PERCEIVED RISK AND RESPONSE TO THE WIND TURBINE ICE THROW HAZARD: COMPARING COMMUNITY STAKEHOLDERS AND OPERATIONS AND MAINTENANCE PERSONNEL IN TWO REGIONS OF TEXAS

by

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DEDICATION

The author would like to dedicate this dissertation to the men and women who work in the wind energy industry who at times put themselves in harm's way in order to provide for their families and also supply this great nation with a clean, renewable source of electricity.

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ABSTRACT

Risk managers who work directly with wind energy know that accumulations of ice on wind turbine blades pose a substantial risk to wind farm employees and a lesser extent to the general public. However, overall, the hazards of ice throw are not generally known to the public, as there has not been a significant event in the U.S. which has drawn any media attention. As we continue to install more and more turbines, the number of people exposed greatly increases, and it is only a matter of time before the industry suffers a severe incident or even a fatality. Thus, the goals of this research were threefold: 1) to understand the extent to which two at-risk groups—community stakeholders as well as operations and maintenance personnel at wind farms might differ in their perceived levels of risk to the ice throw hazard; 2) to understand the degree to which community stakeholders and operations and maintenance might differ on choosing measures of protection for their affected areas; and 3) to improve safety by identifying protective measures that all stakeholders—community citizens, wind farm employees, contractors, and land owners—are willing to undertake to mitigate their risk against the ice throw hazard which includes adopting measures to reduce their own risk toward the hazard, as well as, their community's vulnerability toward the hazards and threat of ice throw from wind turbines. This research also makes a valuable contribution to the theoretical body of risk research with respect to a technological hazard for which little is known.

This research found that the two groups differed on statistically significant variables for observed risk, perceived personal risk, risk to the community, levels of trust in safety leaders, best protective actions, and preferred warning systems; however, there was no statistical significance between the groups on perceived benefits of wind energy.

1. INTRODUCTION

The Energy Policy Act of 1992 created a Production Tax Credit (PTC) for the generation of electricity from utility-scale wind turbines. With the promulgation of this act, the wind energy industry in the United States has experienced upward and strong growth across the country in the number of wind farms, as well as, energy capacity. In July 2008, the U.S. Department of Energy (DOE) under the Bush Administration issued a report entitled, "20 percent Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply," which indicated that wind power could play a major role in helping the nation meet its growing energy demand. As predicted in the 2008 DOE report, over the past five years, the industry has achieved, on average, a 35 percent annual growth rate in the number of wind farms. Currently, 38 states now have utility-scale wind turbines (AWEA 2014), and of those states there are 16 which have installations of 1,000 megawatts (MW) or more. The top five are listed in Table 1.1 below:

Table 1.1 Top Five States for Wind Energy Generation, 2014*

1. Texas	12,354 MWs
2. California	5,829 MWs
3. Iowa	5,177 MWs
4. Illinois	3,568 MWs
5. Oregon	3,153 MWs

*Installed megawatt capacity.
Source: American Wind Energy Association 2014.

Texas holds the largest number of wind installations in the U.S. and, in 2014, generated approximately 9 percent of the state's electricity demand. For the country as a whole, over 8,900 MW of power are currently under construction representing nearly 100 separate projects spanning 31 states, including Puerto Rico. According to the *2011 Annual Market Report* of the American Wind Energy Association (AWEA), "the U.S. wind industry has added over 35 percent of all new generating capacity over the past 5 years, second only to natural gas, and more than nuclear and coal combined" (AWEA 2011, 3). Furthermore, at the end of 2014, the U.S. wind industry totaled 61,327 MW of cumulative wind capacity (www.awea.org). Considering that the age of the wind turbine determines MW output, energy output can vary from 300 kilowatts (KW) to 2.7 MWs per turbine. AWEA estimates the total number of operating utility-scale wind turbines in the U.S. is greater than 48,000. Figure 1.1 displays the locations and MW capacities of wind farms across the United States.

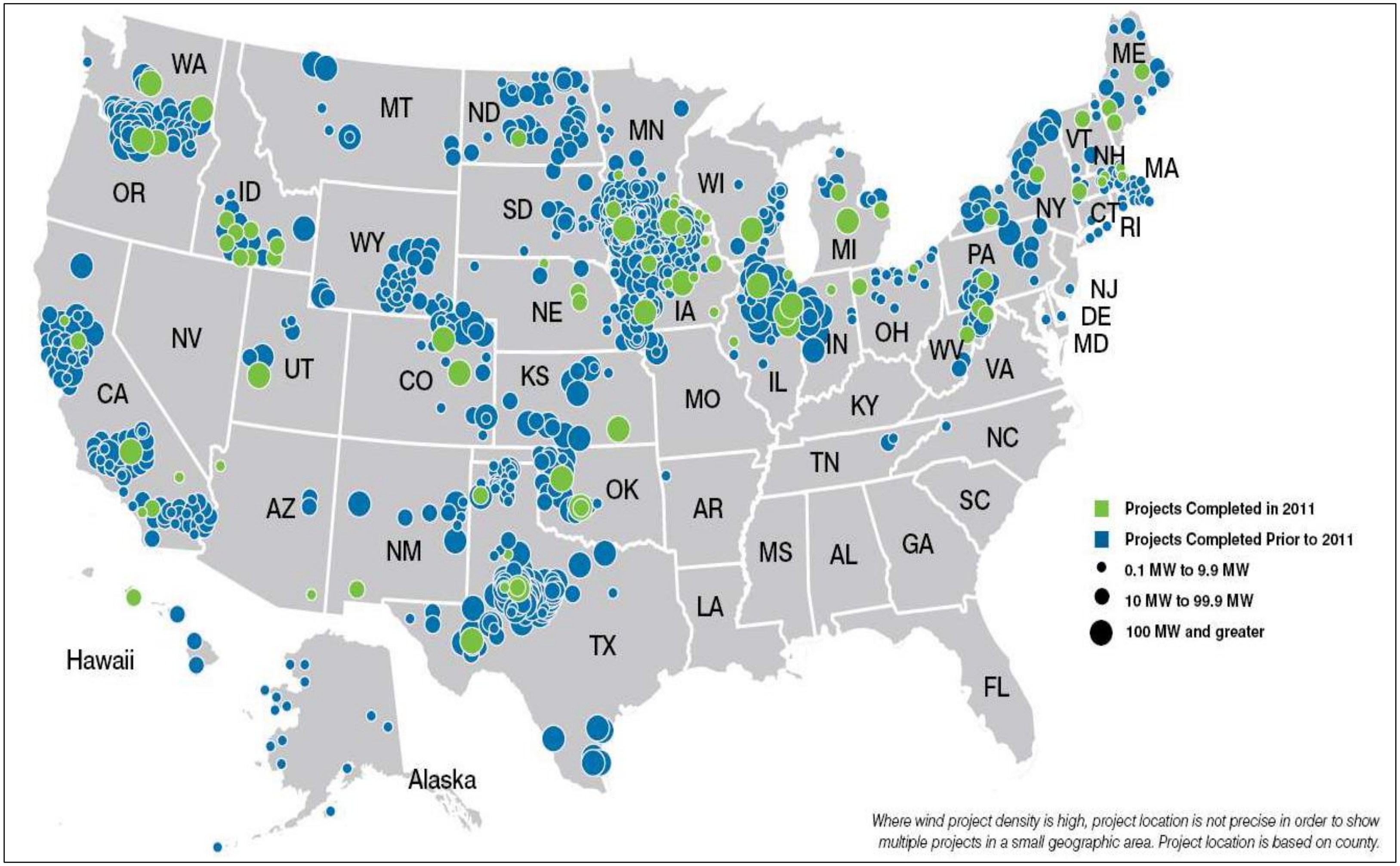


Figure 1.1 Locations of wind energy farms across the United States and estimated amounts of megawatt energy produced since 2011. Source: American Wind Energy Association (AWEA) 2012 Annual Market Report. http://www.eere.energy.gov/windpoweringamerica/wpa/wind_maps.asp

Utility-scale wind energy projects are located in areas of the country where wind energy resources are consistent. Wind resources are characterized by wind-power density classes ranging from Class 1 (the lowest) to Class 7 (the highest). The U.S. Department of Energy's National Renewable Energy Laboratory publishes a United States Wind Resources Map which identifies the range of wind classes across the U.S. and is a valuable tool for wind energy developers to use in planning projects. In general, Class 3 with average annual wind speeds of 7 meters per second (15 miles per hour) is needed to generate energy from utility-scale wind turbines.

Areas of the country with poor wind energy resources, such as the southeast portion of the U.S. and the Four Corners region of the West, have very little chance of attracting wind energy development; however, these are very attractive for utility-scale solar projects. Other factors which determine the location of wind energy projects include accessibility to the electric grid, congestion restraints with the local electric grid system, state renewable portfolio standards, the ability to secure power purchase agreements with local utilities, and environmental factors such as endangered species or bird and bat mortalities.

The benefits associated with wind energy are numerous and include non-renewable resource conservation, job creation for manufacturing, transportation, construction, and maintenance sectors. In addition, tax revenue may be generated for depressed rural communities and incomes supplemented for farmers and ranchers who lease their properties to wind turbine operators. According to the 2008 DOE Study, every megawatt of wind power installed: 1) powers almost 300 homes; 2) is equivalent to taking 315 cars off the road; 3) avoids the release of 1,800 tons of carbon dioxide per year; and 4) eliminates roughly 9 tons of sulfur dioxide — a leading cause of acid rain. Thus, the implementation of wind energy projects has not only reduced greenhouse gas emissions, but according to projections between 2007 and 2030 by the DOE's Energy Efficiency and Renewable Energy Division, wind power is also estimated to potentially reduce cumulative water consumption in the electric sector by 8 percent or roughly 4 trillion gallons (12.3 million acre feet) (www.eere.energy.gov).

Problem Statement: The Ice Throw Hazard

While the benefits of wind energy are well publicized, the hazards and risks associated with their operation are not well known. Opponents of wind energy often point to issues such as noise, aesthetics, and bird mortality. Wind turbines affect the visual appeal and aesthetics of the landscape, especially in pristine untouched environments such as, the Big Bend region of Texas. The level of a wind turbine's visual impact is subjective and depends upon the perception of the individual and local community in which they are located (Elliot 1997). How the visual impact of a wind turbine is perceived depends on factors such as, people's attitudes towards the existing landscape as well as their attitudes to wind turbines and renewable energy in general (Gipe 1995a). Also, property owners who lease their lands on which turbines operate, share in the royalties that each one generates (typically $3,000-$7,000/yr.) and/or receive annual rent for each turbine (typically $5,000/yr.) as part of their leasing agreement. Thus, some people view wind turbines as a visual advantage for their economic and environmental benefits (Coleby et al. 2007). On the other hand, aesthetics play a larger role for individuals adjacent to wind farms. These property owners have expressed concern over perceived declines in property values as a result of the visual impact (Bell et al. 2005).

Presently, however, general agreement on the impact of aesthetics is inconclusive and further studies need to be conducted to validate this claim (Good 2006).

Like any tall man-made structure, wind turbines have a negative impact on birds, which can be killed or injured by colliding with the rotating blades. Turbines are also a disadvantage for migrating, breeding and nesting birds because they reduce the available bird habitat. However, some would argue that the overall negative effect of wind turbines is small compared to the negative impacts on birds from domestic and feral cats, or losses of habitat through property development (Pruett et al. 2009). For example, the Australian Wind Energy Association conducted a study which determined that on average two birds per wind turbine die per year (www.auswind.org).

The negative impact on birds may be reduced by undertaking a proper site evaluation during the planning stage. For example, wind turbines may be planned for locations that avoid bird migration corridors and/or restricted within specific bird habitats. Also, whenever possible all electrical lines might be placed underground (which is a current industry practice). Furthermore, to mitigate the negative impact on birds, new wind turbine designs can achieve higher power output using slower-turning blades (as compared to turbines installed in the U.S. in the 1990s), which will reduce bird mortality.

However, in our haste to apply this new “green energy” technology on such a massive scale, we have exposed ourselves to unintentional consequences associated with the technological hazards of operating wind farms in close proximity to homes and public roads. The most serious hazard generated from the operation of wind turbines is *ice throw* from wind turbines which poses a significant risk not only to the surrounding community but also to those who work every day at these wind farms in performing routine maintenance activities necessary to keep the turbines in operation.

Being struck by an ice fragment is a low probability-high consequence event even though ice throw incidents occur at every wind farm in every state. Prior research suggests that it may be difficult to engage in unbiased attempts to discuss low probability hazards without, at the same time, increase the perceived probability of those hazards (Slovic 2000). The act of simply engaging the public in a discussion of any low-probability hazard may result in increasing the judged probability of that hazard regardless of what the historical data indicates (Slovic 2000). A prime example of this scenario is provided by the continued debate over nuclear power risks which have led to an increased resistance to this technology.

Risk managers who work directly with wind energy know that accumulations of ice on wind turbine blades pose a substantial risk to wind farm employees and, to a lesser extent, the general public. However, overall, the hazards of ice throw are not generally known to the public, as there has not been a significant event in the U.S. which has drawn any media attention. As we continue to install more and more turbines, the number of people exposed greatly increases, and it is only a matter of time before the industry suffers a severe incident or even a fatality. This is underscored by Cutter and colleagues (2008) who assert that, “although there may be recognition of hazards in many communities, risk reduction and vulnerability of their communities often are not salient concerns until after the disaster occurs. Residents have other issues that assume priority, and local elected officials do not want to dwell on the hazard vulnerability of their communities as it might hurt economic investment and growth” (598). Thus, the goals of this research were threefold: 1) to understand the extent to which two at-risk groups—community stakeholders as well as operations and maintenance personnel at wind farms, might differ in their perceived levels of risk to the ice throw hazard; 2) to understand the degree to which community stakeholders and operations and maintenance personnel might differ on choosing measures of protection for their affected areas; and 3) to improve safety by identifying protective measures that all stakeholders—community citizens, wind farm employees, contractors, and land owners—are willing to undertake to mitigate their risk against the ice throw hazard which includes adopting measures to reduce their own risk toward the hazard, as well as, their community's vulnerability toward the hazard and threat of ice throw from wind turbines.

This research also makes a valuable contribution to the theoretical body of risk research with respect to a technological hazard for which little is known by employing the precepts of the Protective Action Decision Model (PADM) developed by Lindell and Perry (2012). Discussed below, the PADM is a multistage model based on research findings that investigated individuals' responses to environmental hazards, including technological hazards and disasters. Guided by the PADM, this study sheds perspective on how two affected stakeholder groups might perceive and interpret their levels of risk and potential losses to wind turbine ice throw.

Purpose of Study and Theoretical Framework

The International Council for Science (ICSU) states that, "The risk associated with environmental hazards depends not only on physical conditions and events but also on human actions, conditions (vulnerability factors, etc.), decisions and culture. The seriousness of the consequences of any disaster will depend also on how many people choose, or feel they have no choice but, to live and work in areas at higher risk" (12). To facilitate understanding of the interplay of human response to environmental hazards, Lindell and Perry (2012) developed the revised PADM to explain the interactions among three core elements: 1) threat perceptions, 2) protective perceptions, and 3) stakeholder perceptions. It is proposed that these three perceptions form the basis for decisions about how people respond to an imminent or long-term threat. The model serves as a framework for assessing risk levels, or degrees of vulnerability, for communities who have adopted wind energy installations and, therefore, now experience increased risk in terms of risk exposure and levels of threat to the ice throw hazard.

Research Design

Guided by the precepts of the PADM, the surveys solicited information pertaining to the wind turbine technician's and community stakeholders' experiences with ice throw, general perceptions of safety involving wind turbine operations, as well as demographic information. The data collected from the surveys was analyzed both quantitatively and qualitatively to provide a description of the respondent's general perception of risks associated with turbine operations and ice throw hazards.

A sequential mixed methods approach in two phases was developed for this research. Phase 1 of this study identified wind farms and communities that fall within the two study areas; West Texas and South Texas. Hazard managers in operations departments as well as original equipment manufacturers (OEMs) who perform all maintenance activities for each wind farm identified were sent a cover letter introducing the study to request their participation as well as a survey questionnaire. Participant letters were followed up with a phone call to each recipient to answer any questions or concerns they may have about the study or the data to be collected and analyzed.

To collect information during Phase 1, a non-probability sampling technique known as “convenience sampling” was used to gather data from peer groups of hazard managers at various wind farms in each study area. Hazard managers at each wind farm were asked to survey personnel at their respective projects using forums such as monthly employee safety committee meetings. The survey questionnaire solicited information from wind farm operators, contractors, and maintenance personnel. These stakeholders were selected because they have the most direct contact with the wind turbines as part of their day-to-day operations and maintenance activities.

To accomplish Phase 2, a survey instrument was developed to assess community vulnerability of ice throw from wind turbines (Appendix B – Survey Instruments). A non-probability sampling method known as “convenience sampling” was also applied to this phase of the study to gather information from surrounding communities. Other stakeholder groups, community officials, and at-risk citizens (landowners/neighbors) in the study areas, in proximity to, as well as, at a distance to the wind farms were included.

Both surveys targeted wind farm operations and their communities in Texas as it is the state with the largest number of wind turbines in operation (Table 1.1) and thus the largest number of communities at risk. Although Texas will not have the same duration of “icing seasons” as facilities in northern climates, incidents of ice throw do occur during the winter months. The information gathered during this study and the forthcoming findings may be broadly applied throughout the industry.

Affected stakeholders that comprise the samples in each community include:

- Landowners (including buildings, infrastructure, and livestock)
- Wind farm project owners and operators
- Wind farm original equipment manufacturer (OEM) representatives
- Wind farm project maintenance personnel and contractors
- Neighbors
- Visitors
- Citizens in surrounding communities (including public roadways surrounding a project)

Questions that Guided this Study

The following questions followed logically from the components that comprise the theoretical framework of the Protective Action Decision Model, and guided this study:

1) To what extent have operator and maintenance personnel witnessed an ice throw hazard incident?
2) What are the perceived levels of risk from ice throw by operator and maintenance personnel at wind farms?
3) What are the perceived levels of safety from ice throw by OMP workers for their site?

4) What are the perceived levels of effectiveness of safety procedures by OMP workers toward ice throw?

5) What perceived levels of safety do OMP workers have for the surrounding community?

6) To what extent do OMP workers trust in safety representatives in protection against ice throw incidents?

For community stakeholders, this research asked:

1) To what extent have community stakeholders witnessed an ice throw hazard incident? What type of environmental cues might they respond to, and what are their opinions toward the cues?

2) What are the perceived levels of risk toward the ice throw hazard by community stakeholders?

3) To what extent might community stakeholders be willing to report an incident?

4) To what extent will community stakeholders engage in personal protective actions?

5) To what extent do community stakeholders trust that wind farm operators will inform community leaders of increased risk to the ice throw hazard?

6) To what extent do community stakeholders trust wind farm operators to inform local media for disseminating an ice throw warning?

Next, this research asked: To what extent might the two groups be compared on: actual and observed risk, experience with the ice throw, willingness to report an incident, evidence of leadership in managing an ice throw hazard, and general opinion of benefit of wind energy to the U.S. Is there a statistically significant difference between the two?

Finally, this research asked: To what extent might regression be used to predict risk perception of the community, as well as, whether witnessing an ice throw event has any impact on ice throw hazard protective response.

Propositions

For the most part, data were analyzed employing statistical tests, however, a portion of the data were not conducive to formal testing, but, yet were important to achieving the objectives of this research—therefore, propositions were set forth instead of formal hypotheses. All data types—quantitative, descriptive, qualitative data—pointed to important issues and challenges concerning personal and community risk, decision-making toward that risk, and willingness to respond to the ice throw threat. Therefore, guided by the precepts of the revised Protective Action Decision Model, as well as from the risk literature, the following propositions were set forth:

1) That there will be differences between the two groups in witnessing ice throw hazard incidents.
2) That there will be differences in perceived risk to the community between the two groups from the ice throw hazard.

3) That the two groups are likely to have significantly different reactions to, and opinions toward environmental cues related to the wind turbines, and the threat of ice throw from them.

4) That operation and maintenance personnel have different levels of perceptions of work safety at the site, as well as, the effectiveness of safety procedures, and trust of representatives.

5) That community stakeholders are willing to report an incident, but unlikely to engage in protective actions.

6) That few channels exist for disseminating warning messages associated with the wind turbine ice throw hazard.

7) That demographic information such as age and gender will differentiate the groups seeking information on protective action.

Discussion of these propositions will appear in the Conclusion chapter. Implications from formal statistical testing will be expanded upon.

Importance of the Study: Contribution to the Research Literature

Thus far, the research associated with ice throw from wind turbines has focused on how ice forms on turbine blades, projections of fall distances and throw distances, and proposed mitigation measures. No study has yet been conducted to solicit wind turbine operators, mechanics, and contractor personnel or the surrounding communities concerning their personal experiences with ice throw to understand the perception of risk associated with this hazard. This is primarily due to the relatively recent broad application of this technology which has occurred over the past decade in the United States and primarily in Texas.

The wind energy boom in Texas which began in 2006 when generation went from 2736 MW to 4353 MW in a single year (www.awea.org) is now ten years strong. This timeframe allows those working on wind farms to gain enough relevant experience to provide a true picture of ice throw hazards and risk.

Cutter writes that technological hazards often have no visual or auditory cues, leaving individuals with few ways to discern their risk. As a result, where technological hazards are concerned, the public turns to the scientific community and regulators for guidance in the assessment of their risk (1993, 1). Thus, owners and operators of wind farms have a responsibility to ensure the safety of the general public as well as their own personnel, contractors, and visitors. This research will assist the wind energy industry with recommendations that may be applied to develop future regulations and guidelines for dealing with the potential dangers arising from ice throw and ice fall from wind turbines.

Scope of the Study

The results of this study will provide insight and information for wind farm operators, developers, landowners, planning authorities and local governments to better understand and communicate the hazards and risk associated with ice throw from wind turbines. It is intended to facilitate these stakeholders in identifying and implementing mitigation measures to reduce the exposure for wind farm workers and the public.

Wind farm operators and developers in particular will benefit from the results of these surveys to comprehend the frequency and severity of ice throw hazards as experienced by their own personnel in the field. Planning authorities and local governments need to be better informed on ice throw hazards in order to implement correct “setback criteria” for wind farm construction to keep turbines at safer distances.

A major assumption of this study is that all participants answered the survey questions truthfully. But, depending on the “safety culture” at different wind farms and among various employers, some respondent may have felt compelled to under-report the incidents they have witnessed. To encourage honesty and foster confidentiality, a cover letter accompanied each survey to guarantee their anonymity as participants and that the information gathered is for academic research and is not affiliated with their employer.

It is beyond the scope of this study to provide details on engineering controls or turbine designs to mitigate or inhibit ice throw. Rather, based on the survey results hazard managers will identify operational and procedural controls to reduce risk as well as proactive measures to help eliminate it.

2. PREVIOUS APPLIED RESEARCH, EFFORTS AT QUANTIFYING OBJECTIVE RISK, AND SOCIAL CONTEXT OF THE ICE THROW HAZARD

One basic question every risk-benefit analysis attempts to answer: *Is the activity/technology acceptably safe?* Wind energy technology benefits are numerous when compared to other forms of energy production. They include a significant reduction in greenhouse gas emissions, conservation of water resources, and conservation of non-renewable fuel resources, provide a new tax base and jobs for local communities, and generate income for landowners in the form of rent and royalty payments. Besides ice throw hazards, other risks associated with wind energy include blade failure, turbine collapse, oil spills, fire hazards, electrical hazards, and bird/bat mortality. Risk assessments with objectives to reduce and control accidents associated with technological hazards must be guided by assessments of probability and severity. This determination will identify what risks are considered tolerable and those which are intolerable.

A German Wind Energy Institute study by Morgan et al. (1998) titled, *Assessment of Safety Risks Arising from Wind Turbine Icing*, concluded that the chance of being struck by an ice fragment from a wind turbine was comparable to the odds of being struck by lightning. Although this may sound low, the National Oceanic and Atmospheric Administration (NOAA) revealed that during the past 30 years, lightning killed an average of 58 people per year (the number of people struck but not killed was not provided) (lightningsafety.noaa.gov). This number is slightly higher than 57 deaths per year caused by tornadoes and average 48 deaths to hurricanes. Because lightning usually claims only one or two victims at a time and does not cause mass destruction of property, it is considered an underrated risk. Documented lightning injuries in the United States average about 300 per year, although it is estimated that this number is low due to underreporting and poor recordkeeping.

Ice can only form on a stationary rotor because "blade flexing" prevents ice formation during turbine operations. Thus, ice buildup typically occurs when the wind turbine generators are curtailed overnight when energy demand is lowest. When energy demand quickly increases in the early morning hours, turbines are restarted to meet the grid load, and, as a result, ice which has formed overnight is dropped from the turbine nacelle as the generator heats up and is thrown from the turbine blades after melting in the daylight sun.

Quantifying Objective Risk toward the Ice Throw Hazard

The majority of research studies pertaining to the ice throw hazard from wind turbines have been conducted in central Europe where wind energy has been in use for more than a decade longer than the bulk of U.S. installations. The lack of research on the subject of ice throw hazards may reflect the fact that there has never been a reported injury or fatality despite the installation of more than 175,000 megawatts worldwide with 48,600 megawatts of installed capacity in the U.S. alone.

Below (Figure 2.1) is a diagram identifying the key components of a wind turbine which will be referred to in the review of determining objective risk as well as discussing other issues related to the technological hazards aspects of ice throw. Please note that the hub and blade components are collectively referred to as the "rotor" section of the wind turbine.

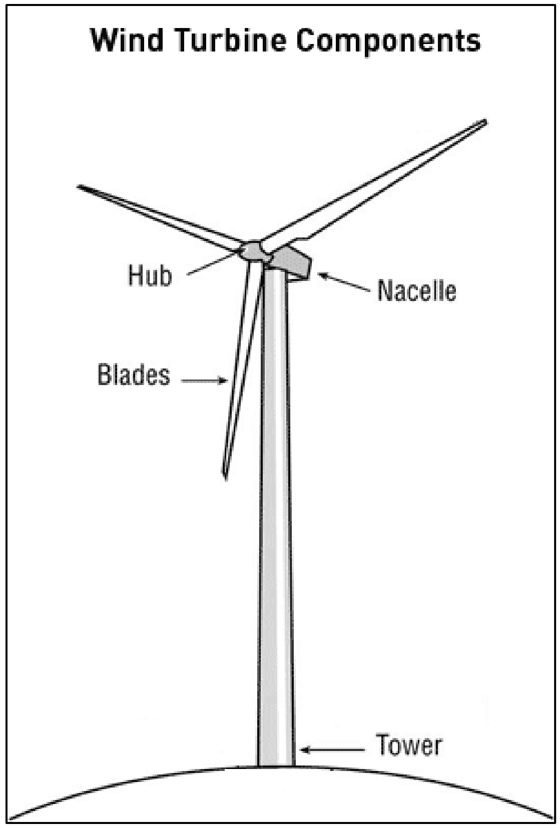


Figure 2.1 Wind turbine components. Source: American Wind Energy Association (AWEA).

The first study to address this issue was conducted by Morgan and Bossanyi (1996) as part of a project titled, "Wind Energy in Cold Climates," coordinated by the Finnish Meteorological Institute which ran from 1996 to 1998. One element of the study titled, "*Wind turbine icing and public safety – a quantifiable risk,"* was the first of its kind to address the issue of ice throw from wind turbines. One primary goal of this study was to "produce safety guidelines for wind developments in ice-prone areas" (1996, 2). Essentially, the aim of researchers was to educate and inform wind project developers so that they might use the study's findings to identify minimum set-back distances for wind turbines from public roads, homes, and other landowner structures.

The Morgan and Bossanyi study analyzed results of a questionnaire that was sent to turbine operators in Europe that requested information about the frequency of occurrence of blade ice throw, the mass of the object thrown, and the observed distance of the ice debris from the tower base. Factors that caused ice throw to become a hazard from wind turbines included:

1) Speed of rotation (especially the blade tip speed which can reach 145 mph);
2) Blade pitch (the position of the ice on the blade);
3) Blade profile/geometry;
4) Wind speed;
5) Aerodynamic drag (associated with the size of the debris); and
6) Slingshot effect (blade azimuth position)

The final factor, called "Slingshot Effect" only affected ice fragments which became detached while the blade was travelling upwards. Typically, an ice fragment becomes detached close to the rotor hub and slides all the way down along the leading edge of the blade until it reaches the blade tip prior to being ejected at 45 degrees from horizontal.

Slingshot velocity is greatest for those fragments leaving the blade tip at the point where the blade is vertically downward because there is little time for deceleration to terminal velocity prior to hitting the ground. If field observations determine that ice is much more likely to be shed from the blade tip than close to the hub (and sliding to the tip) then the effect of slingshot will become much less significant because the ice fragments will be much smaller. The speed at which ice fragments travel as they are being thrown from the turbine blades is calculated at 40-60 meters per second (m/s) (89-134 mph) without factoring in the slingshot effect. With the slingshot effect factored in, the fragment speed increases to 80 m/s (179 mph).

The Morgan and Bossanyi (1996) *Quantifiable Risk* study developed a model for projecting ice fragment throw distances as well as trajectory predictions from wind turbines, and included mapping of results. The study used a reference case consisting of a blade tip speed of 65 m/s (145 mph) with a range of wind speed from 13-25 m/s (29-56 mph) giving a range of distance thrown from 175-200 meters (574-656 feet). The results were generated using a Monte Carlo analysis first introduced by Stanislaw Ulam (1949). The study assumptions included:

1. That an ice fragment was equally likely to become detached at any blade azimuth angle.
2. That the probability of ice detachment at the blade tip was three times greater than at the hub.
3. That ice fragments have a mass of 1 kilogram (2.2 lbs.).
4. Rotor speed was zero when wind speed is outside the range of 5-25 m/s.
5. Rotational speed was 25 rpm when wind speed is within the 5-25 m/s range.

Thus, the actual or measured risk of a person being struck by an ice fragment thrown from a wind turbine was dependent on:

1. The probability that the turbine would have ice build-up on the blades;
2. The likelihood that ice fragments would become detached from the blade;

3. The point on the ground where the detached ice fragment would land; and
4. The probability that a person would be exposed to the risk in the area as well as having little or no awareness of the hazard and, thus foregoing safety precautions.

The modeling of ice throw by Morgan and Bossanyi (1996) generated an output of a calculated “safe distance” (also called a “threshold distance”) beyond which there is negligible risk of injury from ice throw, including a factor for slingshot effect.

Using data collected during field observations and the results of the ice throw modeling, Morgan and Bossanyi (1996) identify an ice throw “safety threshold” of 200-250 meters (656-820 feet) from any wind turbine. This equals a distance range between 219 and 273 yards, or 2-3 football fields of circumference around every turbine.

In 1998 Morgan and Bossanyi teamed up with Hassan and Seifert of DEWI (German Wind Energy Institute) to generate a second study for the ‘Wind Energy in Cold Climates’ (WECO) project titled, *Assessment of Safety Risks Arising from Wind Turbine Icing.*

One of the three central objectives of the WECO project was “to produce safety guidelines for wind developments in ice-prone areas” (114). Building on the results of their previous study in 1996, the researchers estimated that the threshold “safe” distance from a wind turbine with icing conditions was 250 meters (820 feet).

The team also identified *rime ice* formation as being the most common type of ice that forms on wind turbine blades. Rime ice develops when water droplets in fog conditions freeze to the outer surfaces of objects. Rime ice typically accumulates on the leading edges and control surfaces of aircraft and meteorological equipment in cold climates.

In 2003 Michael Durstewitz with Germany's 'Institut für Solare Energieversorgungstechnik'(Division Information and Energy Economy) published a report titled "*On-Site Cold Climate Problems"* as part of a larger study "Wind Turbines in icing environment: improvement of tools for siting, certification and operation (New Icetools)" which focused on wind turbine impairment in operations due to icing condition. Durstewitz identified two types of turbine ice formation and describes the differences between rime ice and glaze ice:

a) "Glaze Ice" forms when a warm front drifts above cold air, the falling freezing rain is a super-cooled droplet that freezes on the surface of objects with temperatures below 32 degrees Fahrenheit and will build up a solid layer of ice.
b) "Rime Ice" occurs when turbines are exposed to low temperatures in combination with fog or clouds of super-cooled water droplets (also known as in-cloud icing).

Ice accretion may be collected by all parts of the turbine structure, not just the turbine blades. Ice accretion on turbine blades changes the surface and geometric dimensions of the blade and thus affects the aerodynamic design properties (Figure 2.2).

Figure 2.2 Ice forming on the leading edge of a wind turbine blade. Source: Wind turbine at Aapua-fjell, Sweden. Photo by Kent Larsson.

This in turn can reduce the power output of the turbine for only small amounts of ice adhered to the blade's leading edge. Ice accretion on blades applies static and dynamic loads which may cause emergency shutdowns (protective trips) due to severe vibrations of the whole structure.

The constraints of wind turbine operations due to icing in cold climates are usually not considered during the wind farm planning phase. Even project development setback distance recommendations are not strictly adhered to.

The German Wind Energy Institute (DEWI) (Seifert, Westerhellweg, and Kröning, 2003) commissioned the study "*Risk Analysis of Ice Throw From Wind Turbines"* to evaluate the exposure of landowners, equipment operators, and the general public to the hazards of ice throw. Typically, wind turbines are sited with consideration of setback distances from homes, but turbines are erected close to existing roads in order to avoid building long and expensive access roads for turbine erection and maintenance activities. The turbines with close proximity to public roads introduce a risk for ice throw to persons passing by the wind turbines.

When ice accumulates on a wind turbine two types of hazards may occur:

1. The ice fragments are thrown off the rotor and blades when the turbine is started due to centrifugal and aerodynamic forces (Ice Throw).
2. The ice fragments fall down from the turbine as the gearbox and generator in the nacelle heat up, or as sunlight melts the ice on a turbine rotor and blade which has been curtailed (Ice Drop).

Field observations indicate that the ice fragments do not hit the ground as long slender parts, but break apart immediately after detaching from the blade into smaller fragments; although there have been cases of fragments as long as two meters (6.5 feet) being reported and investigated. Smaller ice particles produce less aerodynamic drag and will hit the ground in a closer radius to the turbine base.

Wind speed and direction play a significant role in the trajectory and distance an ice fragment may travel. Every wind turbine is equipped with an anemometer on top of the nacelle. The information collected by the turbine anemometer can be used to determine when a turbine with icing conditions should be shut down (curtailed) if the yaw motors direct the turbine towards a public road for example (engineering control).

Using the calculation introduced by the WECO Study (Morgan & Bossanyi 1996) a risk circle" can be identified for each turbine:

$$d = (D + H) \times 1.5$$

where,

d = maximum throwing distance in meters

D = rotor diameter in meters

H = hub height in meters

This simplified equation is only an estimate but can be used as a project development tool in planning the position of wind turbines close to streets or other objects.

Ice fall hazards exist when snow and ice accumulate on top of the nacelle (size and shape varies depending on the manufacturer). When the turbine is in operation, heat from the gearbox and generator inside the nacelle causes the ice on the surface to melt resulting in a water film that allows the ice and snow above it to slip down. These large and heavy ice fragments present an extremely dangerous hazard for turbine operators and maintenance staff.

The Morgan and Bossanyi (1996) study identifies the following input data needed to assess the risk for a person near a wind turbine during icing conditions:

1. Number of icing events per year;
2. Wind direction; wind speed frequency distribution;
3. Location, number, and mass of individual ice fragments thrown off or falling off a wind turbine; and

4. Number of persons passing the risk area per year.

Field observations indicate that most *ice shedding* occurs as temperatures rise and the ice begins to thaw from the rotor. This is typically in the early morning hours when turbines are brought back on line to meet the growing grid demand. Observers in the field note that there is a tendency for ice fragments to be dropped off rather than thrown off the rotor. It also tends to be shed off the tip in preference to other parts of the blade and large ice pieces tend to break up in flight. Ice fragments were observed to fall predominantly downwind of the rotor plane.

Morgan and Bossanyi's (1996) research also identified a tendency for turbine operators to over-ride any protective measures when keeping a wind turbine generator (WTG) off-line due to ice buildup. This often leads to heavy ice shedding, as well.

Turbine Icing Safety Program Development

Operations and maintenance personnel work more regularly and in closer proximity to the wind turbines and, therefore, are exposed to more risk than members of the general public. Thus, it is clear that risk needs to be communicated to the workers by developing Turbine Icing Safety Programs to increase awareness of exposure to the hazard, not only for the welfare of the wind farm employees and contractors, but also to protect the general public from these hazards.

Conventional safety programs identify and address hazard exposure using the "hierarchy of control" method (Occupational Safety & Health Administration: https://www.osha.gov/dte/grant_materials/fy10/sh-20839-10/hierarchy_of_controls.pdf).

The first step in this process is to assess whether the hazard might be mitigated, and second, calls for the application of engineering controls, third, operational controls are specified such as, safe work procedures, and, finally, personal protective equipment (PPE) is promulgated as the last line of defense.

Engineering controls that might be applied to mitigate this hazard include:

a) Ice detection systems;
b) Turbine blade vibration sensor trip;
c) Heat tracing; or
d) Blade coatings which may inhibit ice formation.

Some operational/procedural controls that might be employed to reduce the risk include:

1. The development and training of an Operation and Maintenance (O&M) "Turbine Icing Procedure;"
2. Public warning signs;
3. Continued curtailment of turbines with observed icing conditions until the ice melts and falls at the base of the tower; or
4. No overnight curtailment of turbines during weather conditions conducive to icing (dependent on availability of wind).

If a wind turbine with observed icing conditions is to be kept in the off position until the ice which has formed is melted and fallen from the blades there will be an operations and management (O&M) concern that large chucks of ice might fall on the exposed turbine pad mount transformer below. Damage to the turbine pad mount transformer could create an environmental hazard because these transformers contain roughly 500 gallons of mineral oil for cooling purposes.

An O&M Turbine Icing Procedure would require the field technicians to first “yaw” the nacelle using the “yaw motor” to turn the nacelle to a locked position where the turbine blades are not directly over the pad mount transformer. This operation would be limited by the current wind speed. If the wind speed is too high the turbine must be allowed to yaw freely to avoid stress on the turbine.

Another element of a Wind Turbine Icing Procedure might include an approach guideline directing personnel to access the turbine from an upwind direction since most fragments fall downwind of the wind turbine generator (Figure 2.3).

Figure 2.3 Ice fragment thrown from a wind turbine. Source: Munnsville Wind Farm, New York. Photo by Fred Gamlin.

3. LITERATURE REVIEW

The study of "risk" spans a large and varied literature and, until recently, has been divided in to two main arenas: 1) the quantitative study of objective risk—exposure, estimates of probabilities, measurement, scenario modeling, etc., and 2) behavioral—human perceptions and interpretations of risk, the social and psychological construction of risk within cultural boundaries, risk management, and the question of levels of acceptance or rejection. In the second arena, research approaches, methods and applications are diverse encompassing quantitative, qualitative and mixed methods approaches and are from various disciplines. However, all involve elements of human behavior, choice, perceptions, and/or interpretations of risk.

Because the previous chapter dealt with the background and context of the ice throw hazard, including ways that the industry quantifies objective risk, this chapter will first focus on the human-side of determining one's risk—the cognitive and behavioral elements of risk perception/interpretation as found in the research literature which is relevant to this research. Second, this literature review will discuss more recent risk research that calls for subsuming traditional research within broader conceptual frameworks theorizing that social contexts and constructs determine levels of risk, for entities at all geographic scales. Included in this discussion will be concepts of "vulnerability" and "resiliency" of nations, regions, and communities that have emerged in the literature to describe the extent to which people and their communities are exposed to, and deal with levels of risk in their daily lives.

Research on Individual Risk Perception, Interpretation, and Behavior

Risk research began with systematic study of natural hazards and disasters by Gilbert F. White, and his students Ian Burton and Robert Kates. The “natural hazards paradigm,” developed by these pioneers found roots in the work of White’s mentor, Harlan Barrows (1923) who promoted the human-ecological tradition—that is, the relationship between people and their environment. White and colleagues viewed the management of hazards as a series of adjustments in both the human use and natural events systems. Thus, risk was synonymous with the distribution of these extreme events, or natural features that gave rise to them (Cutter 1993). Much of the early hazards work called for mapping the locations of extreme events to delineate risk and observed “adjustments” that humans made in response to an event at a certain location.

Concomitantly, while geographers studied risk from a human-ecological perspective, other disciplines, particularly psychology and social psychology wrestled with understanding individuals’ perceptions, interpretations, and behavior choices related to risk.

The Theory of Acceptable Risk

What Gilbert White is to *natural* hazards, Chauncey Starr is to *technological* hazards. After serving as Dean of the UCLA School of Engineering and Applied Science from 1967 to 1973, Starr founded the Electric Power Research Institute in 1973 and served as its first president. His prominent paper “Social Benefit versus Technological Risk” (1969) marked a pivotal moment in technological risk assessment from his conclusion that people are willing to tolerate higher risks from activities which they view as highly beneficial (such as wind energy). For new technologies, Starr demonstrated that the *acceptable risk* becomes that level of safety associated with ongoing activities having similar benefit to society (other forms of electricity generation).

Starr (1969, 1972) also determined that society is able to perform a risk-benefit ratio that reveals *social preferences* to predict what risk levels are acceptable when establishing policies or introducing new technologies (such as wind energy). In particular, Starr's measure of risk is the statistical expectation of fatalities per hour of exposure to the activity under consideration. For "involuntary activities" the benefit was assumed to be proportional to the contribution that activity makes to an individual's annual income. Therefore, according to Starr's formulations, and because most wind energy projects are located on leased property, the monetary benefits for the local resident landowner are extremely high.

After conducting a number of studies on natural and human-made risk, Starr made several important conclusions: a) the public seems willing to accept "voluntary risks" roughly one thousand times greater than "involuntary risks" at a given level of benefit; b) the *acceptability of risks* is roughly proportional to the real and perceived benefits; and c) the acceptable level of risk is inversely related to the number of persons participating in the activity. However, another prominent researcher, psychologist Paul Slovic and his colleagues (1980b) pointed out that the acceptable level of risk is not the ideal risk. They proposed "ideally" the level of risks should be zero. Slovic and colleagues contend that:

> The acceptable level of risk is a level that is good enough, where "good enough" means you think the advantages of increased safety are not worth the costs of reducing risk by restricting or otherwise altering the activity. If an activity

> presents a level of risk that is acceptable, no special action need be taken to increase its safety (137).

This conclusion emanated from research in which Slovic and colleagues (1980b) evaluated the perceived risk from 90 hazards—"solar electric power" received the lowest perceived risk score ranking 90th. Their study also revealed that greater risks are tolerated for more beneficial activities. Thus, the perceived low level of risk for solar energy, today, might be a reflection of society's perceived benefit of renewable energy in general; and, this may translate also into an equally low risk perception of the benefits of wind power. Lave (1972) from the discipline of Mass Communication noted that involuntary hazards (such as those posed by energy production) typically affect larger numbers of people and, therefore, require stricter safety standards for such hazards, however, this may merely reflect the greater amount of money that groups would be willing to pay for safety, relative to what an individual would be willing to pay. Thus, since electric power generation is typically considered an involuntary activity exposure, but wind farm projects are located on private land which is leased from landowners, one might ask: "Does this change their exposure to a voluntary activity?"

Research on Perception of Risk

Perceived risk declines as perceived benefit increases. Starr (1969) believed that the characteristic that strongly correlated with perceived risk was the degree to which a hazard evokes *feelings of dread*. In fact, most experts appeared to see riskiness as synonymous with expected annual mortality. However, Kates (1962) found that people living in hazard prone areas preferred to forego their risk assessment responsibilities and leave the decision making to the experts. This begs the question: "How safe is safe enough?" That is, what is a reasonably optimal balance between the benefit from an activity and its risk? Thus, this led to the development of "Risk-Benefit Ratios" to answer this question.

Once the results of a hazard analysis are available they need to be communicated to relevant stakeholders and policy makers. People tend to evaluate their risk by applying general *inferential* rules, also called *judgmental* rules, which are based on what they remember hearing or observing about the risk in question. These rules are known technically as "heuristics" (Slovic 2000). Tversky and Kahneman (1973) defined one heuristic that has special relevance for risk perception as "the availability heuristic." People apply this heuristic to judge an event's likelihood if instances of its occurrence are easy to imagine or recall. Thus, perceived risk is influenced (and often biased) by the "imaginability" and "memorability" of the hazard (Slovic 2000). In a study to determine levels of availability biases in estimating the frequency of 40 causes of death in the U.S., lightning was one of the most underestimated causes of death (Lichtenstein et al. 1978). In general, most of the underestimated causes of death tended to be unremarkable events which claim only one victim at a time and are common in non-fatal form.

Many people are insensitive to the fallibility of the assumptions on which their judgments about risks are based. This overconfidence may be dangerous. It shows that we often do not realize how little we know (you don't know what you don't know) and how much additional information we need about the various risks we face. Through education and information contained in risk communication programs we can improve understanding of risk by moving from, *not knowing that we don't know, to knowing that we don't know.*

Slovic (2000) defines "informativeness" as the degree to which an incident or mishap tells society something they may not have known about the hazardousness of a specific activity. Even a small accident may greatly enhance perceived risk and trigger tough corrective action because it increases the judged probability of future accidents. The incident at Three Mile Island which did not directly result in a single fatality is a good example of this phenomenon.

Technology and Perceptions/Interpretations of Risk

Social psychologists Fischhoff and colleagues (1979) identified four approaches toward determining whether a given technology is sufficiently safe:

1. Cost-Benefit Analysis – weighing costs against benefits, and vice-versa.
2. Revealed Preferences- determining whether risks are greater than those of currently tolerated technologies of equal benefit;
3. Expressed Preferences- examining the extent to which people indicate that a certain level of risk toward a threat is acceptable; and
4. Natural Standards- accepting that risks are no greater than those accompanying the development of the human species (18).

Each of these perspectives of technological risk will be discussed below.

History has shown us that the advancement of new technology also generates associated adverse side effects which pose new risks to society. Efforts to reduce these risks often entail a reduction of benefit. Wind turbines form ice on their blades during overnight periods when energy demand is low and the units are shut down; the following morning when energy demand increases, instead of starting the turbines up and causing the ice to sling off the blades, the affected units should be curtailed until the ice melts and falls at the base of the tower structure. The “curtailment period” creates a reduction in benefit in the form of income generation loss.

Traditionally, the first step in conducting a *cost-benefit analysis* is to determine the expected cost of a project by identifying all of the adverse consequences that might occur as a result of its implementation. Next, the probability is assessed of each adverse consequence as well as an estimate of the cost or loss to society for each occurrence. A standard formula calls for multiplying the expected cost of each consequence by the probability that it will be incurred; then, the total expected cost is calculated by summing up all of the expected losses associated with the various consequences. A similar procedure is then applied to estimate the expected benefits of the project. The costs are then compared to the benefits.

One persistent challenge for cost-benefit analyses is how to assess the value of a human life. We do currently make these types of assessments when we make decisions about purchasing and installing safety features, buying life insurance, or accept a more hazardous job for extra salary. Linnerooth (1975) evaluated the traditional approach of economists to equate the value of a life with the value of a person’s expected future earnings. Kinder and Richards (1974) applied a second approach which equates the value of a human life with court awards given to a victim’s family. Slovic et al. (1976) indicated that, in the modern era, people have more control over the level of risks they face, but any reduction in risk often entails a reduction of benefit, as well. Building on the concepts of cost-benefit analysis and Starr’s risk-benefit ratio, the researchers offered a risk-benefit analysis, in which special attention is given to assessing the probability of hazardous events and quantifying the costs associated with fatal incidents or debilitating events. Although we can estimate the economic costs stemming from medical expenses and lost wages a persistent challenge for researchers was identifying a suitable scheme for evaluating the worth of human life and health to society. In a study to evaluate the perceived risks and benefits of 30 activities and technologies, which included the original eight used by Starr (1969), electric power (non-nuclear) had the highest benefit to lowest risk ratio (Fischhoff et al. 1978).

A literature review of technological hazard assessment would not be complete without mentioning the Ford Pinto case (*Grimshaw versus Ford Motor Company* 1978) and its relevance for cost-benefit risk assessment. Ford personnel discovered a design problem with the installation and location of fuel tanks on the Pinto model. Decision makers allegedly declined to initiate a recall to correct the problem (estimated at approximately $11 per vehicle) after a cost-benefit analysis determined it would be cheaper to pay off any lawsuits for any resulting deaths or injuries, a document which became known as the *Ford Pinto Memo.* A 1972 accident which killed one woman and severely injured a 13-year old boy (Richard Grimshaw) led to a lawsuit which resulted in compensatory damages of $2.5 million and punitive damages of $3.5 million against Ford. Slovic (2000) proposed that had Ford performed a psychometric study of the hazard, it might have "highlighted this particular defect as one whose seriousness and higher order costs (lawsuits, damaged company reputation) were likely to be greatly underestimated by cost-benefit analysis" (199).

Starr (1969) advocated the *revealed preference* method which defines acceptable risk for a new technology as the level of safety associated with ongoing activities having a similar benefit to society. If the primary activity of a wind energy project is to provide electricity, then the comparison of risk associated with other forms of energy production show an improved level of safety overall.

The *cost-benefit analysis* and *revealed preference* methods both try to infer public values indirectly whereas, the *expressed preferences* approach asks people directly what levels of safety they deem acceptable. One of the principle benefits of this approach is that it allowed for broad public participation in decision making and was thus politically acceptable (Fischhoff et al. 1979).

Some methods of obtaining *expressed preferences* included opinion surveys, detailed questioning of selected groups of citizens to produce qualitative analysis of their responses, one-on-one interviewing of stakeholders, and public hearings. Studies utilizing the expressed preferences approach indicated that people believed that greater risks should be tolerated for more beneficial activities. There is an assumption that the current overall perception of wind energy is that it is a highly beneficial activity. This may be a contributing factor in the widespread acceptance of ice throw hazards and risks within the industry.

If the technological hazards associated with wind energy are dealt with one at a time, many will be neglected. One approach lies within the turbine setback criteria. If setback limitations are broadened and strictly adhered to, they will address a multitude of hazards besides ice throw.

One challenge for the application of mitigation strategies to address ice throw hazards is that a safety measure (within the hierarchy of control) which is reasonable in a cost-benefit sense may not appear reasonable from a cost-effectiveness sense. Safety dollars are limited, thus finding that the benefits of an identified safety measure outweigh its costs does not mean that even greater benefits will not be reaped with similar expenditures elsewhere.

The risks posed by wind energy are significantly lower than those presented by other forms of energy generation such as coal power production which includes hazards associated with mining operations. Thus, for every megawatt of wind energy that offsets production from other sources such as coal, gas turbine, and nuclear, there has been a net reduction in risks to our society as a whole.

The Development of Prospect Theory

In 1979 Kahneman and Tversky developed "Prospect Theory" to describe decisions between alternatives that involve risks that have defined probabilities. They asserted that low-probability events tended to be overestimated, although special weight is given to events which are certain. From an insurance perspective, they determined that people are more likely to protect themselves from a probable hazard if they realized that they are at risk and will remain so unless they take protective action.

Kahneman and Tversky (1979) also identified "framing" as a key component in decisions about risk. "Framing Theory" is applied in sociological studies to describe individual preferences and perceived values which are based on prior experience and assumptions. Therefore, the way a problem is posed, how questions are phrased, and the ways that questions elicit responses can have a significant impact on judgments that are supposed to identify people's preferences. Various research methods have been shown to both distort values and should be avoided, as well as educate and deepen awareness for respondents.

In an article titled "Informing people about risk," Slovic et al. (1980a) cited a growing public awareness of the risk people face in their everyday lives. This has resulted in increased pressure on designers and regulators of hazardous enterprises to educate and inform people about these risks.

Wind Turbines and Ice Throw as a Technological Hazard

The Oxford Dictionary of Environment and Conservation (Park 2007) defines a technological hazard as:

> A hazard created by people, as opposed to a natural hazard. Examples include the release of air pollutants such as CFCs, serious industrial accidents such as oil spills at sea and explosions at nuclear power stations and toxic chemical plants, and the creation of waste materials (such as nuclear wastes) that are toxic and persistent and which natural environmental systems are incapable of breaking down (427).

Unlike the definition of a *natural* hazard, identifying the technology *per se* as the primary causal agent, for a technological hazard is problematic, since technological hazards often involve natural processes and are set in a socioeconomic and political context. For example, in this study, the ice throw hazard emanates from the operation of wind turbines and is considered a technological hazard; however, human factors and extreme weather are contributing elements (Cuff and Goudie 2005).

In comparing technological hazards to natural hazards, Cutter wrote that:

> Technological hazards arise from our individual and collective use of technology and present a very different set of problems and responses than

> natural hazards. Since technological hazards are often more pervasive and less publicly recognized than natural hazards, they also pose some unique management problems. For example, the public's response to technological hazards is often ambiguous, resulting in over-reactions, under-reactions, or no reactions (1993, 178).

Depending on the type and/or intent of research, the entity undertaking the study, the nature of the problem, the primary technology involved (e.g., nuclear power plants, automobiles, pesticides, wind turbines, etc.), the types of consequences (e.g., human health, economic impacts, ecological damage), the type of human health effect (e.g., cancer, heart disease, birth defects), the routes of exposure (e.g., air, land, or water), and/or the populations exposed (e.g., workers, young, old, pregnant), various taxonomies/categorizations have appeared in the literature (e.g., Litai et al. 1983; Von Winterfeldt and Edwards 1984; Slovic 1987).

Hohenemser et al. (1983b) divided technological hazards into six classifications:

1. Source (power plant emissions);
2. Use (medical X-rays);
3. Potential for harm (ice throw from wind turbines);
4. Population exposed (wind farm technicians);
5. Environmental pathways (air pollution); or
6. Varied consequences (property loss) (380).

The authors noted that most technological hazards fall into several categories. They further characterized technological hazards in terms of those which involved potentially hazardous releases of energy (ice throw) or materials (oil spill).

Hazards were defined as threats to humans and what they value, whereas risks were quantitative measures of hazard consequences typically expressed in terms of conditional probabilities of experiencing harm. For example, we think of automobile usage as a hazardous activity but consider the lifetime probability of dying in an automobile accident as a small percentage (2-3 percent) of all ways of dying (Hohenemser 1983b).

Within the definition of hazards there is a distinction between incidents resulting from *energy releases* and those from *material releases*. Based on a study of 33 incidents of energy releases and 60 material releases, Hohenemser et al. (1983a) identified four basic differences:

1. Energy releases occur for short periods, typically averaging less than one minute; whereas material releases persist for a week or more on average.
2. The consequences from energy hazards are immediately known; whereas material hazards exposure-consequences may be delayed for up to one month.
3. Energy release hazards only have a minor effect on future generations; whereas material hazards effect, on average, one future generation.
4. Non-human mortality is infrequent with energy releases (14).

Using the descriptions above, it is easy to categorize ice throw from wind turbines as an energy release hazard. The effects of ice throw occur for short periods, are immediately known, have minor transgenerational effects, and little potential for non-human mortality.

Over 30 years ago, Kates (1977) found that 40-50 technological hazards received widespread national news media attention each year. He theorized that each new hazard that is identified goes through a similar sequence that includes problem recognition, assessment, and managerial action. When incidents resulting from technological hazards occur there is often an immediate need for some type of managerial response. A thorough hazard and risk assessment of ice throw from wind turbines will provide strategies for reducing incidents, mitigating the effects, and prepare industry leaders to respond to hazards.

People's judgments about risk are often inaccurate and tend to be heavily influenced by their memory of past events and the *imaginability* of future events. Morgan et al. (1985) determined that risks associated with "dramatic or sensational causes of death" such as homicides, accidents, and natural disasters, tended to be greatly overestimated, especially when those events receive heavy media coverage.

Because people's perceptions of risk are often inaccurate, there is a need for public education programs. But how do you relay this information without causing fear and frustration within the general public? In the Morgan et al. (1985) study to determine people's judgment of risk associated with high voltage transmission lines, researchers found that groups who were provided a description of findings concerning the possible health effects of long-term exposure to transmission lines were more concerned about their health risks than prior to being shown the information. Therefore, it may be inferred that information programs concerning risks associated with ice throw from wind turbines may cause fear in the general public surrounding a wind farm and result in a overestimation of their exposure to this hazard. But, for a wind farm operator or contractor this fear may be a useful tool to raise their level of awareness and encourage them to comply with safe work procedures.

Numerous studies (Fischhoff 1983; Weinstein 1979) have shown that people prefer being told that the risks they face are being managed by trained professionals who are working diligently to maintain their safety. If the assurance cannot be made, they want to be informed about their risk exposure, even though this knowledge may lead them to feel anxious or scared. In general, the wind energy industry is staffed with qualified safety professionals and engineers who would be able to address the hazards of ice throw without alarming the general public.

Technological hazard assessments often compare competing technologies that provide the same service or product. Electricity generating technologies such as coal and nuclear power are often compared with an evaluation of the hazards associated with each in terms of human mortality estimates. An example is Inhaber's (1979) *Risk of energy production*, which estimated that mortality rates associated with coal technology are 50 times those for nuclear power technology, and that coal also exceeded nuclear power in terms of environmental effects as well. Thus, one might surmise that if wind energy was included in a hazard assessment comparing competing traditional electricity generating technologies, it would have the lowest estimate of human and non-human mortality.

Starr evaluated technological hazards from several industries and concluded that acceptability of risks from an activity is roughly proportional to the third power of the benefits for that activity. And, the public will accept risks from voluntary activities (such as driving a car) that are roughly 1000 times as great as it would tolerate from involuntary hazards (such as nuclear plant accidents) that provide the same level of benefit (1969).

The hazards posed by wind energy are relatively unknown as this technology is only now seeing wide-spread implementation in America. This means that people who work at or live near wind farms possibly have not yet formed opinions on their risk of exposure to this form of energy production. These naïve views may be easily manipulated by the way risks are "framed" when presented to workers or the general public. The framing of hazards shapes perception of risks.

When presenting risk information researchers suggest placing risks in perspective. The most effective method for accomplishing this has been to provide comparisons rather than absolute numbers or probabilities. As mentioned above, Morgan et al. (1998) compared the likelihood of an area near a wind turbine being struck by an ice fragment to the risk of being struck by lightning.

Psychology researchers developed a "psychometric paradigm" which uses psychological scaling methods and multivariate analysis that measure risk perception and attitudes. The researchers typically ask study participants to rate the current riskiness of a varied set of hazardous activities or technologies and then indicate a desired level of risk reduction or regulation of the hazards each presents (Slovic et al. 1980b). This method provided a means for assigning a quantitative measurement of risk perception and a tool for identifying similarities and differences among groups.

Renn (1991), claimed that "risk communication efforts are destined to fail unless they are structured in a two-way process" where each side, public and expert, has a chance to contribute (479). In this process, each side respects the intelligence and insights of the other. The challenge in risk communication of ice throw hazards with the neighboring public is how to inform and educate them without scaring and/or over-sensitizing them.

Wind farm technicians, contractors, and landowners each deserve to be informed about the hazards of ice throw which they face as part of their daily activities. Fischhoff (1983) advocated a “theory of informed consent” which identifies criteria for evaluating the adequacy of risk information programs. He contended the goal of informed consent should be to enable the exposed individual to make decisions that are in their own best interest. Slovic (2000) further noted the difficulty associated with communicating risk information puts a heavy burden on the informer who distributes the message. Without properly testing its comprehensibility the informer may be guilty of negligence.

Risk information must include equal portions of two primary ingredients-probabilities and consequences. Slovic (2000) believed “neglecting to educate people about consequences is a serious shortcoming in risk-information programs” (195). The consequences of being struck by a softball-size ice fragment travelling between 89-179 mph include severe to fatal injuries.

Risk assessments should be designed to evaluate three critical elements to aid in: 1) identifying; 2) characterizing; and 3) quantifying risk (220). Starr (1969) pioneered a method of risk assessment by weighing technological risk against benefits to answer the question, “How safe is safe enough?” He called it a “revealed preference” approach which assumed that through trial and error society had arrived at an “essentially optimum" balance between the risks and benefits associated with any activity. This was determined to reveal patterns of acceptable risk-benefit trade-offs. It can be hypothesized that wind energy thus has a much lower technological risk perception within society when compared with other forms of electricity generation such as nuclear or coal power. Although, specific hazards such as ice throw are not generally known to the public.

Subsequent studies of expressed preferences seemed to support Starr's contention that people were more willing to tolerate higher risks from activities which are viewed as highly beneficial. But these studies also determined that voluntariness of exposure was not the only key mediator of risk acceptance. Expressed preference studies found that other perceived characteristics such as familiarity, control, catastrophic potential, equity and level of knowledge also contributed to perceived risk, perceived benefit and risk acceptance (Slovic, Fischhoff and Lichtenstein 1980b).

Risk analysis is often used to model the impacts of a significant event in terms of direct harm to people and property damage. But the impact of such events can extend beyond the immediate harm and include indirect costs associated with business or industry reputations. A major incident may affect all companies in an industry, regardless of which company was responsible for initiating the event. Slovic (2000) compared these events to a stone dropped in a pond where the ripples spread outward first encompassing the directly affected victims, then the responsible company and, in the extreme, reaching other companies and industries. Thus, the impacts resulting from serious ice throw incidents might include:

1. Regulatory constraints in the form of new Occupational Health and Safety Administration (OSHA) rules governing wind turbine safety;
2. OSHA Citations and fines;
3. Litigation from local governments, land owners, adjacent non-participating land owners, and families of persons injured or killed;
4. Community opposition with respect to serious incidents which receive extensive media coverage and may result in a “Social Amplification of Risk”, and where many projects have plans for future expansion;
5. Investor flight including the inability to effectively negotiate power purchase agreements; and
6. Higher insurance premiums.

One important element of the risk-perception problem which has been the focus of numerous articles and surveys is the role of trust. These studies have also documented the extreme distrust people have in the individuals, industries, and institutions responsible for risk management. This pervasive distrust has been identified as a driving force behind risk perception and political activism to reduce risk (Bord and O’Connor 1990; Flynn et al. 1992).

Extensive studies (primarily by Bella 1987; Slovic 1993) conducted in the late 1980s and early 1990s clearly point to “lack of trust” as a critical factor causing divisive controversies that surround the management of technological hazards. Slovic identified that high public concern about a risk issue (for example, nuclear waste disposal) is associated with distrust of the managers responsible for that issue. Conversely, low public concern (for example, medical uses of radiation) is associated with trust of risk managers

(Slovic 1993). Therefore, trust in risk management is negatively related to risk perception. It is important for risk managers to understand trust, or lack thereof, as it is related to risk perception and the acceptance or rejection of a technological hazard. Establishing trust must be a primary component in any risk communication strategy. Without trust, effective risk communication is virtually impossible. Slovic concluded that "trust is more fundamental to conflict resolution than is risk communication" (1993, 677). Thus, one may ask: How will risk managers (safety professionals) in the wind energy industry establish trust with land owners, neighbors, wind farm employees, and contractors when developing risk communication programs for ice throw?

Currently, there appears to be a "crisis of confidence" between the general public and those who manage technological risks. Industry's response has been to turn to the field of risk communication in search of methods to bring experts and lay people into agreement and make conflicts over technological decisions easier to resolve (National Research Council 1989).

For risk communication efforts to be effective it is essential the risk manager establish trust with the receivers of this information. If you can establish trust, the information will be well received. But without trust, no form or process of risk communication will be satisfactory (Fessenden, Fitchen and Heath 1987).

Massive amounts of time, money, and resources have been dedicated to scientific studies designed to identify and quantify risks, but science has failed to learn how to manage those hazards once identified (Slovic 2000). In a 1993 case, the New York State Court of Appeals ruled that landowners whose property is taken for construction of high-voltage power lines can collect damages if the value of the rest of their property falls because of public fears about safety, regardless of whether that fear is reasonable (*Criscuola et al. versus New York Power Authority*, 1993). This case demonstrates that public perception of technological hazards has been linked with monetary compensation for a possible future decline in the economic value of property.

Kasperson et al. (1988) demonstrated how some technologies can become stigmatized as a result of some critical event, accident, or report of a hazardous condition often amplified by the reporting power of the mass media. A significant ice throw incident which receives extensive local media coverage may result in neighboring non-participating land owners filing claims that their property values have now been negatively affected due to their proximity to the wind turbines. This occurs because the non-participating land owners are already unhappy that their property was not selected to receive a turbine (with subsequent rent and royalty payments) and, thus, are likely to take advantage of any negative publicity.

The search for cleaner and safer energy generation technologies like wind power requires us to face difficult trade-offs between new and old sources of risk, costs and benefits. There are hazards associated with wind energy, but they result in fewer injuries and deaths than those posed by other technologies such as coal, natural gas, and nuclear power (U.S. Department of Labor- Bureau of Labor Statistics http://www.bls.gov/home.htm). Risk managers should address these hazards through effective risk-communication efforts first targeting those most likely to be exposed, the wind farm technicians. Risk communication programs for ice throw aimed at land owners and neighbors will need to be more complex to ensure these efforts don't result in inflated levels of perceived risk. As mentioned above, historically there is typically a lack of trust in the management of technological hazards. Wind energy risk managers must help their industry build that trust and ensure that land owners and neighbors believe that they care for their wellbeing.

Covello et al. (1983) examined the dichotomy between experts (risk managers) and the general public. They proposed that experts base their judgments on *real risks* and were viewed as objective, analytic, wise and rational; however, in contrast, the public was judged to rely on *perception of risk* which could be irrational, subjective, emotional, and often hypothetical.

Slovic (2000) proposed a new approach to the concept of risk which highlights the subjective nature of risk and "conceptualizes risk as a game in which the rules must be socially negotiated within the context of a specific problem" (392). Slovic contended in order to manage risk, we must first ask the question: "What is risk?" *Merriam-Webster's* (2003) defines risk as, "the possibility of suffering harm or loss" and "to expose to the possibility of loss or damage" (613).

Slovic (2000) explained the probabilities and consequences of adverse events are assumed to be produced by physical and natural processes in ways that can be objectively quantified by risk assessment. Ice throw from wind turbines is a product of the introduction of a new technology (physical process) into a climate capable of depositing ice on the turbine blades during specific periods (natural process). Both of these elements can be quantified and communicated through risk analysis. The steps for conducting a risk analysis include:

1. Defining the problem;
2. Selecting and measuring risks in terms of particular outcomes;
3. Determining the people at risk and their exposure parameters; and
4. Framing the risk for decision makers (394).

To highlight the importance of framing of risk, McNeil et al. (1982) demonstrated that different methods for presenting the same risk information can lead to different evaluations and decisions by the receivers. They conducted a study asking a group of people to imagine they have been diagnosed with lung cancer and then to choose between two different lung cancer treatment alternatives, each framed differently in terms of detail concerning death and predicted survivability. When they framed the statistics of a treatment alternative in terms of chances of dying the selection of that therapy was significantly lower than when framed as chances of survivability.

Thompson and Dean (1996) called the frame-sensitive nature of risk decisions a “contextualist conception” which places probabilities and consequences on the list of relevant risk attributes along with voluntariness, equity and other relevant contextual parameters (363). Slovic (2000) further elaborated that “on the contextualist view, the concept of risk is more like the concept of a game than the concept of the eye. Games have time limits, rules of play, opponents, criteria for winning or losing and so on, but none of these attributes is essential to the concept of a game, nor is any of the characteristic of all games” (395).

Gender plays an important role in risk assessment. Multiple studies have documented the finding that men tend to downplay risk and view threats as less problematic than women (Brody 1984; Dejoy 1992). Since wind energy workers in the U.S. are predominantly male, this suggests that risk communication programs might need to take into consideration this bias and hazards related to ice throw might be underestimated. To this end, the survey of wind farm employees from this study will generate useful information on their perceptions of this risk. Future researchers might develop a survey of wind farm workers to be performed prior to and just after exposure to a risk information program to gauge degrees of changes in their perceptions of risk.

Psychologists believe risk perception is influenced by the interplay of psychological, social, cultural, and political factors. Slovic (2000) pointed out that this explains why members of the public and risk managers (experts) disagree about risk "because they define risk differently, have different worldviews, different affective experiences and reactions or different social status" (409). Risk management is a social relationship which relies heavily on trust. Trust in risk management correlates with gender, race, and worldviews. Risk managers within the wind energy industry have the trust of their coworkers, therefore it can be hypothesized that ice throw risk communication programs should be well received.

Damasio (1994) proposed the tenant of "affect marking images" which motivates behavior in making judgments or decisions about risk. These images are marked by positive and negative affective feelings. Slovic (2000) expanded on the idea to suggest people use an "affect heuristic" to make judgments. He said representations of events in people's minds are tagged with varying degrees of affect. For example, people do not look at a car and just see a car; they see a *pretty* car, an *ugly* car, an *economical* car, a *pretentious* car, etc. Affect, along with *imaginability* and *memorability* serve as cues for probability judgments. Thus, one may ask: What mental affects do people form when they see wind turbines? How do wind farm technicians view the overall hazardousness of the machines they are working on?

Alhakami and Slovic (1994) observed there is an inverse relationship between perceived risk and perceived benefit because of an affective feeling referred to when the risk or benefits of a specific hazard are judged. They concluded “a person's general affective evaluation of the item was the major predictor of the risk-benefit correlation. Strong negative correlations were associated with unfavorable evaluations, whereas weak negative correlations were associated with favorable attitudes” (1095). If the item (activity) was ‘liked,’ people tended to judge its risks as low and its benefits as high. Therefore, ‘affect’ is often an important evaluation mechanism in determining risk perception.

Researchers would gauge a group’s perceived benefits and risks associated with a technology and then provide the group with additional information highlighting either the benefits or risks of the technology to determine the level of manipulation this information had on their initial assessments. Alhakami and Slovic (1994) observed marked differences in elicited responses after survey participants were exposed to manipulation of benefit and risk information. Damasio (1994) concluded that these types of studies suggest that risks and benefits are linked in people’s perceptions and consequently in their judgments of technological hazards.

Risk information programs for wind turbine ice throw hazards will need to consider the effect this information will have on the perception and judgments of the risk for those individuals receiving the training. The primary goal of a program shall be to raise awareness and improve safety for wind farm technicians and the surrounding community.

The Effect of "Framing" Risk on Risk Perception

An important element of risk perception involves 'framing' of risk. Gray (2003) defined framing as the process of constructing and representing our interpretations of the world around us. Furthermore, "we construct frames by sorting and categorizing our experience weighing new information against our previous interpretations" (12). A 'frame' is a reflection of what is going on around us and how we see ourselves and others implicated by what is happening. Therefore, people 'frame' potential risks differently (13).

Gray (2003) contended a 'frame' provides a heuristic for how to categorize and organize risk information data into meaningful chunks. When we frame risk information, we put it in perspective by relating it to other information we already "know."

Frames are used to:

a) Define issues;
b) Shape what actions should be taken and by whom;
c) Protect oneself;
d) Justify a stance we are taking on an issue; and
e) Mobilize people to take action or refrain from action on issues (15).

People who favor wind energy tend to frame issues in terms of economic and environmental benefits, whereas opponents primarily focus on issues such as avian and bat mortality, noise, and visual/scenic impacts. In the United Kingdom, a Department of Trade and Industry poll survey interviewed residents living near a wind project in Cemmaes Wales both immediately after construction was completed and one year later (Gipe 1995b). Three fourths of those interviewed saw the turbines every day. After one year of operation, 95 percent were "supportive" of wind energy. Only 16 percent thought that the wind turbines were "noisy." The overwhelming majority concluded that the turbines did not "spoil" the scenery, whereas 22 percent believed that they did. More than four-fifths of those surveyed (86 percent) favored the Cemmaes wind project after construction, and 11 percent were neutral. Only 3 percent objected.

Elliot (1988) proposed that there were marked differences in the way technical and lay populations frame risk. Those with technical understanding of the hazards present stress prediction and prevention of risks, whereas lay persons are more concerned about risk detection and repairing damage from risks that have occurred.

Gray (2003) identified three generic types of frames which are prevalent in most conflict cases: identity frames, characterization frames, and conflict management frames. Identity frames include one’s social identity and self-image which is shaped by the individual’s social and cultural experiences as well as any memberships they may have affiliation with; for example, an “environmentalist” or a “cattle rancher” or a “Texan” (wind farm technician, turbine land owner, neighbor).

Characterization frames resemble identity frames in that they are statements made by individuals about how they understand someone “else” to be. They are based on attributions of blame and causality about prior experiences concerning what others have done to shape our experiences. How would the "characterization" of a wind energy project change as a result of an ice throw event which injured or killed a member of the surrounding community?

Conflict management frames involve different stakeholder preferences for how a conflict should be managed or dealt with. This may involve a spectrum of options ranging from discussion to negotiation, to all out fighting. Litigation may result which could in turn lead to policy changes. A significant ice throw event may result in a public outcry for more stringent turbine setback limitations defined at the state or local level.

Holistic Views of Hazard/Risk Management

Given that loss of properties and lives continued unabated on into the second half of the 20th century, a "radical critique" arose in the research literature that countered the prevailing human-ecological, "Natural hazards paradigm." These researchers argued that perception of risk and adjustment to hazards are mediated by cultural, economic, political and social forces.

From the 1980s onward, researchers and practitioners have called for integration of individual risk perception/interpretation into more holistic frameworks to study and answer questions related to disaster risk reduction at any geographic scale—local, regional, national, and global.

In 2005, governments attending the World Conference on Disaster Reduction (also called the Hyogo Conference) agreed that:

> We can and must further build the resilience of nations and communities to disasters through people-centered early warning systems, risks assessments, education and other proactive, integrated, multi-hazard, and

> multi-sectorial approaches and activities in the context of the disaster reduction cycle, which consists of prevention, preparedness, and emergency response, as well as recovery and rehabilitation. Disaster risks, hazards, and their impacts pose a threat, but appropriate response to these can and should lead to actions to reduce risks and vulnerabilities in the future (UN/ISDR, 2005a, p.2)

From this conference, five priorities for action were stated as part of the Hyogo Framework for Action (UN/ISDR 2005b) and are to:

1. Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation;
2. Identify, assess and monitor disaster risks and enhance early warning;
3. Use knowledge, innovation and education to build a culture of safety and resilience at all levels;
4. Reduce the underlying risk factors; and
5. Strengthen disaster preparedness for effective response at all levels (UN/ISDR, 2005b, p.6).

From the ISDR and other international agreements and statements of organizations, the International Council for Science Union (ICSU) proposed a research program centered on disaster risk and disaster risk reduction at all geographic scales. In their 2008 document, A Science Plan for Integrated Research on Disaster Risk, the ICSU stated:

> Risk depends not only on hazards but also on exposure and vulnerability to these hazards, making risk an inherently interdisciplinary issue. In order to reduce risk, there needs to be integrated risk analysis, including consideration of relevant human behavior, its motivations, constraints and consequences, and decision-making processes in face of risks. This inevitably requires that natural scientists and engineers work together with social or behavioral scientists in promoting relevant decision-making in the risk management area. Moreover, the

> understanding of risk patterns and risk-management decisions and their promotion require the integration and consideration of scales that go from the local through to the international level (12).

Theory Guiding This Research: The Protective Action Decision Model

As introduced in Chapter 1, Lindell and Perry (2012) developed a revised Protective Action Decision Model (PADM) centered on three core elements: 1) threat perceptions, 2) protective perceptions, and 3) stakeholder perceptions. It is proposed that these three perceptions form the basis for decisions about how people will respond to an imminent or long-term threat. The core perceptions are influenced by inputs such as social cues, information sources, and warning messages (Figure 3.1) that affect three pre-decision processes: exposure, attention, and comprehension. Not all decisions on protective actions follow every stage in the model or even the sequence provided; the model simply characterizes the way people typically make decisions about adopting actions or mitigation strategies to protect against environmental hazards, or in this study protect against the technological hazard of ice throw from wind turbines.

As Figure 3.1 illustrates, one input to the PADM information flow comes from *environmental cues* which comprise the physical environment component and includes technological processes that generate a hazard. Working or living in close proximity to wind turbines alone does not immediately generate an exposure risk of ice throw from wind turbines. The hazard risk also needs a meteorological element (weather conditions favorable for ice formation) also to be present.

Environmental cues may be generated by sights and sounds that indicate hazard onset. The simple act of seeing large sheets of ice on wind turbine blades or hearing the ice crack as a wind turbine begins to power up in the morning after sheets of ice have formed overnight may be relevant for people's threat response mechanisms to drive protective action decision making. Surveying wind farm workers and surrounding residents about turbine icing experiences will identify those individuals with higher levels of perception toward risk to themselves as well as their communities and, therefore, might be more likely to seek out protective action information.

For wind farm workers, just observing ice formation on a turbine's hub, blades, or nacelle is a significant enough environmental cue to stimulate protective actions such as evacuation of the immediate area, and/or issuing site "stand down orders" (similar to what occurs whenever lightning strikes within 25 miles of the wind farm) requiring all technicians to stop work and return to the administrative building until the hazard no longer exists.

Figure 3.1 also shows that sources of *information flow* from the *social context* into the PADM include "messages from people who may transmit information about hazards and protective actions as well as providing assistance to reduce the hazard or providing material resources that assist protective response" (Lindell and Perry 2012, 618). *Social cues* for ice throw hazards may include warning messages from wind farm safety professionals, turbine manufacturers, or wind farm operations and maintenance management team members. For the residents living in close proximity to a wind farm, social cues may come from several sources: 1) neighbors' experiences with ice throw incidents and observations, 2) warning messages from wind farm workers and family members who live in the community, and/or 3) from the local media if an ice throw incident causes an accident or near-miss. (A media example appears in Appendix A).

The Protective Action Decision Model (Figure 3.1) identifies *warning messages* as an important input for protective action decision making. Some wind farms operations may choose to implement channels for disseminating warning messages such as, a warning network which might include signage at the facility that addresses hazards affecting turbine access roads to communicate the hazard of ice throw to anyone entering the area.

Whether people heed or ignore hazard information is determined by *receiver characteristics,* that is, their expectations, prior levels of direct and indirect experience, and intrusiveness of the information (Fiske and Taylor 2008). This process is also known to be affected by the warning recipient's age (Mayhorn 2005).

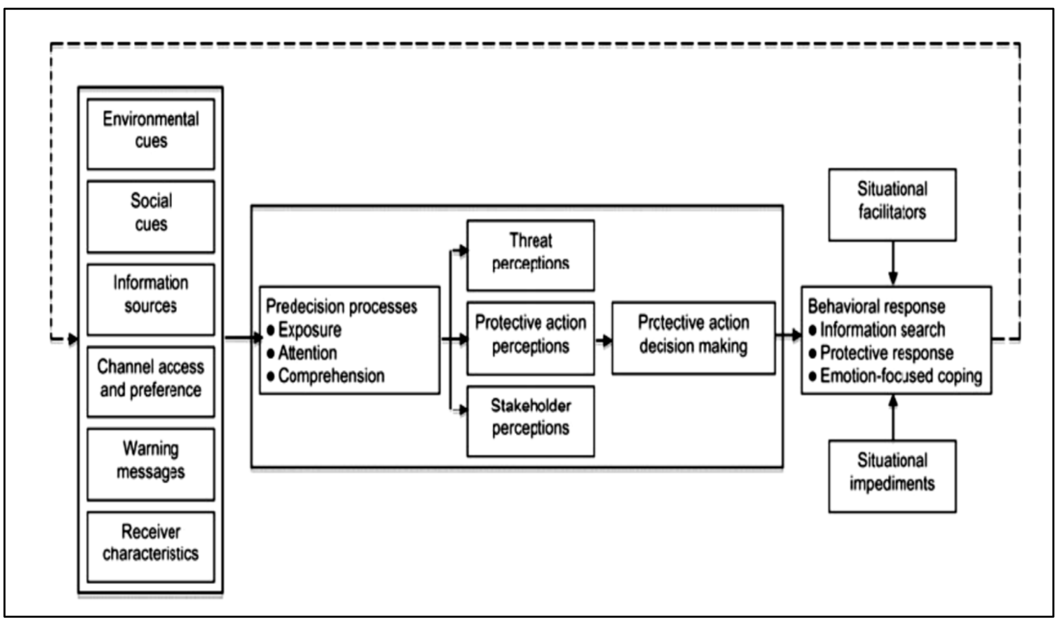


Figure 3.1 The Protective Action Decision Model (revised). Source: Lindell, Michael K., and Ronald W. Perry. 2012. The Protective Action Decision Model: Theoretical Modifications and Additional Evidence. Risk Analysis 32 (4):617.

Input variables in the PADM –environmental cues, social cues, warning messages, channels of dissemination together with receivers' characteristics of previous levels of experience with the hazard agent, produces a “situational perception of personal risk” (Lindell and Perry 2012, 620). This includes risk of death, injury, property damage, or disruption of daily activities that is characterized by beliefs about the way that environmental conditions (which includes technological hazards) produce specific personal impacts.

The conceptual model also specifies that as information in the model flows through three pre-decision processes—exposure, attention, and comprehension— three types of core perceptions emerge—threat perceptions, protective action perceptions, and stakeholder perceptions. These perceptions activate a series of protective action decision making stages of: risk identification, protective action information search, protective action assessment, protective response, and emotion-focused coping. All of which are influenced by situational factors and situational impediments (Figure 3.1) (Lindell and Perry 2012). Stages of the PADM characterize the way people “typically” make decisions about adopting actions to protect against environmental hazards, including technological hazards. The last stage in the PADM is a feedback loop in which people seek to either confirm or contradict the warning information they received by evaluating other sources of information or to obtain additional information about the threat. The value in application of the PADM tool is that it helps to break down the characteristics of different protective actions to identify which ones are most likely to be adopted (and the reasons why) so that future risk communication programs can repeat that success and hopefully lead to broad adoption.

4. RESEARCH DESIGN

As presented in the Introduction, hazards related to ice throw from wind turbines are not generally known to the public, as few significant ice throw incidents have occurred in the U.S.; however, as more and more wind turbines are installed, the numbers of people exposed to the risk of ice throw incidents greatly increases. The overall goal of this research is to shed perspective on how two at-risk groups—operations and maintenance personnel and community stakeholders—perceive and interpret their levels of risk and respond to potential losses generated from wind turbine ice throw. Specifically, the goals of this research are threefold: 1) to understand the extent to which two at-risk groups—community stakeholders as well as operations and maintenance personnel at wind farms might differ in their perceived levels of risk to the ice throw hazard; 2) to understand the degree to which community stakeholders and operations and maintenance personnel might differ on choosing measures of protection for their affected areas; and 3) to improve safety by identifying protective measures that all stakeholders—community citizens, wind farm employees, contractors, and land owners—are willing to undertake to mitigate their risk against the ice throw hazard including adopting measures to reduce their own risk toward the hazard, as well as, their community's vulnerability toward the hazards and threat of ice throw from wind turbines. To achieve the objectives, a survey methodology was chosen, and a questionnaire developed and disseminated to two diverse groups of stakeholders—operation and maintenance personnel and community stakeholders—in two regions of Texas to gather the necessary data for analysis.

An Institutional Review Board (IRB) exemption application (EXP2015G406662O) was submitted to the University's Office of Research Compliance and approved on August 3, 2015 to survey study participants.

The revised Protective Action Decision Model (PADM), as well as research from the literature on individual and community risk exposure, discussed in Chapter 3, informed this study. The focus of this research centers on the three core elements of the revised PADM—threat perception, stakeholder risk perceptions, and protective actions perceptions—which generated study questions for the two groups that guided this research. For operations and maintenance personnel (OMP) this research asked:

1) To what extent have operator and maintenance personnel witnessed an ice throw hazard incident?
2) What are the perceived levels of risk from ice throw by operator and maintenance personnel at wind farms?
3) What are the perceived levels of safety from ice throw by OMP workers for their site?
4) What are the perceived levels of effectiveness of safety procedures by OMP workers toward ice throw?
5) What perceived levels of safety do OMP workers have for the surrounding community?
6) To what extent do OMP workers trust in safety representatives in protection against ice throw incidents?

For community stakeholders, this research asked:

1) To what extent have community stakeholders witnessed an ice throw hazard incident? What type of environmental cues might they respond to, and what are their opinions toward the cues?
2) What are the perceived levels of risk toward the ice throw hazard by community stakeholders?
3) To what extent might community stakeholders be willing to report an incident?
4) To what extent will community stakeholders engage in personal protective actions?
5) To what extent do community stakeholders trust that wind farm operators will inform community leaders of increased risk to the ice throw hazard?
6) To what extent do community stakeholders trust wind farm operators to inform local media for disseminating an ice throw warning?

Next, this research asked: To what extent might the two groups be compared on: actual and observed risk, experience with ice throw, willingness to report an incident, evidence of leadership in managing an ice throw hazard, and general opinion of benefit of wind energy to the U.S. and is there a statistically significant difference between the two.

Finally, this research asked: To what extent might regression be used to predict risk perception of the community, as well as, whether witnessing an ice throw event has any impact on ice throw hazard protective response.

Propositions

Guided by the revised Protective Action Decision Model, as well as the research literature, the following propositions are set forth:

1) That there will be differences between the two groups in witnessing ice throw hazard incidents.

2) That there will be differences in perceived risk to the community between the two groups from the ice throw hazard.

3) That the two groups are likely to have significantly different reactions to, and opinions toward environmental cues related to the wind turbines, and the threat of ice throw from them.

4) That operation and maintenance personnel have different levels of perceptions of work safety at the site, as well as, the effectiveness of safety procedures, and trust of representatives.

5) That community stakeholders are willing to report an incident, but unlikely to engage in protective actions.

6) That few channels exist for disseminating warning messages associated with the wind turbine ice throw hazard.

7) That demographic information such as age and gender will differentiate the groups seeking information on protective action.

Discussion of these propositions will appear in the Conclusion chapter. Implications from formal statistical testing will be expanded upon. However, because some of the data collected could not be tested by formal statistical means, the above were stated as propositions. Nonetheless, all data together—quantitative, descriptive, qualitative data—point to important issues and challenges concerning personal and community risk, decision-making toward that risk, and willingness to respond to the ice throw threat.

Study Areas

The state was divided into two study areas based on the regions where wind energy activities are concentrated (Figure 4.1). Central, East, and Southeast Texas were not included because those areas did not have wind recourses sufficient to sustain wind farm development.

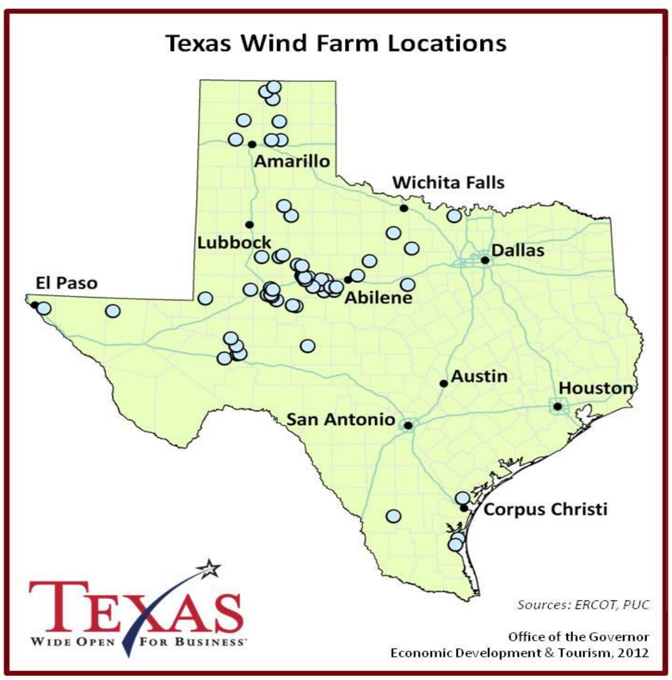


Figure 4.1 Texas wind farm locations. Source: Office of the Governor- Economic Development & Tourism, 2012 www.TexasWideOpenForBusiness.com.

The two study areas included:

1. West Texas (Abilene / Sweetwater / Lubbock) Area
2. South Texas / Coastal Area

The geographic location of these two study areas provided a contrast between regions which experience different icing seasons. The West Texas area has more turbine icing days per year than wind farms located in the South Texas Area.

Table 4.1 provides a list of the 26 largest wind farms in Texas. This list was divided among the two study areas to identify which wind farm counties fall into each area for solicitation to participate in the survey. A survey participation solicitation letter was developed and then sent to the wind farms in each region.

Table 4.1. Large Wind Farms in Texas. Source: American Wind Energy Association-State Wind Energy Statistics- Wind Projects in Texas, www.awea.org/resources/state

Large Wind Farms in Texas			
Wind Farm	**Installed Capacity (MW)**	**Turbine Manufacturer**	**County**
Brazos Wind Ranch	160	Mitsubishi	Scurry/ Borden
Buffalo Gap Wind Farm	523	Vestas	Taylor/ Nolan
Bull Creek Wind Farm	180	Mitsubishi	Borden
Capricorn Ridge Wind Farm	662	GE Energy/ Siemens	Sterling/ Coke
Desert Sky Wind Farm	160	GE Energy	Pecos

Table 4.1 continued.

Large Wind Farms in Texas

Wind Farm	Installed Capacity (MW)	Turbine Manufacturer	County
Goat Mountain Wind	150		Coke/ Sterling
Gulf Wind Farm	283	Mitsubishi	Kenedy
Hackberry Wind Project	165	Siemens	Shackelford
Horse Hollow Wind Energy Center	735	GE Energy/ Siemens	Taylor/ Nolan
Inadale Wind Farm	197	Mitsubishi	Scurry/ Nolan
King Mountain Wind Farm	278.5	Bonus/ GE Energy	Upton
Langford Wind Farm	150	GE Energy	Tom Green/ Schleicher/ Irion
Lone Star Wind Farm	400	Gamesa	Shackelford/ Callahan
McAdoo Wind Farm	150	GE Energy	Dickens
Notrees Windpower	150	Duke Energy	Ector/ Winkler
Panther Creek Wind Farm	458	GE Energy	Howard
Papalote Creek Wind Farm	380	Siemens	San Patricio
Peñascal Wind Farm	404	Mitsubishi	Kenedy
Pyron Wind Farm	249	GE Energy	Scurry/ Fisher/ Nolan

Table 4.1 continued.			
Large Wind Farms in Texas			
Wind Farm	**Installed Capacity (MW)**	**Turbine Manufacturer**	**County**
Roscoe Wind Farm	781	Mitsubishi	Nolan
Sherbino Wind Farm	300	Vestas	Pecos
Sweetwater Wind Farm	585	GE Energy/ Siemens/ Mitsubishi	Nolan
Trent Wind Farm	150	GE Energy	Taylor
Turkey Track Energy	169.5		Nolan/ Coke
Wildorado Wind Ranch	161	Siemens	Oldham/ Potter/ Randall
Woodward Mountain Wind Ranch	159	Vestas	Pecos

Sample Selection and Data Collection

A two-phase sequential approach was developed for data collection. The first phase quantified objective, or actual risk that exists at wind farms which operate within the two study areas. This phase also determined what actions hazard managers have undertaken in the way of adopting measures to protect their personnel as well as the surrounding communities against increased risk of damages and injuries from the ice throw hazard. To collect information during this phase a non-probability sampling technique known as “convenience sampling” was used to gather data among peer groups of hazard managers at various wind farms in each study area. Hazard managers at each wind farm were asked to survey wind farm operators, contractors, and maintenance personnel at their respective projects using forums such as monthly employee safety committee meetings.

The second phase of this study called for the development of a community survey to assess individuals’ levels of awareness, perception of their own personal risk, and what protective actions they have adopted based on their levels of knowledge, experience, and perceptions. The community survey instrument which appears in Appendix B was used to gather information from community stakeholders in two study areas: 1) the West Texas area, and 2) South Texas Coastal area. The communities included: Sweetwater, Roscoe, Big Spring, Forsan, Loraine, and Abilene for West Texas; Corpus Christi, Taft, Portland, Gregory, Skidmore, Sinton, Sarita, Falfurrias, Riviera, and Kingsville for South Texas.

Community stakeholders in each area were chosen for proximity to the targeted wind farms as well as at a distance from the wind farm. A non-probability sampling method known as “convenience sampling” was applied to this phase of the study to gather information from surrounding communities. These communities were chosen because individuals who work or live in close proximity to wind farms have a high level of exposure, as do those who work or live at a distance because they must travel through wind farms as part of their daily commutes for work, leisure, and so forth. The two-phase study groups (wind farm workers and surrounding residents) within the communities were selected because they have the most direct contact with the wind turbines as part of their day-to-day operations and maintenance activities, or daily lives and commutes living adjacent to wind farms.

The survey instrument solicited information following the three core elements of the PADM pertaining to the wind turbine technicians' and community stakeholders': 1) threat perceptions, 2) protective perceptions, and 3) stakeholder perceptions. These three core elements are informed by actions, such as: awareness of environmental cues; social cues, such as through networks and organizations in the communities; the availability of information sources for warnings; levels of perception (threat, protective action, and stakeholder perceptions) and experience with ice throw; general perceptions of safety involving wind turbine operations; and receiver characteristics such as age, level of education, ethnicity, gender, length of residence, and attachment to place. Hazard proximity also appears to play a significant role and was included as a variable.

Survey respondents were also asked to give their opinions on what they determined as situational facilitators as well as situational impediments. The data collected from the surveys was analyzed both quantitatively and qualitatively to assess the differences between the two groups—operation and maintenance personnel and community stakeholders—toward the ice throw hazard as well as differences between them concerning levels of perceived risk associated with turbine operations and ice throw hazards, and willingness to undertake measures to respond to the hazard.

Approach to Data Processing and Analysis

Descriptive statistics provided an initial exploration of the data and appears in the next chapter. Descriptive data analysis pointed to patterns in the data and identified variables that emerged as important for multivariate analysis. In addition, a demographic profile for each of the two stakeholder groups assisted in an overall understanding of characteristics of participants.

Following descriptive exploration of the data, Chapter 6 presents analysis and results from multivariate analysis that statistically tested associations and relationships between the OMP and community stakeholder groups. Because of the non-random nature of data collection, non-parametric tests were chosen to determine associations and/or relationships in the data. The form of data responses from each question determined whether a Chi-Square Test of Independence was applied (categorical data responses) or a Mann-Whitney U-test (for ratio, or ratio/interval data). These analyses explored responses within each group (OMP and community stakeholder) as well as between each group. Regression analysis was performed on each group for determining variables that might predict perceptions of community risk, as well as, whether observing actual risk (i.e., number of ice throws witnessed) resulted in behavioral response, that is, willingness to adopt preparation and mitigation measures toward reducing risk from the ice throw hazard.

5. EXPLORATORY DATA ANALYSIS

Building from Chapter 4, “Research Design” this chapter presents descriptive data for the two stakeholder groups—operations and maintenance personnel, and community stakeholders. Descriptive analysis proved useful for understanding patterns in the data, and identifying variables to consider for statistical testing of associations and relationships between the two groups. Inferential and regression analysis follow in Chapter 6, “Multivariate Analysis.”

Part 1. Descriptive Analysis for Each Stakeholder Group

A. Operators and Maintenance Personnel (OMP) Group

A total of 84 operations and maintenance personnel (OMP) surveys were used for analysis with 50 coming from the West Texas region and 34 from the South Texas region. The goal of achieving 50 surveys from the south region could not be met when post-survey results revealed that there had been no turbine icing events at the Pattern Energy Gulf Wind Project in Kenedy County during its operating history which commenced in 2009.

Actual, observed risk of OMP by witnessing an ice throw hazard occurrence.

Descriptive analyses revealed that 75.0% of operations and maintenance personnel had witnessed an ice throw incident from a wind turbine (*N* = 63). More than two-thirds (66.7%) of those who witnessed an ice throw incident from a wind turbine came from the West Texas region (*N* = 42) (Figure 5.1).

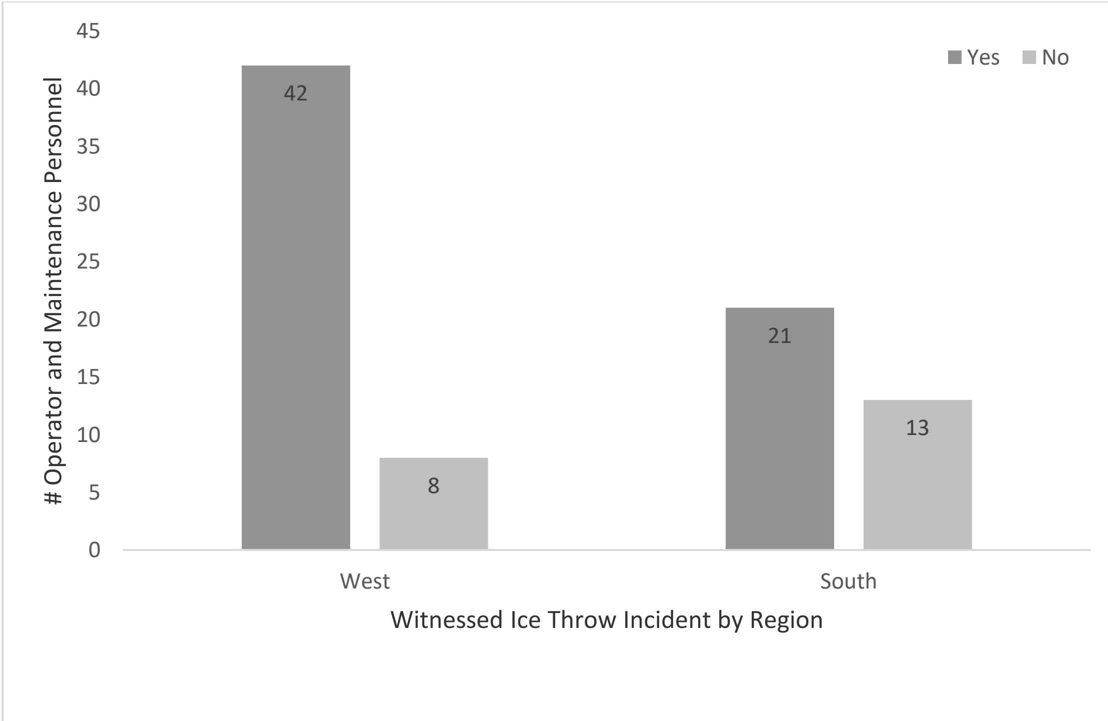


Figure 5.1. Numbers of ice throw incidents witnessed by operator and maintenance personnel by region.

For the OMP respondents who observed an ice throw incident, the average number of incidents witnessed was 15 (μ = 15.45, *SD* = 21.77) with a range of 1 to 101 incidents. The most frequent number was five (5) (*N* = 10), with the highest (50+) emanating from the West Texas region (62.5%; *N* = 5). Moreover, the West Texas region (μ = 22.64, *SD* = 22.11) had a higher average number of incidents than the South Texas region (μ = 16.52, *SD* = 24.59) (Figure 5.2).

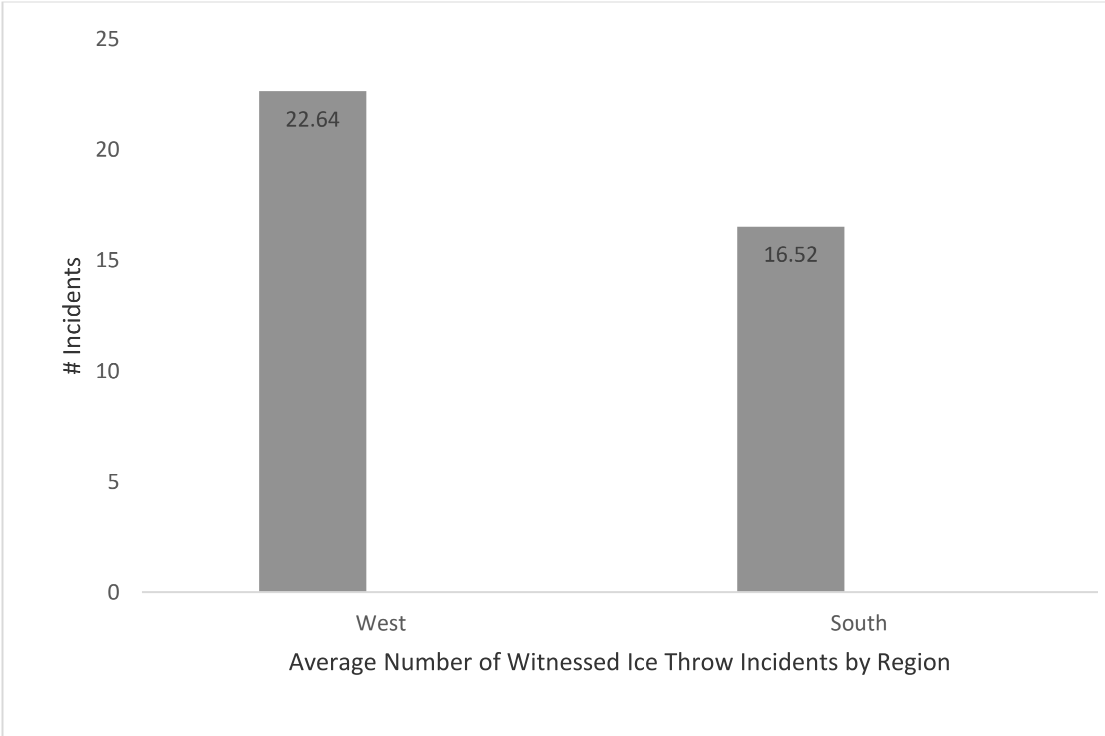


Figure 5.2. Average numbers of ice throw incidents witnessed by operator and maintenance personnel by region.

Operations and maintenance personnel who witnessed an ice throw event from a wind turbine were asked to describe the damage caused by the event. The most common answer was damage to vehicles (company, vender, or contractor, N = 33) followed by damage to electrical equipment or transformers (N = 28), and damage to heavy or construction equipment (N = 21). Some respondents reported no damage or near-miss experiences (N = 17). Others indicated damage to land or the ground (N = 13). Finally, two participants saw lights being knocked off of wind turbines (N = 2).

It is important to note that company vehicles are not typically parked at or near wind turbines when not in use. Each wind farm has an operations and maintenance building where work is staged from, and company vehicles are parked overnight. Most of the time when a company vehicle is at or near a wind turbine, technicians are performing work in the field. Therefore, operations and maintenance personnel who witness damage to company vehicles from ice throw events may also be unwilling participants in a near-miss event with high potential for serious consequences.

The second highest observed incident was damage to electrical equipment or transformers which are traditionally located just under the wind turbine tower. Damage to these pad-mounted transformers often pose a serious risk to wind farm workers (and anyone else who might venture too close) as damage has the potential to cause an electrical arc in the 34,500-voltage system. In addition, wind turbine pad-mounted transformers store approximately 500 gallons of mineral oil which is likely to ignite and/or explode during an arc flash. Finally, damaged transformers might also leak mineral oil into the surrounding environment.

No operations and maintenance personnel witnessed any injuries caused by ice throw from wind turbines (N = 84); however, one respondent indicated that they had witnessed two deaths caused by ice throw from wind turbines while 98.8% did not witness any deaths (N = 83). The individual who witnessed the two deaths was an operator from the West Texas region. [Note: it is possible that these deaths did not occur in the U.S. which is explained further in a later section.]

Perceived levels of risk by operator and maintenance personnel.

Figure 5.3 summarizes levels of risk where "1" represents "extreme low" and "10" represents "extreme high" levels of risk. The highest percentage of operations and maintenance personnel indicated *moderate levels of risk* (5 out of 10) in regards to the exposure that wind farm workers have from the ice throw hazard *during winter months*

(22.6%; *N* = 19). This was followed by estimates of *extreme high risk* (10 out of 10; 13.1%; *N* = 11). The *average level of risk* indicated was 5.71 out of 10 (μ = 5.71, *SD* = 2.42) (Figure 10, left). On a *daily* basis, however, OMP respondents indicated higher levels of risk (Figure 10, middle). Almost three-quarters (72.7%) of operations and maintenance personnel who believed that wind farm workers had *extreme high risk exposure* from the ice throw hazard came from the South Texas region (*N* = 8) where ice throw is not as likely to occur.

Figure 5.3, far right shows that a majority of operations and maintenance personnel indicated *extremely low risk* to affected citizens in the surrounding community as residents go about their daily activities (1 out of 10; 57.1%; *N* = 48), while 84.5% of OMP respondents indicated a 3 or below (*N* = 71). The average level of risk was indicated to be 2.12 out of 10 (μ = 2.12, *SD* = 1.85), relatively low risk. Higher levels of risk tended to come from OMP in the South Texas region (8-10; 64.0%; *N* = 16). In contrast, 68.8% of those who indicated *extreme low risk* were from the West Texas region (N = 33).

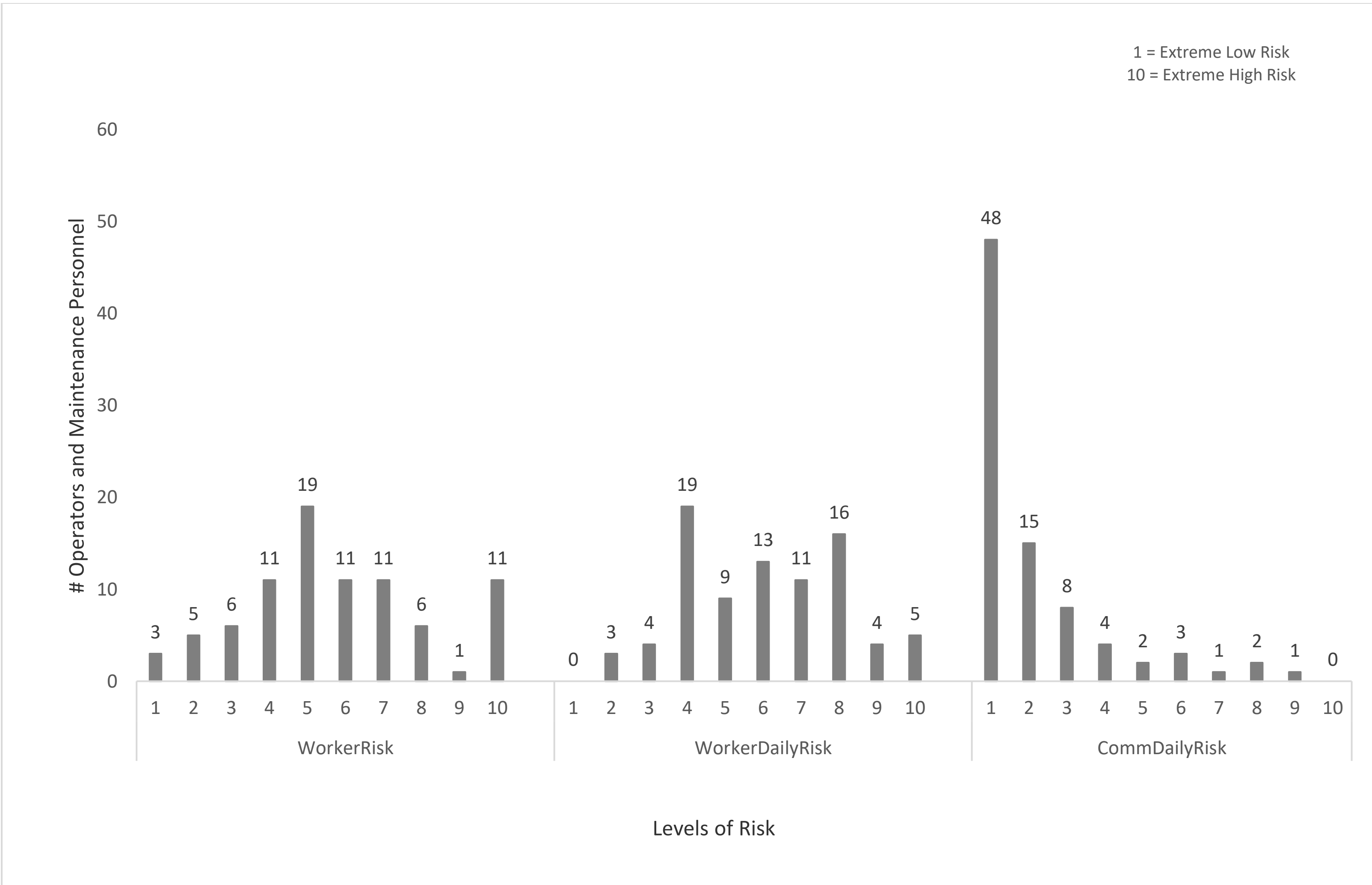


Figure 5.3. Perceived risk levels of operator and maintenance personnel.

Perceived levels of safety for the site.

Not only do operations and maintenance personnel perceive a relatively moderate risk to themselves, 28.6% of respondents estimate extremely *high levels of safety* for wind turbine operations and maintenance at their site (10 out of 10; N = 24). Figure 5.4 shows that 85.7% of OMP respondents indicated 8 or higher (N = 72). The average level of safety indicated was 8.61 out of 10 (μ = 8.61, SD = 1.39) where a 10 represents *extreme high safety*.

The reason that operations and maintenance personnel perceived *extremely high safety* levels for their site might be attributed to survey data indicating that 82.1% of OMP respondents revealed that their company/facility did currently have safety procedures in place for wind turbine icing (N = 69), with 6.0% indicating their company did not have a wind turbine icing safety procedure (N = 5) and 11.9% did not know (N = 10).

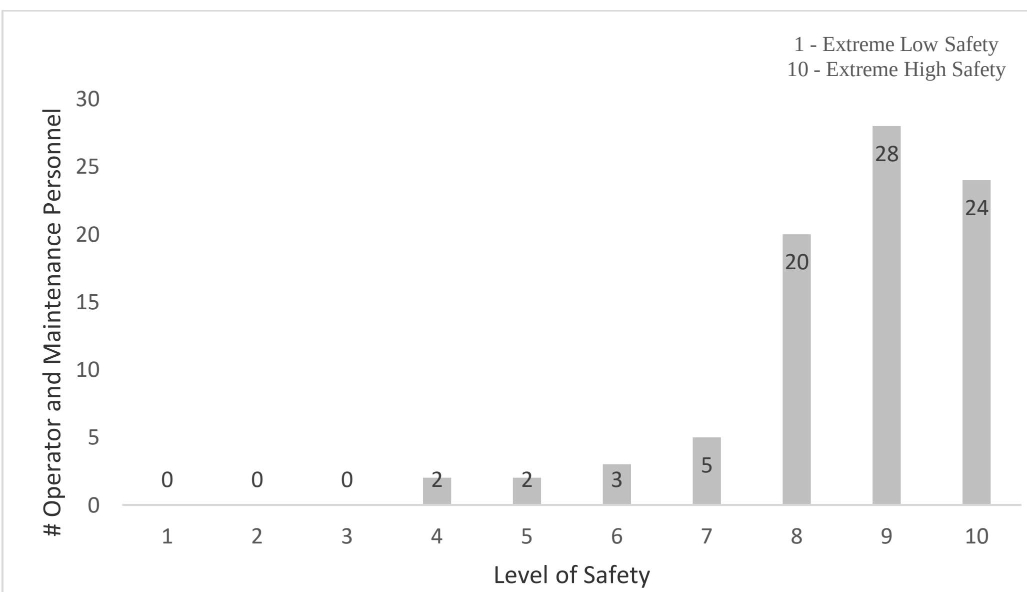


Figure 5.4. Perceived level of safety of wind turbine operations by operator and maintenance personnel.

Perceived levels of effectiveness of safety procedures.

For those who selected "Yes," almost 80% (79.7%) of operations and maintenance personnel indicated that their safety procedures were *very* to *extremely effective* for protecting them in the event of an ice throw occurrence (8-10; *N* = 55). Most of these OMP respondents were from the West Texas region (63.8%; *N* = 44) and, male (72.5%; *N* = 50). The average level of effectiveness was 6.71 out of 10 (μ = 6.71, *SD* = 3.61) where a 10 represented *extremely effective.* The lowest effectiveness levels tended to come from the South Texas region (1-5; 83.3%; *N* = 5) (Figure 5.5, left).

Perceived levels of safety for the surrounding community.

Analysis of operations and maintenance personnel indicated that 50.7% believed that their safety procedures were *extremely effective* for *protecting citizens in* the surrounding communities in the event of an ice throw occurrence (10 out of 10; *N* = 35) (Figure 5.5, right). Most were from the West Texas region (94.3%; *N* = 33) and, male (88.6%; *N* = 31). The average level of effectiveness was 6.19 out of 10 (μ = 6.19, *SD* = 4.06). The lowest effectiveness levels tended to come from the South Texas region (1-4; 76.9%; *N* = 10).

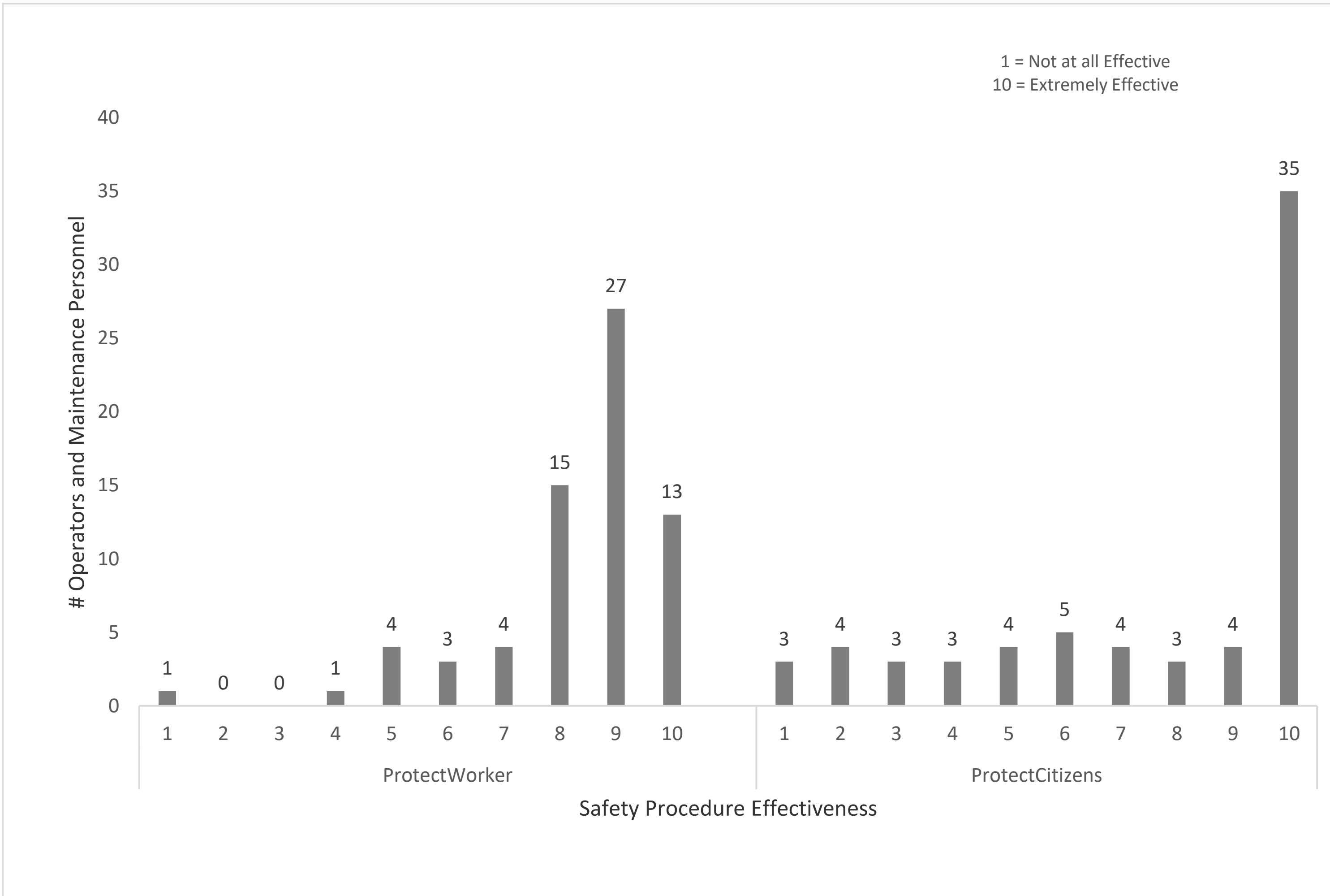


Figure 5.5. Perceived effectiveness of safety procedures for workers and perceived levels of safety for the surrounding community by operations and maintenance personnel.

Perceived trust in safety representatives.

The OMP respondents mostly perceived *extreme high levels of trust* that safety representatives from *their own wind farm operations* would inform them of general wind turbine hazards and risks from working in and around wind turbines (10 out of 10; 48.8%; $N = 41$), with 83.3% of operations and maintenance personnel indicating an 8 or higher ($N = 70$) (Figure 5.6, left). The average level of trust was 8.71 out of 10 ($\mu = 8.71$, $SD = 1.85$) where a 10 represents extreme high trust.

Operations and maintenance personnel mostly indicated *extreme high trust* that safety representatives from their wind farm operations would inform *citizens in the surrounding community* of general wind turbine hazards and risks (10 out of 10; 34.5%; $N = 29$). Almost two-thirds (63.1%) of respondents indicated an 8 or higher ($N = 53$) (Figure 5-6, right). The average level of trust was 7.44 out of 10 ($\mu = 7.44$, $SD = 2.84$) where a 10 represents extreme high trust. Over 80%, (82.8%) of respondents who indicated *extreme high trust* came from the West Texas region ($N = 24$).

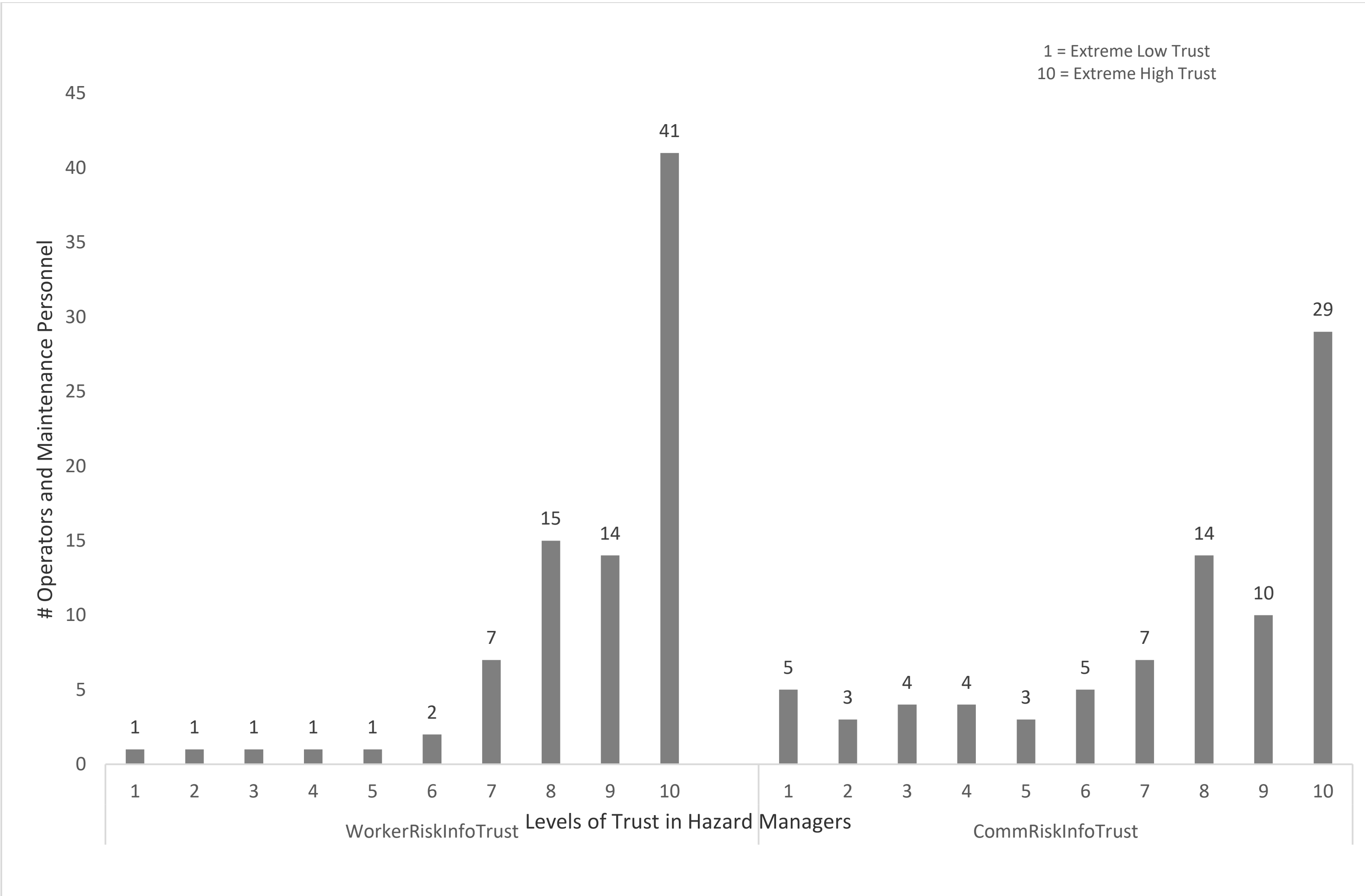


Figure 5.6. Levels of trust in safety representatives by operator and maintenance personnel.

General demographic profile of operations and maintenance personnel.

Age. Demographic elements of the wind farm operations and maintenance group indicated that the highest percentage of operations and maintenance personnel were between the ages of 30 to 39 (33.3%; *N* = 28) followed by 40-49 (23.8%; *N* = 20). Seven respondents were aged 60 or above (N = 7). The oldest individuals tended to come from the West Texas region (50-60+; 94.7%; *N* = 18). No individuals were 19 or younger (Figure 5.7).

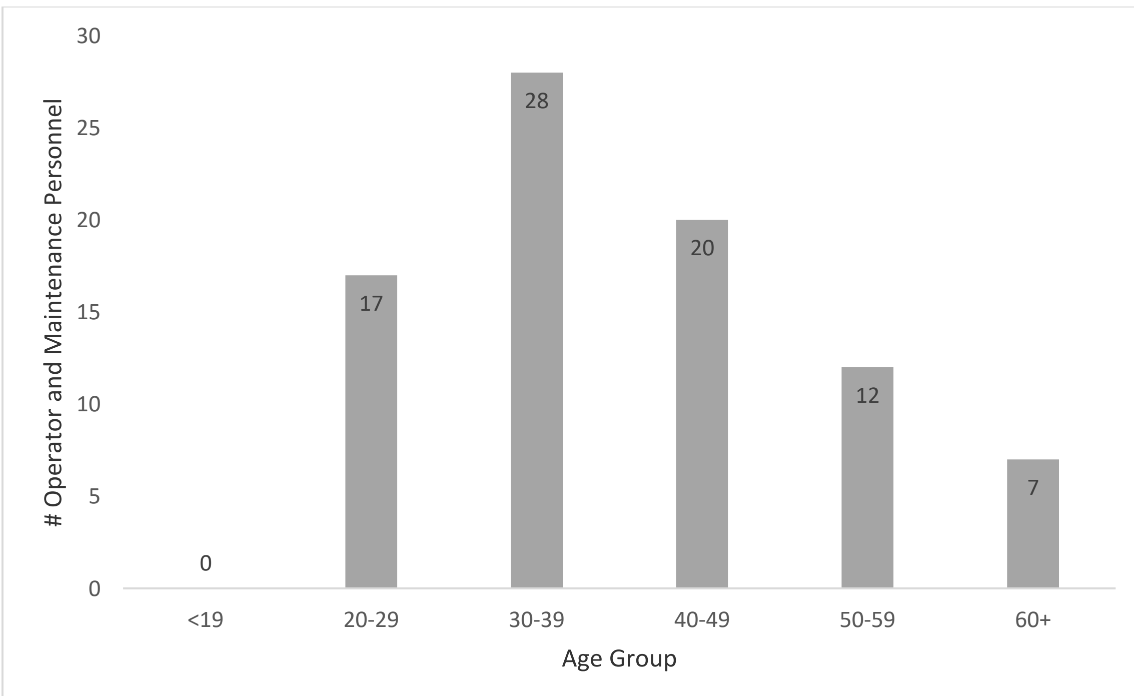


Figure 5.7. Age groups of operations and maintenance personnel.

Levels of education. Most operations and maintenance personnel either had a high school diploma (31.0%; *N* = 26) or some college (31.0%; *N* = 26). Those with the highest level of education (Masters or Ph.D. degree) were all males from the West Texas region (*N* = 6 & 1, respectively) (Figure 5.8).

Almost three-quarters (72.6%) of respondents indicated some type of training in addition to their education (*N* = 61), while 83.6% of these individuals received technical training (*N* = 51). The other 16.4% endorsed professional, or on-the-job, training (*N* = 10). More individuals had training in the West Texas region (*N* = 42) than the south (*N* = 19) and most were male (90.2%) (Figure 5.8).

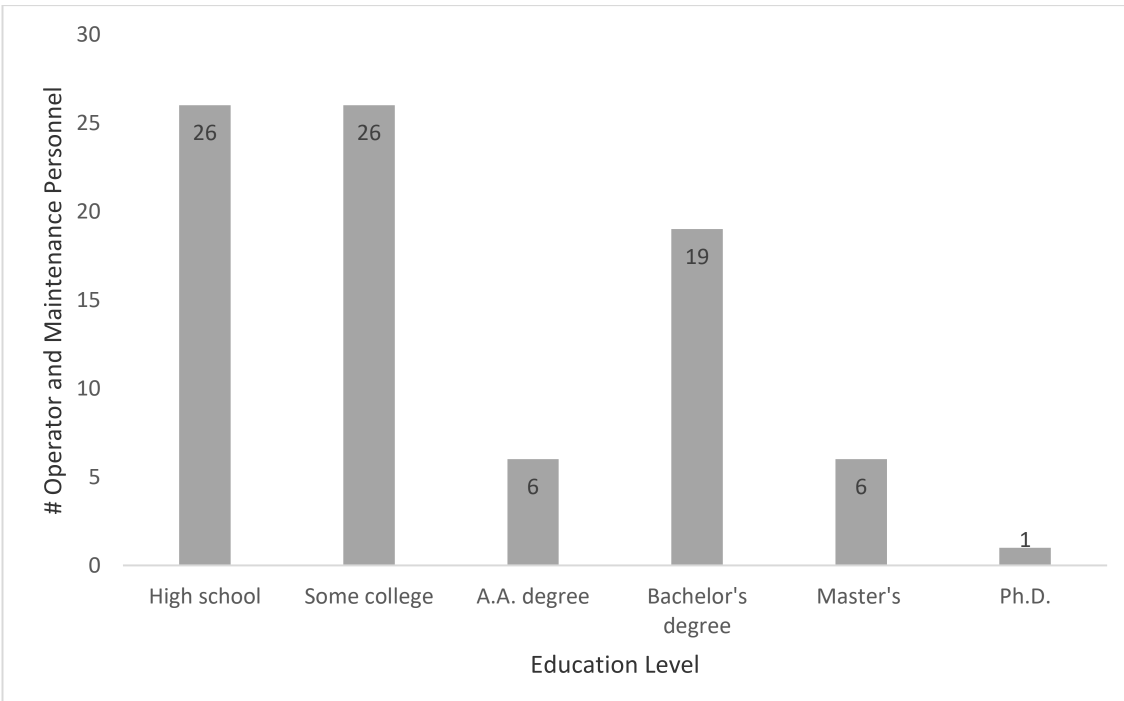


Figure 5.8. Levels of education of operation and maintenance personnel.

Levels of work experience. The majority of operation and maintenance personnel had 6 to 10 years of experience working in the wind industry (44.0%; *N* = 37) with 23 from the West Texas region and 14 from the south region. Over 80% of respondents had between 2 and 15 years of experience (*N* = 70). Only four participants had 16 or more years of experience (Figure 5.8) and all were males from the West Texas region (Figure 5.9).

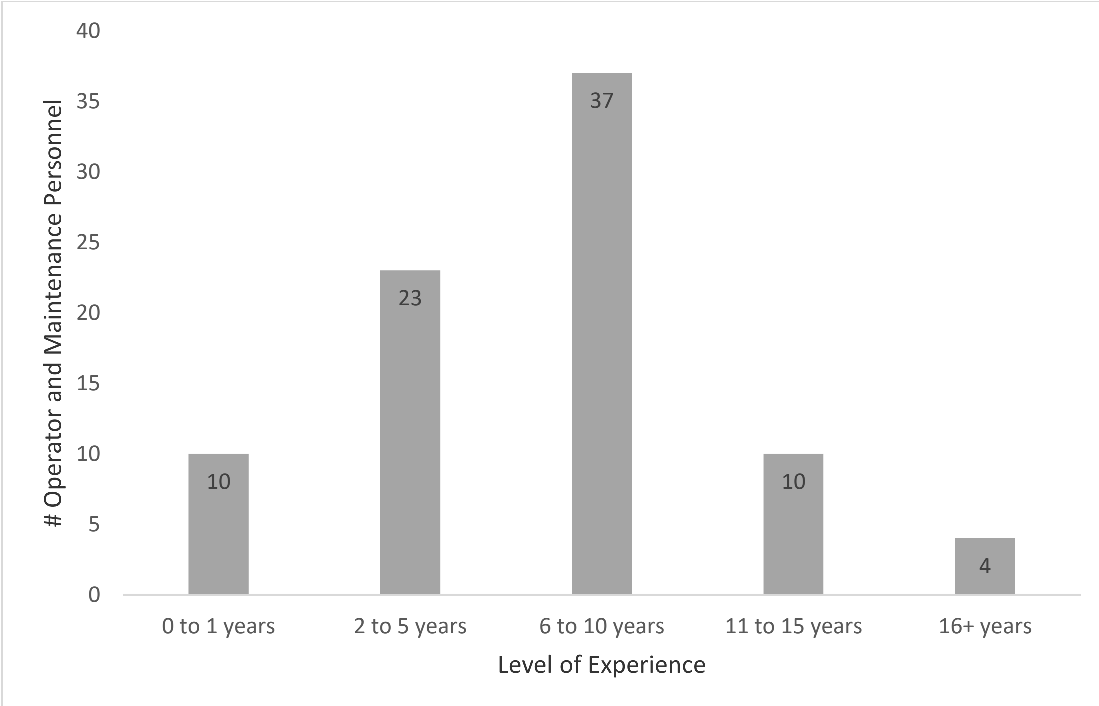


Figure 5.9. Levels of experience of operation and maintenance personnel.

Gender. Of the surveys analyzed, 91.7% of respondents were male (N = 77) and 8.3% were female (N = 7). Over half of OMP respondents' job functions were primarily in the maintenance section (N = 47) while the other 44.0% were in operations (N = 37). All females worked primarily in operations. All maintenance section workers were male with approximately half from each region (N = 24, south; N = 23, west).

Regarding perceived levels of risk, males (μ = 5.73, SD = 2.46) tended to estimate slightly higher risk levels than females (μ = 5.57, SD = 2.07). For questions regarding perceived levels of trust, females (μ = 8.79, SD = 1.68) tended to have slightly higher trust levels than men (μ = 8.02, SD = 2.40).

B. Community Stakeholder Group

A total of 96 community stakeholder surveys resulted, with 48 from the West Texas region and 48 from the South Texas region used for analysis. There were four surveys which were eliminated due to incompleteness or inconsistent data that would have skewed overall results.

Actual, observed risk exposure of community stakeholders.

A majority of respondents indicated that their wind turbine exposure was primarily a function of being a community member (51.0%; *N* = 49) followed by exposure during commuting (25.0%; *N* = 24), and knowledge of neighbor's experience with the hazard (20.8%; *N* = 20) (Figure 5-10). Only 3.1% of community stakeholders had actual, observed exposure to wind turbines primarily as a landowner (*N* = 3) and these individuals were all from the West Texas region. Additionally, 57.3% of community stakeholders responded that their daily commute took them through an area where wind turbines were running (*N* = 55) while 42.7% did not (*N* = 41).

Community stakeholder surveys indicated that 88.5% of participants have never observed ice accumulating on a wind turbine (*N* = 85) while 10.5% had seen an occurrence (*N* = 11). Those that had never seen ice accumulating on a wind turbine (81.8%) came from the West Texas region (*N* = 9). Additionally, 92.7% of community stakeholders had never observed an ice throw incident from a wind turbine (*N* = 89). For the 7 respondents who had observed an ice throw incident, the average number of incidents was 4 (μ = 4.00, *SD* = 2.94) with a range of 1 to 10 incidents. All ice throw incidents observed occurred in the West Texas region (Figure 5.10).

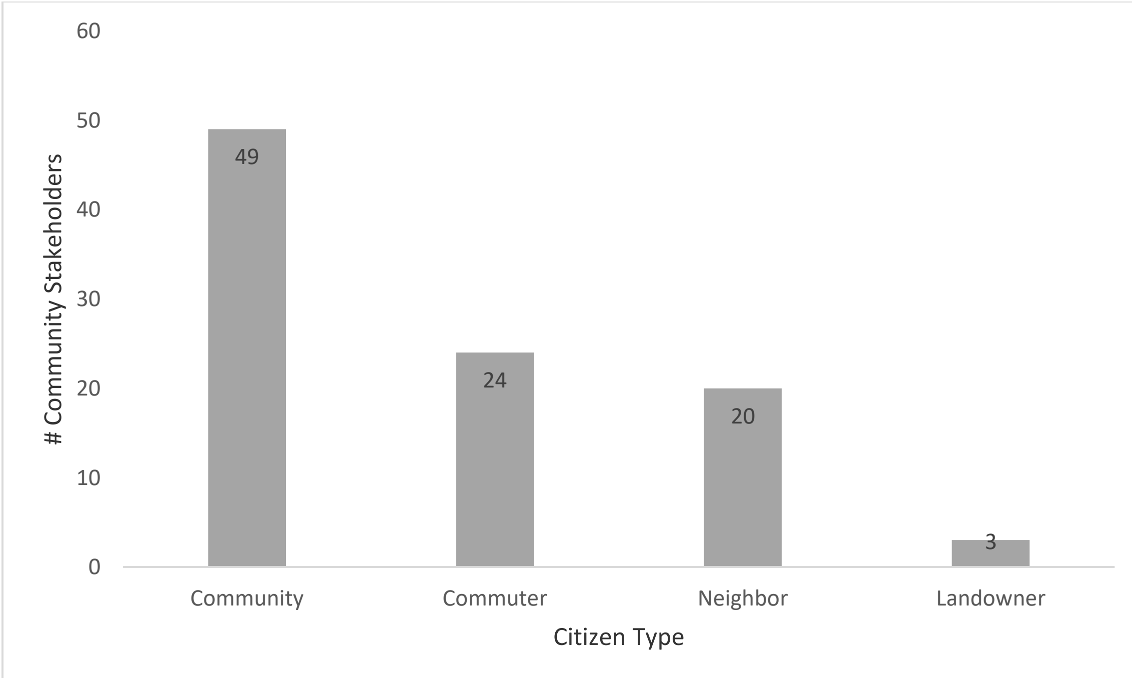


Figure 5.10. Wind turbine actual, observed risk exposure by citizen type.

Those who witnessed incidents were asked to describe the damage that occurred. Five community stakeholders reported no damage caused by the ice throw incidents (*N* = 5). Participant C14 observed 4 ice throw incidents and witnessed damage to land. Participant C30 observed 10 ice throw incidents and witnessed ice hitting a water well pump house, breaking all pipes. No community stakeholder ever witnessed any injuries or deaths caused by ice thrown by wind turbines (*N* = 96).

Community respondent's willingness to report an incident.

A majority of community stakeholders (61.5%) indicated that they would attempt to report an incident if they observed ice being thrown from a wind turbine or if they had a near-miss experience with an ice event (*N* = 59); 38.5% indicated they would not report an incident (*N* = 37). A majority of those who said they would attempt to report came from the West Texas region (52.5%; *N* = 31) (Figure 5.11).

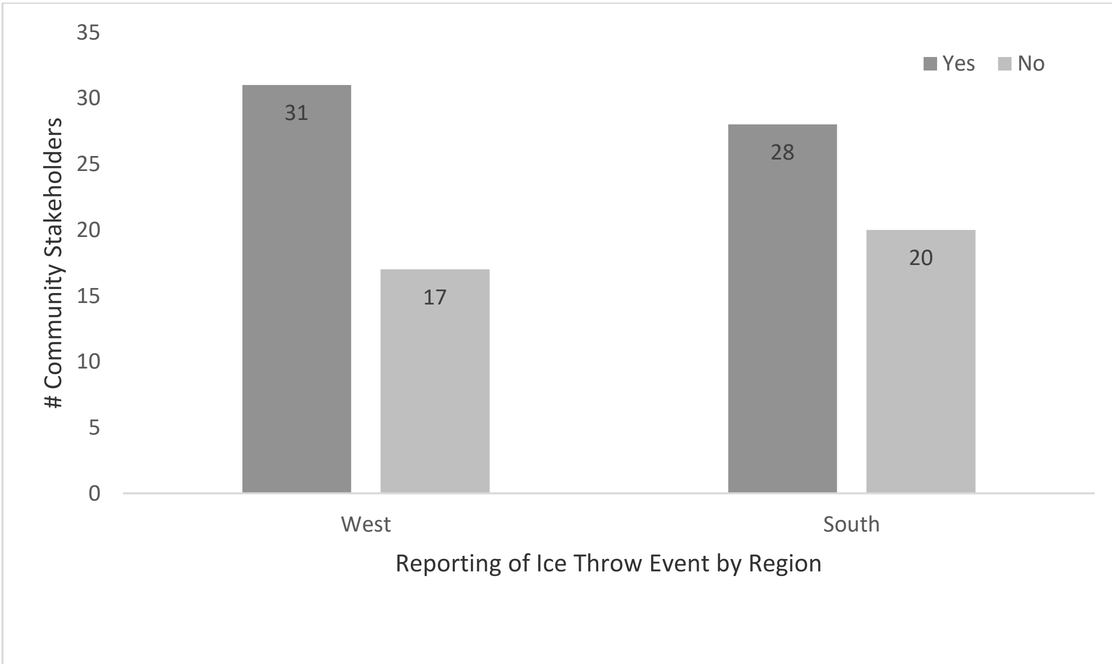


Figure 5.11. Willingness to report an ice throw event by community stakeholders by region.

Protective actions by community stakeholders.

Community stakeholders were asked if they observed ice being thrown from a wind turbine, what actions would they take to protect themselves from another incident. The most common response was to “stay away” or “keep their distance” from wind turbines (*N* = 35). This was followed by “avoid,” “never get close to,” or “don’t go around wind turbines” (*N* = 16), “call the police” (*N* = 12), and “report it to wind farm operations” (*N* = 9). A few respondents endorsed a common theme of being careful, keeping an “eye out,” and understanding surroundings better (*N* = 6). Another common theme involved vehicles, including “keep driving,” “don’t drive near a wind turbine,” or “stay in your vehicle” (*N* = 5). Finally, three respondents said to “run away” (*N* = 3).

Perception of risk by community stakeholders.

Over one-third of community stakeholders (36.5%) believed that citizens in the surrounding community had an *extremely low risk* from ice throw hazards in *winter months* (1 out of 10; *N* = 35). The average risk level was 2.86 out of 10 (μ = 2.86, *SD* = 2.08) where a 10 represents *extreme high risk*. A majority of respondents (42.7%) indicated *low levels of risk* (2-4; *N* = 41) while 13.5% indicated *moderate levels of risk* (5-6; *N* = 13). Only 7.29% of respondents indicated *high levels of risk* (7-10; *N* = 7), with 71.4% of those indicating high levels of risk coming from the West Texas region (*N* = 5) (Figure 5.12).

Levels of trust of community stakeholders that OMP would inform community leaders.

The highest percentage of community stakeholders had *moderate levels of trust* (5 out of 10) in regards to *safety representatives* from wind farm operations *informing leaders* in the surrounding communities of the ice throw hazard in winter months (19.8%; *N* = 19) followed by *extreme high trust* (10 out of 10; 18.8%; *N* = 18) (Figure 5.12). The average level of trust was 6.10 out of 10 (μ = 6.10, *SD* = 2.97). A majority of community stakeholders (72.2%) who had *extreme high trust* in safety representatives were from the South Texas region (N = 13).

Levels of trust of community stakeholders that OMP would inform local media.

The highest percentage of community stakeholders also had *moderate levels of trust* (5 out of 10) in regards to *safety representatives* from wind farm operations *informing local media* of the possibility of an ice throw hazard during winter months (24.0%; $N = 23$) followed by *extreme high trust* (10 out of 10; 18.8%; $N = 18$) (Figure 5.12). The average level of trust was 5.98 out of 10 ($\mu = 5.98$, $SD = 2.81$). Again, a majority of community members (61.1%) who had extreme high trust levels that safety representatives would inform local media of the possibility of an ice throw hazard were from the South Texas region ($N = 11$). For both of the above questions, it appeared that respondents from the South Texas region tended to have higher levels of trust as compared to those from the West Texas region; 54.2% from the South Texas region for both questions indicated a 6 or above ($N = 26$).

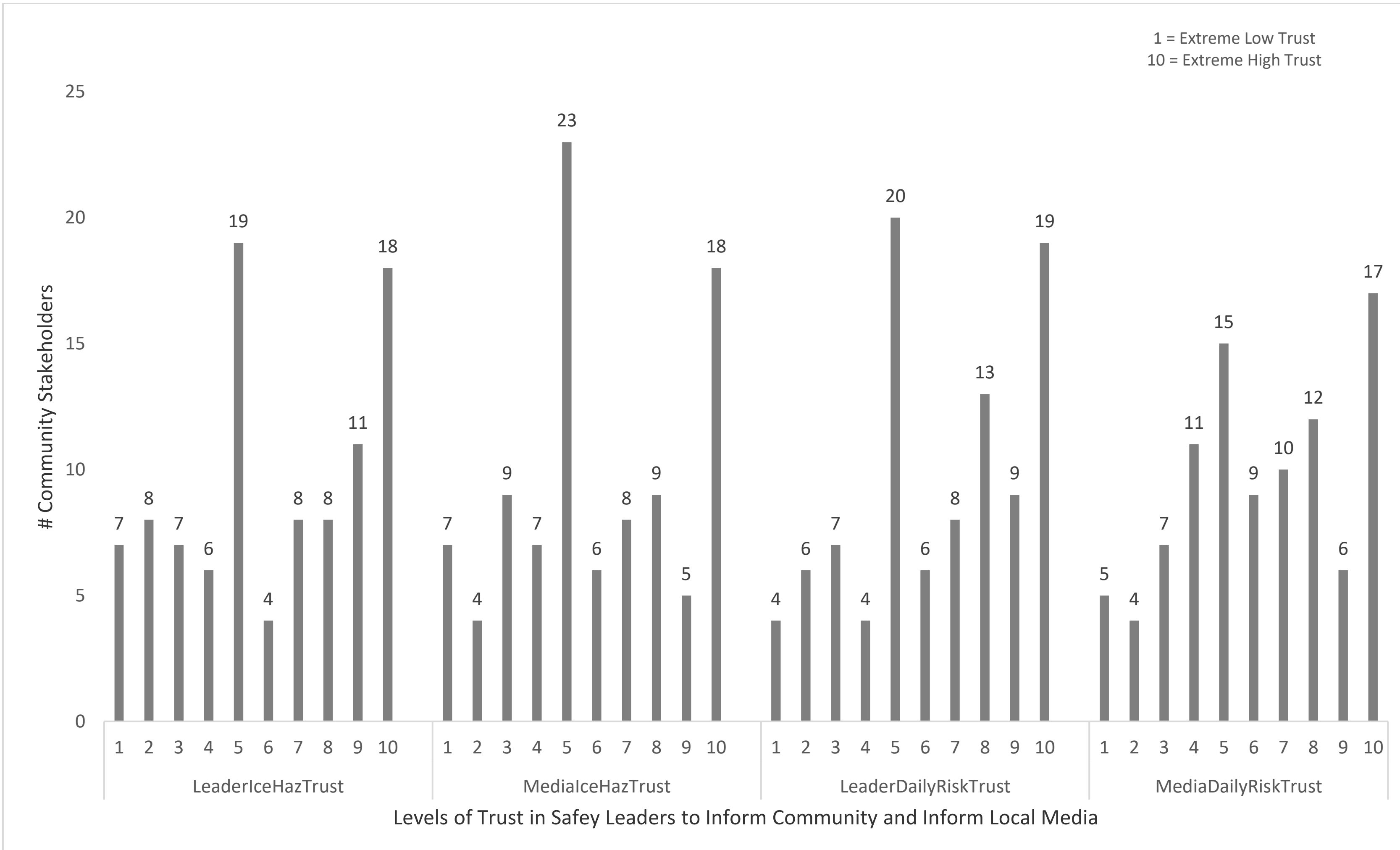


Figure 5.12. Levels of trust of community stakeholders.

General demographics of the sample of community stakeholders.

Age. Descriptive analysis indicated that 37.5% of community stakeholders surveyed were between the ages of 20-29 (*N* = 36), with 13.5% between age 40-49 and 60+, respectively (*N* = 13); 12.5% were between age 50-59 and under 19, respectively (*N* = 12). Finally, 10.4% were between age 30-39 (*N* = 10) (Figure 14). The oldest individuals (50-59, 60+) were primarily from the West Texas region (80.2%; *N* = 77). The youngest individuals (>19, 20-29) also were primarily from the West Texas region (41.7%; *N* = 40). Females (μ = 3.69, *SD* = 1.75) tended to be slightly older than males (μ = 2.81, *SD* = 1.49) (Figure 5.13).

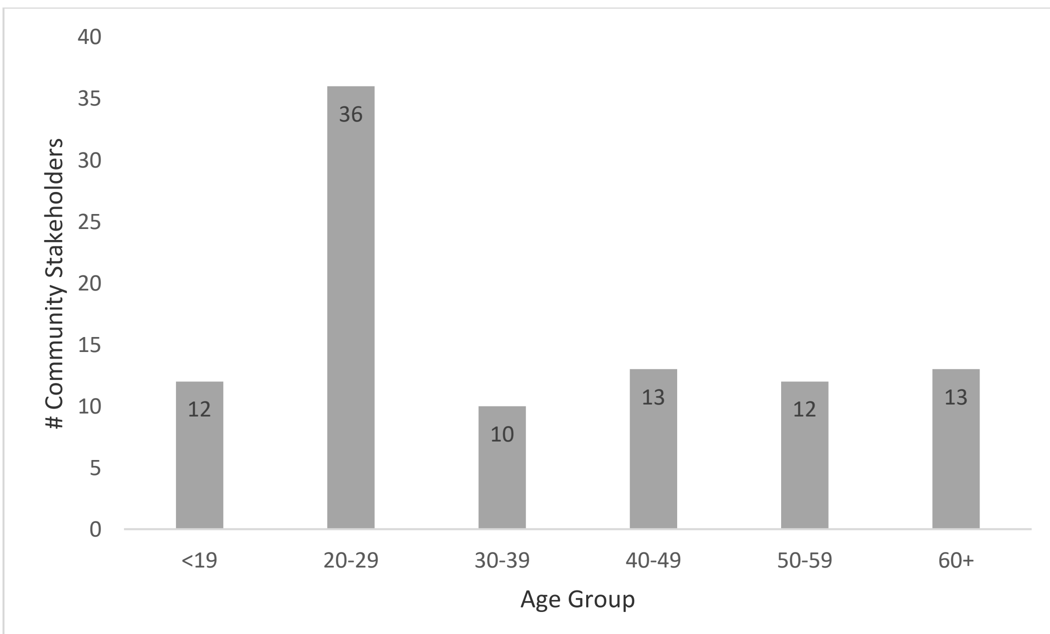


Figure 5.13. Age groups of community stakeholders.

Levels of education. The highest percentage of community stakeholders surveyed had obtained a high school diploma (47.3%; *N* = 43) followed by some college (42.9%; *N* = 39). Three respondents had an Associate's degree and four had a Bachelor's degree (*N*

= 3 & 4, respectively) (Figure 15). Those with the highest level of education (Masters or Ph.D. degree) all came from the West Texas region (*N* = 2) (Figure 5.14). Males (μ = 1.75, *SD* = 0.947) tended to have slightly more education than females (μ = 1.69, *SD* = 0.950).

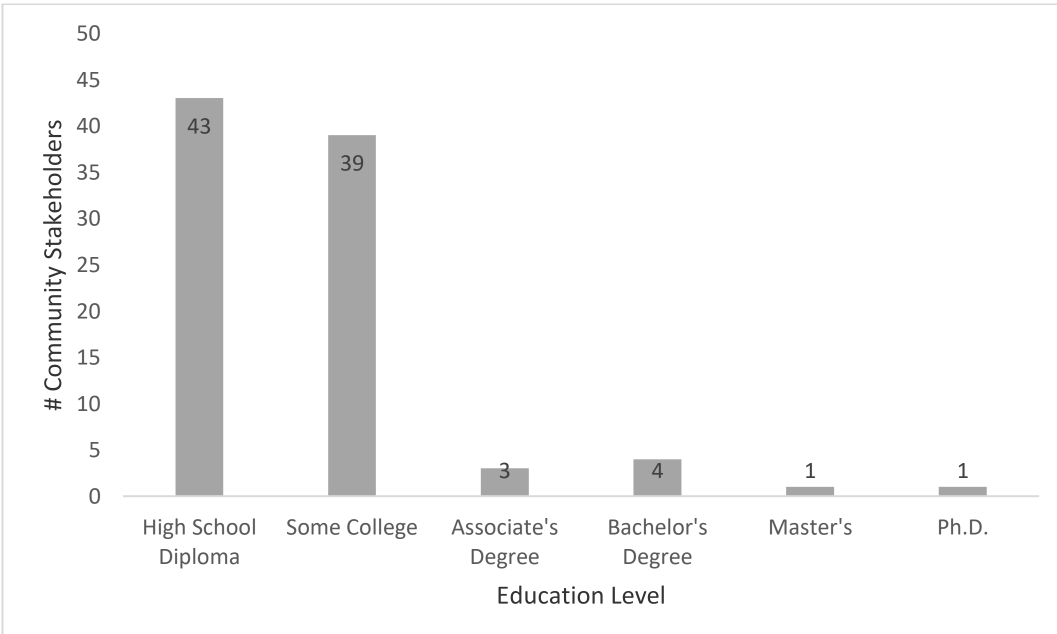


Figure 5.14. Levels of education of community stakeholders.

Survey results showed that over three-quarters (76%) of community stakeholders lived within sight of a wind turbine (*N* = 73), approximately 2.86 miles from a turbine, on average (μ = 2.86, *SD* = 3.22), with 43.2% of community stakeholders living within 1 mile or less from a wind turbine (*N* = 32). Community stakeholders in the South Texas region (71.4%; *N* = 40) tended to live closer to wind turbines (1 or 2 miles) than those in the west region (28.6%; *N* = 16).

Gender. Totals from the sample of community stakeholders, reported that 59.4% of respondents were male (N = 57) and 40.6% were female (N = 39). Towards *reporting* *an ice throw incident,* females (μ = 1.33, *SD* = 0.478) tended to be slightly more likely than males (μ = 1.42, *SD* = 0.498) to report if they observed or had a near-miss experience with an ice throw event. Regarding *average levels of perceived risk to* the ice throw hazard, males in the communities (μ = 2.96, *SD* = 2.12) tended to indicate slightly higher perceived risk levels of an ice throw hazard during winter months from wind farm operations than females (μ = 2.72, *SD* = 2.03) (Figure 5.15).

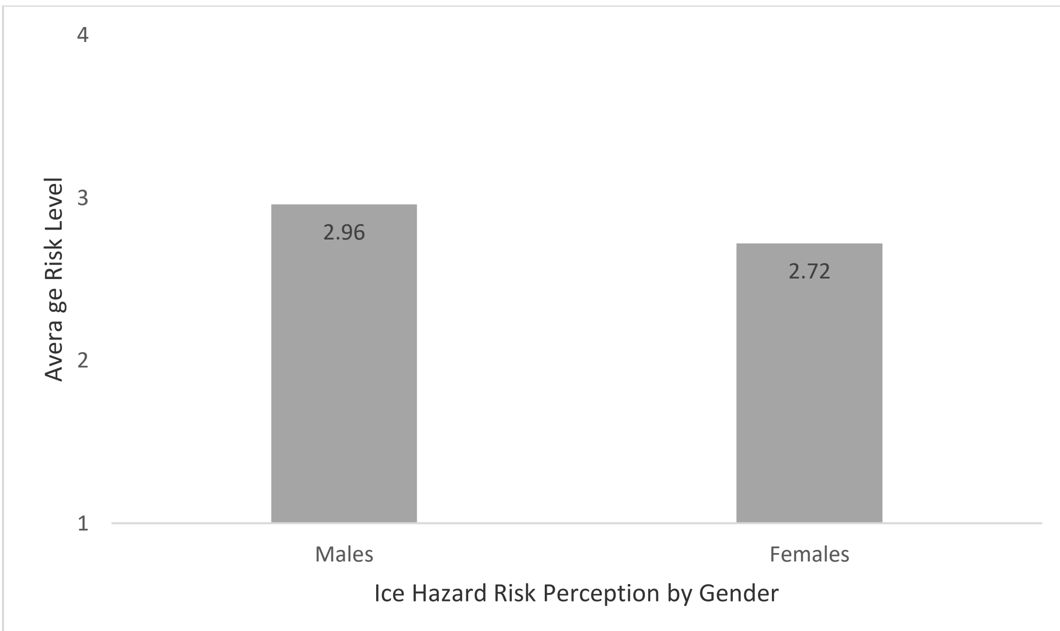


Figure 5.15. Average risk level by gender (on a 1-10 scale).

Concerning levels of trust in safety representatives from wind farm operations, males (μ = 6.14, *SD* = 2.77) tended to indicate *similar trust levels* as females (μ = 6.05, *SD* = 3.26). Regarding levels of trust that OMP officials would inform community leaders as well as the local media, males (μ = 6.05, *SD* = 2.69) and females (μ = 6.03, *SD* = 3.19) tended to indicate similar *moderate levels of trust* that safety representatives from wind farm operations would inform *leaders* in the surrounding communities as well as the *local media* of the possibility of an ice throw hazard.

Part 2. Descriptive Data that Point to Relationships between the Two Stakeholder Groups

Demographic data.

Age. Demographic data comparison shows that community stakeholder participants were generally younger than the operations and maintenance group representatives (Figure 5.16).

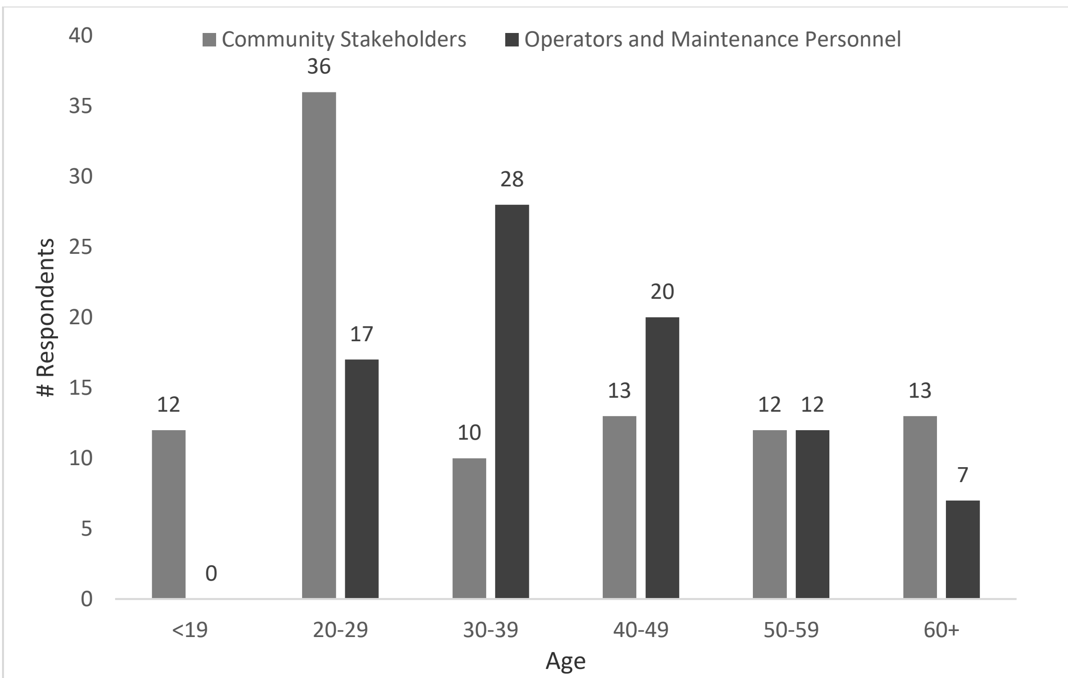


Figure 5.16. Comparison of age groups between both groups.

Levels of education. When we look at educational level attainment between the two groups, the community stakeholders have the higher number of respondents with high school or some college, whereas the operations and maintenance personnel have the majority of higher levels of attainment (Figure 5.17).

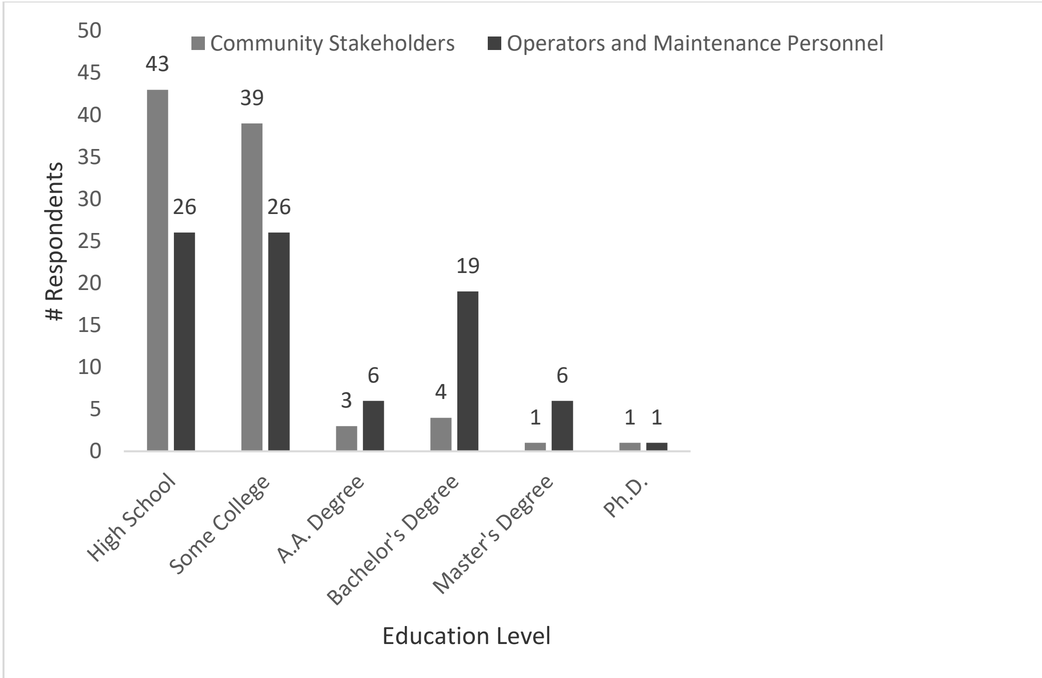


Figure 5.17. Comparison of levels of education of both groups.

Gender. A review of the gender data from the surveys shows that male participants dominate representation from the operations and maintenance participants (Figure 5.18). This result was expected as the wind energy industry is typically a male-dominated workforce. Prior research suggests that males tend to downplay risks and view threats as less problematic than females (Brody, 1984; Dejoy 1992). Both genders were well represented in the community stakeholder group.

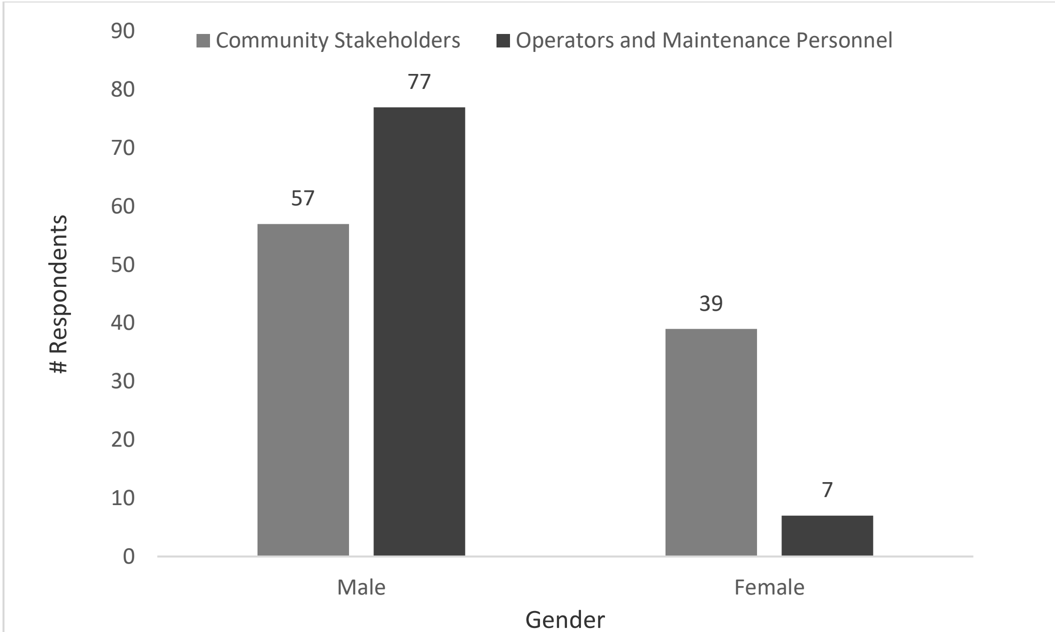
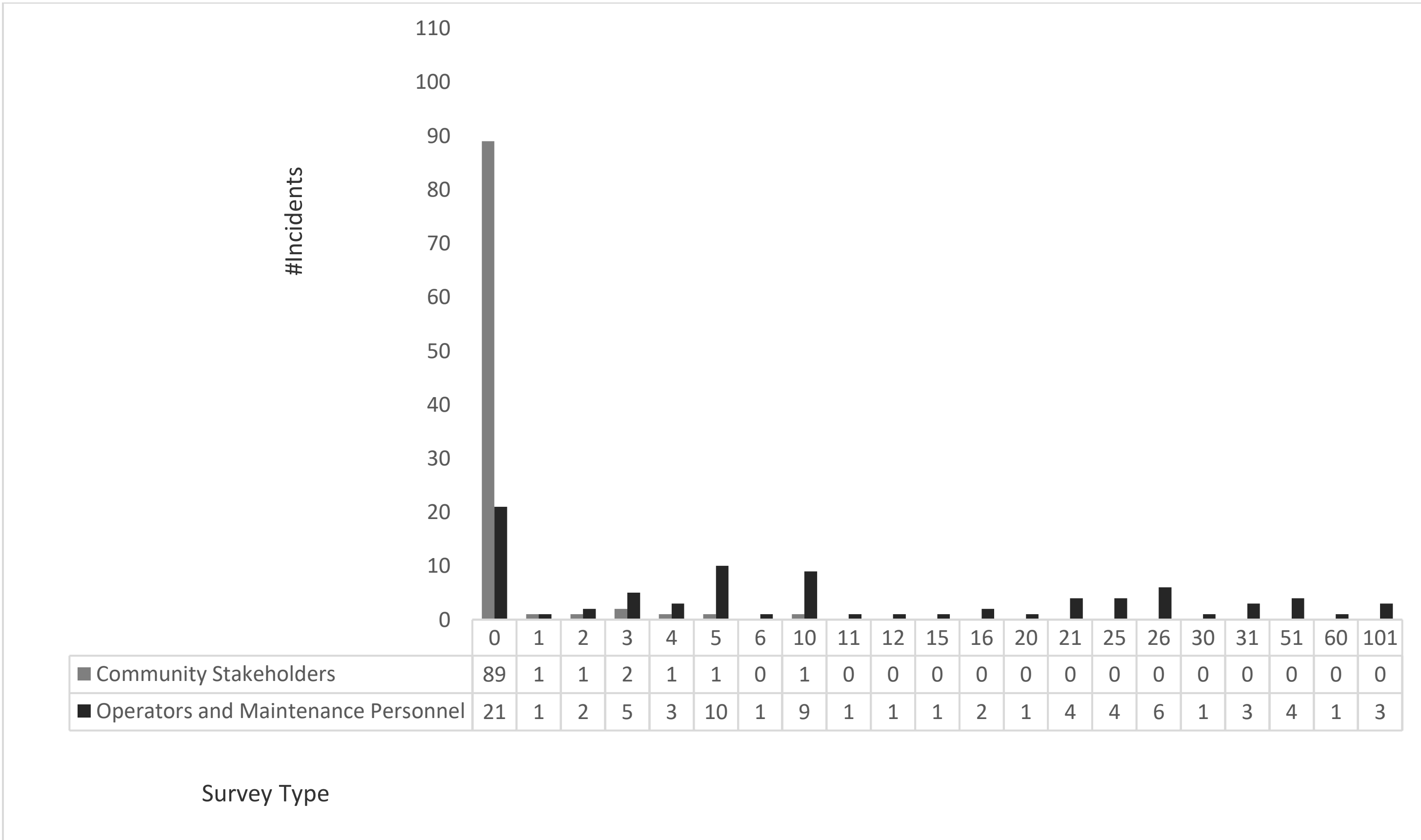


Figure 5.18. Comparison of gender designation of both groups.

Comparison of actual, observed risk witnessing an ice throw incident.

A majority of community stakeholders had never witnessed an ice throw incident from a wind turbine (89 out of 96) with only 7 study participants having ever witnessed an event. Whereas, Seventy-five percent of operations and maintenance personnel (63 out of 84) had witnessed an ice throw incident from a wind turbine. Figure 5.19 shows that operations and maintenance personnel have witnessed over 1,298 incidents during their careers.



	0	1	2	3	4	5	6	10	11	12	15	16	20	21	25	26	30	31	51	60	101
Community Stakeholders	89	1	1	2	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Operators and Maintenance Personnel	21	1	2	5	3	10	1	9	1	1	1	2	1	4	4	6	1	3	4	1	3

Figure 5.19. Number of ice throw incidents witnessed by each group.

Comparison of perceived citizen risk to the surrounding community.

Comparisons between groups concerning ice throw hazard risk to local citizens in the surrounding communities indicate that both operations and maintenance personnel and community stakeholders agree in their risk perceptions that ice throw poses an *extremely low risk* to citizens in the surrounding community (Figure 5.20).

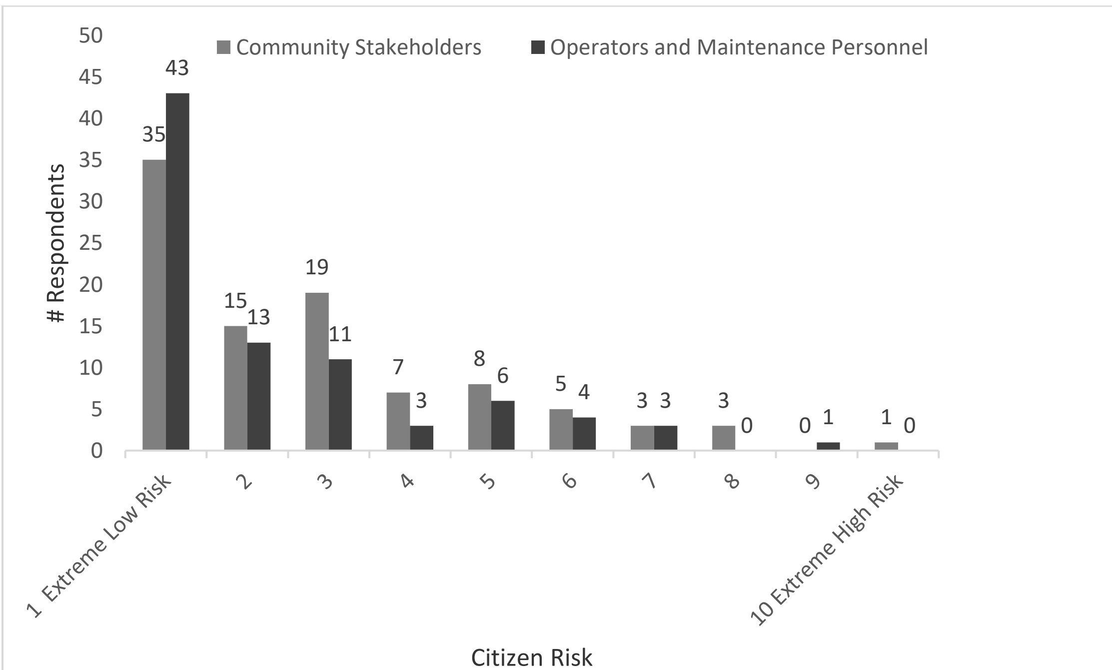


Figure 5.20. Comparison of levels of risk perception by both groups.

Comparison of benefits of wind energy.

Starr proposed (1969) that people are willing to accept higher risks from activities if they view them as highly beneficial. Survey results indicated that both groups viewed wind energy as an extremely beneficial activity (Figure 5.21).

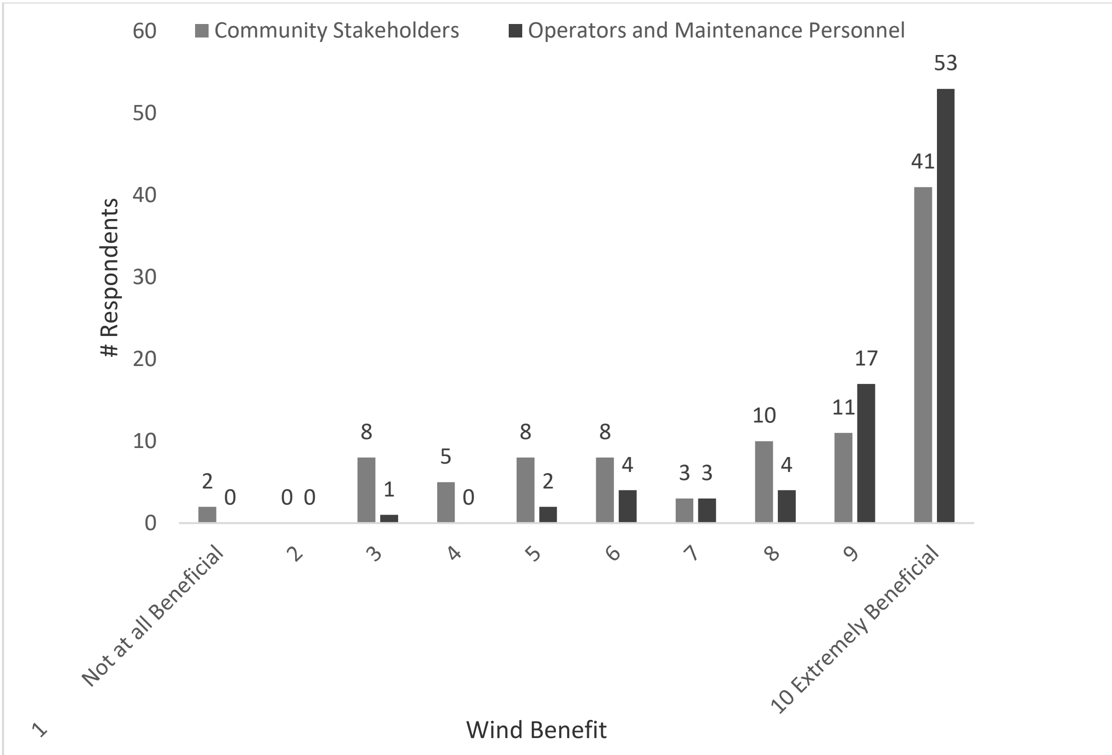
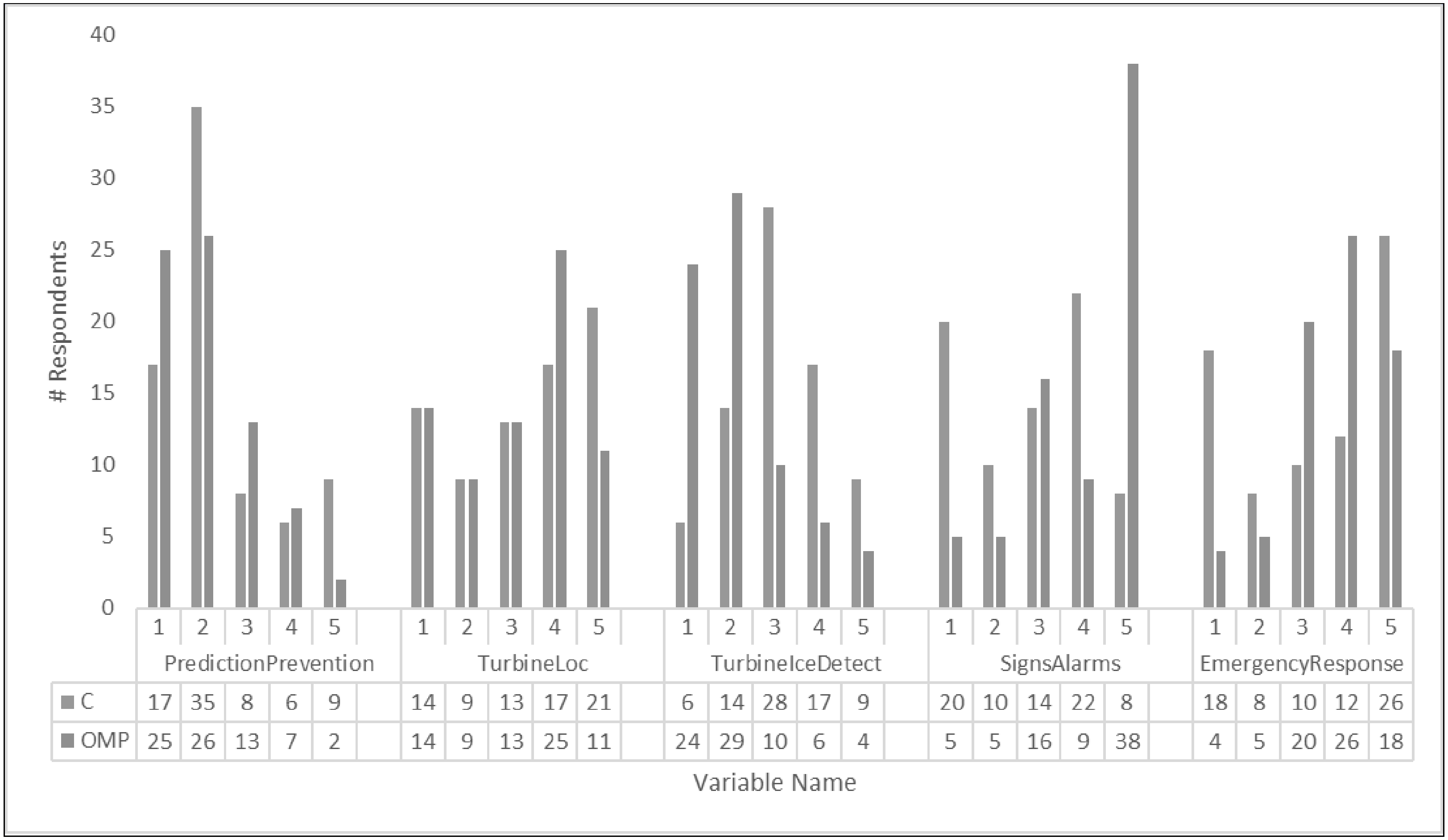


Figure 5.21. Comparison of benefits of wind energy by both groups.

Comparison between community stakeholders and operation and maintenance personnel for the best protective actions.

Community stakeholders indicated that the best protective actions that wind farm operators should be taking to reduce the risk of ice throw from wind turbines in the surrounding community are: Warning Signs and Alarms (26.7%; 1; *N* = 20) followed by Prediction and Prevention (47.3%; 2; *N* = 35), Turbine Icing Condition Detection (37.8%; 3; *N* = 28), and Turbine Location Planning (30.0%; 4; *N* = 17). The least preferred (or essentially worst) action to take to reduce the risk of ice throw from wind turbines in the surrounding community was Emergency Response Planning for Ice Throw Events (35.1%; 5; *N* = 26) (Figure 5.22). No other actions were specified.

Operations and maintenance personnel indicated that the best protective action that wind farm operators should be taking to reduce the risk of ice throw from wind turbines in the surrounding community or communities was Prediction and Prevention (34.2%; 1; *N* = 25) followed by Turbine Icing Condition Detection (39.7%; 2; *N* = 29), Emergency Response Planning for Ice Throw Events (27.4%; 3; *N* = 20), and Turbine Location Planning (34.2%; 4; *N* = 25). The least preferred (or essentially worst) action to take to reduce the risk of ice throw from wind turbines in the surrounding community or communities was Warning Signs and Alarms (52.1%; 5; *N* = 38). Other protective actions specified included common sense (*N* = 1), not going near a turbine if there was ice on the blades (*N* = 1), and safety awareness briefings (*N* = 1) (Figure 5.22).



	PredictionPrevention 1	2	3	4	5	TurbineLoc 1	2	3	4	5	TurbineIceDetect 1	2	3	4	5	SignsAlarms 1	2	3	4	5	EmergencyResponse 1	2	3	4	5
C	17	35	8	6	9	14	9	13	17	21	6	14	28	17	9	20	10	14	22	8	18	8	10	12	26
OMP	25	26	13	7	2	14	9	13	25	11	24	29	10	6	4	5	5	16	9	38	4	5	20	26	18

Figure 5.22. Comparison of best protective actions by both groups.

Comparison of preferences for warnings.

Community stakeholders ranked the types of warning system that they believed to be the best for communicating falling ice from wind turbines. Results showed that TV News (46.1%; 1; $N = 35$) was the best warning system followed by Warning Signs (21.3%; 2; $N = 16$), Local Newspaper Articles (20.0%; 3; $N = 15$), Information Pamphlets sent by mail (21.3%; 4; $N = 16$), Websites of Communities (17.3%; 5; $N = 13$), and Public Meetings with Stakeholders (28.0%; 6; $N = 21$). The website of Wind Farm Companies (36.0%; 7; $N = 27$) was cited as the least preferred (or worst) warning system for communicating a falling ice hazard for wind turbines (Figure 5.23). Three respondents added an 8^{th} warning system of a cell phone alert similar to an Amber or Emergency Alert. Another respondent suggested a door-to-door warning system.

Operations and maintenance personnel ranked the type of warning systems they preferred for communicating a falling ice hazard from wind turbines during winter months with Warning Signs being the best (37.1%; 1; $N = 23$), followed by Information Pamphlets sent by mail (33.9%; 2; $N = 21$), the Websites of Wind Farm Companies (38.7%; 3; $N = 24$), Public Meetings with Stakeholders (29.0%; 4; $N = 18$), Local Newspaper Articles (37.1%; 5; $N = 23$), and Websites of Communities (40.3%; 6; $N = 25$). The least preferred, or essentially the worst, preferred Local TV News warnings for communicating falling ice from wind turbines (51.6%; 6; $N = 32$) (Figure 5.22).

Twelve respondents specified other preferred warning systems with 83.3% suggesting daily or regular site/company briefings ($N = 10$). The remaining individuals suggested site safety advisories and procedures ($N = 2$).

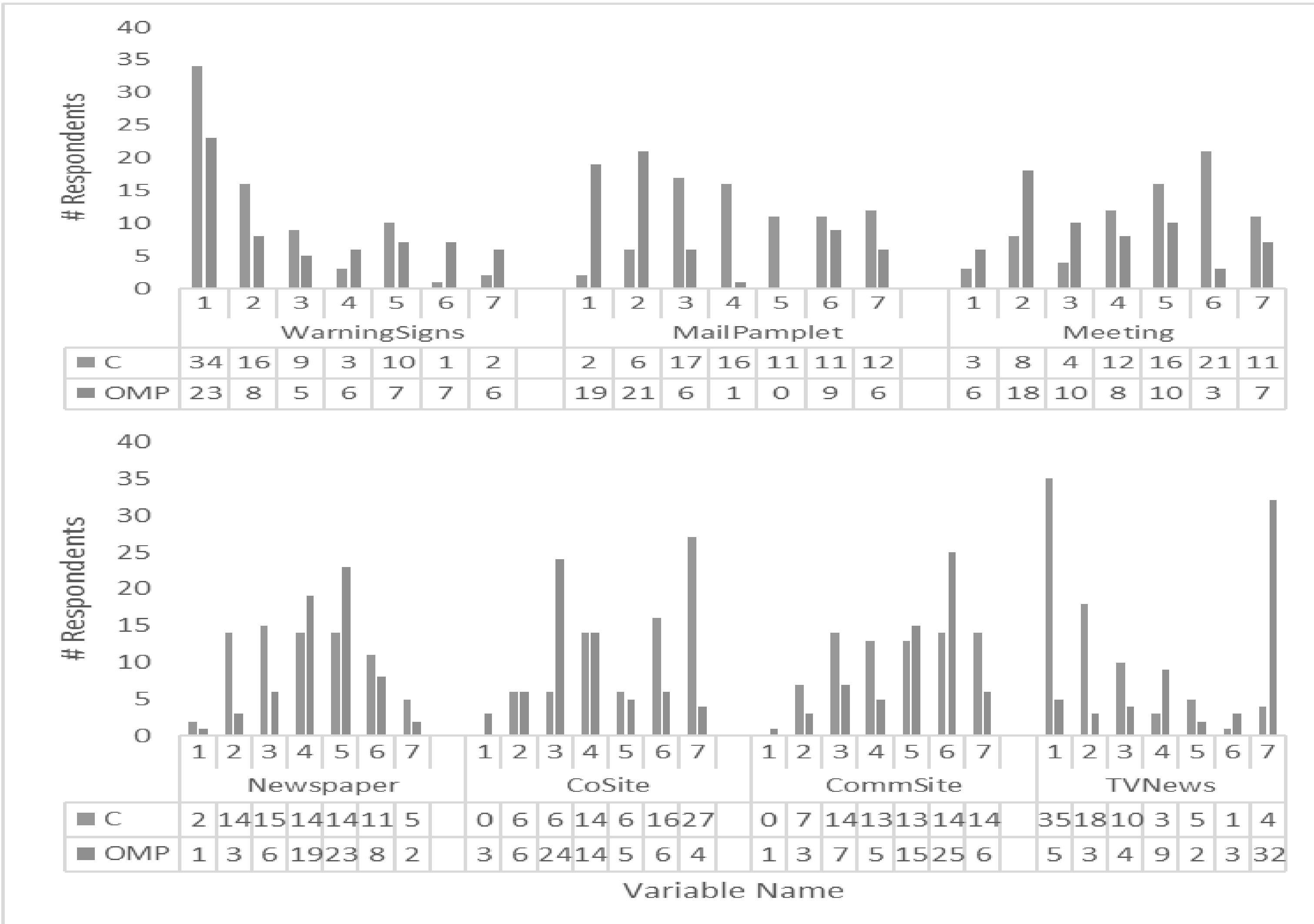


Figure 5.23. Comparison of preferred warning systems by both groups.

6. MULTIVARIATE ANALYSIS

Part 1. Tests of Association on Categorical Variables

A. Between the Two Stakeholder Groups

Chi-Square Tests of Independence were performed on categorical variables that were present in both community stakeholders and operators and maintenance personnel survey tools to assess whether there was a statistically significant difference between the two groups. That is, more formally, to evaluate the differences between expected (hypothesized) and observed results. The test was also applied to each study group for analysis by region. Table 6.1 summarizes results from chi-square analysis.

Table 6.1. Chi-Square Test Results with Variable Names and Significance Levels.

Chi-Square Tests	**Variable**	**χ^2**	**Sig**
Stakeholders x Maintenance Personnel	Ice Throw	86.420**	0.001
	Witness Deaths	1.149	0.284
Community Stakeholders by Region	Report Ice Event	0.396	0.529
	Decision Maker	0.211	0.646
	First Responder	1.043	0.307
Operators and Maintenance Personnel by Region	Stand Down	4.926*	0.026
	Supervise	14.334**	0.001

*$p<0.05$
**$p<0.01$

Actual and observed risk: witnessing number of ice throw.

Both groups were surveyed concerning their actual, observed experiences with the ice throw hazard. Specifically, each group was asked: “Have you ever observed an ice throw incident from a wind turbine?” In this case, the chi-square test helped to determine whether there was a statistically significant difference between the community stakeholder group and operation and maintenance personnel group to give insight on awareness of actual and observed risk from witnessing ice throw incidents.

Results indicated that community stakeholders and operators and maintenance personnel differed in their observations of ice throw incidents from wind turbines, $\chi(1) = 86.420$, $p = <0.001$, $\varphi = 0.693$, and therefore, are likely to differ in their perceptions of personal and community risk from the hazard. More operators and maintenance personnel (N = 63) witnessed an ice throw incident from a wind turbine than community stakeholders (N = 7); however, 92.7% of community stakeholders (N = 89) and only 25.0% of operators and maintenance personnel (N = 21) never observed an ice throw incident. Overall, 61.1% of respondents have never witnessed an ice throw incident from a wind turbine (*N* = 110) while 38.9% have (*N* = 70).

Experiences with ice throw: deaths and injuries.

Both groups were asked if they had ever witnessed any injuries or deaths related to ice throw from wind turbines. For witnessing *injuries,* there was no need to perform a chi-square test because all respondents from *both groups* (N = 180) answered *"No."* Chi-square testing was not necessary as no community stakeholder had ever witnessed a *death* caused by ice throw from wind turbines (N = 96), and most operators and maintenance personnel had *never witnessed any deaths* caused by ice throw from wind turbines (N = 83). Only one individual, who was an OMP worker from the West Texas region, indicated that s/he had witnessed two deaths.

B. Tests of Association within the Community Stakeholder Group by Region

Likely to report an ice throw incident.

This research proposed that social cues such as neighbor's experiences with ice throw, and warning messages from wind farm operators, or the local media will influence a community member's decision to report an incident. Community stakeholders were asked: "If you observed ice being thrown from a wind turbine or had a near-miss experience with an ice event would you attempt to report the incident?" Chi-square test results indicated that community stakeholders did not differ regarding whether they would attempt to report an ice event by region, $\chi(1) = 0.396$, ***n.s***. Overall, 61.5% of community stakeholders indicated that they would attempt to report an ice event (N = 59) and 38.5% indicated that they would not (N = 37). More community stakeholders would attempt to report an ice event from the west region (N = 31) than the south region (N = 28). More community stakeholders would not attempt to report an ice event in the south region (N = 20) than the west region (N = 17).

Evidence of community leadership for dealing with an ice throw incident.

Community stakeholders were asked if they were decision makers and thus would be involved in managing an ice throw incident. Chi-square results indicated that community stakeholders did not differ in leadership in a decision making role by region, $\chi(1) = .211$, ***n.s***. Overall, 94.8% of community stakeholders indicated that they were not leaders in a decision making role in their community (N = 91). More community stakeholders were leaders in a decision-making role from the West Texas region (N = 3) compared to the South Texas region (N = 2).

Further, community stakeholders were asked if they were a first responder for their community. Results indicated that community stakeholders did not differ in being first responders in their community by region, $\chi(1) = 1.043$, ***n.s***. Overall, 95.8% of community stakeholders indicated that they were not first responders in their community (N = 92). More community stakeholders were first responders from the South Texas region (N = 3) compared to the West Texas region (N = 1).

C. Tests of Association within Operators and Maintenance Personnel Group by Region

Environmental cues relationship to stand down orders.

The risk literature indicates that environmental cues, such as weather conditions conducive for ice formation, observing ice on wind turbines, or wind farm workers hearing ice cracking or falling will elicit protective action. Operations and maintenance personnel were asked: "Does your wind farm issue site stand down orders for areas where turbine icing has been observed or when ice throw incidents occur?"

The chi-square test indicated that operators and maintenance personnel differed in their responses for regions where turbine icing had been observed or when ice throw incidents had occurred by region, $\chi(1) = 4.926$, $p = .026$, $\varphi = .242$. Overall, 92.9% of OMP indicated that their wind farm site issued stand down orders (N = 78) while 7.1% said that their wind farm did not (N = 6). More OMP indicated "Yes" from the West Texas region (N = 49) as compared to the south region (N = 29). Conversely, more OMP indicated "No" from the South Texas region (N = 5) compared to the west region (N = 1).

When operations and maintenance personnel were asked: “Do you supervise anyone?” Results indicated that operators and maintenance personnel differed in whether they supervised anyone by region, χ (1) = 14.334, *p* =<0.001, φ = 0.413. Overall, 57.1% of OMP indicated that they did supervise (N = 48) while 42.9% say that they did not (N = 36). More OMP supervised operations from the West Texas region (N = 37) as compared to the south region (N = 11). Meanwhile, more operators and maintenance personnel did not supervise from the South Texas region (N = 23) compared to the west region (N = 13).

Part 2. Tests on Ratio/Interval Data Comparing Groups

The Mann-Whitney U Test is a non-parametric test for independent samples for comparing two groups; in this research the two groups were community stakeholders and operator and maintenance personnel. The test was also applied to compare survey results by region (west and south).

Perceived levels of risk exposure for the community between OMP and community respondents.

The first proposition presented in this research suggested that there will be a statistically significant difference in *perceived risk* between the stakeholder groups from the ice throw hazard. Both groups were asked: “What level of risk exposure from wind farm operations do you believe citizens in the surrounding community(ies) have from ice throw hazard in the winter months?”

A Mann-Whitney U Test indicated that perceived level of risk exposure was statistically significant at the 0.05 significance level between community stakeholders and operators and maintenance personnel, *U* = 3369.500, *p* = 0.046; that is, 36.5%, where community stakeholders believed that citizens in the surrounding community or communities had slightly lower levels of risk exposure from ice throw hazard, while the operators and maintenance personnel believed that citizens in the surrounding communities had relatively higher level of risk exposure from the ice throw hazard during winter months from wind farm operations (1 out of 10; 51.2%; *N* = 43). The average risk level for OMP was 2.86 out of 10 (μ = 2.86, *SD* = 2.08) where a 10 represents extreme high risk. The community stakeholder group (1 out of 10; *N* = 35) had a slightly lower average level of risk at 2.36 out of 10 (μ = 2.36, *SD* = 1.89) where a 10 represents extreme high risk (Tables 6.2 and 6.3).

Table 6.2. Descriptive Statistics Supporting Chi-Square Tests.

Chi-Square Test Descriptive Statistics	**Variable**	**Yes**	**-**	**No**	**--**
Community Stakeholders (CS) Operators and Maintenance Personnel (OMP)		N	%	N	%
CS	Ice Throw	7	7.3	89	92.7
OMP		63	75	21	25
CS	Witness Deaths	0	0	96	100
OMP		1	1.2	83	98.8
CS	Report Ice Event	59	61.5	37	38.5
CS	Decision Maker	5	5.2	91	94.8
CS	First Responder	4	4.2	92	95.8
OMP	Stand Down	78	92.9	6	7.1
OMP	Supervise	48	57.1	36	42.9

Table 6.3. Mann-Whitney U Tests with Variable Names and Significance Levels by Survey Type.

Mann-Whitney U Tests	**Variable**	**N**	***U***	**Sig**
Community x OMP	Citizen Risk	180	3369.5*	0.046
Community x OMP	Wind Benefit	180	2815.5**	0.001

*p<0.05
**p<0.01

Perceived benefit of wind energy for the U.S. between OMP and community respondents.

Additionally, both survey groups were asked: "In your opinion, how beneficial is wind energy to U.S. society as a whole?" Mann-Whitney results indicated that there was a statistically significant difference in perceived benefit of wind energy differed between OMP respondents, U = 2815.500, p = <0.001. Over 40%, (42.7%), of community stakeholders indicated that wind energy was extremely beneficial to the U.S. (10 out of 10; N = 41). Community stakeholder respondents (76.0%) indicated a 7 or above (N = 73). The average level of wind energy benefit for this group was 7.75 out of 10 (μ = 7.75, SD = 2.62) where a 10 represents extremely beneficial.

The majority of OMP respondents considered the use of wind energy to be extremely beneficial to U.S. society as a whole (10 out of 10; 63.1%; N = 53), with 88.1% of respondents indicating an 8 or higher (N = 74). The average wind benefit for the OMP group was 9.20 out of 10 (μ = 9.20, SD = 1.43).

Table 6-4. Descriptive Statistics Supporting Mann-Whitney U Tests

Mann-Whitney U Tests Descriptive Statistics	**Variable**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Community Stakeholders (C), Operators and Maintenance Personnel (OMP)											
	Citizen Risk	**N, %**	**N, %**	**N, %**	**N, %**	**N, %**	**N, %**	**N, %**	**N, %**	**N, %**	**N, %**
C		35, 36.5%	15, 15.6%	19, 19.8%	7, 7.3%	8, 8.3%	5, 5.2%	3, 3.1%	3, 3.1%	0, 0%	1, 1.0%
OMP		43, 51.2%	13, 15.5%	11, 13.1%	3, 3.6%	6, 7.1%	4, 4.8%	3, 3.6%	0, 0%	1, 0.6%	0, 0%
	Wind Benefit	**N, %**	**N, %**	**N, %**	**N, %**	**N, %**	**N, %**	**N, %**	**N, %**	**N, %**	**N, %**
C		2, 2.1%	0, 0%	8, 8.3%	5, 5.2%	8, 8.3%	8, 8.3%	3, 3.1%	10, 10.4%	11, 11.5%	41, 42.7%
OMP		0, 0%	0, 0%	1, 1.2%	0, 0%	2, 2.4%	4, 4.8%	3, 3.6%	4, 4.8%	17, 20.2%	53, 63.1%

Part 3. Defining a Model of Community and OMP Respondents' Perceptions of Community Risk and Community Response: Regression Analysis

Regression analyses were conducted to determine which independent variables present in both groups might explain the variance perceptions of community risk (i.e., *citizen risk*) and personal risk through *witnessing of ice throw* events. An analysis was conducted for each group—community stakeholders and operators and maintenance personnel—on both types of risk perception—risk to the community and personal risk from the ice throw hazard. A multiple regression analysis was used for "Citizen Risk" (perceived community risk) as the dependent variable while a logistic regression was used for "Ice Throw" (perceived personal risk) as the dependent variable.

For the multiple regression analysis, all variables were entered simultaneously. Ranked variables were recoded so that the model treated each protective action or warning system as the #1 or top ranked variable. That is, variables given a rank of 1 were kept the same while all other ranks were recoded as zero. The warning system variables "CoSite" (Website of Wind Farm Company) and "CommSite" (Website of Community) were found to be constant and therefore thrown out or not entered into the multiple regression model. In addition to these two variables, the variable "Experience" was also found to be constant and was therefore thrown out or not entered into the logistic regression model. The variable "Age" was recoded so that younger individuals (Under 19 to 39) were given a value of 1 and older individuals (40 to 60+) were given a value of 0. The variable "Education" was recoded so that less educated individuals (High School to Some College) were given a value of 1 and more educated individuals (A.A. Degree to

Ph.D.) were given a value of 0. The variable "Gender" was recoded so that males were given a value of 1 and females were given a value of 0.

Community stakeholders: predictors for perceived community risk (citizen risk) and personal risk (witnessing an ice throw incident).

Multiple regression analysis was used to test if rank and demographic variables significantly predicted community respondents' ratings of perceived citizen risk for their communities from ice throw hazard during winter months where a 1 represents extreme low risk and a 10 represents extreme high risk. Results indicated that predictors explained only 15.4% of the variance, $R^2 = 0.154$. While the overall model was not significant, $F (13, 77) = 1.078$, n.s., it was found that age significantly predicted community risk perception, $\beta = 1.053$, $p = 0.048$ (Table 6.5). Younger individuals (under 19 to 39) tended to perceive higher risk for their communities from the ice throw hazard, than older individuals (40 to 60+).

Logistic regression analysis was used to test if rank and demographic variables significantly predicted perceived personal risk from an ice throw incident (Yes or No). A test of the full model against a constant was not statistically significant indicating that the predictors as a set did not reliably distinguish between witnessing and not witnessing an ice throw incident from a wind turbine, $\chi(13) = 22.297$, ***n.s***. Nagelkerke's R^2 of 0.519 indicated a moderate relationship between prediction and grouping. Moreover, prediction success overall was 92.3% (97.6% for No and 28.6% for Yes) (Table 6.5).

Operators and maintenance group: predictors for perceived community risk (citizen risk) and perceived personal risk (witnessing an ice throw incident).

Multiple regression analysis was used to test if rank and demographic variables significantly predicted OMP respondents' perceptions of citizen community risk from ice throw hazard where a 1 represents extreme low risk and a 10 represents extreme high risk. Results indicated that predictors explained 36.3% of the variance, $R^2 = 0.363$. The overall model was significant, $F(16, 67) = 2.389$, $p = 0.007$, and it was found that the warning system Newspaper significantly predicted perceived risk of the community, $\beta = 0.362$, $p = 0.003$ (Table 7). Those who cited a local newspaper article as the best warning system for communicating a falling ice hazard during winter months for wind turbines tended to indicate higher risk levels for citizens from ice throw hazard during winter months (Table 6.5).

Logistic regression analysis was used to test if rank and demographic variables significantly predicted OMP respondents' perceived personal risk by witnessing an ice throw incident (Yes or No). A test of the full model against a constant only model was not statistically significant indicating that the predictors as a set did not reliably distinguish between witnessing and not witnessing an ice throw incident from a wind turbine, $\chi(15) = 24.871$, ***n.s***. Nagelkerke's R^2 of .380 indicated a moderate relationship between prediction and grouping [however, for social science research, a relatively low R^2 (between .30 and .50, say) is quite common]. Moreover, prediction success overall was 79.8% (95.2% for No and 33.3% for Yes) (Table 6.5).

Table 6.5. Summary of Regression Analyses for Variables Predicting Perceived Community Risk (Citizen Risk) and Perceived Personal Risk (Ice Throw) Incident.

	Community Stakeholders		Operators and Maintenance Personnel	
Variable	*β*	*p*	*β*	*p*
Gender	-0.084	0.860	0.197	0.095***
Age	1.053	0.048*	0.055	0.638
Education	1.320	0.122	-0.186	0.118
Prediction Prevention	0.765	0.513	-0.280	0.122
Turbine Location	0.979	0.395	-0.086	0.580
Turbine Ice Detect	0.773	0.574	-0.143	0.428
Signs Alarms	0.291	0.790	-0.213	0.095***
Emergency Response	-0.322	0.786	0.031	0.788
Warning Signs	-0.481	0.661	0.203	0.134
Mail Pamphlet	0.826	0.667	-0.090	0.508
Meeting	-0.164	0.923	0.134	0.246
Newspaper	-0.497	0.792	0.362	0.003**
TV News	-0.081	0.944	0.040	0.738
R^2		0.154		0.362
F		1.078		2.389**

*p<.05
**p<.01
***p<.10

7. CONCLUSION

Propositions stated in the research design suggest that significant differences between the two study groups will emerge in terms of perceived risk, reacting to environmental cues, and engagement of information sources. Demographic information was also proposed that significant differences between the study groups would be related to demographic information as it relates to seeking information on protective action. Guided by the revised Protective Action Decision Model, as well as the research literature, seven propositions were set forth in Chapter 4, Research Design, and are reintroduced here to facilitate a more in-depth discussion from analyses and results in Chapters 5 and 6.

Proposition 1 stated that there will be differences between the two groups in witnessing ice throw hazard incidents. Both descriptive and statistical testing revealed that there were significant differences between the two groups on their perceptions of actual and observed risk through witnessing ice throw incidents. This is likely due to the greater amount of exposure operations and maintenance personnel (OMP) have to wind turbines than members of the community. Results also showed OMP who worked in the West Texas study area witnessed more ice throw incidents than those from the South Texas study area, which was expected because climate conditions conducive to turbine ice formation occur more frequently in West Texas.

It is notable that 75.0% of operations and maintenance personnel (63 out of 84) had witnessed an ice throw incident from a wind turbine. Descriptive analysis of survey results showed that operations and maintenance personnel who witnessed an ice throw event, collectively, had witnessed over 1,298 incidents during their careers.

Proposition 2 stated that there will be differences in perceived risk to the community between the two groups from the ice throw hazard. This proposition cannot be supported by the analysis results which found that comparisons between groups indicate that both operations and maintenance personnel and community stakeholders agree in their risk perceptions that ice throw poses an *extremely low risk* to citizens in the surrounding community. More than half of OMP surveyed (48 total) ranked citizen risk a 1 on a 1 to 10 scale, despite the overwhelming numbers of OPM who personally witnessed an event.

Proposition 3 specified that the two groups are likely to have significantly different reactions to, and opinions toward, environmental cues related to the wind turbines, and the threat of ice throw from them. As previously stated above, the risk literature indicates that environmental cues, such as weather conditions conducive for ice formation, observing ice on wind turbines, or wind farm workers hearing ice cracking or falling will elicit protective action. For 92.9% of operations and maintenance personnel, survey results showed the principle reaction to environmental cues was for their wind farm to issue site stand down orders which suspends all field work in an attempt to reduce exposure risk.

Community stakeholders were asked if they observed ice being thrown from a wind turbine what actions would they take to protect themselves from another incident.

The most common response was to "stay away" or "keep their distance" from wind turbines.

Proposition 4 offered that operation and maintenance personnel have different levels of perceptions of work safety at the site, as well as, the effectiveness of safety procedures, and trust of representatives. Analysis results show that not only do operations and maintenance personnel perceive a relatively moderate risk to themselves, 28.6% estimate extremely high levels of safety for wind turbine operations and maintenance personnel at their site. The reason that operations and maintenance personnel perceived extremely high levels of safety for their site might be attributed to survey data indicating that 82.1% of OMP respondents revealed that their company/facility did currently have safety procedures in place for wind turbine icing. Additionally, almost 80% (79.7%) of operations and maintenance personnel indicated that their safety procedures were *very* to *extremely effective* for protecting them in the event of an ice throw occurrence. OMP respondents mostly perceived *extreme high levels of trust* that safety representatives from their own wind farm operations would inform them of general wind turbine hazards and risks from working in and around wind turbines, with 83.3% of operations and maintenance personnel indicating an 8 or higher on a 1 to 10 scale.

Proposition 5 stated that community stakeholders are willing to report an incident, but unlikely to engage in protective actions. Chi-square test results indicated that community stakeholders did not differ regarding whether they would attempt to report an ice event by region, $\chi(1) = 0.396$, *n.s***.** Overall, 61.5% of community stakeholders indicated that they would attempt to report an ice event and 38.5% indicated that they would not. Qualitative data from community surveys indicated the most common response for protective action was to “stay away” or “keep their distance” from wind turbines. This was followed by “avoid,” “never get close to,” or “don’t go around wind turbines.”

Proposition 6 projected that few channels exist for disseminating warning messages associated with the wind turbine ice throw hazard. Survey results showed a majority of community stakeholders reveal that they do not know if their local wind farm has warning signs posted to communicate the risk of ice throw or falling ice from wind turbines. Only 2 out of 96 respondents (2.08%) endorse “yes” their local wind farm has posted warning signs and both are from the South Texas region.

The community stakeholders knowledge of posted warning signs is especially relevant given that operations and maintenance personnel ranked the type of warning systems they preferred for communicating a falling ice hazard from wind turbines during winter months with Warning Signs being the best method, followed by Information Pamphlets sent by mail, the Websites of Wind Farm Companies, Public Meetings with Stakeholders, Local Newspaper Articles, and Websites of Communities. The least preferred method was Local TV News warnings.

Proposition 7 stated that demographic information such as age and gender will differentiate the groups seeking information on protective action. Multiple regression analysis was used to test if rank and demographic variables significantly predicted OMP respondents’ perceptions of citizen community risk from ice throw hazard where a 1 represents *extreme low risk* and a 10 represents *extreme high risk.* Results indicated that predictors explained 36.3% of the variance, $R^2 = 0.363$. The overall model was significant, F (16, 67) = 2.389, p = 0.007, and it was found that the warning system *Newspaper* significantly predicted perceived risk of the community, β = 0.362, p = 0.003. Those who cited a *local newspaper article* as the best warning system for communicating a falling ice hazard during winter months for wind turbines tended to indicate higher risk levels for citizens from ice throw hazard during winter months.

Logistic regression analysis was used to test if rank and demographic variables significantly predicted OMP respondents' perceived personal risk by witnessing an ice throw incident (Yes or No). A test of the full model against a constant only model was not statistically significant indicating that the predictors as a set did not reliably distinguish between witnessing and not witnessing an ice throw incident from a wind turbine, $\chi(15) = 24.871$, *n.s*. Nagelkerke's R^2 of 0.380 indicated a moderate relationship between prediction and grouping [however, for social science research, a relatively low R^2 (between 0.30 and 0.50, say) is quite common]. Moreover, prediction success overall was 79.8% (95.2% for No and 33.3% for Yes).

Overall, operations and maintenance personnel tended to endorse higher levels of risk associated with an ice throw hazard than community stakeholders. Higher risk levels tended to come from the West Texas region. A majority of operations and maintenance personnel also indicate that their wind farm has a wind turbine icing safety procedure and they tend to endorse these programs as extremely effective. OMP respondents indicated the best protective action to reduce the risk of ice throw in the surrounding community was prediction and prevention.

Operations and maintenance personnel tend to endorse higher levels of trust than community stakeholders that safety representatives from their wind farm operations will (or have) informed leaders in the surrounding community and the local media of wind turbine hazards and risks. Many indicate that observing safety procedures and protocols is the best way to protect oneself from an ice throw incident.

In the U.S. we currently have over 32,000 wind turbines in 38 different states with each of these wind turbines in each of these states having the potential for ice throw hazards. Previous studies have determined that wind turbines produce ice fragments on the turbine blades which are typically 1 kilogram in mass (2.2 pounds) and can be projected at 179 mph for up to 820 feet.

The wind industry needs to implement ice throw risk information programs, adequate turbine setback criteria, and turbine icing safety procedures to address this hazard. The purpose of this dissertation is to conduct a hazard and risk assessment of ice throw from wind turbines to better understand the perceived risk. The theoretical framework of the Protective Action Decision Model was used for studying community risk, vulnerability and response to the ice throw hazard.

As mentioned in the Introduction section above; there are twelve questions that guide this study. Survey instruments were developed for two groups of study participants: 1) wind farm operations and maintenance personnel; and 2) citizens in the surrounding community of wind farm operations (Appendix C & D below). It is primarily through these surveys that study questions were answered.

It was expected that wind farm operations and maintenance personnel will have a significantly higher level of exposure to ice throw hazards and therefore a greater perception of risk than members of the surrounding community. This group is also expected to seek out protective actions at a higher level as a result of their experiences with ice throw.

Appendix A below, "Stigmatization of the Ice Throw Hazard" demonstrates a real-world example of how a single ice throw incident can affect an entire community. With wind power technology being applied on a broad scale in the U.S. it is only a matter of time until similar events happen here, hopefully without a fatality.

Importance of Study: Application for Future Research

Based on the recommendations of this study, a data collection program can be developed for each wind farm to implement comprehensive Turbine Icing Safety Programs to establish:

1. A Risk Information Program for disseminating Wind Turbine Ice Throw Hazard information for Wind Farm Operations, Maintenance, and Contractor Personnel.
2. A separate (less technical) Risk Information Program for Landowners (both participating and non-participating) and the General Public.
3. Guidelines - Federal, State, Local policies that define and enforce Turbine Setback Criteria that include ice throw safety.
4. Recommended minimum requirements for Wind Farm Operations & Maintenance (O&M) Turbine Icing Safety Procedures.

5. Recommendations for amending Wind Farm Site Safety Orientations to include Ice Throw Hazards and safe working requirements and reporting procedures.
6. Wind Farm Vulnerability Maps.

Finally, additional research is also needed to examine previously applied research related to the ice throw hazard to assess whether the following risk mitigation strategies for turbines closest to the general public, neighbors, operators, and contractors are viable: 1) Curtailing operation of turbines during periods of ice accretion; 2) Implementing turbine control features that prevent operation during periods of ice accretion; 3) Re-siting of some turbines to remove them from areas of risk; 4) The use of warning signs alerting anyone in the area of the risk (at the edge of the defined safety zone); and 5) Training staff, original equipment manufacturer (OEM) workers, and contractors on the hazards of ice throw, falling ice, and safe approach distances.

APPENDIX SECTION

Appendix A - Stigmatization of the Ice Throw Hazard: A Media Example

Below are excerpts from a newspaper article written by Kristen Beacock for the *Peterborough Evening Telegraph*, published on February 12, 2008 which details an ice throw incident which occurred in the United Kingdom.

Wind turbine's deadly ice shower

Residents were left fearing for their safety after shards of melting ice fell on homes and gardens from the blades of a giant wind turbine. For about four hours people in King's Dyke, Whittlesey, had to take cover as huge lumps (some two feet long) showered them from the 80 meter high tower on Saturday morning.

Resident Peter Randall, whose son's house lays a stone's throw away from the turbine, said: "Somebody is going to get killed. There were huge lumps of ice shooting off and landing everywhere. No one wants to leave the house because they are frightened and worried about the ice falling."

Freezing overnight temperatures had caused the ice to form and after frantic calls to Truro-based firm Cornwall Light and Power, which owns the turbine, the machine was eventually turned off.

Maria Clark, who owns King's Dyke Karpets, based yards from the turbine, said: "It has been really frightening; the turbine has been stopping and starting all morning. The ice makes such a loud noise when it shatters we thought a bomb had gone off in the yard. It scared a customer away. They were in the shop when it landed and said they did not want to risk their car and ran out."

This is not the first time the turbine has courted controversy. Last month The Evening Telegraph revealed how residents had lodged complaints with the environmental health department at Fenland District Council due to alleged noise pollution and had demanded the turbine's removal. The huge machine, which measures 80 meters at its hub and 125 meters when one of its three blades is vertical, was put up in August.

A spokesperson for Cornwall Light & Power said: "We received a report of an ice shedding incident near our Whittlesey turbine on Saturday morning and immediately made arrangements for it to be switched off. The turbine will remain stopped until we have a clear understanding of what happened and any safety concerns have been fully addressed. Cornwall Light & Power is a reputable operator with a proven track record of generating clean electricity safely and we will act quickly to resolve this issue."

MP for Cambridgeshire North East Malcolm Moss said the turbine should remain closed until a new risk assessment could be made, as the problem could also have national implications. He said: "I had no idea this turbine was going up, it came out of the blue really and I am surprised they put one so close to homes and businesses. I assume that a risk assessment was put with the planning application, but if it was not then a full inquiry should be undertaken."

Whittlesey councilor Ronald Speechley today said he would by lobbying the council to find out what can be done. He said: "I have received a lot of complaints and the fact that ice has fallen off should be brought to light. This should have been thought of before they put the turbine so close to houses and the road."

The newspaper article demonstrates a “stigmatization of hazards” closely related to perception of risk. For example, nuclear waste disposal sites have been stigmatized though NIMBY-ism, activism, and the media while “green energy” technologies, such as wind and solar energy, have been the recipient of much positive publicity. This positive press serves also to hide or reduce an individual’s perceived risk of personal danger from ice throw in comparison with a much higher level of actual or observed risk where the threats from wind energy are concerned.

Often, the impetus for stigmatization is the occurrence of some critical event which sends a strong signal of abnormal risk (Kasperson et al., 1988). An ice throw incident in the U.S. which would cause significant damage or fatal injuries could attract media attention that might result in a heightened awareness of this hazard and generate a "social amplification of risk".

Several studies using content analyses of media reporting on specific hazards (such as nuclear power) have identified a number of instances of sensationalism and distortion of facts. Due to the complex subject matter associated with technological hazards, journalists must rely on expert sources for information. But most hazards are complex issues and require input from experts in different areas of concentration to paint the full photo. Unfortunately, few journalists have the scientific background to sort through this complex material and recognize the limits of their own understanding (Fischhoff, 1985). Cohen (1983) suggested that the distorted views of hazards and risks portrayed in the media often result in a public overreaction to risk.

Appendix B - Cover Letter

Cover Letters for Phase 1 Participants, "Wind Farm Operators and Maintenance Personnel" and Phase 2 Participants, "Citizens in the Surrounding Community."

"UNDERSTANDING RISK PERCEPTIONS OF WIND TRUBINE ICE HAZARDS"

I am Greg Klaus, a doctoral student in the Department of Geography at Texas State University in San Marcos, Texas. I am pursuing a Doctor of Philosophy in Environmental Geography and am conducting a research project concerning risk perception and protective measures surrounding ice hazards from wind turbines. I am conducting this research under the supervision of my doctoral advisor, Dr. Denise Blanchard, Professor of Geography.

The aim of this study is to understand perception of risk associated with ice hazards from wind turbines by surveying both wind farm workers and members of the surrounding communities to assess their experiences working with, and living in close proximity to, wind turbines.

All information collected through this survey will remain anonymous and confidential. Names, companies and organizations will not be identified. You do not have to answer any questions that make you feel uncomfortable in any way. You may also have the option of completing this survey by the means of a phone interview or an in-person interview. If this is more convenient for you, please contact me and I will gladly make the necessary arrangements.

If you have any other questions, comments, or concerns please contact me, or my advisor, Dr. Blanchard. Thank you for taking the time to participate in this-research. You will not be contacted again. Your responses are very important to this study. Please e-mail Mr. Klaus or Dr. Blanchard if you would like a copy of the final report, due out spring of 2016.

Questions, comments, or concerns contact:

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Appendix C - Phase 1 Survey Instrument for Wind Farm Operators and Maintenance Personnel

Wind Farm Operators & Maintenance Personnel Survey

Questions 1-12 ask for your experience, beliefs and opinions regarding the ice throw hazard from wind farm operations.

Q-1 Have you ever witnessed an ice throw incident from a wind turbine? Yes_____ No_____

If "No," please continue on to Q-5.

Q-2 If you answered "Yes" to the question above, please estimate the number of ice throw incidents you have seen during your time as a wind energy professional:

_______________ (Please place a number for your estimate).

Q-3 In your own words, please describe the damage caused by the event(s):____

____

____

Q-4 Have you ever witnessed any injuries or deaths caused by ice throw from wind turbines?

Injuries: YES________ #___________ NO _______________

Deaths: YES________ #___________ NO _______________

Q-5 In general, what level of risk exposure do you believe wind farm workers have from the ice throw hazard during winter months? (Please circle the number of your estimate where 10 represents "Extreme High Risk" and 1 represents "Extreme Low Risk"):

EXTREME HIGH RISK									EXTREME LOW RISK
10	9	8	7	6	5	4	3	2	1

Q-6 In general, what level of risk exposure from wind farm operations do you believe citizens in the surrounding community(ies) have from the ice throw hazard during winter months? (Please circle the number of your estimate where 10 represents "Extreme High Risk" and 1 represents "Extreme Low Risk"):

EXTREME HIGH RISK									EXTREME LOW RISK
10	9	8	7	6	5	4	3	2	1

Q-7 Does your company/facility currently have a Wind Turbine Icing Safety Procedure?

YES_____ NO_____ DON'T KNOW _________

(If NO, or DON'T KNOW, please skip to Q-10)

Q-8 In your opinion, in the event of an ice throw occurrence, how effective is/are the safety procedure(s) for protecting wind farm operators and maintenance personnel? (Please circle the number of your estimate where 10 represents "Extremely Effective" and 1 represents "Not At All Effective"):

EXTREMLY EFFECTIVE									NOT AT ALL EFFECTIVE
10	9	8	7	6	5	4	3	2	1

Q-9 In your opinion, in the event of an ice throw occurrence, how effective is/are the safety procedure(s) for protecting citizens in the surrounding community(ies)? (Please circle the number of your estimate where 10 represents "Extremely Effective" and 1 represents "Not At All Effective"):

EXTREMLY EFFECTIVE									NOT AT ALL EFFECTIVE
10	9	8	7	6	5	4	3	2	1

Q-10 In the blank space to the right, please rank your preferences for protective actions listed below for reducing the risk of ice throw from wind turbines where 1 represents the best action, 2 represents the second best, and so forth:

Prediction and Prevention _____

Turbine Location Planning _____

Turbine Icing Condition Detection _____

Warning Signs and Alarms _____

Emergency Response Planning for Ice Throw Events_____

Other (Please Specify):_________________________________

Q-11 Does your wind farm issue site stand down orders for areas where turbine icing has been observed or when ice throw incidents occur? Yes_____ No_____

Q-12 Does your wind farm have warning signs posted to communicate the risk of ice throw or falling ice from wind turbines? Yes_____ No_____

Q-13 In the blank space to the right, please rank the type of warning system(s) that you prefer for communicating a falling ice hazard for wind turbines during winter months, where 1 represents the best action for warning, 2 represents the second best action, and so forth:

Warning Signs	_____
Information Pamphlet sent by mail	_____
Public Meeting with Stakeholders	_____
Local Newspaper Article	_____
Website of Wind Farm Company	_____
Website of Community	_____
Local TV News	_____

Other (Please Specify):____________________

Questions 14-19 ask for your experience, beliefs and opinions regarding general wind farm operations.

Q-14 What level of trust do you have that safety representative(s) from your wind farm operations will inform, or have informed you, of general wind turbine hazards and risks from working in, and around, wind turbines? (Please circle the number of your estimate where 10 represents "Extreme High Trust" and 1 represents "Extreme Low Trust"):

EXTREME HIGH TRUST TRUST — EXTREME LOW

10 9 8 7 6 5 4 3 2 1

Q-15 What level of trust do you have your safety representative(s) will inform, or have informed, citizens in the surrounding community(ies) of general wind turbine hazards and risks? (Please circle the number of your estimate where 10 represents "Extreme High Trust" and 1 represents "Extreme Low Trust"):

EXTREME HIGH TRUST TRUST — EXTREME LOW

10 9 8 7 6 5 4 3 2 1

Q-16 Please rate your estimate of the overall safety of wind turbine operations and maintenance for this site. (Please circle the number of your estimate where 10 represents “Extreme High Level of Safety” and 1 represents “Extreme Low Level of Safety”):

EXTREME HIGH SAFETY | EXTREME LOW SAFETY

10	9	8	7	6	5	4	3	2	1

Q-17 How beneficial do you consider the use of wind energy to be to U.S. society as a whole? (Please circle the number of your estimate where 10 represents “Extremely Beneficial” and 1 represents “Not At All Beneficial”):

EXTREMLY BENEFICIAL | NOT AT ALL BENEFICIAL

10	9	8	7	6	5	4	3	2	1

Q-18 In your estimation, how much risk from wind farm operations, do you believe that wind farm operators and maintenance technicians experience in their daily work activities? (Please circle the number of your estimate where 10 represents “Extreme High Risk” and 1 represents “Extreme Low Risk”):

EXTREME HIGH RISK | EXTREME LOW RISK

10	9	8	7	6	5	4	3	2	1

Q-19 In your estimation, how much risk from wind farm operations, do you believe that citizens in the surrounding community(ies) experience in their daily activities? (Please circle the number of your estimate where 10 represents “Extreme High Risk” and 1 represents “Extreme Low Risk”):

EXTREME HIGH RISK | EXTREME LOW RISK

10	9	8	7	6	5	4	3	2	1

Questions 20-28 ask for general demographic information, as well as, any additional comments that you would like to offer about the ice throw hazard, or wind turbine operations.

Q-20 How many years have you worked in the wind industry?

0 to 1 years _____
2 to 5 years _____
6 to 10 years _____
11 to 15 years _____
16+ years _____

Q-22 Indicate whether your job function is primarily:
Operations Section _____
Maintenance Section _____

Q-23 Do you supervise anyone? Yes_____ No_____

Q-24 Please indicate your age range?

18-19 _____
20-29 _____
30 to 39 _____
40 to 49 _____
50-59 _____
60+ _____

Q-25 Please indicate your education and training:

HIGH SCHOOL _____
TECHNICAL TRAINING _____
ON-THE-JOB TRAINING _____
SOME COLLEGE _____
COLLEGE GRADUATE
A.A Degree______Bachelor's Degree_____
GRADUATE DEGREE Masters ______Ph.D.________

Q-26 Please indicate: _______Male _______Female

Q-27 In the space below please provide any additional information you think is important for understanding the hazards and risks associated with <u>ice throw in the winter months</u> from wind turbines (use back of sheet if necessary):

____
____
____
____
____

Q-28 In the space below please provide any additional information you think is important for understanding the hazards and risks associated with general day-to-day operations from wind turbines (use back of sheet if necessary):

THANK YOU FOR YOUR PARTICIPATION IN THIS SURVEY

Appendix D - Phase 2 Survey Instrument for Citizens in the Surrounding Community(-ies) of Wind Farm Operations

Community Stakeholders' Survey of Wind Farm Operations

Questions 1-15 ask for your experience, beliefs and opinions regarding the ice throw hazard from wind farm operations.

Q-1 Do you currently own land with a wind turbine leasing agreement? Yes_____ No_____

Q-2 Do you live within sight of a wind turbine? Yes_____ No_____

If YES, approximately how many miles do you live from a wind turbine and/or wind farm operations? ___________________________

Q-3 Does your daily commute take you through an area where wind turbines are running?

Yes_____ No_____

Q-4 Have you ever observed ice accumulating on a wind turbine? Yes_____ No_____

Q-5 Have you ever observed an ice throw incident from a wind turbine? Yes_____ No_____

If "No," please continue on to Q-8

Q-6 If you answered "Yes" to the question above, please estimate the number of ice throw incidents you have seen during your time as a wind energy professional:

_______________ (Please place a number for your estimate).

Q-7 In your own words, please describe the damage caused by the event(s):____

____

Q-8 Have you ever witnessed any injuries or deaths caused by ice throw from wind turbines?

Injuries: YES________ #___________ NO _______________

Deaths: YES________ #___________ NO _______________

Q-9 If you observed ice being thrown from a wind turbine or had a near-miss experience with an ice event would you attempt to report the incident? Yes_____ No_____

Q-10 If you observed ice being thrown from a wind turbine what actions would you take to protect yourself from another incident?

____

____

Q-11 In general, what level of risk exposure from wind farm operation do you believe citizens in the surrounding community(ies) have from the ice throw hazard in winter months? (Please circle the number of your estimate where 10 represents "Extreme High Risk" and 1 represents "Extreme Low Risk"):

EXTREME HIGH RISK									EXTREME LOW RISK
10	9	8	7	6	5	4	3	2	1

Q-12 What level of trust do you have that safety representative(s) from wind farm operations will inform, or have informed, leaders in the surrounding community(ies) of the ice throw hazard in winter months? (Please circle the number of your estimate where 10 represents "Extreme High Trust" and 1 represents "Extreme Low Trust"):

EXTREME HIGH TRUST TRUST									EXTREME LOW
10	9	8	7	6	5	4	3	2	1

Q-13 What level of trust do you have that safety representative(s) from wind farm operations will inform, or have informed, local media (TV, radio, emergency broadcast channel) of the possibility of an ice throw hazard during winter months? (Please circle the number of your estimate where 10 represents "Extreme High Trust" and 1 represents "Extreme Low Trust"):

EXTREME HIGH TRUST TRUST									EXTREME LOW
10	9	8	7	6	5	4	3	2	1

Q-14 In the blank spaces, please rank your preferences for protective actions that you believe wind farm operators should be taking to reduce the risk of ice throw from wind turbines in the surrounding community(ies) where 1 represents the best action, 2 represents the second best, and so forth:

Prediction and Prevention _____

Turbine Location Planning _____

Turbine Icing Condition Detection _____

Warning Signs and Alarms _____

Emergency Response Planning for Ice Throw Events_____

Other (Please Specify):________________________________

Q-15 Does the local wind farm have warning signs posted to communicate the risk of ice throw or falling ice from wind turbines? Yes_____ No_____Don't Know________

Questions 16-22 ask for your experience, beliefs and opinions regarding general wind farm operations.

Q-16 In the blank space to the right, please rank the type of warning system(s) that you believe is/are best for communicating a falling ice hazard during winter months for wind turbines, where 1 represents the best action, 2 represents the second best, and so forth:

Warning Signs _____

Information Pamphlet sent by mail _____

Public Meeting with Stakeholders _____

Local Newspaper Article _____

Website of Wind Farm Company _____

Website of Community _____

Local TV News _____

Other (Please Specify):___________________

Q-17 What level of risk exposure from wind farm operations do you believe citizens in the surrounding community(ies) have from daily operations of wind turbines? (Please circle the number of your estimate where 10 represents "Extreme High Risk" and 1 represents "Extreme Low Risk"):

EXTREME HIGH RISK									EXTREME LOW RISK
10	9	8	7	6	5	4	3	2	1

Q-18 What level of trust do you have that safety representative(s) from wind farm operations will inform, or have informed, leaders in the surrounding community(ies) of general hazards and risks associated with daily operations of wind turbines? (Please circle the number of your estimate where 10 represents "Extreme High Trust" and 1 represents "Extreme Low Trust"):

EXTREME HIGH TRUST TRUST | EXTREME LOW

10	9	8	7	6	5	4	3	2	1

Q-19 What level of trust do you have that representative(s) from wind farm operations will inform, or have informed, the local media (TV, radio, emergency broadcast channel) of general hazards and risks associated with daily operations of wind turbines? (Please circle the number of your estimate where 10 represents "Extreme High Trust" and 1 represents "Extreme Low Trust"):

EXTREME HIGH TRUST TRUST | EXTREME LOW

10	9	8	7	6	5	4	3	2	1

Q-20 In your opinion, how beneficial is wind energy to U.S. society as a whole? (Please circle the number of your estimate where 10 represents "Extremely Beneficial" and 1 represents "Not At All Beneficial"):

EXTREMLY | NOT AT
ALL
BENEFICIAL
BENEFICIAL

10	9	8	7	6	5	4	3	2	1

Q-21 Have you ever gone to the website of the nearby wind farm operations to learn about hazards and risks associated with living near wind turbines?

Yes_____ No_____Don't Know________

Questions 22-30 ask for general demographic information, as well as, any additional comments that you would like to offer about the ice throw hazard, or wind turbine operations.

Q-22 Please indicate whether your wind turbine exposure is primarily as a:

Landowner _____
Neighbor _____
Commuter _____
Community ______

Q-23 Do you work for the nearby wind energy company?
YES_________NO_________

If YES, How many years have you worked in the wind industry?

0 to 1 years _____
2 to 5 years _____
6 to 10 years _____
11 to 15 years _____
16+ years _____

If YES, is your job function primarily:

Operations Section _____
Maintenance Section _____

Q-24 Are you a leader in a decision making role your community?
YES_________NO________

Q-25 Are you a First Responder in your community? YES_________NO_________

Q-26 Please indicate your age range?

18-19 _____
20-29 _____
30 to 39 _____
40 to 49 _____
50-59 _____
60+ _____

Q-27 Please indicate your education and training:

HIGH SCHOOL _____
TECHNICAL TRAINING _____
PROFESSIONAL TRAING _____
SOME COLLEGE _____
COLLEGE GRADUATE A.A Degree______Bachelor's Degree_______

GRADUATE DEGREE Masters ______Ph.D.________

Q-28 Please indicate: _______Male _______Female

Q-29 In the space below please provide any additional information you think is important for understanding the hazards and risks associated with ice throw in the winter months from wind turbines (use back of sheet if necessary):

____
____
____
____
____

Q-30 In the space below please provide any additional information you think is important for understanding the hazards and risks associated with general day-to-day operations from wind turbines (use back of sheet if necessary):

____
____
____
____
____

THANK YOU FOR YOUR PARTICIPATION IN THIS SURVEY

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