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Preparedness, Response, and Communication Preferences of Dairy Farmers During Extreme Weather Events: A Phenomenological Case Study

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Abstract: In 2021, Winter Storm Uri severely affected several Texan agricultural sectors, including dairy production. To understand how dairy producers experienced this extreme weather event, this qualitative phenomenological case study explored perceptions of preparedness, coping strategies, and information needs and preferences for dealing with extreme weather events among dairy producers in Texas, conducting individual semi-structured interviews. The findings indicated that farmers felt unprepared to deal with extreme weather events and suffered significant economic losses due to this lack of preparedness. In response to winter storm Uri, dairy farmers modified traditional operations and management practices to mitigate negative impacts on farm labor, infrastructure, and herds. Our results, along with the existing literature on communication for extreme weather event management, highlighted that dairy farmers do not receive adequate information to effectively prevent and cope with similar occurrences in the future. Consequently, this study recommends exploring effective strategies to help agricultural producers develop plans to manage the effects of extreme weather events. Additionally, it integrates place-based, pluralistic, and demand-driven approaches to identify the best communication practices, enhance timely information dissemination on extreme weather, and strengthen the technical capacities of public and private entities, including Cooperative Extension Systems, as trusted resources for agricultural producers.

Keywords: climate change; disaster preparedness; farming; risk; vulnerability

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1. Introduction

Humanity is constantly threatened by natural and anthropogenic extreme weather events, causing significant losses in human life, crops, and livestock production, and severely impacting the economy, society, and the environment [1,2]. According to the Intergovernmental Panel on Climate Change (2023), an extreme weather event is an abnormal alteration of climatic conditions at an unusual intensity, place, or time of the year [3]. Extreme weather events are characterized by their potential to cause severe damage and loss, as well as their unpredictable intensity and frequency, resulting in direct or indirect impacts beyond the immediate destruction of infrastructure and production capacity. Although extreme weather events occur regularly, with high intensity and frequency, they can reach

levels of aggressiveness that turn them into natural disasters. Francescutti et al. [4] defined a natural disaster as an event capable of causing severe harm and destruction to people, infrastructure, and the environment. Francescutti and collaborators emphasized that such disasters overwhelm an affected community's ability to respond and cope with the created conditions. Using the above definitions for natural disasters and extreme weather events, this study acknowledges that winter storm Uri was an extreme weather event that reached a natural disaster category. Therefore, "natural disaster" and "extreme weather events" were used interchangeably to investigate the 2021 winter storm Uri. The National Centers for Environmental Information (NCEI) reported that, since 1980, 400 extreme weather events and natural disasters in the U.S. have caused approximately $2.785 trillion in damages. The years 2021–2023 marked the highest number of such events, totaling 66, which included droughts, wildfires, and floods. These events resulted in a combined cost of $441.8 billion ($147.3 billion per year) and 1690 deaths (averaging 563 per year) [5]. As incidences of natural disasters and extreme weather events increase, so has the interest in preparing for, and responding to, these occurrences by both academics and the greater public.

These extreme weather events, often exacerbated by climate change, disrupt agricultural and food systems, in particular by intensifying heatwaves, extending wildfire seasons, and creating severe conditions such as flooding and drought [6]. Although United States agriculture produces about $350 billion in commodities each year, with 50% of the overall value in this sector coming from livestock production [7], $21.94 billion (about $68 per person in the U.S.) was lost due to extreme weather events. Direct impacts, such as loss of labor, may include casualties, impairments, or injuries resulting in disturbed or interrupted production, ending with decreased planned production output [8]. While the direct costs of extreme weather events are substantial, there are also indirect impacts to consider, such as damage to infrastructure such as storage spaces, irrigation, buildings, equipment, and machinery [9,10]. These events also disrupt ecosystems, leading to further losses that ripple across agricultural sectors.

One such sector affected by these disruptions is dairy production, a rapidly expanding industry marked by steady growth in the number of productive farms and increasing productivity rates across the United States. Notably, five states, including Texas, contribute to more than 50% of the national dairy production [11]. Further, the vulnerability of this vital sector to extreme weather events underscores the broader implications of climate change on food security and economic stability. Minton [12] stated that Texas had 2890 dairy farmers in 1975, producing around three billion pounds of milk per annum. Spencer and Piñeiro [13] observed that from 2002 to 2019, Texas saw a significant rise in milk production regarding absolute and relative scales, with an annual increase in milk production of 8.55 billion pounds, a 160% increase from 2002 to 2019. Despite higher milk production and sales, the number of Texas dairy farms has fallen by 88% over the last 45 years due to challenges in the dairy industry [13]. In 2023, despite challenges from extreme events such as the COVID-19 pandemic in 2019/2020 and winter storm Uri in 2021, Texas ranked fourth in the nation for milk production and the consolidation of dairy farms, with New York following closely behind [11]. According to Lane et al. [14], dairy farms are influenced by several variables, such as proximity to human settlements, labor availability, environmental laws, and extreme weather events and conditions. The 2021 winter storm Uri was an unprecedented event that accumulated significant snow, severely destroying people and infrastructure. Power blackouts spanned most of the state on 18 February, exacerbating the situation [15]. Winter storm Uri, which struck 14–20 February 2021, had a profound impact on the state's infrastructure, economy, and agricultural sector. A mid-March 2021 survey by the University of Houston Hobby School of Public Affairs revealed that 69% of Texans experienced power outages during Uri, while nearly half (49%) faced water

service disruptions. Uri was responsible for at least 210 deaths and estimates from the Federal Reserve Bank of Dallas projected storm-related financial losses of between $80 and $130 billion [15]. Smith [16] highlighted that Texas and other southern states faced prolonged disruptions due to persistent Arctic air and below-freezing temperatures.

The agricultural sector bore significant losses, as outlined in a preliminary assessment by Texas A&M AgriLife Extension Service. Uri inflicted at least $600 million in agricultural damages, including $230 million in citrus losses, $228 million in livestock losses, and $150 million in vegetable crop losses [17]. These figures highlight the widespread economic and environmental toll of winter storm Uri on Texas' agricultural productivity and overall resilience. The Texas livestock industry, specifically the dairy sector, is a vital pillar of the state's economy, supporting rural livelihoods and driving agricultural productivity [18]. Despite its importance, the dairy sector faces persistent challenges, compounded by inadequate government support for disaster preparedness and response. This shortfall leaves farmers vulnerable to extreme weather events, resulting in feed shortages, declining animal health, and fragile infrastructure [19]. Hampton et al. [20] highlight that these recurring issues, exacerbated by natural and human-made disasters, threaten the long-term sustainability of dairy farming in Texas. The challenges confronting the sector are diverse and interconnected. Extreme weather events such as droughts and floods disrupt feed supplies, drive up costs, and expose supply chain vulnerabilities [21]. Livestock health deteriorates due to insufficient veterinary support during crises, further reducing productivity. Additionally, weak infrastructure for production, processing, and value addition amplifies these vulnerabilities. According to Rasool et al. [21], disasters have inflicted $11 billion in losses on the livestock sector, with droughts accounting for 44% and floods 39%, underscoring the critical need for enhanced preparedness measures. Texas dairy farmers face frequent and severe weather events, including floods, droughts, heat waves, and hurricanes [22–24]. Flooding contaminates water sources, submerges grazing lands, and disrupts transportation networks, delaying feed and milk distribution [25]. Similarly, droughts reduce pasture availability and water supplies, negatively affecting livestock fertility and milk yields. Rising temperatures from heat waves exacerbate cattle heat stress, while hurricanes devastate infrastructure, displace livestock, and halt operations [26].

2. Natural Disaster Management in Agricultural Production

The devastating impact of natural disasters on the Texas dairy industry was evident during winter storm Uri, which severely affected ranchers and commercial agricultural producers across the state. Research by Sen and Chander [27] highlighted that livestock exposure to natural disasters can result in a shortage of food and water supply and an increased risk for pests and infectious diseases. Natural disasters often substantially impact the mental health of livestock farmers and ranchers, as they face emotional and financial stress, reduced farm productivity, and increased herd mortality. While it is undoubtedly essential for dairy industry stakeholders to plan for severe weather-related events, there are some incidents in which doing so might be a challenge. Queenan et al. [28] highlighted that effective livestock management can provide numerous benefits, mitigating damages to ecosystems and their services and improving biodiversity. Therefore, having a disaster management system that integrates preparedness and response strategies could be an effective alternative. Chaudhary and Piracha [29] described disaster management as a system that includes measures conducted before and after a natural disaster to prevent and control the adverse impacts of the event. This study used the comprehensive disaster management model (Prevention/Mitigation, Preparedness, Response, and Recovery (PPRR)), developed by Yu et al. [30], to theoretically understand dairy farmers' experiences during winter storm

Uri (Figure 1). The PPRR presents a cyclic two-phase process (before and after the event) and four stages (preparedness, prevention/mitigation, response, and recovery).

Figure 1. Disaster Management Phases. Note. Taken from Yu et al. [30].

The Natural Research Council, Division on Earth and Life Studies & Committee on Disaster Research in the Social Sciences [31] opined that the preparedness phase involves a network of plans that encompasses actions taken before a disaster occurs, anticipating unforeseen circumstances that may arise during disaster response and recovery. These actions include creating a formal emergency operations plan for the dairy farm, regularly updating the plan, training all farm employees, and assigning specific emergency management tasks to designated team members. Additionally, preparedness involves providing shelter for both animals and employees, allocating financial resources, and fostering collaboration among extension agents, veterinary practitioners, and local emergency management organizations. Mileti [32] and the NRC [31] further added that prevention or mitigation comprises measures implemented before severe weather incidents to minimize or prevent potential impacts, such as physical harm or social disruption, on the dairy farm. Mitigation approaches are categorized into structural and non-structural strategies. Structural mitigation uses physical infrastructures such as levees, high concrete walls to reduce flooding, windbreaks like corn stacks, and bedding materials such as wood shavings.

In contrast, non-structural mitigation aims to reduce the exposure of employees, animals, buildings, and infrastructure to disasters through policies and regulations. For instance, land-use acts designate specific areas for development that are habitable and secure from extreme weather events, zoning ordinances used to limit the density of human occupancy, and preferential taxation can enhance incentives to ensure minimal population in certain hazardous areas. Additionally, the response phase refers to activities performed during and immediately after a disaster [33–35]. These activities require swift decision-making and resource availability. They include disseminating predictions and warnings, organizing evacuations or shelter-in-place measures for livestock and employees, directing and coordinating emergency operations, and mobilizing resources. Response efforts also involve collaboration with local and national emergency organizations, volunteers, and

material resources and conducting search and rescue operations for at-risk individuals and animals. Additionally, a rapid needs assessment facilitates quick damage control and restores essential amenities critical for disaster management.

Finally, the recovery phase is a vital phase following any disaster. The extent of recovery depends on the resilience of the dairy farm. Recovery may be a short-term or long-term process and includes activities such as reconstructing infrastructure, providing assistance efforts, and addressing the psychological and mental well-being of individuals on the farm. Recovery can take many days, weeks, or several years depending on the duration and size of the disaster, severity of the disaster, the speed of its onset, and the available resources to resolve the problem [32].

This study emphasizes the disaster preparedness and response phases, as they represent the initial stages on both ends of the disaster management spectrum (before and after the event) and serve as the foundation for effective disaster management [29,36,37]. By examining dairy farmers' preparedness and response actions during the 2021 winter storm Uri through the lens of the disaster management model, the study aims to provide a comprehensive understanding of the measures taken to mitigate impacts and facilitate recovery from Uri. On the contrary, Moreau et al. [38] emphasized that mitigation and adaptation are key strategies for addressing extreme weather events. However, Khillare and Kaushal [39] highlight that livestock, due to their size, feeding needs, housing space, and transportation demands, require special preparation to cope with such events. Meanwhile, Rasool et al. [21] suggested that adequate measures such as disaster kit preparation, animal transportation facilities, safe shelter, and improved coordination and cooperation among disaster-management agencies should be established to reduce severe losses to human lives, livestock, and property. Notwithstanding the favorable forecast for global dairy output, extreme weather events may continue to pose direct and indirect threats to dairy production and the growth of the dairy sector in the West Texas region under study. Several studies have been conducted on how extreme weather events affect agricultural production. For example, the vulnerability of dairy farming and other agricultural operations to the increased variability of extreme weather events has been extensively studied. [40–42]. Even more, research has been done on how natural disasters affect livestock farming, such as the perceptions of attitude toward hazard risks and susceptibility in rural Texas [43].

However, there remains a notable gap in the literature regarding Texas dairy farmers' preparedness and response to extreme weather events such as winter storm Uri in 2021. Addressing this gap is crucial for enhancing the resilience and sustainability of the Texas dairy industry, ensuring it can withstand future disruptions. The purpose of this study was to explore the crisis preparedness and response of Texas dairy farmers during the 2021 winter storm Uri through the following research questions: (1) How prepared did Texas dairy farmers perceive themselves to respond and manage natural disasters?; (2) How did the 2021 winter storm Uri impact the Texas dairy farmers' farms and operations?; and (3) What do Texas dairy farmers need the primary support to do to manage and recover from natural disasters?

3. Materials and Methods

This study, approved by the [University] Internal Review Board (IRB2023-85), employed an interpretative phenomenological case study design. This methodology aims to uncover and describe individuals' significant lived experiences, providing a deeper understanding of the nature or meaning of these phenomena within a bounded system [44,45]. The study sought to identify and analyze thematic patterns while preserving the original details and experiences of the participants. To ensure ethical conduct, participants were fully informed through their organization's email and phone contact before participating

and provided with informed written consent. Semi-structured interviews were conducted with Texas dairy farmers in May 2023. The AgriLife Extension Service database served as a sample frame, identifying approximately 351 dairy farmers across Texas. Fifteen dairy farmers were selected for the study using a homogeneous purposive sampling method [46]. As noted by Nyimbili and Nyimbili, homogeneous purposive sampling involves selecting individuals who share closely related characteristics, such as occupation, age, gender, and background. This definition is corroborated by Patton [47], who emphasized that purposive sampling involves selecting participants based on their ability to provide rich information in line with the research criteria. Recruitment of participants was facilitated by contacting them via the phone numbers registered in the AgriLife Extension Service database. However, only eight farmers (53%) participated, with the remaining seven (47%) declining due to the demands of the productive farming season. Creswell [48] recommended a sample size of 20–30 participants to achieve data saturation in grounded theory qualitative inquiry. Dworkin [49] suggested that since qualitative research aims for a deep understanding rather than generalization, a sample size between five and fifty participants is sufficient. For this study, the selection criteria required participants to have (1) been actively engaged in farm operations for the past ten years, and (2) focus on commercial production. All participants were male, over thirty-five, and had more than ten years of commercial production experience. To maintain confidentiality, participants were assigned pseudonyms (e.g., Dairy Farmer 1 (DF1)). Table 1 provides an overview of the dairy farmer participants.

Table 1. Dairy farmer participants' distribution.

Gender	Participants	Participants' Pseudonyms	Extension Service Districts Number	Extension Service District Name
Male	Dairy farmer one	DF1	District one	Panhandle
	Dairy farmer two	DF2	District one	Panhandle
	Dairy farmer three	DF3	District one	Panhandle
	Dairy farmer four	DF4	District one	Panhandle
	Dairy farmer five	DF5	District two	South Plains
	Dairy farmer six	DF6	District two	South Plains
	Dairy farmer seven	DF7	District two	South Plains
	Dairy farmer eight	DF8	District two	South Plains
Age	Above 35 years			
Commercial production (Years)	Above ten years			

Note. This table depicts the participatory distribution of dairy farmers sampled in this study by pseudonyms and their respective extension service districts in Texas' Panhandle and South Plains regions. All participants were male, above 35 years of age, and had been actively engaged in commercial dairy production for over ten years.

Additionally, the principal investigator conducted observational tours with participants across three dairy facilities. The farm owner led these tours, providing relevant information on the study's focus and an overview of the operation. Integrating observations and reflective notes into the findings enhanced data triangulation for this research. As Kowalewski and Barttomiejski [50] highlighted, observational tours are an effective method for documenting the study environment and facilitating informal interactions between the researcher and participants, thereby supporting contextualized inquiry. Throughout the tours, the lead researcher intermittently posed questions to the participants. Out of the twelve AgriLife Extension Districts, four participants were from Extension District One (D1; Panhandle) and the other four from Extension District Two (D2; South Plains). Figure 2 illustrates the map of Texas Extension Districts.

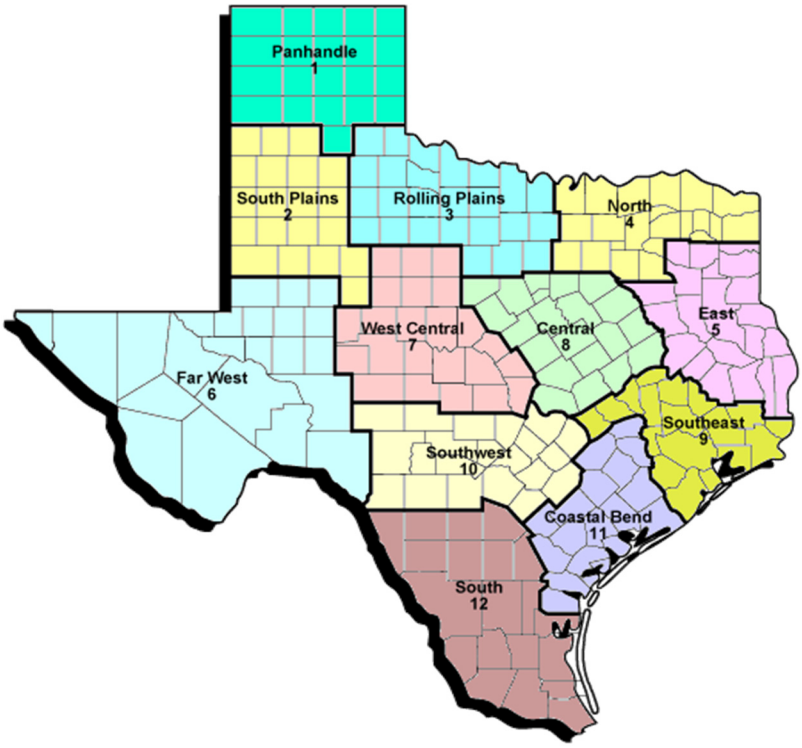

Figure 2. Texas A&M AgriLife Extension Districts Map. Note. The map depicts the twelve-district region of Texas A&M AgriLife Extension Service. Retrieved [51], from https://countyprograms.tamu.edu/district-office-websites/ (accessed on 25 May 2023).

Personal reflexivity necessitates researchers to "reflect on and clarify their goals, assumptions, and both conscious and subconscious reactions to situations, participants, and data" [52], (p. 244). In the current study, the first author is a male researcher and acknowledges his position as an international doctoral student and research assistant in [Department]. Many of his research ideas stem from his studies on natural disaster preparedness and response and pre- and post-disaster environmental health and safety of agricultural producers and the community. While initially lacking field experience in dairy production, the researcher undertook extensive literature reviews and engaged with experts in the field to ensure a well-informed and unbiased approach to the research.

The research team developed a semi-structured interview protocol (Appendix A) consisting of four sections. The protocol was reviewed by a professional panel (three individuals) with expertise in agricultural extension, agricultural economics, and dairy sciences, as well as previous research and outreach experience with farmers. The study interview protocol was designed to retrospectively elicit information from the participants using the following questions. In Appendix A.1, participants were asked about their previous experience with natural disasters and general disaster preparedness. In Appendix A.2, participants were specifically asked about their awareness of winter storm Uri. Additionally, in Appendix A.3, dairy farmers were asked about their preparedness for winter storm Uri. Finally, in Appendix A.4, dairy farmers were asked about their resource needs in responding to and recovering from winter storm Uri. The authors followed up with probing questions in each section to obtain rich information and clarify any answers that seemed ambiguous.

The primary author, trained with previous qualitative research experience, conducted semi-structured interviews at the dairy farms and at the time scheduled by each participant. We ensured all the recommendations from the ethical review board for the privacy of qualitative data collection. Face-to-face semi-structured interviews lasted 45–60 min and

were recorded using a smart device with the participant's consent. The researcher built rapport with the participants by first assuring them that their responses were valid, even if they did not remember every detail, which helped maintain a balanced power dynamic. Additionally, the researcher eased interview tension by asking introductory questions like, "Tell me about your favorite day(s) in the barn". Interviewees' responses were transcribed using a Microsoft Word 365 package, and personal information was de-identified from all transcriptions using pseudonyms. Transcripts were printed to double-check against the original recording, field notes, and further systematic reading. Respondent validation or member checking was implemented to verify the accuracy of the farmers' responses. It was necessary to offer interviewees the chance to read and amend their transcripts as a validity strategy [53].

Data were analyzed using an inductive coding approach, as Creswell [48] recommended. Inductive methods seek to aid the comprehension of meaning in dense information by generating summary themes or categories from raw data [54]. The first level of coding was open coding, which, according to Liu [54], involves coding line by line to identify emerging codes. After the participants validated the responses, the author began with open coding, transcribing line by line to identify recurring phrases that captured the participants' voices and ideas. The next level of coding was axial coding, which involved identifying connections between the open codes to generate core codes. According to Strauss and Corbin [55], Core (major) codes emerge as aggregates of the most strongly associated or overlapping open codes, for which supporting evidence is crucial. The researcher conducted axial coding by categorizing the phrases that emerge from the open coding and interview memos (field notes) into articulable words or meaningful short sentences. Finally, the author developed the study themes by identifying similarities from the axial codes and drawing assertive meaning to data units (codes) to answer this study's research questions.

4. Findings

Eight Texan dairy producers participated in the study. Using a literature-based interview protocol to delve deeper into Texas dairy farmers' experiences during winter storm Uri in 2021, the following six themes emerged: (1) the uncertainty of natural disasters; (2) economic loss for dairy farmers; (3) increased awareness and need for preparedness for natural disasters; (4) lack of technical and financial resources and support; (5) organizational communication; and (6) coping and adaptation strategies.

4.1. Theme I: The Uncertainty of Natural Disasters

All participants affirmed having previous experiences facing natural disasters and extreme weather events in their dairy operations. Participants' previous experiences were highly uncertain, with elevated levels of unpredictability, particularly regarding the length and severity of each occurrence. All participants acknowledged that their perceived uncertainty regarding natural disasters has resulted in inadequate and inconsistent preparedness. Participants were producing under two types of production systems (free stall system and open lot system). Even though dairy farmers acknowledge the advantages and disadvantages of each production system, they still need to decide which production system possesses less risk for dairy cattle when facing natural disasters. Several participants constantly questioned whether they had made the right choice of production system. For instance, DF1 commented:

> The biggest thing probably is heavy rain events. I would say that every three years, there is a cycle of continuous rain affecting the cows tremendously. Especially being in an open lot facility, as you may be aware, it is hard to control that environment.

Participants described their overwhelming uncertainty when deciding the dimensions of strategies or practices that should be implemented to cope with a natural disaster. However, unanimously, dairy farmers affirmed they have learned from previous experiences responding to and managing natural disasters. DF3 reported that:

> Drought. . .Certainly, we have dealt with drought quite a bit. We aim to always keep three years' worth of feed in the place. We have not gotten to that main event yet, although we came close because the previous drought in 2011/2012 was bad. So, we learned at that time to build up towards three years. A year ago, we started another drought. We are down to probably one year's feed.

The participant further mentioned that:

> The only other disaster we had was a blizzard, I think, back in 2015, and we were prepared. We made hay walls to the north of all the pens; we put hay walls to block the wind, which I think kept us from losing only sixty-five cows in the blizzard. Several dairies lost more to blizzards.

There is an increasing trend in the frequency and severity of natural disasters and extreme weather events. One participant noted that heat is a significant concern for both cattle and the safety of farm workers. They recognized that temperatures continue to rise in the summer/dry season, and more resources are required to ensure herd and workforce safety. The participants reported similar tendencies for the cold months of the year. For example, DF4 stated:

> The weather got colder than ever. We recorded −29 °F here, and there was no wind chill. Of course, that is just a straight temperature. We had bought extra heaters, put hay bales up, which we do every winter, and got cows a spot to lie down on. We did not realize the severity of that storm.

Dairy farmers were aware of the need for strategies targeted to the nature of each occurrence. Several mentioned additional water sources for droughts and heaters for blizzards. However, farmers perceived they could have responded more efficiently to previous events despite having yet to make significant efforts. DF5 stated:

> The farm was prepared for blizzards. How bad a crisis is, you are never really prepared for a crisis. You can only prepare for what could happen, and we tried to do our best; we happened to lose a couple of cows to winter storm Uri.

Furthermore, the dairy farm industry, specifically in Texas, is known as an open lot production system associated with high intensity of weather, which distinctively affects the cattle's productivity by increasing or decreasing the temperature. For instance, DF7 mentioned:

> I think the three biggest natural disasters we have faced are high wind, snow, and severe rainfall. We practice an open lot system. There is no cross-vent barn or anything else. Hence, it is the risk that we must endure as a dairy producer in the Texas panhandle.

4.2. Theme II: Economic Loss for Dairy Farmers

All the participants identified that winter storm Uri incident triggered a staggering increase in the cost of their farm inputs, such as bedding materials (corn stalks), feedstock, labor, and heating supplies. Farmers recognized that the storm disrupted their expenses and resulted in fewer economic outcomes once extra investment was added. For example, DF6 stated:

> So, like, in the last winter storm was super cold for the last couple of years, I guess; they have been the coldest; I think 14 February 2021, was when the temperature

> dropped below freezing point, like −26 to 30 degrees below 0. The good thing is that we did not have high winds in those days so that we could operate, but it went higher, especially with much bedding. Of course, we try to bed, bed, and bed because we are trying to avoid damage to the cattle teats.

DF6 further mentioned that "frozen cattle teats can be catastrophic because, I mean, you cannot milk those cows, and they will be shipped off as beef cattle."

Farmers were divided in their opinions regarding the direct impact on the cost of feeding that the 2021 winter storm Uri caused. Those who perceived a connection between the storm and higher prices attached this change to the losses in other agricultural sectors. More cohesiveness in opinion emerged regarding the increase in the cost of labor operating the farms during and after the winter storm. From additional hours on the farm, as exemplified by DF3; "Well it caused more input for preparation and, of course, more work for everybody on the farm, all employees stayed on the farm for 48 h, and we lost production"; to a need for additional employees to support farming operations under the weather conditions, as mentioned by DF4 who shared his experience saying:

> So there was an increase in labor cost. . . we had to hire non-essential workers as extra help with busted water pipelines, unfreeze frozen alleys, and haul sand into the alley to spread on the ice. . . we had extra guys in the barn because they were slowly getting in and out of the barn. We needed to continue milking them, and it took extra labor and time.

In the same vein, DF6 corroborated, stating that:

> We had to increase the number of laborers and their shift hours because the weather was so cold, and we needed to constantly change bedding materials as soon as possible when they got so wet. We also added more workers to increase the times of the cattle to meet their energy requirements.

Consequently, farmers registered low production during winter storm Uri. They affirmed that there was a meager feed conversion ratio due to inadequate or irregular weather conditions. For instance, DF2 explained this consequence:

> The biggest impact was that it was icy for quite a few days, and so that had an impact on the production of the cows themselves; the cows are going to eat more to hold their body temperature. So, our feed cost increases and then milk production drops slightly.

Environmental conditions required farmers to invest in additional equipment and supplies to keep cows comfortable and safe. Farmers affirmed that the cold temperatures reached never-seen levels, so purchasing additional supplies became imperative for herd survival. For instance, DF4 stated:

> So, we have some disaster protocols to keep the barn full of cows and to keep them warm, we bought extra heaters that are brand new because it is overwhelming how things break during a winter storm, and then if you go to town, you will not find anything available to buy because it is already gone. So, we bought and stored a couple of three or four-heaters. We have made other maintenance improvements to our heating system.

More direct losses resulted from interrupting dairy farmers' service providers' operations. As the state faced water, energy, and gas interruptions, participants were forced to discharge dairy production due to the lack of running infrastructure to store and process it appropriately. For example, DF3 reported:

> As for running the business, we were in decent shape, but there was a drop in cow production during that winter storm Uri. The cows did not produce incredibly well because they were so cold all the time, and they were eating profusely because the wind was blowing cold.

The participant further reported that during winter storm Uri, dairy cooperatives ended up dumping milk because the power plant in Littlefield was shut down; that was the big, big, and big loss". DF8 corroborated, saying that "dairy cooperatives ended up dumping milk because the power plant in Littlefield was shut down; that was a big, big, and big loss". This service interruption reached farmers directly. Contrastingly, participants experienced generalized operation interruptions due to the lack of power.

However, those with higher technological operations reported more drastic alterations to the regular farm functioning. When comparing economic losses during winter storm Uri, farmers perceived higher rates than other similar events in the past. DF8 said:

> I think we were in surprisingly decent shape, ready for the storm. Financially, the biggest problem of that storm was that the gas company called our milk cooperatives and said they would turn the gas off at the Littlefield plant, the power plant where we process our milk. The gas company said we have orders to turn off the gas. The winter storm cost us more; we lost milk in winter storm Goliath, but more was lost in winter storm Uri; I cannot remember how many loads because we could not process the milk.

4.3. Theme III: Increased Awareness and Need for Preparedness for Natural Disasters

All participants who perceived previous natural disasters (e.g., Winter Storm Goliath in 2015) have increased their awareness and preparedness to respond to and manage natural disasters on their farm operations. The participants perceived these past experiences as incentives for adopting disaster management plans that facilitated coping with the 2021 winter storm Uri. Two of the participants affirmed that disaster management was permanently in place. For instance, DF1 mentioned:

> We had bought diesel one week ahead of time for the diesel heater; we also had to park all the equipment in the shop and cover them up to avoid freezing up; this is one of the things we do not normally do, but we learned the hard way in previous weather events (DF1 laughed), but we did it, and also we increased the wind breaks on the side of all the pens because the wind was cold, it was below, (DF1 paused) I think it was below 30 degrees and windy, we stop dipping the cows to prevent frozen teats.

Farmers enlisted a series of disaster preparedness and response strategies/activities implemented during the 2021 winter storm Uri, including adding new or more inputs for production and overall operation, changes in operation and maintenance practices, and additional shelter and animal welfare practices. DF1 mentioned:

> The things that we did. Certainly, we opened the drip valves, even more, to avoid water freezing up; we purchased extra salt ice creepers, defrosters, and these kinds of things, and we made sure all the heating systems were good for both cows and the maternity barn.

Similarly, DF2 added:

We went through all the farm equipment making sure that all was serviced and up to date. Clearly, we did everything we could to put up windbreaks to stop issues of drifting across the pen and to mitigate the pressure from the storm.

Dairy farmers had more common disaster preparedness and response strategies/practices during winter storm Uri, as changes in personnel functions and working shifts and hours.

All farmers mentioned how the weather conditions required workers to focus on safeguarding and providing warm shelter for the animals, stopping other farm operations, and improving general activities.

DF2 shared: "We had extra labor to feed cattle and break the ice almost three times a day. We had equipment ready to clear the roads so the employees would be able to (DF2 paused) drive back and forth, feed deliveries, and milk transportation."

DF6 added: "We have learned a lot from previous snowstorms, and we obviously prepared with more people. We have an emergency notification system where we can alert everyone to what is going on with the weather and how to prepare in terms of clothes, food, etc.; we have kept a two-month inventory of feedstock for the worst-case scenario. We certainly provided diesel for diesel tanks, and we kept the heaters up and running. . . we have some people work some extra time to keep the farm operation running."

DF7 stated: "So, we have an emergency plan for tornadoes and blizzards. We have not had to execute that plan yet for either one we have experienced because we feel we are prepared. When we see the cold temperatures coming, we open the water troughs for heat circulation; any other exposed water lines are wrapped with heat tape. Tractors: we plug them into the heater to make sure the tractors will start. We added additives to the diesel so it did not freeze up; we also ensured we had extra salt bags on hand, just in case some lanes got slippery or icy, so that cows could move around."

4.4. Theme IV: Lack of Technical and Financial Resources and Support

When participants began describing their experience of the need for resources and support to recover from the 2021 winter storm Uri, all participants noted that they had no support from either the government or agricultural extension agent. For instance, DF4 shared:

> When you are up here, you are pretty well on your own. You better know what you are doing; we have our mechanics and everything if the equipment goes down. So, luckily for us, we had no major thing go down that we could not fix ourselves.

In addition, DF4 relayed that:

> There is no insurance for a storm. Most people cannot afford insurance coverage, and it is just too expensive. (DF4 paused) Moreover, I do not think there is any government program either. We applied for coverage in Austin, but the ag department ruled that we were not eligible for any coverage. The benchmark was −30 °F (−34 °C), and they said it got −29 °F (−33 °C). So, we had no indemnity, insurance, or disaster help because we were 1 degree warmer than they allowed. They did not treat us correctly over there. We recorded −33 °F (−36 °C) or −34 °F (−37 °C), and they said officially it was −29 °F (−33 °C) and that −30 °F (−34 °C) was the benchmark.

DF4 added that:

> If you are of the large dairies and you do not know more than the ag advisor or Extension agent, you are in for big trouble (DF4 paused and laughed). Right now, I think the extension agent could have provided little or no help in terms of coping strategies for winter storm Uri, you should know what you are doing. If you have these many cows and have been in this business this long.

Moreover, the study identified other nuances from the dairy farmers' responses to understand how participants received and communicated information before and during the 2021 winter storm Uri. When the participants described how they learned about the 2021 winter storm Uri occurrence, their response developed the following theme.

4.5. Theme V: Organizational Communication

Most dairy farmers need a well-structured communication network on their farms. However, only some participants noted that they have emergency notification systems in their farm operations and peer group associations.

DF4 relayed that, "every morning we have a meeting, we look at the weather forecast, and they had a surprisingly good prediction on the 2021 winter storm Uri and several others. So, we look at the weather on your iPhone".

DF5 responded similarly; "you check your phone's weather forecast. We also listen to a radio station and watch the news on television every day to keep up with what is going on".

Participants relayed that they belong to dairy groups and associations, where they get notifications on adverse weather and other related events that could harm dairy farm operations.

DF3 mentioned, "so, there is somebody, probably multiple people, about three or four of us checking the weather forecasts all day for either rain and obviously in the winter we are looking for storms and anything else". Additionally, the dairy farmer added that:

We do belong to select milk co-ops, so if there is anything unusual coming on that will affect the dairy farm, we get text notifications from them to warn us ahead of time. However, otherwise, we are trying to watch over our area, friends, and neighbors.

DF6 commented:

> We have managerial meetings to brainstorm events ranging from weather-related issues to farm operations. We have a monthly meeting that talks about natural disasters like winter storms, and we brainstorm how they will impact us and how to control them. We also look at the local media, which means watching the news and checking weather applications on our phones.

4.6. Theme VI: Coping and Adaptation Strategies

Texas dairy farmers implemented strategies that allowed them to cope with changes in daily conditions and risks that arose during winter storm Uri. They shared how these strategies were aimed at safeguarding the safety and well-being of their workers and animals and, finally, those that allowed them to continue their farm operations. Farmers affirmed they made preparedness decisions without evidence, resulting in failed attempts to respond to the storm. For example, during the days of Uri, temperatures fell to approximately −29 °F (−33 °C) degrees, generating a windless snowstorm. Most dairy producers invested in installing windbreaks and were unaware of the risk that the presence of snow would generate.

Physiological damage to animals emerged as the biggest concern farmers sought to address during the freezing weather caused by Uri. One of the producers commented on the increase in the use of bedding to protect cows' udders. Although farmers have not systematically evaluated the practice of bedding, their perceptions are sufficient to affirm that it is an effective strategy. Regarding the above DF6, he commented:

> The good thing is that we did not have high winds on those days, so we were able to operate, especially with a lot of bedding. We try to bed, bed, and bed because we are trying to avoid damage to the cattle teats.

Other strategies reported by participants include changes in operational routines, particularly in feeding times, to prevent weather damage to the organoleptic characteristics of the food and employee work schedules. While essential employees increased their working hours, non-essential employees were put on rest to prevent accidents.

5. Discussion

Although our study asked dairy farmers to reflect and situate their responses within their experiences during the 2021 winter storm Uri, our findings support the growing need to raise awareness and capacity among farmers on the importance of preparing across all types of extreme weather events, as these phenomena become more common and aggressive [56]. As Pyne and Samantha [57] recommended, farmers should establish disaster preparedness strategies to minimize adverse consequences on agricultural production operations and infrastructure. Even though disaster management plans share common characteristics, they must consider the productive features of each farm sector and the productive environment's socioeconomic and human capital conditions.

5.1. Uncertainties of Natural Disasters

Participants' experiences in preparing and responding to natural disasters were fraught with significant natural disaster uncertainty and challenges in adopting effective decision-making on disaster preparedness and response. Aligned with other studies [58–60], we identified the need to increase farmers' preparedness to manage the uncertainties of natural disasters. Scientists claim that uncertainty is inherent to the coping and management process of natural disasters [61,62]. Bagley and collaborators further noted that within their uncertainty, farmers will develop probabilistic and evaluative orientations about the world. While probabilistic orientations are the perceived characteristics of an object or event, evaluative orientations are defined as an object's negative or positive value [63]. Looking at this during a natural disaster, Bagley et al. [61] affirmed that the mind forms both an expectation of the likelihood (probabilistic orientation) of a natural disaster and how bad the disaster will be (evaluative orientation). The interaction between these orientations (between belief and value) affects how they process the uncertainty surrounding disasters. Even though our study did not measure the uncertainty level Texas dairy farmers experienced, our results indicate that the high experience rate among dairy farmers suggests that conditioned response time and strategies be implemented. However, more research is needed to investigate the relationship between uncertainty and response mechanisms to natural disasters in agrifood systems, mainly how influential uncertainty is in farmers' decision-making processes for natural disaster preparedness and response.

5.2. Economic Loss for Dairy Farmers

All the respondents were congruent with the impacts perceived on their farm infrastructure and operations. However, the responses regarding the extent of the economic implications of winter storm Uri were less precise. Nevertheless, dairy farmers' economic losses are similar to those reported by other studies regarding natural disasters. For example, Wei et al. [64] affirmed that severe economic implications from natural disasters in agriculture are noticed in the reduction of production capacity and direct and indirect losses derived from infrastructure, human, and other assets' damages and risks. This consistency highlights the economic relevance of preparedness and response approaches to natural disasters, which must ensure agricultural productivity and economic stability; equally important is to address farmers' lack of capacity to accurately register and estimate their economic losses during a natural disaster. The impact of the 2021 winter storm Uri increased the cost of agricultural inputs for many farmers. Other literature reviews noted that dairy farming aims to achieve the highest possible milk production with minimal input cost while maintaining animal welfare. For example, an appropriate microclimate in the building [65,66], especially in the case of satisfying the essential needs of cows, such as continuous access to feed and water and a relatively constant milking time [67,68].

During the 2021 winter storm Uri, temperatures dropped significantly, creating unforeseen challenges for dairy farmers. As noted by the participants, ensuring the physical

well-being of farm employees and livestock was the primary concern related to changes in extreme weather conditions. Preparation plans to manage human and animal welfare issues during extreme weather events continue to challenge dairy farmers. Participants in this study knew that cattle were vulnerable and susceptible to frozen teats during winter storm Uri, which often, as dairy farmers explain, could drastically change their daily behaviors and productivity and, in the worst-case scenario, enable their inability to produce milk. The results of this study are congruent with what Rasool et al. [21] claimed, ensuring that livestock change their feeding and water consumption behaviors in extreme weather events, directly affecting their productive potential.

Additionally, Rasool and his collaborators emphasized the relevance of adequate disaster preparedness and response plans to manage potential illness outbreaks or physical harm as the risk for those health-related issues increases as the climate conditions fluctuate. Many studies have shown that agricultural producers adapt their operations to weather events regardless of the productive sector [69,70]. All the practices implemented by participants in the face of storm Uri were coping strategies. Implementing a temporary coping mechanism is known as a coping strategy. On the contrary, if the practice is permanently installed, it is an adaptation strategy [71]. For example, during the days of the 2021 winter storm Uri, temperatures fell to approximately −29 °F (−33 °C), generating a windless snowstorm. This type of discrepancy between extreme weather events and traditional climate conditions could be explained by the abrupt changes in climate derived from the current climate crisis [72]. Most dairy farmers invested in installing windbreaks and needed to prepare for the presence of snow.

Additionally, the temperature change increased the need for raw materials, bedding materials, heating systems, and labor, which were already at a higher cost due to the demand and consumption dynamic temporarily created by winter storm Uri. The findings of this study regarding the appropriateness of the coping strategies implemented by study participants align with the literature review by Shang et al. [73], which showed that three essential actions are needed to minimize the damage caused by snow disasters and advance sustainable growth of livestock: decrease the intensity of grazing, increase the amount of winter forage available, and expand warm barn space for livestock. However, the farmers recorded no evidence of effectiveness, leaving an open gap between the adoption of a strategy and effectiveness in coping with natural disasters.

5.3. Natural Disaster Preparedness and Response Strategy

The study identified that the 2021 winter storm Uri recorded low temperatures of −29 °F to −34 °F (−33 °C to −36 °C), which increased the cost of raw materials, bedding materials, heating systems, and labor. The assumed range of neutral temperatures for dairy cattle is around 23 °F to 77 °F (−5 °C to +25 °C) [74]. Excessive cooling of the cows' body can cause thermoregulation or fertility problems, cold stress, and reduced milk production accompanied by increased feed consumption [75]. Dairy farmers appeared prepared to take response measures for winter storm Uri. Before the 2021 winter storm Uri, study participants planned to notify employees through an emergency notification system, provide food and shelter, erect cornstalk windbreaks and hay walls, and provide additional heating supplies in holding pens and maternity barn. They also did their best to cover farm equipment and provided additional diesel with antifreeze additives for tractors and heating equipment. Food was stored for the cows, and water pipes were insulated with heat tape to minimize freezing levels.

Our results demonstrated that farmers know natural disaster preparedness is necessary to face the current environmental productive context. However, the need for pre-established management plans and recordkeeping during winter storm Uri prevents accurate estimates

of those responses' effectiveness. Sutton and Tierney [37] also affirmed that developing a priori strategies to ensure natural disaster preparedness plans, gathering resources necessary for an effective response, and acquiring knowledge and skills to complete disaster-related tasks successfully are additional activities frequently associated with successful disaster preparedness and response and easy recovery. However, our results highlight through the farmers' experiences that the low-capacity farmers must design, implement, and evaluate natural disaster preparedness and response plans. Farmers acknowledge their need while pointing out several technical and resource support areas that could enhance their preparedness and response capacity.

5.4. Natural Disaster Communications

Along with an urgent claim for assistance, farmers were concerned about the effectiveness of organizations' communication channels in disseminating information about natural disasters. These findings suggest the relevant role organizations—such as extension services, local governments, and farmers' organizations—must play in assisting farmers during a natural disaster and, even more importantly, helping develop capacities and build a culture of disaster preparedness.

Farmers must prepare a disaster management plan to protect assets, resources, and farm animals during a natural disaster. Each farm is responsible for disseminating disaster management information to all the appropriate stakeholders. It is recommended, based on this study's findings, to create a directory of emergency contact information, including staff, workers, neighbors, para veterinarian, local veterinary specialists, poison control, animal welfare organizations, local extension services, agricultural institutions, raw material suppliers, and humane groups that can assist farmers and other community members in case of emergency.

Finally, future research should explore the response strategies implemented by farmers in other geographic and socioeconomic areas to identify replicability and effectiveness potential. As highlighted by the previous results, it is imperative to develop training and outreach programs focused on improving farmers' capacities to prepare and respond to a natural disaster, including promoting a model that ensures all the farm's stakeholders receive adequate information to act effectively and adequately during a natural crisis.

6. Conclusions

The study investigated the experiences of eight Texas dairy farmers during and after winter storm Uri. The authors recognized that this sample size might not achieve data saturation. Nonetheless, the study's goal is not to generalize the findings but to offer reliable data that can be methodologically transferable. The findings of this study revealed that while dairy farmers were somewhat prepared for winter storm Uri due to prior experience, a lack of standardized disaster management plans persisted. Instead, participants relied on weather forecasts, farm meetings, and informal networks with neighboring farmers for operational adjustments. This highlights a significant gap in dairy farmers' knowledge of disaster management strategies and access to external resources during overwhelming natural disasters. Despite their adaptive coping strategies, participants reported financial and material losses due to the storm. The findings underscore the urgent need to enhance programs and initiatives that bolster dairy producers' capacity to respond effectively to future extreme weather events. Dairy farming is a sensitive and demanding industry where cattle must be milked daily to maintain production efficiency and ensure the animals' health. Failure to milk dairy cattle daily due to inadequate preparedness and response to extreme weather events can lead to significant social, economic, and environmental repercussions. The implication of the study's major findings associated with natural disaster

uncertainty, inadequate disaster preparedness and response strategy, and economic loss for dairy farmers during winter storm Uri impacts negatively the three pillars of sustainability. Socially, extreme weather events and the resulting disruption in dairy production pose risks to food security and nutrition, particularly in regions where dairy products are staples. Milk is a critical source of protein, calcium, and vitamins. A decline in supply disproportionately affects low-income communities, exacerbating nutritional deficiencies and driving migration among families reliant on agriculture for economic stability.

Economically, neglecting to milk cattle due to extreme weather events compromises productivity and profitability through health issues such as reduced fertility rates, poor feed conversion ratios, increased mortality rates, loss of dairy cattle to beef production, and heightened veterinary costs. Additionally, untreated cattle face a higher risk of mastitis, further raising veterinary expenses and potential livestock loss. Extreme weather events, such as the 2021 winter storm Uri, exacerbate these challenges by imposing financial strains that can lead to business closures. The dairy sector, one of the largest economic contributors in Texas, faces a cascading effect: supply chain disruptions result in price volatility for dairy products and increased costs for consumers. Over time, these disruptions negatively impact agricultural processing industries dependent on dairy inputs—such as cheese, butter, and yogurt production—creating economic instability in related sectors.

Environmentally, the continuous milking of dairy cows is vital for the efficient management of feeding, water, and land resources. Diseased cattle necessitate increased antibiotic use, which can contribute to antimicrobial resistance and pollute soil and waterways, compounding ecological risks. This study explored the sustainability of dairy farms in the context of extreme weather events, focusing on their impact on livestock productivity and resilience.

Consequently, we found that dairy farmers lack adequate and credible natural disaster management information, primarily due to their limited reliance on extension services and disaster management agencies. This gap can be explained through the Diffusion of Innovations Theory, which highlights that trust, perceived relevance, and access has a profound effect on how new knowledge and practices are adopted. Building on this, a demand-driven approach—where services are designed and tailored to meet the specific needs and preferences of farmers—could enhance the relevance of extension programs and improve dairy farmers' engagement with disaster management initiatives. Additionally, many dairy farmers may hesitate to seek information beyond their familiar sources due to the perceived risks of adopting unvetted strategies, whether from neighboring farmers or even credible sources. To address these challenges, a pluralistic approach that incorporates multiple credible sources could enhance the accessibility and trustworthiness of disaster management agencies. Furthermore, empowering dairy farmers through participatory approaches and farmer-led networks could efficiently and effectively bridge the information gap, foster trust, and build resilience within dairy farming communities.

This study further provides policy recommendations. Affordable extreme weather index insurance: implement and subsidize extreme weather index insurance tailored for smallholder dairy farmers to ensure financial resilience and sustainable production. Standardized disaster management plans: mandate the development and implementation of standardized disaster management plans across the dairy industry. These plans should include training programs, access to external resources, and protocols for safeguarding lives, properties, and livestock during extreme weather events. Support for social, economic, and environmental sustainability: strengthen initiatives that protect low-income communities from nutritional deficiencies by stabilizing dairy supply chains. Promote sustainable resource management practices to minimize environmental risks, such as antimicrobial resistance and pollution. Policymakers can secure the sustainability and resilience of the

dairy sector by addressing these priorities while mitigating the broader socio-economic and ecological impacts of extreme weather events.

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Appendix A Qualitative Interview Protocol

Appendix A.1

- **Dairy farmers' previous experience and general disaster preparedness**
  Natural Disasters (floods, drought, storms, etc.) are one of the biggest human and agricultural threats.
  - ○ What has been your farm's experience with natural disasters including types, frequency, and severity?
  - ○ How prepared do you feel your farm is in general for a natural disaster regardless of the type of natural disaster?

Appendix A.2

- **Winter Storm Uri Awareness**
  From your viewpoint, what do you know about winter storms (for example, the frequency you experience them each year, the severity of the winter storm)?
  - ○ How would you categorize winter storms? Do you consider them to be a natural event, man-made, or hybrid)?

  The state of Texas experienced Winter Storm Uri in 2021
  - ○ How did the winter storm Uri 2021 affect your dairy operations in terms of:
  - ○ farm inputs (electricity, decision-making, machinery, feedstock, veterinary services, labor, quality control, etc.)
  - ○ farm outputs (labor productivity, milk storage, processing, and distribution).

Appendix A.3

- **Winter Storm Uri Preparedness**
  - ○ How did you initially learn about the possibility for and potential impact of Winter Storm Uri?

  Reflecting, how prepared were you before Winter Storm Uri hit in 2021?
  - ○ During the 2021 Winter Storm Uri, what action plan and strategies did you employ to mitigate the impact on your farm?
  - ○ Now after Uri, what strategies do you wish you would have done?

Appendix A.4

- **Need for Resources**

  After a natural disaster occurrence, recovery starts taking place.

  - What resources were available at your disposal after the 2021 Winter Storm Uri?

  Tell me about the role of government after the Winter Storm Uri in 2021.

  - How did state and/or federal government policies assist you? (Insurance, relief fund, etc.)
  - What role or type of assistance did you receive from the Agricultural Extension Services in your county?

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