region in the survey. In some cases, there may be a single vote represented in a region, but given the already low numbers of protest and keener votes with which to work, applying a minimum threshold number of protest/keener respondents could result in loss of data to an extent that mapping them becomes of minimal use.

5.3.1 Statistical analysis of the probability of being a protester or keener

Next, we investigate the influence of several things on the probability of a respondent being a protester or keener. These things are: objective and subjective knowledge, personal energy work experience, age, residential landownership, community compensation, support of oil as an energy source, risk perception, urbanity, informational meeting attendance, years living at current residence, social media use frequency, use of social media as a source for oil and gas information, gender, education level, the frequency with which oil and gas discussions are followed, and the general level of concern over oil and gas topics. The aim is to determine whether these items can explain the probability of a respondent being either a keener or a protester.

Table 5.2 shows the marginal effects of probit model results for protest votes, and Table 5.3 shows the marginal effects for keener votes. The model results are also visualized in the plot in Figure 5.9. These models are based on probit models like those described using Equation 3.6 and Equation 3.7 in Section 3.4.1. These equations were used to determine the probability of a respondent being a protest or keener voter based on their own inherent characteristics and how they answered other survey questions. We look at the marginal effects of the probit model results – how much (on average) the probability of the outcome changes when we increase the independent variable in question by one unit. This is measured on a scale from 0–1, and the value can be either positive or negative to indicate increasing or decreasing probability. This marginal effect is listed as the dy/dx value, where y is the probability of a given outcome (either protest or keener), and x is the independent variable in question. The marginal effects are calculated using the "margins" command in Stata/IC 15 (StataCorp LLC, 2019), which also gives the standard error and p-value (measure of statistical significance) of each independent variable as an output.

The dy/dx value is the percent increase or decrease, due to the independent variable (leftmost column), in the likelihood of being a protester or keener when all other variables are kept constant, or its "marginal effect." For example, an increase of one point in the objective knowledge category (measured on a six-point scale of increasing knowledge levels, assessed via the true and false statements in section three of the survey) decreases the likelihood of a respondent being a protest voter by approximately 1.7%. The interpretation column in Table 5.2 and Table 5.3 gives a short description of the result for each explanatory variable, using ↑ and ↓ as shorthand for increase and decrease, respectively. The rightmost column identifies whether the result is statistically significant or not. In the case of Table 5.2 and Table 5.3, a dy/dx result is considered significant if it has a p-value < 0.100, or a less than 10% probability that the calculated value is incorrect. A result is listed as only slightly significant if it has a higher acceptable p-value between 0.05 and 0.100.

These models include the following as explanatory variables:

- objective knowledge as assessed with the true and false statements in section three of the survey (six-point scale from "failed" (0 out of 5 correct) to "excellent" (5 out of 5 correct)),
- subjective knowledge as self-assessed by the respondent (four-point scale from "not at all knowledgeable" to "very knowledgeable"),
- personal energy work experience (binary "have" or "have not"),
- age category (seven-category scale, listed in Appendix A.8, ranging from "18–24" to "over 75" years of age),
- residential landownership (binary "own" or "do not own"),
- compensation to community influences respondent's opinion of oil and gas operations (five-point scale from "strongly disagree" to "strongly agree"),
- support of oil as an energy source (five-point scale from "strongly oppose" to "strongly support"),
- risk perception (given as an aggregate of six risk assessment questions, each evaluated on a five-point scale from "very safe" to "very risky"),
- urbanity (binary "urban" or "not urban"),
- informational meeting attendance (binary "have attended" or "have not attended"),
- years living at current residence (five-point scale from "less than one year" to "more than 10 years," as seen in Appendix A.1),
- social media use frequency (five-point scale from "never" to "many times per day," as seen in Appendix A.1),
- social media as a source for oil and gas information (binary "source used" or "source not used"),
- female (originally measured using a four-category scale of "female," "male," "other," and "prefer not to say." Very few responses were of the "other" and "prefer not to say" categories and this category was coded to be binary "female" or "not female"),
- education level (six-point scale from "no formal qualifications" to "graduate degree;" other options listed in Appendix A.8),

- frequency with which oil and gas discussions are followed (five-point scale from “never” to “frequently”), and
- general level of concern over oil and gas topics (given as an aggregate of 16 concern assessment questions, listed in Appendix A.6, each evaluated on a five-point scale from “very unconcerned” to “very concerned”).

Table 5.2: Marginal effects of probit model results for protest voters.

Protest vote	**dy/dx**	**Std. Err.**	**p-value**	**Interpretation**	**Significant?**
Objective knowledge	-0.0168	0.00416	0.000	↑ objective knowledge = ↓ in protest likelihood	Yes
Subjective knowledge	0.0189	0.00457	0.000	↑ subjective knowledge = ↑ in protest likelihood	Yes
Personal energy work experience	-0.00494	0.00739	0.504	Having energy experience = ↓ in protest likelihood	No
Age category	0.0112	0.00245	0.000	↑ age = ↑ in protest likelihood	Yes
Residential landowner	0.0249	0.00752	0.001	Owning residential property = ↑ in protest likelihood	Yes
Compensation influences opinion	-0.0189	0.00232	0.000	↑ influence due to compensation = ↓ in protest likelihood	Yes
Support of oil	-0.0343	0.00310	0.000	↑ support = ↓ in protest likelihood	Yes
Risk perception	0.0129	0.000893	0.000	↑ perception of risk levels = ↑ in protest likelihood	Yes
Urban	-0.0192	0.00721	0.008	Residing in an urban area = ↓ in protest likelihood	Yes
Info meeting attendance	-0.0147	0.00796	0.066	Attending an informational meeting = ↓ in protest likelihood	Slightly
Years living at current residence	-0.00641	0.00308	0.038	↑ length of time living at current residence = ↓ in protest likelihood	Yes
Social media use frequency	-0.0112	0.00299	0.000	↑ frequency = ↓ in protest likelihood	Yes
Social media source for O&G info	0.00461	0.00743	0.535	Using social media as a source = ↑ in protest likelihood	No
Female	-0.00217	0.00389	0.576	Being female = ↓ in protest likelihood	No
Education level	-0.00413	0.00250	0.099	↑ level of education = ↓ in protest likelihood	Slightly
Frequency with which O&G discussions are followed	0.0107	0.00411	0.009	↑ frequency = ↑ in protest likelihood	Yes
Concern level	0.000859	0.000262	0.001	↑ level of concern = ↑ in protest likelihood	Yes
Number of observations	6,318	Likelihood Ratio Chi-Square	1824.42	Likelihood Ratio Chi-Square degrees of freedom	17
Log likelihood	-1437.3969			Prob > Chi-Square	0.0000

Table 5.3: Marginal effects of probit model results for keener voters.

Keener vote	dy/dx	Std. Err.	p-value	Interpretation	Significant?
Objective knowledge	0.00723	0.00497	0.146	↑ objective knowledge = ↑ in keener likelihood	No
Subjective knowledge	0.0109	0.00424	0.010	↑ subjective knowledge = ↑ in keener likelihood	Yes
Personal energy work experience	-0.00203	0.00741	0.784	Having energy experience = ↓ in keener likelihood	No
Age category	0.0126	0.00207	0.000	↑ age = ↑ in keener likelihood	Yes
Residential landowner	0.00373	0.00634	0.556	Owning residential property = ↑ in keener likelihood	No
Compensation influences opinion	-0.00868	0.00226	0.000	↑ influence due to compensation = ↓ in keener likelihood	Yes
Support of oil	0.0933	0.0145	0.000	↑ support = ↑ in keener likelihood	Yes
Risk perception	-0.00143	0.000739	0.054	↑ perception of risk levels = ↓ in keener likelihood	Slightly
Urban	-0.0158	0.00580	0.006	Residing in an urban area = ↓ in keener likelihood	Yes
Info meeting attendance	0.00339	0.00596	0.570	Attending an informational meeting = ↑ in keener likelihood	No
Years living at current residence	-0.00719	0.00309	0.020	↑ length of time living at current residence = ↓ in keener likelihood	Yes
Social media use frequency	0.0125	0.00258	0.000	↑ frequency = ↑ in keener likelihood	Yes
Social media source for O&G info	-0.0139	0.00598	0.020	Using social media as a source = ↓ in keener likelihood	Yes
Female	-0.0245	0.00585	0.000	Being female = ↓ in keener likelihood	Yes
Education level	-0.00893	0.00201	0.000	↑ level of education = ↓ in keener likelihood	Yes
Frequency with which O&G discussions are followed	-0.00566	0.00443	0.202	↑ frequency = ↓ in keener likelihood	No
Concern level	-0.00347	0.000219	0.000	↑ level of concern = ↓ in keener likelihood	Yes
Number of observations	6,318	Likelihood Ratio Chi-Square	1108.49	Likelihood Ratio Chi-Square degrees of freedom	17
Log likelihood	-990.05466			Prob > Chi-Square	0.0000

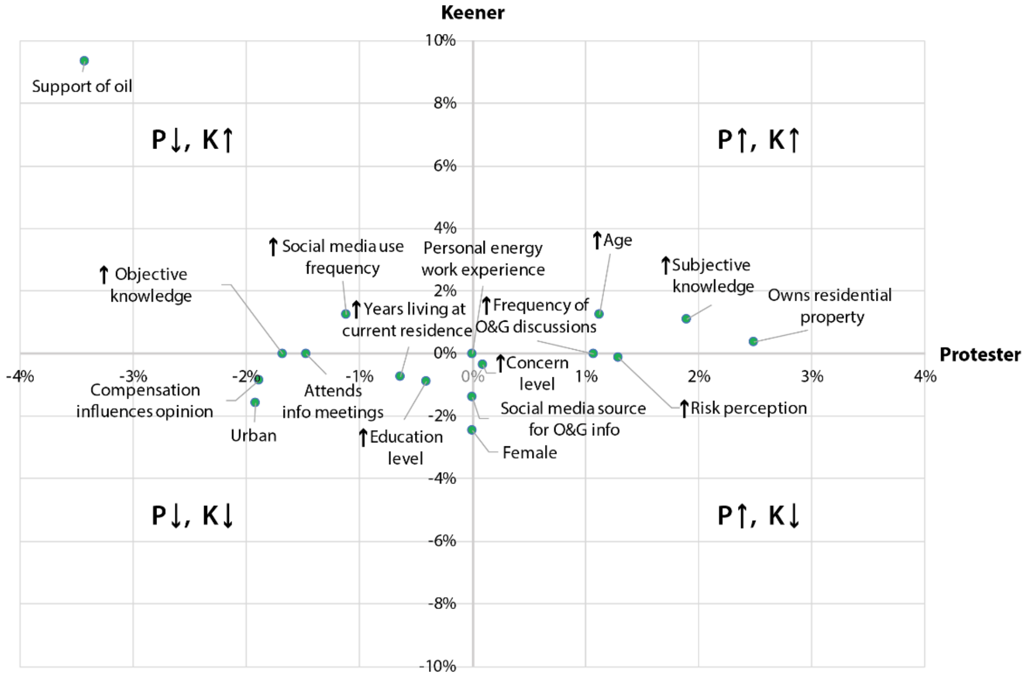


Figure 5.9: Visualization of the dy/dx data from Table 5.2 and Table 5.3. Categories that were not statistically significant (p-value > 0.100) are given a value of 0 in this figure.

Many of the variables used in the probit models are control variables that are inherent to the respondent, but others could be influenced by policy and communication efforts. These include: objective and subjective knowledge levels, support of oil as an energy source, risk perception, informational meeting attendance, social media as a source for oil and gas information, frequency with which oil and gas discussions are followed, and general level of concern over oil and gas topics.

From Table 5.2 we can see that the likelihood of a respondent being a protest voter is *increased* (to the right of the y-axis in Figure 5.9) by higher subjective knowledge, increasing age, property ownership, higher perception of risk levels, higher frequency of oil and gas discussions, and higher levels of concern. These characteristics are counteracted by higher objective knowledge, being increasingly influenced by compensation, increasing support of oil as an energy source, residing in an urban area, attending an informational meeting, increasing length of time living at current residence, increasing frequency of social media use, and increasing level of education, which all contribute at slightly significant to significant levels in *decreasing* the likelihood that a respondent will be a protest voter (to the left of the y-axis in Figure 5.9). The item that appears to influence respondents the most towards being a protest voter is being a residential landowner. The item that appears to influence respondents the most towards not being a protest voter is supporting oil as an energy source.

Many of these seem to make intuitive sense. A protest voter is more likely to be somebody who thinks they have sufficient knowledge of the potential scenarios, owns their residence and therefore has something to lose if an HF operation causes damage of any kind, feels that many oil and gas operations are more risky than safe, and has high levels of concern about items related to oil and gas operations.

Someone who owns their residence is more likely to be of an older age, and someone who has higher levels of concern would be more likely to follow discussions about oil and gas topics that could affect them negatively. Additionally, a person who has a relatively high objective knowledge of HF, feels they will be positively compensated for HF operations, supports oil as an energy source, lives in an urban area that is less likely to be the site of an HF operation, has attended informational meetings, and has had access to more education would be less likely to protest an HF operation based solely on principle (i.e. the likelihood of them being a protester is decreased).

Some results deviate from previous findings. While we found that *increasing* age led to an increasing likelihood that a person would vote in protest, Jacquet (2012) found that *younger* respondents in Pennsylvania were more likely to view shale gas developments, including HF, negatively. Boudet et al. (2014) also found that younger American respondents were less likely to support fracking than their older counterparts. We also found that increasing levels of education led to decreasing likelihood that a person would be a protest voter, which agrees with findings from Boudet et al. (2014), but other studies have found that those with higher education were more likely to view HF negatively (Jacquet, 2012), or even desire a ban on HF entirely (Crowe et al., 2015). It is also unclear why someone who has lived a long time at their current residence would be less likely to be a protest voter, or why someone who has a higher frequency of social media use would be less likely to be a protest voter. Further study would be needed to adequately address these questions, but a guess may be that lower levels of social media use correspond to lower exposure to a variety of information and ideas that could challenge a protest line of thinking. In the case of residence time, perhaps longer residency contributes to a nuanced sense of the pros and cons associated with HF operations in their community.

In Table 5.3 we see that increasing subjective knowledge, increasing age, increasing support of oil, and increasing frequency of social media use contribute in significant ways to *increasing* the likelihood that a respondent will be a keener voter (above the x-axis in Figure 5.9). We also see that being increasingly influenced by compensation, increasing perception of risk levels, residing in an urban area, increasing length of time living at current residence, using social media as a source for oil and gas information, being female, increasing education level, and increasing levels of concern over oil and gas topics contribute at slightly significant to significant levels in *decreasing* the likelihood that a respondent will be a keener voter (below the x-axis in Figure 5.9). The item that appears to influence respondents the most towards being a keener voter is supporting oil as an energy source. The item that appears to influence respondents the most towards not being a keener voter is identifying as female. It is also important to note that being more (or less) likely to be a keener does not necessarily make a respondent less (or more) likely to be a protester.

Again, several of these points make intuitive sense. A keener voter is more likely to be somebody who believes they have sufficient knowledge of oil and gas operations and supports oil as an energy source. Somebody who has a higher perception of risk levels and higher levels of concern over oil and gas topics is less likely to be a keener voter. Intuitively, a keener voter is likely voting on principle, so being more influenced by potential compensation (i.e. outside influence rather than an internal guiding principle) would indeed correspond to a decreasing likelihood of being a keener voter. It is unclear, albeit interesting, why being female decreases the likelihood of being a keener voter but does not have a significant effect on protest voter likelihood.

There are several crossover effects between protest and keener voters. Increasing support of oil and increasing frequency of social media use decrease the likelihood of being a protest voter and increase the likelihood of being a keener voter (top left quadrant of Figure 5.9). Higher perception of risk levels and higher levels of concern increase the likelihood of being a protest voter and decrease the likelihood of being a keener voter (bottom right quadrant of Figure 5.9).

Some of the crossover effects of both protest and keener vote influences indicate that the effect adds complexity to the risk assessment of the respondent, rather than a direct effect of increasing protest likelihood while decreasing keener likelihood, or vice versa. Higher subjective knowledge and increasing age increase the likelihood of both protest and keener votes (top right quadrant of Figure 5.9). A person who believes they have sufficient knowledge to hold an informed opinion seems to hold that opinion more strongly. Older respondents also seem to hold their opinions more strongly.

Being increasingly influenced by compensation, residing in an urban area, increasing length of time living at current residence, and increasing level of education decrease the likelihood of both protest and keener votes (bottom left quadrant of Figure 5.9). A person who can be influenced by external factors, like compensation, are less likely to hold a strongly ingrained opinion. Urban respondents are less likely to be personally affected by HF operations, and so are less likely to be strongly for or against them. Increasing length of time living at current residence indicates a higher likelihood of understanding the merits and drawbacks HF operations may bring to their community. A higher level of education may mean that the respondent has been exposed to a wider variety of opinions and information regarding HF operations, and so they may have a view that is evaluated on more of a case-by-case basis than a blanket opinion.

Both protesters and keeners share a handful of characteristics. Increasing support of oil and increasing frequency of social media use make it more likely that a person will be a keener and less likely that they will be a protester. Higher perception of risk levels and higher levels of concern make it more likely that a person will be a protester and less likely that they will be a keener. This information may be of interest when attempting to improve public perception of HF. For example, targeted social media campaigns that address potential risks and concerns may have an impact.

Both protesters and keeners are more likely to have a higher level of subjective knowledge and be from higher age categories. These factors appear to add complexity and nuance to the risk assessment and opinion of the respondent, rather than directly swaying the respondent between support and opposition to HF operations.

Both protesters and keeners are less likely to: be highly influenced by compensation, reside in urban areas, have lived at their current residence for a long period of time, and have higher levels of education. These four characteristics seem to be things that might make a person more open-minded about HF operations.

Chapter 6: Comparing earthquake experience with "Did You Feel It" and geologic data

Seismic hazard maps give important information about the likelihood that an earthquake will cause damage to infrastructure at or just below the surface. An earthquake with the potential to cause damage is also likely to be felt by humans. It stands to reason, then, that comparing an existing seismic hazard map with information about earthquakes that have been felt could validate and improve the accuracy and reliability of the seismic hazard map.

In Canada, the Earthquakes Canada group within Natural Resources Canada (NRCan) collects information about earthquakes that have been felt by the public. Unfortunately, although they produce maps of the seismic events themselves, there is no readily available map of "Did You Feel It" (DYFI) data for the public to access. There are seismic hazard maps of Canada, as seen in Figure 6.1, but the models behind these maps could potentially be strengthened by a systematic comparison with DYFI data.

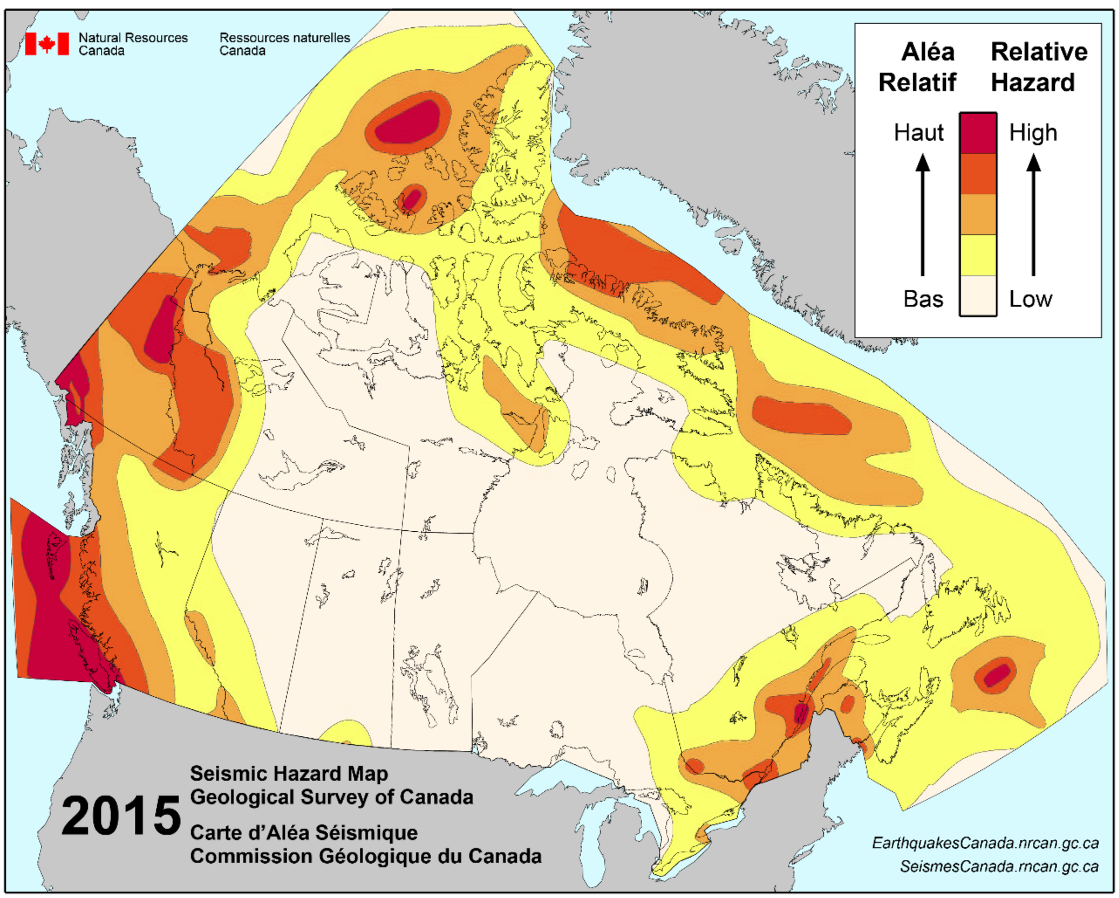


Figure 6.1: Seismic hazard map produced by the GSC in 2015. Obtained from NRCan (n.d.-b).

In addition to the DYFI data collected by NRCan, we collected felt seismicity data from respondents in our survey. The interest now is in seeing how the NRCan DYFI data compares geographically with the survey responses.

It is also of interest to examine whether there are correlations between the felt seismicity data (from both NRCan and the survey) and independent data sources. Since felt seismicity data depends on members of the public being able to feel earthquakes at the surface, we must consider the influence of population distribution as well as the influence of geological conditions on surface intensity and the distance from the epicenter that an earthquake can be felt (Lowrie, 2007). Allen and Wald (2007) use topographic slope as a proxy for the shear wave velocity at a depth of 30 m from the surface (V_S^{30}). In addition to comparing the two sources of DYFI data with the seismic hazard maps, there is also an opportunity to compare these with the V_S^{30} data prepared by Allen and Wald (2007).

The inclusion of survey questions regarding whether respondents had ever experienced an earthquake (see questions in Appendix A.7) and their location was intended to give a broad picture of both respondents' experiences as well as data that would allow us to investigate the correlation between felt seismicity, seismic events, and geological settings. This knowledge could enhance existing seismic hazard maps and be a relevant source of information for policy makers. There were a handful of specific questions to investigate: How many respondents have felt earthquakes where they live? Do the "felt" locations correlate with recorded earthquakes? What might contribute to certain earthquakes being felt while others are not, for example topography, subsurface composition, or population distribution? Is a person who has felt an earthquake of any kind more (or less) likely to be concerned about induced seismicity (IS)?

6.1 Methods and data

In our survey, we asked respondents whether they had ever experienced an earthquake, and if so, whether they had ever experienced one where they currently live. We also asked for the first three characters of their postal code, or Forward Sortation Area (FSA), which allowed us to map regions where residents have felt earthquakes.

NRCan collects DYFI data on their website using an earthquake questionnaire — https://www.earthquakescanada.nrcan.gc.ca/index-en.php. We were granted access to these data, giving us the ability to map them and compare them with our own felt seismicity data. We also consider our data in the context of the population distributions of Alberta and British Columbia to see whether a region of higher population may correlate with a higher incidence of felt seismicity.

Allen and Wald (2007) were provided with several sets of V_S^{30} data from a handful of different sources, primarily covering areas of California, Utah, Tennessee, Missouri, Kentucky, Arkansas, Puerto Rico, Australia, Turkey, Taiwan, and Italy. Their intent was to correlate these V_S^{30} data with topography data, which they obtained from the Shuttle Radar Topography Mission 30-sec (SRTM30) global topographic data set.

Their first step was correlating V_S^{30} (m/s) with topographic slope (m/m) at each V_S^{30} measurement point for data in active tectonic areas. The overall trend from this correlation is that V_S^{30} increases as slope increases, which is indicative of faster, more competent materials holding steeper slopes. Unfortunately, there is no easy, direct, physical relationship between slope and V_S^{30}. As such, Allen and Wald (2007) chose to characterize the relationship in terms of discrete steps in shear velocity values tied to National Earthquake Hazards Reduction Program (NEHRP) V_S^{30} boundaries. Slope values for each bin were assigned and quality checked on a subjective basis depending on the amount of available data for a region. These correlations were broken into two categories: active tectonic regions and stable continental regions. The related models were then applied globally and made available via mapping software through the USGS website (USGS, n.d.-a), where we downloaded data for our specific region for the purpose of comparing them with the DYFI data sets.

6.2 Results from the survey

Figure 6.2 shows the distribution of earthquake experience among respondents. We then broke positive felt-responses down into location-based experience, which is shown in Figure 6.3. In general, we see that there is a roughly even split between respondents who have experienced at least one earthquake and those who have experienced none, but there was a decreasing number of respondents who have experienced greater numbers of earthquakes. Responses for Figure 6.3 are composed only of those who indicated that they had felt at least one earthquake at some point in their life (Figure 6.2) and who did not leave this second question unanswered, which is approximately 43.4%–43.9% of all respondents.

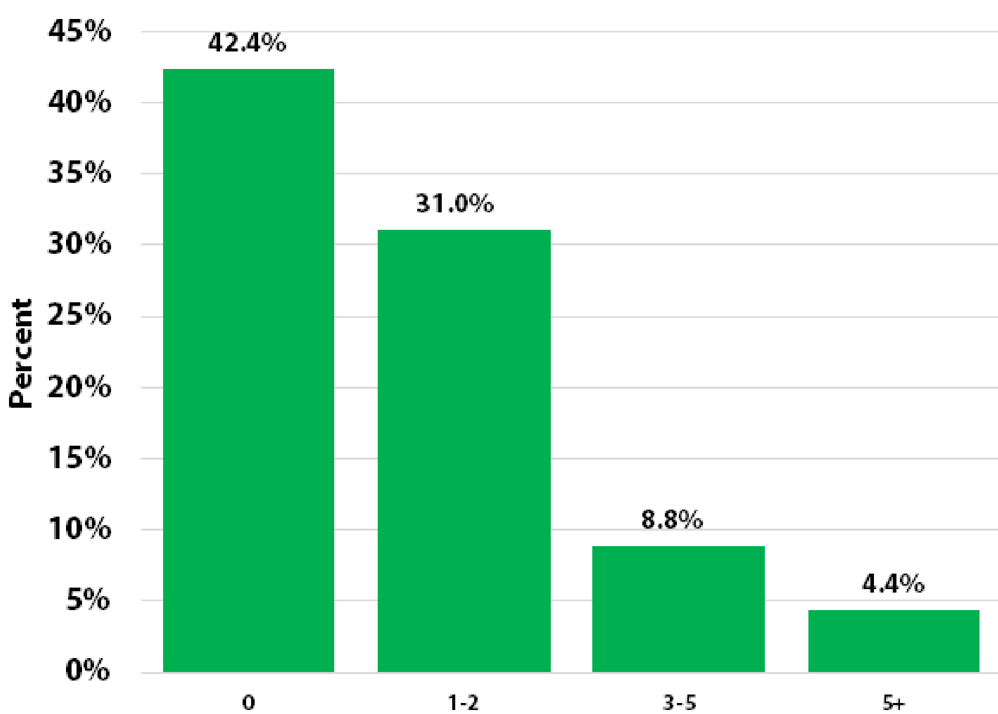


Figure 6.2: Number of earthquakes experienced by respondents in their lifetime. Given as percent of total respondents, n = 1,311. A total of 13.4% of participants did not respond to this question in the survey.

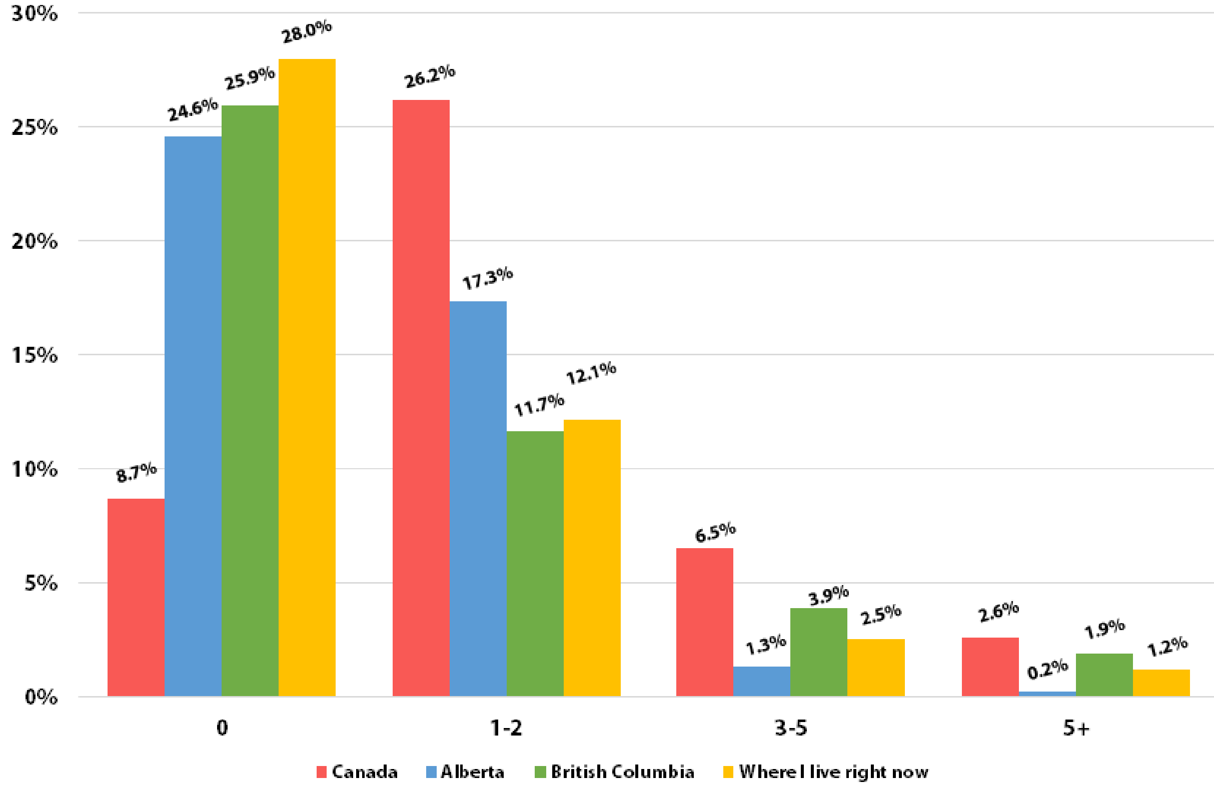


Figure 6.3: Number of earthquakes experienced by respondents at various locations. Given as percent of total respondents, n = 1,311. Responses for this figure include only those participants who indicated in Figure 6.2 that they had felt at least one earthquake in their lifetime and who gave a response for this question, which is approximately 43.4%–43.9% of all respondents.

Figure 6.4 gives a map of respondents who have felt an earthquake where they live. A total of 208 respondents (~15%) said they had felt an earthquake where they live, and 147 of those gave a valid FSA. Two of those were in Ontario, leaving 145 responses with which to create the colour map used in Figure 6.4 (i.e., the sum of responses of the red to blue regions is 145). Regions in red have many reported felt earthquakes, while regions in blue have few. The opacity of the colours indicates the percent of total respondents per region that have reported felt earthquakes. For example, the northwest Yukon is blue, indicating few respondents have felt an earthquake there, and the colour is very opaque, indicating that these few respondents form a large percentage (if not the entirety) of the total respondents from that region in the Yukon.

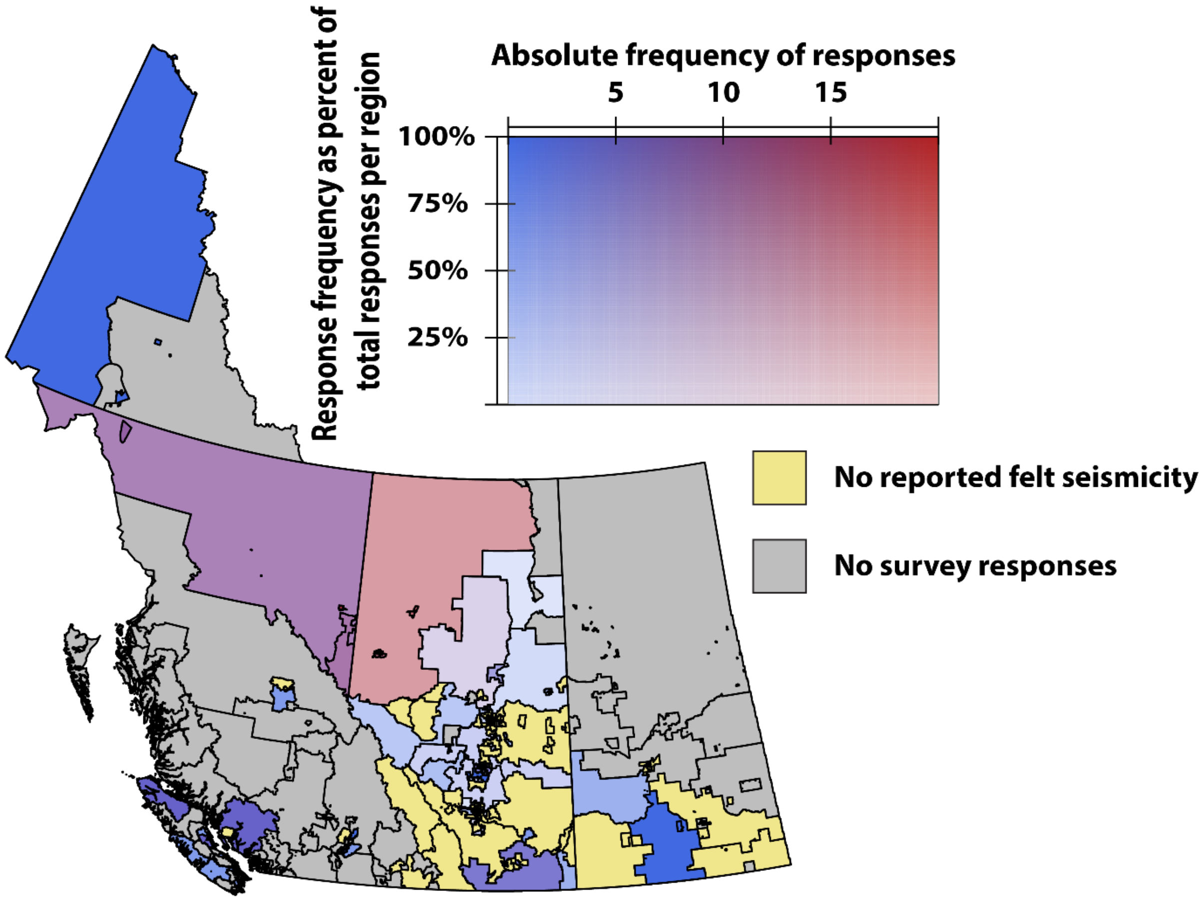


Figure 6.4: Map of survey respondents who have felt an earthquake where they live. Regions in red have many reported felt earthquakes, regions in blue have few. Opacity of the colours indicates percentage of the total respondents from that region who have felt an earthquake. Regions where we had survey respondents who did not indicate feeling seismicity are shown in light yellow. Regions where we had no survey responses are shown in grey. Total sum of respondents shown in the red to blue colour scale in this figure is 145; total number of respondents used to create opacity filter in this figure is 1,311.

6.3 Interpretations, discussion, and comparison with Natural Resources Canada

Regardless of whether they are natural or induced events, earthquakes are often felt by humans. From Figure 6.2, we know that approximately 44.2% of survey respondents have felt an earthquake in their lifetime. If this earthquake experience were to significantly negatively affect the public perception of IS during oil and gas operations, it may be prudent for operators to avoid producing felt seismicity as much as possible. We examined whether earthquake experience had an influence on perceptions of IS. In Figure 6.5, we see that having experienced an earthquake (or not) does not appear to significantly change the shape of the distribution for the level of concern related to IS. In Figure 6.6, we see that the mean level of concern for each grouping of earthquake experience is similar, keeping in mind that there were fewer respondents who had felt more earthquakes.

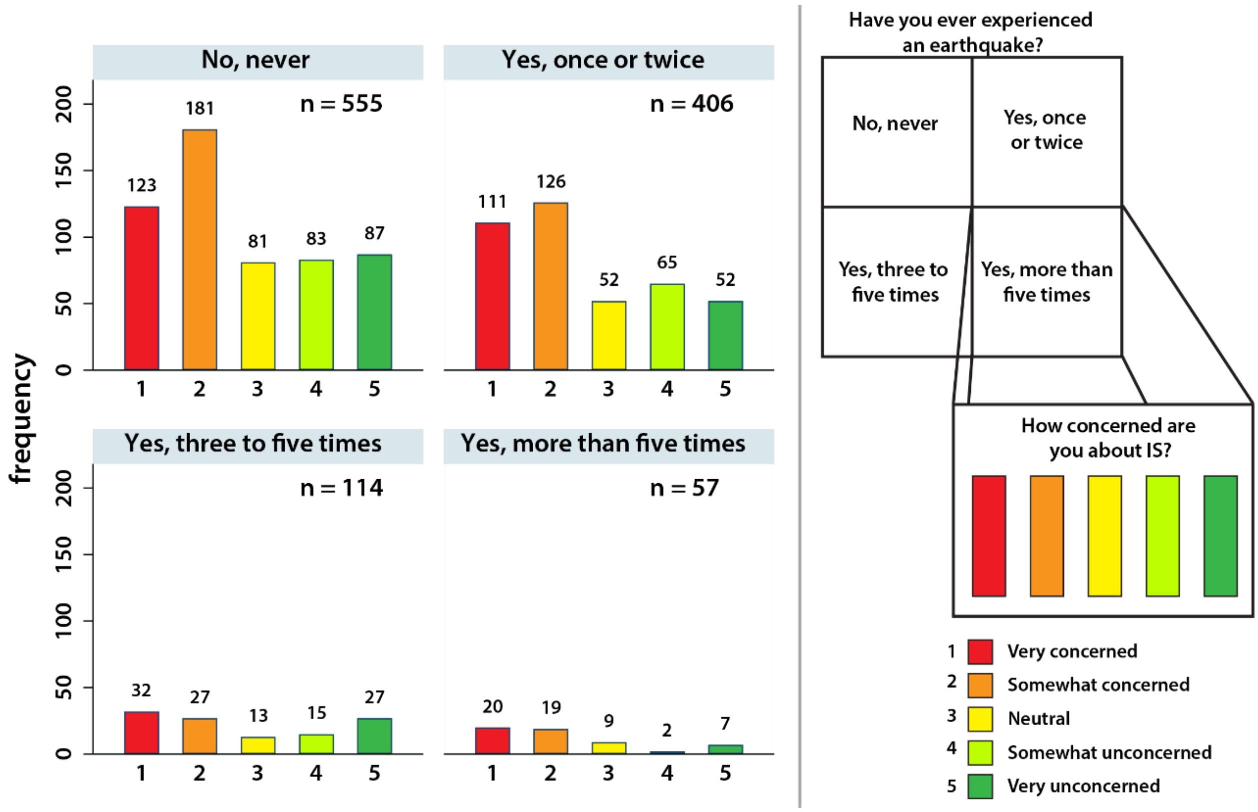


Figure 6.5: Effect of earthquake experience on IS concern levels. Number of respondents who participated in both questions was n = 1,132.

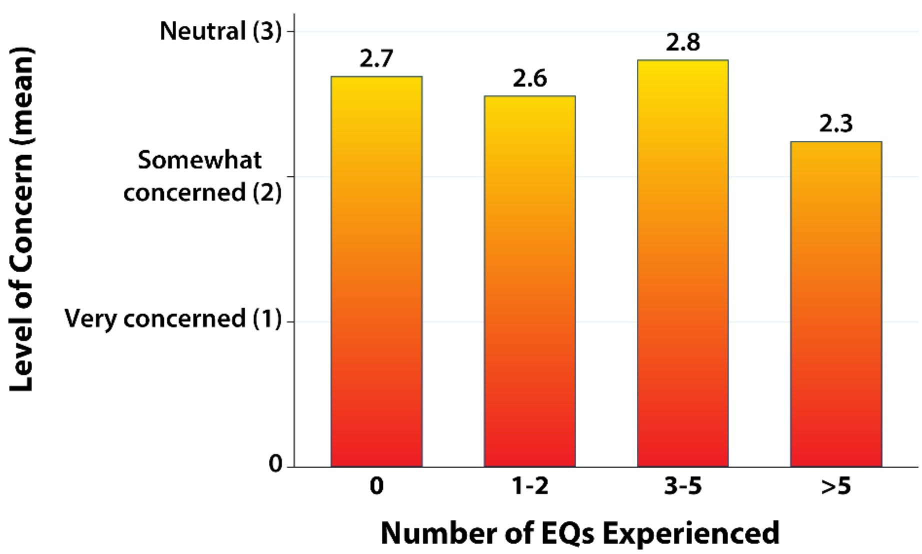


Figure 6.6: Mean level of concern related to IS for respondents grouped by earthquake experience. Number of respondents responding to both questions was n = 1,132.

Although earthquake experience in general does not appear to significantly affect IS concerns, it could be interesting to investigate whether experiencing earthquakes that are definitively confirmed to be IS would affect concern levels. Investigating whether experiencing IS would affect opinions on hydraulic fracturing (HF) and the oil and gas industry could also be enlightening. If experiencing IS has a negative effect on opinions about HF and the oil and gas industry, operators may wish to spend more effort on IS prevention measures and regulators may wish to tighten IS-related regulations. This investigation could be done by surveying or interviewing participants who have experienced an event that is considered highly likely to have been induced by oil and gas operations to evaluate their perceptions of HF operations and the oil and gas industry.

Regardless of whether they are natural or induced, seismic events are recorded by the Earthquakes Canada group within NRCan. NRCan also records where humans have reported feeling seismic activity. Figure 6.7 and Figure 6.8 show histograms of felt seismicity reported to NRCan by the public and the associated recorded seismic events, respectively. Figure 6.9, Figure 6.10, and Figure 6.11 show the locations of those seismic events and where they have been felt by humans. The information about where they have been felt was collected by NRCan using the DYFI questionnaire on their website. The events in these figures are magnitude 2.5 or greater. The minimum threshold for humans to feel an event is generally agreed to be magnitude 3, as discussed in Section 2.3.3.

From the NRCan database, the maximum number of people reporting a single given event was 79, with 42 of those reports indicating a community decimal intensity (CDI) of 2, and one indicating the highest reported CDI of 4.9. The CDI is similar to the Modified Mercalli Intensity scale and on average approximately equal. The recorded magnitude of that highly reported event was M_L 4.1, and its location and date were reported to be approximately 41 km southeast of Penticton, BC on September 10, 2016. For the M_L 4.6 event that occurred on March 4, 2019 approximately 18 km west of Red Deer, AB, there were 53 reports submitted, of which 13 reported a CDI of 2 and the max CDI reported was 4.6. For the M_W 4.0 event that occurred on March 10, 2019 approximately 30 km northwest of Rocky Mountain House, AB, there were 19 reports submitted, of which 6 reported a CDI of 2 and the max CDI reported was 4.6.

In Figure 6.7 we see that the majority of reported events in our region of interest are indicated to have a CDI of 1.5–2, with very few reporting CDI levels of 5 or greater. The highest CDI reported was a 7.6. In Figure 6.8 we see the distribution of magnitudes for the earthquakes associated with the felt reports. Events of magnitude 3–3.5 are the largest category of events associated with felt reports, and the maximum magnitude associated with felt reports is 4.6. The smallest magnitude associated with felt reports was 1.8, which is smaller than what is typically expected as the minimum magnitude that can be felt by humans.

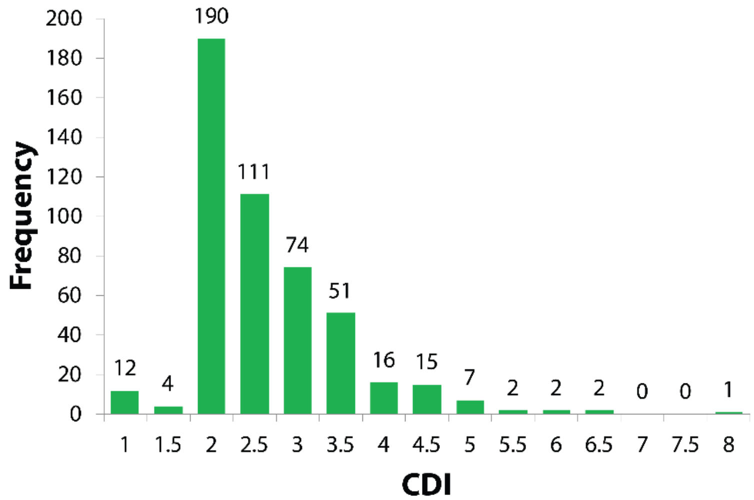


Figure 6.7: Histogram of reported CDI levels in the NRCan DYFI database for our region of interest. Data obtained from NRCan. Number of felt reports for the selected region is n = 487.

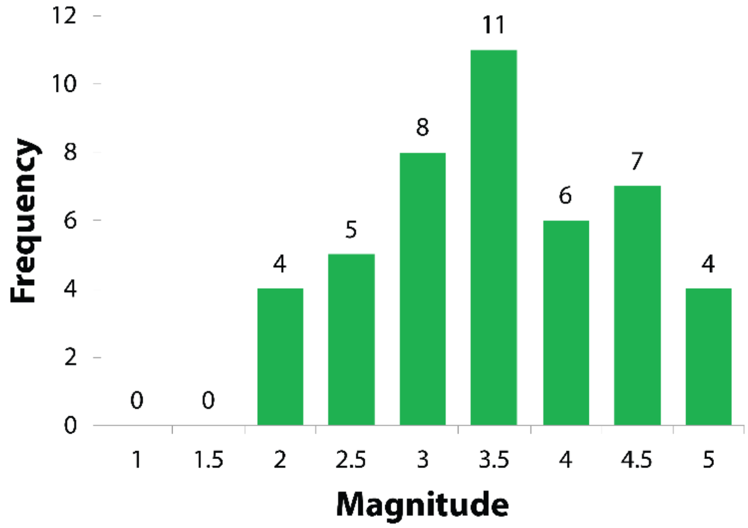


Figure 6.8: Histogram of magnitudes for felt earthquakes in the NRCan DYFI database for our region of interest. Data obtained from NRCan. Number of recorded events for the selected region is n = 45.

In Figure 6.9 and Figure 6.10, NRCan-recorded events are shown with blue circles and locations where people reported having felt them are shown with red stars. The size of the blue circles corresponds to the magnitude of the event. Each location of felt seismicity (red star) is connected back to its corresponding seismic event (blue circle) with a line, giving an idea of the distance over which events are felt.

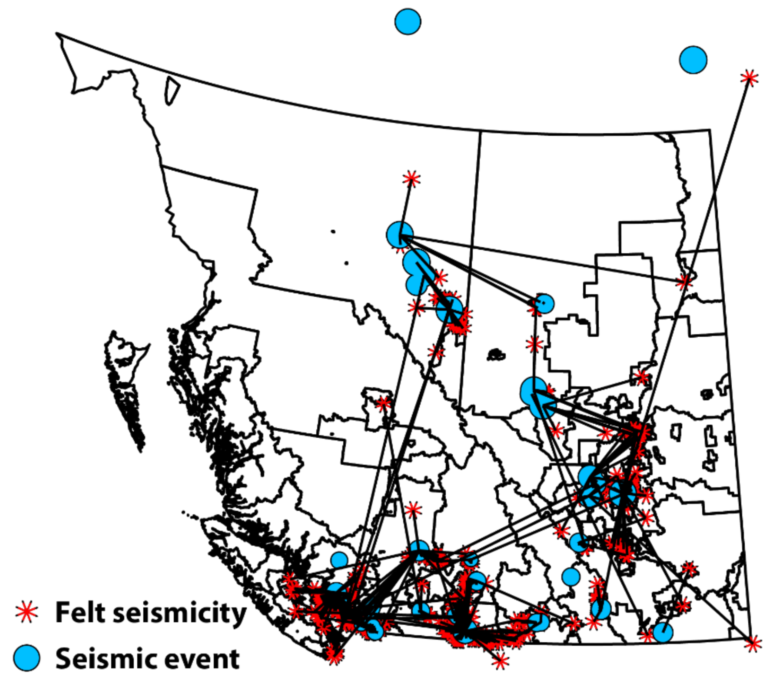


Figure 6.9: Comparison of locations of seismic events ≥M2.5 (blue circles) and locations where events were felt and subsequently reported (red stars). Event bubble sizes correlate to reported magnitude. Data obtained from NRCan.

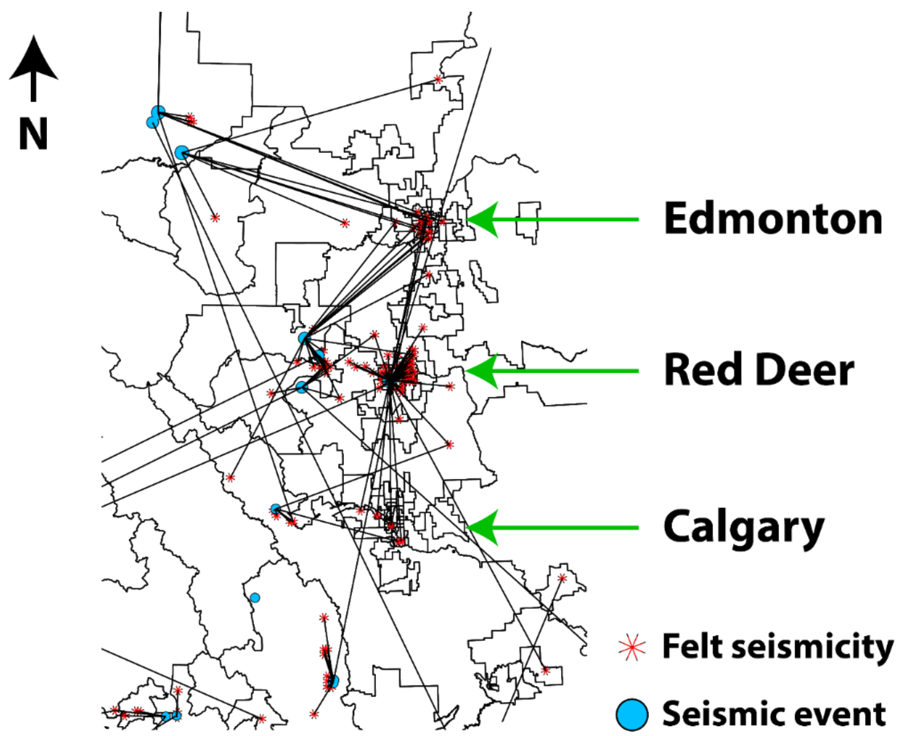


Figure 6.10: Comparison of locations of seismic events ≥M2.5 (blue circles) and locations where events were felt and subsequently reported (red stars). Event bubble sizes correlate to reported magnitude. Zoomed in to show the Edmonton-Calgary corridor in Alberta. Data obtained from NRCan.

Figure 6.11 combines the information from NRCan shown in Figure 6.9 and Figure 6.10 with FSAs where survey respondents indicated they had felt an earthquake. It is important to note that 68% of survey respondents have lived at their current residence for 10+ years (distribution for years of residence is shown in Figure B.1 in Appendix B), while the DYFI database used in this investigation begins in 2014. Generally speaking, there appears to be agreement between locations where survey respondents have felt an earthquake and where events were reported to NRCan as being felt. There is a difficulty in directly comparing the two types of reported events, as the survey only recorded the first three characters of the postal code, often leading to very large geographic areas being lumped together. This is evident in rural areas and particularly in the northern regions.

Figure 6.12 gives the population density of Alberta based on the 2016 census and Figure 6.13 gives the population density of British Columbia, which allows us to understand whether regions of high responses are representative of a higher population or of a higher interest in this topic.

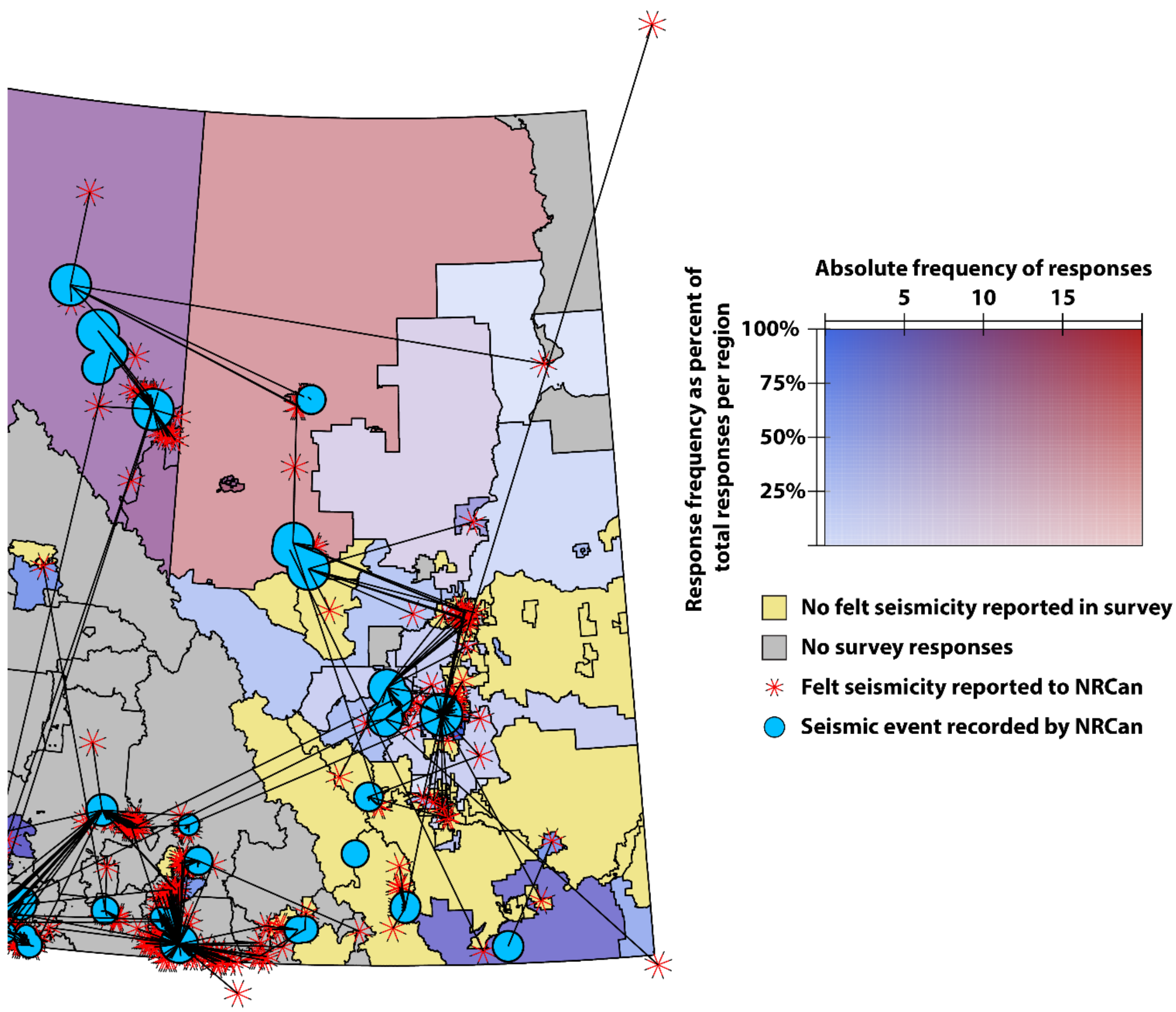


Figure 6.11: Comparison of locations of seismic events ≥M2.5 (blue circles) and locations where events were felt and subsequently reported to NRCan (red stars) with FSAs of respondents who indicated they had felt an earthquake (colour map). Event bubble sizes correlate to reported magnitude. Zoomed in to show Alberta and NE British Columbia. Data obtained from NRCan.

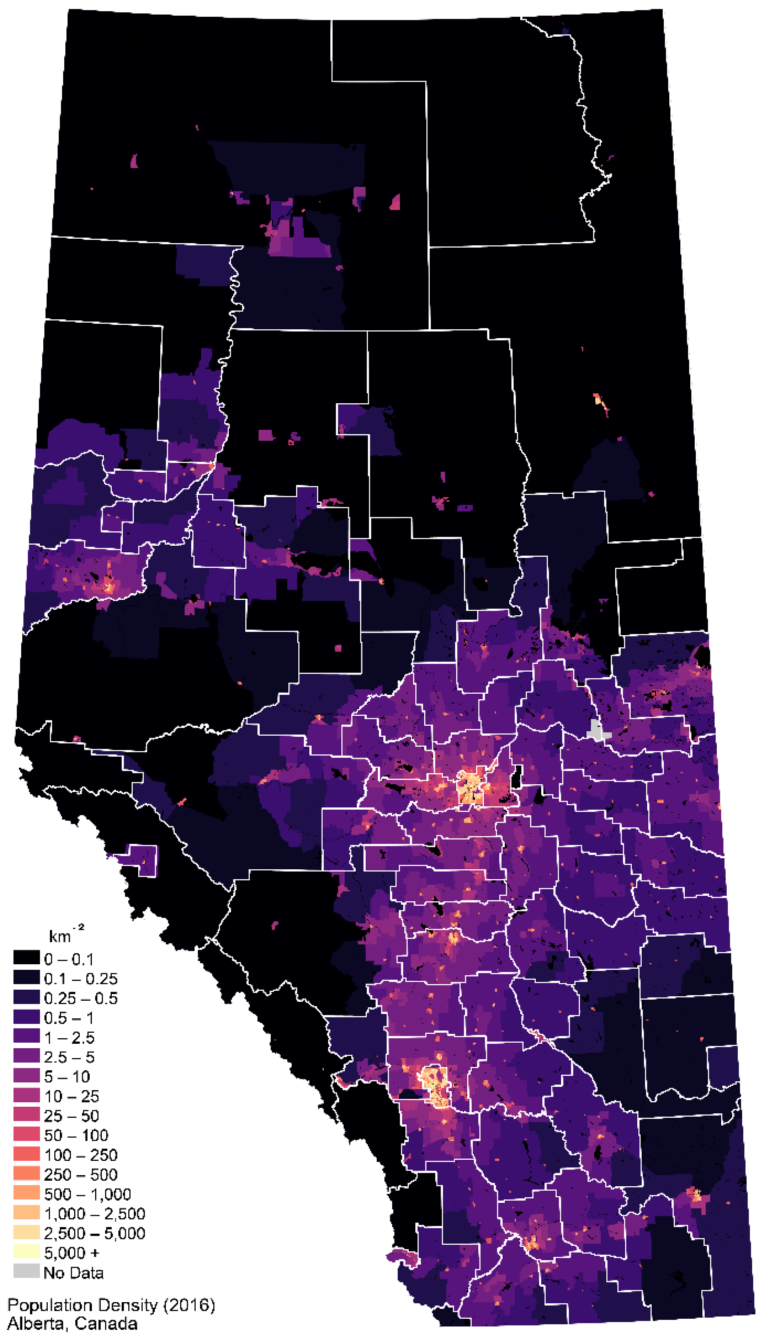


Figure 6.12: Population density of Alberta, 2016. Data from Canadian 2016 census. Figure obtained through Wikimedia Commons from awmcphee (username) (2020), with text size increased for easier viewing.

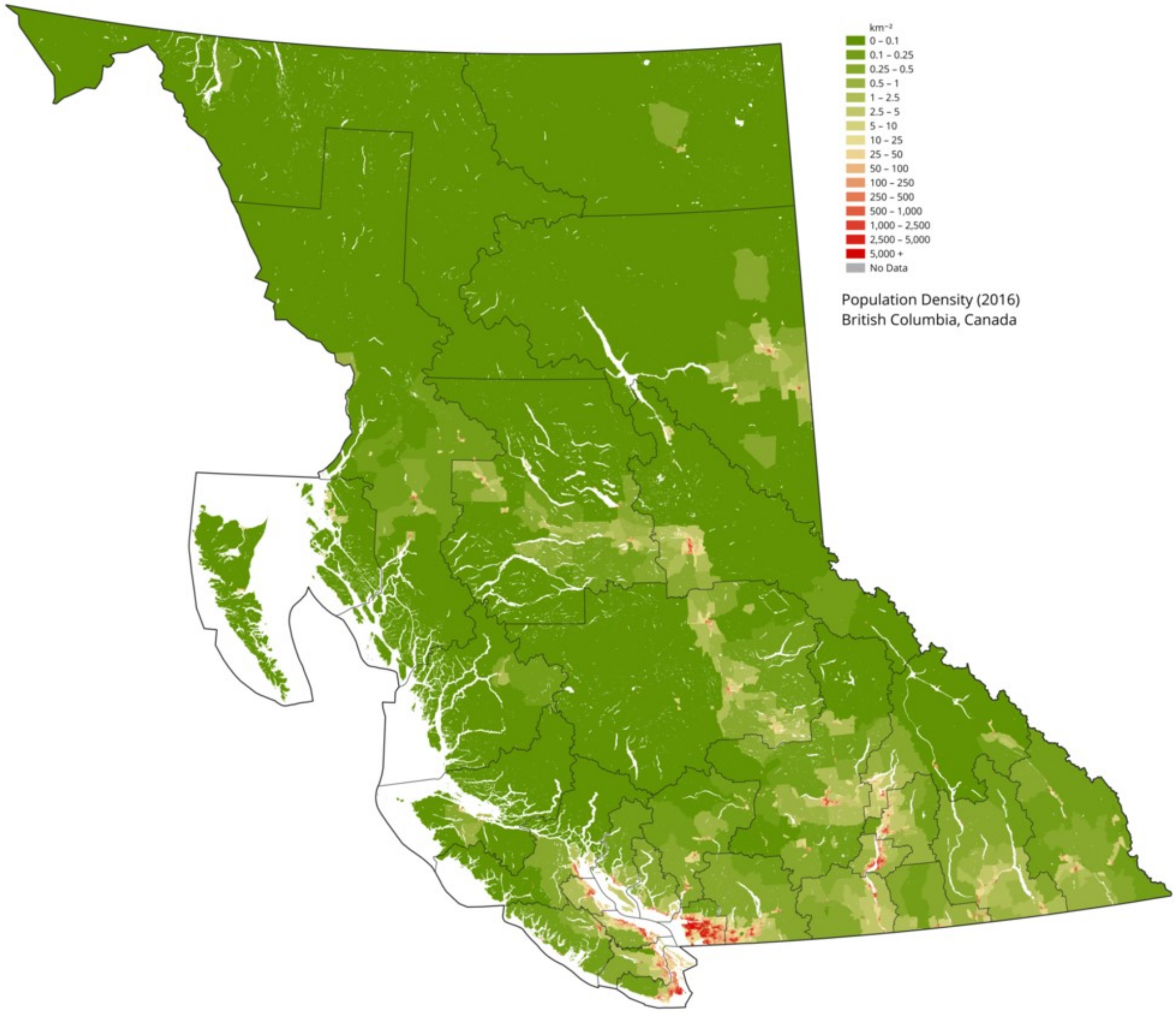


Figure 6.13: Map of the population of British Columbia in 2016. Data from Canadian 2016 census. Figure obtained through Wikimedia Commons from awmcphee (username) (2019).

Comparing Figure 6.11 with Figure 6.12, we see that the northwest corner of Alberta has a lower population density compared to central and southern Alberta, and yet it had a high number of responses. The same goes for the northeast corner of British Columbia, with a low population as seen in Figure 6.13. This higher rate of reported felt seismicity may be due to an increased level of oil and gas activity in northeast British Columbia and northwest Alberta, leading to a higher level of interest in the survey. It may also be due to higher levels of historic natural seismicity, such as the M5.3 event at Dawson Creek in 2001 (Cassidy et al., 2010). It could also be because earthquakes occur more frequently in this area (Kao et al., 2018), and as a result the DYFI tool may be more widely known and used by residents in this region. However, this discrepancy of population sizes and reported felt seismicity rates does not necessarily mean that these results should be discarded. Rather, this trend of high rates of reported seismicity in areas of lower population should be further investigated in future research by focusing on remote areas that experience more frequent seismic events.

Figure 6.9, Figure 6.10, and Figure 6.11 also highlight that events can be felt and reported by people despite a great geographic distance between them and any earthquake events. Surface intensity depends on geological conditions, which influences how far away from its epicenter an earthquake may be felt (Lowrie, 2007). Ground motion may be intensified in areas of looser materials as compared to areas of very hard subsurface. Looser and softer materials tend to accumulate in regions of flatter topography, whereas areas with higher relief tend to be comprised of harder, more competent materials that can better sustain higher slope angles. Allen and Wald (2007) used topography as a proxy for the shear wave velocity at a depth of 30 m ($V_S{}^{30}$) to create a global map with their interpretation of $V_S{}^{30}$ predictions.

In Figure 6.14, we compare this predicted $V_S{}^{30}$ data with the DYFI data from NRCan. The FSA regions used in the survey are overlaid as well for a visual aid to compare with other figures. Areas of high $V_S{}^{30}$ (green) are interpreted to be comprised of more competent materials than areas of low $V_S{}^{30}$ (white).

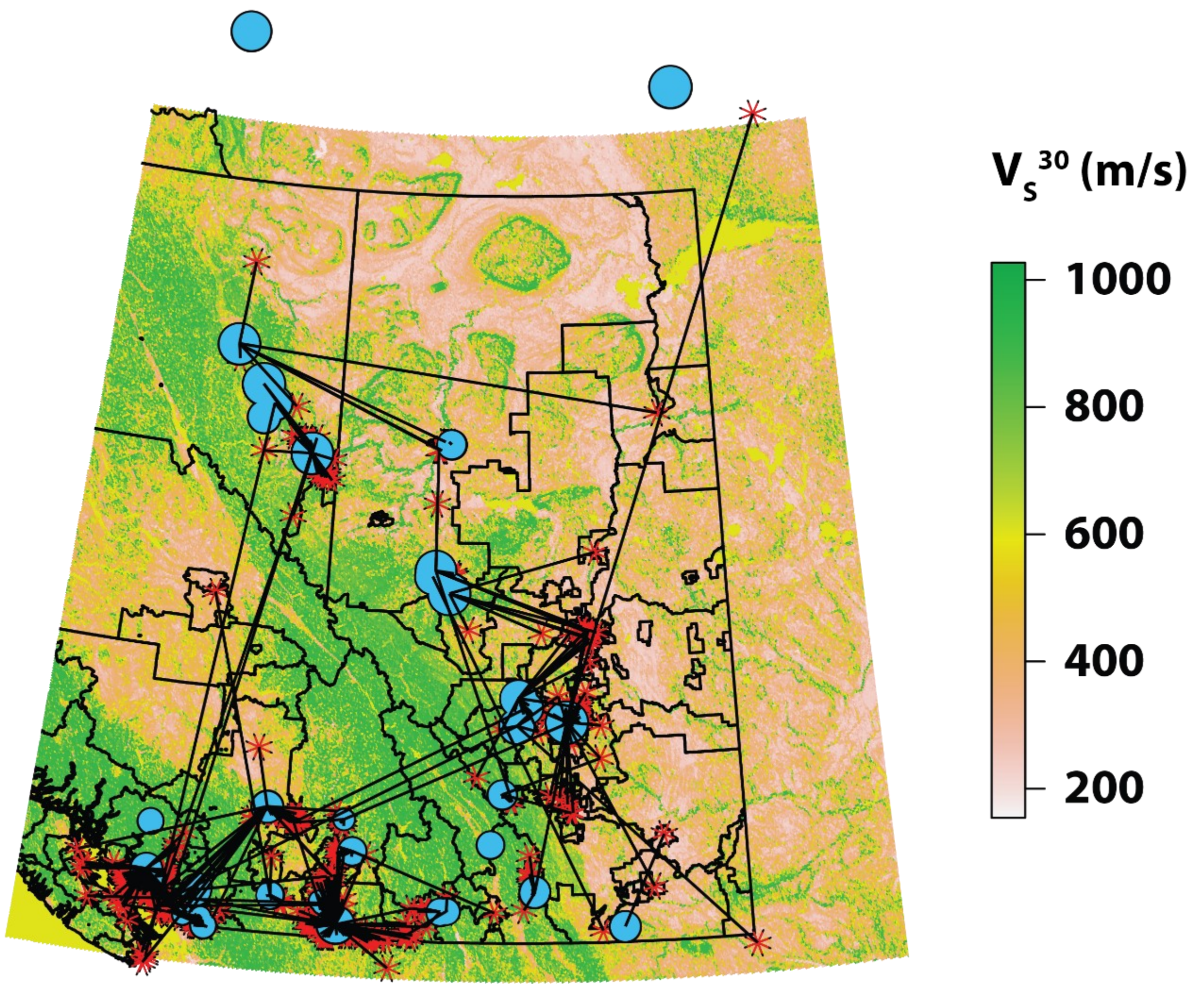


Figure 6.14: Comparison of locations of seismic events ≥M2.5 (blue circles) and locations where events were felt and subsequently reported (red stars). Event bubble sizes correlate to reported magnitude. Event and felt location data obtained from NRCan. Underlay shows predicted average shear wave velocity from the surface to a depth of 30 m ($V_S{}^{30}$), determined using topography as a proxy. $V_S{}^{30}$ data obtained through Allen and Wald (2007).

From Figure 6.14, we do see some correlation between V_S^{30} values and felt seismicity; namely that seismicity tends to be felt more in areas of lower V_S^{30} with looser materials. This looser material may allow shaking to be felt at greater distances from earthquake epicenters, as we see with the red star in the far top right of the image being connected back to its corresponding event in central Alberta, and the northeasternmost star within Alberta being connected back to an event in northeastern British Columbia. These two locations coincide with regions of relatively low V_S^{30}. However, flatter regions tend to be more populated due to ease of agriculture and access, meaning that there are more people in those regions to feel the seismicity as well. We see this population distribution in Figure 6.12 and Figure 6.13.

Although there are vast swaths of land in northern Alberta where seismicity has not been reported as felt, this does not mean that there has not been seismicity. We saw from Figure 6.12 that northern Alberta is sparsely populated, meaning there would be a lower chance of someone being in the right place at the right time to feel seismicity and report it. This may also be true for the region west of Edmonton along the mountains, although from Figure 6.14 we see that region has high V_S^{30} values, which suggest a lower likelihood of ground motion occurring at a level humans would feel. It must be considered that areas of higher population have more people available to feel potential seismicity and report it, so areas of higher population may report more seismicity. This does not necessarily mean that the hazard in those regions is higher. However, areas with high rates of seismicity reports may benefit from investigation into local seismic hazards.

From visual inspection, locations of felt seismicity reported to NRCan seem spatially correlated with regions where our 145 survey respondents have felt earthquakes. The locations of felt seismicity reported to NRCan also appear to be spatially correlated with regions of low V_S^{30}. This makes sense, as areas of lower V_S^{30} would tend to be comprised of looser materials which can amplify ground motion, increasing the likelihood that a seismic event will be felt by humans at the surface. However, locations of felt seismicity from both the survey and NRCan data appear to have some amount of correlation with population distribution as well. Logically, if there is nobody there, the earthquake will not be felt and reported.

Information such as DYFI reports could be used to update and enhance existing seismic hazard maps in Canada. This is a routine procedure in the United States (USGS, n.d.-b, n.d.-c) and undoubtedly the intention behind collecting Canadian DYFI data. However, it is possible that the Canadian version is less well known and thus less used by the general public. Future research could investigate spatial correlations between V_S^{30} and DYFI data and use that information to check the validity of Canadian seismic hazard models. Future research could also include a more extensive survey of whether residents have felt earthquakes where they live, using a more balanced sample that is a closer representation of Alberta’s and British Columbia’s population distributions.

Chapter 7: Limitations, additional analyses, and future research topic extensions

There are numerous ways to analyze a survey. While I have presented some in this thesis, there are many more that would shed light on different aspects of the data. There are also some limitations to this research. Below, I discuss some of the limitations, further analyses that I believe would be useful with these data (or similar studies), and possible future research topic extensions that would expand from our research questions. This research took us on a journey of survey design and analysis as well as discovery about Canadian and Albertan opinions. Some of the best journeys in life end where they began, and in the same way, some of the analysis techniques I used prior to designing and analyzing this survey could be useful in future analyses of these data.

Prior to the creation of the survey this thesis focuses on, we used a toy model (Marzuoli, 2018) and a small test survey to understand the process and nuance of survey creation and analysis. The first step of this process was to design a toy model of simplified simulated data in which it was known how the respondents fit together before we analyzed the "responses." The toy model allowed us to create a preliminary analysis workflow which included histograms, dendrograms, correlograms, stacked bar plots, and plots of median responses.

I then applied this workflow to the small test survey to analyze responses of industry professionals in an induced seismicity (IS) survey. The survey was designed and distributed by Scott McKean, a geomechanical engineering PhD student at the University of Calgary, as part of his research into IS in the REDEVELOP program. Since his survey aligned so closely with my thesis topic, he asked me for advice in his design, and then generously offered me the collected data to work with.

The workflow developed for the toy model and used on McKean's survey was ultimately not what I applied to the survey in this thesis, but these were essential stepping stones in the process of learning to create and analyze a survey. It allowed me to have a better understanding of the types of questions I could and should ask, and the amount of work that goes into analysis. Pieces of the original workflow may also be useful in future analyses of the main survey, as I will discuss below.

7.1 Limitations

As with any research, the survey study in this thesis has some limitations. Due to the manner of contacting potential respondents, via word of mouth, it is difficult to know if our survey reached a truly representative sample of Alberta. While this word of mouth method suited our budget and provided us with an ample number of responses, a more targeted survey distribution may have provided a more streamlined set of representative data.

Due to the nature of Factorial Survey Experiment (FSE) scenario designs, we could not reasonably include more attributes than we did, making the outcome of this section partially limited. Future research using the same or similar methods could adjust the FSE scenario attributes to change the focus of the research slightly if desired, perhaps to compare different energy sources.

We collected only the first three characters of each respondent's postal code (on a voluntary basis), which allowed the respondents to remain more anonymous. However, in some rural regions this leads to vast geographic sections being evaluated as one unit, while urban areas are more finely divided. Collecting a more precise location from each respondent, for example using the whole postal code, would allow for more precise geographic investigations.

The majority of responses we collected were from Alberta, giving a relatively clear picture of opinions and perceptions across the province. The minimal and patchy responses from other provinces means that we are unable to compare opinions and perceptions between provinces.

While we collected a variety of demographic data from our respondents, we did not ask what their political views were. In the UK, Whitmarsh et al. (2015) have shown that political affiliation can be a strong predictor of attitudes towards shale gas and hydraulic fracturing (HF). In the open-ended comment box at the end of the survey, some respondents indicated that they would have given different answers under a different government. The use of open-ended questions can clearly be enlightening, and while they tend to be more tedious to analyze than quantitative questions, we may have learned even more from our participants had we included a few more of them throughout the survey.

A final limitation I will touch on is our use of the category "environmental organization" in our questions about work experience and about the various stakeholder parties regarding trust, transparency, and responsibility for adverse outcomes. At the time of creating the survey, it was clear in our minds that we meant organizations that typically hold anti-HF and anti-oil and gas views. However, during the analysis we realized that some of our respondents may have interpreted this to mean organizations that work in environmental monitoring and remediation, many of whom work closely with the oil and gas industry. A clearer communication of our intended usage would have allowed us to also explore the difference in opinion between those who have energy-industry work experience, those who have experience working with typically anti-industry groups, and those who have no experience with either. A better understanding of their similarities and differences could be valuable in communication efforts and policy-making.

7.2 Additional analyses

We have presented a variety of analyses in this thesis but of course there are many more options out there. Sometimes an exploratory analysis, where one looks at the data for patterns before asking a specific research question, can be valuable and inform the direction of the rest of the analysis. One such exploratory method is the cluster analysis. This can help expand a simple analysis such as a mean, median, mode analysis, into something that is more nuanced and balanced when independent clusters respond noticeably differently.

Patterns can also be found and examined using a latent class (LC) analysis. This examines underlying variables, which are often not recorded in the survey, and their effect on some of the variables that were collected and analyzed.

Here, I briefly discuss the use of cluster analyses, visualization tools, and LC analyses in the context of survey data. It is my belief that they would provide useful insights to the data from this survey or others like it, and I would recommend them for additional future research techniques.

7.2.1 Cluster analysis

A cluster analysis, in the form of a dendrogram for example, can be used to determine any existing patterns among responses or respondents. Different groups may be made up of a specific age category, educational background, gender, location, etc., or they may be combinations of multiple categories. These groups may then be influenced differently from one another by various aspects of consideration. Knowing which groups of people respond in specific ways can be useful when it comes to making recommendations based on the survey. Two examples of hierarchical cluster analyses using dendrograms are given below: one from the toy model and one from McKean's survey.

In the toy model we developed, we started with two groups, A and B. There were four yes/no "questions," and each group contained 10 "respondents." These data are shown in Table 7.1 below. The first two questions clearly identify groups A and B, which demonstrate opposing views. Question three has more ambiguity with an 80-20 split in responses for each group. The responses in question four are equally divided.

Table 7.1: Simulated response data to four-question, binary option survey with two groups (A & B) of 10 respondents each. (Toy model)

Group	ID Number	Question 1	Question 2	Question 3	Question 4
A	1	Yes	No	Yes	Yes
	2	Yes	No	Yes	Yes
	3	Yes	No	Yes	Yes
	4	Yes	No	Yes	Yes
	5	Yes	No	Yes	Yes
	6	Yes	No	Yes	No
	7	Yes	No	Yes	No
	8	Yes	No	Yes	No
	9	Yes	No	No	No
	10	Yes	No	No	No
B	11	No	Yes	Yes	Yes
	12	No	Yes	Yes	Yes
	13	No	Yes	No	Yes
	14	No	Yes	No	Yes
	15	No	Yes	No	Yes
	16	No	Yes	No	No
	17	No	Yes	No	No
	18	No	Yes	No	No
	19	No	Yes	No	No
	20	No	Yes	No	No

We then used a dendrogram to illustrate the hierarchical clustering of these data, as shown in Figure 7.1 below. Groups A and B are shown in red boxes, but we can also see that certain subgroups emerge. Within group A, numbers 1–5 are the most similar to one another (indeed, they are identical if we look at Table 7.1), then somewhat similar to numbers 6–8 (who, again, are identical to one another), and least similar to numbers 9 and 10. Looking at Table 7.1, we can see where these distinctions are made, illustrated using dashed lines within each group.

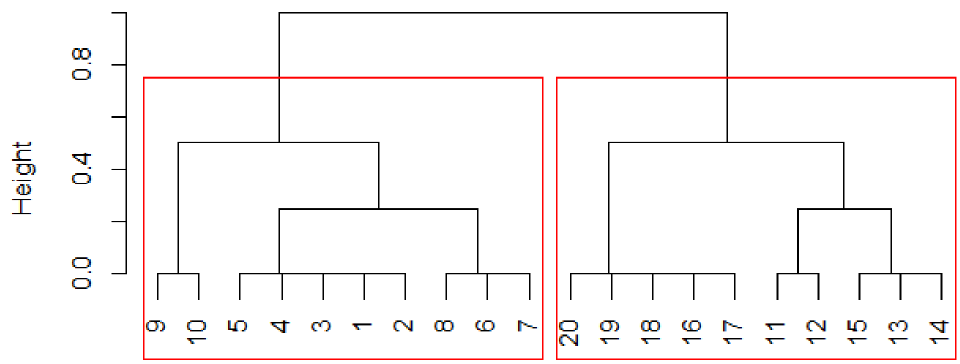


Figure 7.1: Dendrogram of toy model data with groups A and B (clusters one and two, L–R) shown in red boxes.

This analysis was also applied to the data in McKean's survey, resulting in the dendrogram in Figure 7.2. These data are significantly more "messy" than the data in the toy model, which is to be expected, but there still appear to be four distinct clusters, illustrated by the dashed red boxes.

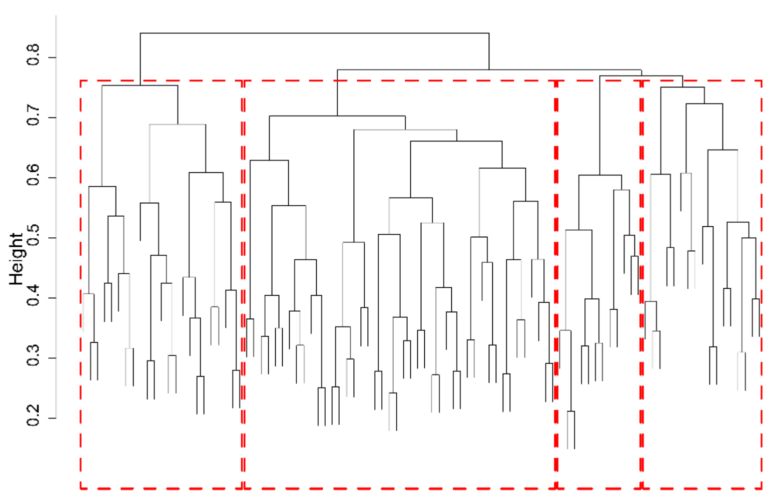


Figure 7.2: Dendrogram of data from McKean's survey with four clusters shown in dashed red boxes. Clusters are numbered 1–4 from L–R.

A point against this type of clustering analysis is that the number of clusters chosen depends on the researcher, and different people may reach different conclusions based on the same data set if they choose a different number of clusters (Schreiber & Pekarik, 2014).

In general, a cluster analysis can help identify different opinions and influences on different groups so that each group can be approached and interacted with appropriately. For example, if one clustered group is particularly concerned about use of fresh water in HF operations but not very likely to attend informational sessions in their community, operators and regulators would not find hosting an informational session about water use to be particularly impactful. Knowing this ahead of time could give the opportunity to prepare other forms of communication that may be more effective.

7.2.2 Visualizations of cluster analyses

Cluster analysis is a very useful tool and opens up many other avenues of analysis. Once clusters have been identified, the differences between them can be visualized using stacked bar plots and median response plots. These visualizations help us to see what nuances there may be in the data that could affect planning outcomes. In some of the examples below, I use planning the advertising and layout of a theme park to demonstrate this.

7.2.2.1 Stacked bar plots

Stacked bar plots can be useful when visualizing the different response distributions of each cluster, allowing us to easily see useful patterns in the data. With a stacked bar plot, we can easily see patterns both between clusters and within clusters. An example from the toy model is shown in Figure 7.3, which gives stacked bar plots of the two clusters for all four questions.

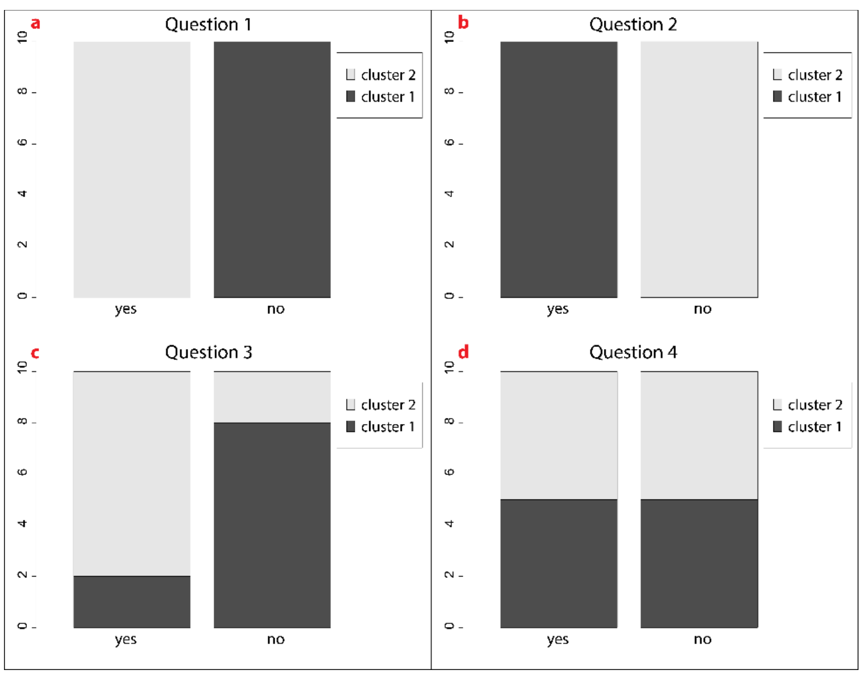


Figure 7.3: Stacked bar plots of the frequency of synthetic responses to the four questions in the toy model. (a) and (b) show the opposing viewpoints of the two clusters, (c) shows the 80–20 split in Question Three, and (d) shows the equal division of responses to Question Four.

With this type of visualization, we can compare the two clusters to one another and also examine the distributions within each cluster. Looking at Question 3 in Figure 7.3, we can see that cluster one is skewed towards "no" and cluster two is skewed towards "yes." We can compare distributions within clusters, as I just did, or between clusters — for example, in Question 1 cluster one answered unanimously "no" while cluster two answered unanimously "yes." Let us imagine that Question 3 asked "Do you enjoy thrill rides at theme parks?" and that cluster one contains older adults while cluster two contains younger adults and children. We would now have the information to be able to decide on an effective advertising strategy for that theme park since we have a better idea of who our target market is. Knowing more about your target demographic can lead to more effective policy and communication strategies, making stacked bar plots a useful tool for easy interpretation of cluster data.

7.2.2.2 Median response plots

Median response plots allow comparison of two or more questions with regard to the proportion of responses each cluster had to each question. That is, we can analyze the relationship between two or more variables. A plot of the median response to a question, as well as the spread between the 33rd and 67th percentiles, allows comparison of several questions at once. They also show us some of the nuance behind each question. For example, the regular histogram of Question 3 is shown in Figure 7.4. It would appear that there is a plain 50-50 split in responses, but is there more to this story?

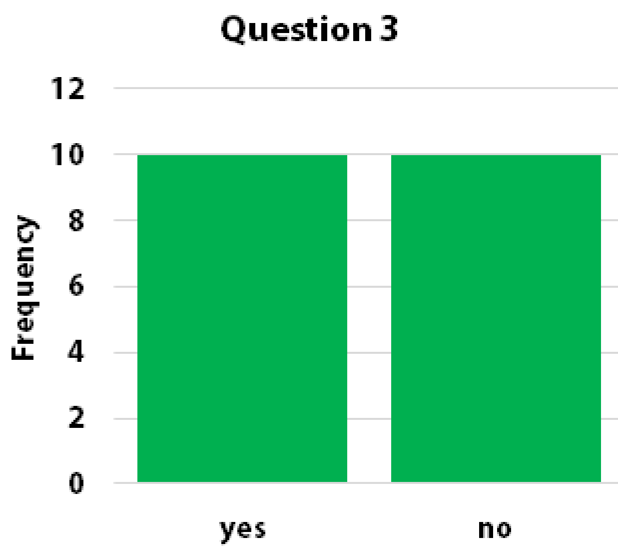


Figure 7.4: Histogram of responses to Question 3 of the toy model.

An example of a median response plot is seen in Figure 7.5, with the accompanying scale in Figure 7.6. The scale in Figure 7.6 indicates that a value of 0.5 is "yes" and 1 is a "no" for the toy model data displayed in Figure 7.5. We see that the two clusters had opposite median responses in Question 3, a nuance that is not obvious from the histogram in Figure 7.4.

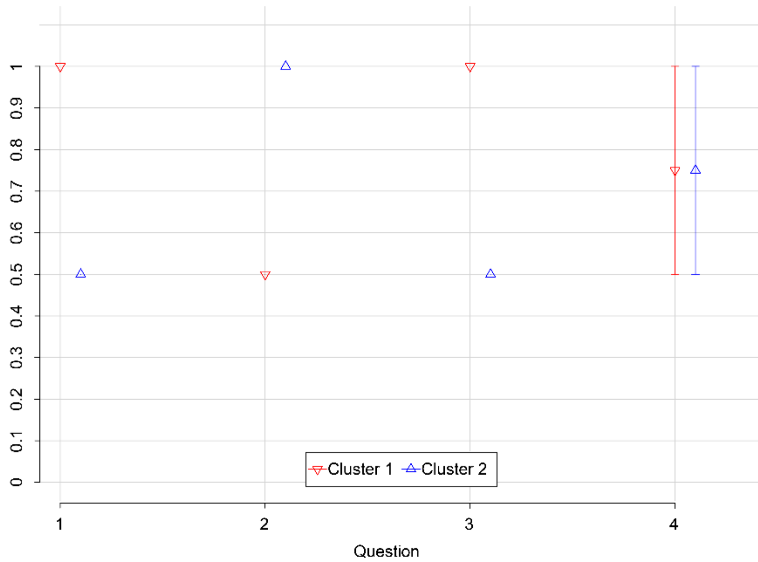


Figure 7.5: Median and spread of responses within each cluster for the toy model. The accompanying scale is shown in Figure 7.6. If no spread is visible, the 33rd and 67th percentiles were the same as the median response.

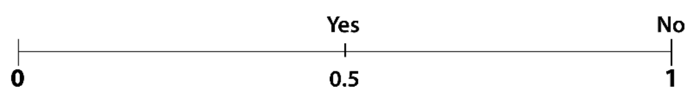


Figure 7.6: Scale from 0 to 1 indicating corresponding response options for questions in the toy model. Accompanies Figure 7.5. Responses were either "yes" (0.5) or "no" (1).

Let us again imagine that Question 3 asked "Do you enjoy thrill rides at theme parks?" and that cluster one contains older adults while cluster two contains younger adults and children. Let us also now imagine that Question 1 asked "Do you like cotton candy?" We can now infer that a cotton candy cart parked near a thrill ride lineup is most likely to have customers who are young adults and children. Information like this would help us plan the layout of our theme park. Had we used only plain histograms like the one in Figure 7.4, we would not have known nearly as much about our target market, which may lead to suboptimal layout plans for our theme park.

Median response plots are also useful for more complex data and questions, like that of McKean's survey. In Figure 7.7, we see the median and spread of responses within each cluster for four questions of interest from McKean's survey. The questions themselves are withheld for privacy reasons, but I instead provide an example to aid comprehension. The y-axis represents the response options available to participants; for example, from strongly disagree to strongly agree. The accompanying scale can be seen in Figure 7.8. It should be noted that "not sure" has been placed between slightly disagree and neutral, as it is most similar to neutral rather than either strongly disagree or strongly agree (as placement on the far left or far right hand sides would suggest). Normalizing response options to a scale of 0 to 1 allows comparison of multiple questions on the same plot, even if they have a variety of response categories.

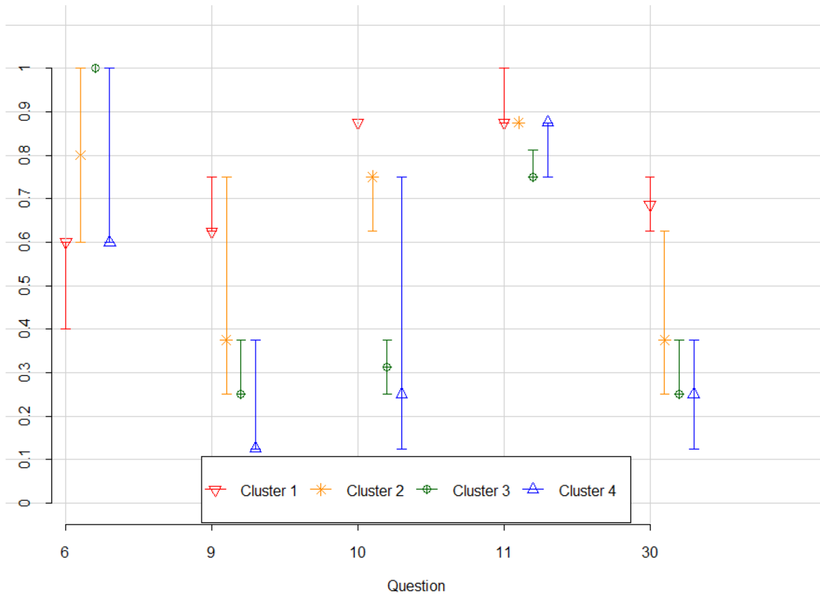


Figure 7.7: Median and spread of responses within each cluster for four questions of interest from McKean's survey. The accompanying scale is shown in Figure 7.8. If no spread is visible, the 33rd and 67th percentiles were the same as the median response.

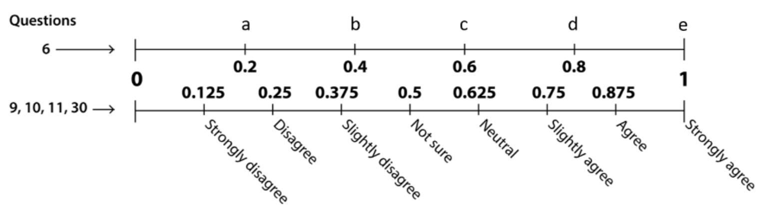


Figure 7.8: Scale from 0 to 1 indicating corresponding response options for four questions of interest from McKean's survey. Accompanies Figure 7.7. Question six has five different options, and questions 9, 10, 11, and 30 range between strongly disagree and strongly agree. "Not sure" was placed to the left of neutral to avoid associating it with either strongly agree or strongly disagree.

For example, let us imagine that Question 10 asked participants to respond to the statement "I enjoy Top 40 Pop Music" and that clusters one through four contain children under 18, university-aged adults, middle-aged adults, and elderly adults respectively. Let us also imagine that Question 6 asked "What is your favourite planet?" with "a" through "e" response options of Earth, Mars, Jupiter, Saturn, and Uranus, respectively. We can now compare these two questions and infer that a pop song about Jupiter would likely be most popular with children under 18, with some university-aged and elderly adults enjoying it but few, if any, middle-aged adults. Therefore, if we know our theme park will primarily cater to children and young adults, this type of song would be appropriate to play over the speakers on the grounds. The median response plot is allowing us to analyze the relationship between the two variables of music style and planet preference among different clusters of age groups. We are also easily able to compare multiple questions at once.

As a visualization tool for a cluster analysis, median response plots have the potential to reveal a considerable amount of information from a survey, hence the recommendation of its future application to this or other studies. These plots allow us to explore the interaction between variables and draw out information that could be useful in policy and communication strategies.

7.2.3 Latent class analysis

While we have thus far examined the relationships between directly observed variables, it is also possible that some of these apparent relationships can be explained (or nullified) by an underlying or latent variable which was not directly measured in the survey (Hagenaars & McCutcheon, 2002; Vermunt & Magidson, 2004). For example, a variable we did not measure was socioeconomic status. This could underly things like education level or whether a respondent owns land, which in turn appear to have an effect on the likelihood of being a protester or keener as we saw in Section 5.3.

LC analyses can also be used in cluster analyses, called an exploratory latent class analysis or latent class cluster analysis (Hagenaars & McCutcheon, 2002; Vermunt & Magidson, 2004). In fact, there is some evidence that LC cluster analyses perform better than other clustering methods, including K-means and hierarchical (Schreiber & Pekarik, 2014; Vermunt & Magidson, 2004). With this in mind, it may be informative to perform both a hierarchical clustering analysis, resulting in a dendrogram like the ones shown in Section 7.2.1, and an LC clustering analysis on this survey data or similar studies in the future.

7.3 Future research topic extensions

In general, there continues to be room for expansion in knowledge and research around oil and gas-related issues of interest to the public and policy makers in western Canada. Oil and gas are resources that are relied upon and the impacts of related policies on the economy, industry, and public should be solidly understood by policy makers, industry groups, and the public alike.

There are some specific issues and results that should be further explored, based on the findings in this thesis, which I will discuss below. Whether these are explored using the same techniques as this thesis, or the techniques suggested earlier in this chapter, or any other of the multitude of valid analysis techniques would be up to whichever researcher takes up the task.

Although this research took a basic look at whether there were spatial correlations in opinions of HF, this could be done in greater detail. It may be enlightening to look at areas of HF and oil and gas activity in comparison with areas of non-activity. Do areas of activity have a more polarized opinion? Higher ratings? Lower ratings? Areas of high activity may have economic ties to the industry, improving perceptions, but also take a larger share of potential negative impacts, worsening perceptions. Studying regional effects may require an expanded data set and more surveys. This is especially true if one is interested in examining rural areas in greater detail, as using only the first three characters of the postal code lumps large swaths of rural areas into one region, potentially obscuring useful data. Perhaps a future survey could be targeted to these areas of interest, and respondent location data collected more precisely (e.g. full postal code instead of partial), so as to examine the details of opinions in these regions. Results of this may be of interest to industry operators and regulators and affect policy decisions.

The level of knowledge a respondent has seems correlated with their opinion of HF scenarios. Future research should explore the extent to which knowledge will influence HF perceptions. Will information campaigns have a significant impact on the perceptions of oil and gas operations (or indeed, any contentious topic)? Is there a significant difference in influence between objective and subjective knowledge? Perhaps short knowledge assessments and opinion surveys could be distributed both before and after informational sessions in communities to explore this, or researchers could ask those same questions before and after a short informational video.

Another immediate recommendation for future work includes determining external factors that could influence protest and keener voters, such as availability of accurate and easy to understand information, how it is presented (visual, verbal, numerical, etc.), the medium in which it is presented (social media, news, informational meetings, etc.), and who presents it (academic, industry, regulatory, or environmental groups), rather than intrinsic factors such as the respondent's age or gender. This suggestion would be tricky to fulfill, but identifying whether respondents are aware of existing resources or feel that existing resources are unavailable or difficult to interpret and then comparing that against the strength of their support or opposition to HF operations could be a start.

An intrinsic factor that we did not explore was political leanings, although this has been investigated in previous studies including those by Whitmarsh et al. (2015) and Corner et al. (2012), in the context of HF and climate change, respectively. This could be an interesting avenue to explore from a policy perspective in future research, and could be accomplished by asking which party from a list of options the respondent would be most likely to support, as Whitmarsh et al. (2015) did.

The correlation between V_S^{30} data and “Did You Feel It” (DYFI) data discussed in Chapter 6 could prove valuable in updating and validating seismic hazard models of Canada. Future research could investigate spatial correlations between these two types of data and use that information to check the validity of Canadian seismic hazard models.

Future research could also include a more extensive survey of whether residents have felt earthquakes where they live, using a more balanced sample that is a closer representation of Alberta's population distribution.

The final question of the survey was open ended, allowing respondents to include additional information or comments on the survey. One theme that is brought up by multiple respondents is the lack of climate change consideration in the survey. This was left out of the survey in order to keep the scope to a manageable size, as climate change is a complex issue on its own. However, it is undeniably related to the oil and gas industry, particularly in terms of public perception, and investigation into how climate change attitudes and beliefs relate to oil and gas perceptions could be extremely helpful in informing policy decisions in the future. A potential study focus could be whether strong belief in climate change and the belief that something can and should be done to mitigate its effects is correlated with opinions of HF and the oil and gas industry. Were this to be true, organizations that are forthcoming and transparent about their efforts to mitigate potential negative impacts to the environment and climate could see a rise in their social license to operate.

Chapter 8: Conclusions and recommendations

8.1 Conclusions

The combination of typical survey questions and Factorial Survey Experiment (FSE) vignette scenarios used for this thesis gives a more thorough view into public perceptions of oil and gas in western Canada than currently exists in this field. Those of our respondents who shared their location were primarily from Alberta (953), with additional responses from British Columbia (99), Saskatchewan (14), Manitoba (2), Ontario (9), Quebec (2), Nova Scotia (1), and Yukon (1).

About 69% of our respondents were in their prime working years of 25–64, matching the approximately 69.3% of Canadians who fall into the same range according to the 2016 census. Approximately 74% of our respondents had some form of post-secondary education, which is slightly higher than the typical value for Canada, where roughly 65% of the working-age population has some post-secondary education according to the 2016 census. Of the respondents who chose to share their gender with us, 46.8% were male, 36.3% were female, and 0.6% were other. This is not truly representative of the roughly 50-50 split in genders in Canada, but as energy is assumed to be a topic that primarily interests men, it is not surprising they are the larger group.

We asked about work experience with a handful of organizations related to the energy industry, and found that roughly half of our respondents had work experience or a family member who had work experience directly in the energy industry, while about a third had no work experience connection to energy-related organizations at all. We also asked how knowledgeable respondents felt themselves to be about the energy industry in western Canada, and approximately a third responded that they were “somewhat knowledgeable.” Less than a quarter indicated that they were “very knowledgeable,” but only 4% said they were “not at all knowledgeable.” To further test their knowledge, we asked five true or false questions about hydraulic fracturing (HF). The mode level of objective knowledge was five out of five questions correct, and the median was four out of five correct. This indicates that respondents were fairly knowledgeable about HF, and relatively accurate in their assessment of their own knowledge about the energy industry. Two of these true or false questions had a higher rate of incorrect responses. They related to how long HF has been in use in Alberta and the depth at which HF operations occur in the subsurface. It seems that although respondents understand the basics of what HF is, there is some confusion about how old the practice is and the depths at which it typically takes place in western Canada.

We found that coal was strongly opposed, and support for nuclear energy was low, while oil, natural gas, solar, wind, and geothermal energy sources were all relatively well supported. These findings suggest that although there is significant support for oil and natural gas, there may also be public support for investments into renewable energy in western Canada.

In a list of six items related to the oil and gas industry, transporting petroleum products via pipeline was rated the safest with a mean rating of “somewhat safe.” Transporting petroleum products via train was rated the riskiest, with a mean rating between “uncertain” and “somewhat risky.” Placing oil and gas wells near drinking water wells or surface water bodies was also rated to be fairly risky. Traditional vertical oil and gas wells, HF, and economic reliance on oil and gas exploration formed the middle section (in order of increasing risk ratings). The relatively risky rating of economic reliance on oil and gas exploration signifies that diversifying the economy may be prudent in the eyes of the public. Combined with the positive support for renewable energies, it may be time for oil and gas industry operators to add renewables to their repertoire.

When we asked respondents to rate their level of concern for an array of items related to the oil and gas industry, we found that the top three were surface spills, overuse of local fresh water, and underground contamination of freshwater aquifers. This makes water-related items the category of highest concern. Light pollution at night was the least concerning, and we found that induced seismicity (IS) had a similar concern distribution to odours and dust/air pollution; all three categories were in the middle of the pack for level of concern.

In asking about trustworthiness and transparency of different stakeholder parties related to the oil and gas industry, we saw that the two characteristics seem to be correlated. The top three most trusted parties were local oil and gas companies, government regulators, and local municipalities, while local politicians were the least trustworthy. Likewise, the top three most transparent parties were local oil and gas companies, government regulators, and local municipalities. The least transparent was tied between local politicians and environmental organizations. This correlation of trust and transparency hints that transparency from industry may positively affect the perceived trustworthiness of stakeholders in the oil and gas industry, particularly when combined with balanced coverage of oil and gas topics in the media.

Acceptability of HF was found to be bimodal when respondents were asked outright, with opinions likely influenced by potential compensation and the economic impacts of oil and gas operations. We also found that acceptability of potential IS from HF operations could be increased if certain measures were taken, such as sharing research data related to the decision-making with the public. This action would display transparency, which could improve trust in the oil and gas industry.

From the FSE vignette scenarios, we learned that acceptability of HF often depends on the trade-offs each operation entails. There was generally higher support for (hypothetical) operations that were located farther from homes, involved at least some minimum level of community consultation, offered economic or financial benefits to the community, and anticipated lower levels of seismicity. This amounts to an overall “Not In My Back Yard” (NIMBY) attitude combined with a desire for people to be informed about what goes on in their community and sharing of economic benefits.

There was a correlation between higher subjective knowledge and higher scenario ratings, which implies that information campaigns may have influence over public opinion of HF. However, public opinion is a multi-faceted, nuanced topic that will be influenced by more than just knowledge, and so any effort to change opinion must not focus solely on knowledge and expect spectacular results.

The FSE vignette scenarios also allowed us to see that some respondent characteristics make a person less likely to be a protester, and more likely to be a keener: increasing support of oil and increasing social media use. We also saw that higher perception of risk levels and higher levels of concern increased the likelihood of being a protester and decreased the likelihood of being a keener. Both keeners and protesters tended to indicate that they had a higher level of subjective knowledge and that they belonged to higher age categories. On the other hand, respondents who were more influenced by compensation, lived in an urban area, lived in their current area for longer periods of time, and had higher levels of education tended to be less likely to be either a protester or a keener.

When we asked respondents about their earthquake experience, we found that nearly half had experienced at least one earthquake at some time in their life. Approximately 15% of our respondents had experienced at least one earthquake where they currently lived. Only 145 of these also shared a valid Forward Sortation Area (FSA) with us, but this allowed us to do a preliminary comparison of spatial distribution of felt seismicity between our respondents and the Natural Resources Canada “Did You Feel It” (DYFI) database. From visual inspection, we found that there was good spatial correlation between locations of felt seismicity found in the survey and DYFI felt seismicity locations. There also appeared to be spatial correlation of felt seismicity with regions of low V_S^{30}, where there is anticipated to be looser subsurface materials that are more prone to large amounts of shaking. We also found that earthquake experience did not seem to affect a respondent’s opinion of IS acceptability, hinting that acceptability rides more on potential consequences of IS than it does on the actual shaking.

This thesis encompassed a broad range of topics related to perception of the oil and gas industry, and the journey was highly instructive. It answered a handful of preliminary questions but also opened the door for further investigation along many different avenues, as discussed in Chapter 7.

Our six main research questions were:

1. **What is the process of designing and analyzing a survey on public perceptions of the oil and gas industry in western Canada?**
   The design process for a survey was complex and took over 10 months to complete. Learning to design a survey included the use of a toy model and a small “real” survey in order to work out the kinks and get the hang of things. The analysis included the toy model and small survey, and then used mean, median, mode, histogram, and linear regression model techniques on the main survey to tease out answers to the rest of the research questions.
2. **What is the state of public perception, and therefore social license, of the industry?**
   Opinion and support of a variety of oil and gas-related topics were often bimodal and polarized. Public perceptions could be improved by increasing transparency and providing easy access to accurate, unbiased information about local operations to the public.

3. **Of the studied attributes, which have the highest influence on support for or opposition to HF scenarios?**
   Community benefits had the strongest positive influence on the FSE scenario ratings, while increasing levels of anticipated seismicity had increasingly negative impacts on ratings. However, distance from the operation and community consultation, communication, and involvement also had significant impacts on the FSE scenario ratings. Together, these four attributes appeared to form the largest part of the picture when evaluating the FSE scenarios.
4. **What underlying characteristics contribute to support for HF scenarios?**
   HF scenarios that were located farther from homes, had a minimum level of community consultation, provided financial or economic benefits to the community, and had lower levels of anticipated seismicity showed higher levels of support from respondents. Overall support of oil and gas as energy sources tend to be associated with higher support for HF scenarios, as do lower levels of concern and negative risk perceptions associated with oil and gas activities.
5. **Which respondent characteristics influence the likelihood of being a protester or keener with regard to HF operations?**
   Increasing support of oil and increasing frequency of social media use make it more likely that a person will be a keener and less likely that they will be a protester. Higher perception of risk levels and higher levels of concern make it more likely that a person will be a protester and less likely that they will be a keener.
   Both protesters and keeners are more likely to have a higher level of subjective knowledge and be from higher age categories.
   Both protesters and keeners are less likely to: be highly influenced by compensation, reside in urban areas, have lived at their current residence for a long period of time, and have higher levels of education.
6. **How do locations of felt earthquakes compare to HF locations? To topography? To population distribution?**
   HF locations appear to have little correlation with felt seismicity, and little correlation with protest and keener locations. There does appear to be some correlation of felt seismicity and topography, with felt seismicity tending to be located in flatter regions where the subsurface is composed of looser material that is more disposed to ground motion. There also appears to be some correlation of felt seismicity with population distribution. Areas of higher population density tend to have more reports of felt seismicity than sparsely populated areas. The population distribution itself also seems to be correlated with topography, with greater populations in flatter areas that are easier to access and to use for agricultural purposes.

8.2 Recommendations

Based on the findings in this thesis, some recommendations can be made to industry and policy makers.

Industry operators should be transparent in their operations, for example by publicly sharing information and data related to decision-making processes that affect communities. Theodori et al. (2014) also recommend this. Sharing information with the public, including incidents and project design decisions, includes communities in the decision-making process and allows residents to develop informed opinions on local operations. It would seem that trust is correlated with transparency, and so having greater transparency in operations could improve public trust. This would also apply to regulators, as transparency of regulations will increase trust of both the operators who must adhere to regulations as well as the public who are affected by how operations are regulated and completed.

News media is a major source of information about the oil and gas industry, which gives it the power to influence public perceptions. It is important that objective and clear information on oil and gas topics be easily accessible to the general public such that they can educate themselves on the topics to form their own opinions. This need not be restricted to news media sources and could include communication via social media or informational sessions.

Ensure there is fair compensation for communities impacted by HF operations through actions such as economic investment in the community, use of local services, and so on. The risks and concerns from HF operations are often valid, and compensation may help balance the risks with some rewards. It may be difficult to walk the line between fair compensation and what could be perceived as inappropriate incentives, but operators who treat the communities they work in fairly are likely to see smoother operations, more social license, and more cooperation from the community.

A resource for the public to access information about operations in their community should be created and maintained. Whether this is done by regulators or industry groups is not of major concern, although sharing information freely in this manner could allow industry groups to be perceived as more transparent, and therefore more trustworthy. Some examples of online resources are fracfocus.ca, BOEreports.com/well-map, and aboutpipelinesmap.com. This resource should include the types of operations occurring at a given location, the company in charge, a point of contact for questions or concerns, and a record of incidents, such as spills, and near misses (e.g. the type of information already required to be submitted to regulators and available to the public if they know where to look).

Energy operators in western Canada may wish to diversify into renewable energy. Although there was good support for oil and natural gas as energy sources, there was also a strong level of support for renewable sources. This includes geothermal energy, despite its associated IS risks. In fact, in Switzerland, IS due to geothermal operations was considered to be more acceptable than IS due to fossil fuel operations (Knoblauch et al., 2018). Our survey also found that economic reliance on oil and gas exploration was considered to be relatively risky. Environmental considerations aside, public perception of an operator may be influenced by their commitment to renewable energy development.

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Supplementary Material and Appendices

Appendix A: Survey questions

Below are all the questions presented in the main survey. Sections correspond to those described in Table 3.1 in Chapter 3. Further discussion of sources and themes can be found in Chapter 3.

A.1 Survey section 1: Demographics

Below are the questions included in section 1 of the survey.

1. How long have you lived in the area that you currently live in?
   - o Less than 1 year
   - o 1-3 years
   - o 4-6 years
   - o 7-10 years
   - o More than 10 years
   - o Prefer not to say
2. Please indicate whether you own land in the area. Do you… *Please select all that apply*
   - o Own a residential property
   - o Own an acreage
   - o Own small land holdings (less than 250 acres)
   - o Own large land holdings (more than 250 acres)
   - o None of the above
   - o Prefer not to say
3. Please indicate the extent to which you agree or disagree with the following statements.
   - The place where I live means a lot to me
   - I highly value the natural environment in the place where I live.
   - I highly value the sense of community in the place where I live.
     - o Strongly agree
     - o Somewhat agree
     - o Neither agree nor disagree
     - o Somewhat disagree
     - o Strongly disagree
     - o Prefer not to say

4. Please select all that apply for the following questions.
   - Do you, or have you ever, work(ed) in any of the following?
   - Does or did any of your family work in any of the following?
     - Energy industry (in a company office or the field, e.g. on a drill rig)
     - Energy-related government position
     - An industry hired by the energy industry
     - Environmental organization
     - None of the above
     - Prefer not to say
5. How often do you use social media?
   - Many times per day
   - Once or twice per day
   - Weekly
   - Monthly
   - Never
   - Prefer not to say
6. Please indicate the frequency with which you follow discussions about the oil and gas industry and the environment.
   - How often do you follow discussions about the oil and gas industry in western Canada?
   - How often do you follow discussions about the environment in western Canada?
     - Frequently
     - Often
     - Occasionally
     - Rarely
     - Never
     - Prefer not to say

7. Please indicate your main information sources for each question. *Please select all that apply.*
   - Where do you primarily go to access information about the oil and gas industry?
   - Where do you primarily go to access information about the environment?
     - o Social media
     - o Print and online news media, including magazines and newspapers
     - o TV
     - o Radio
     - o Friends and family
     - o Colleagues
     - o Prefer not to say
8. Have you engaged in informational meetings related to oil and gas operations in your community?
   - o Yes, recently
   - o Yes, a while ago
   - o No, never
   - o Prefer not to say
9. Are you a member of any of the following types of organizations? *Please select all that apply.*
   - o Community (e.g. church, school council, sports, etc.)
   - o Environmental
   - o Professional
   - o Other
   - o None of the above
   - o Prefer not to say

A.2 Survey section 2: Hydraulic fracturing factorial survey experiment scenarios

The scenarios described in Section 3.4 and listed in Appendix C were presented to respondents in this section of the survey, before other more direct questions, to minimize potential bias. Each respondent received six scenarios to evaluate, which were prefaced by the following introduction.

> We are interested in your views on current hydraulic fracturing practices in the oil and gas industry.
>
> We will now show you 6 hypothetical scenarios about hydraulic fracturing operations in your community. Please carefully read each scenario and rate it based on how much or how little you would support it. Choose only one response for each scenario.

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 fresh water 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.

<u>You may find the following definitions useful:</u>

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.

<u>Please note:</u> if you do not wish your responses to be included in this study, please exit at this time.

A.3 <u>Survey section 3: Knowledge of hydraulic fracturing and oil and gas</u>

Below are the questions included in section 3 of the survey.

1. We are interested in your level of familiarity with hydraulic fracturing. Please read the following statements very carefully, and then indicate whether you believe each statement to be True or False.
    - The process of hydraulic fracturing has been in use in Alberta since the 1950s.
    - Fluids used for hydraulic fracturing operations are composed primarily of water, with sand and chemicals being other common components.
    - Hydraulic fracturing will always cause earthquakes, which can always be felt by humans at the surface.
    - Hydraulic fracturing operations occur deep under the surface, well below groundwater aquifers.
    - Hydraulic fracturing is the pumping of fluids at high pressures into the ground to break the rock and remove oil or gas.
        - o True
        - o False
2. How would your friends and family rate your knowledge of the energy industry in western Canada?
    - o Very knowledgeable
    - o Knowledgeable
    - o Somewhat knowledgeable
    - o Not at all knowledgeable
    - o Prefer not to say

A.4 <u>Survey section 4: Acceptability of hydraulic fracturing, oil and gas, and induced seismicity</u>

Below are the questions included in section 4 of the survey.

1. We are interested in your views on the acceptability of oil and gas operations. Please indicate the extent to which you agree or disagree with the following statement.
    - Hydraulic fracturing is an acceptable way to extract hydrocarbon resources.
        - o Strongly agree
        - o Somewhat agree
        - o Neither agree nor disagree
        - o Somewhat disagree
        - o Strongly disagree
        - o Prefer not to say

2. Please indicate the extent to which you agree or disagree with statements related to compensation and your local community's economy.
   - Compensation to my community in some form is an important factor in my opinions regarding oil and gas operations.
   - I consider the economic impacts of oil and gas operations in my community to be of high importance.
   - I consider the economic impacts of oil and gas operations in my province to be of high importance.
   - My community currently benefits economically from nearby oil and gas activities.
     - o Strongly agree
     - o Somewhat agree
     - o Neither agree nor disagree
     - o Somewhat disagree
     - o Strongly disagree
     - o Prefer not to say
3. Please indicate the extent to which you agree or disagree with each concluding statement about different types of community involvement. I would find it acceptable to experience a human-induced earthquake, which could be felt but caused no damage in my local area and resulted from a technology that was only implemented after…
   - …procedures were put in place to allow people like me to appeal a decision that I did not support.
   - …people like me were able to express their views to the people in charge of the decision.
   - …the best scientists put their heads together and came up with the plan on their own without consulting any community members.
   - …research data related to the decision-making were made freely accessible to the public.
   - …the authorities who made this decision have personally met with me and I felt they treated me with respect.
     - o Strongly agree
     - o Somewhat agree
     - o Neither agree nor disagree
     - o Somewhat disagree
     - o Strongly disagree
     - o Prefer not to say

A.5 <u>Survey section 5: Risk</u>

Below is the question included in section 5 of the survey.

1. How risky do you consider each of the following items?
    - Hydraulic fracturing
    - Traditional vertical oil and gas wells
    - Transporting petroleum products through inhabited areas by pipeline
    - Transporting petroleum products through inhabited areas by train
    - Economic reliance on oil and gas exploration
    - Placing oil and gas wells near drinking water wells or surface water bodies
        - Very risky
        - Somewhat risky
        - Uncertain
        - Somewhat safe
        - Very safe
        - Prefer not to say

A.6 <u>Survey section 6: Energy support and concerns, and stakeholder roles</u>

Below are the questions included in section 6 of the survey.

1. Please indicate the extent to which you support or oppose the following energy sources.
    - Oil
    - Natural gas
    - Coal
    - Nuclear
    - Solar
    - Wind
    - Geothermal
        - Strongly support
        - Somewhat support
        - Neither support nor oppose
        - Somewhat oppose
        - Strongly oppose
        - Prefer not to say

2. Please indicate your level of concern about the following items related to oil and gas exploration.
    - Induced earthquakes
    - Surface spills
    - Overuse of local fresh water supplies
    - Underground contamination of fresh water aquifers
    - Disposal of produced salt water from oil and gas wells
    - Increased volume of heavy equipment traffic with associated noise/dust/safety issues
    - Odours
    - Light pollution at night
        - o Very unconcerned
        - o Somewhat unconcerned
        - o Neither concerned nor unconcerned
        - o Somewhat concerned
        - o Very concerned
        - o Prefer not to say
3. Please indicate your level of concern about the following items.
    - Potential for damage to personal items, homes, or local infrastructure due to induced earthquakes
    - Potential for groundwater contamination due to induced earthquakes
    - Potential for surface water contamination due to induced earthquakes
    - Active working hours of the operation (day vs night)
    - Noise levels
    - Traffic congestion on local roadways
    - Dust / air pollution
    - Increased potential for traffic incidents due to increase in heavy vehicle traffic and equipment on local roadways
        - o Very unconcerned
        - o Somewhat unconcerned
        - o Neither concerned nor unconcerned
        - o Somewhat concerned
        - o Very concerned
        - o Prefer not to say

4. When it comes to hydraulic fracturing, please indicate your level of trust for the following parties.
    - Local oil and gas companies operating in western Canada
    - Multinational oil and gas companies operating in western Canada
    - Government regulators
    - Local politicians
    - Environmental organizations
    - Local municipalities
    - Your provincial government
        - Very trustworthy
        - Somewhat trustworthy
        - Uncertain
        - Somewhat untrustworthy
        - Very untrustworthy
        - Prefer not to say
5. In your opinion, how responsible should each of the following parties be for potential adverse effects of hydraulic fracturing?
    - Local oil and gas companies operating in western Canada
    - Multinational oil and gas companies operating in western Canada
    - Government regulators
    - Local politicians
    - Environmental organizations
    - Local municipalities
    - Your provincial government
        - Fully responsible
        - Mostly responsible
        - Somewhat responsible
        - Not at all responsible
        - Prefer not to say

6. Please rate the following parties regarding their transparency of information sharing with the public.
    - Local oil and gas companies operating in western Canada
    - Multinational oil and gas companies operating in western Canada
    - Government regulators
    - Local politicians
    - Environmental organizations
    - Local municipalities
    - Your provincial government
        - o Very transparent
        - o Somewhat transparent
        - o Uncertain
        - o Somewhat non-transparent
        - o Not at all transparent
        - o Prefer not to say

A.7 <u>Survey section 7: Earthquake experience</u>

Below are the questions included in section 7 of the survey.

1. I have experienced an earthquake in my lifetime.
    - No, never
    - Yes, once or twice
    - Yes, three to five times
    - Yes, more than five times
    - Prefer not to say
2. Please tell us more
    - I have experienced an earthquake in Canada.
    - I have experienced an earthquake in Alberta.
    - I have experienced an earthquake in British Columbia.
    - I have experienced an earthquake where I live right now.
        - o No, never
        - o Yes, once or twice
        - o Yes, three to five times
        - o Yes, more than five times
        - o Prefer not to say

A.8 Survey section 8: Concluding demographics

Below are the questions included in section 8 of the survey.

1. Gender
    - Female
    - Male
    - Other
    - Prefer not to say
2. Age
    - 18-24
    - 25-34
    - 35-44
    - 45-54
    - 55-64
    - 65-74
    - 75 or over
    - Prefer not to say
3. Highest Educational Attainment
    - High school
    - College
    - Undergraduate degree
    - Graduate degree
    - Technical or trade certificate
    - Prefer not to say
4. Do you live in Canada?
    - Yes
    - No
    - Prefer not to say
5. *(If "Yes" selected for question 4)* Please indicate the first 3 characters of your postal code.
5. *(If "No" selected for question 4)* Which country do you live in?
6. Is there anything else you would like to share, or any comments or questions for the researchers?

Appendix B: Other survey results

While most of the survey results are contained in the main body of this thesis, some are presented here instead. These results include: years of residence, property ownership, place attachment, social media use, frequency of oil and gas discussions, frequency of environment discussions, informational meeting engagement, membership in various community/professional organizations, and expectations of responsibility from stakeholder parties for potential adverse effects of hydraulic fracturing (HF) operations. Below are presented the histograms for each of these results.

Figure B.1 shows that the majority of our respondents have lived at their current location for over 10 years, which would imply a level of knowledge and vested interest in the area that they live.

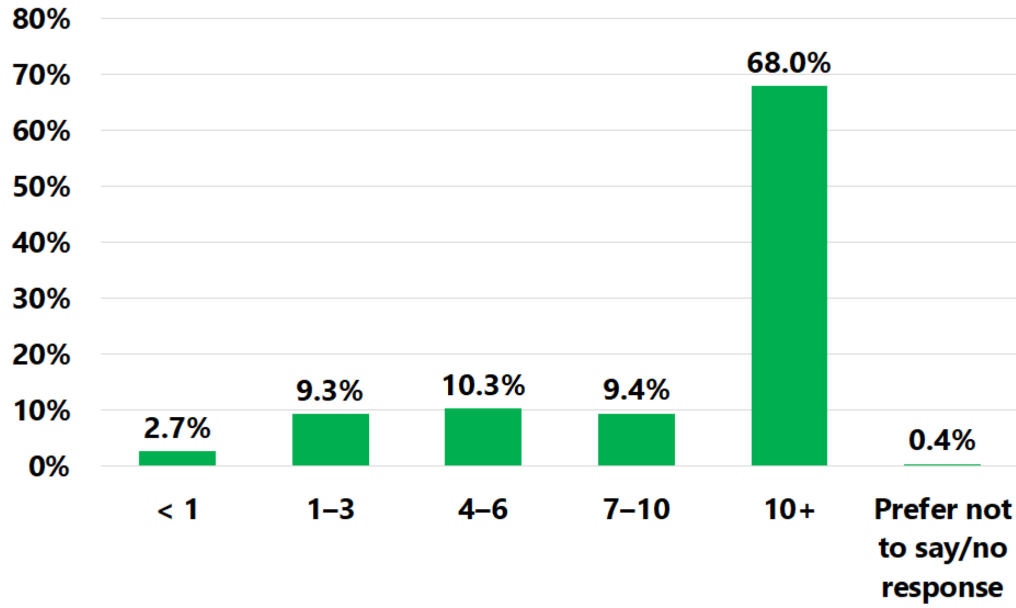

Figure B.1: Number of years respondent has resided at their current location. Given as percent of total respondents, n = 1,311.

Figure B.2 shows the level of ownership respondents reported. Most of the respondents own residential property, but there is a not-insignificant number of people who do not own property or land. A small number of respondents own an acreage or land holdings of some size. As mentioned in Section 3.3, the threshold size between small and large land holdings was decided to be 250 acres after researching average farm sizes in North America (Dunckel, 2013; Statistics Canada, 2018a).

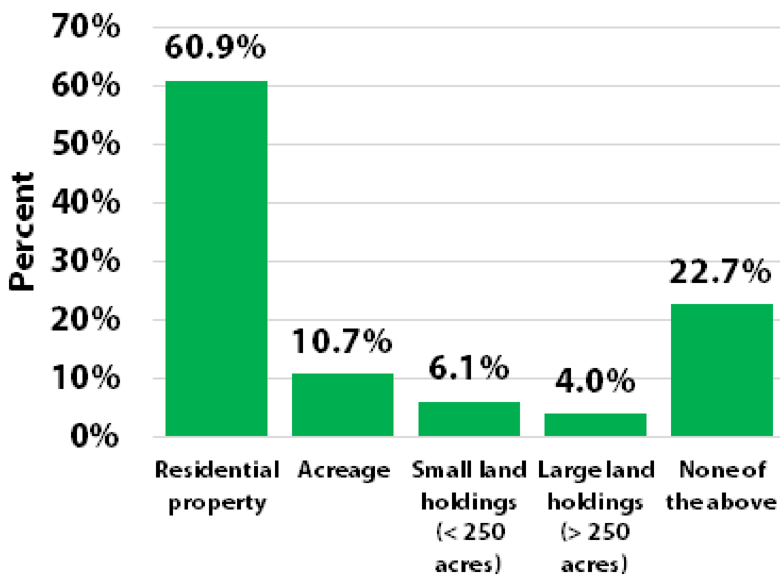

Figure B.2: Ownership of various types of property. Given as percent of total respondents, n = 1,311. This question was a "check all that apply" question.

Figure B.3 shows the level of agreement with three statements that measure place attachment. For all three statements, the majority of respondents indicate some level of agreement, which demonstrates a vested interest in the place where they live. As discussed in Section 3.3, this question was adapted from Raymond et al. (2010).

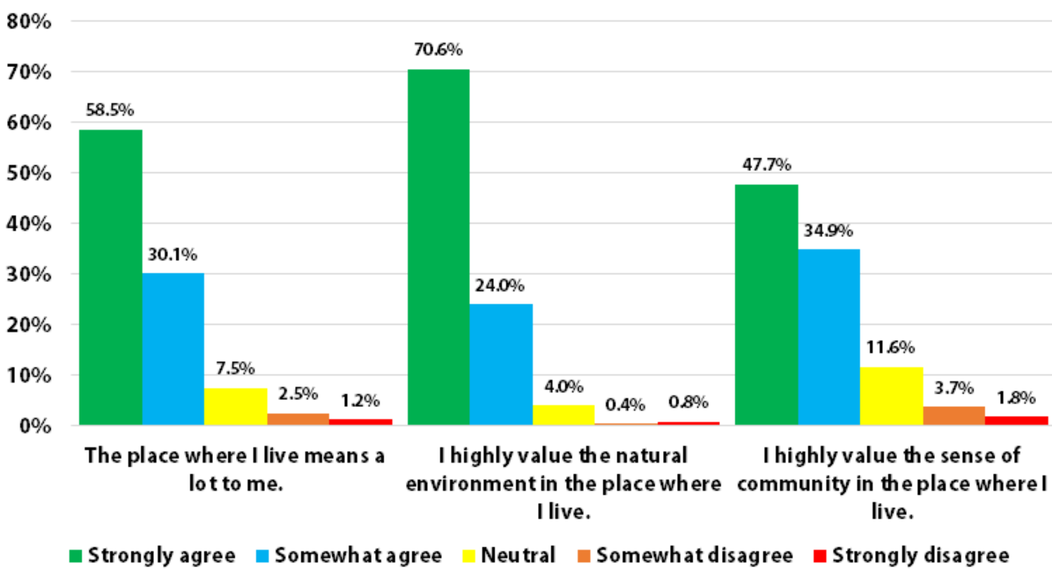

Figure B.3: Questions indicating level of place attachment. Given as percent of total respondents, n = 1,311.

Figure B.4 measured the frequency of social media use of respondents. This information was collected to determine the level of influence social media might have on opinions regarding the oil and gas industry. The majority of respondents use social media regularly, with over half indicating that they use it many times per day.

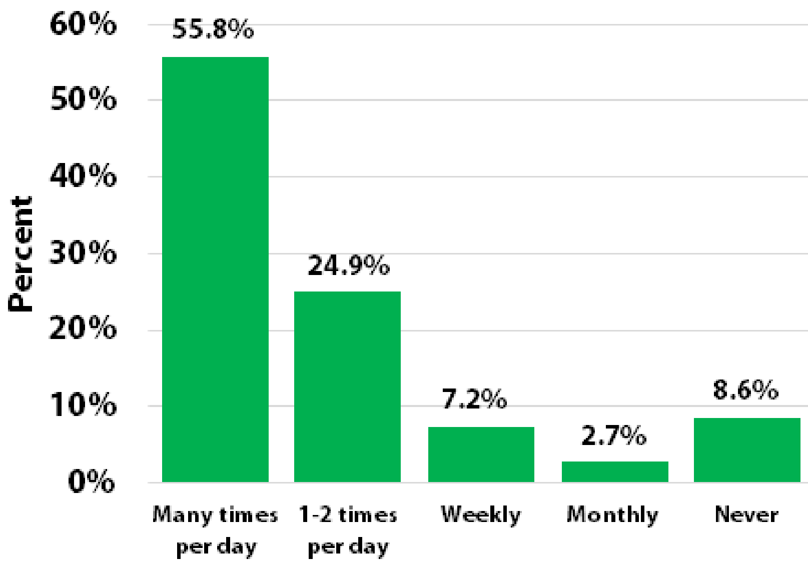

Figure B.4: Social media use of respondents. Given as percent of total respondents, n = 1,311.

Figure B.5 shows the frequency with which respondents follow or participate in discussions about the oil and gas industry (green) and about the environment (blue). With the higher percentages in the "frequently" and "often" categories, the responses to the survey questions are likely somewhat biased by background information previously obtained by respondents.

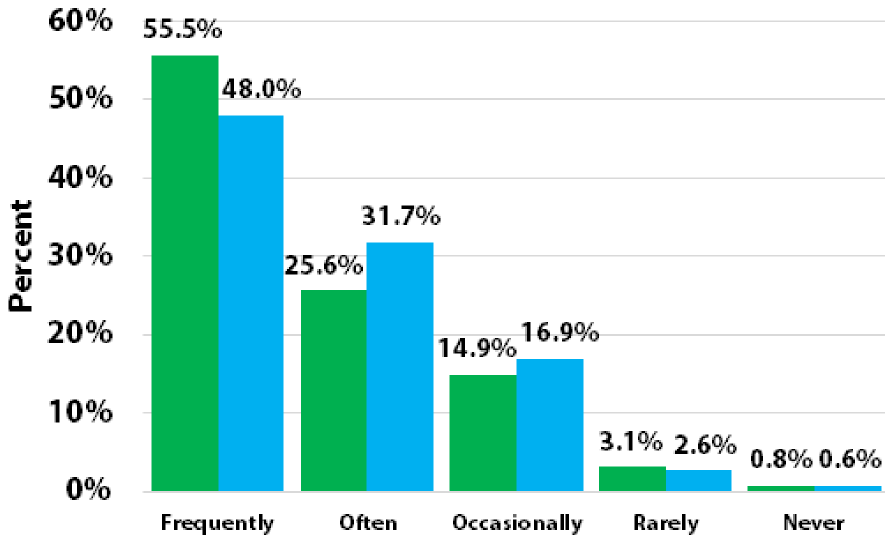

Figure B.5: Frequency with which respondents follow discussions about the oil and gas industry (green) and the environment (blue) in western Canada. Given as percent of total respondents, n = 1,311.

Figure B.6 shows the distribution of respondents who have or have not engaged in informational meetings about oil and gas in their community. A slightly higher number of respondents have never been to an informational meeting, but the number of people who have at some point engaged in this manner is non-trivial.

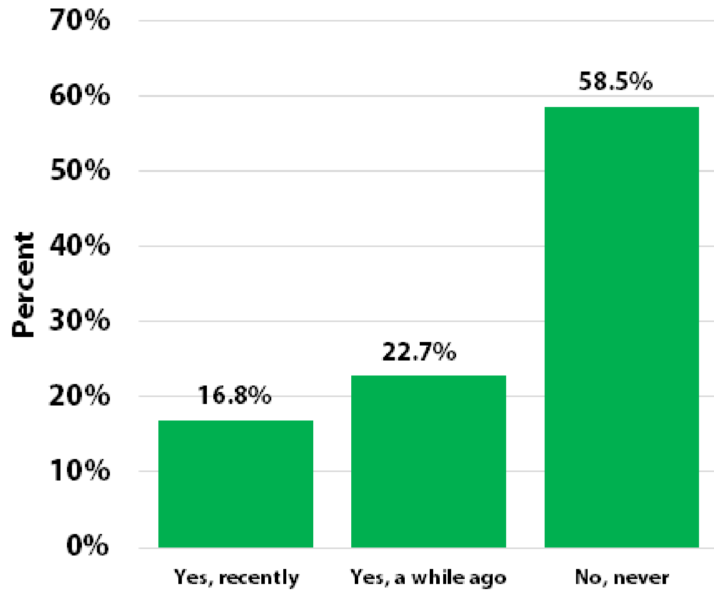

Figure B.6: Percent of respondents who have or have not engaged in informational meetings about oil and gas in their community. Given as percent of total respondents, n = 1,311.

Figure B.7 shows the types of organizations that respondents are members of, giving some indication of engagement in their communities and thus possible vested interests in community developments such as oil and gas operations.

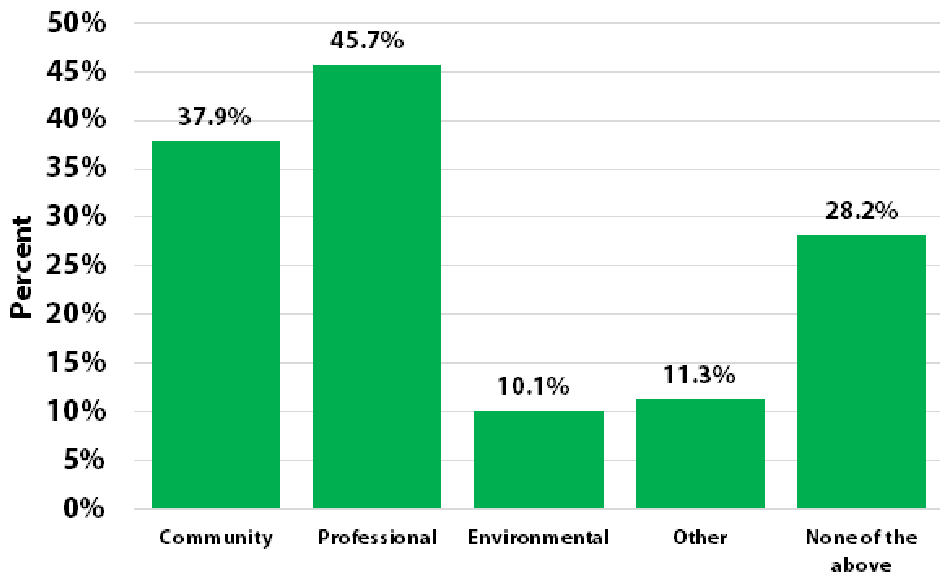

Figure B.7: Types of organizations that respondents are members of. Given as percent of total respondents, n = 1,311. This was a "check all that apply" question.

Figure B.8 shows the distribution of each stakeholder party's expected responsibility for potential adverse effects of HF operations. Local and multinational oil and gas companies are expected to be highly responsible for potential adverse effects, while environmental organizations are generally not expected to be as responsible.

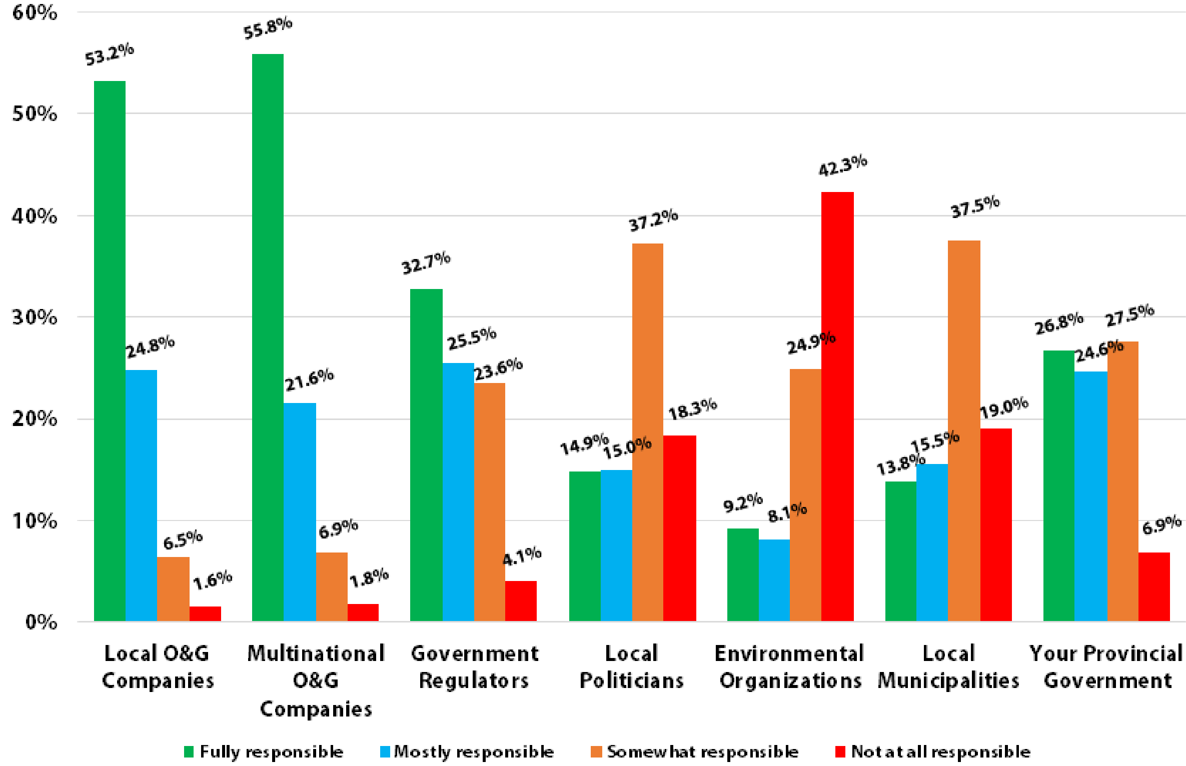

Figure B.8: Expectations of stakeholder party responsibility for potential adverse effects of HF operations. Given as percent of total respondents, n = 1,311.

Appendix C: Factorial Survey Experiment vignette scenarios

There were 144 FSE vignette scenarios used in this study. Each scenario followed the structure:

A hydraulic fracturing operation is proposed to be located **[location]** from your home. The operation will involve **[trucks]** with associated noise and dust travelling in the area per day **[time]**, in addition to traffic already in the area. **[Consultation]** the operation. The company involved has a history of policies that involve **[benefits]** local communities. Seismicity related to the operation is anticipated to be **[seismicity]**.

Table C.1 gives the key for dimension levels in each scenario. Table C.2 lists all 144 scenarios used in this study. Each scenario has an identification number from 1 to 144 and belongs to one of two foldover blocks. For more about foldover design, see Section 3.4.1.

Table C.1: Key for dimension levels listed in Table C.2.

	Location	Trucks	Time	Consultation	Benefits	Seismicity
0	less than 3 km	up to 10 heavy equipment trucks	between 8 am and 8 pm	Your community will not be informed of plans for	providing no financial benefits to	nonexistent
1	between 3 and 15 km	10–50 heavy equipment trucks	at all hours of the day	Your community will be informed of plans for	preferential use of local services and employers to benefit	too small to be felt
2	over 15 km	over 50 heavy equipment trucks		Directly affected landowners in your community will be consulted during the planning process of	donating community grants ranging from $10,000 to $25,000 annually to	persistent and repeating, but too small to cause structural damage
3				Your community will have full two-way consultation in every step of the planning process of	donating fully funded community projects, such as building recreational community centres, to	infrequent, but large enough to potentially cause moderate structural damage

Table C.2: FSE vignette scenarios used in this study.

Scenario ID	Location	Trucks	Time	Consultation	Benefits	Seismicity	Foldover block
1	1	2	0	0	0	0	1
2	2	0	0	0	0	0	1
3	0	1	0	0	0	0	1
4	2	1	1	2	2	3	1
5	0	2	1	2	2	3	1
6	1	0	1	2	2	3	1
7	1	2	1	0	1	2	1
8	2	0	1	0	1	2	1
9	0	1	1	0	1	2	1
10	2	1	0	2	3	1	1
11	0	2	0	2	3	1	1
12	1	0	0	2	3	1	1
13	2	1	0	1	1	3	1
14	0	2	0	1	1	3	1
15	1	0	0	1	1	3	1
16	1	2	1	3	3	0	1
17	2	0	1	3	3	0	1
18	0	1	1	3	3	0	1
19	1	1	1	1	3	1	1
20	2	2	1	1	3	1	1
21	0	0	1	1	3	1	1
22	2	2	0	3	1	2	1
23	0	0	0	3	1	2	1
24	1	1	0	3	1	2	1
25	0	0	1	0	2	2	1
26	1	1	1	0	2	2	1
27	2	2	1	0	2	2	1
28	2	2	0	2	0	1	1
29	0	0	0	2	0	1	1
30	1	1	0	2	0	1	1
31	0	2	1	1	0	0	1
32	1	0	1	1	0	0	1
33	2	1	1	1	0	0	1
34	2	0	0	3	2	3	1
35	0	1	0	3	2	3	1
36	1	2	0	3	2	3	1
37	2	2	0	1	0	3	1
38	0	0	0	1	0	3	1
39	1	1	0	1	0	3	1
40	0	0	1	3	2	0	1
41	1	1	1	3	2	0	1
42	2	2	1	3	2	0	1

Scenario ID	Location	Trucks	Time	Consultation	Benefits	Seismicity	Foldover block
43	0	1	1	1	1	1	1
44	1	2	1	1	1	1	1
45	2	0	1	1	1	1	1
46	1	0	0	3	3	2	1
47	2	1	0	3	3	2	1
48	0	2	0	3	3	2	1
49	1	0	0	0	2	1	1
50	2	1	0	0	2	1	1
51	0	2	0	0	2	1	1
52	0	1	1	2	0	2	1
53	1	2	1	2	0	2	1
54	2	0	1	2	0	2	1
55	1	1	0	0	3	0	1
56	2	2	0	0	3	0	1
57	0	0	0	0	3	0	1
58	0	0	1	2	1	3	1
59	1	1	1	2	1	3	1
60	2	2	1	2	1	3	1
61	2	0	0	1	2	2	1
62	0	1	0	1	2	2	1
63	1	2	0	1	2	2	1
64	0	2	1	3	0	1	1
65	1	0	1	3	0	1	1
66	2	1	1	3	0	1	1
67	1	0	1	0	3	3	1
68	2	1	1	0	3	3	1
69	0	2	1	0	3	3	1
70	0	1	0	2	1	0	1
71	1	2	0	2	1	0	1
72	2	0	0	2	1	0	1
73	1	0	1	3	3	3	2
74	0	2	1	3	3	3	2
75	2	1	1	3	3	3	2
76	0	1	0	1	1	0	2
77	2	0	0	1	1	0	2
78	1	2	0	1	1	0	2
79	1	0	0	3	2	1	2
80	0	2	0	3	2	1	2
81	2	1	0	3	2	1	2
82	0	1	1	1	0	2	2
83	2	0	1	1	0	2	2
84	1	2	1	1	0	2	2
85	0	1	1	2	2	0	2
86	2	0	1	2	2	0	2

Scenario ID	Location	Trucks	Time	Consultation	Benefits	Seismicity	Foldover block
87	1	2	1	2	2	0	2
88	1	0	0	0	0	3	2
89	0	2	0	0	0	3	2
90	2	1	0	0	0	3	2
91	1	1	0	2	0	2	2
92	0	0	0	2	0	2	2
93	2	2	0	2	0	2	2
94	0	0	1	0	2	1	2
95	2	2	1	0	2	1	2
96	1	1	1	0	2	1	2
97	2	2	0	3	1	1	2
98	1	1	0	3	1	1	2
99	0	0	0	3	1	1	2
100	0	0	1	1	3	2	2
101	2	2	1	1	3	2	2
102	1	1	1	1	3	2	2
103	2	0	0	2	3	3	2
104	1	2	0	2	3	3	2
105	0	1	0	2	3	3	2
106	0	2	1	0	1	0	2
107	2	1	1	0	1	0	2
108	1	0	1	0	1	0	2
109	0	0	1	2	3	0	2
110	2	2	1	2	3	0	2
111	1	1	1	2	3	0	2
112	2	2	0	0	1	3	2
113	1	1	0	0	1	3	2
114	0	0	0	0	1	3	2
115	2	1	0	2	2	2	2
116	1	0	0	2	2	2	2
117	0	2	0	2	2	2	2
118	1	2	1	0	0	1	2
119	0	1	1	0	0	1	2
120	2	0	1	0	0	1	2
121	1	2	1	3	1	2	2
122	0	1	1	3	1	2	2
123	2	0	1	3	1	2	2
124	2	1	0	1	3	1	2
125	1	0	0	1	3	1	2
126	0	2	0	1	3	1	2
127	1	1	1	3	0	3	2
128	0	0	1	3	0	3	2
129	2	2	1	3	0	3	2
130	2	2	0	1	2	0	2

Scenario ID	Location	Trucks	Time	Consultation	Benefits	Seismicity	Foldover block
131	1	1	0	1	2	0	2
132	0	0	0	1	2	0	2
133	0	2	1	2	1	1	2
134	2	1	1	2	1	1	2
135	1	0	1	2	1	1	2
136	2	0	0	0	3	2	2
137	1	2	0	0	3	2	2
138	0	1	0	0	3	2	2
139	1	2	0	3	0	0	2
140	0	1	0	3	0	0	2
141	2	0	0	3	0	0	2
142	2	1	1	1	2	3	2
143	1	0	1	1	2	3	2
144	0	2	1	1	2	3	2