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Industry Leaders' Perceptions of Residential Wood Pellet Technology Diffusion in the Northeastern U.S.

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Abstract: Within a shifting climate of renewable energy options, technology innovations in the energy sector are vital in combating fossil-fuel-driven climate change and economic growth. To enter this market dominated by fossil fuels, renewable energy innovations need to overcome significant barriers related to cost, relative advantages compared to fossil fuels, and policy incentive programs. A better understanding of the innovation diffusion of new technologies in establishing the renewable energy industry can aid policy makers in designing and implementing other renewable energy support programs and improving adoption rates within existing programs. This study assessed industry leaders' perceptions through semi-structured interviews. We explored the innovation diffusion process of wood pellet residential heating technology, as well as policy needs and barriers within this industry that are hindering successful long-term diffusion and sustainability. We show that while there is high potential to the wood pellet industry in terms of local resources and overall advantages to fossil fuels, it can be difficult to achieve sustainable economic growth with current cost barriers and further policy programs and incentives are needed in addition to improved communication to reduce adoption barriers for wood pellet technology.

Keywords: wood pellets; diffusion of innovation; forest products business; energy policy; qualitative interviews; industry leaders; wood economy; residential heating technology

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1. Introduction

Renewable energy, including types made from forest products, plays a critical role in sustaining the social and economic well-being of societies while combating fossil-fuel-driven climate change [1–3]. While innovations in the heating, transportation, and electricity sectors have allowed renewable energy sources to become more convenient and economically affordable for consumers, there are still significant barriers in place preventing the widespread diffusion of many renewable energy and forest product innovations [4–6]. The slow growth of the residential wood pellet industry in New England provides a valuable case study.

Despite initial development of automated wood pellet heating supply and demand, the diffusion of this technology within the region has not reached the tipping point in the product life cycle from take-off to growth. These take-off periods vary by individual innovation, with take-off periods lasting more than ten years not being uncommon [7]. The concept of innovation diffusion is a critical foundation for establishing continued support for innovative forest products and technology, including various forms of renewable energy. Innovation diffusion is the process by which an innovation is communicated through channels among the members of a social system over time and eventually adopted

and integrated as the norm within that system [7]. To enter a fossil-fuel-dominated market, a new renewable energy product often needs to overcome barriers such as high initial cost and low consumer awareness [8,9]. Policy support is critical in such a risky and uncertain diffusion process of new innovations [10,11]. Many policy support programs are designed to help new renewable energy products reach a stage of self-sustainment that infers continual supply and demand growth for the product. Without policy support, however, producers paving the path for innovative technologies often have significant financial hurdles to overcome, which can lead to lower participation in the technology and reduced likelihood that the product will reach self-sustainment.

A number of studies have examined different innovations from various perspectives, including customer characteristics and their responses to innovation, developing market entry strategies, and modeling of innovation processes [4,5,7,12,13]. However, little research has been conducted from the perspective of change agents or the managers of an innovation seeking to establish its industry and create economic growth. In this case study, our focus are leaders of equipment firms, bulk delivery companies, and pellet mills within the forest products sector. As they work at the forefront to promote a renewable energy innovation and specialized forest products industry, managers' experiences and perceptions could provide rich accounts of and insights into the opportunities and challenges faced in other real-world renewable energy diffusion processes.

This case study focused on the perspectives of wood pellet industry producers in order to provide in-depth perspectives on the diffusion of a renewable energy product innovation: residential wood pellet heating technology. We specifically hone in on residential use of this renewable innovation. An assessment of the diffusion of this technology can help to identify the influence of barriers to renewable energy products industry success, such as a decline in competing alternative prices or limited policy incentives, while also identifying patterns of consumer adoption from the industry leaders attempting to diffuse this technology into a highly competitive energy market. The two central objectives of this study were (1) to assess the innovation diffusion process of wood pellet heating technology from the perspective of industry leaders and (2) to identify barriers to consumer adoption and industry needs to achieve successful diffusion, long-term product sustainability, and, ultimately, a market for residential wood pellets and related heating technology. Studies exploring the diffusion process often focus on the preferences of consumers from the perspectives of consumers, or they focus on production from the perspective of producers [2,14]. We focus specifically on insights regarding the challenges of market development from industry leaders seeking to build a robust market for automated wood pellet heating systems. Specifically, we focused on analyzing industry leader perceptions of relative advantages, disadvantages, external influences, and incentive programs related to the wood pellet industry using the diffusion of innovation theoretical framework. Our discussion focuses on recommendations that can support the development and growth of the residential wood pellet market and may have broader implications for emerging markets of other renewable energy products.

2. Case Study Context

The northeastern region of the United States consumes 86% of the 4.4 billion gallons per year of fuel oil burned nationwide, primarily for space and water heating [15]. Peak oil prices in 2009 spurred greater policy interest in a wood–heat transition. Wood-based fuel helps fulfill heating needs, is a readily available resource in northern New England, and is associated with the strong wood-based economic identity of the region. The region has a longstanding history of burning wood, with firewood being a longstanding rural community staple. In Maine specifically, half of residents have indicated that they plan to use wood as a primary or secondary heating source in the future [16]. However, in New England over 55% of homes continue to be heated with oil [2].

With the recent decline in the paper and pulp industry in the United States over the last several decades, studies have begun to show the potential of wood-based alternatives

to heating oil (such as wood pellets) in resurging declining forest industry economies [17]. Northern New England's vast forested lands are sources of economic vitality. The timber and wood products industries provide a quarter of the timber resources—$33 billion and 178,000 jobs' worth—for the entire nation [18,19]. However, the closure of several major pulp and paper mills in the region has resulted in a severe decline in low-grade wood markets, posing threats to the livelihoods of the region's rural communities and logging infrastructure [19,20]. Developing a more robust wood heating sector could contribute significantly to regional social, economic, and environmental well-being.

Around the time of the 2009 spike in oil prices, wood pellet heating technology—specifically automated, high-efficiency boiler systems—were being introduced to northern New England as a wood heating innovation and an alternative to heating oil at a higher rate than ever before [2]. The scale of these heating systems ranged from residential homes to smaller-scale community or commercial applications like apartments, schools, and municipal buildings. At the time this innovation was introduced to the market oil prices were reaching over $100 per barrel. A stark decline in oil prices beginning in mid-2014 added uncertainty to the diffusion process and raised concern about total market failure for wood pellet heating systems. The nominal price of crude oil had fallen to $30 per barrel by the end of 2015 and had stabilized in the range of $40 to $50 per barrel through 2017, eventually reaching a peak of just over $70 per barrel prior to the COVID-19 pandemic [21,22]. In general, lower oil prices reduced the competitiveness of renewable energy sources by enhancing the relative economic costs to purchase renewable energy products [23]. As oil prices fell, wood pellet heating equipment firms in northern New England reported stagnant sales growth. Wood energy subsidies have taken place exclusively at the state level, while tax preferences and subsidies that shift incoming oil reserves into economic profitability happen at the national level [24].

Compared to pellet stoves or convertible boilers that fit on existing fossil fuel heating systems, new residential pellet heating systems feature an automated pellet feeding system, can heat the entire home, allow homeowners to control the temperature from a thermostat, and are self-cleaning. Professionals deliver pellets in bulk to homeowners, saving those homeowners time and effort. States in this region (Maine, New Hampshire, Vermont, and New York) have established varying policies to increase adoption of wood heating systems as a way of reducing their dependence on fossil fuels. All four states have developed subsidy programs that offset the initial purchase cost of wood heating systems for consumers. All states require proven fossil fuel energy reductions to qualify, and New York has additional offsite outdoor wood pellet storage requirements. In addition to state-level subsidy programs, some banks in the region offer loan programs that allow residents to purchase wood heating systems with low interest rate loans. Furthermore, non-profit organizations such as the Northern Forest Center launched community-based education and incentive programs to promote clustered demand in selected communities. Pellet manufacturers, bulk delivery companies, and equipment firms established informal and opportunistic networks to supply automated pellet heating throughout the region [25]. Cost in comparison to the price of oil heating units remains a significant barrier towards the adoption of this technology, a barrier that can only be alleviated through further development of more cost-efficient automated wood pellet boilers or through policy incentive programs. As the cost of advanced wood pellet heating units starts at $10000 USD and can be in excess of $20,000 USD, the current existing state-level incentive programs are often insufficient in competing with the price of oil heating units [14]. Recent federal policy developments, such as the Wood and Pellet Heater Investment Tax Credit, will prove critical in incentivizing homeowners to move away from oil heating.

3. Theoretical Framework

The theory of diffusion of innovations has been widely adopted in renewable energy research [4,5,26–29]. The innovation diffusion process can be characterized by how extensively and quickly an innovation spreads through the market [30]. The rate of adoption

describes the relative speed with which an innovation is adopted by members of a social system [7]. It is often measured by the length of time required for a certain percentage of members to adopt an innovation. Plotted on a cumulative frequency basis over time, adoption rates often result in an S-shaped curve similarly described by the Bass Diffusion Model, a simple equation that describes the process of how new products are adopted in a population [12,31]. The curve is marked by two distinct turning points: take-off, the sudden spike in sales that follows an initial low-sales period, and slowdown, the sudden leveling in sales that follows a period of rapid growth [12,31].

Critical mass is a key component of diffusion of innovation theory, and it occurs when enough individuals in a system have adopted an innovation that further adoption occurs due to saturation rather than to innovator action [7]. Reaching a critical mass could mean that sales of a new product reach a level sufficient to reduce the distribution costs for suppliers and the initial cost for customers [29]. More individuals in the social system may consider the innovation common and ordinary, which could lead to further adoption [7]. It is essential for an innovation to move from the take-off to the growth stage in order to achieve sustainability. Four strategies for getting to critical mass have been identified: (1) targeting highly respected individuals in a system's hierarchy for initial adoption of the innovation, (2) shaping individuals' perceptions of the innovation to imply that the adoption is inevitable or that critical mass will soon occur, (3) introducing the innovation to intact groups in the system whose members are likely to be relatively more innovative, and (4) providing incentives for early adoption [7]. Within the New England region, poor networking has been identified as a barrier for innovation adoption, especially in the realm of forest products where it has been found that those harvesting wood-based resources often have poor lines of communication with public research and education institutions [4].

Relative advantage, particularly consumer perceptions of these advantages, is often described as one of the strongest predictors of an innovation's rate of adoption [7,32–34]. Relative advantage is characterized as economic profitability, social prestige, the saving of time and effort, and the immediacy of reward. However, there is rarely universal agreement about the relative advantage of an innovation based on objective and systematic comparison. The actual or perceived characteristics of an innovation may change in the diffusion process. For example, large demand may reduce the initial cost to adopt and increase the amount of innovation diffusion [7,29,31]. Large numbers of adopters may reduce the level of consumer uncertainty regarding switching from heating oil to wood pellets and increase the likelihood that individuals will perceive the advantage of the innovation [29]. One key advantage that exists for wood pellet technology is the existence of infrastructure in the region to utilize the vast biomass resources which can be transformed to wood pellets. Loggers are looking for more ways to utilize these resources which are often wasted in the woods [4,5]. One key aspect of the relative advantage of an innovation is its ability to be tested by potential adopters [7,35]. High efficiency wood pellet boiler systems are not typically a product that consumers can test, due to their complexity and the cost associated with installation. Increasing the number of adopters is often thought to be the best way to give potential future adopters a trial by proxy through the testimony of members of their social group.

4. Materials and Methods

Our case study examined the high-efficiency wood pellet heating industry in northern New England. Data were collected through semi-structured interviews from 2016 to 2017. Before data collection, four scoping interviews were conducted with staff from a non-profit organization that was active in promoting automated pellet heating technology diffusion (Figure 1). Using these scoping interviews, as well as searching wood pellet industry association membership directories, and other online sources, we identified businesses in the region that were directly involved in wood pellet production for residential use, ranging from wood pellet manufacturers to residential heating equipment installers. A total

of 21 wood pellet industry leaders and other stakeholders (e.g., state industry association leaders and residential technology business owners) were specifically identified as being the primary relevant industry leaders surrounding wood pellets in northern New England. Eighteen of the twenty-one invited participants agreed to be interviewed. One invited participant from an equipment firm refused to participate due to lack of interest, while two invited participants from pellet mills did not respond. Our response rate of 86% led to a final group of 18 participants, who represented active pellet mills, automated pellet boiler equipment firms, bulk delivery service providers, and installers in Maine, New Hampshire, and Vermont. We identified data saturation by open coding the interviews in the order in which they were conducted and evaluating the number of new codes generated by each new interview. In total we identified 1023 codes from the 18 in-depth interviews, which we narrowed into thematic categories based on innovation diffusion theory.

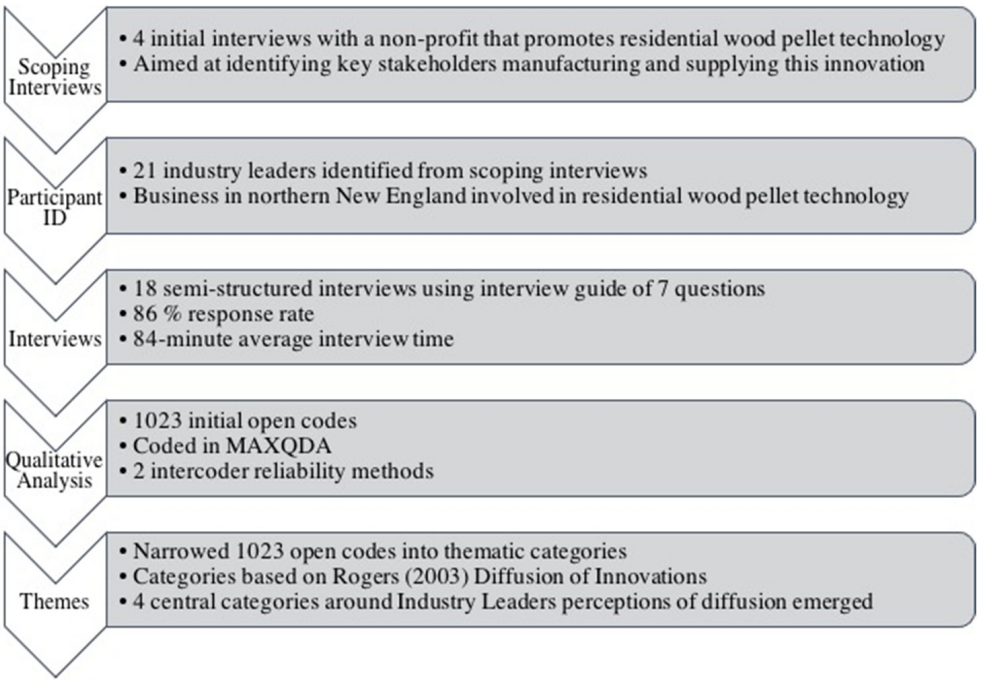

Figure 1. Research methods approach taken for qualitative interview procedure.

All interviews were conducted at company sites where participants worked. Interviews lasted anywhere from 48 to 89 min with a mean length of 84 min. Questions, based on interview guides, addressed study objectives and included: (1) In your experience, is the demand for wood pellets increasing or decreasing, and why?; (2) What in your opinion is the future for automated wood pellet boiler systems?; (3) Would you consider automated wood pellet boiler technology mature?; (4) Do you share customer satisfaction, decision-making, or relevant technological information with others in your industry?; (5) What may be the biggest challenge facing the industry, and what are the goals for your company in the upcoming five years?; (6) How do oil prices influence your business?; (7) What is your vision for the wood pellet and boiler equipment industry? The exact wording and order of these questions changed based on the flow of the interviews.

All transcripts were first open-coded in MAXQDA version 12 (VERBI GmbH, Berlin, Germany), resulting in a total of 1023 initial codes. These codes were further analyzed and narrowed in several rounds of merging and organizing codes based on study objectives and components of the diffusion of innovations theory. Coded transcript segments were then reviewed based on specific thematic categories to check whether the coding was true to the participants' original meaning in the context of the question. Several themes regarding the diffusion process of automated pellet heating and the influence of barriers arose in the process. We compared participants' perspectives on each theme and findings against

the diffusion of innovation theory. We conducted two intercoder reliability checks. First, we had a second coder review all transcripts for coding and themes related to the diffusion of innovation theory. Second, the themes were reviewed and confirmed by four additional members of the research team which included academics and practitioners. To complete the analysis, we organized the themes by research objective and organized into a logical hierarchy based on both concept and frequency. Quotations from the transcripts were then selected to present participants' thoughts in their own wording for the results section.

5. Results

5.1. Description of Interviewees

A total of 18 individuals were interviewed, including managers from two automated pellet boiler equipment firms, one equipment and bulk delivery company, four bulk delivery companies, and six pellet mills, as well as a leader from a regional pellet industry trade association and a consultant working extensively in the pellet and automated pellet heating industry. The sample captured data from 13 of the 16 known companies within the study region, representing more than 80% coverage of the industry. All participants were males between the ages of 30 and 69 years. Participants had a wide range of tenure in the pellet heating industry, ranging from one year to over two decades. All companies and organizations represented in the study were physically located in Maine, New Hampshire, or Vermont.

5.2. The Complex Question of Innovation Diffusion Take-Off

Most industry leaders noted the slow growth in automated pellet heating demand since 2010, with an emphasis on the struggle in achieving critical mass against the standard residential oil burner most commonly used in the region. There was a spectrum of beliefs held by participants regarding how likely their product was to completely diffuse within the renewable energy market. Participants' views on the stage of diffusion were informed by their different assessments of the eventual future number of adopters. These assessments, in turn, were influenced by how participants viewed perceptions of the relative advantages of the automated pellet heating industry, perceptions of achieving critical mass, and other external factors influencing adoption such as incentives and oil prices. We conceptualize the key themes from our interviews with industry leaders on their perceptions of the diffusion of wood pellet residential technology in New England (Figure 2).

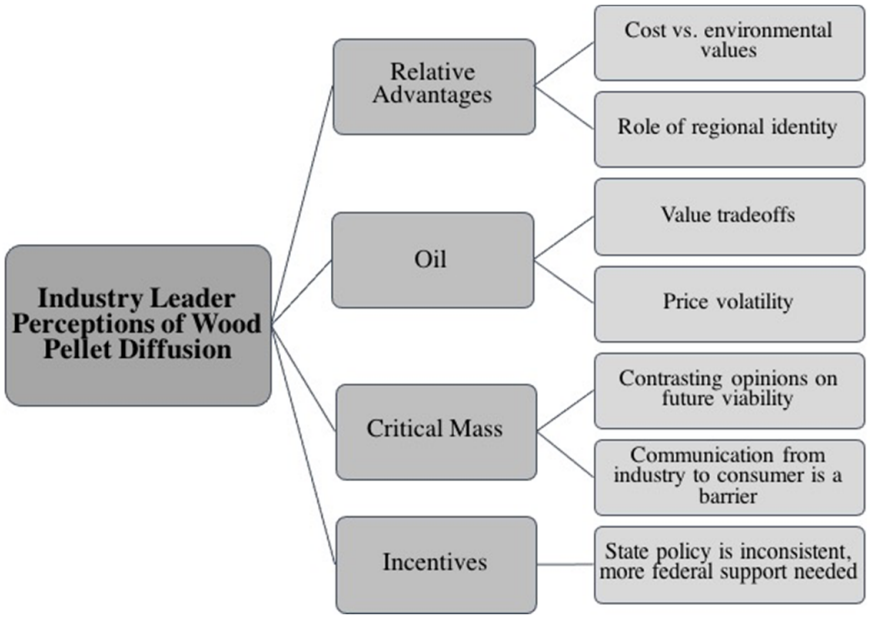

Figure 2. Conceptual model of coded thematic categories that emerged from interviews.

5.2.1. Perceptions of Relative Advantages

Compared to pellet stoves or other traditional wood combustion equipment, participants agreed that automated pellet heating was more efficient, easier to use, more tolerant of pellet quality, more convenient, renewable, required less maintenance, and was overall "a simple piece of equipment that really can work for everyone." Participants found that many individuals in the region were familiar with burning cordwood or pellets and had a genuine enjoyment of wood heat compared to oil. Automated pellet heating technology in turn was an upgrade from traditional wood heat and appealed to such a market, while also having specific benefits over the standard oil heater. Industry leaders noted:

> *"They tell me how much they love their wood stove or pellet stove. But they never once told me how much they love their oil boiler. So, I think it's just natural."*

> *"Once people have their pellet stove in or pellet boiler in, they love that heat. Wood heat is a lot different than oil heat."*

> *"From my experience, most people don't want oil. So, if you don't want oil in your house, it's not a hard pitch. The simplicity of the operation, the ease of the ash removal, the bulk delivery–it's wood heat for everybody."*

Automated pellet heating has relative advantages over traditional wood combustion equipment and is compatible with some individuals' preferences, such as the convenience of the pellet heating systems for aging customers.

> *"People who have burned traditional firewood their whole lives love wood heat. So, they're looking to not have to cut firewood because it's very labor-intensive and hard work, and they're aging out of being able to do that, and so the pellets are a great alternative to still have that wood heat but not the work."*

These industry leaders also noted conflicting perceptions regarding the influence that local or regional identity played in the adoption process. Some interviewees indicated that pellets or pellet systems had a relative advantage over oil due to the regional wood-based economy.

> *"So, you really still need a consumer who wants wood heat, likes wood heat, believes it's better, wants to support a local economy. That's their Northern Forest . . . They know it's a lumber mill in town. They know it's supporting their region."*

> *"It's renewable. It keeps the dollars in our local economy, and it really gets rid of heating oil. That's one thing I really love about what we do is we literally take that oil out of the network, and it's gone. This house is oil free now totally. A lot of people are keen on that."*

While supporting a local economy was likely important to most consumers, interviewee responses indicate an uncertainty regarding whether or not consumers associate the purchase of wood pellet products with supporting local industries and whether or not industry leaders are communicating this relative advantage to consumers.

One disadvantage of automated pellet heating cited was the high equipment cost. With current demand level, this cost is unlikely to drop in the near future. When oil prices were high, such a disadvantage could be mitigated by the stability of pellet cost and overall savings on fuel price, as one interviewee noted:

> *"You can justify a high capital cost, and these boiler systems cost two to three times what a conventional oil or gas does, by the fact that you are going to save a lot of money on your fuel bill."*

> *"The drawbacks are, number one, the low price of heating oil right now. But, we all know that's not going to be forever. It's too sporadic and, what's the word, volatile. So, if there was some type of education program out there that would help people see, just because the price of heating oil is low today doesn't mean it's going to be low next year. And pellet prices have been relatively stable for years and years and years."*

With the oil price decline, the savings were not "there the way they were a few years ago, so the financial cost/benefit is . . . the calculation is very different today." This factor may explain the sales dip after the oil price decline. However, how the reduction in payback influenced the diffusion of automated pellet heating was unclear, particularly since the trajectory of oil prices was uncertain. One noted:

> *"Ninety-five out of 100 consumers make their decision based on pure economics, not is this going to reduce greenhouse gasses? Is this better for the environment? Will my dollars stay local?"*

In contrast, others stated:

> *"Nobody really wants to burn it [oil]. We just have to give them reasons not to. And some people you can push without the financial picture being perfect for them. Some people won't. They don't like it. But, they're not willing to pay to move away from it yet. But, that's okay. They will once—there are people like that, when oil goes back up, they're going to pick up the phone."*

> *"Once it [oil prices] stabilized, I think we go back to our normal mindset of, "I don't want to burn oil." The conception that it's not cheap is still there. It may be cheap at the moment. Nobody goes—I don't think any consumers go, "Well, we're going to have cheap oil for the next ten years." They might not see that it's going to spike to five dollars a gallon again."*

These opposing observations led to different predictions about the eventual number of adopters (i.e., market size) based on the perceived relative advantage of the innovation. However, once again, disagreement arose about consumer perceptions towards oil pricing. Aforementioned participants indicated a concern that consumers perceive oil as being generally cheaper, while others relayed that consumers understand the volatility of oil markets at this point.

Some participants were concerned that residential automated pellet heating would remain a niche market and suggested switching attention to other commercial-scale markets for wood heating technology such as schools, governmental buildings, and hospitals. Others thought there was still large demand for automated pellet heating and that the market just required time to get there. There was also concern about current wood pellet industries in New England competing with markets outside of the Northeast region. An industry consultant indicated the following in response to a question about whether New England had a competitive advantage:

> *"Not so much within this region. It's more within other regions of the country that have lower power businesses. The Southern Appalachian states have access to cheap power. And they do ship product into this region . . . They have lower wood costs, lower electricity, lower labor costs. They have the disadvantage of a 500- or 600-mile trek to get to where the market is, so they kind of balance out."*

These findings demonstrated the difficulty in clarifying the relative advantage of an innovation and predicting cumulative adoption rates. The role of environmental values on consumer behavior to adopt wood pellet heating innovations was stated a few times, such as the eagerness to switch away from oil heating. Few interviewees, however, directly mentioned climate change as a relevant factor in consumer decisions on whether or not to purchase wood pellet boilers. Some participants expressed concerns regarding how environmentally friendly their technology was perceived to be.

> *"The states are continuing to push ahead for the most part with clean energy policy objectives and priorities. But, as you know, there is a whole sector of the environmental community out there that does not view this [wood pellet burning] as being renewable or clean."*

External disturbances, such as declines in oil price, might make certain disadvantages more salient to potential adopters and change agents. If change agents stopped their

promotional efforts due to these external disturbances, it could in turn slow the diffusion of innovation in the future.

5.2.2. Perceptions of Achieving Critical Mass: Can This Innovation Take Off?

Many participants expressed doubt regarding the future viability of wood pellet heating systems. Other participants maintained a determined optimism regarding the industry, suggesting that there is hope in the future and expressing frustration in the current lack of innovation diffusion. Some indicated an awareness of the concept of critical mass and what is needed to achieve it.

> *"The infrastructure in the state is set up for heating oil. I mean, there's heating oil delivery trucks and dealers everywhere you look. You drive down the road, and you'll meet five delivery trucks from five different companies. Well, here in southern Maine, there's only really two legitimate wood pellet delivery companies, and there isn't even enough–there aren't enough customers really to support those two. So, we need a lot more infrastructure and need a lot more people to convert to pellet heat to make it economically feasible and sustainable."*

> *"We want to make pellet heating–pellet central heating, pellet boilers–common and ordinary. Once it becomes common and ordinary, people will feel comfortable adopting the technology."*

Many participants were actively working with customers on the adoption of wood pellet systems in urban areas such as Portland, Maine. Others expressed doubts that there existed a viable urban market for wood pellet systems.

> *"Another thing is these are systems that are generally going to be used in a rural area, and they're not cost-effective compared to natural gas. So, any urban area that has natural gas is not going to install a wood pellet boiler."*

Some participants had more stated optimism regarding the growing market for residential wood pellet heating technology.

> *"The market's definitely not saturated. I don't think we have to worry about that for a long time still. I think it's mostly–we have not–the one thing we've not done well as an industry is to promote bulk delivery. But, those of us who are out there are pretty well established now."*

5.2.3. Incentives or Lack Thereof

A consistent theme among participants was the need for improved policy incentives for the wood pellet heating industry in order to achieve innovation diffusion. Some participants noted differences between the practices of states in the Northeast, identifying the advantages of some states' renewable energy incentives (albeit confusing bill requirements and recommendations) and the disadvantages of other states' incentives or lack thereof.

> *"It helps to have additional financial incentives for sure. So, those are state policies that provide added funding for these systems. That's probably the most important one [incentives]. And then the other is more like don't have policies that get in the way of these and being installed and working well. The state of New York has some really restrictive requirements around getting its incentive, like they require that you store the pellets outdoors, which adds to the cost and not everyone wants to store their pellets outdoors."*

> *"So, there's certainly advantages to buying Maine wood products in these businesses [due to incentives]. Now, Vermont just passed a bill that, by 2030, 35 percent of all public buildings have to be fueled by wood, either chips or pellets. So, they're looking ahead."*

Maine and Vermont were consistently identified by participants as having more effective incentive programs than New York (cited frequently) or New Hampshire (cited infrequently). Participants linked incentive programs, such as rebate policies, with consumer decision-making.

> *"It's [rebate policies] probably the only reason anybody is selling any of those systems right now with very few exceptions, is because there are rebates available to offset the capital, some portion of the capital costs."*

Along with comparing these programs across states, participants expressed what future needs and concerns should be addressed regarding renewable energy incentives. Some identified other policy changes that could greatly aid the diffusion of wood pellet heating innovation:

> *"I see the customer will [adopt] if oil and energy prices are high enough to definitely make some big gains, right? I'm talking very kind of incremental gains. But, to have a big transitional way, I think it has to happen primarily at the policy level. And that can be carbon taxes or taxes on fossil fuels or bigger subsidies on products like this."*

Several participants observed that policy incentives coming from the state level need federal support. These interviews were collected prior to the development of the Wood and Pellet Heater Investment Tax Credit which begins in 2021 but expires in 2023.

> *"These states will grow weary of providing subsidies. And they'll want to put their money in other areas that are showing greater promise or potential for real market growth and development. That's a problem."*

> *"The states are delivering all the rebate incentives for stoves and boilers, but nothing is happening at the federal level. And then, even at the state level, it is nothing like they do with these other energy technologies."*

Interviewees consistently agreed that improved policy incentives or subsidies would improve market conditions and the future viability of their renewable innovation, and some indicated that improved incentives would be vital for continued innovation and diffusion.

> *"You get better at supply chain when you have more demand for your produce and services. That's what forces innovation and delivery of services. It creates competition, price competition. It gets more companies into the market. Good ones get better and bad ones don't survive. Those dynamics really aren't in play right now. So, all the factors that push a sector to get better are not at play to the same extent that they were a few years ago because of the market."*

5.2.4. The Role of Oil Prices

Not surprisingly, industry leaders reported being impacted by the oil price decline that began in 2014; however, they differed in their perceptions of how long the impact would last and what the future market conditions would be like as a result. All participants reported decreased sales following the decline of oil prices in 2014. Participants from bulk delivery companies commented on a similar trajectory of booming business when oil prices were high and reduced sales after the oil price decline. The two bulk delivery companies that entered the market earlier recovered more quickly from the oil price decline. One pellet delivery company commented, *"Last year, there was a lot more burning oil. This year, some came back on the pellets."* Another bulk delivery company manager reported, *"We've had probably the best first quarter sales year I've ever had. Part of that is just becoming established, and the equipment is starting to become more common and ordinary."* It was more challenging for companies who entered the bulk delivery market more recently. One participant described winter 2015 as being *"disastrous."* He added that winter 2016 brought marginally better sales but the business was still not profitable.

While oil price declines proved to be tough competition for the wood pellet industry, some producers indicated that overall weather and climate have a more direct impact on market viability than the stability or current status of oil prices. Most pellet mill managers attributed the weak wood pellet market from 2015 to 2017 to warm winter weather. A participant mentioned that the weather cut the market in half.

> *"Well, the number one factor that affected the softness of the market status is weather. I think low oil prices is going to have a 10% impact, where the weather has a 90% impact on the market."*

Oil price falls accelerated the economic impacts brought by winter weather and formed a perfect sequence of events for pellet sales and manufacturers.

The equipment firms and bulk delivery companies were key change agents in promoting automated pellet heating technologies. However, the oil price decline impeded their ability to continuously promote the diffusion through marketing and education, seek policy support, improve products, and attract and maintain investment. The findings suggest that the oil price decline impacted the diffusion of automated pellet heating technology first by directly influencing the industry players who were key change agents. The following quotes from stakeholders within the industry expressed such concerns:

> *"And right now, there's nothing, basically almost zero education or–and for instance, in our business, we can't even break even–we're not making a profit, we're losing money and business right now. So, there's zero dollars for advertisement."*

> *"When you have a stagnant and soft market, the resources of any company and then even the interest at the political level, it's just not there."*

> *"From the investment we made, what's our return? Right now, I don't think there's much return on any of them. I think the growth is going to be limited until that changes."*

While this concern was stated throughout interviews, many participants also countered that they believed consumers remember past oil price fluctuations and understand the natural volatility of the oil market.

> *"Once it [oil prices] stabilized, I think we go back to our normal mindset of, "I don't want to burn oil." The conception that it's not cheap is still there. It may be cheap at the moment. Nobody goes 'well we're going to have cheap oil for 10 years now'."*

6. Discussion

This case study examined the ongoing innovation diffusion process of automated pelleting heating technology in the northeastern U.S. from the perspective of the region's industry leaders. While there was agreement that this technology was undergoing a slow diffusion process, industry leaders had differing perceptions of the potential of automated wood pellet heating technology to achieve critical mass or simply establish a more sustainable and consistent market. Critical mass has been established within the diffusions of innovations literature to be key to achieving sustainable take-off of an innovation [7]. Some producers believed that achieving critical mass was possible in the near future due to the abundant wood supply in the Northeast and to the particular values that consumers held regarding using wood products or combatting climate change by reducing oil consumption. Others indicated that achieving critical mass would not be feasible due to the technology's high entrance cost for both producers and consumers, with the current affordability of oil heating being a major barrier for consumers to switch. Skjevrak and Sopha [36] echo this finding that affordability is one of the largest barriers for potential early adopters of wood pellet technology. They also found that reliability of the technology was a major barrier, a finding not reflected by our industry leaders. Some industry leaders, however, felt that the affordability of oil was less important than the role of climate and weather on winter conditions and the need for heat. There was also a conveyed sense by the industry leaders that consumers held a general understanding of the volatility of oil prices and market fluctuations, and that it is not a permanently cheap fuel source.

Interview participants highlighted that consumers appreciated the perception of the wood burning experience as a relative advantage versus burning oil. The technological innovation of automated pellet heating is also compatible with consumer identity preferences in the region for wood heating based on regional wood supply and a desire to support local

rural economies, which ties back into regional and place-based identities. The economic benefits of automated pellet heating rely mostly on long-term payback through stable pellet fuel prices. The oil price decline significantly reduced such payback. Participants disagreed on how the advantages of the technology and its compatibility with regional values influenced individual decision-making regarding the innovation. Some believed economic considerations dominated individual decisions while others maintained that preferences for wood heat or regionally sourced products (place-based identity) could overcome economic barriers and that consumers generally understood the volatility of oil prices. Both of these assumptions can be true based on variances in consumer values, socio-economic status, purchasing behavior, and situational context. The more pressing question is what percentage of people in the population follow certain decision-making rules and under what conditions might they change them (i.e., how many would be willing to switch from oil to wood pellet heating). Future research should continue to explore the role that place-based or value-based identities play in consumer decision-making, particularly as it applies to renewable energy adoption.

Contradicting beliefs among industry leaders regarding critical mass could potentially undermine the progress of wood pellet systems towards reaching critical mass by weakening public perception that widespread adoption of automated wood pellet heating technology is inevitable [7,37]. In this regard, perceptions held by producers themselves could be potential barriers to achieving critical mass or continued diffusion through the market. Consistent messaging is needed from all levels of producers focusing on agreed relative advantages of residential wood pellet heating: long-term affordability of wood heat, the volatility of oil prices, supporting local markets, and combating climate change through reduced fossil fuel use, would go a long way to achieving a more sustainable diffusion process.

Future research is needed to address the complex decision-making process of homeowners in choosing among home heating options, as past research indicates that the decision-making factors used by homeowners at one stage (e.g., early adopters) are different from the factors that motivate behavior at later innovation diffusion stages [14]. The industry may be particularly interested in whether the preference-driven group, those who prefer wood heat over other types of heat, is large enough for automated pellet heating to reach critical mass and transition into a self-sustained growth stage or if there are other values, such as ones related to climate change, that will stir motivation to purchase this technology. Future research should also seek to more clearly define the economic relationship between external factors such as oil price with the long-term growth of residential wood pellet heating technology. Future studies could also compare perceptions of consumer adoption behaviors by industry leaders to the actual beliefs of consumers. This would provide valuable insight into potential gaps between the consumer decision-making process and the perceptions of consumer beliefs and expectations held by industry leaders. Presently, there have been few studies that explore both industry and consumer perceptions of wood pellet technology, and those that exist are focused on economic and policy barriers rather than the consumer decision-making process [38].

Our findings have implications for those involved in renewable energy policy, especially state-level policy makers and renewable energy industry leaders. Our study confirmed several challenges and barriers in renewable energy diffusion and transition. Policymakers, in their decision making, need to take into consideration the time needed for a technology to take off and the likelihood of unexpected external disturbances or large policy shifts affecting that take off. The recent re-entrance of the U.S. into the Paris agreement will have yet undetermined effects on the wood pellet industry, but the policy could expand the exporting demand of the industry in the Northeast. Future studies could provide valuable insight into the role that broad climate policies like the Paris Climate Accord have on consumer decision-making and renewable energy adoption. Policy makers have been found to face a "lock-in" effect with existing technology, waiting for proven examples of success before considering replacement of outdated infrastructure [39–41].

This can be difficult for innovations that have slow and long periods of initial adoption and take-off. Supplementing the natural diffusion process with incentives such as state or federal rebate programs can help catalyze the take-off of a diffusion, especially one that shows signs of a slow start. Given the uncertainty that both producers and consumers feel about the future growth of the industry, it could remain stagnant without increased state and federal incentives. Increased incentive programs can alleviate financial barriers for both producers and potential future adopters, while also increasing the saliency of the technology as an individual method of reducing household carbon emissions. It is both tempting and dangerous to rely on immediate market conditions such as low oil prices to judge whether an innovation is worth investing in from a policy or incentive perspective. Policy makers could support the energy transition diffusion, specifically of automated wood pellet heating, in other ways. For example, programs could be designed to help train technicians and contractors in automated pellet heating system installation and troubleshooting. Participants mentioned carbon taxes or taxes on fossil fuels as being essential for achieving widespread adoption of their innovation. For industry practitioners, it is important to keep in mind that despite the challenges, slow diffusion does allow more time to improve product quality and customer service, making for a stronger industry in the long run.

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